U.S. Department of the Interior / Geological Survey

NATIONAL COASTAL GEOLOGY PROGRAM

A Plan of Geologic Research on Coastal Erosion, Coastal Wetlands, Polluted Sediments, and Coastal Hard-Mineral Resources

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Department of the Interior
U.S. Geological Survey

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National Coastal Geology Program

Executive Summary

Issues: More than 50 percent of the population of the United States live within 50 miles of one of the Nation's oceans or Great Lakes. These coastal areas are presently being stressed by both human activities and natural processes.

- All of the 30 coastal states and the island territories are experiencing problems related to coastal erosion.
- Over the past 200 years, more than 50 percent of our wetlands have been lost due to a combination of natural and man-made causes.
- Nationwide, approximately one-third of the shellfish beds are closed or restricted because of polluted sediments.
- Onshore sources for hard-mineral resources, such as sand and gravel used for construction purposes, are becoming increasingly difficult to find. New sources are being sought in coastal waters.

Stresses on our coasts will likely increase in the future with expanding population, additional development, and anticipated sea-level changes caused by climate change and other factors.

Developing effective solutions to these coastal problems requires a thorough understanding of coastal geology, i.e. coastal sediments and landforms, how the landforms evolved, and the processes responsible for coastal changes. The U.S. Geological Survey (USGS), as the Nation's principal earth science agency, conducts research on coastal geology. A National Coastal Geology Program would increase our understanding of coastal problems, with the emphasis on improving predictive capabilities required to properly manage and utilize the Nation's coasts.

Strategy: In the FY 1990 Department of the Interior appropriations bill, the U.S. Congress directed the USGS to prepare a research plan to address coastal issues nationwide. In preparing the Plan, information on research needs and data gaps was gathered from coastal states, island territories, Federal agencies, and university researchers. The Plan outlines a broad-based research Program composed of four Subprograms: **Coastal Erosion, Coastal Wetlands, Polluted Sediments,** and **Coastal Hard-Mineral Resources.** Similar to coastal studies currently underway, the National Program would be conducted in close cooperation with states, universities, and Federal agencies.

Research: The overall objective of the proposed research is to improve our predictive capabilities by better understanding physical processes and the geologic framework within which the processes operate. Many of these processes are unknown or poorly understood. With increased understanding, we would be able to predict more accurately future coastal erosion, the fate of wetlands, where polluted sediments might accumulate, and the location of economically valuable hard minerals. An important part of the research would be assessing the impacts of man on the coastal environment.

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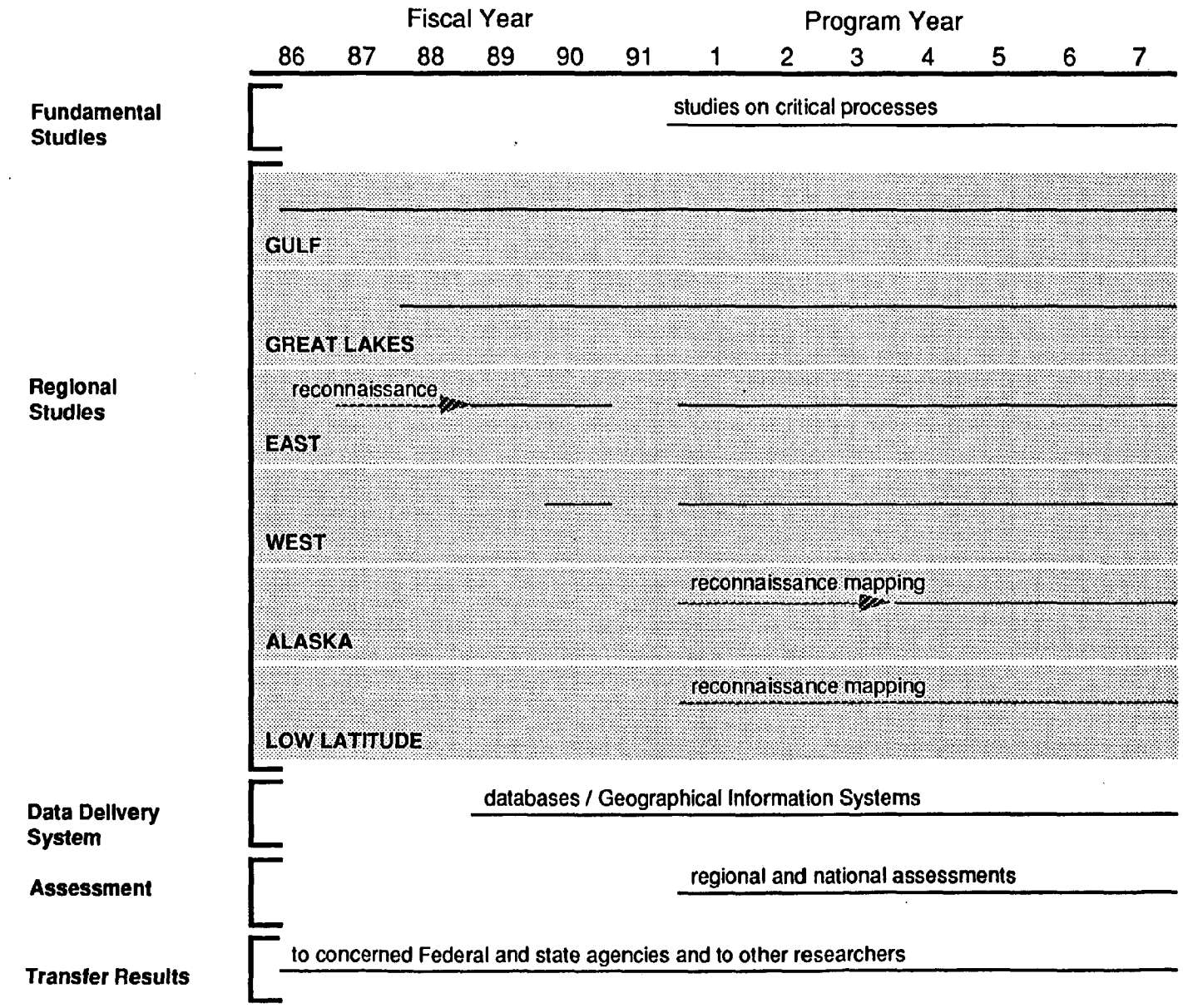
We would conduct two complementary types of research:

- o Fundamental studies focusing on critical processes, which are relevant to most coastal regions and can be applied nationally, and

- o Regional studies to improve understanding of natural and man-induced processes and geologic evolution of the coast within specific regions. A series of phased studies would be undertaken in each region of the country (see Summary Schedule).

Applications/Products: The research would provide a number of well defined products ranging from Geographic Information Systems, which are computer map displays showing overlays of data useful for management purposes, to regional assessments which would use understanding of the interrelated processes of coastal systems to predict natural and man-induced processes. These products would be used by coastal managers, engineers, and other research scientists to structure decisions and future work plans regarding protection and preservation of the coastal environment. An integral part of the Program would be regular meetings and workshops between the USGS and other Federal agencies and the affected states in order to define and monitor the national scope of coastal problems. These activities would facilitate information exchange and maximize coordination to insure that studies underway by Federal and state agencies complement each other. A series of national assessments would be conducted including rates of erosion and locations of hard-mineral resources.

National Coastal Geology Program: **Summary Schedule**



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Cover: LANDSAT photograph of Chesapeake Bay and the Virginia barrier islands. From the 28th International Geological Congress field trip guide "Flyover Showing Geomorphology and Coastal Processes Along the Atlantic Shoreline" by S. Jeffress Williams (1989).

INTRODUCTION

More than 50 percent of the U.S. population currently live within 50 miles of an ocean, Great Lake, or major estuary. According to forecasts, the concentration of people along our coastlines will continue to increase into the 21st century. In addition to residential and commercial buildings and facilities worth tens of billions of dollars, the coasts and associated wetlands are natural resources of tremendous value, with estimates in excess of $13 billion per year for commercial and recreational fisheries alone.

Human activities and natural processes are stressing the coastal environment.

- Each of the coastal states and island territories is suffering problems related to coastal erosion.
- Deterioration of wetlands is widespread and of great public concern.
- Pollutants carried by rivers or runoff are discharged directly into coastal waters and accumulate in the sediments on the sea floor, in some areas causing damage to living resources and presenting a threat to public health.
- Onshore sources for hard-mineral resources, such as sand and gravel used for construction purposes, are becoming increasingly difficult to find. New sources are being sought in coastal waters.

Coastal issues will become even more important into the next century if sea level is significantly influenced by climate change and other factors.

Lack of scientific understanding of coastal problems and inadequate historical data bases are major impediments to addressing today's and future problems. Coastal erosion, wetlands deterioration, polluted sediments, and the scarcity of hard-mineral resources are problems which are dependent, to varying degrees, on coastal geology. Devising effective solutions requires thorough understanding of coastal sediments and landforms, how the landforms evolved, and the multidisciplinary processes responsible for coastal modifications. Several Federal agencies have program initiatives relating to coastal and ocean topics, but none focus on the geologic conditions and processes affecting coastal and ocean environments. The U.S. Geological Survey (USGS), as the Nation's principal earth science agency, conducts research on various aspects of coastal geology. The National Coastal Geology Program is intended to increase our understanding of coastal problems, with the emphasis on improving predictive capabilities required for proper management and rational utilization of our coasts.

COASTAL ISSUES

Coastal Erosion

Coastal erosion is a serious national problem with long-term economic and social consequences. Developed areas are threatened with potential loss of life and billions of dollars in property damage as a result of storm impacts and long-term erosion. Of the 30 states bordering an ocean or Great Lake, all have erosion problems, and 26 presently are experiencing net loss of their shores. For example:

- Louisiana's barrier islands are eroding in places up to 60 feet per year. Historically, the islands have decreased in size, some by as much as 75 percent in 100 years. While these islands are not extensively developed, they protect valuable coastal wetlands from waves and currents of the open marine environment. Thus, as the barriers erode, coastal wetlands become more exposed, accelerating their destruction.

- In 1986, water levels in the Great Lakes reached their highest elevations in this century. The resulting shoreline erosion was severe and threatened highly populated areas like Chicago. There is geologic evidence that lake levels have exceeded the 1986 levels in the recent geologic past (several hundred to several thousand years). This suggests that, in the future, lake levels might rise significantly higher than present levels, greatly accelerating flooding and erosion. Knowledge to predict future lake levels is critically important to state and Federal agencies involved in coastal zone planning and erosion mitigation.

- Florida is bounded on the Atlantic and the Gulf of Mexico by low-lying barrier islands, many of which are heavily developed and undergoing erosion and periodic storm damage. Much of the $23-billion-a-year tourist industry is dependent on the coastal resources, and Florida's population is projected to increase in the future. The State of Florida has plans to nourish its beaches with sand from both onshore and offshore sources at a cost of roughly $500 million over the next 10 years. However, known sources of sand are insufficient to satisfy the demand.

The National Academy of Sciences[1] and the Environmental Protection Agency (EPA) have forecasted increasing rates of sea-level rise during the next century. Although the predicted rates are controversial, any rise in sea level will increase erosion of our coasts. In addition, global warming is likely to result in additional hazards for coastal communities by increasing the frequency and magnitude of tropical storms and hurricanes.

Coastal Wetlands

When the first European settlers reached America over 200 years ago, approximately 215 million acres of wetlands existed. Since that time, more than 50 percent have been lost due to draining and filling or coastal erosion and land loss; fewer than 94 million acres of wetlands remain today. Wetlands continue to be lost, due to natural and man-made causes, at a rate estimated to be 450,000 acres each year.

Wetlands are important ecologically and serve numerous functions.

- Salt marsh wetlands are the most productive ecosystems known to man.

- Freshwater wetlands rank third in productivity behind saltwater marshes and tropical rain forests.

- Eighty percent of the Nation's coastal commercial and recreational fisheries are dependent upon wetlands for spawning, hatchery, and nursery activities.

- Over one-third of the listed endangered species use wetlands for habitat as do many other species of wildlife, waterfowl, and migratory birds.

- Wetlands serve as natural water reservoirs and as ground-water recharge areas.

- The presence of wetlands in a flood plain can reduce flood peaks by as much as 80 percent.

- Wetlands serve as natural water filters, helping to cleanse water supplies.

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[1] National Research Council, 1987, Responding to Changes in Sea Level - Engineering Implications: National Academy Press, Washington, D.C., 148 p.

Excluding the Exclusive Economic Zone (EEZ), the Department of the Interior is custodian of 500 million acres of the Nation, with wetlands being an important part of that responsibility. As part of the President's goal of "no net loss of wetlands," research on wetlands processes and functions is important in any effort by Federal, state, and local agencies and public and private organizations to preserve, protect, and restore wetlands.

Polluted Sediments

Many of the water bodies surrounding our coastal urban areas have polluted bottom sediments. Pollutants include heavy metals, organic chemicals including petroleum residues, and excess organic productivity and sulfur accumulation. The discharge and accumulation of pollutants in coastal waters have created problems associated with health and safety, commercial and biological resources, and recreational activities.

- In Boston Harbor, as a result of discharge of sewage sludge and effluent, there is a high occurrence of fin rot and liver cancer in winter flounder. Of 4,700 acres of shellfish beds, 60 percent are closed and the remainder restricted.
- In Chesapeake Bay, once one of the most fertile spawning and seafood producing areas in the Nation, spawning of striped bass has nearly collapsed, and oyster production has fallen to one-seventh of pre-20th century values.
- Commencement Bay (Tacoma, Washington) and New Bedford Harbor (Massachusetts) have concentrations of heavy metals and contaminants so high that they are at EPA Superfund site levels.
- Nationwide, approximately one-third of the shellfish beds are closed or restricted because of polluted sediments.

In addition to hazards to human health from contaminated seafood, the discharge of domestic and industrial wastes has impacted the abundance and diversity of marine organisms at all levels of the food chain.

Coastal Hard-Mineral Resources

As a result of the long-term geologic processes associated with coastal erosion and sea-level rise of more than 350 feet over the past 20,000 years, nearshore regions of the U.S. continental shelves offer high potential for certain hard-mineral resources. The materials of greatest value - sand, gravel, gold, platinum, and titanium - occur in deposits having origins that are the result of the dynamic processes at the coast. Sand and gravel mining currently is the largest non-fuel mineral industry in the United States.

With the U.S. population becoming increasingly concentrated along our coasts, the need for new and replacement cultural and engineering structures is placing large demands on sand and gravel resources. The offshore offers the only reasonable domestic sources for these materials as available onshore sources dwindle due to alternative land uses, increasing transportation costs, and environmental concerns. Coastal areas have potential as an important source for many strategic heavy minerals, such as minerals containing chromite, for which the Nation presently is dependent on potentially unreliable foreign sources. Heavy minerals serve as sources for a number of commodities which presently must be imported, such as zirconium, platinum group minerals, and tin.

STRATEGY

Since 1986, the USGS has been directed and funded by Congress to conduct four coastal geology studies. These studies are ongoing and include research on:

- The processes causing the extreme rate of erosion of Louisiana's barrier islands,
- The multidisciplinary processes leading to the extraordinary rates of wetlands loss on the Mississippi River Delta plain,
- Geologic evidence for past elevated lake levels and the processes causing shore erosion in Lake Michigan,
- The processes of polluted-sediment transport and erosion in Mississippi and Alabama.

In addition, at the direction of Congress, the National Oceanic and Atmospheric Administration (NOAA) and USGS have developed a study plan for mapping topography, bathymetry, and geology along the Great Lakes shorelines. The USGS is conducting cooperative investigations with the State of Massachusetts and EPA on polluted sediment transport in Boston Harbor-Massachusetts Bay. Each of the studies examines natural and man-induced processes and will produce technical results useful in devising plans to mitigate and manage coastal problems. (These present and planned studies are discussed in more detail in Appendix A.)

Realizing that coastal processes are complex and extend across entire regions without respect for state borders and that our present studies are localized, Congress directed the USGS, in the FY 1990 Department of the Interior appropriations bill, to design a plan for addressing coastal problems on a national scale and in an organized and systematic fashion. In preparing this plan, information on research needs and data gaps was solicited from the geological surveys of the 30 coastal states, the U.S. island possessions and territories, and appropriate Federal agencies. Coordination and information gathering activities over the past 12 months are shown in Table 1. A number of workshops and meetings were held around the country, a written solicitation and questionnaire was mailed to each of the coastal states, the island territories, and several Federal agencies, and numerous presentations were made.

- Of the 22 states and 6 territories that responded to the questionnaire, 24 ranked erosion and wetlands loss as the most important coastal problem, and 16 ranked coastal pollution as the second most pressing problem (Table 2). In general, hard-mineral resources was ranked third in importance.
- EPA, NOAA, Federal Emergency Management Agency (FEMA), and U.S. Fish and Wildlife Service (FWS) listed both erosion and wetlands loss and coastal pollution as first-priority issues.
- Coastal dynamics and sediment dynamics and composition were listed most often by the states as areas where additional information is needed.

Synthesis and evaluation of the information and research needs indicate that solutions to critical coastal issues require the acquisition of a broad knowledge base which is currently lacking. For example, many coastal processes are unknown or poorly understood and not adequately quantified. The rates at which these processes have operated in the past and man's impact on the processes and their rates are also poorly known. To obtain this critically needed knowledge base, the National Coastal Geology Program proposes investigations aimed at better understanding of the physical processes and geologic framework within which the processes operate. Examples include processes leading to coastal erosion, to the creation, maintenance, and destruction of wetlands, to the accumulation and transport

Table 1. Chronology of steps in preparing the National Plan

Great Lakes Region Workshop (70 Federal, state, local, industry attendees).	30-31 Mar. '89
Nearshore Processes Workshop of coastal scientists from Federal research organizations and universities to prioritize research needs.	23-26 Apr. '89
Written input solicited from 33 coastal states, territories, possessions.	10 Oct. '89
Meetings with individual coastal states on coastal needs, information gaps.	Oct. '89 ——————→ Mar. '90
Presentations made to Federal, State, industry attendees at USGS-NOAA EEZ Symposium.	14-16 Nov. '89
Workshop of USGS coastal research scientists.	29-30 Nov. '89
Presentation made/written input solicited at USGS-NOAA JOMAR Federal Coordinating Committee Meeting (14 Federal agencies).	10 Jan. '90
Written input solicited from DOI bureaus.	6 Feb. '90
Input from EPA, NOAA, and USACE on polluted sediment needs.	Feb.-Mar. '90
Meeting with NOAA and FEMA.	21 Mar. '90

Table 2. Summary of Inputs from Federal and State agencies for the National Coastal Plan.[1]

	ME	MA	RI	NJ	PA	MD	SC	FL	AL	MS	LA	TX	AK	WA	OR	CA	WI	IL	IN	MI	OH	PR	VI	AS[3]	MP[4]	GU[5]	EPA	NOAA	FEMA	MMS	FWS	PMB	HI	MO[6]
Coastal Coordinator	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Research Activities[2]																																		
Erosion and Wetlands Loss	1	1	-	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	-	1	-	1	2
Pollution	2	2	-	1	2	1	3	2	2	2	2	2	2	1	3	1	2	3	2	2	3	3	2	2	2	2	1	1	1	-	1	-	3	3
Hard-Mineral Resources	3	3	-	3	3	3	2	3	3	3	3	3	3	1	1	2	3	2	3	3	2	1	3	3	3	3	3	-	-	1	-	-	2	1
Problems																																		
Coastal Erosion	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	
Wetlands Loss	x	x		x	x	x	x	x	x	x	x	x	x	x						x	x	x	x	x	x	x	x	x				x		
Pollution	x	x		x	x	x	x	x	x	x	x	x	x			x				x	x	x	x	x	x	x	x	x			x		x	
Hard-Mineral Resources		x			x		x	x		x	x	x	x		x	x				x	x	x	x	x	x		x	x			x			
Sediment Accretion									x																								x	x
Present/Planned Research																																		
Coastal Dynamics		x								x	x	x	x	x				x					x				x			x			
Coastal Erosion	x				x	x		x		x	x	x		x				x		x	x	x												
Sediment Dynamics/ Composition	x	x		x	x	x		x	x	x	x	x	x	x				x																
Barrier Studies		x						x		x	x	x																						
Shoreline Change		x				x		x	x	x	x	x		x				x			x													
Lake/Seafloor Mapping	x							x										x		x								x						
Coastal Mapping						x		x	x	x	x	x		x			x	x										x	x						
Sea-Level Change	x										x			x																				
Coastal Stratigraphy					x					x	x	x		x																		x		
Neotectonics	x																															x		
Wetlands Loss	x							x			x			x									x				x			x			
Habitat Mapping									x		x			x								x	x			x				x				
Coastal/Estuary/ Lake Pollution				x	x	x		x		x	x			x													x	x			x			
Mineral Resource Assessmnt/Mapping		x		x				x	x	x	x	x	x	x	x							x							x			x	x	
GIS	x										x			x														x	x	x	x			
Info Needs/Gaps																																		
Coastal Dynamics	x	x		x	x	x		x	x	x	x	x	x	x			x	x		x	x	x	x	x	x	x	x		x	x			x	
Coastal Erosion					x			x		x	x		x	x	x	x	x	x		x	x	x	x	x	x	x			x	x			x	
Sediment Dynamics/ Composition	x	x		x	x	x		x	x	x	x	x		x		x				x	x	x					x	x	x				x	
Coastal Mapping		x		x	x			x		x	x		x		x	x		x			x	x		x	x	x	x	x	x		x		x	x
Shoreline Change		x			x			x	x	x	x	x	x			x		x			x	x	x	x	x	x	x	x	x		x		x	x
Sea-Level Change								x			x	x		x		x					x	x	x	x	x	x	x	x			x		x	x
Coastal Stratigraphy				x	x					x	x					x					x						x							x
Lake/Seafloor Mapping	x							x	x									x		x														
Core/Grab Data	x			x				x	x	x	x	x	x		x	x						x						x						
Offshore Geophysics				x					x	x	x				x	x					x	x												
Wetlands Loss	x					x		x	x	x	x	x	x					x	x	x	x		x	x	x	x	x			x			x	
Habitat Mapping									x		x												x	x				x			x			
Mineral Resource Assessmnt/Mapping		x						x	x	x	x	x	x	x	x	x						x	x	x	x	x				x				x
Geochemical Studies				x					x			x													x		x							
Pollution	x			x	x	x		x		x			x									x	x			x	x				x			
Water Resources/ Movement	x			x	x	x							x												x		x	x			x			
GIS											x	x			x											x	x	x		x	x			

[1] Information is based on written returns, meetings, and feedback from presentations.
[2] Numbers indicate relative priority order.
[3] American Samoa
[4] Northern Mariana Islands
[5] Guam
[6] Palau

of polluted sediments, and to the concentration of mineral resources. Without understanding how coastal systems operate, we will not be able to predict natural processes or the impacts of man.

In carrying out the Program, cooperative efforts with state agencies and universities would be emphasized. The studies would build on and be structured similar to our current coastal studies. For example, in Louisiana, scientists from the Louisiana Geological Survey and Louisiana State University work with USGS scientists in conducting barrier island and wetlands research. The Illinois State and Indiana Geological Surveys are involved in USGS studies of southern Lake Michigan. The Alabama and Mississippi Surveys are working cooperatively with the USGS on the Gulf Coast.

The Program would require close coordination and cooperation with other Federal agencies, such as EPA, NOAA, U.S. Army Corps of Engineers (USACE), FEMA, Minerals Management Service (MMS), FWS, and Bureau of Mines (BOM). The interagency relationships would range from cooperative research with other agencies to transfer of results through meetings and publications. For example, the USACE is responsible for developing a comprehensive plan to manage wetlands loss in Louisiana. As a member of a coordination committee composed of the appropriate Federal and Louisiana agencies (USACE chairs the committee), the USGS is providing technical information for use in the USACE's planning process. The USGS also is an active member on the Coastal and Shoreline Erosion Subcommittee of EPA's newly formed Gulf of Mexico Program, again providing technical information derived from our studies. The USGS provides expertise in coastal matters to advisory boards to the Federal Government. The most recent example is USGS participation on the National Academy of Sciences' committee that wrote the report "Managing Coastal Erosion."[2]

DESCRIPTION OF THE NATIONAL COASTAL GEOLOGY PROGRAM

The Program consists of four Subprograms: Coastal Erosion, Coastal Wetlands, Polluted Sediments, and Coastal Hard-Mineral Resources (Figure 1). Investigations are proposed to improve our capability to predict natural and man-induced processes. Specifically, we would improve our ability to predict future erosion, the fate of wetlands, where pollutants might accumulate, and the locations of economically valuable hard minerals. We propose two interdependent avenues of research for each of the Subprograms.

- Fundamental studies would be conducted to improve understanding of processes critical to improving predictive capabilities. These critical processes are relevant to most regions and hence can be applied nationwide. Examples include processes causing sand transport on beaches and processes producing concentrations of economically important heavy minerals. Specific studies would involve theoretical, laboratory, and/or field research.

- Regional studies would apply knowledge gained from fundamental studies to improve understanding of processes, geologic framework, and evolution of the coast within specific regions. An emphasis of the regional studies would be to compare and contrast natural and man-induced processes of well-defined coastal systems where processes are interdependent. Regional studies would involve primarily field research in different parts of the country, which has been divided into six regions: East, Gulf, Great Lakes, West, Alaska, Low Latitude (Figure 2).

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[2] National Research Council, 1990, Managing Coastal Erosion: National Academy Press, Washington, D.C., 182 p.

National Coastal Geology Program

Issues:

EROSION, COASTAL WETLANDS, POLLUTED SEDIMENTS, HARD-MINERAL RESOURCES

Develop Predictive Capabilities Through:

FUNDAMENTAL STUDIES, understanding processes critical to developing predictive capabilities and applicable to most coastal regions

REGIONAL STUDIES, understanding natural and man-induced processes and the geologic evolution of the coast within specific regions

Research Applications:

Data delivery systems
- data gathered from studies that are useful for management (for example, geographical information systems)

Assessments
- regional assessments of natural and man-induced processes
- national status of specific issues (for example, rates of erosion nationwide)

Information transfer
- to state and Federal agencies through workshops, meetings and publications
- to other researchers by publications in technical journals

Figure 1

National Coastal Geology Program: **Regions**

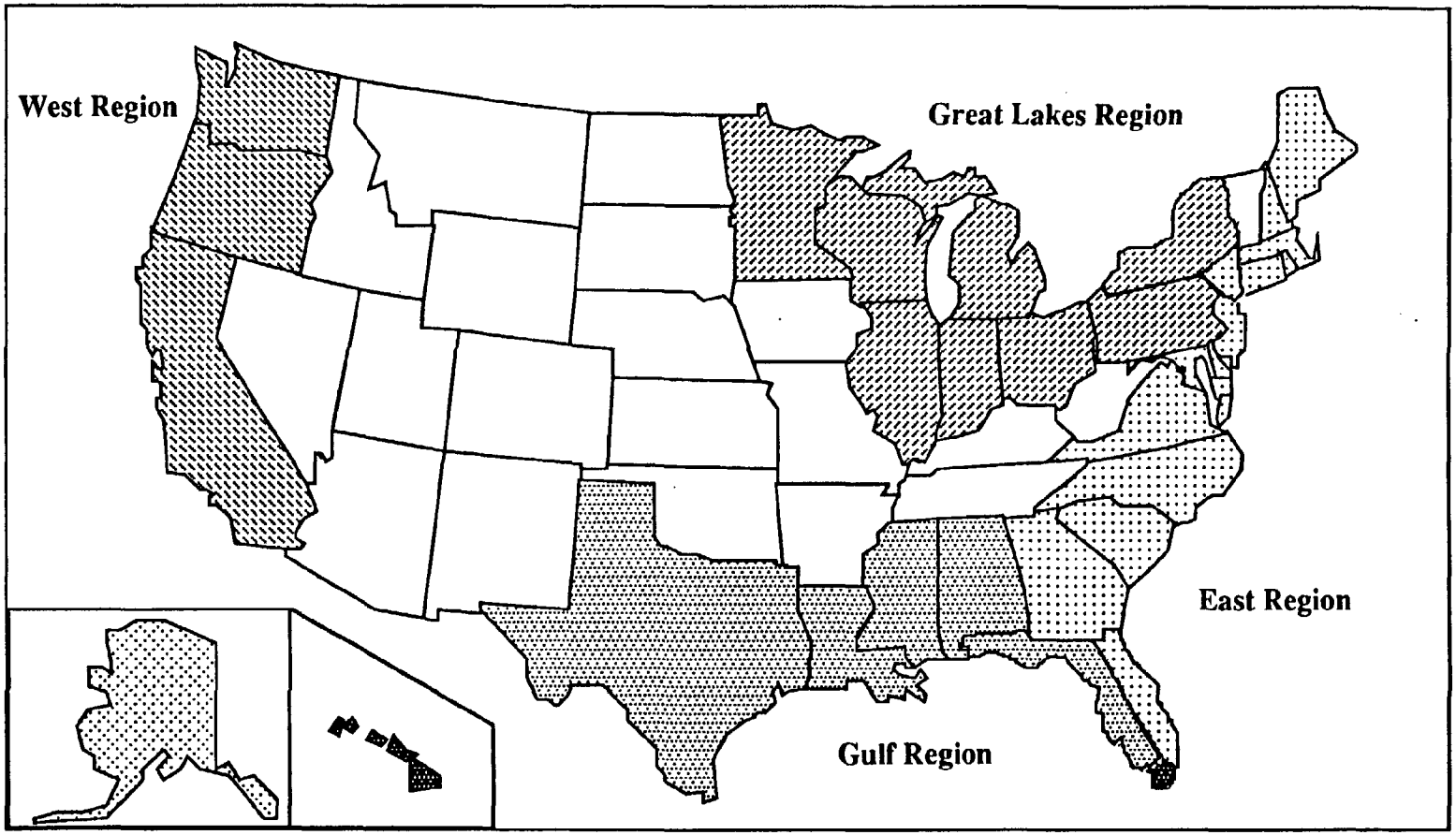


Figure 2

The locations of initial regional studies are shown in Figures 3 and 4. These regional studies are distributed nationally to address the broad range of natural processes and diverse impacts of man affecting the Nation's coasts. Note that each study is classified according to one or more Subprograms. The studies shown in Figures 3 and 4 and discussed below are the initial studies to be implemented by the Program through year 7. Clearly, additional research beyond year 7 would be required to thoroughly investigate the variability of processes nationwide. A synopsis of coastal problems within each region is in Appendix B.

Specific types of products which would be derived from the fundamental and regional studies are discussed below.

- Various data delivery systems would be produced, including data bases containing raw data which could be used for other applications by researchers, engineers, and coastal managers. Types of data range from the size and direction of nearshore waves to characteristics of surface and subsurface sediments. Geographic Information Systems (GIS) allow merging of data bases with the capability to generate computer map displays of data at any scale. The systems are particularly useful in overlaying different types of data to reveal interrelationships. With recent advances in computer systems, GIS are rapidly becoming a powerful application tool for coastal managers and engineers as well as a research tool for coastal scientists. For example, in our present Louisiana wetlands study, we are developing a GIS consisting of important factors relevant to wetlands loss for the Louisiana delta plain. The GIS is being developed in close cooperation with other Federal and state agencies.

- In the context of the regional studies, assessments of the natural and man-induced processes operating within specific coastal systems would be undertaken. The emphasis would be on how coastal systems operate and how changes in processes, whether natural or man-induced, lead to changes in the systems. In addition, national assessments would be made on the status of specific coastal issues. The intent is to provide national assessments of erosion rates and hard-mineral resources.

- The transfer of results from the Program's studies to concerned Federal and state agencies would be a priority, undertaken through workshops, meetings, and publications as well as through participation in interagency standing committees as described in the section on Strategy. In addition, an important part of scientific research is the publication of technical results in scientific journals so that other researchers in the relevant fields can be kept informed of new advances. Such dissemination of research results would promote new advances that would eventually benefit man's utilization and management of the coast.

Coastal Erosion

The objective of the Erosion Subprogram is to improve our capability to predict erosion caused by natural processes and activities of man. At present, our understanding of the processes leading to coastal erosion is rudimentary, at best. Without understanding the processes, prediction is difficult, if not impossible.

Our approach would be to increase understanding of sediment budgets, the rates and pathways of sediment movement within coastal systems. We would develop improved methodologies for determining budgets of sediments and apply these results to different coastal systems around the country. Knowledge of sediment budget is basic information required to predict erosion and to determine whether mitigation is cost effective and warranted. With the present state-of-the-art, the sediment budget of a region is very difficult to determine accurately.

National Coastal Geology Program:
Initial Regional Studies

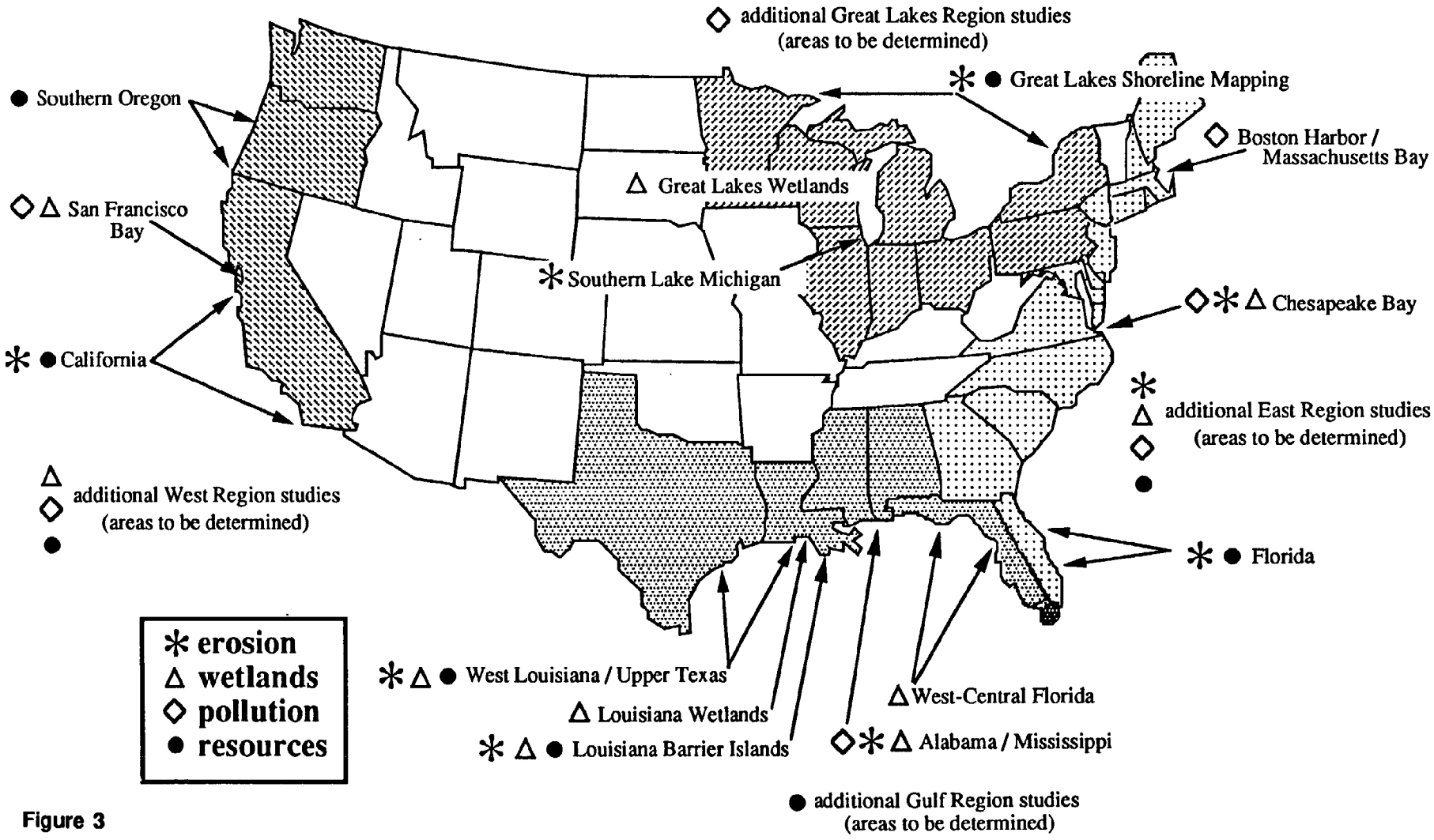


Figure 3

National Coastal Geology Program:
Initial Regional Studies (continued)

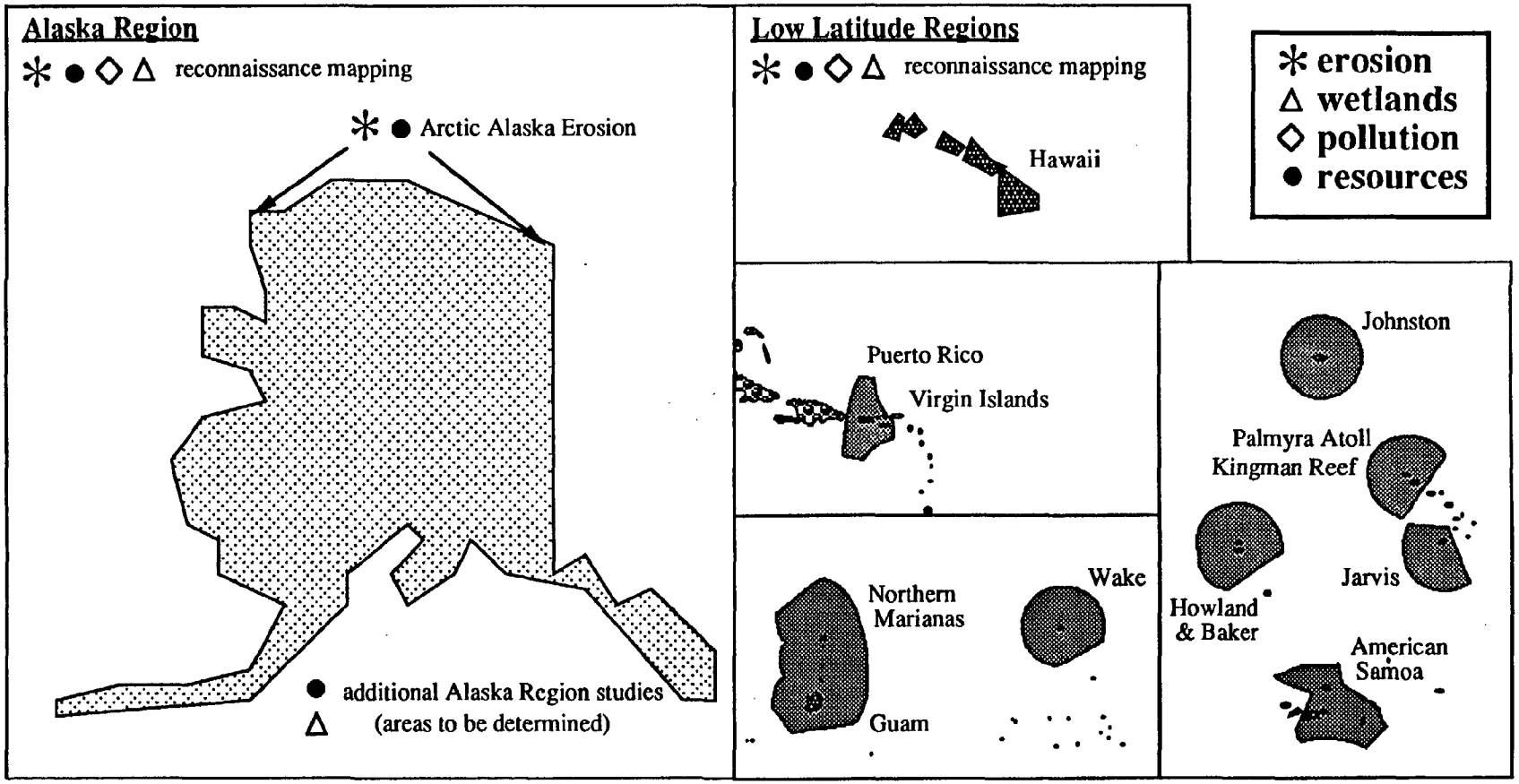


Figure 4

Components of the Erosion Subprogram are discussed below. The priorities and phasing of individual efforts are shown in Figure 5.

Fundamental Studies: Some processes critical to understanding sediment budgets and predicting coastal erosion are applicable to all coastal regions. One of these processes is the physics of sediment transport. The USGS hosted a workshop in April 1989 to discuss important research directions in nearshore processes. Five agencies sponsored the workshop: USGS, Office of Naval Research (ONR), National Science Foundation, NOAA, and USACE. Participants included most of the nearshore physical oceanographers and sediment transport experts in North America (with additional international participation). A consensus of the participants was that the research area least understood and in need of additional support was sediment transport in the nearshore, a particularly complex environment where both waves and currents act together to move sediment. Without the ability to accurately predict the rate of movement of sand along a shoreline under a variety of conditions and in different settings, prediction of coastal erosion is extremely difficult. A research program focused on sediment transport would include both theoretical and field investigations. Agencies such as USACE and ONR are also interested in the topic of sediment transport from different perspectives and concerns. The research to be done in this Program would be closely coordinated with and complement research by other Federal agencies and academic researchers. The physics of sediment transport is an extremely difficult research problem and would benefit from coordinated efforts by several concerned agencies using different approaches.

In addition to sediment transport, other critical problems would be identified and addressed. A particularly important problem is the effect on the coast of sea-level rise. How much erosion would result for a given sea-level rise? How can we predict the impact of sea-level rise on different coastal types, e.g. barrier islands versus bluffs.

Regional Studies: Nationwide, there is great variability in the processes causing coastal erosion and in the geologic framework within which the processes operate. For example, the processes causing erosion of sandy barrier islands along the East and Gulf of Mexico Coasts are quite different from the processes eroding the rugged cliff coasts common to the West Coast and much of the Great Lakes.

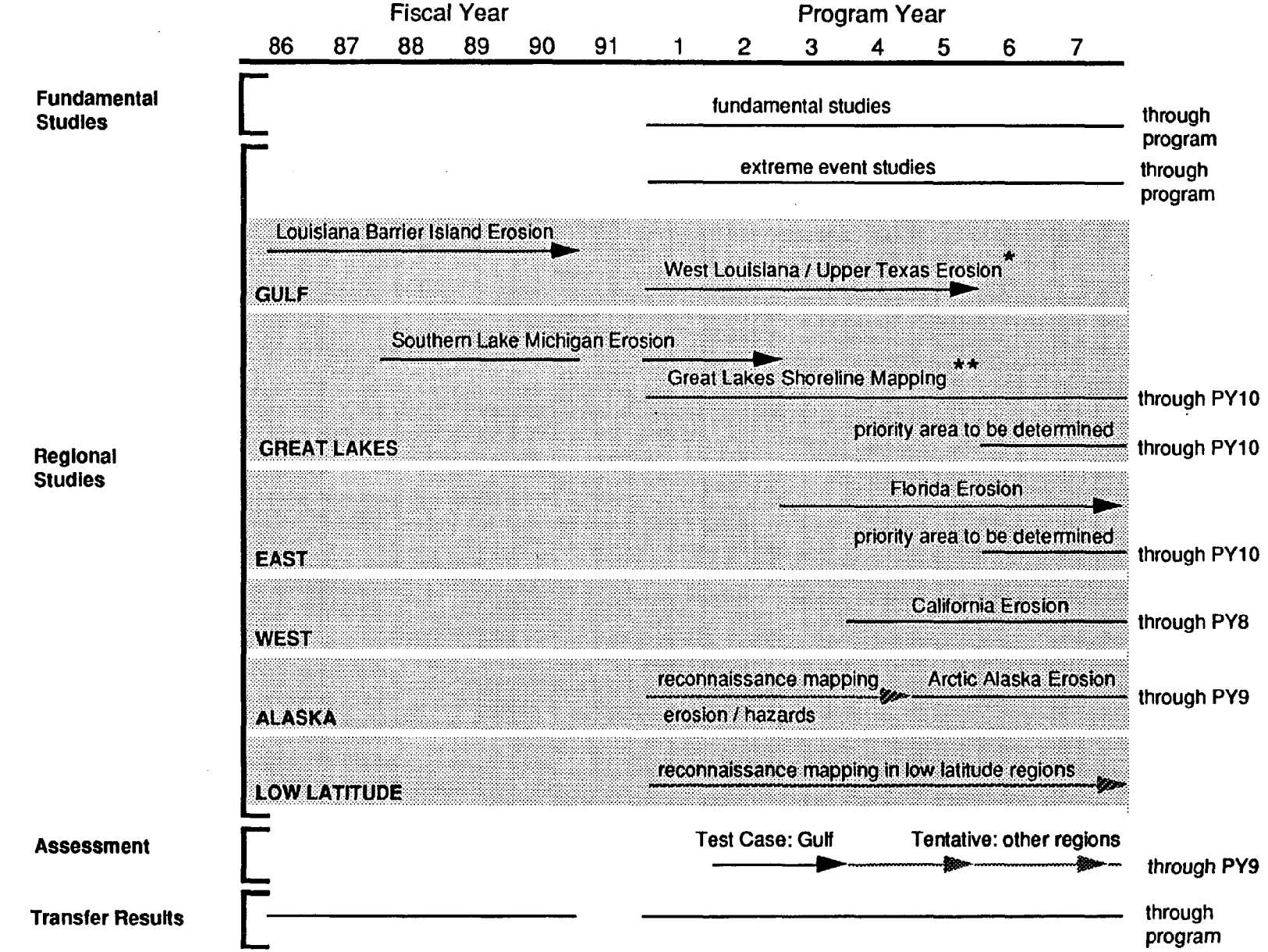
Studies within different regions in the country would be undertaken to better understand the diversity of processes and the sediment budget for specific coastal systems. These studies would be conducted in a phased approach. We would first complete and build upon the erosion studies begun earlier, i.e. Louisiana Barrier Islands and Southern Lake Michigan (Figure 5). Additional studies proposed for each region are:

- **Gulf Region:** The West Louisiana/Upper Texas study would extend the barrier island effort to a very different environment, which is also subject to extreme erosion at rates of 20 to 40 feet per year. The chenier plain of west Louisiana is composed of ridges of sand separated by muddy sediments, quite different than the barrier islands of central and eastern Louisiana. Fluid mud occurs along some of the coast, greatly affecting the wave climate.

- **Great Lakes Region:** Great Lakes Mapping, in cooperation with NOAA, would build upon the southern Lake Michigan effort and would systematically map geology, topography, and bathymetry for all of the Great Lakes shorelines (more details in Appendix A).

- **East Region:** The Florida study would focus on the processes of erosion along the highly developed Atlantic shoreline. Different than many other barrier island coasts, erosion results to a large extent by disruptions in sand transport at numerous tidal inlets.

National Coastal Geology Program: **Erosion Schedule**



* Study addresses coastal wetlands and resource issues as well as erosion.

* * Study plan submitted separately to Congress, U.S. Great Lakes Shoreline Mapping Plan (December 1989), by NOAA and USGS.

Figure 5

- **West Region:** The West Region study would focus on erosion processes of rugged, cliff coasts in California. Problems arising from erosion are common in the West, even though the rugged coast typically erodes at rates lower than the East and Gulf barrier islands.

- **Alaska Region:** Reconnaissance mapping of erosion and other coastal hazards would be implemented in areas where little information is available. More detailed work is planned on the role of ice and freeze/thaw processes in causing erosion in Arctic Alaska, an area where erosion inhibits oil and gas development.

- **Low Latitude Region:** Systematic reconnaissance mapping of erosion (but also relevant to resources, pollution, and wetlands) would be undertaken, where needed, throughout the Low Latitude Region.

Objectives and approach are tailored to each specific study. However, each of the studies have common components.

- **Geologic Framework:** Understanding processes of erosion and sediment budget requires knowledge of the geologic framework within which the erosion is taking place. These studies would provide a broad regional understanding of the types and variability of sediments and rocks and of the historical development of the coast and the important processes involved. Understanding the development of the coast serves as an indication of natural variability and of the state of the coast prior to man's intervention. The types of data gathered to understand geologic framework include cores of sediment from the sea floor and geophysical data to reveal different layers of sediment beneath the sea floor.

- **Processes of Erosion:** In each study, we would investigate the processes important to the sediment budget for a specific coastal system. The goal would be to quantify pathways and rates of sediment transport. We would focus our research on important processes that are poorly understood and difficult to predict, but are approachable experimentally. For example, on barrier islands, an important process is the overwash of waves and currents over the barrier during storms. In contrast, on cliff coasts, waves hit and reflect off the cliff, contributing to erosion of the cliff. These types of investigations would involve measurements in the field and mathematical models.

- **Reconnaissance Mapping:** In regions where there has been little previous research on coastal erosion, low-cost reconnaissance mapping helps define problems. The reconnaissance maps would depict the general coastal geology including areas subject to erosion and other coastal hazards, sediment types, the form of the coast, directions of sand transport, and occurrences of hard-mineral resources. Information would be presented uniformly from area to area for use by other geologists, planners, and engineers and to provide the basic framework for more detailed follow-up studies. The maps would provide relevant information for wetlands, resources, and pollution problems as well as erosion.

As a special type of regional study, investigations would be conducted on the impact of extreme erosional events that occur anywhere in the country. Following the recent impact of Hurricane Hugo on the South Carolina coast, NOAA, the State of South Carolina, and the USGS joined in a cooperative effort to investigate the impact of the hurricane. The National Ocean Service of NOAA (NOAA-NOS) collected aerial mapping photography of the post-Hugo shorelines; USGS shared in the costs. The USGS is in the process of comparing pre- and post-Hugo photography to determine amounts of shoreline erosion. For future storm impacts, similar cooperative efforts with NOAA and other agencies are clearly warranted. We also plan to investigate the potential use of emerging technology in responding to storm events. The new technology allows for improved resolution of satellite imagery and for applying video/image processing techniques to monitoring beach processes.

Assessment: Using the sediment budget for specific coastal systems, we would assess the role of natural processes and man in contributing to coastal erosion. In addition, using information gathered during the studies described above as well as other available data, we propose an investigation to determine the feasibility of a national assessment of coastal erosion. First, we would conduct an assessment of the status of erosion along the U.S. shoreline of the Gulf of Mexico. The assessment would include the rates of erosion along the coast and the historic variability of erosion with time. A report would be prepared discussing pros and cons of the assessment, how the assessment could be improved, and whether the assessment should be expanded nationwide. The report also would include discussion of the feasibility of periodic assessment updates in cooperation with NOAA-NOS and other appropriate agencies. Dependent on satisfactory results from the Gulf assessment, a nationwide assessment would be undertaken in phases.

Coastal Wetlands

The focus of the Wetlands Subprogram would be understanding specific wetlands systems where many interrelated processes operate to maintain, create, and destroy wetlands. By better understanding how these wetlands systems function, we would improve our ability to predict the impact of natural and man-induced processes. For example, by knowing how sediment is dispersed in wetlands of Louisiana, we can assess the utility of man's attempts to introduce new sediment into the wetlands by large scale diversions of the Mississippi River. The results of these studies would aid other agencies, particularly the USACE and FWS, in evaluating and regulating wetlands areas and in reducing and mitigating the loss of wetlands in all coastal regions of the United States.

Fundamental Studies: Some of the physical processes that are critical to assessing and predicting the natural and man-induced deterioration of coastal wetlands are common to wetlands in different regions around the Nation. Example topics would be the hydrodynamics of shallow flows over marsh vegetation, the physics of sediment transport in the presence of different kinds of marsh grasses, and the physical processes responsible for erosion of marsh shorelines. The studies would involve laboratory and/or field investigations. Field work would not be confined to a specific region, but would be conducted wherever the setting is most appropriate to examine a given process.

Regional Studies: Wetlands across the Nation display a wide range of variability in their geologic framework and setting and in the processes responsible for their evolution and deterioration. Coastal wetlands in Florida and along the Atlantic Coast are in coastal plain settings in which sea-level rise over the past several thousand years has been a major factor in their origin and evolutionary development. Coastal wetlands around the Gulf Coast are also greatly influenced by changes in sea level, and particularly in Louisiana, river discharge and periodic shifts in position of the river channels. Wetlands that fringe the Great Lakes have a close relationship to the glacial processes that formed the Great Lakes basins during the "ice ages." These wetlands originated with the filling of the Great Lakes and are greatly influenced by historic fluctuations in lake levels.

The regional wetlands studies would be conducted in a phased approach as shown in the schedule in Figure 6. The Louisiana delta plain study in the Terrebonne and Atchafalaya Basins, started in FY 1989, would continue to its completion. New work would include:

- *Gulf Region:* In contrast to the wetlands of the Louisiana delta plain, that are experiencing rapid sea-level rise due to subsidence, the wetlands of west central Florida are exposed to relatively stable sea level. By comparing processes in each environment, we would learn more of the response of wetlands to sea-level rise.

National Coastal Geology Program: **Coastal Wetlands Schedule**

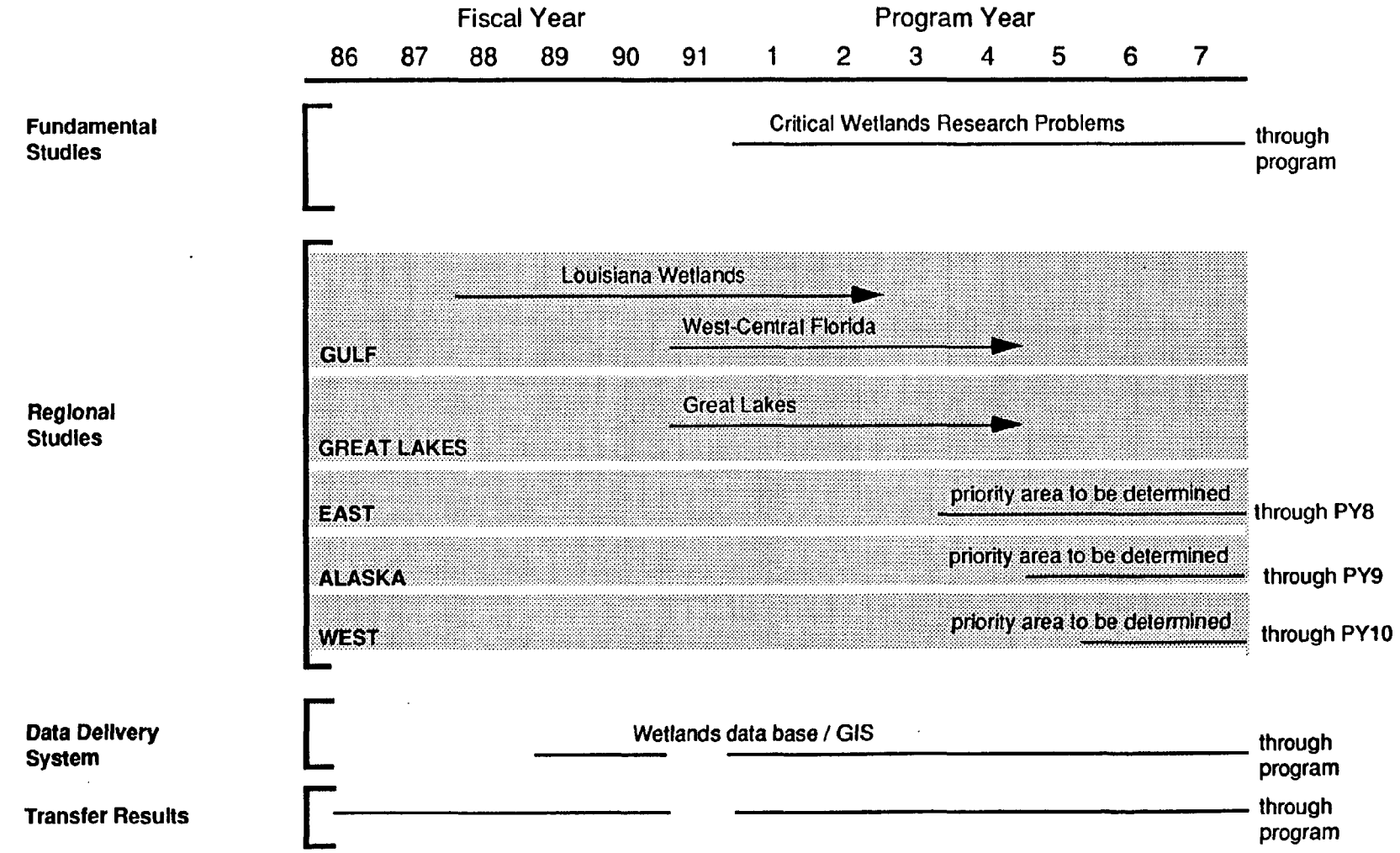


Figure 6

- **Great Lakes Region:** We plan to focus initially on wetlands around Lake Michigan, building upon our ongoing erosion work in southern Lake Michigan.

- **East, Alaska and West Regions:** New studies would be phased in these regions beginning in year 4 (East), year 5 (Alaska) and year 6 (West) of the Program.

Each of the regional studies would focus on specific coastal systems and would have similar research components.

- **Geologic Framework:** The geologic setting of the wetlands habitat defines the framework within which processes take place and in which long-term evolution occurs to produce a succession of lakes, bays, swamps, marshes, and peats. Examination of the sediments in wetlands areas, both at the surface and in the subsurface, is necessary to understand the role of geologic materials in wetlands dynamics. In particular, studies which examine the geologic history of wetlands evolution over the last several thousand years are essential in order to understand how wetlands evolve.

- **Wetlands Processes:** For each regional study, an interdisciplinary team would examine critical processes responsible for wetlands creation, maintenance, and deterioration. Examples of such processes are: (1) dispersal processes of fresh and brackish waters, (2) transport patterns of fine-grained organic and inorganic sediments, (3) salt water intrusion processes, (4) processes responsible for the development of wetlands soils, (5) geochemical processes as related to transport of pollutants into and out of wetlands, and (6) role of sea-level or lake-level changes in coastal wetlands deterioration.

Data Delivery Systems: The wetlands studies in each of the regions would ultimately result in a large and high quality base of information. Assembling a digital data base and a GIS network composed of data from USGS studies and other sources is a major objective of the present study in Louisiana. This effort would be expanded with each new wetlands study.

Assessment: For the wetlands systems studied, we would assess the integrated processes, both natural and man-induced, responsible for maintaining, creating, and destroying wetlands systems. This information is directly applicable to managing wetlands resources and mitigating wetlands loss.

In addition, assessing the status and changes in habitats of wetlands is very important for measuring success of the Administration's "no net loss" policy. The responsibility for making such assessments rests with FWS and NOAA as part of their wetlands mapping and characterization missions. We would transfer the technical results from the USGS studies to these agencies to be used in combination with results of their own studies to make the necessary assessments.

Polluted Sediments

A number of Federal agencies have responsibilities relevant to polluted sediments. EPA and NOAA are involved in assessing and mapping their extent; USACE is concerned with disposal of polluted sediments which have been dredged from navigation channels. The USGS is responsible for understanding geologic processes, and many geologic processes can be applied to the prediction of where polluted sediments are likely to accumulate in coastal areas. Hence, the focus of the USGS Program is to improve predictive capabilities through research on geologic processes. The research would be closely coordinated with activities of other concerned agencies in order to avoid duplication of effort and to share technical information.

Basic questions which concern pollutants in coastal waters are:

- What are the primary sources of pollutants, how are they transported, where do they accumulate and how fast?
- Are the pollutants diluted by natural sedimentation?
- Will polluted sediments continue to be a source of toxins even after the primary source of contamination is reduced or eliminated?
- What measures might be taken by coastal managers to decrease the impact of polluted sediments in coastal embayments?

Because many of the pollutants adhere to and are transported on fine-grained sediments, answers to these questions require an understanding of the geology of nearshore regions and of the processes which transport and distribute sediments in coastal waters. These processes are often poorly understood or documented and limit our ability to make wise management decisions about uses of the coast. Accumulation of pollutants is often especially severe in areas adjacent to major population centers where pollutants have been added to the ocean for many decades. Sediments and pollutants typically accumulate in low-energy, semi-enclosed embayments where the currents or waves are not strong enough to transport the material.

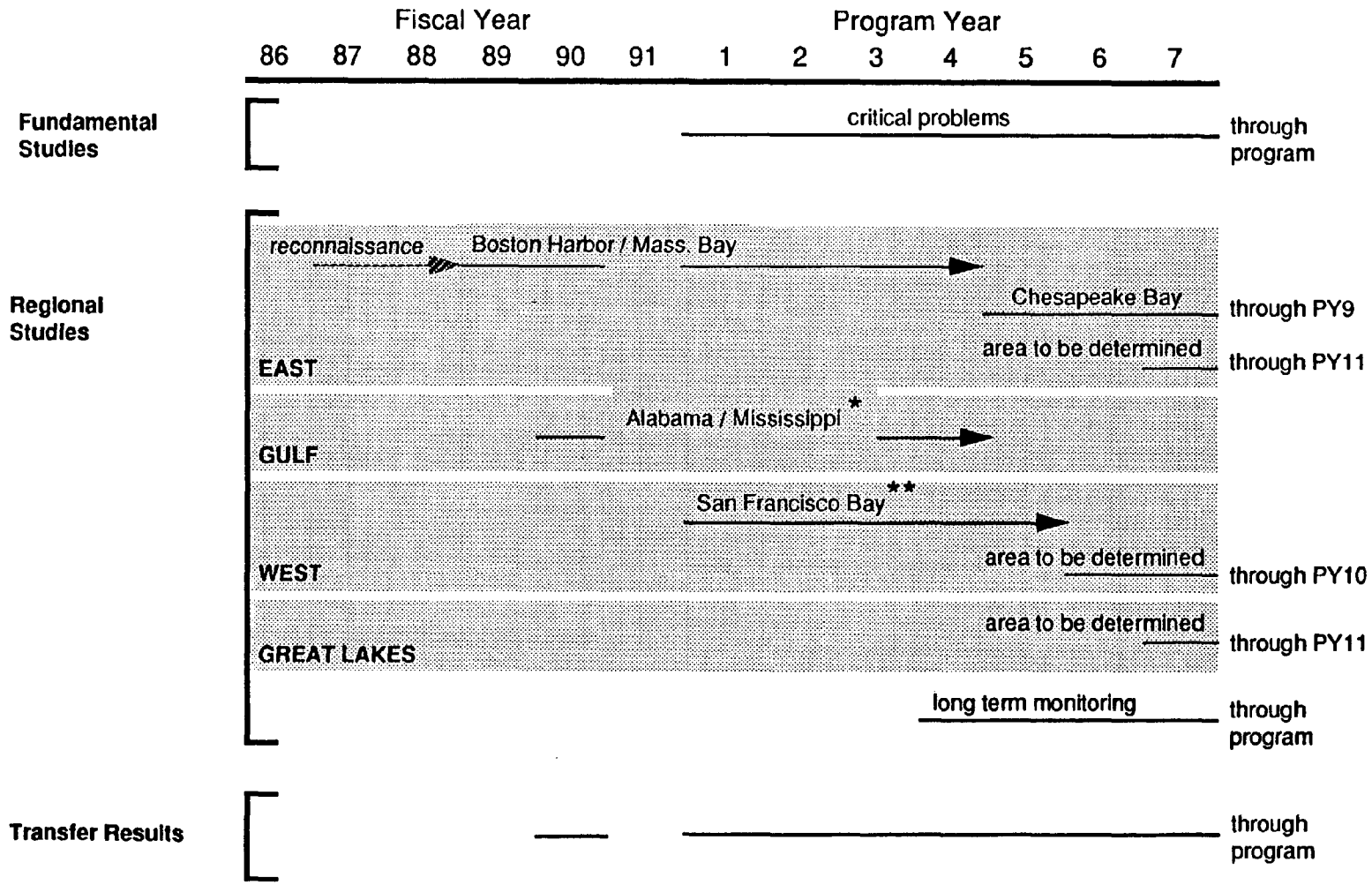
In many heavily-used coastal areas, numerous, often detailed and expensive, studies have been conducted to evaluate a specific site for a sewer outfall, disposal of dredge spoil, or major construction. However, these site-specific studies often lack a regional, long-term perspective, which is essential to determine the implications of a particular activity. The proposed multidisciplinary studies would provide a regional and national system-wide perspective. The long-term objective of the Polluted Sediments Subprogram is to develop the capability to identify and predict the locations and rates of accumulation of sediments and pollutants in the coastal waters in sufficient detail to aid in management decisions. The importance of many of these topics is discussed in a recently released book by the National Academy of Sciences.[3]

Fundamental Studies: In order to develop a predictive capability of sediment and pollutant transport and accumulation, it is essential to understand fundamental sedimentary processes. Although the importance of these processes may vary from region to region, several deserve special attention at present. Understanding the physics of sediment transport is essential to develop a predictive capability for pollutant transport; of special importance is an understanding of the transport of fine-grained and cohesive sediments. These fine-grained sediments behave quite differently than sand, which is addressed in the Erosion Subprogram. Advances in this area would require theoretical investigation as well as field and laboratory studies. A second fundamental process is the activity of the biological community in mixing and reworking bottom sediments and pollutants. Finally, an understanding of the water circulation in semi-enclosed embayments and the exchange of water and suspended particles between these embayments and adjacent water bodies is essential to understand the ultimate fate of pollutants discharged into them.

Regional Studies: Each of the proposed regional studies would focus on a particular coastal embayment; the regions have been selected because of existing environmental problems or because of anticipated problems caused by heavy use. The first priority would be to complete the studies currently underway in Boston Harbor-Massachusetts Bay and Alabama-Mississippi (Figure 7). Although classified as a pollution study, the Alabama-Mississippi Study addresses erosion and wetlands

[3] National Research Council, 1989, Contaminated Marine Sediments: National Academy Press, Washington, D.C., 508 p.

National Coastal Geology Program: **Polluted Sediments Schedule**



* Study addresses coastal wetlands and erosion issues as well as polluted sediments.

** Study addresses coastal wetlands issues as well as polluted sediments.

Figure 7

issues as well. The first proposed study would be conducted in San Francisco Bay; understanding patterns and rates of sediment transport would significantly improve the capability to predict the fate of dredged sediments and the locations where polluted sediments would concentrate. This work, which would also address wetlands issues, would build upon current USGS investigations of water circulation in San Francisco Bay. Investigations of other major estuaries would be phased later (Figure 7).

Basic components of the regional studies are described below. Study elements and objectives would be tailored for each region.

- **Geologic Framework:** A first step towards understanding the transport and fate of polluted sediments is to document the geologic and sedimentary environment. These studies would provide a broad regional perspective of the sedimentary regime, including major sediment sources, bottom topography, sediment texture, and selected pollutants. This phase would provide critical insight about the sedimentary framework, geologic history, and long-term effect of processes operating in the study area and identify hypotheses of polluted sediment pathways for evaluation in more detailed process-oriented studies.

- **Pollutants in Sediment:** Toxic heavy metals and organic compounds are responsible for environmental degradation; therefore, the concentrations of these substances in water, organisms, and sediments give an index of the health of the system. Concentrations of contaminants in sediments provide the most stable index of pollution because toxin concentrations in sediments change relatively slowly. By the same token, sediments may continue to release pollutants to overlying waters, particulate matter, and organisms for many years. For these reasons, analysis of contaminant concentrations in sediments is basic to the understanding of transport, effect, and ultimate fate of pollutants. Sediment cores would be taken and analyzed for concentrations of selected heavy metals and toxic compounds.

  The EPA and NOAA, through such programs as E-Map and Status and Trends, are beginning to provide national assessments of the present status of pollutants in coastal sediments and their change with time. To determine pollutants in sediments for proposed regional studies, USGS would work closely with EPA, NOAA, USACE, and state agencies to develop unified goals and consistent methodology and to share information. Geology provides a critical key in the assessment of contaminants in sediments by providing an understanding of the areas and rates of sediment accumulation. A long-term goal would be to include understanding of sediments and geologic processes as part of an interagency national inventory of polluted sediments.

- **Processes of Pollutant Transport:** In each regional study, process-oriented studies would be conducted to understand the frequency, direction, and rate of sediment transport and the principal processes causing transport. Numerical models would provide insight into the pattern of tidal currents; these models would be especially important in regions of complex topography and geometry where field measurements sufficient to adequately map the long-term circulation pattern are impossible to obtain. Direct measurements of sediment concentrations and currents would be made to validate predictive models of sediment transport in a variety of field conditions. An essential part of the process-oriented work would be long-term observations to document extreme sediment transport events as well as seasonal and inter-annual variability.

Coastal Hard-Mineral Resources

For most coastal areas, available information is not sufficient to construct geologic models which can reliably predict hard-mineral resource occurrences. Consequently, the economic potential of possible resources cannot be adequately

established. A more comprehensive data base and a better understanding of resource potential in nearshore areas are necessary for planning at the Federal, state, and local levels. This was a recommendation from the recent USGS-NOAA EEZ Symposium (1989) and the subject of a recently published Office of Technology Assessment report[4] on marine minerals.

An objective of the Resources Subprogram is to locate and quantitatively assess detrital hard-mineral resources, along the coast or in nearshore regions, that might have economic value. The minerals of greatest interest are sand, gravel, shell, and placer heavy minerals, such as gold, chromite, platinum, and titanium minerals. A second objective is to improve understanding of the complex geologic history and evolutionary development of the U.S. coast and inner continental shelves and to define the critical processes responsible for the formation of nearshore sand bodies which are enriched with heavy minerals or provide potential sand and gravel resources.

Specifically, the USGS would conduct regional characterizations of coastal hard-mineral resources. Focus would be placed on areas with known or suspected potential, as evidenced by previous mining history or by the economic character of areas where the hard minerals originated. The characterization would include:

- A description of the mineralogy of the sediment in terms of its potential economic components,
- Development of geochemical, geophysical, and sedimentologic models, for accumulation of economic concentrations, that can serve as a basis for further regional evaluation and for developing exploration strategies,
- Testing of these models by drilling or coring,
- A description of those aspects of the potential deposits that relate to possible environmental problems associated with the development of the deposits (e.g. sediment plumes, trace metal content),
- A general description of the environmental processes that bear on the impact associated with the recovery of the resource.

Components of the Resource Subprogram are given below. A schedule for the studies is shown in Figure 8. At present, the USGS is conducting a cooperative assessment of hard-mineral resources with MMS, BOM, and the State of Oregon. This work would be used to guide subsequent investigations. Our first step would be to complete the Southern Oregon work and to set regional priorities. Subsequently, resource investigations would proceed in a phased approach.

Fundamental Studies: Geologic models for resources are built on an extrapolation from data obtained by sampling and geophysical surveys. The extrapolation relies on an interpretation of the origin and nature of occurrence of the resource. At present, we do not have a clear understanding of the origin of most accumulations of resources, such as heavy minerals, sand and gravel deposits, and phosphates, and the models, accordingly, are incomplete. The approach would be to conduct investigations of critical processes. A potential topic involves the processes responsible for thick concentrations of heavy minerals on beaches. The studies would not be restricted to any particular region; field location would be chosen in order to best test hypotheses on the origin of the resource. Laboratory investigations, involving for example experimental facilities which simulate field conditions, would also be used.

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[4] U.S. Congress, Office of Technology Assessment, 1987, Marine Minerals: Exploring Our New Ocean Frontier, OTA-0-342, U.S. Government Printing Office, 349 p.

National Coastal Geology Program: **Hard-Mineral Resources Schedule**

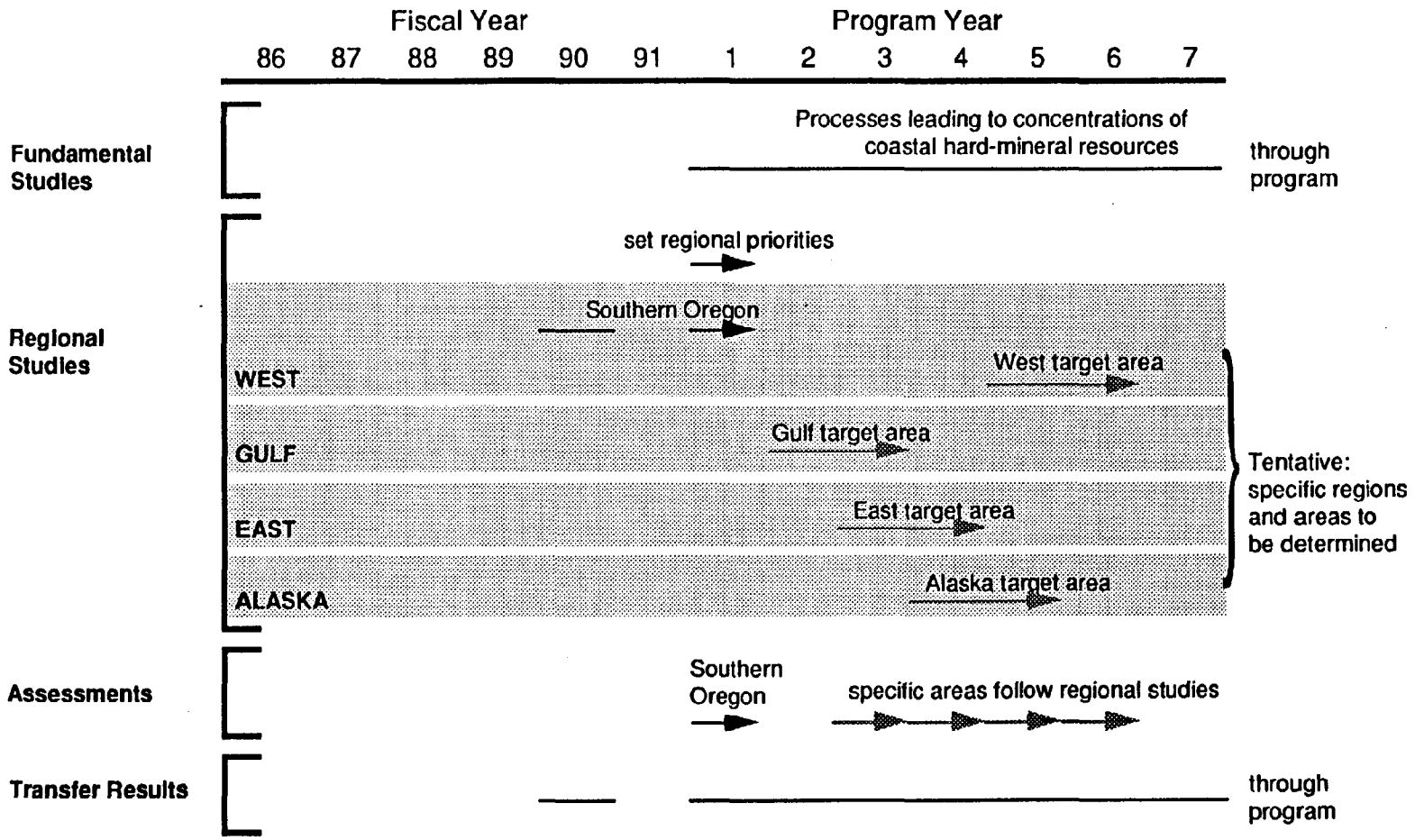

Figure 8

Regional Studies: Hard-mineral resources, such as sand and gravel and heavy minerals, occur in a wide variety of coastal environments and are the result of a wide variety of concentrating processes. Each of the regional studies would have similar components.

- **Geologic Framework:** Because most recoverable hard minerals occur in unconsolidated sediments, primary investigations would focus on the seabed and at shallow subbottom depths. Several types of geophysical records would be collected to determine the layers of sediment and the geometry of buried features, such as river and tidal-inlet channels. Continuous sediment cores would be collected at specified target areas. The cores would aid in interpretation of the geophysical records, and analyses of the sediment would provide quantitative information on sediment texture and composition and content of important heavy minerals.

- **Processes of Formation:** From existing information, we know that marine minerals are most likely to occur in discrete sand bodies that owe their origins to a variety of geologic processes. In some cases, old river channel deposits and deltas are hosts. In addition, linear shoals are common sea floor features, having dimensions of several miles and containing large volumes of clean, coarse sand. For most sand bodies, a clear understanding of the processes responsible for their origin and maintenance under present conditions is lacking, and regional studies as well as focused fundamental studies are needed.

- **Processes of Environmental Concern:** Because coastal areas typically are sites of multiple and conflicting land use, mining of mineral resources commonly presents problems to coastal managers. The consequences of development can best be assessed where the physical processes which operate in the environment around the resource are adequately understood. We propose to conduct studies of these processes in order to predict the consequences of attempting to utilize the resource. The environmental costs associated with their utilization bears strongly on their economic potential.

The regional studies would be scheduled to provide maximum input to the Department of the Interior's Joint State-Federal Hard-Mineral Task Force studies of non-energy minerals on the continental shelves and the MMS's offshore continental shelves resource evaluation activities. The USGS regional studies would provide geologic framework, processes, and characterization information for the Task Forces. Currently, the Task Forces are supporting placer-type heavy mineral or sand and gravel studies offshore Oregon, Georgia, and in the Gulf of Mexico region. Results from the USGS Program would aid in developing resource models, in cooperation with university researchers and state geological surveys, for use by MMS and BOM in subsequent economic evaluations.

Assessment: Assessment of the economic potential of coastal mineral resources would include two phases: the development of a geologic model of the deposits in a specific area, that would include the dimensions, composition, grade of the deposit, and amount of overburden, and an economic evaluation of the resource based on current economic models. The USGS would have responsibility for developing the geologic models, and MMS and BOM would conduct the associated economic evaluations. The future regional studies specified on the schedule are tentative; priorities for regional studies would be based on considerations of national and local needs, potential economic importance, and extent of understanding of the region's mineral resource character.

Appendixes

Appendix A A26

PRESENT MAJOR COASTAL STUDIES A26

Louisiana Barrier Island Erosion A26

Louisiana Wetlands Loss A26

Southern Lake Michigan Coastal Erosion A26

Alabama-Mississippi Erosion and Pollution A27

Boston Harbor Pollution A27

NOAA/USGS Plan of U.S. Great Lakes Shoreline Mapping Effort A28

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NATIONAL COASTAL GEOLOGY PROGRAM REGIONS A29

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Great Lakes A32

Alaska A32

Low Latitude A33

Appendix A

PRESENT MAJOR COASTAL STUDIES

The existing major coastal studies, ongoing or planned, are:

Louisiana Barrier Island Erosion (in cooperation with the Louisiana Geological Survey): The overall objective of the study is to improve our understanding of the processes causing erosion of the barriers. These barrier islands are eroding in places up to 60 feet per year. An initial step in determining processes of erosion is to establish the shallow geologic framework within which the barriers formed, eroded, and migrated landward. The geologic framework refers to understanding the interrelationships between sediments composing the barrier islands and those of offshore areas where the barriers originated at an earlier time. These studies involve coring the sediments and using geophysical techniques which look beneath the bottom to help interpret layers of different sediments.

Another part of the study focuses on understanding specific erosion processes. Processes which are not well understood but are approachable experimentally include: sea-level rise, storm overwash, onshore-offshore movement of sand, and longshore sediment transport. The efforts involve direct measurements of waves and currents during storms, modeling, and determination of historical patterns of erosion and accretion.

The results of the study are directly applicable to various practical problems. For example, a better understanding of the rates of removal of sand from the beaches is crucial to determining how often an artificially nourished beach would need replenishment. Investigations of the geologic framework within which barriers formed also lead to identification and assessment of sand resources useful for beach nourishment as well as a greater capacity to forecast accurately future coastal conditions. The study is in the final year of a 5-year effort.

Louisiana Wetlands Loss (in cooperation with FWS): The processes causing wetlands loss are complex, varied, and not particularly well understood. Both human activities (e.g. flood control, navigation, river damming, and canal dredging) and natural processes (e.g. land subsidence and sea-level rise) have greatly accelerated wetlands loss and deterioration over the past 100 years. There is much debate about which of the many processes (both natural and man-made) are most significant in contributing to wetlands loss. With increased understanding of the processes, a clearer consensus on methods to retard loss and restore wetlands should emerge. Recognizing the need for better understanding, the U.S. Congress directed the USGS and FWS to conduct research on wetlands loss in Louisiana.

In cooperation with the State of Louisiana, the USGS and FWS are in the second year of a research study of select Louisiana coastal wetlands. Emphasis of the study is on understanding the critical physical processes that cause the extreme rates of wetlands loss in coastal Louisiana and the identification of the best management practices to address those losses. The USGS/FWS wetlands study includes four parts: (1) Baseline data is being compiled and put into a computer-retrievable format as part of a GIS network; (2) On a basin scale, research is being conducted to better understand critical processes causing wetlands loss; (3) At specific sites, research is being conducted on the effects and utility of various wetlands management activities on the processes; and (4) The information and results from these studies are being transferred to the user community by means of reports, maps, newsletters, and workshops. The results will provide information critical to the design and construction of mitigation structures.

Southern Lake Michigan Coastal Erosion (in cooperation with the Illinois State Geological Survey and Indiana Geological Survey): This study, which began in FY

1988, is focusing on better understanding of past lake levels so that the potential for high lake levels in the future can be assessed and critical processes leading to erosion caused by high lake levels can be predicted more accurately. The study is a 5-year effort, and some of the results may be applicable to other regions, since lake-level rise and erosion are problems affecting all of the Great Lake states. In the short term, the study is providing technical data needed by other Federal and state agencies responsible for developing cost-effective mitigation of the extreme rates of erosion. For example, preliminary results of surveys along the Chicago breakwater indicate that the level of required repairs is less than previously thought. This new information will reduce costs by tens of millions of dollars. Longer term results, developed over the course of the study, will help assess the impact of future erosion. These results can be used to help plan future utilization of the coast and in designing mitigation schemes.

The study is closely coordinated with activities of other local, state, and Federal agencies, such as the Chicago Park District, USACE, EPA, and NOAA. USGS scientists are working cooperatively with scientists from the Illinois State and Indiana Geological Surveys and local universities. Specifically, the USGS is drawing upon the expertise of the Illinois and Indiana Surveys to help implement the program including monitoring coastal erosion in their respective States and determining historic lake levels.

Alabama-Mississippi Erosion and Pollution (in cooperation with the State Geological Surveys of Alabama and Mississippi): The Alabama-Mississippi coastal region is a dynamic, interrelated system of barrier islands, tidal inlets, wetlands, and estuaries, that is currently undergoing environmental and physical change due to both natural processes and man's activities. The region is experiencing erosion at rates up to 9 feet per year in places and is subjected to hurricane impacts on the average of once every four years. For example, in 1985, Hurricane Elena destroyed nearly 50 percent of the houses located on the western part of the developed area of Dauphin Island, Alabama. Furthermore, the region is increasingly threatened by pollution from various sources. Wetlands in Mobile Bay are undergoing rapid change, and more are threatened with increased offshore activity for oil and gas development.

At the direction of the U.S. Congress and in cooperation with the State Geological Surveys of Alabama and Mississippi, the USGS prepared a study plan titled "Sediment and Pollutant Distribution and Geologic Framework of Coastal Alabama and Mississippi" in April 1989. This study plan was developed in consideration of available data and scientific information needs, which are required for better understanding of this dynamic coastal system and wise management of the region. The multi-phased study, which will span a 5-year period (FY 1990-1994), is being conducted cooperatively by researchers from the USGS, the Geological Survey of Alabama, the Mississippi Bureau of Geology, other Federal and state agencies, universities, and private contractors. With an emphasis on deciphering the geologic framework of the coastal plain, the plan focuses on understanding the physical processes causing erosion and movement of pollutants in the coastal zone. Our ability to predict future erosion and dispersal of pollutants will improve with increased understanding of these processes.

Boston Harbor Pollution (in cooperation with EPA and the State of Massachusetts): The USGS initiated a reconnaissance study of the geologic and oceanographic conditions in the Boston Harbor area in 1987. The study has been closely coordinated with EPA and other state and Federal agencies involved in developing a plan to eliminate waste discharge to the Harbor. Wastes from the Boston metropolitan area have been discharged into Boston Harbor for decades, and the Harbor has been identified by the EPA as the most polluted major estuary in the Nation. Massachusetts is presently under court order to construct new treatment facilities and ocean outfall at an estimated cost of $6 billion. The USGS reconnaissance study in the Harbor addresses the geologic processes affecting the deposition and fate of fine-grained sediments and associated contaminants. The study provides a regional perspective which is essential to developing and

implementing management strategies for waste disposal and restoration of environmental quality in Boston Harbor and adjacent Massachusetts Bay.

NOAA/USGS Plan of U.S. Great Lakes Shoreline Mapping Effort (written jointly with NOAA-NOS): To effectively plan for the effects of high water levels of the Great Lakes, the International Joint Commission (IJC) requested "updated and accurate large-scale maps of the shoreline and coastal zone." Subsequently, the U.S. Congress, through PL 100-220, the Great Lakes Shoreline Mapping Act of 1987, directed NOAA and USGS in FY 1990 to "submit to the U.S. Congress a plan for preparing maps of the shoreline of the Great Lakes." To meet this mandate, the recently formed USGS/NOAA Joint Office for Mapping and Research (JOMAR) would coordinate and integrate the efforts of the two agencies to focus on a systematic regional mapping of the U.S. Great Lakes shorelines. The plan contains a schedule to update existing maps and to develop new ones, where needed, which depict the geographic and geologic framework of the Great Lakes shorelines and the areas of erosion and accretion. Within a 10-year period, geodetically controlled shoreline photography would be obtained to determine precise topographic and bathymetric information. These data would be combined with acquired bathymetric data, forming a continuous data set from onshore to offshore. Tentatively, the study would start in Lake Michigan, followed by Lakes Huron, Erie, Ontario, and Superior. Priority would be given to areas subject to high risk of erosion (>1 foot/year) or frequent flooding. The study plan was submitted to Congress in December 1989 and is under consideration for NOAA's appropriations bill in FY 1991.

Appendix B

NATIONAL COASTAL GEOLOGY PROGRAM REGIONS

In this appendix, an overview of each of the Program's regions is provided. This is not intended as an exhaustive description of the many diverse problems in each region; rather, it presents examples of important problems which would be better addressed with increased understanding of coastal geology.

CHARACTER OF U.S. COASTAL REGIONS

The more than 92,000 miles of U.S. shoreline, and associated wetlands and adjacent continental shelves, are highly variable in character and form due to marked differences in geology and physical processes. The East Region has a broad and low relief continental shelf, and much of the coast consists of sandy barrier islands separated from the mainland by lagoons and wetlands marshes. The Gulf Region, similar in many respects to the East, is composed mostly of low-lying barrier islands and dominated in the north central part by the Mississippi River Delta plain. Northern Alaska also has a broad continental shelf and low-lying barrier islands. In contrast to the above, the West Region and southern Alaska are tectonically active, with cliffed shorelines and narrow to essentially nonexistent continental shelves. The Great Lakes Region has a wide range of coastal types due to the diversity of the geologic character of the coast and the influences of glaciers over the past few million years. The Low Latitude Region includes the tropical areas of the U.S. where coral reefs actively grow. To varying degrees, all of these regions are subject to problems arising from coastal erosion, wetlands deterioration, polluted sediments, and scarcity of hard-mineral resources.

EAST REGION

The East Region, extending from Maine to Florida, encompasses the glaciated northeastern coast from Maine to Long Island and the southern coastal plain from New Jersey to Florida. Sandy beaches and barrier island systems are the dominant land forms, ranging from heavily developed (e.g. western Long Island, Atlantic City, Ocean City, Virginia Beach, Miami Beach) to natural and pristine seashores (e.g. Fire Island, Virginia barriers on the Eastern Shore, Bull Island, Cumberland Island). Many of the beaches are economically vital as public recreational assets, and the barriers protect ecologically important wetlands marshes and productive estuaries. The wide and low relief continental shelf has been transgressed by the sea several times in the recent geologic past, resulting in the formation of large shoals which contain abundant deposits of sand, gravel, and, potentially, other hard minerals. These sandy shoals are also ecologically important for fishery resources.

Within the East Region, erosion of the oceanic shorelines averages 2.4 feet per year.[5] The states with the most rapid erosion rates are Virginia (13 feet per year), South Carolina (6 feet per year), Maryland (4.5 feet per year), and New Jersey (3 feet per year). Roughly 80 percent of the East Region is undergoing long-term net erosion. Like the barrier island coasts to the south, the more rugged, glaciated coasts in the Northeast also are undergoing erosion, although at lower rates. For example, Maine has a long-term net erosion rate of 1.2 feet per year.

[5] May, S.K., Dolan, R., and Hayden, B.P., 1983, Erosion of U.S. shorelines: EOS, Transactions, American Geophysical Union, v. 64, n. 35, p. 521-523.

The East Region contains a number of large estuaries and coastal embayments subject to coastal problems. Boston Harbor and Massachusetts Bay have been discussed under Polluted Sediments and in Appendix A. Other examples are:

- **Chesapeake Bay:** The largest estuary in the United States, the Chesapeake Bay has roughly 4,600 miles of shoreline, and more than 8 million people live near its shores. In terms of dollars, the Bay has the third largest fishery in the United States. Pollution threatens the ecosystem, human health, and the quality of life within and along the Bay. Extensive coastal wetlands which occur around the margins of the Bay are deteriorating due to the pressures of man and other processes. Erosion of the Bay's shoreline is of the same order as the oceanic coasts, roughly 2.1 feet per year. Other large estuaries in the East Region (e.g. Delaware Bay) are subject to similar problems.

- **New York Bight:** More than 20 million people live along the 250-mile long coastal embayment from the eastern tip of Long Island to Cape May. This area is heavily used for waste disposal, coastal recreation, fishing, commerce, transportation, and as a source of building aggregate; it will be subject to increased pressures in the next decade as the coastal population increases. Headlands like Sandy Hook are being eroded, whereas barrier islands (such as Fire Island and Jones Beach) are being eroded or lengthened. Sand deposits on the inner shelf may reach 38 million short tons and be worth about $152 million, but these estimates need to be verified by additional study.

- **South Atlantic Bight:** Extending from Cape Hatteras, North Carolina, to Cape Canaveral, Florida, the South Atlantic Bight encompasses beach and barrier island systems ranging from heavily developed to pristine National Seashores. The barrier islands shelter ecologically important wetlands and estuaries. Deposits of sand and gravel on the inner shelf are potentially important resources for beach nourishment; other hard minerals which may be present in significant quantities include phosphorites and placer deposits. The extensive areas of exposed hardbottom in offshore areas are sensitive fisheries habitats. The region falls within the hurricane-prone section of the Atlantic Coast, and as was emphasized by the impact of Hurricane Hugo on South Carolina, extreme storms may drastically reshape the coast. Within the region are areas of extreme coastal erosion such as Myrtle Beach and Folly Island, South Carolina. Compared to many other coastal areas in the U.S., the South Atlantic Bight has not been extensively investigated. For example, little is known about the shallow geologic framework in the Bight, particularly offshore of South Carolina.

GULF REGION

The arcuate Gulf Region extends from Florida west to the Texas/Mexico border and comprises about 20 percent of the U.S. coastline. Most of the region consists of low-lying barrier islands protecting shallow bays and wetlands. The central Gulf Coast is dominated by the Mississippi River Delta plain. Bluffs occur in limited areas, such as part of the Florida Panhandle. The Region is, overall, the most low-lying region of the U.S., making it particularly susceptible to flooding during storms and to sea-level change brought about by global climate change.

The Gulf Region is impacted by frequent hurricanes, tropical storms, and winter cold fronts. On average, a hurricane makes landfall on the central Gulf Coast once every four years, causing extensive damage and erosion. In 1985, Hurricane Elena destroyed approximately 50 percent of the houses on the low-lying western part of Dauphin Island, Alabama. With the potential for global warming, the frequency of hurricanes and tropical storms may increase.

Erosion rates of open coast shorelines within the Gulf Region are typically the highest in the United States. On average, erosion is occurring at 5.4 feet per year.[5]

The most erosive area is the Louisiana delta plain, with rates in places exceeding 60 feet per year. The shorelines of Alabama and Texas are eroding on the average of 3.3 feet per year. In places, erosion is much more rapid; erosion averages 10 feet per year on parts of Dauphin Island.

Many barrier islands in the Gulf Region are heavily developed and important for the tourist industry. To mitigate the effects of shoreline erosion, the State of Florida and other Gulf Region states are committed to using beach nourishment to raise and broaden the shore, but the volumes of sand fill required for such large projects greatly exceeds existing onshore resources. The use of offshore sand is an alternative.

The Gulf Coast has 46 percent of the coastal wetlands and 60 percent of the salt marsh within the conterminous United States. In Louisiana, where the bulk of these wetlands occur, they are disappearing at alarming rates of up to 40 square miles per year. In other areas, such as west-central Florida, where wetlands are directly exposed on the open coast, they are being seriously impacted by development in support of a rapidly expanding population.

Similar to the East Region, large coastal embayments and estuaries are subject to pollution. Examples are Tampa Bay and the Mobile Bay/Mississippi Sound areas.

WEST REGION

The West Coast of the conterminous U.S. is characterized by an irregular, mountainous coastline over much of its length. Coastal lowlands, which typically have formed either near the mouths of larger rivers or in areas of active tectonic subsidence, have become sites of major population centers. The most populated areas are the southern California coast between Santa Barbara and the U.S./Mexico border, the San Francisco Bay-Monterey Bay area, and the Puget Sound area. Smaller cities are scattered along the rest of the coast.

Many population centers have developed around large estuaries which, consequently, have lost much of their wetlands and become polluted. An increased public awareness of coastal/estuarine problems has led to intense conflicts between environmental and development factions. Often, impacts on the largest estuaries have far-reaching effects. For example, the supply of water to southern California could be threatened by erosion in the Sacramento Delta; this can be related to the transport of sediment in San Francisco Bay.

Like the other regions, problems related to erosion, pollution, wetlands, and resources are common in the West Region. Examples of specific problems are:

- **San Francisco Bay Polluted Sediments:** Sediment movement into, through, and out of San Francisco Bay is a matter of major consequence to the coastline of the Bay, the central California coast, and the Sacramento Delta. The amount of sediment entering and exiting the Bay has changed dramatically since the introduction of a huge volume of sediment into the system by 19th-century hydraulic mining. Changes in San Francisco Bay caused by fluctuations in sediment addition, loss, and redistribution bear on living resources within the Bay, dredging requirements, and loss of wetlands. In places, sediments contain high levels of pollutants. Dredging of polluted sediments to clear shipping lanes poses additional problems, such as locating acceptable dump sites for contaminated sediments. Other estuaries in the West are subject to similar problems. For example, three heavily polluted areas of Puget Sound have been designated by EPA as Superfund sites.

- **Southern California Erosion:** This area consists of about 200 miles of coast which is home to nearly 10 percent of the Nation's population. Due to

complexities in offshore bathymetry, normal methods of predicting wave energy and direction and, ultimately, sand transport and beach erosion are not adequate. Compared to the East and Gulf Coasts, the terrain is steep, but sea-level rise could still seriously impact preservation of beaches and accelerate cliff erosion. The magnitude of these potential impacts is unknown.

- **Resources:** The West Region has high potential for hard-mineral resources. As discussed above, potential economic occurrence of heavy minerals offshore Oregon is being investigated cooperatively with the State, MMS, and BOM. Examples of other areas with high heavy mineral potential are Gold Bluffs (California), Columbia River mouth (Washington/Oregon), and Point Conception-to-Morro Bay (California).

GREAT LAKES REGION

The coasts of the five Great Lakes exhibit a wide range of shoreline types depending on the geologic character of the rocks at the shore and the influences glaciers have had over the past several million years. Some shores have large deposits of glacial sediments, while others have been scoured to bedrock. Also, the lake shores vary considerably from being high bluffs of rock or glacial drift to being low plains and freshwater wetlands associated with ancestral lake bottoms, formed when lake water levels were much higher than present.

The Great Lakes are one of our greatest water resources, containing 95 percent of the Nation's and 20 percent of the world's fresh surface water. Fifteen percent of the U.S. population and fifty percent of Canada's population - about 40 million people - live close to the Great Lakes. Pollution is a problem of great and immediate concern. The Great Lakes Water Quality Board has identified 42 "Areas of concern," 25 of which are located in U.S. waters. The principal problem is toxic wastes: PCB's and polynuclear aromatic hydrocarbons, and heavy metals, such as lead and copper. Examples of problems are:

- Fish in the St. Louis River and St. Louis Bay contain PCB's and mercury,
- In Lake Erie, sediments at the mouth of Maumee River contain cyanide, metals, and ammonia.

The average erosion rate for the Great Lakes shorelines of the U.S. is 2.1 feet per year. Fifteen percent of the Great Lakes shorelines have been classified as subject to severe erosion. During 1985-86, lake levels reached their highest elevation in this century, and erosion of the shorelines was severe. For example, on the Ohio shore of Lake Erie, the low clay banks at Maumee Bay retreated 22 feet per year. Fifty-foot high bluffs retreated up to ten feet per year. Understanding the periodicity and magnitude of lake-level changes is important not only for predicting high levels and the impact on future erosion but also for predicting low levels which might necessitate dredging polluted sediments from channels and harbors to improve navigation.

ALASKA REGION

The Alaska coast is highly varied and includes the extremely rugged southern coast exposed to the Pacific Ocean, the barrier islands and the Yukon Delta plain on the Bering Sea Coast, and the nearly continuous barrier islands bordering the Arctic Ocean. These coasts are shaped by diverse processes. Active tectonism occurs in southwest Alaska where historically great volcanic eruptions and earthquakes have occurred. Wave energy ranges from very high in the North Pacific to relatively low on the ice covered Arctic Ocean. Ice and freeze/thaw processes are very important in shaping the coast in the Arctic.

Alaska is the Nation's last remaining great wilderness area. Oil extracted from the fragile arctic coast is trans-shipped from the tectonically active southeastern coast. The billion-dollar-a-year tourism industry relies heavily on coastal attractions such as luxury cruises, fishing, and the coastal wildlife and natural splendor. The regions fishery is the largest in the Nation.

- **Wetlands:** The forty-five percent of Alaska classified as wetlands - an area equal the size of Texas - is heavily used for breeding, nursery, and feeding by local and migratory wildlife. Coastal wetlands are critical to the food supply, health, and survival of numerous whale and bird species.

- **Pollution:** The Exxon Valdez oil spill occurred in Prince William Sound, where the geologic processes affecting the coasts are virtually unknown. With continued high tanker traffic, the area is subject to future spills.

- **Tectonics:** Seventy-five percent of Alaska's population are located on coasts subject to major earthquakes. Tsunamis (large waves) generated by landslides and other processes have inundated communities and climbed the sides of mountains to 1,200 feet above sea level.

- **Erosion:** One quarter of domestic oil production originates from the Arctic Coast area. Rapid shoreline erosion, which is equal to or greater than that in the remainder of the U.S., alters habitat, hinders oil extraction, and redefines political boundaries. Unique ice-related processes control erosion along the Arctic Coast.

- **Hard-Mineral Resources:** Coastal areas of the Bering Sea have relatively high potential for heavy minerals. Mining for gold is ongoing offshore of Nome in the northern Bering Sea, and coastal mining is contemplated in the Arctic (sand and gravel), southern Bering Sea (platinum group), and Gulf of Alaska (gold).

LOW LATITUDE REGION

The Low Latitude Region includes the tropical areas of the U.S. where coral reefs actively grow. These include the Florida Keys, Hawaiian Islands, Puerto Rico, U.S. Virgin Islands, American Samoa, Commonwealth of the Marianas, Guam, and the possessions of Howland, Baker, Jarvis, Johnston, and Palmyra Islands. Excluding south Florida, this region represents approximately 12 percent of the U.S. shoreline. Although this region has similar resource, erosion, and pollution problems as other U.S. coastal regions, there are several unique aspects of coral reef environments that deserve attention.

- The living "healthy" reef is a resource in itself. For example, nearly $400 million annually is generated from tourists who want to dive on small Molasses Reef off the south Florida coast. Nearly $3.4 billion per year of reef-related tourist income is generated in a three-county area of south Florida alone. Coupled with the major tourist industries of Hawaii, Guam, the Virgin Islands, and Puerto Rico, a significant amount of money is spent annually for recreational purposes in coral reef areas.

- Sand and gravel resources are a particularly acute problem in island settings. Many low-lying coastal areas have limited on-land construction materials, and nearshore sources are needed to supply local construction needs and for beach nourishment where coastal erosion is severe. Exploration for such resources has increased during the 1980's and would be an essential element of any serious coastal program for the next decade.

- Coastal erosion is widespread and serious but a poorly understood process within the low latitude areas because no significant data is available. Erosion problems are known to exist along the west coast of Guam, the island of Saipan

in the Northern Marianas, the south coast of Tutuilla, American Samoa, and at numerous localities on the Hawaiian Islands. Tourism is a major source of income for these areas, and beach stability is a primary concern. For example, Puerto Rican beaches receded up to 30 feet during the passage of Hurricane Hugo with estimated losses over $1 billion. In addition, severe wetlands loss and mangrove destruction occurred along the northeast coast.

- Coastal pollution is widespread, and in many areas, it is severe enough to warrant warnings to prohibit swimming in lagoons (e.g. the west coast lagoons of Saipan). Because of their intimate relationship with coral reefs, low latitude areas are acutely susceptible to pollution and the potential effects associated with climate change.

NATIONAL COASTAL GEOLOGY PROGRAM

A Plan of Geologic Research on
Coastal Erosion, Coastal Wetlands, Polluted Sediments,
and Coastal Hard-Mineral Resources

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