United States
Environmental Protection
Agency

Louisiana
Geological
Survey

April 1987
EPA-230-02-87-026

Saving Louisiana's Coastal Wetlands

The Need For a Long-Term Plan of Action

Report of The Louisiana Wetland Protection Panel

Library of Congress Cataloging-in-Publication Data

Louisiana Wetland Protection Panel (1985: Grand Terre
Island, La.)
Saving Louisiana's coastal wetlands.

Held in Grand Terre Island, La., September 17-19, 1985.
Bibliography: p.

1. Wetland conservation—Louisiana—Congresses.
2. Wetland—Louisiana—Congresses. 3. Sea level—
Louisiana—Congresses. 4. Greenhouse effect,
Atmospheric—Congresses. I. Louisiana Geological
Survey. II. Unites States Environmental Protection
Agency. III. Title.
QH76.5.L8L68 1985 333.91'816'09763 87—5400

SAVING LOUISIANA'S COASTAL WETLANDS

The Need for a Long-Term Plan of Action

Report of the Louisiana Wetland Protection Panel

Convened By

Louisiana Geological Survey

U.S. Environmental Protection Agency

SUMMARY

America's largest wetland community is losing its marshes and swamps to the Gulf of Mexico. The wetlands of coastal Louisiana are being converted to open water at a rate of fifty square miles per year, largely as a result of maintaining shipping lanes, the dredging of canals, flood control levees, and the withdrawal of oil and gas. If current trends continue, an ecosystem that supports the nation's oldest bilingual culture, 25 percent of the nation's fishing industry, and North America's largest fur-producing area, will be mostly lost in the next century. This process could be further accelerated if sea level rises one or more feet as a result of the projected global warming from the greenhouse effect.

Over the last twenty years, various solutions have been suggested to save Louisiana's coastal wetlands. Proposals have included unharnessing the Mississippi River; breaching the levees to allow river water to reach the wetlands; building giant levees along the entire coast; restoring the rapidly disintegrating barrier islands; filling the many canals that have been dredged through the marsh; or combinations of these alternatives. Thus far, however, most investigations have focused on specific impacts and responses, not on a comprehensive solution. No one has systematically synthesized the available information to determine what must be done to save 10, 25, or 50 percent of Louisiana's coastal ecosystem, or developed a comprehensive tool for such an analysis.

Although additional scientific research will be necessary, sufficient information is available to assess this question and commence the development of a plan for saving Louisiana's wetlands. The Louisiana Wetland Protection Panel was convened by the Louisiana Geological Survey and the U.S. Environmental Protection Agency to outline a study to evaluate strategies to substantially reduce wetland loss in coastal Louisiana through the end of the next century, for use in developing a comprehensive wetland protection plan.

This report provides an overview of the problem and outlines the analysis that must be synthesized to develop a plan, describing the causes of wetland loss, possible options to protect wetlands, and ongoing activities to address the problem, and laying out a study to evaluate comprehensive solutions to wetland loss in Louisiana.

Many federal, state, local, and private organizations will eventually have to address the loss of Louisiana's wetlands. We hope that this report accelerates the process by which these groups become part of the solution to the problem of wetland loss in coastal Louisiana.

CONCLUSIONS

1. **Wetland loss in Louisiana is a problem with national importance.** The coastal wetlands of Louisiana support a major fraction of the U.S. fishing, hunting, and trapping industries, and indirectly, the poultry industry. Unlike wetland loss elsewhere which mostly results from private actions, the coastal wetland loss in Louisiana results primarily from activities conducted or authorized by government agencies.

2. **Although natural processes are involved, human activities are responsible for the net loss of wetlands.** These activities include levees, channelization, canals, draining and filling of land, and human modification of drainage patterns.

3. **Wetland loss could be reduced by combinations of marsh restoration and management;** Mississippi river diversion of freshwater, nutrients, and sediment; barrier island and beach stabilization; and modification of human activities.

4. **A comprehensive plan of action is needed.** Such a plan should have a reasonable chance of protecting a large fraction of Louisiana's wetlands through the next century. This document has outlined twenty options to be evaluated in the formation of such a plan.

5. **A number of institutional impediments must be overcome before a consensus can be obtained on the design and implementation of a plan of action.**

6. **No single approach will adequately curtail wetland loss in Louisiana.**

7. **Initial formulation of an action plan should not await completion of additional scientific studies.** Nevertheless, development of the plan will define additional research needs.

8. **Ongoing and approved remedial measures should go forward on schedule.** The need for a comprehensive plan of action does not imply that previously approved projects should be delayed.

9. **If projections that the greenhouse effect will raise sea level one foot or more in the next fifty years are accurate, the need for immediate action is much greater than previously thought.** The global warming has not so far been an important factor in causing wetland loss in Louisiana. However, long-term plans should consider the rise in sea level that could occur in the next fifty to one hundred years. The possibility that sea level may eventually rise one or more meters is not a reason to give up on efforts to protect coastal wetlands. It is another reason to implement measures to restore the delta's former ability to keep pace with subsidence and sea level rise through sedimentation and other processes.

LOUISIANA WETLAND PROTECTION PANEL

Barney Barrett
Louisiana Department of Wildlife and Fisheries
Baton Rouge, Louisiana

Robert Buisson
U.S. Army Corps of Engineers
New Orleans, Louisiana

David Chambers
Louisiana Geological Survey
Baton Rouge, Louisiana

Mark Chatry
Louisiana Department of Wildlife and Fisheries
Grand Isle, Louisiana

Adrian Combe
U.S. Army Corps of Engineers
New Orleans, Louisiana

David Fruge
U.S. Fish and Wildlife Service
Lafayette, Louisiana

Sherwood Gagliano
Coastal Environments, Inc.
Baton Rouge, Louisiana

Chip Groat
Louisiana Geological Survey
Baton Rouge, Louisiana

Oliver Houck
Tulane Law School
New Orleans, Louisiana

Ted LaRoe
U.S. Fish and Wildlife Service
Washington, D.C.

Irving A. Mendelssohn
Louisiana State University
Baton Rouge, Louisiana

Donald Moore
National Marine Fisheries Service
Galveston, Texas

Stanley Riggs
East Carolina University
Greenville, North Carolina

Jens Sorensen
Brookline, Massachusetts

Robert Stewart
U.S. Fish and Wildlife Service
Slidell, Louisiana

Johnny Tarver
Louisiana Department of Wildlife and Fisheries
Baton Rouge, Louisiana

Paul Templet
Louisiana State University
Baton Rouge, Louisiana

Gordon Thayer
National Marine Fisheries Service
Beaufort, North Carolina

Norman Thomas
U.S. Environmental Protection Agency
Dallas, Texas

James G. Titus
U.S.Environmental Protection Agency
Washington, D.C.

John Weber
U.S. Army Corps of Engineers
New Orleans, Louisiana

TABLE OF CONTENTS

Introduction ___ ***1***

Causes of Wetland Loss ___ ***3***

(1) Sediment Deficit ___ **9**

(2) Canals ___ **10**

(3) Reclamation ___ **10**

(4) Wave Erosion ___ **12**

(5) Subsidence ___ **14**

(6) Sea Level Rise ___ **16**

(7) Saltwater Intrusion ___ **16**

Measures for Curtailing Wetland Loss ___ ***19***

Barrier Island Restoration ___ **21**

Wetland Restoration ___ **21**

Marsh Management ___ **23**

Canals and Land Use ___ **25**

Diversion ___ **25**

Authorized and Planned Projects for Curtailing Wetland Loss ___ ***29***

Authorized Projects ___ **30**

Planned Projects ___ **36**

The Need to Move Forward ___ **37**

Towards a Strategic Plan: A Proposed Study ___ ***38***

The Need To Examine the Big Picture ___ **38**

Phase I: Strategies for Achieving Particular Levels of Wetland Protection ___ **39**

Phase II: The Benefits of Wetland Protection ___ **42**

Conclusion ___ ***45***

Bibliograghy ___ ***46***

CHAPTER 1

INTRODUCTION

America's largest wetland community is losing its marshes and swamps to the Gulf of Mexico. Coastal Louisiana is being replaced by open water at a rate of fifty square miles per year, largely as a result of federal navigation policy, the dredging of canals, flood control levees, and the withdrawal of oil and gas. If current trends continue, an ecosystem that supports the nation's oldest bilingual culture, 25 percent of the nation's fishing industry, and North America's largest fur-producing area, will be destroyed in the next century. This destruction could be further accelerated if sea level rises one or more feet as a result of the projected global warming from the greenhouse effect.

Are these marshes and swamps worth saving? For how long? Who is responsible for seeing that a decision is made? These are questions for policy makers, not a technical panel. Yet for them to make a reasoned judgment, they will need to know how to solve the problem, what it will cost, and the likely results for various measures.

Over the last twenty years, various solutions have been suggested to save Louisiana's coastal wetlands. Proposals have included unharnessing the Mississippi River; breaching the levees to allow river water to reach the wetlands; building giant levees along the entire coast; restoring the rapidly disintegrating barrier islands; filling the many canals that have been dredged through the marsh; or using combinations of these alternatives. Thus far, however, most investigations have focused on specific impacts and responses, not on a comprehensive solution. No one has systematically synthesized the available information to determine what must be done to save 10, 25, or 50 percent of Louisiana's coastal ecosystem, nor has anyone developed a comprehensive tool for such an analysis.

Although additional scientific research will be necessary, sufficient information is available to assess this question and begin to develop a plan for saving Louisiana's wetlands. The Louisiana Wetland Protection Panel was convened by the Louisiana Geological Survey and the U.S. Environmental Protection Agency, and met on Grand Terre Island September 17-19, 1985. The purpose of the panel was to specify strategies likely to substantially reduce wetland loss in coastal Louisiana through the end of the next century, for use in a subsequent effort to develop a comprehensive plan. Based on the available body of scientific literature, the panel reached the following conclusions:

1. **Wetland loss in Louisiana is a problem with national importance.** The coastal wetlands of Louisiana constitute 40 percent of all U.S. coastal wetlands, and support a major fraction of the U.S. fishing, hunting, and trapping industries, and indirectly, the poultry industry. Unlike wetland loss elsewhere which mostly results from private actions, the coastal wetland loss in Louisiana results primarily from activities conducted or authorized by government agencies. Many of the options for protecting wetlands cannot be implemented without the cooperation of the federal government.

2. **Although natural processes are involved, human activities are responsible for the net loss of wetlands.** These activities include levees, channelization, canals, draining and filling of land, and human modification of drainage patterns.

3. **Wetland loss could be reduced by combinations of marsh restoration and management;** Mississippi river diversion of freshwater, nutrients, and sediment; barrier island and beach stabilization; and regulation of human activities.

4. **A comprehensive plan of action is needed.** Such a plan should have a reasonable chance of protecting a large fraction of Louisiana's wetlands through the next century. This document has outlined twenty options to be evaluated in the formation of such a plan.

5. **A number of institutional impediments must be overcome before a consensus can be obtained on the design and implementation of a plan of action.** Among the impediments are incentives for private property owners for the development and implementation of restoration plans; incentives for leaseholders and others affected by proposed remedial strategies; criteria and values assigned to wetlands; the role of cost-benefit analysis; conflicts within and between agency missions; and ownership of newly created lands.

6. **No single approach will adequately curtail wetland loss in Louisiana.**

7. **Initial formulation of an action plan should not await completion of additional scientific studies.** Nevertheless, development of the plan will define additional research needs.

8. **Ongoing and approved remedial measures should go forward on schedule.** The need for a comprehensive plan of action does not imply that previously approved projects should be delayed.

9. **If projections that the greenhouse effect will raise sea level one foot or more in the next fifty years are accurate, the need for immediate action is much greater than previously thought.** The global warming has not so far been an important factor in causing wetland loss in Louisiana. However, long-term plans should consider the rise in sea level that could occur in the next fifty to one hundred years. The possibility that sea level may eventually rise one or meters is not a reason to give up on efforts to protect coastal wetlands. But it is another reason to implement measures to restore the delta's former ability to keep pace with subsidence and sea level rise through other processes.

This report provides an overview of the problem and outlines the analysis that must be synthesized to develop a plan. Chapter 2 describes the causes of wetland loss. Chapter 3 discusses a variety of possible options to protect wetlands. Chapter 4 describes ongoing activities to address the problem. Chapter 5 lays out a study to evaluate comprehensive solutions to wetland loss in Louisiana.

Many groups will eventually have to address the loss of Louisiana's wetlands, including the Federal Emergency Management Agency's Flood Insurance Administration, the Fish and Wildlife Service, the National Park Service, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, the Army Corps of Engineers, the State of Louisiana, coastal parishes, the U.S. Congress, the Louisiana Legislature, and the private sector. We hope that this report accelerates the process by which these groups become part of the solution to the problem of wetland loss in coastal Louisiana.

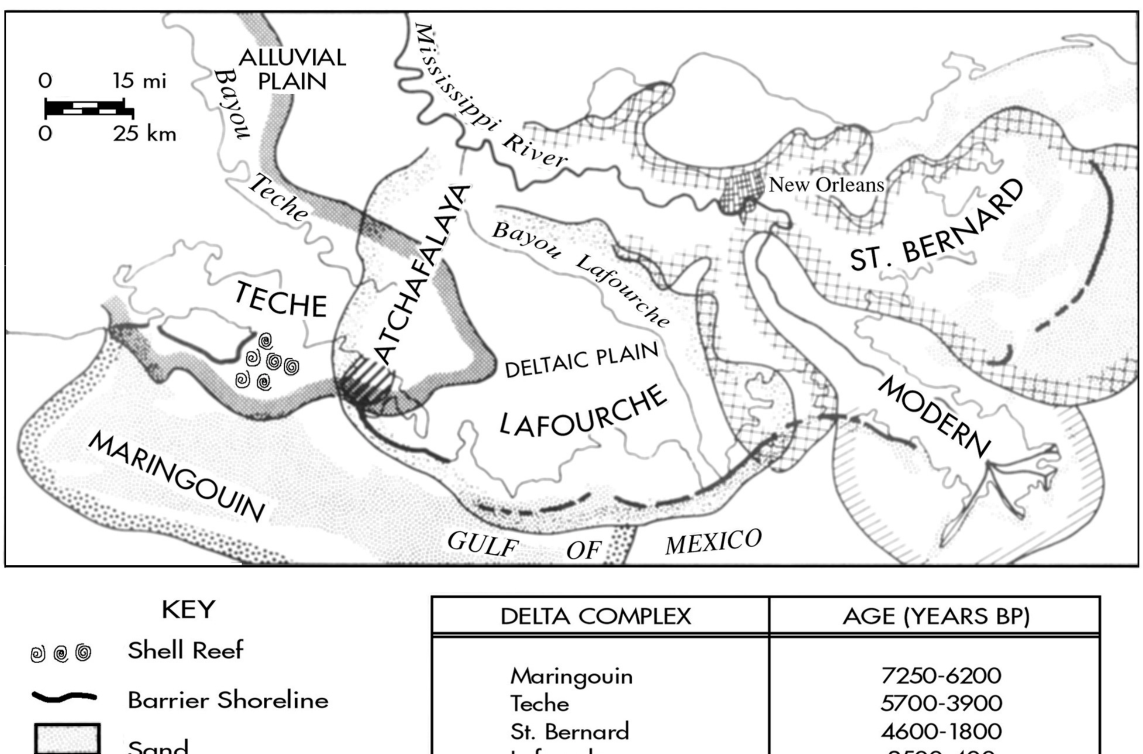
A number of the wetland restoration and management activities discussed in this report fall under existing federal programs, such as those authorized under sections 401 and 404 of the clean Water Act, Section 10 of the River and Harbor Act, and the Coastal Zone Management Act, as well as state regulatory programs. In particular, the regulatory program established by Section 404 provides the major avenue of federal involvement in material. This program was designed to ensure that discharges into wetlands and other waters covered by the program do not result in unacceptable adverse impacts on aquatic environments. Anyone who intends to discharge material into wetlands, even if the propose is to protect wetlands from rising sea level, should contact EPA or the Army Corps Engineers to determine whether a permit for the proposed activity is necessary.

CHAPTER 2

CAUSES OF WETLAND LOSS

Over the last seven thousand years, the sediment washing down the Mississippi River created Louisiana's coastal wetlands. The river deposited sediment along its main channel and distributaries to the sea, creating land just above sea level that supported marsh and swamp vegetation. The delta building processes gradually lengthened the main channel's route to the sea. Every thousand years or so, the river switched to a shorter course, and built a new delta along this route (Coleman and Gagliano 1964; Frazier 1967). Figure 1 shows the delta "lobes" that have formed in the last seven thousand years; Figure 2 illustrates a generalized model of delta building and deterioration processes.

Once the river changed course, the wetlands along the old channel would gradually deteriorate and revert partially back to open water. The deltaic sediments have always tended to compact and sink while at the same time sea level has been slowly rising. Deprived of new sediment, the marshes would be unable to maintain their elevation above the surface of the water. As a result, the vegetation would die, and the marsh would deteriorate and "convert" to (be replaced by) open water. The change in river course would also reduce the availability of freshwater supplied to the wetlands, which would allow saltwater from the Gulf of Mexico to encroach inland, killing freshwater marshes and swamps, often converting them to open water as well.



DELTA COMPLEX	AGE (YEARS BP)
Maringouin	7250-6200
Teche	5700-3900
St. Bernard	4600-1800
Lafourche	3500-400
Modern	Active
Atchafalaya	Active

Figure 1. Sequence of Mississippi River delta lobe formation (modified from Frazier 1967).

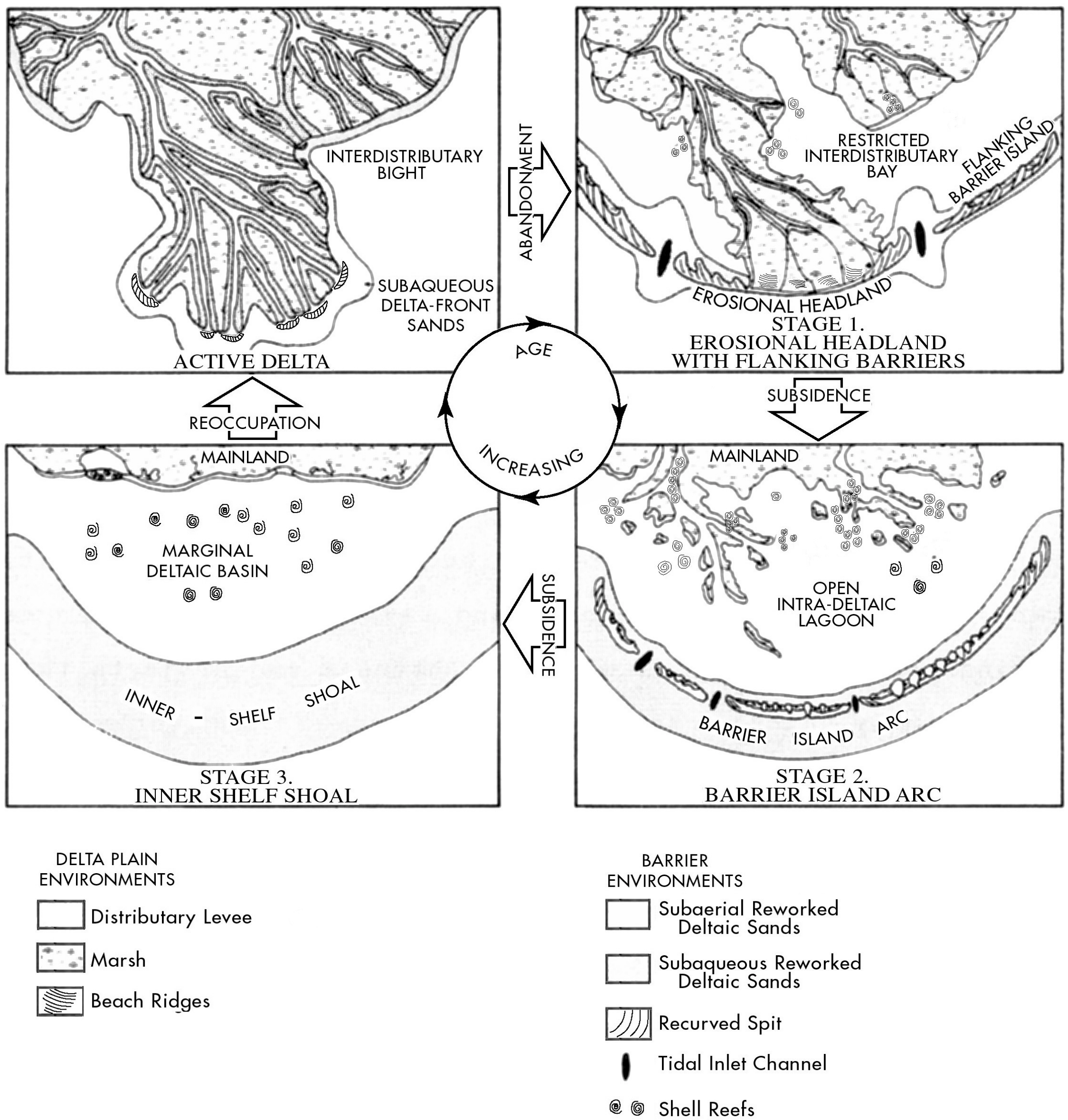


Figure 2. Cycle of delta growth and decay (after Penland and Boyd 1961).

Coastal Louisiana has always experienced natural wetland loss in the abandoned delta after the river changed course. Until recently, however, the loss was always more than offset by creation of wetlands in the new delta. Seven thousand years ago Louisiana's Gulf of Mexico shoreline was along a line corresponding to the present locations of Slidell, Baton Rouge, Lafayette, and Lake Charles; today it is fifty to one hundred miles south of that location.

In the last century, human activities have disrupted the natural delta-building cycle. Levees along the Mississippi River built for flood protection prevent the river from overflowing its banks and conveying freshwater and sediment to the wetlands during annual floods. Navigation channels and projects that artificially maintain the river's banks speed the river's flow, preventing sediment from settling out. Many distributaries have been closed. As a result, the sediment, freshwater, and nutrients carried by the Mississippi River now wash out into the deep waters of the Gulf of Mexico, rather than spreading out to nourish and build Louisiana's coastal wetlands.

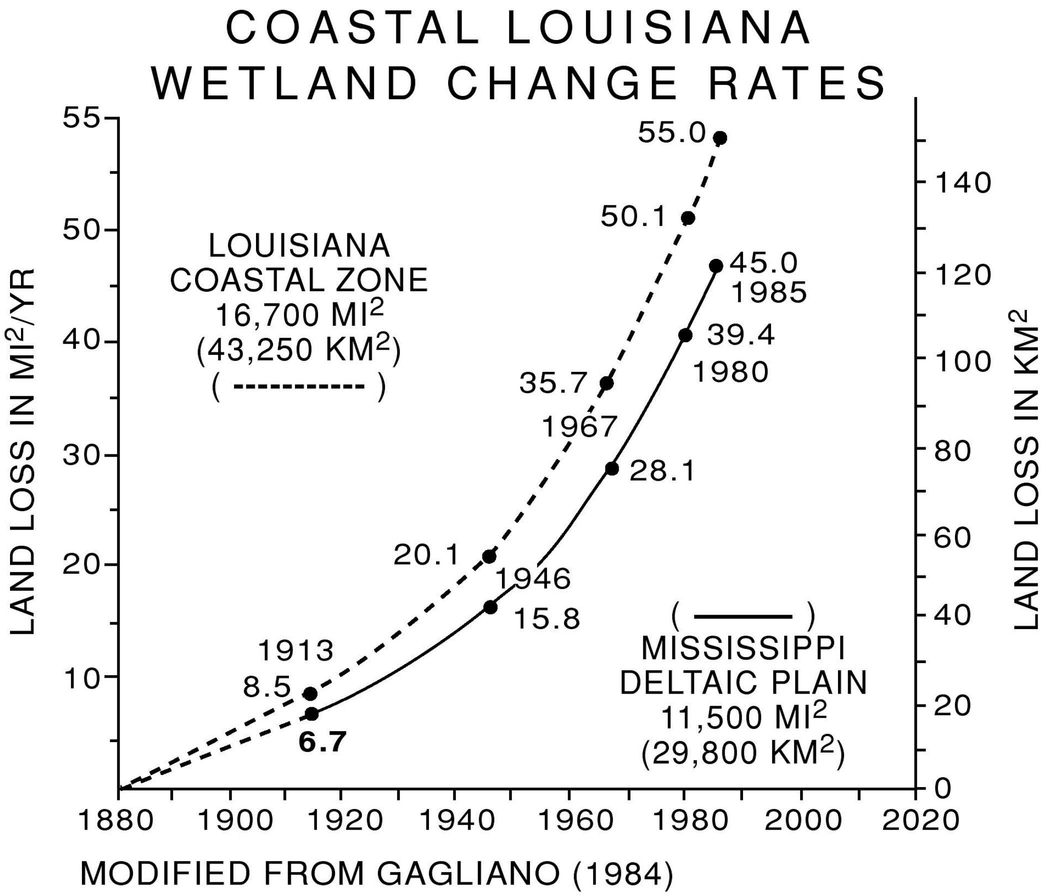


Figure 3. Rates of wetland loss in the Louisiana coastal zone compared with loss in Mississippi Deltaic Plain.

Human activities have also prevented the Mississippi from changing its course to the Atchafalaya River. Although this river does capture 30 percent of the Mississippi River's flow and is creating a small delta at its mouth, without the upstream control structure built by the U.S. Army Corps of Engineers, the majority of the river's flow would reach the Atchafalaya delta and a far larger amount of wetlands would be created.

Canals dredged through the marsh have also contributed to the loss of wetlands in a number of ways. In some parts of Louisiana, the direct losses from dredging the canals themselves are quite large. Waves from boats traversing the canals further erode the marsh. The canals also provide a conduit for saltwater to advance rapidly inland into cypress swamps and freshwater marshes that cannot tolerate saltwater, particularly where the flow of freshwater from the river to the wetlands has been blocked. Finally, spoil banks from dredging canals interrupt the flow of water and nutrients. Other activities also contribute to wetland loss, including draining and filling for development, agriculture, sanitation, and navigation.

As a result of these human factors, the historic expansion of the Mississippi Delta has been reversed. Coastal residents and some scientists first noticed marsh deterioration and shoreline erosion more than fifty years ago (e.g., Russell 1936). However, the rate of land loss was not established until Gagliano and van Beek (1970) estimated that Louisiana was losing 16.5 square miles per year. Wicker (1980) later showed that the deltaic plain lost 39 square miles per year between 1955 and 1978. Gagliano et al. (1981) concluded that the rate of wetland loss has been increasing geometrically over the last century. As Figure 3 shows, the rate of wetland loss in 1985 for the deltaic plain alone is 45 square miles per year. The

Chenier Plain in southwestern Louisiana is losing an additional 10 square miles per year (Gosselink et al. 1979), bringing the total land loss within the Louisiana coastal zone to approximately 55 square miles per year (nearly 100 acres per day). Figure 4 illustrates average rates of wetland loss for various portions of coastal Louisiana. Figure 5 illustrates the land loss that has taken place at the mouth of the Mississippi River, where the rate of loss is among the highest.

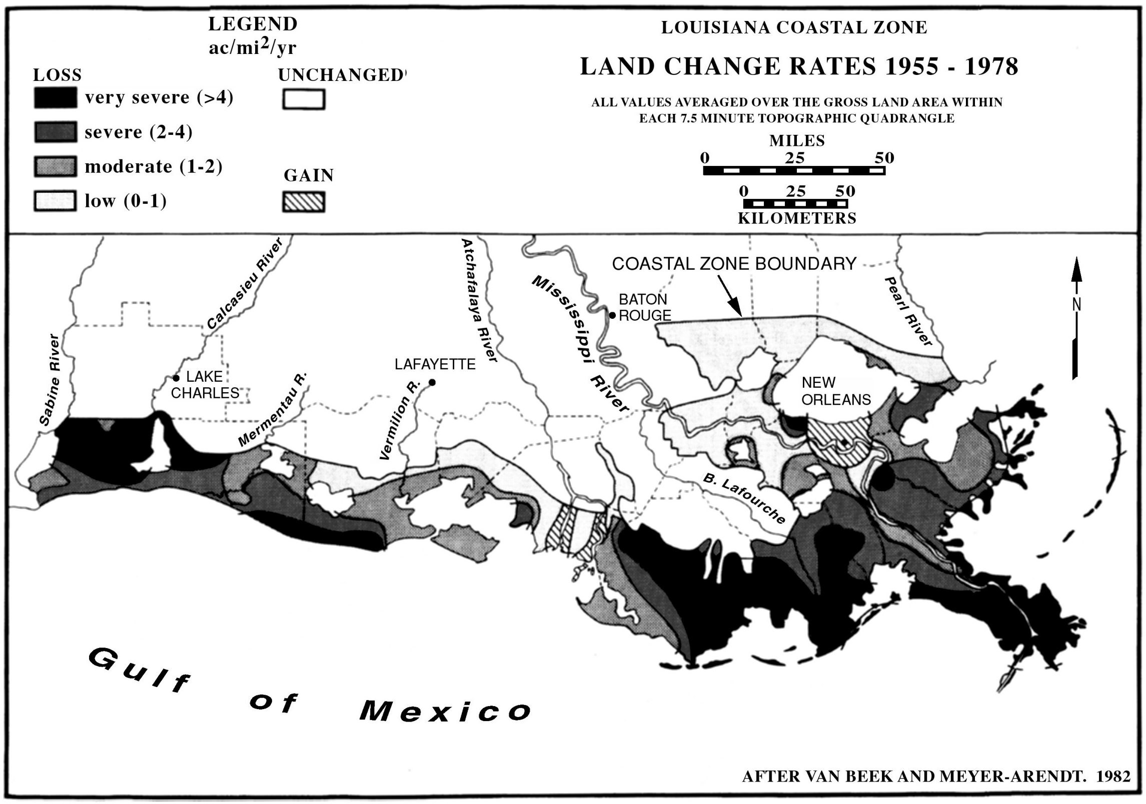


Figure 4. Land change rates in the Louisiana coastal zone, 1955 – 1978.

Recent studies by the U.S. National Academy of Sciences (Charney 1979; Smagorinsky 1982; Nierenberg et al. 1983) and international meetings of atmospheric scientists (e.g., UNEP/WMO/ICSU 1985) suggest that the rate of wetland loss may further accelerate in the future. Increasing concentrations of carbon dioxide and other gases are expected to cause a global warming that could raise sea level one meter (three feet) or more in the next century (Revelle 1983; Hoffman et al. 1983 and 1986; Meier et al. 1985). Such a rise would represent a major acceleration of the historical trend of 10 to 15 centimeters (4 to 6 inches) per century, and could eventually double or triple the rate of wetland loss. Figures 6a and 6b illustrate projections of the state's shoreline for current sea level trends and a 55-centimeter rise by the year 2033.

Many of the panel members initially recommended that this report place less emphasis on the issue of accelerated sea level rise. Not because it is not a serious possibility, but because a one-meter rise could have implications so profound as to cast doubt upon the wisdom of undertaking major efforts to protect Louisiana's wetlands, and might thereby lead to a delay in several pending projects. Moreover, the predictions of future sea level rise are still very uncertain. However, the panel concluded that the possibility of an accelerated rise in sea level implies that these projects would be even more essential to buy time, while a long-range strategy is formulated.

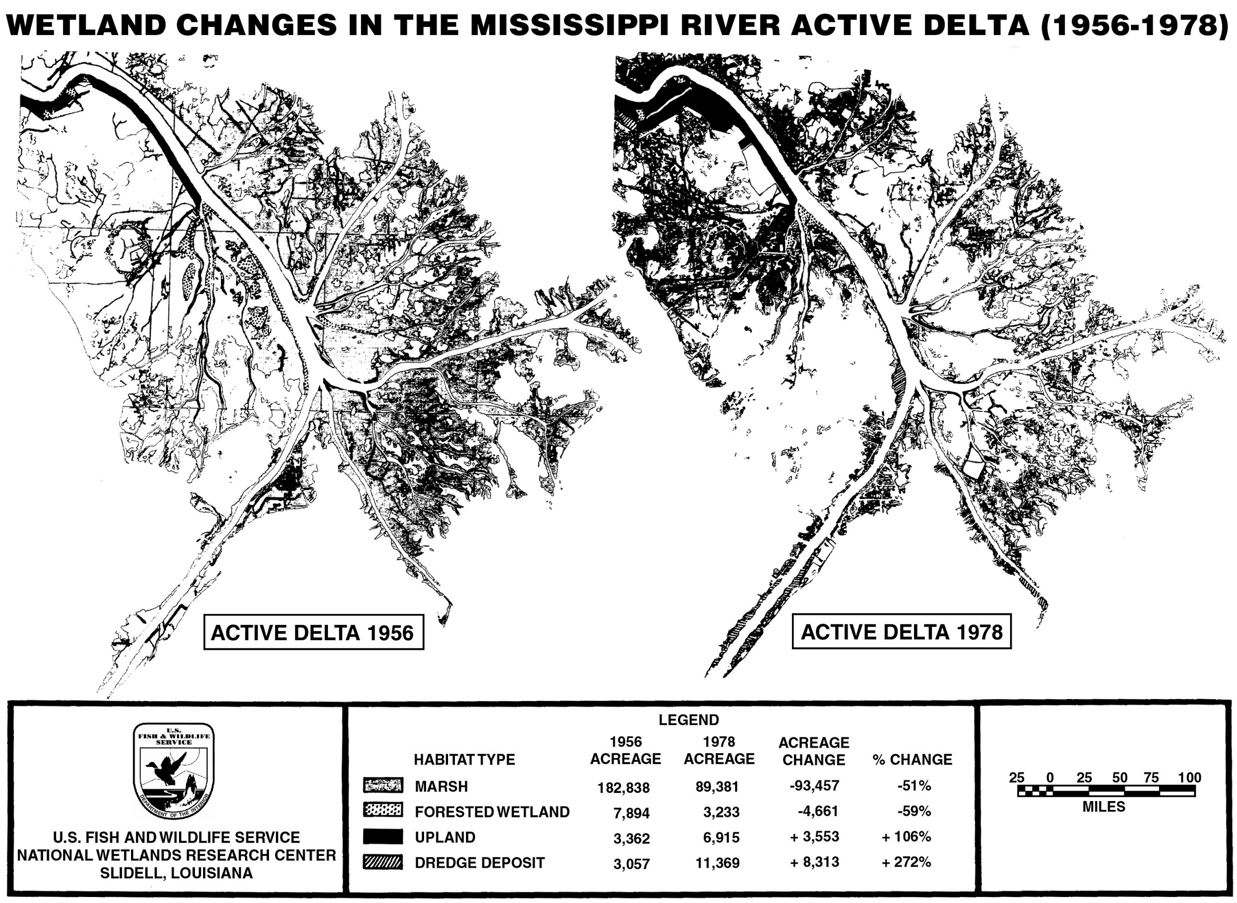


Figure 5. Illustration of wetland loss at the mouth of the Mississippi river.

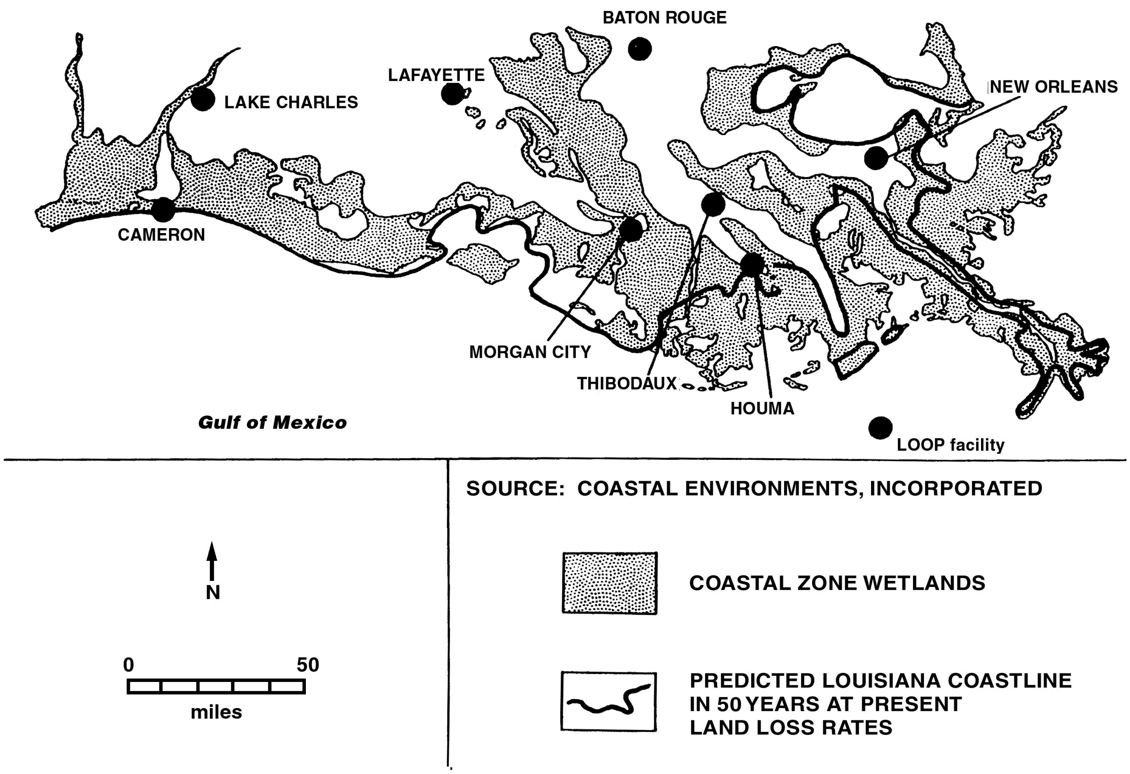


Figure 6a. Louisiana shoreline in the Year 2030.

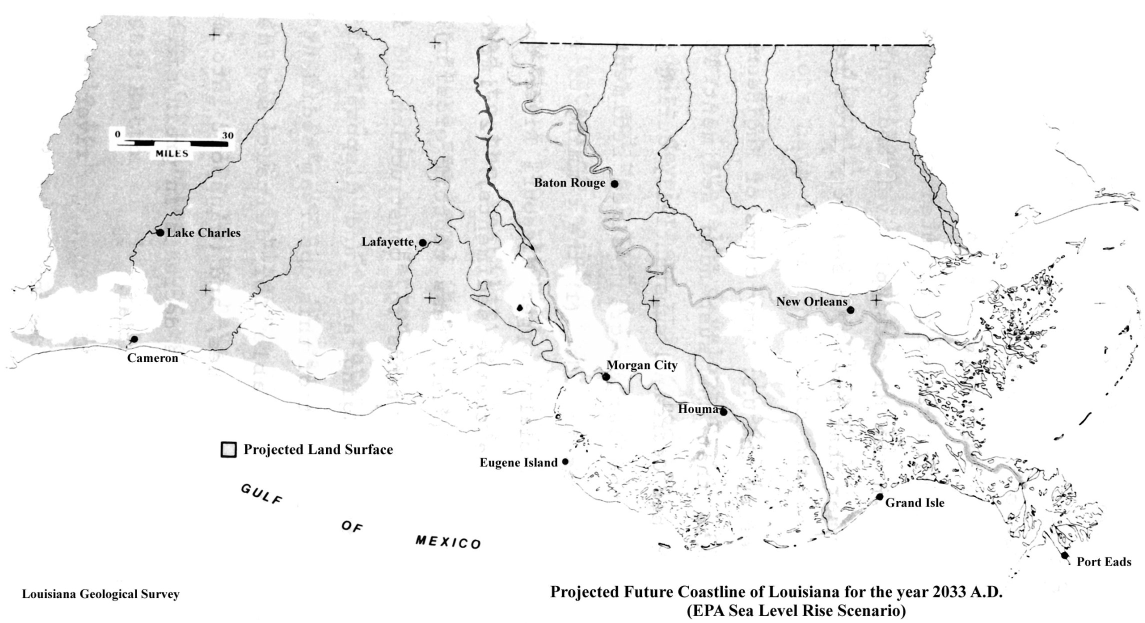


Figure 6b. Projected future coastline of Louisiana (after Ramsey and Moslow 1987) for the Year 2033 A.D. Given a rise in sea level of 54.9 cm as predicted in the high scenario (from Hoffman et al. 1983).

The remainder of this chapter discusses the factors causing land loss in more detail.

(1) Sediment Deficit

A major cause of wetland loss in Louisiana involves the reduction in sediment available to maintain the wetlands above sea level. This reduction can be attributed to two causes: less sediment flowing down the Mississippi River and confinement of the river in a manner that prevents sediment from reaching the wetlands.

Recent studies by the U.S. Army Corps of Engineers (Keown et al. 1980) indicate that the suspended sediment load of the Mississippi River has decreased substantially during the last 20 years, especially the larger-grain-sized sediments (sands). Causes of these changes include: (1) the damming of Mississippi River tributaries (especially upper Missouri River tributaries, sources of most of the coarse sediments); (2) improved soil conservation practices (i.e., less topsoil erosion); (3) the mining of pointbar (river) sands for construction and industrial usage; and (4) the dredging and land disposal of riverine sediments. The net effect of this upstream sediment use is to reduce the amount available for deltaic sedimentation, nourishment of barrier beaches, and transport into marshes by floods and tidal currents. The decrease in grain sizes has also reduced the land-building potential.

Although the sediment washing down the river has decreased, there is some doubt regarding the extent to which this reduction should be implicated as a source of wetland loss. The sediment loading that prevailed during the first half of the twentieth century may have been unusually high, due to altered farming practices and the dust bowl of the 1930s. However, there is little doubt that confinement of the Mississippi River resulting from artificial levee construction along practically its entire length has played an important role in the disintegration of Louisiana's wetlands. Levees and control structures restrict the flow into distributary channels and crevasses. These human modifications have interfered with natural delta building processes, such as overbank flooding and sedimentation, distributary and subdelta development, and broader, long-term cycles of delta development and abandonment (Frazier 1967). As a result, the sediment that does wash down the river is funneled offshore, instead of reaching the wetlands.

A significant proportion of Louisiana's land loss is directly attributed to the inability of the marsh to maintain its elevation above sea level (Baumann and DeLaune 1982; DeLaune et al. 1978 and 1983; and Hatton et al. 1983). Between 1954 and 1963, for example, subsidence rates were about 1.2 centimeters (0.49 inches) per year. Streamside marshes have accreted approximately 1.32 centimeters (0.52 inches) per year, while backmarsh accretion rates have been only approximately 0.72 centimeters (0.28 inches) per year (DeLaune et al. 1978; DeLaune et al. 1983; Hatton et al. 1983). Thus, only streamside marshes have been able to keep pace with subsidence and sea level rise. Away from streamside locations, where tidally transported mineral sediments are deposited, the marshes are rapidly eroding because of this sediment deficit.

Different marsh types show considerable variability. Hatton et al. (1983) found that intermediate and brackish marshes(0.1-1.0 percent salinity) exhibited the highest rates of conversion to open water. While exhibiting higher conversion rates, freshwater marshes have often converted to more saline marsh rather than open water.

The interference with distributary and subdelta formation processes has not only altered sedimentation patterns but delta building mechanisms in general. By maintaining the course of the Mississippi River within its present channel with various engineering controls, large-scale "delta-switching" has been prevented. During the 20th century, an increasing proportion of Mississippi River water has been flowing down the Atchafalaya River (a distributary of the Mississippi), which could become the new main channel. To prevent this from happening, the Flood Control Act of 1954 directed the U.S. Army Corps of Engineers to regulate Atchafalaya discharge to approximately 30 percent of total Mississippi River discharge by constructing the Old River Control Structure near Simmesport, Louisiana (Figure 7). The nearly completed Old River Auxiliary Structure will further reduce the possibility of a natural diversion. In spite of flow restrictions, Atchafalaya River sedimentation has filled its inland depressions in the Atchafalaya Basin and is now actively building a delta out into Atchafalaya Bay. Although this delta is only about 10 square miles today, Wells et al. (1983) project that it will grow to 80 square miles by 2030. The active sedimentation there represents the only significant wetland creation in Louisiana today.

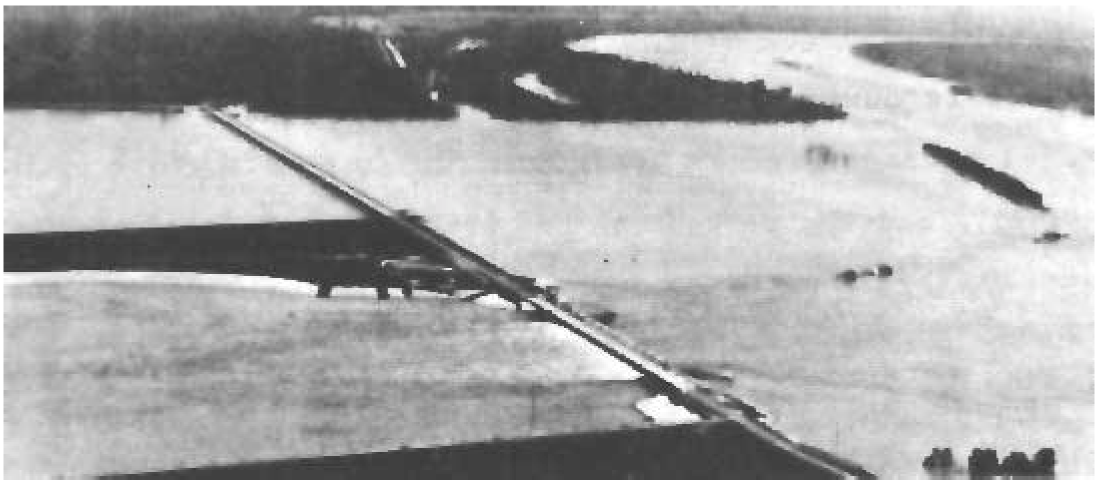


Figure 7. Old River Control Structure near Simmesport, Louisiana.

(2) Canals

Canals currently comprise about 2.5 percent of the total coastal surface area in Louisiana (Craig et al. 1980; Turner et al. 1982), and the percentage has been accelerating through time. Historically, canals have been dug for drainage and access. Today the greatest share of canalization is attributed to the oil and gas industry (Figure 8). In 1984, 70 to 80 percent of the coastal management permits issued for canals were for oil and gas activities. The primary reasons for the myriad of canals in the Louisiana coastal zone include navigation, pipeline routes, and access to drilling sites.

Although dredging canals has only directly converted 2.5 percent of the wetlands to open water, their impact is much greater. Spoil banks composed of the material dredged from the canals tend to smother adjacent marshes, converting wetlands to uplands, often interrupting natural hydrologic processes, and blocking the distribution of sediment. Canals oriented perpendicular to water flow tend to impound water and reduce sediment availability, and ponding of water can drown a marsh. Canals parallel to water flow tend to lessen freshwater retention time and allow greater inland penetration of saltwater. Turner et al. (1982) estimate that as much as 90 percent of Louisiana's land loss can be attributed to canals.

(3) Reclamation

Reclamation of water or wetlands--via fill, dredge and fill, or drainage--is usually undertaken for purposes of creating dry land that can be used for residential (see Figure 9), industrial, or agricultural purposes. Consequently, the areas in which reclamation poses the greatest threats are near large urban areas (notably New Orleans) and along the backswamps that fringe populated natural levees.

At the turn of the century, many agricultural ventures took place in the Louisiana wetlands, later resulting in the numerous rectangular water bodies that now dot the coastal landscape due to failed levees and inundated fields. Urban and agricultural reclamation of backswamp wetlands continues to have substantial impacts.

Figure 8. Canals dug in Louisiana's coastal marshes for oil and gas drilling and production operations.

Figure 9. Wetlands dredged and filled for residential development along the north shore of Lake Pontchartrain.

(4) Wave Erosion

A. Gulf Shoreline Erosion. Rates of shoreline erosion appear to have increased during the last several decades, due to human activities (e.g., jetty construction, reef removal, sand mining), indirect human impacts (e.g., reduction in available sediment, accelerated subsidence), sea level rise, and increased frequency of hurricane landfall (Morgan & Morgan 1983; Penland and Boyd 1982; Penland and Suter 1984; Penland et al. 1985; van Beek and Meyer-Arendt 1982). Rates of shoreline erosion exceed ten meters (thirty-three feet) per year, along much of the barrier coast, in both the deltaic plain and the chenier plain. (See Figure 10.) These high rates threaten established development along the coast. (They no longer threaten the base line from which the three-mile offshore state/federal boundary is measured, which has been fixed by Congress.) The rapid disintegration of the barrier islands and beaches also threatens Louisiana's first line of defense against incoming stormsurges. (See Figure 11.) If the beaches and marshes disappear, cities such as New Orleans, Houma, and Morgan City will be subjected to higher storm surges and direct wave attack during severe storms.

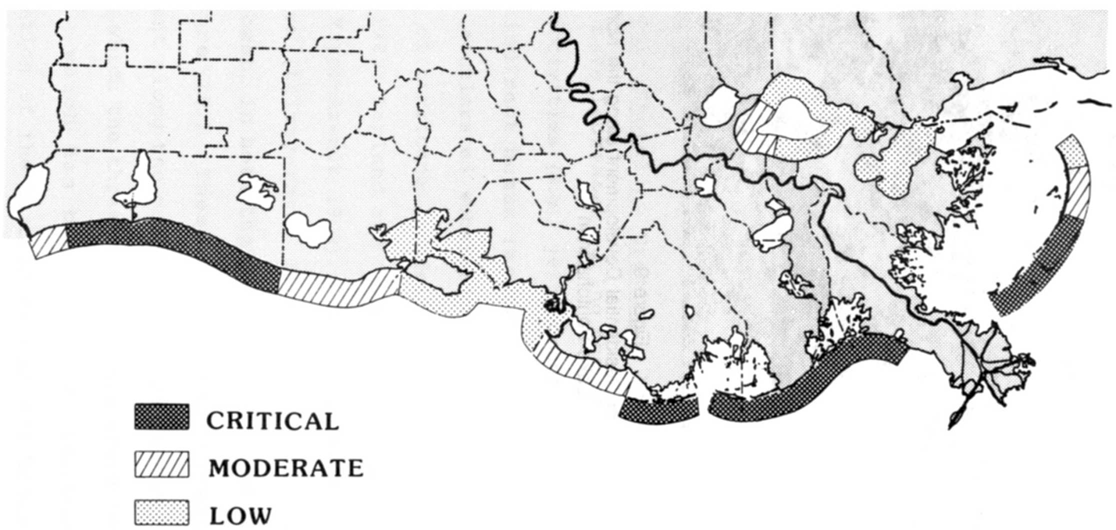
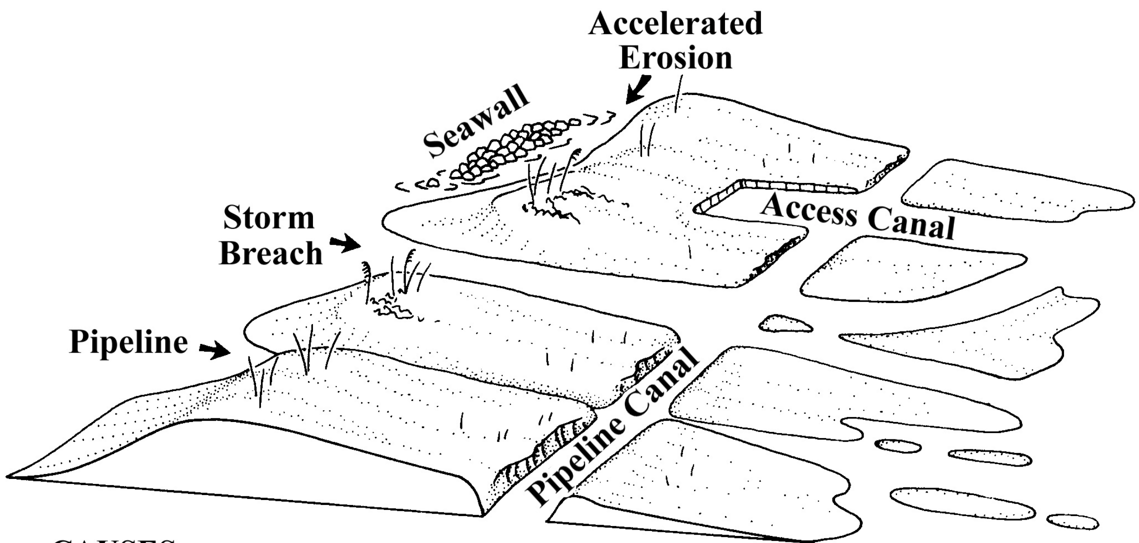


Figure 10. Severity of Louisiana shoreline and barrier island erosion.

B. Lake/Bayshore Erosion. The physical process of waves interacting with the shoreline also occurs within estuaries and is an important factor, especially along the shores of larger lakes or bays.

Unlike the Gulf shoreline where incoming waves have been generated at distant locations, wave generation within the estuaries is localized and depends primarily upon prevailing winds and boat wakes. Wind-generated wave energy is a function of wind speed, duration, fetch (distance across water body), and depth. Theoretically, the highest bayshore erosion rates should occur in the largest bays, other factors remaining equal. Bayshores facing prevailing winds (NW during winter, S-SE during summer) appear to be the most vulnerable. One study of bayshore erosion, however, determined that factors varied from location to location (Adams et al. 1978).

PRESENT CONDITIONS
DETERIORATING SHORELINE AND BARRIER ISLAND



CAUSES:

- **SUBSIDENCE-INDUCED SEA LEVEL RISE**
- **MAN'S IMPACTS: EFFECTS OF JETTIES, SEAWALLS, CANALS, AND OTHER STRUCTURES**
- **REPEATED STORM IMPACTS**

Figure 11. Existing conditions on many of Louisiana’s deteriorating shorelines and barrier islands.

Figure 12. Rapid widening of canals occurs as a result of boat wake and tidal erosion along the banks of major navigation channels.

C. Canal/Bayou Erosion. Canals and natural waterways are widening as a result of bank erosion, but the causal factors are man-made and thus much more recent and somewhat different from those in the previous two cases. (See Figure 12.) Wind and fetch-related factors are less important, while boat wakes and tidal hydraulic energy (i.e., the ebb and flow of the tides) are more important. Several studies have documented canal widening from ship traffic (e.g., Howard et al. 1984; Johnson and Gosselink 1982; Turner et al. 1982; Doiron and Whitehurst 1974), and an excellent schematic of bank erosion is presented by Howard et al. (1984). Tidal hydraulic energy in Louisiana estuaries increases in response to subsidence (i.e., increased tidal prism) and tidal inlet widening, both attributed to a combination of subsidence and barrier island erosion. Although few hard data are available, it is likely that boat wake erosion in canals and bayous is more destructive to adjacent marshes than tidal erosion.

(5) Subsidence

Because Louisiana's coastal zone is extremely flat, even a slow rate of land subsidence can result in large-scale disappearance of marshlands if no additional sediment is provided to the system. (See Figures 13 and 14.) The subsidence that occurs in Louisiana can be divided into two general categories: tectonic subsidence and consolidation/compaction (modified from Adams et al. 1976 and Mossa 1980).

Figure 13. Marsh tract that has been able to keep pace with subsidence.

Tectonic subsidence refers to the large-scale downward geologic displacement caused by sedimentary loading and associated settlement processes (Adams et al. 1976). This type of subsidence is directly linked to the Mississippi River system,which built Louisiana's deltaic plain during the last seven thousand years (Coleman and Gagliano 1964; Boesch et al. 1983). Beneath the present active delta,for example, as much as 1,000 feet of sediments have accumulated, and land subsidence rates have been estimated at 1.5 to 3 meters (5 to 10 feet) per century (Russell 1936). Away from the active delta, the rate of sedimentary loading and associated subsidence decreases. Although present subsidence rates in the lower deltaic plain are estimated at approximately ten millimeters per year (three feet per century) by Nummedal (1983), longer-term rates have been estimated between 1 and 5 millimeters per year (4 to 22 inches per century) (Boesch et al. 1983).

The consolidation/compaction aspect of subsidence is attributed to a variety of causes including overlying weight, subsurface withdrawal, and dewatering.

Figure 14. More typical view of coastal wetlands that are not receiving enough new sediment to offset the effects of subsidence and are disappearing below the water surface.

A. Overlying Weight. Examples include physical features, such as natural levees, man-made levees, buildings, spoil mounds, and even marsh-buggy traffic. The net consequence of this overlying weight is localized surface sinking as soils are compressed. In the case of natural levees, adjacent marsh soils are also often compressed to the point where waterfilled "levee-flank depressions" result (Russell 1936). Although soil compression from marsh buggies may be temporary, rebounding often does not occur, and the ruts evolve into permanent water scars.

B. Subsurface Withdrawal. The withdrawal of oil, gas, and groundwater from subsurface sedimentary strata results in subsidence, which can manifest itself in the form of localized surface subsidence (Martin and Serdengecti 1984). Based on studies in Texas and California, it is generally agreed that withdrawal from strata less than approximately 10,000 feet below the surface can cause the land surface to subside (Boesch et al. 1983; van Beek and Meyer-Arendt 1982). Although Martin & Serdengecti (1984) estimate that normally pressurized oil and gas reservoirs in Louisiana should have a maximum equilibrium subsidence of only 2 centimeters (0.8 inches), the high localized land loss rates near major hydrocarbon reservoirs (e.g., Hackberry Dome, Venice Dome, Garden Island Dome) led Adams et al. (1978) to suspect higher compaction rates.

C. Dewatering. The water table is essentially at or near the surface in a wetland environment. When it is lowered because of drainage activities, the dewatered upper soils are subjected to processes of biochemical oxidation, soil shrinkage, and wind erosion (Mossa 1980). Although "natural" factors, such as marsh burning, have been cited as causing soils to dry out and subside (Adams et al. 1976), it is primarily human efforts related to urban expansion, agricultural drainage and reclamation, and flood control that have led to widespread localized surface subsidence. In terms of land loss, the most severe environmental impacts have resulted from the failed agricultural reclamation projects that proliferated in the early decades of this century (Gagliano 1973). After these large areas of former wetlands subsided because of dewatering associated with drainage, the subsequent failure of protection levees caused rapid inundation of the entire tracts.

(6) Sea Level Rise

Because of the difficulty of separating the effects of subsidence and sea level rise during any analysis of relative changes between land and water levels, many researchers have packaged the two factors together for convenience under headings such as "relative subsidence" or "relative sea level rise." Because surface processes are a function of the net effect of the two causal factors, their separation is largely academic.

Based on various studies of tidalgauges throughout the world, commonly accepted rates of present eustatic (global) sea levelriserange from 1.0 to 1.5 millimeters per year (4 to 6 inches per century) (Gornitz et al. 1982; Barnett 1984). Tidal gauges along the coast of Louisiana indicate that the rate of relative sea level rise is 9 to 13 millimeters per year (3 to 4 feet per century) (Baumann and DeLaune 1982; Ramsey et al. 1985). Thus, global sea level rise accounts for about 10-15 percent of relative sea level rise along the Louisiana coast.

Recent developments suggest that sea level could become more important in the future. Three panels of the U.S. National Academy of Sciences, and international conferences of climatologists and oceanographers have concluded that increasing concentrations of carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, and other gases will warm the planet several degrees in the next century (Charney et al. 1979; Smagorinsky et al. 1982; Nierenberg et al. 1983; UNEP/WMO/ICSU 1985). Such a warming could cause sea level to rise by expanding ocean water, melting mountain glaciers, and eventually causing polar glaciers to melt or slide into the oceans.

In 1983, two independent reports published estimates of future sea level rise. The National Academy of Sciences Climate Research Board estimated a 70-cm rise by 2080, assuming that the possible disintegration of Antarctic glaciers does not begin by that date (Revelle 1983). The Environmental Protection Agency developed a variety of scenarios to incorporate uncertainties regarding future emissions on "greenhouse gases", the resulting impact on climate, oceanic heat absorption, and the response of glaciers to the warming, and estimated that a global rise in sea level of 26 to 39 centimeters by 2025 and 91 to 137 centimeters by 2075 is most likely (Hoffman et al. 1983). A 1985 report by the National Academy of Sciences Polar Research Board for the first time provided models of the response of specific ice fields to the projected global warming. Meier (1984) and Bindschadler (1985) estimated that alpine and Greenland glaciers, respectively, could raise the sea 10 to 30 centimeters by 2100. Thomas (1985) estimated that the contribution of Antarctica by 2100 is most likely to be about 30 cm, but that a contribution of 1 to 2 meters is possible. The panel did not revise Revelle's estimate of thermal expansion. Hoffman et al. (1986) revised their earlier projections in light of this new information, estimating the rise by 2025 to be between 10 and 21 centimeters, and 36 to 191 centimeters by 2075.

Table 1 summarizes available estimates of global sea level rise and relative sea level rise along the coast of Louisiana implied by current subsidence. Current trends would result in a 90-centimeter (3-foot) relative rise by 2085; the most conservative scenario of future sea level rise implies that such a rise will take place by 2060; but a 90-cm rise by 2040 cannot be ruled out. The current rate of relative sea level rise (1 cm/year) could double by 2030 and perhaps triple by the end of the next century.

(7) Saltwater Intrusion

Saltwater intrusion is technically not an active process but a passive response to the aforementioned processes. Canals and the reduction of freshwater supplied to the wetlands caused by levees and channelization have been the primary causes of increased salinity levels in the wetlands. Land subsidence, sea level rise, and barrier island erosion also cause saltwater ntrusion. The inland encroachment of higher salinities, evidenced especially by the changing distribution of oyster-growing areas (Van Sickle et al.

1976) is held responsible for a number of environmental impacts. For example, the optimal oyster-growing areas in each basin are shifting inland closer to sources of freshwater but also closer to sources of urban runoff, which may have high concentrations of contaminants. Although the more saline marsh types may be less valuable to furbearing animals and birds, they can be more important as estuarine nursery grounds. Some of the most severe impacts of saltwater intrusion include the destruction of cypress forests (Figure 15) and floating fresh marsh (flotant), neither of which can survive in brackish or saline water. Although fresh and brackish marshes are often replaced by brackish and salt marshes, respectively, cypress swamps frequently convert to open water instead of being replaced by more saline vegetation.

Table 1

Estimates of Future Worldwide Sea Level Rise
(centimeters above 1980 level)

	2000	2025	2050	2075	2080	2100
<u>Global Sea Level Rise</u>						
Current Trends	2.4	5.4	8.4	11	12	14
Revelle (1983)					70	
Meier et al. (1985)						50-200*
Hoffman et al. (1983)						
Low	4.8	13	23	38	-	56
mid-low	8.8	26	53	91	-	144
mid-high	13.2	39	79	137	-	217
High	17.1	55	117	212	-	368
Hoffman et al. (1986)						
Low	3.5	10	20	36	44	57
High	5.5	21	55	191	258	358
<u>Louisiana Relative Sea Level Rise</u>** (Wordwide sea level rise plus sibsidence)						
Current Trends	22	50	78	106	112	134
Revelle (1983)					170	
Meier et al. (1985)						170-320
Hoffman et al. (1983)						
Low	25	58	93	133	-	176
mid-low	29	71	123	186	-	264
mid-high	33	84	149	232	-	337
High	37	100	187	307	-	488
Hoffman et al. (1986)						
Low	24	50	90	111	144	177
High	26	61	125	286	358	478

* Assuming Revelle's model for thermal expansion, which implies 40 cm by 2100.
** Assuming subsidence of 1 cm per year.

Figure 15. Destruction of a former cypress swamp by saltwater intrusion.

CHAPTER 3

MEASURES FOR CURTAILING WETLAND LOSS

The possible options for curtailing wetland loss are numerous. They include diverting freshwater and sediment into the marshes; changing the course of the Mississippi River; modifying patterns of water and sediment flow to the marshes; maintaining wetlands artificially; restoring the barrier islands; and shifting away from the types of canals, channels, and levees that have destroyed wetlands to alternative transportation and flood protection strategies that have less adverse environmental impacts. This chapter briefly describes each of these measures.

Table 2 lists several of the options that have been proposed for curtailing wetland loss; Table 3 lists the measures that have been authorized by the Louisiana Legislature, planned by the Louisiana Geological Survey, or constructed by other organizations.

Table 2
Options for Curtailing Wetland Loss

Barrier Island Restoration, Marsh Building and Restoration
1. Restore diked, drained, dredged wetlands
2. Build marsh with materials from dredging projects instead of re-suspending dredged material in the lower river or creating spoil banks.
3. Require offsetting marsh creation for wetlands conversion due to development.
4. Raise the elevation, seal breaches, re-nourish beaches of barrier islands

Marsh Management
1. Construct tidal barriers and otherwise manage flow of water to and from marsh
2. Dike wetlands and manage artificially.
3. Thin layer deposition
4. Regulate marsh fires
5. Restore suitable marsh vegetation

Regulatory
1. Limit creation of new canals
2. Fill existing canals
3. Limit boat speeds in waterways
4. Restrict marsh buggies
5. Require mitigation for private wetland destruction
6. Subsidize new technologies

Diversion
1. Increase flow through the Atchafalaya River
2. Freshwater and/or sediment diversion to wetlands
3. Diversion to Mississippi River Gulf Outlet
4. Increase water flow to Bayou LaFourche
5. Separation of navigation from river flow using locks
6. Avoidance of additional levee construction in lower Atchafalaya

Table 3

Authorized, Planned, and Completed Projects for Curtailing Wetland Loss

Authorized by Louisiana Legislature (funded)

(1) Restore barrier islands and shorelines
- (a) Isles Dernieres
- (b) Fourchon Island
- (c) Shell Island
- (d) Timbalier/E. Timbalier Islands
- (e) Holly Beach
- (f) Grand Isle (Corps)

(2) Diversion
- (a) Caernarvon Diversion (joint state/federal project)
- (b) Pass a Loutre Marsh Creation (small diversion pilot project)

(3) Marsh Management
- (a) Montegut-Terrebonne
- (b) St. Bernard Parish
- (c) St. Charles Parish-LaBranche Wetlands

Planned by Louisiana Geological Survey (presently unfunded)

(1) Barrier Island/Shoreline Restoration and Nourishment
- (a) Plaquemines Parish Barrier Shorelines
- (b) Timbalier/E. Timbalier
- (c) Holly Beach-Cameron Parish
- (d) Caminada-Moreau shoreline

(2) Diversion (joint federal/state projects)
- (a) Davis Pond
- (b) Bonnet Carre

(3) Large Scale Wetland Protection Program (Outgrowth of this Study)

Completed by Other Agencies

(1) Barrier Island/Shoreline Restoration and Nourishment
- (a) Eastern Isles Dernieres Restoration (Terrebonne)
- (b) Timbalier Island Repair Project (Texaco, Inc.)
- (c) Grand Isle Hurricane Protection Levee (Corps)

(2) Marsh Management (numerous individual land owners)

Barrier Island Restoration

The measure with the highest priority has been the restoration of Louisiana's barrier islands--the first line of defense against the sea--by raising their surfaces and closing breaches. (See Figures 16-19.) Although storm protection has been the primary motivation, restoring these islands will also limit wave erosion of interior marshes. Furthermore, they will help to prevent additional increases in the salinity of the bays behind them by limiting tidal mixing with the high-salinity waters of the Gulf of Mexico.

PHASE I
SHORELINE AND BARRIER ISLAND RESTORATION

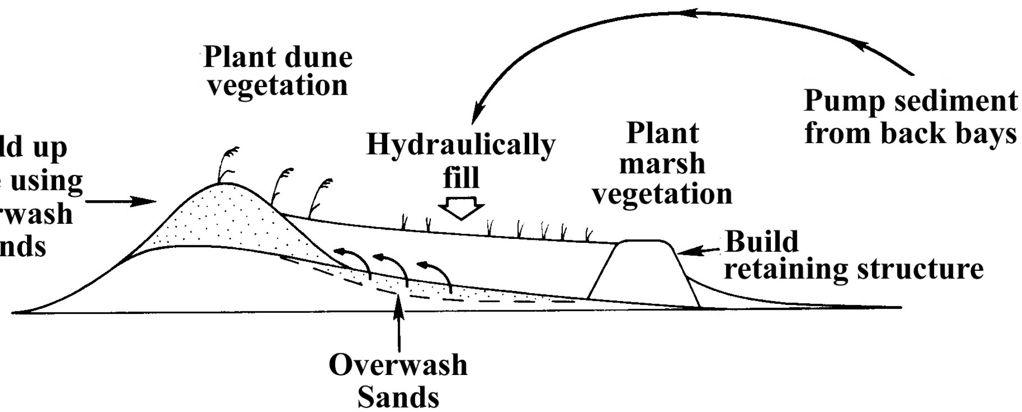


Figure 16. Cross-sectional view of shoreline and barrier island restoration plans (Phase I of the Louisiana Coastal Protection Master Plan).

Restoring barrier islands has the advantage of not interfering with existing social patterns and has thus faced little, if any, opposition. On the other hand, its ability to curtail wetland loss in the long run is limited. This measure does not prevent wetlands from being submerged as relative sea level rises, nor does it prevent marsh erosion along canals. The beneficial impacts on wetland salinity will generally be small compared with the salinity increases caused by other factors.

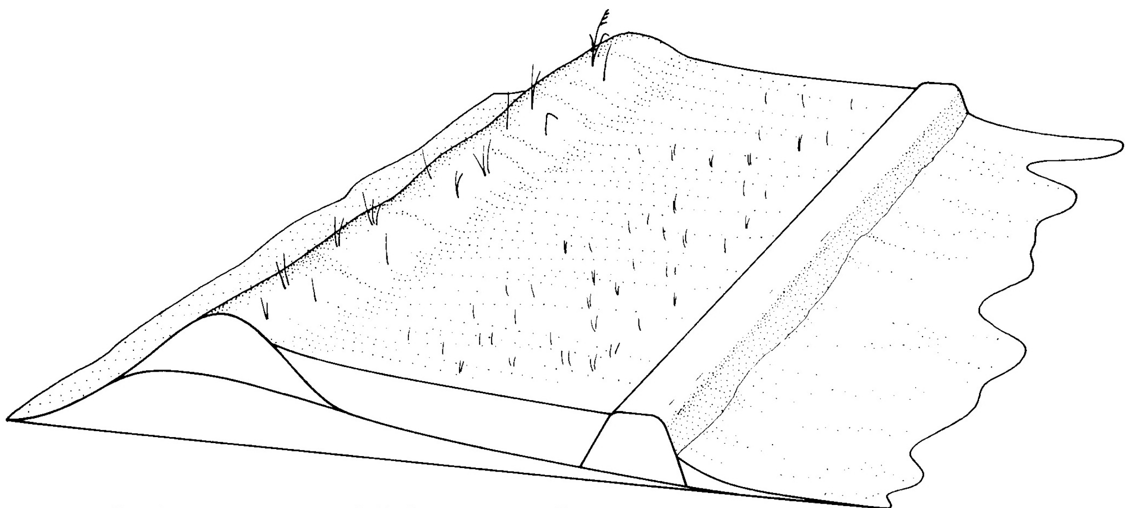
Wetland Restoration

A widely used wetland mitigation approach throughout the United States is to require those who destroy wetlands for a project to create wetlands nearby, either by lowering the surface of an upland or filling a channel or bay and planting marsh vegetation. The general procedure could be applied in Louisiana. For example, instead of resuspending material dredged from the Mississippi River, those who maintain shipping lanes could use this material to build marsh, which is currently done with some dredge spoil from Southwest Pass. Material dredged for canals could also be used to create marsh. Areas that have been diked or drained could be converted back to wetland. The Corps of Engineers (1984) has identified eight navigation channels where dredged material could support creation of 43,000 acres of marsh.

Although marsh creation has been a popular mitigation measure in the United States, its practical utility in solving the Louisiana wetland loss problem may be limited to cases where dredging of navigation channels provides material. The Corps of Engineers estimates the incremental cost of creating marsh at $700-4,100 per acre, given the existence of dredging projects that would require the disposal of dredged material. However, due to the lack of available sediment and other logistical problems likely to be encountered in creating fifty square miles of wetland per year, the cost per acre would almost certainly be an order of magnitude greater if this method were applied as a general solution to wetland loss. Accelerated sea level rise would further increase the amount of wetland creation required annually.

PHASE I COMPLETED

SHORELINE AND BARRIER ISLAND RESTORED



- **SHORELINE EROSION REDUCED**
- **DUNES RESTORED**
- **ISLAND WIDTH AND HEIGHT INCREASED**
- **BACK BARRIER RETAINING STRUCTURE COMPLETED**
- **BREACHES SEALED**
- **MANMADE CANALS FILLED**

Figure 17. Oblique aerial schematic of restored barrier island (Phase I completed).

PHASE II

SHORELINE AND BARRIER ISLAND NOURISHMENT

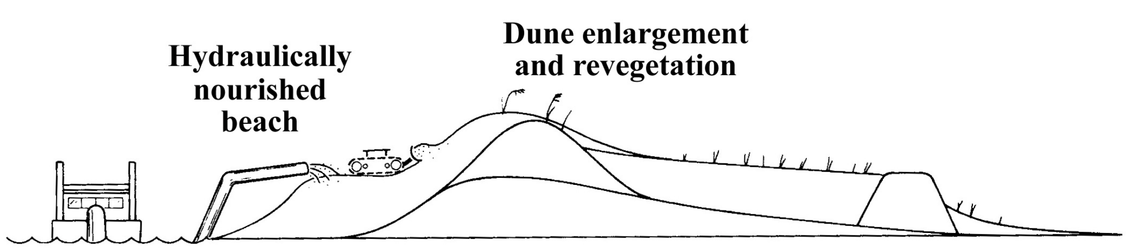


Figure 18. Cross-sectional view of shoreline and barrier island nourishment (Phase II of the Louisiana Coastal Protection Master Plan).

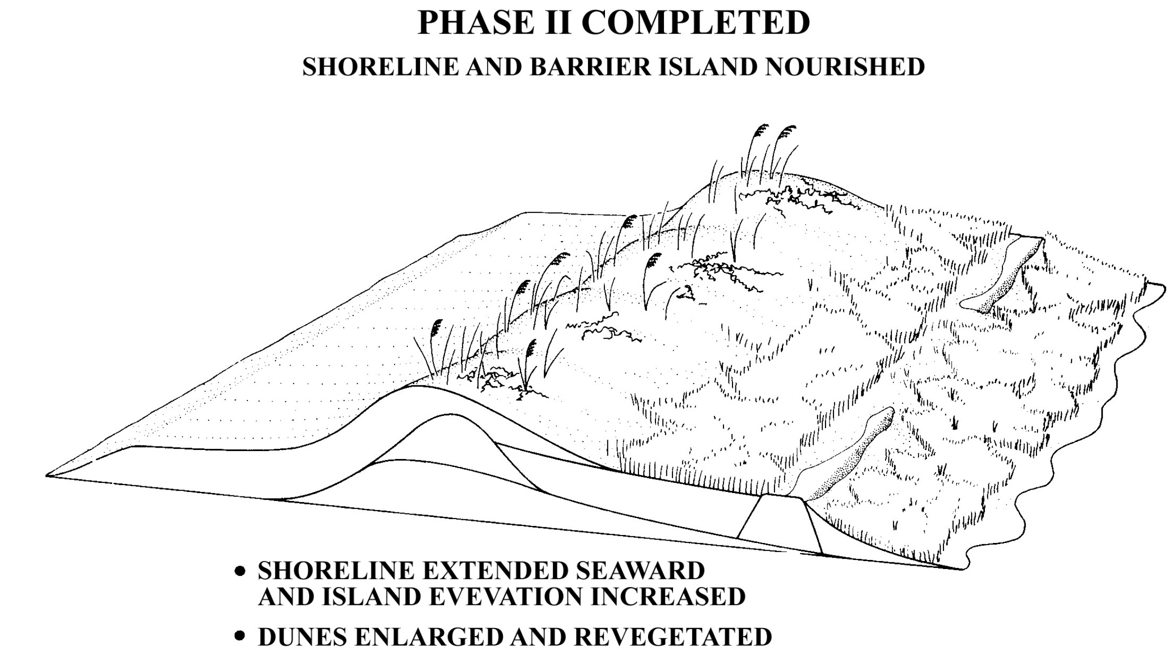


Figure 19. Oblique view of shoreline and barrier island nourishment (Phase II completed).

Marsh Management

The term "marsh management" refers to a variety of activities. The philosophy behind this approach is that human activities have so disrupted the natural wetland system that the best hope for maintaining these ecosystems is for society to step in and limit further damage. The most common form of marsh management in Louisiana is to regulate the flow of water in and out of the marsh, with the general goal of limiting salinity and controlling water levels, and to plant vegetation.

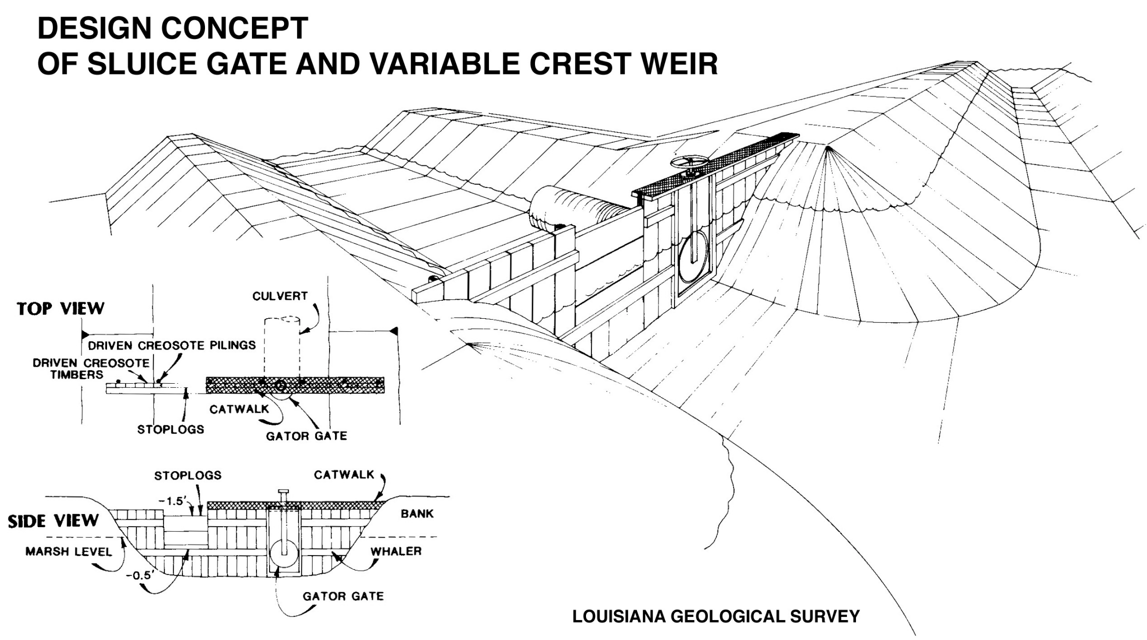


Figure 20. Design concepts for sluice gate and variable crest weir structures.

Such schemes typically involve regulating water flow in or out of wetland management units ranging in size from several acres to about five thousand acres. Wetland tracts larger than this are difficult to manage and are often partitioned into smaller units. Water flow is regulated by a system of retaining levees or dikes and some form of water control structure. Commonlyused structures include fixed- and variable-crest weirs, single- and double-flapgated culverts, and sluice gates. (See Figure 20 These structures can be operated to allow juvenile marine organisms some access to internally managed wetlands for use as nursery and feeding areas. Other management schemes involving forced drainage (mechanical pumping) to regulate water levels may prevent marine organisms from using managed areas. Currently, forced drainage is limited to populated areas.

Though goals of individual marsh management plans may vary widely, most plans usually incorporate features that enable control of water levels and salinity by preventing inflow of excess saltwater and by regulating freshwater output or inputs (rainfall, runoff, or introduced freshwater) until the desired water level or salinity is reached.

Examples of wetland areas utilizing passive (gravity-operated) marsh management schemes include much of the state-owned Department of Wildlife and Fisheries refuges and numerous privately maintained marsh tracts. These areas are often managed to optimize vegetation growth and to maintain water level conditions best suited for waterfowl that winter in these wetlands. Management of commercial crawfish ponds and other aquacultural efforts typically involves active pumping to achieve desired water levels.

An important advantage of this approach (as well as wetland restoration) is that major landowners can implement these measures themselves. Since conversion of land to open water can deprive them of income from mineral extraction, fishing, hunting, and trapping, landowners often have an incentive to manage their marshes without help from the public sector. However, because federal activities that have benefited all of society have contributed to much of the wetland loss, an argument can be advanced for public subsidies of these activities. This may be particularly advantageous if such subsidies would result in more wetland protection than equivalent expenditures for federal, state, and local wetland protection projects. Although the recent reform of the federal tax code suggests that new federal tax incentives are unlikely, the current code permits deduction of contributions to conservation groups that restore or protect wetlands.

The restoration potential of these measures is also limited. Most important, as relative sea level rises, passive management of water flow will become increasingly difficult. While tidal gates and gravity may be sufficient to adequately drain wetlands today, if sea level rises a few more feet, it will be necessary to actively pump the water out.

Terrebonne Parish is considering a plan for long-term marsh management. A tidal surge levee through the interior of the parish would be built, and marsh inland of that levee would be actively managed by forced and gravity drainage, even after the sea has risen a few feet above the marsh. The parish estimates the cost at over $100 million. This plan, however, would only be a partial solution. Although birds, animals, and some fish would benefit from the protected vegetation, active pumping systems currently do not allow shrimp and other marine organisms to pass from one side of the levee to the other. Until cross-levee migration becomes possible, this approach would do less to benefit commercial fisheries than other methods of protecting an equivalent number of acres. Nevertheless, it might be more practical than increasing sediment supplies in places that are far from active distributaries such as eastern Terrebonne Parish, particularly if sea level rise accelerates.

A final marsh management technique involves periodic spraying of sediment on the marsh to increase its rate of vertical accretion. Technologies to accomplish this goal have only recently emerged, and have some of the same logistical and cost problems as marsh creation. In spite of these difficulties, this technique may prove useful in certain areas that are just barely being submerged due to a sediment deficit. Clearly, it would be far cheaper to supply sediment to an existing, living marsh than to fill a bay to the level necessary to create a new marsh; it would also disrupt ecosystems less. (This practice is being applied to a limited extent to marsh adjacent to new canals in Terrebonne Parish.)

Canals and Land Use

Thus far, we have examined specific technical solutions without regard to how they might be implemented. Barrier island restoration will almost certainly be a public program, while marsh building and marsh management can be undertaken either as public or private efforts. By contrast, decreased speeds for boat traffic, a cutback in marsh buggy traffic, and less conversion of wetlands to dry land would generally involve public regulation of private activities. Curtailing the adverse impacts of canals could involve regulatory programs or public works.

Several researchers have proposed that the use of canals be replaced with less damaging alternative forms of transportation, such as hovercraft, which are used by oil companies in Alaska but not Louisiana. A halt to the dredging of canals would decrease the loss of wetlands. However, existing canals would continue to convey saltwater into freshwater wetlands, and would continue to convert marsh to open water as they widened.

For this reason, some have suggested that a portion of existing canals be filled or plugged. Such a strategy might be accomplished either as a regulatory program or as a public work. A regulatory program might, for example, require that for every mile of new canal, two miles of old canals must be filled or plugged. Such a policy could gradually reduce the damage caused by canals. However, it might also make the use of canals economically less attractive than alternative forms of transportation such as hovercraft, in which case the dredging of new canals would end and no canals would be sealed off.

Although reducing canalization of Louisiana's wetlands would have environmental benefits, the cost of doing so would be very great. Moreover, even a complete restoration of the original marsh would not prevent wetlands from being submerged, which could destroy a large fraction of Louisiana's wetlands in the next century if the present confinement of the Mississippi River continues.

Diversion

A class of options collectively called "diversion" would enable at least a fraction of Louisiana's wetlands to keep pace with even an accelerated rise in sea level. These options have the greatest chance of permitting the long-term survival of Louisiana's wetlands because they imitate the natural processes that have created and sustained these wetlands for the last several thousand years. Unfortunately, these measures would also impose higher costs than the shorter-term solutions discussed above.

The most imminent diversion strategy is the construction of freshwater diversion structures. (See Figure 21.) Such projects would partly offset the freshwater starvation caused by the river levees, decreasing marsh salinities and thereby slowing the rate of marsh loss. Although some sediment would also be supplied to the marsh, the amounts would not be sufficient to enable extensive areas to keep pace with current or projected rates of subsidence and sea level rise. Moreover, as long as there is a need for a self-scouring main channel of the Mississippi, there will be a limit to how much water can be diverted before the flow of the river slows more than navigation policy makers will accept. Nevertheless, freshwater diversion structures could provide important protection of wetlands as part of a short-term strategy to buy time while a long-term strategy is put into place.

Figure 21. Freshwater diversion structure at Bayou LaMoque in Plaquemines Parish, LA.

Table 4 illustrates estimates by the Corps of Engineers (1984b) of the potential for two proposed freshwater diversion structures in Barataria Basin and Breton Sound. The projected wetland loss of close to one half million acres in these two basins by 2035 could be reduced by almost one hundred thousand acres. These projections illustrate both the potential and the limitations of diversion structures.

Table 4
Potential Wetland Acreage Saved by Two Proposed Freshwater Diversion Structures
(thousands of acres)

	Barataria	Breton Sound
Current (1985) Acreage	430.5	182.9
Remaining Wetland by 2035*		
Without Diversion	245.1	131.4
With Diversion	327.8	147.8

*Assuming current rates of sea level rise.

Planned structures would reduce to 23 percent the expected 39 percent wetland loss in the next fifty years. This would represent a 20 percent reduction in the rate of statewide wetland loss.

Source: U.S. Army Corps of Engineers (1984b).

A widely advocated diversion scheme that might have a greater long-term impact would be to allow the Mississippi River to change its course to the Atchafalaya River. If this happened, the sediment flowing down the river into the shallow waters of Atchafalaya Bay would create new wetlands, rather than be carried off the edge of the continental shelf, provided that the Atchafalaya River was not subsequently modified in the fashion that has occurred with the main channel of the Mississippi River.

This latter qualification is important because the river levees being built and planned along the Atchafalaya would prevent sediment and freshwater from reaching western Terrebonne Parish. We are not certain whether the Atchafalaya will be engineered to deliberately convey all sediment off the continental shelf, or whether there will be the same need for a deep draft (50-foot) self-scouring channel.

While permitting the formation of a major new delta, diversion to the Atchafalaya would cause problems for many people. Substantial sedimentation would occur in the part of the Mississippi River immediately below the Old River Control Structure. Fortunately, the need for increased dredging in this area would not be prohibitive, because ocean-going vessels do not venture this far upstream. Another important consequence is that saltwater would be able to move farther up the Mississippi, perhaps reaching the drinking water intakes for New Orleans. (Although a shift to alternate supplies would be costly, such costs might prove to be a "blessing in disguise." The current water supply is of such low quality that one-third of the city's residents drink bottled water; Houma is currently making such a shift.) Increased Mississippi River salinity would also force some industrial users to install corrosion-resistant pipes.

An increased flow down the Atchafalaya would require the federal government to change its policy of maintaining the present flow ratio, in which it has invested billions of dollars. Finally, a new course for the river would require Morgan City and other communities along the Atchafalaya River to be either abandoned or protected with ring levees. Although abandoning a few communities voluntarily on a planned basis may be preferable to a subsequent eventual involuntary (unplanned) abandonment of the entire coastal zone, our political system might tend to avoid wrestling with difficult short-term problems by gravitating toward the latter no-action alternative.

Another diversion option that would permit wetlands to keep pace with an accelerated rate of sea level rise would be to separate navigation from the flow of the river. The rationale for such a measure is that navigation's need for a rapidly flowing self-scouring channel and the wetlands' need for freshwater and sediment are mutually exclusive.

Several measures for separating navigation from stream flow have been investigated. The New Orleans Dock Board considered diversion of shipping to a set of parallel canals along the Mississippi River Gulf Outlet, and the Corps has investigated a new channel to replace Southwest Pass. If ships used locks instead of the main channel, it would not matter if the flow of the river were slowed by freshwater diversion structures or breaches in river banks south of Venice, and new wetlands could form in substantial numbers.

The major disadvantage of this approach is the initial construction costs. In addition, shellfish production in some areas would decline, although the long-term reductions in production throughout the state would be far greater if no measures were taken. Other options, such as a new, deep water port, might also be feasible, but would have greater initial costs.

Other diversion schemes may also be worth investigating. Bayou Lafourche was an active Mississippi River distributary until it was sealed off by the Atchafalaya and Lafourche Levee Boards under the authority of the River and Harbor Act of 1902. Although the substantial development that subsequently took place (and still exists) along Louisiana's original "main street" would make a complete reactivation costly, the bayou might be used to convey a limited amount of freshwater to Terrebonne and Lafourche Parishes. The Corps has also investigated schemes to divert freshwater down the Violet Canal; however, much of the water could be lost down the Mississippi River Gulf Outlet, bypassing most of the marsh.

Although diversion of the Mississippi River to the Atchafalaya or separation of navigation from streamflow would be likely to achieve the maximum degree of wetland protection and creation, we have serious reservations about whether they would be politically feasible. Nevertheless, assessments of technically viable options should consider these measures and allow the political process--not this panel--to accept or reject options due to political feasibility.

SUMMARY

Although the loss of wetlands in Louisiana is becoming increasingly serious, it is not for a lack of options to control that loss. The problem is that the conditions that have created wetland loss are intertwined with such indispensable activities as flood prevention, shipping, and petroleum extraction. Projects have been authorized--though not funded--which would significantly slow the rate of wetland loss due to saltwater intrusion. But restoring the sediment supply necessary for the wetlands to keep pace with current subsidence (as well as projected sea level rise) would require an end to the current situation in which most of the sediment of the Mississippi River flows into the Gulf instead of the wetlands.

Given the practical realities of today, many of the panel members doubt that this will ever happen. Diversion of the Mississippi River to the Atchafalaya would require a reversal of a major long-standing policy and separation of navigation from streamflow would increase the cost of shipping. Both measures would cost billions of dollars, and no other methods have been identified to completely restore sediment supply. Nevertheless, the panel has concluded that if no politically feasible means of stopping 50 to 100 percent of the wetland loss can be identified, it is more prudent to consider measures that do not appear to be politically feasible today than to limit a long-term evaluation to measures that can only delay the inevitable.

However, it would be wrong to conclude that long-term evaluations warrant delay or reconsideration of authorized projects. If costly long-term programs of diversion or canal filling must ultimately be implemented, the planned freshwater diversion and barrier island restoration projects will still be necessary. Whether or not sea level rise accelerates, these short-term measures complement development of a long-term strategy and will help buy time for its eventual implementation.

The next chapter discusses the currently authorized projects in moredetail, while the following chapter lays out a plan for assessing the long-term options.

CHAPTER 4

AUTHORIZED AND PLANNED PROJECTS FOR CURTAILING WETLAND LOSS

For over twenty years, the Corps of Engineers, the State of Louisiana, coastal parishes, and university scientists have been studying the problems associated with wetland loss in coastal Louisiana. Under a 1967 U.S. Senate resolution the Corps' Louisiana Coastal Area Studies have evaluated mitigation options. The "Freshwater Diversion to Barataria and Breton Sound Basins" study has identified two major diversion sites that would reduce saltwater intrusion and wetland loss and improve the habitat and productivity of fish and wildlife resources. The "Land Loss and Marsh Creation" study is now focused on determining the monetary value of wetlands as (1) real estate, (2) a buffer against hurricane-induced flooding and saltwater intrusion, and (3) a producer of commercial and recreational fish and wildlife resources. Cost-benefit analyses of specific marsh creation and erosion reduction projects will follow.

The "Shore and Barrier Island Erosion" study acknowledges that continued deterioration of the barrier islands and retreat of the shore will accelerate marsh loss. Yet in this study, due to the low economic value assigned to marshes, projects in only two areas had benefit-to-cost ratios that justified further federal involvement. The "Water Supply" study assessed the scope and magnitude of the water supply problems in the coastal communities whose present sources are frequently subject to saltwater intrusion. Other Corps projects that would offset wetland loss include the diversion into Lake Pontchartrain proposed in the Mississippi and Louisiana Estuarine Areas study, and the Grand Isle and Vicinity Hurricane Protection and Beach Erosion project.

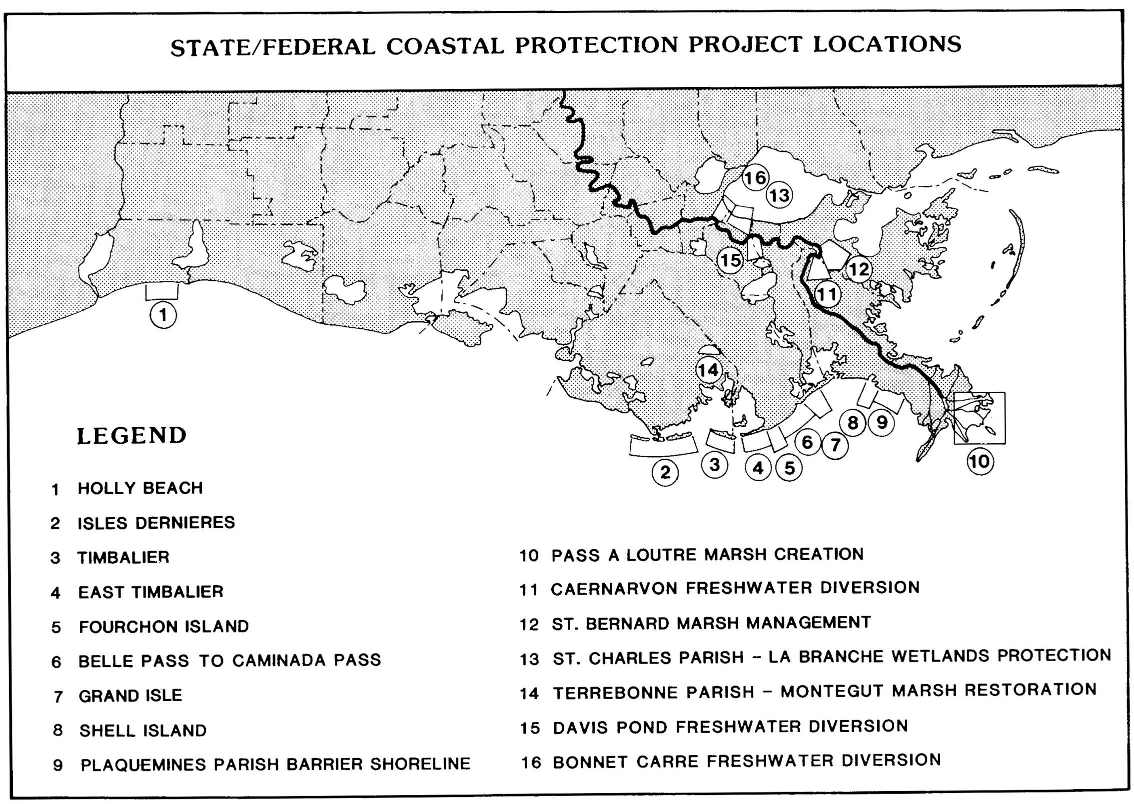


Figure 22. Map of coastal Louisiana depicting locations of state/federal coastal protection projects.

Act 41 of the 1981 special session of the Louisiana Legislature established the Coastal Environment Protection Trust Fundand appropriated $35 million for projects to combat erosion, saltwater intrusion, subsidence, and the loss of wetlands along the Louisiana coast. In 1985 the legislature approved the Coastal Protection Master Plan, which maps a 10-year strategic program for dealing with the problems the coast is experiencing. Although funds are available for implementation of the first two years of the Master Plan, future years will require additional appropriations. The thrust of the plan is to restore the barrier islands and shorelines during phase one (first five years) and to implement the wetland protection program in phase two. Figure 22 illustrates the locations of the projects to be implemented in phase one.

We briefly summarize the authorized and planned projects.

Authorized Projects

(1) Restore barrier islands and shorelines

(a) Isles Dernieres--The major project scheduled to begin in the first year of the Louisiana Coastal Protection Master Plan is the stabilization of the IslesDernieres barrier island, which involves restoring of the low dunes washover breaches,and sealing minor breaches (Figure 23). With a total estimated cost of $23,250,000, the project will relyupon placing dredged material for a width of up to one thousand feet along sixteen miles of barrier island to stabilize the dunes and to enlarge the island base, thus reducing its susceptibility to storm breaching.

(b) Fourchon Island--A cooperative project was undertaken by the state, Port Fourchon, and private interests in 1985 to protect the Fourchon Island shoreline. The efforts included closing old Pass Fourchon, relocating a beach road, and restoring the dune. Damages resulting from the 1985 hurricane season necessitated further state emergency work involving use of a hydraulic dredge to pump approximately 700,000 cubic yards of beachfill material into spoil-retention areas to restore the beach and dunes. The Greater Lafourche Port Commission is expected to revegetate the area for continued stabilization.

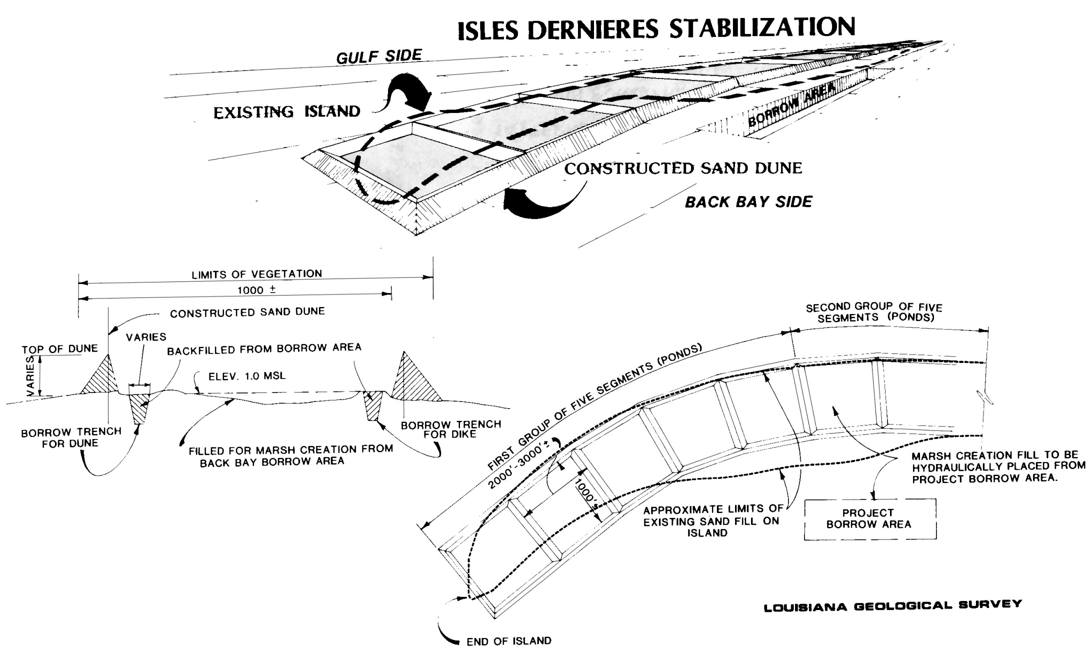


Figure 23. Restoration and stabilization plan for Isles Dernieres in Terrebonne Parish, LA.

(c) Shell Island--The second major project of the Master Plan allocates $7.2 million to restoration efforts in Plaquemines Parish at Shell Island. The project will extend five miles from the Empire Waterway jetties to Grand Bayou Pass and will produce much the same result as the Isle Dernieres project.

(d) Holly Beach--Louisiana Highway 82 is directly exposed to the Gulf waves and storms west of Holly Beach in Cameron Parish. The Office of Highways and the Department of Natural Resources have jointly experimented with heavy revetments (Figure 24) and offshore breakwaters (Figure 25) to protect the highway. These efforts appear to be working and would be complemented by the next phase of the project to continue protection measures for an additional two miles eastward from the project area.

(e) State funds will be used to match Federal Emergency Management Agency funds to replace eroded beach materials from east and west of the existing Timbalier Island seawall. More state and private-sector funds will be used to fill adjacent canals and slips to help prevent breach formation during future storms and hurricanes.

(f) Grand Isle--Portions of the sand dune were heavily damaged by repeated storms during the 1985 hurricane season. Surveys are under way to determine the exact scope of damages. In addition, a repair plan is being developed involving replacement of eroded dune segments, extension of the existing jetties on the east and west ends of the island, and installation of some type of breakwater structures in critical areas.

Figure 24. New revetment installed to protect the shoreline and Highway 82 in Cameron Parish, LA.

Figure 25. Six experimental breakwaters constructed west of Holly Beach, LA. To help protect Highway 82 from storm impacts.

(2) Diversion

(a) Caernarvon Freshwater Diversion (joint state/federal project)--This project was authorized by Congress in 1985. Advanced engineering and design has been completed for the Caernarvon Freshwater Diversion structure to introduce freshwater into the marshes and estuarine waters of Breton Sound, and the project is now ready for construction. That project will reduce marsh loss by an estimated 16,000 acres over the next 50 years. Although state matching funds for construction have been allocated in the Master Plan, federal funding for construction were not provided in the 1987 executive budget. Construction will take two years once funding is received.

(b) Pass-A-Loutre Marsh Creation (small diversion pilot project)--Artificial breaches in the natural levees of the Mississippi River and its distributaries near the mouth of the river will allow water and sediments to flow through and fill open bays and ponds thus creating deltaic marsh. The project calls for three diversions in different locations on the Pass-A-Loutre Wildlife Management Area. Figure 26 shows their locations and the extent of new marsh expected to form. The construction has been completed. Figure 27 shows the breach at the Loomis Pass site.

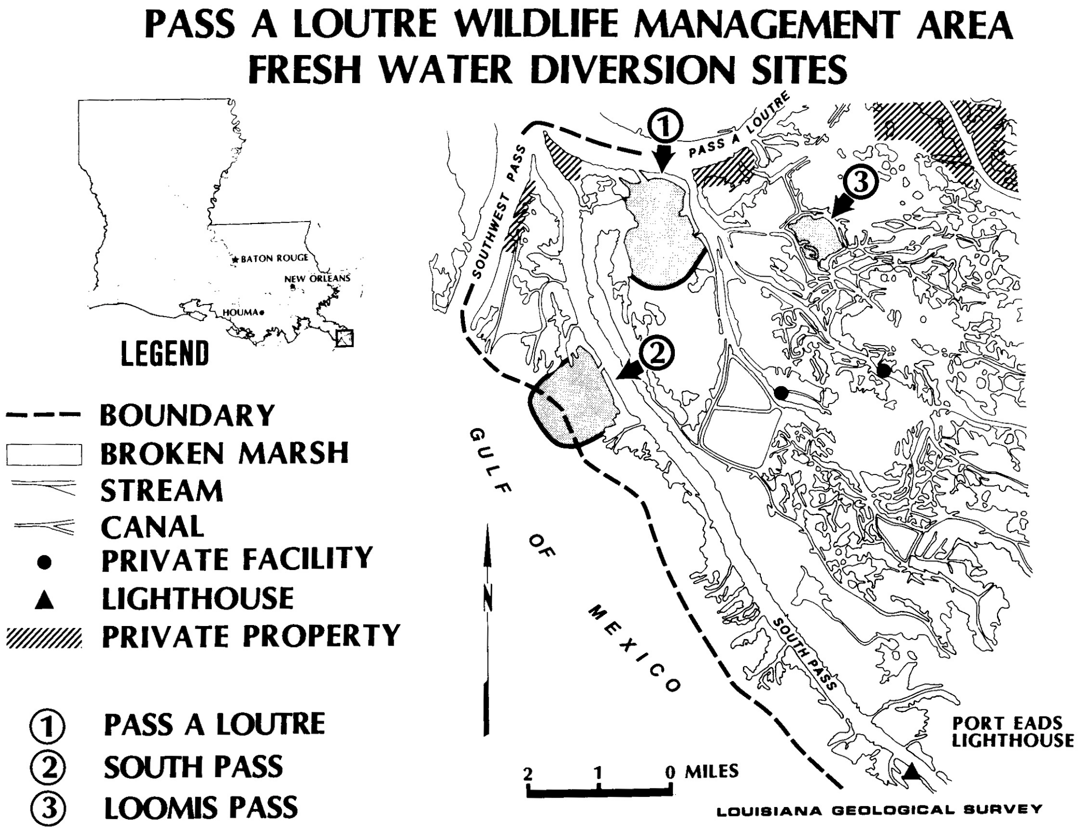


Figure 26. Location of the Pass A Loutre, South Pass, and Loomis Pass breaches and extent of New Marsh expected to form.

Figure 27. Loomis Pass Breach on the Pass A Loutre Wildlife Management Area.

(3) Marsh Management

(a) Montegut (Terrebonne)--The Master Plan provided for this project in the Point Au Chien Wildlife Management Area to use levees, fixed-crest weirs, and a flapgated culvert to stabilize water levels in the area and reduce salinity and turbidity. Anticipated benefits include a reduction in present marsh loss rates, increased production of desirable plant species, and increased fish and wildlife benefits. The project specifications are currently being prepared for advertisement and bidding. Figure 28 illustrates the project area.

(b) St. Bernard Parish--Repair or construction of levees and water control structures by the Parish will be funded by the Trust Fund to allow implementation of the wetland management plans for two of the environmental management areas. This will help offset previous loss of habitat as well as reduce the rate of future habitat degradation and wetland loss. The Parish is obtaining permits and finalizing plans and specifications on the project.

(c) St. Charles Parish-LaBranche Wetlands--This environmentally sensitive area on the southwest margin of Lake Pontchartrain has experienced severe shoreline breaching and erosion. The project calls for restoring the lake shoreline with new material and stabilization or shore protection measures to maintain the new shoreline. The project is currently being advertised for engineering service proposals.

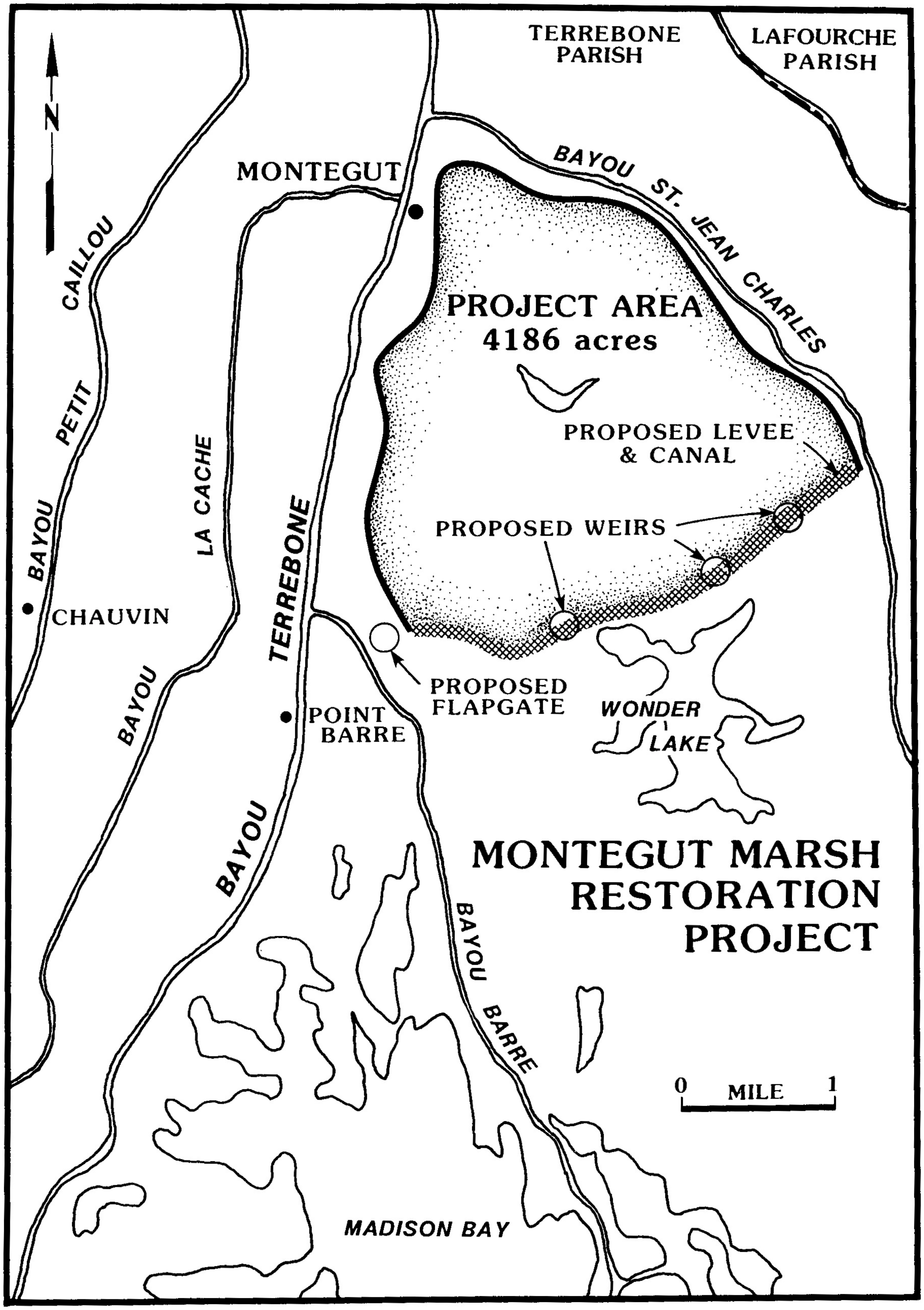


Figure 28. Map of Montegut Marsh Restoration Project.

Planned Projects

(1)Barrier Island/Shoreline Restoration and Nourishment

(a) Plaquemines Parish Barrier Shoreline--Assuming the availability of additional state funding in 1987, the Master Plan allots $31,550,000 to restore the Plaquemines Parish barrier shoreline from Sandy Point to Barataria Pass. A request for engineering services proposals could be advertised upon Legislative approval and authorization of these funds.

(b) Timbalier/E. Timbalier--With a projected initiation date in 1988, the restoration of Timbalier and East Timbalier (Figure 29) will cost $6.5 and $20.3 million, respectively. Again, the future funding of this Master Plan project will depend upon availability of additional state funds.

(c) Belle Pass to Caminada Pass Shoreline--In the last year of Phase I of the Master Plan (1989), the restoration of the shoreline between Belle Pass and Caminada Pass in Lafourche and Jefferson Parishes is scheduled to begin. Costs are estimated at $21.1 million.

Figure 29. East Timbalier Island. Note that the island has continued to subside and wash away despite all company efforts to encircle the island with rock sea walls.

(2) Diversion

(a) Davis Pond--As part of the Louisiana Coastal Area, Freshwater Diversion to Barataria Basin study, the Corps of Engineers, in cooperation with the Governor's Coastal Protection Task Force and St. Charles Parish officials, has selected a diversion site at Davis Pond near Luling to introduce freshwater and sediment into the Barataria Basin. Marsh losses will be reduced by 82,700 acres over the next 50 years if this project is constructed. Advanced engineering and design studies requiring no more than four years to complete can begin after federal funding approval, with construction requiring two additional years. If approved by the Chief of Engineers (Corps of Engineers), the project would be constructed under the authority of Public Law 89-298, passed in 1965.

(b) Bonnet Carre--The Corps' Mississippi and Louisiana Estuarine Area study has recommended that a large freshwater diversion facility be built just north of the Bonnet Carre Spillway. Planning and engineering studies are continuing on this project, which will enhance estuarine habitats in the Lake Borgne-Chandeleur Sound area. The project also awaits Congressional authorization.

(3) Large Scale Wetland Protection Program--Outgrowth of the Study Proposed In Chapter 5

(a) Coastal Vegetation--A component of the Master Plan, the Coastal Vegetation Program will complement the major restoration projects by providing plants, planting machines, and the technology necessary to revegetate the restored barrier islands (see Figure 30) and shorelines. This component will also provide for work in areas where plantings alone will reduce erosion, restore wetlands, or enhance formation of new wetlands.

Figure 30. Sand fencing and vegetation plantings help build and stabilize barrier island sand dunes.

(b) Wetland Protection/Basin Approach--An essential part of Phase I of the Master Plan is to develop a wetland management and protection program that can be implemented during PhaseII (the second five years of the of the Master Plan). This study will help form the basis upon which this wetland protection program will be developed. The best strategy for addressing the problem appears to be adopting a basin approach that uses discrete drainage basins as management units. This approach enables comprehensive protection efforts to address the individual problems and needs of each basin or region.

The Need to Move Forward

A large number of projects for curtailing land loss in Louisiana have been identified and become part of the state's Master Plan. Nevertheless, it would be very misleading to say that these measures will solve the problem. Many of them still await funding from the federal or state government. Because these projects primarily benefit Louisiana, they may be viewed by some as "pork-barrel" projects that tax the nation to support a small constituency. However, a closer examination reveals that proposed federal projects are largely in the nature of corrective action to mitigate adverse environmental impacts of federal activities. Because the benefits of these projects will accrue over many decades, it may be tempting for a state in the midst of a financial crisis to delay these projects a few years. But a realistic look at the costs of protecting wetlands suggests that if the relatively inexpensive means that have been identified are not implemented soon, far more costly solutions will have to be implemented in the 1990s.

Nor does the necessary exercise of developing a long-term plan to address subsidence and sea level rise provide a justification for delaying these projects. The long-term plan will benefit from the experience of testing the proposed measures outlined in this chapter. Moreover, there is little reason to believe that the long-term plan will devise strategies that would in retrospect prove these projects to have been unnecessary. Any long-term solution to the problem of subsidence and sea level rise would, at a minimum, require the diversion of freshwater into the marsh to prevent saltwater intrusion and the restoration of barrier islands. A long-term solution will probably require more substantial actions as well--how much more will depend in part on how long we delay the implementation of measures that have already been approved.

CHAPTER 5

TOWARDS A STRATEGIC PLAN: A PROPOSED STUDY

The Need To Examine the Big Picture

Coastal scientists and government officials have known for several decades that human activities could destroy the bulk of coastal Louisiana's wetlands, and the way of life for the people who depend on them. Since the 1970s, scientists and officials have been aware that such a rapid destruction is, in fact, taking place. In 1981, the Louisiana Legislature created a $35 million trust fund to research, develop, and demonstrate methods to curtail land loss.

Since then, many possible solutions to wetland loss have been identified, and major projects have been planned. Nevertheless, the currently authorized projects are not expected to slow the statewide rate of wetland loss by more than 10-20 percent. Yet each major construction action to date has been hard fought and provides limited protection. The "big picture" of all possible actions, costs, and benefits is missing. To gain this view, a strategic plan will be required that places each action to be taken in a context that addresses the entire problem. To a large extent, such plans can be developed for particular hydrologic units. Nevertheless, some options would affect more than one unit, particularly freshwater and sediment diversion. Thus, a comprehensive plan must look at all the wetlands of the Mississippi deltaic plain.

It is now evident that a program to save a major fraction of Louisiana's wetlands would cost two or more orders of magnitude more than the resources currently allocated to the problem. Moreover, it would require federal government and private-sector interests to cooperate in state initiatives, which may imply restraints or major modifications of their policies and activities.

The political process must resolve whether these costs are justified by the protection of America's largest coastal wetland ecosystem. A political solution, however, will require scientists and analysts to provide policy makers with one or more comprehensive plans for addressing the issue. Thus far, professionals have developed numerous options that could slow wetland loss. But they have not yet provided policy makers with a map of what coastal Louisiana will be like thirty to one hundred years hence for each of the possible options. People have tended to focus on specific projects rather than on determining what must be done to achieve the desired level of wetland protection.

This panel was convened to chart a course for removing this impediment to the planning process. Although much research is still necessary, we believe that the information base is now sufficient to make first-order assessments. Below we outline a study to synthesize available information to evaluate the likely consequences of twenty alternative plans of action.

We do not dismiss the concern of many that after years of research, the time for studies has passed and it is now time for action. But we doubt that sufficient action can take place without a clear picture of the likely economic and social consequences of taking or not taking the necessary measures. This is especially true because many of the parties that must ultimately play a role in the eventual solution are largely unaware of the problem or are not yet convinced that the problem warrants their attention.

In the study we envision, a wide variety of wetland protection options will be considered. For each option or combinations of options, a map of future wetland loss will be developed, along with a cost estimate. When this study is complete, it will be possible for policy makers to say: "If we want to have 50 percent of our wetlands by 2100, it will cost this much; if we want to retain 10 or 25 percent, it will cost this much. In each case, here is what a map of Louisiana would look like." It will also enable policy makers to assess the economic and social costs of losing the land (with no protective efforts) and to compare these long-term revenue losses with shorter-term restoration expenditures.

This information will not guarantee adoption of major actions to protect Louisiana's wetlands. But without such information, implementation of the necessary measures will be extremely unlikely.

Table 5 illustrates the major steps of the proposed study, which can be divided into two parts: (1) Estimating the cost of particular levels of wetland preservation, and (2) evaluating the benefits of various levels of wetland protection and the long-term costs of the no-action alternative. In the first phase, the study will project statewide land loss in the next century for a variety of remedial measures and estimate the cost of implementing those options, for three scenarios of future sea level: current trends, a medium scenario, and a high scenario. It is particularly important that this study consider scenarios of accelerated sea level rise because the many studies conducted by the Corps of Engineers have only used historical trends, which may provide misleading results regarding the relative merits and cost/benefit ratios of various projects. The second phase will consider benefits such as reduced flooding and flood mitigation costs, greater seafood harvests, increased hunting and trapping, and achievement of the nation's environmental goals.

Table 5

Outline of Proposed Study

Phase 1: Strategies for Achieving Particular Levels of Wetland Protection

1. Use existing data to project wetland loss through the year 2100, assuming current trends and two scenarios of accelerated sea level rise, if no additional mitigation measures are taken.
2. Estimate the loss of wetlands likely to result for each of the mitigation measures listed in Table 6 for each of three scenarios of relative sea level rise.
3. Estimate the costs of implementing each of the options in Table 6. Cost estimates include capital and operating costs.
4. Develop maps to show future shoreline.
5. For each of the major uncertainties in projecting wetland loss, base estimates on high and low values that bound the uncertainties.

Phase 2: The Desired Level of Wetland Protection

6. Project values through 2100 for flood damages, navigation, resource production, and all of the other factors that depend on Louisiana's wetlands (listed in Table 7 assuming no additional loss of wetlands.
7. Estimate the value through 2100 of each of the factors listed in Table 7, for each of the scenarios of wetland loss considered in task 2, above.

Phase I: Strategies for Achieving Particular Levels of Wetland Protection

The first step is to project the likely loss of wetlands if current conditions continue. The ongoing study of future coastal conditions by the Louisiana Geological Survey will provide estimates of future conversion of wetland to open water. The conversion to dry land for building sites will also be considered in this base line.

As described in the previous chapter, this panel has reviewed a wide variety of measures for slowing the rate of wetland loss. Those measures can be broadly classified into (1) diverting the Mississippi River in directions that would better enable marsh creation; (2) reducing the number of canals; (3) barriers to prevent flooding and/or intrusion of saltwater into the wetlands; and (4) modifying land-use and land-creation practices.

One of the most difficult challenges facing us has been to pare down the list of options to a manageable set for purposes of a comprehensive analysis. We have used two main criteria: (1) likelihood of implementation; (2) degree of wetland protection offered. Table 6 lists options that we believe should be assessed. Of those measures, we believe that carrying out planned and authorized projects (option 2), construction of additional diversion structures (option 5), a 50 percent reduction in canal dredging (option 6), and marsh management (option 11) are all reasonably likely to occur. Unfortunately, there is little reason to believe that these measures will reduce the loss of wetlands in the next fifty years by as much as 50 percent, particularly if sea level rise accelerates.

Table 6

Wetland Protection Options

Baseline

1. No action.
2. Currently authorized and planned projects.

Diversion

3. Increase the share of the Mississippi River water flowing down Atchafalaya River from 30 percent today to 70 percent over the forty-year period 1990-2030.
4. Free the natural processes of the active delta by constructing locks and canals from the Mississippi River to adjacent open waters, and abandon artificial channels, levees, and bank maintenance projects along the river below the canals.
5. Construct twice as many diversion structures as have been currently planned.

Canals

6. Slow the projected rate of net canal dredging by one-half.
7. Fill existing canals at the same rate that new canals are created, importing material where necessary. Fill existing canals for a net reduction of 1 percent per year for the next fifty years.

Land Use

8. Restore one-half of wetlands that have been diked and/or drained for conversion to pasture or cropland.
9. Wetland creation and maintenance to offset conversion of wetlands for development.
10.

Other

11. Marsh management (weirs, floodgates, restricting marsh buggy traffic)
12. Hurricane levee/saltwater intrusion barrier parallel to Gulf shore.

Combinations

A. Options 2, 5, 6, 11
B. Options 2, 3, 6, 11
C. Options 2, 3, 7, 11
D. Options 2, 3, 8, 11
E. Options 2, 5, 8, 11
F. Options 2, 4, 7, 11
G. Options 2, 4, 8, 11
H. Options 2, 5, 6, 11, 12

To save a substantial fraction of Louisiana's wetlands in perpetuity would require implementing more costly measures. Allowing the river to divert its flow to the Atchafalaya has long been proposed, and would enable a substantial acceleration of marsh creation to take place at this emerging active delta;

option 3 proposes to increase the Atchafalaya share by 1 percent per year for the next forty years. (This option would not necessarily imply a uniform increase for all parts of the year. Diversion of the excess during late winter and early spring would be likely to provide greater sediment with fewer adverse impacts on navigation.) Separating navigation from the natural processes of the active delta through construction of bypass canals and locks from the river above the delta to nearby open waters (option 4) would make it possible for natural deltaic processes to return to the current active delta. Each of these measures ould be expensive. However, they would protect a larger fraction of the wetlands even if sea level rise accelerates.

Filling canals would decrease the loss of wetlands from saltwater intrusion and wave action. Option 7 requires no new net canal formation, while option 8 requires a net reduction in canals of 1 percent per year for the next 50 years. Converting areas that once were wetlands back to wetland (option 9) would offer a one-time opportunity to increase the area of marsh. Hurricane levees with pumping systems (option 12) would be mainly designed for flood protection, but might also slow the loss of wetlands by preventing saltwater intrusion and the drowning of wetlands provided that no development were allowed within the new levees. As discussed above, such areas would no longer serve as nurseries for estuarine fish unless special exchange structures were built to enable fish to cross the levees.

To gain an understanding of the usefulness of the measures at our disposal, it will be necessary to examine various combinations of these measures, also shown in Table 6. All of the combinations we suggest would include currently planned and authorized projects, including the restoration and maintenance of barrier island chains, and enhanced marsh management. In addition to those measures, Combination A would involve a doubling of the construction of river diversion projects and a 50 percent reduction in the rate of canal dredging. Combination B would be similar except that instead of additional diversion structures, we would stop preventing the natural tendency of the Mississippi River to switch to the Atchafalaya channel by allowing increased flow to the Atchafalaya to take place at a rate of 1 percent per year for the next 40 years.

Combinations C and D would be similar to B, except that C would also require no net increase in canals while D would require enough filling of canals to reduce the area of canals by 1 percent per year for the next 50 years. Combination E would also incorporate the drastic reduction in canals dictated by option D, but would only require a doubling of planned diversion structures instead of the major diversion to the Atchafalaya River.

Combinations F and G would employ a different diversion scheme: restoring the natural deltaic processes of the lower Mississippi River by separating navigation from river flow. If shipping were restricted to canals with locks, say, near the existing Mississippi River Gulf Outlet, it would no longer be necessary to maintain river banks and channels downstream of Venice, and sediment could be diverted into shallow water instead of continuing to wash off the edge of the continental shelf. Combination F assumes that this "rediversion" scheme is employed, along with no net increase in canals. Combination G adds the 50 percent reduction in canals to this diversion scheme. Finally, option H offers a completely different combined strategy of slowing the rate of canalization, doubling the number of diversion structures, and employing hurricane levees as barriers to saltwater intrusion.

This list of combinations is not exhaustive. However, by analyzing these combinations it should be possible to better understand the extent to which various strategies complement one another. Options 9 and 10 could also be employed along with these combinations; we left them out of the list only because their contributions could reasonably be expected to be independent of the other options employed.

Projecting wetland loss for these options would be an ambitious task. The many uncertainties suggest that precise estimates will not be possible. Nevertheless, it should be possible to bound the uncertainty limits to provide decision makers with a clearer picture of the likely outcomes of various strategies.

The study we propose would be based on existing information; it would not undertake additional basic research to answer questions that are still hotly debated, although such research should be continued to improve the existing data base. For example, some people may believe that canals are responsible for 25 percent of wetland loss while others believe that they are responsible for 75 percent. Regardless of the relative blame, filling of canals alone would not save the wetlands if the sea level rises rapidly in the future; irrespective of the relative blame, saltwater intrusion resulting from canals can be curtailed either by closing off the canals or by introducing additional freshwater to inland wetlands. In cases where uncertainties about particular processes impede projections of the impacts of particular options, the study will make projections assuming high and low limits to these process contributions, in a manner similar to that employed by the Environmental Protection Agency report Projecting Future Sea Level Rise.

Phase II: The Benefits of Wetland Protection

Phase I will make it possible to provide maps depicting coastal Louisiana as it will appear in the future to the public and to policy makers. This information may be sufficient for some people to decide the level of effort appropriate for protecting Louisiana's wetlands. However, others may require assessments of the implications of various levels of protection.

Table 7 lists the more important impacts that we believe should be estimated. Increased flood damages and the costs of preventing flood damages could be very important to many coastal parishes and, eventually, the City of New Orleans. The impact of such increases on flood insurance rates and claims could be important to the federal government, particularly the Federal Emergency Management Agency, which manages the National Flood Insurance Program. In addition to flood damages, the value of land and structures lost to erosion should also be considered, including infrastructure financed by the federal, state, and local governments.

Table 7

Impacts of Wetland Loss (units in parentheses)

1. Flood Damages (probability of storm equal to current 100-year storm, number of residences lost per decade, dollars)
2. Flood Control Costs (dollars)
3. Flood Insurance Claims and Rates (dollars)
4. Lost Infrastructure (type, quantity, dollars)
5. Private Land and Structures (number of residences, businesses, acreage, dollars)
6. Commercial Seafood Production (pounds, dollars)
7. Commercial Hunting and Trapping (catch, dollars)
8. Recreational hunting and fishing (recreation days, dollars)
9. Other Recreation and Tourism (recreation days, dollars)
10. Shipping (tonnage, costs per ton)
11. Channel and River Maintenance Costs
12. Drinking Water (costs, health effects)
13. Cost to protect hurricane, navigational and flood protection levees from storm waves as protective marsh and barrier islands disappear. (dollars)
14. Employment (jobs, dollars)
15. Water quality improvements (cancers prevented, increased yields)

The value of lost seafood, hunting, fishing, and trapping will also be important. The dollar value will have significance to the local economies; moreover, the resulting drop in nationwide seafood production will be important to a variety of national constituencies, including the restaurant industry and the general public, and the poultry industry, which relies on Louisiana's menhaden. Adverse impacts on tourism should also be considered. Finally, potential increases in some seafood species must also be considered.

Because wetland loss is caused in part by activities designed to aid navigation, shipping-related costs may increase as a result of measures to curtail wetland loss. River diversion projects would slow the flow of the Mississippi, perhaps necessitating additional dredging. Diversion to the Atchafalaya may require dredging downstream of the Old River control structure, although it might also result in decreased dredging costs in the lower part of the main channel. Separating navigation from river flow with the construction of canals and locks would increase shipping costs by the additional time spent waiting for the use of the locks (however, the shorter route with no downstream current to fight may partially or totally offset waiting periods or delays, and save in fuel costs).

Drinking water would also be affected by wetland loss and proposed mitigation options. Wetland loss and many of its causes are likely to continue to increase the salinity of water supplies. On the other hand, diversion of the Mississippi River to the Atchafalaya would enable saltwater to reach farther up the Mississippi channel and may render existing water intake supplies too salty for use. The costs of developing an alternative water supply for New Orleans would thus have to be considered; because such a supply would most likely be of higher quality than the city's current supply, the reduction in the use of bottled water and increased level of health of the city's population would also have to be factored in. Finally, the negative impacts of wetland loss on employment must be considered.

To a large degree, the decision regarding the appropriate level of wetland protection will depend on the cost of mitigation and the benefits of protecting wetlands. Many of the members of this panel are concerned, however, that an overreliance on conventional cost-benefit analysis may justify a level of wetland protection far less than the public at large would favor. Our concern falls into two categories: (1) cost/benefit analysis only considers readily measured commodities traded in the marketplace, and overlooks nonmarket values of environmental resources and societal goals; and (2) formulas commonly used to estimate the benefits of small wetland protection projects may not be consistent with economic theory when applied to projects to protect all of coastal Louisiana.

There is a national interest in maintaining our cultural heritage and environment for future generations. Methods of estimating the value of an acre of wetlands do not generally consider these latter factors. For example, methods used by the Corps of Engineers to estimate the value of wetland protection in Terrebonne Parish generally conclude that the marsh is worth about $2500-6400 (Costanza and Farber 1985). Yet federal, state, and local governments have often required mitigation for wetland destruction outside of Louisiana at costs of $25,000-$35,000 per acre (OFA 1986). This discrepancy suggests that the actual value to society of maintaining coastal ecosystems is far greater than the current cost/benefit methods would lead one to believe.

Even when a conventional market analysis is employed, the value of the entire ecosystem will be far more than what one would estimate by multiplying the value of one acre by the number of acres. A loss of 10 percent of Louisiana's remaining wetlands would increase the risk of flooding in some areas; but if 60 percent of the wetlands are lost, the last 10 percent could significantly increase the risk of flooding in major urban areas.

Furthermore, an accurate analysis of the value of Louisiana's wetlands should include a sound treatment of what economists call "consumer surplus." The economic cost is reflected not only by current market prices, but by what people would be willing to pay for the resources supplied by wetlands. If shrimp costs $3.00 today but would rise to $6.00 with the loss of Louisiana's wetlands, an economic valuation of lost shrimp production should reflect values of shrimp ranging from $3.00 to $6.00, perhaps for an average value of around $4.50. The same situation applies to residential land values. Although a native of coastal Louisiana may have only paid $50,000 for his house, his heritage and fondness for hunting and fishing may so tie him to the area that it would be worth considerably more to him to stay in coastal Louisiana, as long as the character of the area is maintained.

Finally, the choice of an interest rate by which to "discount" future costs of wetland loss into current values plays a very important role. The use of the high rates that have prevailed during the 1980s can be used to trivialize the distant future. Care must be taken to ensure that the discount rates used in the analysis reflect society's tradeoff between present and future generations.

It is important that assessments of the benefits of protecting wetlands focus not only on "bottom line" dollar estimates, but on the uncertainties in such estimates and on noneconomic ways of viewing these benefits. Although middle-level managers must often make decisions on the basis of quantitative cost/benefit information, the achievement of nonquantitative values and objectives can be equally important to political leaders and the public at large.

CHAPTER 6

CONCLUSION

We have reviewed the body of literature concerning the causes and potential consequences of wetland loss in Louisiana. We have tried but have been unable to find any evidence that this ecosystem can be saved without massive efforts to correct the cumulative damage that has occurred over the last fifty years, efforts that will require the assistance of federal, state, local, and private organizations.

Wetland loss in Louisiana is a problem for the nation. The United States benefits from the shipping that passes through the Mississippi River, both economically and in terms of national security; but for the last century, efforts to maintain the shipping lanes have taken a toll on the natural ability of the river to supply the wetlands with sediment. The entire nation has benefited from the extraction of oil and gas, which has been permitted by the federal government; but the canals that were necessary to provide access to the wells have left a legacy of conduits by which saltwater can invade and destroy the wetlands. The federal government has participated in the construction of flood control levees and dams along the Mississippi River and its tributaries, which also deprive the wetlands of sediment.

The Louisiana Legislature has recognized that wetland loss is also a problem for the state, and created the Coastal Environment Protection Trust Fund. Several coastal parishes also have programs to address wetland loss. Private landowners have important economic incentives to take measures to protect their wetlands as well.

While moving forward with the initial set of projects, it is now time to examine the big picture regarding the fate of coastal Louisiana. A lengthy public debate may be necessary. Neither this panel nor its individual members mean to prejudice the outcome of the study we propose in favor of a particular long-term solution. But only if all the facts are laid out on the table for all the technically viable options will it be possible for the state and the nation to arrive at a plan that will make the next generation happy with our actions rather than regret our lack of foresight. While various parties may have different views on the best ways to manage the effort to protect wetlands, we all have a common interest in ensuring that these decisions are based on the best possible understanding of their likely outcomes.

BIBLIOGRAPHY

Adams, R. D., Banas, P., Baumann, R. H., Blackmon, H. H., and McIntire, W.G., 1978. Shoreline Erosion in Coastal Louisiana: Inventory and Assessment. Coastal Resources Program, Louisiana Department of Transportation & Development, Baton Rouge, 139 pp.

Adams, R. D., Barrett, B. B., Blackmon, J. H., Gane, B. W., and McIntire, W. G., 1976. Barataria Basin: Geological Processes and Framework. Sea Grant Publ. LSU-T-76-006, Center for Wetland Resource, Louisiana State University, Baton Rouge.

Baumann, R. H., and DeLaune, R. D., 1982. Sedimentation and ApparentSea-Level Rise as Factors Affecting Land Loss in Coastal Louisiana, in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options (D. Boesch, ed.), FWS/OBS-82/59, Office of Biological Services, U.S. Fish & Wildlife Service, Slidell, LA, pp. 2-13.

Barnett, T.P. 1984. The Estimation of "Global" Sea Level Change: A Problem of Uniqueness. Journal of Geophysical Research. 89(C5):7980-88.

Bindschadler, R.A. 1985. Contribution of the Greenland Ice Cap to Changing Sea Level: Present and Future. In Meier et al. 1985.

Boesch, D. F., ed., 1982. Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options. FWS/OBS-82/59, Office of Biological Services, U.S. Fish and Wildlife Service, Slidell, LA 256 pp.

Boesch, D. F., Levin, D., Nummedal, D., and Bowles, K., 1983. Subsidence in Coastal Louisiana: Causes, Rates, and Effects on Wetlands. U.S. Fish & Wildliife Service, Division of Biological Services, Washington, D.C., FWS/OBS-83/26, 30 pp.

Charney, J., Chairman, Climate Research Board. 1979. Carbon Dioxide and Climate: A Scientific Assessment. Washington, D.C., National Academy Press.

Coleman, J. M., and Gagliano, S.M., 1964. Cyclic Sedimentation in the Mississippi River Deltaic Plain. Transactions, Gulf Coast Association of Geological Societies 14:67-80.

Costanza, R., and Farber, S. C., 1985. The Economic Value of Wetlands in Louisiana, Draft Report to the Coastal Management Section, Louisiana Department of Natural Resources, for the project titled: "Benefits and Costs of Environmental Enhancement Projects in Louisiana," 57 p.

Craig, N. J., Turner, R. E., and Day, J. W., Jr., 1980. Wetland Losses and Their Consequences in Coastal Louisiana, Zeitschrift fur Geomorphologie Suppl.-Bd. 34:225-241.

Davis, D. W., 1982. Economic and Cultural Consequences of Land Loss in Louisiana, Shore and Beach 51(4):30-39.

Day, J. W, and Craig, N. J., 1982. Comparison of the Effectiveness of Management Options for Wetland Loss in the Coastal Zone of Louisiana, in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options (D. Boesch, ed.), FWS/OBS-82/59, Office of Biological Services, U.S. Fish & Wildlife Service, Slidell, LA, pp. 232-239.

DeLaune, R. D., Baumann, R. H., and Gosselink, J. G., 1983. Relationships Among Vertical Accretion, Apparent Sea Level Rise, and Land Loss in a Louisiana Gulf Coast Marsh. Journal of Sedimentary Petrology 53:147-157.

DeLaune, R. D., Patrick, W. H., Jr., and Buresh, R. J., 1978. Sedimentation Rates Determined by 137Cs Dating in a Rapidly Accreting Salt Marsh. Nature 275:532-533. Doiron, L. N., and Whitehurst, C. A., 1974. Geomorphic Processes Active in the Southwestern Louisiana Canal, Lafourche Parish, Louisiana. Research Monograph, Division of Engineering, Louisiana State University, Baton Rouge.

Edmonson, J. and R. Jones. 1984 "Terrebonne Parish Barrier Island and Marsh Management Program." Terrebonne Parish Government, Houma, Louisiana.

Frazier, D. E., 1967. Recent Deltaic Deposits of the Mississippi River: Their Development and Chronology. Transactions, Gulf Coast Association of Geological Societies 17:287-315.

Gagliano, S. M., 1973. Canals, Dredging, and Land Reclamation in the Louisiana Coastal Zone. Hydrologic and Geologic Studies of Coastal Louisiana, Rept. 14, Coastal Resources Unit, Center for Wetland Studies, Louisiana State University, Baton Rouge, 104 pp.

Gagliano, S. M., Meyer-Arendt, K. J., and Wicker, K. M., 1981. Land Loss in the Missssissippi River Deltaic Plain. Transactions. Gulf Coast Association of Geological Societies 31:295-300.

Gagliano, S. M., Light, P., and Becker, R. E., 1973. Controlled Diversions in the Mississippi Delta System: An Approach to Environmental Management. Hydrologic and Geologic Studies of Coastal Louisiana Rept. 8, Coastal Resources Unit, Center for Wetland Studies, Louisiana State University, Baton Rouge.

Gagliano, S. M., and van Beek, J. L., 1970. Geologic and Geomorphic Aspects of Deltaic Processes, Mississippi Delta System. Hydrologic and Geologic Studies of Coastal Louisiana, Rept. 1, Coastal Resources Program, Center for Wetland Resources, Louisiana State University, Baton Rouge. Gornitz, V., Lebedeff, S., and Hansen, J., 1982. Global Sea Level Trend in the Past Century. Science. 215:1611-1614.

Gosselink, J. G., and Baumann, R. H., 1980. Wetland Inventories: Wetland Loss along the United States Coast. Zeitschrift fur Geomorphologie Suppl.-Bd. 34:173-187.

Gosselink, J. G., Cordes, C. C., and Parsons, J. W., 1979. An Ecological Characterization Study of the Chenier Plain Coastal Ecosystem of Louisiana and Texas. FWS/OBS-78/9-78/11 (3 vols.), Office of Biological Services, U.S. Fish & Wildlife Service, Slidell, LA.

Hatton, R. S., DeLaune, R. D., and Patrick, W. H., Jr., 1983. Sedimentation, Accretion, and Subsidence in Marshes of Barataria Basin, Louisiana, Limnology and Oceanography 28:494-502.

Hoffman, J. S., 1983. Projecting Sea Level Rise to the Year 2100, in Coastal Zone '83, Third Symposium on Coastal and Ocean Management, American Society of Civil Engineers, June 1-4, San Diego, pp. 2784-2795.

Hoffman, J.S., Wells, J.B., and Titus, J.G., 1986. Future Global Warming and Sea Level Rise. In Sigbjarnarson, G. ed. Iceland Coastal and River Symposium. National Energy Authority, Reykjavik.

Hoffman, J. S., Keyes, D., and Titus, J. G., 1983. Projecting Future Sea Level Rise: Methodology, Estimates to the Year 2100, and Research Needs. EPA 230-09-007, U.S. Environmental Protection Agency, Office of Policy & Resource Management, Washington, D.C.

Houck, O.A., 1983. Land Loss in Coastal Louisiana: Causes, Consequences, and Remedies. Tulane Law Review 58(1):3-168.

Howard, P. C., Duenckel, T. J., Gagliano, S. M., Gasperecz, G. J., and Leslie, J. C., 1984. The Mississippi River Gulf Outlet: A Study of Bank Stabilization. Coastal Management Section, Louisiana Department of Natural Resources, Baton Rouge.

Johnson, W. B., and Gosselink, J. G., 1982. Wetland Loss Directly Associated with Canal Dredging in the Louisiana Coastal Zone, in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options (D. Boesch, ed.), FWS/OBS-82/59, Office of Biological Services, U.S. Fish and Wildlife Service, Slidell, LA, pp. 60-72.

Keown, M. P., Dardeau, E. A., and Causey, E. M., 1980. Characterization of the Suspended-Sediment Regime and Bed Material Gradation of the Mississippi River Basin. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg.

Kolb, C. R, 1980. Should We Permit Mississippi-Atchafalaya Diversion? Transactions, Gulf Coast Association of Geological Societies 30:145-150.

Martin, J. C., and Serdengecti, S., 1984. Subsidence over Oil and Gas Fields, in Man-Induced Land Subsidence (T. L. Holzer, ed.), Reviews in Engineering Geology VI, Geological Society of America, Boulder, Colorado.

Meier, M.F. 1984. Contribution of Small Glaciers to Global Sea Level. Science. 226(4681):1418-1421.

Meier, M.F. et al. 1985. Glaciers, Ice Sheets, and Sea Level. National Academy Press, Washington, D.C.

Mendelssohn, I. A., 1982. Sand Dune Vegetation and Stabilization in Louisiana, in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options (D. Boesch, ed.), FWS/OBS-82/59, Office of Biological Services, U.S. Fish & Wildlife Service, Slidell, LA, pp. 187-207.

Meyer-Arendt, K. J., and Templet, P. H., 1983. Restoration and Management Measures for Timbalier Island and Isles Dernieres, Terrebonne Parish. Coastal Environments, Inc., Baton Rouge, 45 pp.

Morgan, J. P., and Morgan, D. J., 1983. Accelerating Retreat Rates Along Louisiana's Coast, Sea Grant, Center for Wetland Resources, Louisiana State University, Baton Rouge.

Morton, R. A., 1982. Effects of Coastal Structures on Shoreline Stabilization and Land Loss--The Texas Experience, in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options (D. Boesch, ed.), FWS/OBS-82/59, Office of Biological Services, U.S. Fish & Wildlife Service

Mossa, J., 1980. Subsidence on Reclaimed and Reclaimable Land, in Reclamation (H. J. Walker, ed.), Dept. of Geography & Anthropology, Louisiana State University, Baton Rouge.

Mossa, J., Penland, S., and Moslow, T. F., 1985. Coastal Structures in Louisiana's Barataria Bight. Coastal Geology Technical Report No. 1, Louisiana Geological Survey, Baton Rouge, LA, 28 pp.

Nierenberg, W.A. et al. 1983. Changing Climate. National Academy Press, Washington, D.C.

Nummedal, D., 1983. Future Sea Level Changes Along the Louisiana Coast. Shore and Beach 51(2):10-15.

Office of Federal Activities, (OFA) U.S. EPA. 1986. Personal Communication with Wetland Mitigation Project Manager.

Penland, S., Suter, J., and Boyd, R., 1985. Barrier Island Arcs Abandoned Mississippi River Deltas. Marine Geology, 63:197-233.

Penland, S., Suter, J., and Nakashima, L., 1985. Hurricane Erosion and Barrier Island Protection in Louisiana. Louisiana Conservationist (in press).

Penland, S., and Suter, J. R., 1984. Low-Profile Barrier Island Overwash and Breaching in the Gulf of Mexico, 19th Coastal Engineering Conference Proceedings, ASCE/September 3-7, 1984, Houston, Texas, 2339-2345.

Penland, and R. Boyd, 1982. Assessment of Geological and Human Factors Responsible for Louisiana Coastal Barrier Erosion, in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options (D. Boesch, ed.), FWS/OBS-82/59, Office of Biological Services, U.S. Fish & Wildlife Service, Slidell, LA, pp. 14-38.

Penland, S., and Boyd, R., 1981. Shoreline Changes on the Louisiana Barrier Coast, Oceans (Sept):209-219.

Penland, S., R. Boyd, D. Nummedal, and H. Roberts, 1981. Deltaic Barrier Development on the Louisiana Coast. Transactions, Gulf Coast Association of Geological Societies, 31st Annual Meeting, October 21-23, 1981, 471-477.

Ramsey, K., E., Moslow, F. Thomas, and S.Penland. 1985. Sea Level Rise and Subsidence in Coastal Louisiana, Proceedings from the Association of State Floodplain Manager's Conference.

Revelle, R., 1983. "Probable Changes in Sea Level Resulting from Increased Atmospheric Carbon Dioxide" Changing Climate, National Academy Press, Washington, D.C.

Roberts, D., Davis, D., Meyer-Arendt, K. J., and Wicker, K. M., 1983. Recommendations for Freshwater Diversion to Barataria Basin, Louisiana Coastal Management Section, Louisiana Department of Natural Resources, Baton Rouge.

Russell, R. J.,, 1936. Physiography of the Lower Mississippi River Delta. Louisiana Department of Conservation Geolgoical Bulletin 8:3-199.

Smagorinsky, J., chairman, Climate Research Board. 1982. Carbon Dioxide: A Second Assessment. National Academy Press, Washington, D.C.

Sonnenfeld, D. L. Louisiana Coastal Erosion Monitoring Program. Proceedings of Northern Gulf of Mexico Estuaries and Barrier Islands Research Conference, June 13-14, Biloxi, MS, 129-138.

Thomas, R.H. 1985. Responses of the Polar Ice Sheets to Climatic Warming. In Meier et al. 1985.

Turner, R. E., Costanza, R., and Scaife, W., 1982. Canals and Wetland Erosion Rates in Coastal Louisiana, in Proceedings of the Conference on Coastal Erosion and Wetland Modification in Louisiana: Causes, Consequences, and Options (D. Boesch, ed.), FWS/OBS-82/59, Office of Biological Services, U.S. Fish & Wildlife Service, Slidell, LA, pp. 73-84.

United Nations Environment Programme (UNEP), World Meteorological Organization (WMO), and International Council of Scientific Unions (ICSU). 1985. International Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts. Geneva: United Nations Environment Programme.

U.S. Army Corps of Engineers (USACE), 1982. Louisiana Coastal Area, Louisiana--Freshwater Diversion to Barataria and Breton Sound Basins. 3 Volumes. New Orleans District.

U.S. Army Corps of Engineers (USACE), 1984a. Mississippi River, Baton Rouge to the Gulf, Louisiana, Project. Final Environmental Impact Statement Supplement II, New Orleans District.

U.S. Army Corps of Engineers, 1984b. Louisiana Coastal Area, Louiosiana: Freshwater Diversion to Barataria and Breton Sound Basins. Feasibility Study, New Orleans District.

U.S. Army Corps of Engineers (USACE), 1985. Final Supplemental Environmental Impact Statement, New Orleans to Venice, Louisiana. New Orleans District.

Van Beek, J. L., and Meyer-Arendt, K. J., 1982. Louisiana's Eroding Coastline: Recommendations for Protection. Coastal Management Section, Louisiana Department of Natural Resources, Baton Rouge, 49 pp.

Van Beek, J. L., Roberts, D., Davis, D., Sabins, D., and Gagliano, S. M., 1982. Recommendations for Freshwater Diversion to Louisiana Estuaries East of the Mississippi River. Coastal Management Section, Louisiana Department of Natural Resources, Baton Rouge, 49 pp.

Van Sickle, V. R., Barrett, B. B., and Ford, T. B., 1976. Barataria Basin: Salinity Changes and Oyster Distribution. Sea Grant Publ. LSU-T-76-002, Center for Wetland Resources, Louisiana State University, Baton Rouge.

Wells, J. T., Chinburg, S. J., and Coleman, J. M., 1983. Development of the Atchafalaya River Deltas: Generic Analysis. Contract DACW 39-80-C-0082, U.S. Engineer Waterways Experiment Station, Vicksburg.

Wicker, K. M., 1980. Mississippi Deltaic Plain Region Ecological Characterization: A Habitat Mapping Study--A User's Guide to the Habitat Maps. FWS/OBS-79-07, Office of Biological Services, U.S. Fish & Wildlife Service, Slidell, LA.