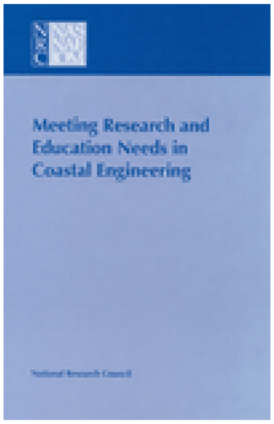

Meeting Research and Education Needs in Coastal Engineering

Committee on Coastal Engineering Research and Education Needs, National Research Council

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Committee on Coastal Engineering Research and Education Needs

Marine Board
Commission on Engineering and Technical Systems
National Research Council

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Preface

BACKGROUND

Traditional coastal engineering education and practices have centered on designing, constructing, and maintaining waterways and port facilities; protecting and stabilizing shorelines, entrances, and channels; and controlling flooding and the effects of storm-driven energy. New practices have steadily evolved during the past two decades to improve water quality and reduce pollution; monitor, calibrate, analyze, and adjust physical aspects of hydraulic and sediment systems; and diminish or mitigate the environmental impacts of water-related problems. Diagnostic procedures have also been developed for determining the effects of coastal processes and the impact of built structures and other restorative measures on the coast.

Coastal engineers are expected to undertake varied activities with sometimes conflicting objectives, depending on the policy and philosophy guiding a particular coastal engineering project. For example, some projects are intended to enhance, restore, or create habitat, while others will inevitably destroy or limit habitat; in some instances, a decision is made to protect coastlines with traditional hard structures, such as seawalls, while in others, natural (soft) shore protection measures, such as beach nourishment and underwater berms, are preferred. Dredged materials may be considered a resource in one project and "spoil" for disposal in another.

Rising sea levels, damaging storm surges, eroding beaches, deteriorating coastal habitats, and aging port and harbor infrastructures present formidable challenges to the integrity of coastal zone resources and ecosystems and the full realization of the economic potential of the coasts. The knowledge base to address these and other problems depends on research and education, as well as on field and laboratory experience.

Support for research and education in coastal engineering, however, has remained level or declined in response to pressures on government agencies to control federal spending and focus on mission-oriented projects. Nevertheless, the need for expertise in coastal engineering has increased with the concentration of population and associated infrastructure in coastal areas and the recent increase in the frequency and intensity of major storms in the Gulf of Mexico and on the East Coast. Because of the economic and ecological importance of coastal engineering, an assessment of the capability of existing institutions to meet the national need for research and education in this field is both necessary and timely.

SCOPE OF THE STUDY

After discussions with the U.S. Army Corps of Engineers, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the Office of Naval Research, the National Research Council (NRC) convened a committee under the auspices of the Marine Board to examine present and anticipated national needs in coastal engineering research and education and assess the adequacy and effectiveness of existing institutions in meeting those needs. In carrying out its charge, the committee undertook the following specific tasks:

- Determine the role of coastal engineering research and education in meeting national needs.
- Assess the capabilities of coastal engineering research and facilities in meeting national needs.
- Evaluate programs and facilities for educating coastal engineers in the context of national needs.
- Assess the adequacy of the nation's investment in coastal engineering research and education in meeting national needs.

The committee had expertise in the following areas: coastal engineering research, coastal engineering applications, marine geology, coastal management, research management, engineering education, and habitat restoration and enhancement. The committee reviewed relevant reports and was briefed on federal and private sector activities related to coastal engineering research and education. Information was solicited from expert researchers and practitioners from federal, regional, state, and local government agencies; industry; and public interest groups.

REPORT ORGANIZATION

The audience for this report includes federal, state, and local government agencies; policy makers; members of the technical and academic communities; and other members of the marine or coastal community, including the general public, with a stake in coastal engineering research and education.

In Chapter 1, the committee examines the national needs for coastal engineering in detail, from beaches to ports to estuaries, highlighting the most important national needs. In Chapter 2, the committee assesses the current academic status of coastal engineering research and education based on a survey of programs and summarizes the status of research in the United States. Chapter 3 presents the committee's findings, conclusions, and recommendations. An Executive Summary provides a summary of the report. Biographies of committee members are given in Appendix A, and the survey and a summary of responses are presented in Appendix B.

ACKNOWLEDGMENTS

The committee wishes to thank the many individuals who contributed their time and effort to this project by presenting material at committee meetings and workshops and by contributing written material or participating by telephone. Representatives of federal and state agencies, as well as private companies in various engineering sectors, provided invaluable assistance to the committee and the Marine Board staff.

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remains confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

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Fred N. Spiess, Scripps Institution of Oceanography

While the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring committee and the NRC.

The committee especially wishes to remember the work of the late Joseph L. Zelibor, Jr., who was the initial staff officer on this project and who assisted the committee in the difficult early stages of this study. His sudden and untimely death is a great loss.

Finally, the chairman would like to thank the members of the committee, not only for their hard work during meetings and in reviewing drafts of this report, but also for gathering information and writing sections of the report.

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Executive Summary

The coastal zone has become increasingly important to the economic well-being of the United States. Recreation, tourism, residential and commercial development, and ports and harbors are all expanding along the shoreline, and populations in coastal counties are growing faster than anywhere else in the country. One in every three jobs is now generated in a coastal county, 90 percent of foreign trade passes through U.S. ports, and 33 percent of the GNP (gross national product) is produced in the coastal zone (NRC, 1990). More tourists from abroad visit beaches than national parks. Ninety percent of all foreign tourist dollars, an estimated $80 billion per year, is spent in coastal states. This constitutes more foreign exchange than is derived from the export of manufactured goods (Houston, 1996).

As populations along the shoreline increase, so do the threats and impacts of natural hazards, such as hurricanes, storm waves, tsunamis, and rising sea level. Most of the sandy coastlines in the United States (including the Great Lakes shorelines) are undergoing erosion caused by a combination of natural processes (e.g., wave impact, coastal bluff failure, rising sea level, and land subsidence) and human activities (e.g., impacts of coastal structures and beach sand reduction). Along the East and Gulf coasts alone, about $3 trillion in infrastructure adjacent to the shoreline is vulnerable to erosion and other natural hazards. Yet national policies for shoreline protection are either inadequate or poorly implemented (IIPLR, 1995; NRC, 1990).

Damage from coastal hazards continues to rise as a result of the increase in vulnerable coastal infrastructure. Hurricane damage from waves, erosion, wind, and flooding now routinely exceeds $1 billion dollars a year. El Niño and northeasters plague the West and East coasts of the country. Tsunamis are a threat to the West Coast. Long-term climate changes, such as sea level rise, may further increase the damage caused by coastal hazards.

As international trade has expanded, the nation's economy has become dependent on increasing volumes of both exported and imported goods, which has intensified pressures on U.S. ports and port facilities. Most harbors must be regularly dredged and often deepened to accommodate large cargo ships. At the same time, contaminants concentrated in the sediments that are deposited in many harbors, along with increasingly stringent dredging and disposal standards (as well as water quality criteria and concerns about wetlands), have made port maintenance and expansion a major economic and environmental issue. In addition, as the density of ship traffic in harbors increases, the design of breakwaters, navigational channels, and ship navigational procedures in harbors will be critical to the safe and efficient operation of ports.

Coastal engineers, along with coastal geologists and physical oceanographers, have traditionally been responsible for studying shoreline and nearshore processes and solving the engineering problems generated by human activities. The domain of the coastal engineer includes port and harbor design, maintenance dredging, the planning and construction of breakwaters, jetties, and groins, and solving shoreline erosion problems. More and more, the role of the coastal engineer is also expanding to encompass environmental and ecological issues, as the role of wetlands and water quality becomes more important. There are also opportunities for environmental remediation in areas where previous coastal engineering practices have caused adverse impacts. As coastal populations continue to expand and dependence on the coastal ocean and shoreline grows, the need for well trained coastal engineers will also grow.

The number of practicing coastal engineers is relatively small, however, as is the number of academic programs training coastal engineers for the future. Although the number of academic institutions that provide graduate education has grown from one to more than 20 in the last 30 years, most of these university programs do not have sufficient laboratory facilities or faculty to provide the necessary education for the coastal engineers of tomorrow. Only four programs have four or more faculty members, and the largest program has only seven. Altogether, the committee found that there are only about 50 faculty members teaching in this field—less than the faculty of a medium-sized school of engineering. Nevertheless, these programs graduate about 60 M.S.-level students and about 20 Ph.D.s annually. These graduates find employment with the U.S. Army Corps of Engineers, consulting firms, state or federal government agencies, and a few academic departments (one or two academic positions are filled per year).

The number and status of various academic programs in coastal engineering and the number of graduate students being trained are determined by a combination of the funding available to support research contracts and grants and the existing job market. Funding for academic research is a strong indicator of the direction of graduate programs in engineering schools: subject areas that are well funded grow; those that are poorly funded decay. Based on its investigations, the committee believes that because coastal engineering is a relatively small field and because research funds are scarce, the number of academic programs (and thus the number of new professionals being trained) is likely to decrease. Furthermore, the current faculty is too small to meet the increasing need for coastal engineers who can help solve the serious problems facing the nation.

No one federal agency is responsible for supporting research and education in coastal engineering. Funding for academic research comes from a variety of sources, including the National Science Foundation, the Sea Grant Program of the National Oceanic and Atmospheric Administration, the Office of Naval Research, the Army Research Office, and the Waterways Experiment Station of the U.S. Army Corps of Engineers, and totals about $4 million per year. This relatively low level of support means that the number of research projects being funded and, therefore, the number of coastal engineers being trained is small. This situation is already having a negative impact on research in coastal engineering and on international competition for coastal engineering projects. Although support for coastal engineering research in the United States is low, the nation's use, protection, and enjoyment of coastal areas will depend on developing and maintaining shoreline infrastructure, reducing the impact of deleterious natural forces on human activities, and mitigating the effects of human activities on the coastal environment. The amount of funding and the mechanism for allocating funds for research and education in coastal engineering should be reevaluated in terms of emerging national needs.

Solving the problems outlined in this report will require both basic and applied research. Basic research focuses on the scientific underpinnings of coastal engineering, such as sediment transport, and applied research focuses on mitigating shoreline erosion, dredge disposal technologies, and environmental issues, such as water quality and habitat protection and restoration. The committee recommends that a consortium of universities coordinate the use of existing academic research facilities to ensure that these valuable resources are used efficiently and effectively to benefit the research community. The committee also recommends that a lead government agency be designated to provide support for each type of academic research—the National Science Foundation for basic research and the U.S. Army Corps of Engineers for applied research.

CONCLUSIONS AND RECOMMENDATIONS

Coastal engineering is important to the vitality of the nation's shorelines and ports. However, academic research in coastal engineering is poorly funded, and the level of funding has not increased in the last decade, which has affected the competitiveness of the United States. The lack of sufficient funds has affected the availability and quality of laboratory facilities and the ability to conduct extensive field experiments. Unlike several other countries, the United States does not have a central government agency that is responsible for the field. The following recommendations are intended to address these problems.

Academic Consortium

Recommendation 1. The committee recommends that the coastal engineering academic community establish a consortium to improve research and education through cooperative arrangements for leveraging major research facilities and educational capabilities. This consortium should assess the available facilities and determine which ones are critical to meeting the national needs. Budgets for maintaining these facilities should be prepared and proposals submitted to the U.S. Army Corps of Engineers and the National Science Foundation under the funding programs recommended in this report, along with a plan for ensuring fair and equitable access to these facilities for researchers whose projects are funded under these programs. The consortium should be responsible for scheduling the use of these facilities.

The consortium should provide academic leadership in coastal engineering education at all levels, from elementary school through postgraduate continuing education. It should also provide guidance to academic programs concerning the evolution of graduate curricula to include courses in port engineering, environmental issues, and public policy. The consortium should also provide leadership in educating the general public about coastal processes.

National Science Foundation

Recommendation 2. The committee recommends that the National Science Foundation establish a program in its Engineering Division to fund fundamental research on coastal engineering. This program should be separately identified and should be directed by a highly qualified coastal engineer. The 1984 Ad Hoc Committee for the Civil and Environmental Engineering Division recommended that funding for this program be gradually increased to $10 million dollars per year. This committee agrees that a comparable level of funding is still appropriate. Funds in this program should also be allocated to the support and maintenance of large experimental coastal facilities.

U.S. Army Corps of Engineers

Recommendation 3. The committee recommends that the U.S. Army Corps of Engineers establish a substantial program to fund applied research in academic coastal engineering programs. The level of support should be comparable to the funding level for basic research. Most of this funding should be used for extramural grants, with a small percentage (less than 5 percent) for administering the program. The committee believes these grants would encourage stronger partnerships with the academic community in coastal engineering, which would strengthen all research and applied programs, as well as the pool of candidates from which the Corps of Engineers recruits coastal engineers.

A review board for academic research should be charged with overseeing the research-funding process. Half of the members should be agency representatives, and half should be qualified external individuals. (The civilian members of the Coastal Engineering Research Board could serve in this capacity, along with academics and others from outside of academia.) The review board would establish research priorities, oversee the solicitation of proposals, and review the external/internal peer-review processes. Matching funding by coastal states could be used to bolster this program.

SUMMARY

The nation's needs in coastal engineering are becoming increasingly urgent to the economy and to our quality of life. However, these needs have far outstripped financial support for research and education in coastal engineering, and the United States is falling behind other coastal nations in its support of research and laboratory facilities. In response to developmental pressures on our coastlines and the international demand for coastal engineering services, the United States must maintain a healthy and vigorous program in coastal engineering education and research.

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1

National Importance of Coastal Engineering

BACKGROUND AND HISTORY

Coastal engineering is defined here as the application of skills, knowledge, expertise, and theory associated with purposeful engineering intervention in the coastal system. This definition includes the application of scientific principles underlying a broad range of traditional engineering disciplines to a zone in which there are significant interactions between water and land, including shorelines, bays, lakes, estuaries, inlets, river mouths, and harbors, and the structures within these environments. Coastal engineering involves the practice of civil engineering, as well as the sciences of oceanography and coastal geology, to control erosion; place, construct, and monitor coastal structures; nourish beaches; and develop and maintain ports, harbors, and related navigation facilities. More and more, the role of the coastal engineer is also expanding to encompass environmental and ecological issues, as the role of wetlands and water quality becomes more important. There are also opportunities for environmental remediation in areas where former coastal engineering practices have caused adverse impacts. Coastal sciences, defined here as nearshore oceanography and coastal geology, are the scientific knowledge base for coastal engineering. A number of coastal engineers are involved in research in many aspects of coastal sciences, such as sediment transport in the surf zone and the mechanics of breaking waves.

The discipline of coastal engineering in the United States began in the 1930s, largely as a result of research and other programs by the U.S. Army Corps of Engineers (USACE) and the U.S. Navy. The Sea Grant Program of the National Oceanic and Atmospheric Administration (NOAA) and the National Science

Foundation (NSF) have also supported the development of education in coastal engineering. Coastal engineering programs have been established at a small number of academic institutions, and the graduates of these programs have carried the technology to government agencies at the federal and state levels and to a small number of professional firms that design coastal works in the United States and around the world (Box 1-1).

Investments in these programs and facilities have remained level or even declined (in real dollars) for a number of years, even though national needs have increased. At the same time, other countries (notably Spain, the Netherlands, Japan, and Denmark) have made significant investments in coastal engineering research facilities and programs and have challenged or overtaken U.S. leadership in a number of areas. Spain and the Netherlands have developed advanced technologies for dredging and beach restoration. Japan has made significant technological advances in port infrastructure and technology. Consulting engineering firms in Denmark and the Netherlands have close ties to first-rate laboratories and advanced design software superior to those developed in the United States.

For U.S. ports to remain competitive in world trade, the United States must accommodate changes in shipping technology developed by Japan and Korea that require more modern and deeper draft facilities. Because many U.S. channels were originally designed to accommodate older, smaller, and shallower draft vessels, these challenges are formidable. The environmental constraints associated with dredging of U.S. ports and the disposal of the often-contaminated material are significant issues that must be resolved.

The following three examples—the effects of El Niño on the California coastline, erosion at St. Lucie Inlet, Florida, and the dredging problems facing the Port of New York and New Jersey—highlight some of the serious problems facing the nation's coastal areas.

El Niño and the California Shoreline

In late January and early February of 1998, the coast of California was hit by a series of powerful El Niño-influenced winter storms, causing 40 counties throughout the state, including most coastal counties, to be declared federal national disaster areas. The coastal damage included severely eroded beaches, flooded oceanfront homes, and the demolition of 10 bluff-top homes in the Pacifica area, just south of San Francisco, due to bluff failure that had undermined their foundations.

Sea-surface elevations recorded in San Francisco during the 1997–1998 El Niño event were higher on average than those observed during the last major El Niño event in 1982–1983 (Flick, 1998), with record numbers of major wave events (Seymour, 1998). Coastal damage, however, was less severe than during the previous El Niño event, which damaged 3,000 homes and 900 businesses along the California coast. The greater damage in 1982–1983 is believed to be

BOX 1-1 History of Coastal Engineering

In 1951, a founder of modern coastal engineering, M.P. O'Brien, wrote:

> Coastal engineering is primarily a branch of civil engineering that leans heavily on the sciences of oceanography, meteorology, fluid mechanics, and others. However, it is also true that the design of coastal works involve[s] many criteria that are foreign to other phases of civil engineering. . . . Along the coastlines of the world, numerous engineering works in various stages of disintegration testify to the futility and wastefulness of disregarding the tremendous destructive forces of the sea. Far worse . . . has been the damage to adjacent shorelines caused by structures planned in ignorance of, and occasionally in disregard of, the shoreline processes . . .

The first practitioners of coastal engineering in the United States were motivated by problems created by fluctuations and migration of the shoreline and a curiosity about the dynamics of the natural system. The early practice of coastal engineering predominantly addressed erosion, as coastal structures were built without concern for their effects on shorelines. During the 1920s and 1930s, New Jersey was the choice oceanfront vacation location in the United States, and the erosion of some New Jersey beaches led to investigations first by the National Research Council Committee on Shoreline Studies and later by the U.S. Army Corps of Engineers through their Board on Sand Movement and Beach Erosion (BSMBE). The BSMBE was replaced by the Beach Erosion Board, created by Congress in 1930, which continues today as the Coastal Engineering Research Board.

The second major impetus to the development of coastal engineering was a result of troop landings through the surf zone during the Second World War. Theories had been postulated since the mid-1800s to describe wave motion, and limited theory had been developed to predict wave transformation over idealized bathymetry. However, additional knowledge was needed to predict wave generation by wind, the transformation of waves over irregular bathymetry, and the onset of wave breaking and wave transformation through the surf zone.

Investigations primarily by the Scripps Institution of Oceanography and the Council of Wave Research at the University of California at Berkeley established a better overall understanding of beach profiles, their response to storms, and sand movement in general. Research continued after the war, and the United States was recognized as the undisputed leader in the field of coastal engineering.

The next major impetus for investigation was the exploitation of offshore petroleum resources in the Gulf of Mexico in the early 1950s. Movement into the Gulf began gradually with wells near the shoreline and then in deeper and deeper water. The vulnerability of platforms in an area subject to hurricanes and storm tides gave rise to a new round of research and development. The waves and wave forces could cause catastrophic platform failure, major economic losses, oil spills, and the possible loss of life.

Recently, concerns about coastal hazards coupled with the rapidly increasing populations in coastal zones and the potential for widespread losses of life and property have stimulated research. Thus, to some extent, renewed concerns about beach erosion and stability are congruent with the early interests of coastal engineers and geologists.

The interested reader is referred to Wiegel and Saville (1996) for further information about the early history of coastal engineering in the United States.

Bluffs cut away by damage from El Niño storms in Santa Cruz, California, March 1998. Courtesy of Monty Hampton, U.S. Geological Survey, Menlo Park, California.

due to the repeated coincidental arrival of storm waves with high tides. Also, since then, a large number of seawalls and revetments have been built along the shoreline, providing some protection. An evaluation of historic coastal storm damage along the central coast of California indicates that in the last 85 years, 75 percent of the damaging storms have occurred in El Niño years (Storlazzi and Griggs, 1998).

St. Lucie Inlet, Florida

The shoreline south of St. Lucie Inlet, Florida, a man-made inlet on the east coast of Florida, has eroded landward hundreds of meters because of the interruption of the natural transport of sand along the coast. At the inlet, the amount of transport driven by the waves from north to south is on average 200,000 cubic yards (153,000 cubic meters) of sand per year. The original inlet was constructed in 1892, and a stabilizing jetty was added along its north side in 1928. Initially, no attempt was made to bypass the littoral drift from north to south, and Jupiter Island to the south soon became one of the most rapidly eroding areas in the state. By 1946, the northern end of Jupiter Island had eroded landward nearly one-half mile and was uninhabitable (see Figure 1-1). In 1983, a jetty was added on the south side of the inlet, and some bypassing of sand was begun, which slightly slowed the rate of erosion.

Jetties and breakwaters have had similar effects on downdrift erosion at a large number of other Atlantic, Gulf, Pacific, and Great Lakes coastal locations,

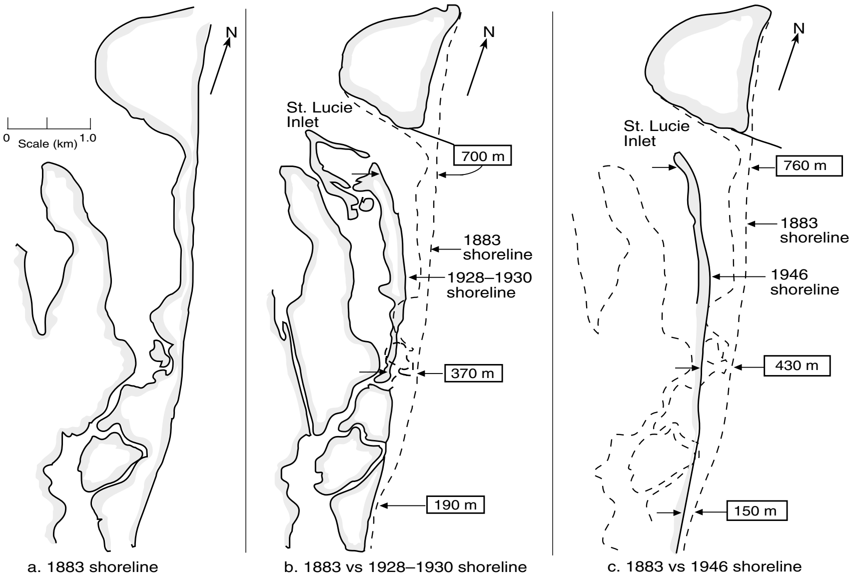

FIGURE 1-1 Progressive shoreline recession at St. Lucie Inlet, Florida. Source: Dean, 1991a.

with associated losses of coastal property. At a few inlets, sand bypassing has rectified most of the erosion caused by the presence of the inlet.

Port of New York and New Jersey

The Port of New York and New Jersey, the nation's largest petroleum port and third largest container port, is in serious jeopardy of losing cargo and experiencing associated economic hardships unless harbors and entrance channels can be deepened and terminals expanded. The Port Authority of New York and New Jersey is no longer able to dispose of dredged material at sea because much of the material in the harbors and the 240 miles of federally maintained navigation channels has been reclassified as contaminated. With the closure of its offshore disposal site, the port is facing immense costs for disposal (including the cost of shipping dredged material to disposal sites in other states). Four to five million cubic yards of contaminated sediments must be disposed of annually (USACE, 1996) and, at the present elevated costs of disposal, hundreds of millions of dollars will have to be spent annually to maintain the Port of New York and New Jersey—an amount nearly equal to the entire federal dredging budget. Many other U.S. ports face similar problems.

CHALLENGES FOR THE FUTURE

The coastal engineer of the future will be faced with new challenges arising from the increasing concentration of population and investment in the coastal zone and the need to ensure that engineering projects are environmentally neutral or beneficial. The presence of diverse stakeholders in the coastal zone and the large risks associated with inappropriate designs and actions have created an urgent need for more authoritative information on which coastal engineers can base designs and on which decision makers can rely for developing long-range strategies for hazard reduction, sand management, port development, protection and restoration of habitat, and education of the public about the importance of managing coastal areas effectively.

Specific challenges to coastal engineers that will become more important in the future are listed below:

- Reduce the impacts and risks associated with coastal hazards, such as hurricanes, shoreline erosion, earthquakes, induced subsidence, and tsunamis.
- Restore the natural sand supply to the shoreline and restore the sand transport pathways along the coastal zone where it has been impacted by human activities.
- Provide sufficient and balanced information for making rational decisions about the shoreline.
- Modernize ports to maintain economic competitiveness and environmental quality.
- Ensure that future coastal engineering projects provide long-term solutions and maximize environmental enhancement.

Coastal and Shoreline Management

Rapid increases in investment along the shore have accompanied rises in income and quality of life. The population densities of coastal areas around the United States are now five times the national average. Currently, 50 percent of the population lives within 75 kilometers of a coast; this number is projected to increase to 60 percent by the year 2010 (Culliton et al., 1990; Williams et al., 1990). In California, the nation's most populous state, 80 percent of the 33 million Californians now live within 50 kilometers of the shoreline.

As the coastal population grows, so does the need for additional facilities for transportation, recreation, waste disposal, and other vital services. At present, approximately $3 trillion of infrastructure adjacent to the Atlantic and Gulf shorelines is vulnerable to coastal storms (IIPLR, 1995). When the West Coast is included, the amount of vulnerable property is even greater because approximately 86 percent of the 1,750 kilometers of the western coastline is eroding

Seawalls destroyed by hurricane Elena in Pinellas County, Florida, September 1985. Courtesy of Robert G. Dean, University of Florida, Gainesville.

(USACE, 1971). The growing population in all coastal zones is also more vulnerable to coastal hazards, such as storms, tsunamis, and long-term coastal erosion.

Beaches are vital to our nation's economic and environmental well-being, both as places for recreation and tourism and as dynamic elements in coastal ecosystems. Because of the economic dependence of coastal communities on beaches and their role in protecting coastal properties and public infrastructures, beach erosion is a major concern for coastal communities and states. Tourism and coastal recreation are the fastest growing contributors to the economies of coastal states and to the overall national economy. Beaches and coastal parks are the primary destinations for foreign tourists to the United States. Ninety percent of their tourist dollars, an estimated $80 billion per year, is spent in coastal states (Houston, 1996).

Shoreline erosion along all U.S. coastlines, whether the erosion of cliffs and bluffs along the Pacific coast or the erosion of barrier islands and beaches along the Atlantic and Gulf coasts, is an ongoing natural process that has been exacerbated by human activities, such as the reduction of coastal sand supplies (e.g., by damming rivers) and the obstruction of littoral drift by coastal structures. The rise in sea level since the last Ice Age is a prime contributor to this erosion.

The continuing migration of people to the coastal states has increased their exposure to natural hazards and the total costs of damages from these hazards.

TABLE 1-1 Insured Losses from Hurricanes, 1989 to 1998

Hurricane	Date	Cost
Hugo	September 1989	$ 4.0 billion
Andrew	August 1992	$15.5 billion
Aniki	September 1992	$ 1.8 billion
Opal	October 1995	$ 2.0 billion
Fran	September 1996	$ 1.8 billion
Georges	September 1998	$ 2.1 billion

Source: The New York Times, October 27, 1998.

Insured losses from recent hurricane damage (hurricanes Hugo, Andrew, Opal, and Fran) and storm damage have exceeded $1 billion per year (see Table 1-1). Hurricanes Andrew and Hugo alone caused damage estimated at $40 billion (Ross, 1995). These costs are expected to increase as construction along the coasts continues unabated. Pielke and Landsea (1998) show that the 10 most damaging hurricanes from 1925 to 1995 would have accounted for more than $10 billion dollars in damage each if they had occurred after 1995 (due largely to the increase in coastal population). In fact, the most damaging storm would have caused more than $70 billion in damages.

A number of coastal engineering problems that are likely to become more serious in the future are discussed below: coastal hazards, beach and inlet management, and changes in shorelines. Following these are discussions of coastal monitoring and public education, which would improve our ability to address these problems.

Coastal Hazards

As coastal populations expand, losses from coastal hazards will continue to increase. These hazards include hurricanes, northeasters, and the rising sea level; earthquakes, bluff erosion, and El Niño-related storm damage on the West Coast; tsunamis in Hawaii, Alaska, and the Pacific coastal states; and the loss of sand supply along many coastlines because of human intervention.

Eighty-six percent of the coastline of California is eroding (USACE, 1971), and the last two El Niño-related storm seasons (1982–1983 and 1997–1998) caused more than $150 million in damage. The 1989 Loma Prieta earthquake was responsible for coastal bluff failure along 200 kilometers of shoreline (Griggs and Plant, 1998), and the Pacific Northwest coastal zone is threatened by a large subduction zone earthquake that could produce a tsunami. An NSF-sponsored report has noted that more people have died in the United States in the last 50 years from tsunamis than from earthquakes (NSF, 1984).

The options for coping with coastal hazards include living with the hazard, reducing the risks, or retreating. The best option will depend on the locale and costs. It is possible to mitigate or reduce the impact of certain coastal hazards (wave impact and inundation, for example); however, it is extremely expensive to eliminate the effects of gradually rising sea level and very large magnitude events such as hurricanes or tsunamis, although storm-surge barriers have been built in many countries, including the United States, and tsunami barriers have been constructed in Japan. Improvements in construction and better mitigation strategies may keep losses at manageable levels, but appropriate responses may vary with time and circumstances.

In their natural condition, shorelines respond dynamically to the forces of storms, as well as to climate-related effects, such as sea level changes or El Niño events. At a particular locality, such as a coastal bluff in California, this response may primarily be episodic bluff failure and shoreline retreat. Along the barrier islands of the Atlantic and Gulf coasts, responses may range from gradual erosion of the shoreline to a seaward and landward oscillation of the shoreline over time. These natural responses challenge coastal engineers first to understand the dynamics and then, if possible, to develop cost-effective ways to minimize the adverse effects of human intervention on these natural systems.

Armoring (i.e., the construction of seawalls or revetments) has been a common approach to stabilizing shorelines and one means of reducing risks from coastal hazards along all coastlines of the United States. As the percentage of armored shoreline has increased in response to both increasing oceanfront development and ongoing cliff and bluff retreat, questions have been raised about the effects of these structures (which are intended to protect property) on public beaches (Pilkey and Wright, 1988). The conflicts between the beneficial and adverse effects of coastal armoring have not been resolved and will certainly become more serious in the future.

The most common approach to maintaining the shoreline is beach nourishment—adding large quantities of beach quality sand to advance the shorelines seaward. Beach fill projects commonly cost millions of dollars and provide only short-term relief to the problem of erosion. Beach fill projects also provide some storm protection by replacing sand that has been washed away. Beach fills have only been studied and monitored to evaluate their effectiveness for a decade or two, and only a few have been monitored adequately. A better understanding of the interactions of beach fill with ongoing coastal processes will help engineers design future projects.

However, because coastal processes are complex and each site is unique, the best basis for predicting the effects of shore protection projects is documentation of previously constructed projects in similar areas. The documentation should span a number of years after project completion because large projects often have subtle effects that can take many years, even decades, to become apparent. In addition to the physical performance of a project, monitoring and documentation must include bathymetric, environmental, and economic performance, including positive and negative effects beyond the project boundary. Monitoring should also include the effects of the project on the biota.

Management tools that would improve coastal engineering include the capability of predicting the efficacy of various strategies (including human intervention and taking no action) for the purpose of formulating long-term shoreline management plans. Management includes more considerations than the physical systems of beach nourishment and armoring; it also involves economic, social, and ecological considerations. Better management tools would enable planners to examine various scenarios and assess their effects. For example, tools could be developed for comparing alternative scenarios with rising sea levels caused by the greenhouse effect and global climate change. The optimal solution to a problem might be to adopt a course of action in the near term that can be adapted or changed when some of the uncertainties are narrowed. In the case of an eroding beach on a barrier island, for example, the near-term option might be beach nourishment. Several decades later, however, after the performance of several projects had been evaluated and the prospects of an accelerated rise in sea level had been clarified, the range of management alternatives could be reevaluated and a new strategy developed.

Prudent beach management is an attempt to maintain sandy beaches and littoral transport[1] along the shoreline. Several options are available for managing beaches, but many of these involve not just the local beach of interest but also a wider geographic area. Historically, each project has been treated separately. Therefore, two projects located within the same littoral cell[2] were often treated completely separately in terms of calculating benefits, assessing needs, developing designs, and planning for engineering and construction. The costs of planning, design, engineering, and construction are much higher for some projects than they would be with a regional systems approach. The Delaware Bay Main Channel Deepening Project, for example, and the Delaware Bay Shore Protection Project have been authorized, designed and engineered, and constructed as independent projects, although it would have been economically and logistically more efficient to combine them. The identification and formulation of long-term management strategies to guide local and state government policy makers in the preservation of beaches and to link independent projects within regional sand basins are essential to protecting our limited sand resources.

[1] Littoral transport refers to the sandy materials moved along a coastline by the action of waves and along-shore currents.

[2] A littoral cell typically consists of a closed littoral circulation system comprised of a source and a sink of sand. An example would be a river that supplies sand to the shoreline and a downdrift submarine canyon that traps the longshore transport and directs it offshore into deep water.

A. Fenwick Island, Delaware, in an eroded condition, with a short beach offering little storm protection or recreational function.

B. Fenwick Island receiving beach nourishment sand pumped from approximately three miles offshore.

C. Fenwick Island after nourishment.

Courtesy of Anthony P. Pratt, State of Delaware, Department of Natural Resources and Environmental Control, Dover.

Beach and Inlet Management

Shoreline erosion is often caused by disruptions in natural sand transport at inlets resulting from jetties, channel dredging with offshore sand disposal, and losses to interior shoals. Improvements in sand bypassing at inlets will reduce beach erosion along the adjacent beaches and could reduce the need for beach nourishment in the future. As part of the recently adopted St. Lucie Inlet Management Plan, located in Martin County, Florida, more than one million cubic yards (765,000 cubic meters) of beach quality sand have been deposited on the downdrift beaches of Jupiter Island.

Long-term, chronic beach erosion is usually the result of the mismanagement of sand resources. An example of beach erosion caused by an inlet are the beaches downdrift of Lake Worth Inlet, Florida, where historic maintenance practices have caused the loss of more than 500,000 cubic yards (383,000 cubic meters) of sand per year in the past decade. Palm Beach Island has begun a large-scale effort to restore the highly eroded 15.5 miles (25 kilometers) of shoreline by armoring more than 60 percent of the island's shoreline. Many other examples of poor inlet sand management practices along beaches fronting the Atlantic, Gulf of Mexico, and Great Lakes shorelines could be cited.

Effective management of the nation's coastal sand resources would significantly reduce the costs of future beach management. Comprehensive studies would lead to a better understanding of the primary sand transport pathways at each inlet and the development of sand management strategies and plans to implement corrective actions. Sound sand management plans would give policy makers a much needed tool for formulating local, state, and national policies.

Tidal inlets and river entrances interrupt otherwise continuous shorelines and are often sites of human intervention, primarily for navigation, such as the deepening of channels and the construction of jetties. Stabilized channel entrances often create accumulations of sand at the updrift[3] jetty and depositions of sand on interior inlet and flood shoals, as well as offshore as a result of natural ebb currents or required maintenance dredging. For many decades, sand dredged from tidal inlets was disposed of offshore, far outside of the natural littoral system. Dean (1988) has estimated that 80 to 85 percent of the shoreline erosion in Florida can be attributed to the effects of tidal inlets. The use of sand bypassing techniques to reestablish the natural sand transport at many inlets will reduce the high costs of long-term, chronic erosion of downdrift beaches and the degradation of biological resources, which often results from the deposition of sand in bays. Otherwise, long-term chronic erosion is likely to continue.

An example of good sand management is Indian River Inlet on the Delaware

[3] Updrift and downdrift refer to the direction of the littoral transport along a shoreline. If the net direction of sand is toward the south along a shoreline, as it is for most of the Florida and California shorelines, the downdrift direction is south, and the updrift direction is north.

coast. Before the sand management plan was put into effect, sand accumulated by the updrift jetty caused severe erosion of the downdrift beach, jeopardizing the major access and hurricane evacuation route for this section of the Delaware coastline. Since 1990, a mobile sand bypassing system has been regularly moving sand across the inlet, which has solved the critical erosion problem (Clausner et al., 1991). This solution was developed by coastal engineers with the USACE and coastal experts in the Delaware state government and at the University of Delaware.

Changes in Shorelines

With more than 75 percent of the nation's sandy shorelines eroding, proper management will require an understanding of coastal dynamics based, in part, on an analysis of historical changes documented through surveys, historical maps, and aerial photographs to determine rates of erosion. Erosion occurs on both developed and natural shorelines and should be the dominant factor in selecting long-term management options.

The documentation of shoreline changes for the barrier island shorelines of the Atlantic and Gulf coasts would be more accurate if it included sand budgets for large-scale littoral systems. Complete documentation would require a long-term database of shoreline positions. In general, historical data are sparse and do not reflect the full effects of human intervention, which can be positive or negative. Historical photographs do not generally capture episodic, seasonal, or storm-induced fluctuations. The development of long-range shoreline management strategies will require that high-resolution hydrographic (bathymetric) data be collected at frequent intervals. Fortunately, with the advent of the global positioning system (GPS) and other modern surveying systems, the nearshore zone can be surveyed rapidly with high spatial density at a relatively low cost.

The rise in sea level has been a topic of considerable debate for several decades, most recently in association with global warming. The long-term rate of 1.2 millimeters per year is apparently increasing and has already had significant effects on the barrier island shorelines of the Atlantic and Gulf coasts, as well as shorelines in the Mississippi Delta area, where, as a result of regional subsidence, the rates are about eight times the average. A number of studies on the effects of global climate change have predicted the worldwide average rates of sea level rise will be substantially greater than the current rate of 1.2 millimeters per year. By the year 2100, rates will range from 50 centimeters to 150 centimeters per century, which is 4 to 12 times the current rate. In an earlier report, the National Research Council's Marine Board (NRC, 1987a) called for more observations of relative rises in sea level and recommended that coastal project designs incorporate reasonable estimates of future rises.

The magnitude and impact of short-term local rises from storm surges or El Niño events are also very important. The 1982–1983 El Niño event elevated sea levels 30 centimeters or more along the coasts of California and Oregon, and the 1997–1998 event produced even larger changes (Flick, 1998). Brief rises in sea levels associated with major hurricanes are even more significant. Hurricane Camille (1969) caused a 22.4 foot (6.8 meter) rise at Pass Christian, Mississippi; Hurricane Hugo (1989) raised the sea level by more than 20 feet (6 meters) in Bulls Bay, South Carolina (Garcia et al., 1990); and Hurricane Opal (1995) raised it by more than 15 feet (4.6 meters) at Panama City, Florida (Leadon, 1995). These surge levels lasted for several hours and caused considerable flooding and loss of property from water damage and wave attack.

Coastal Monitoring

USACE has monitored a number of coastal projects under the aegis of the Monitoring of Completed Coastal Projects Program (MCCPP), which was renamed the Monitoring of Completed Navigation Projects Program (MCNPP) to reflect the scope of the project. Unfortunately, only a few projects (federal or otherwise) have been documented adequately, and the lack of documentation has given rise to misinformation, prolonged debates and disagreements, and faulty designs for future projects. Moreover, some of the projects that have been documented have not been thoroughly analyzed. Some states now require that sponsors of coastal projects monitor the effects and coastal processes in considerable detail. Information from these projects will be invaluable to engineers and project managers developing designs and management strategies for future projects. Because most beach nourishment projects are publicly funded through tax-based revenues, the general public is entitled to better information on project performance. To date, few efforts have been made to publicize evaluations of project performance. Long-term continuous monitoring programs could provide data for a comprehensive database on constructed projects, which could be made available to designers of future projects (NRC, 1995).

Human activities on beaches, marine parks, estuarine and bay waters, and other coastal resources often cause a decline in their overall environmental quality, the very quality of these resources that sustains tourism and recreation. Coastal resources, which are limited to begin with, are coming under increasing pressure by developers and tourists. Recreational use and nature-based tourism should be part of an overall environmental management program that includes protection of the shoreline, monitoring, and educational programs.

Ports and Waterways

Port Operations

Ninety percent of the nation's international trade, more than two billion metric tons per year, flows through U.S. ports and harbors. In recent economic projections, the amount of import cargo will triple by 2020, provided the United States can provide the facilities the shipping industry needs (AAPA, 1998). Nationally, ports and port users generate nearly 13.1 million jobs, contribute approximately $743 billion to the gross domestic product, and provide nearly $200 billion in tax revenues at all levels of government (MARAD, 1997). For states located on major bodies of water (the Atlantic, Pacific, and Gulf coasts and the Great Lakes) and waterways (major rivers and large lakes), ports and harbors play a major role in the regional and local economy.

The trend in the shipping industry is toward larger vessels that can carry more cargo with smaller crews. The primary goal is to load, move, and unload waterborne cargo efficiently. This means ships spend a minimum of time at the berth handling cargo, frequently 36 hours or less, and a maximum of time at sea. World shipping operations that carry international cargo prefer one-stop loading and unloading of their cargo at the user's doorstep. This requires large, efficient vessels and modern shoreside facilities. Water transport is the cheapest means of moving large volumes of cargo, and shipping companies have the option of trying new ports-of-call that provide the most efficient facilities for handling cargo. U.S. ports that cannot meet these shipping requirements are already losing cargo to ports outside the United States (MARAD, 1997).

A major factor that contributed to the success of U.S. ports in the past was continued maintenance dredging and new construction dredging for expansion. The former involved removing approximately 285 million cubic yards (218 million cubic meters) per year of sediment from navigable waterways (USACE, 1997). Continued dredging is essential for U.S. ports to compete internationally. Without it, they cannot accommodate the new large ships that require deeper and wider channels. Ports that cannot provide adequate water depth, safe maneuvering and loading and unloading areas, and modern terminal facilities with efficient land transportation connections will cost shipping companies more for cargo delivery and will eventually lose business to more modern ports.

Most Gulf and East Coast ports and a few West Coast ports have size restrictions. A recent survey showed that U.S. ports that handle international cargo plan to increase their water depths to 40 to 50 feet (12 to 15 meters) at low water. Ports that want to ensure their capability as international ports of call (i.e., that can handle large around-the-world containerships) plan to dredge to 50 to 55 feet (15 to 17 meters) and, if necessary, widen their channels (AAPA, 1998).

Presently, the cost of federal and local maintenance and new construction dredging is $632 million annually (USACE, 1997). This amount does not include funds spent by local port authorities for maintenance or new construction dredging.

The fast and efficient operation of ports that can accommodate large ships will require real-time monitoring and modeling systems of currents, waves, and water levels; well maintained channels and navigation aids; safe, protected berthing sites; efficient methods for loading, unloading, storing, and moving

Dredging operations in the Port of Los Angeles. Courtesy of the Port of Los Angeles.

cargo; and well designed interfaces to land-side transportation. The use of large ships reduces the shipping industry's transportation costs and thus the overall cost of goods. These vessels must be able to enter through safe harbor entrances, transit through adequate channels, and maneuver in turning basins that do not constrict their movement (horizontally or vertically), and arrive at a stable berth for quick unloading and loading of cargo.

Environmental Concerns and the Disposal of Dredged Materials

Federal, state, and local laws have established environmental standards for port waters and the protection of marine habitats. The removal and, more important, the disposal of dredged materials cannot degrade the placement area or the larger marine environment. The environmental sensitivity of each location is unique depending on the chemical and physical properties of the dredge spoils and how and where the dredged material is placed.

With the growing demand for deeper ports and increasingly stringent regulations of contaminated spoils, the cost of dredging to ports and the federal government has increased dramatically. Historically, most dredged material has been placed in open coastal waters, but there is a growing trend toward the use of confined upland and in-water containment areas, when the materials and methods are environmentally compatible. These and other locations present new challenges and associated costs. A recent study comparing dredging, material transport, and placement costs indicates that the unit costs in the United States are 3 to 20 times higher than the average world unit costs due, in part, to concerns about environmental quality (PIANC, 1998).

Environmentally sound methods of disposal are urgently needed. One option under consideration for ports is the use of artificial islands for the containment of contaminated sediment. These islands, which would be among the largest civil engineering structures in the world, would be constructed of caissons or rubble-mound seawalls and would have to withstand severe conditions and have a very long design life. Another option is capping contaminated sediments in pits in the harbor or at offshore disposal sites, which involves placing contaminated material on the ocean floor and covering it with a layer of clean clay and sand as a cap to prevent the material from moving.

Because new port construction and maintenance usually occur in environmentally sensitive areas, ports often compensate for damage caused by dredging or other work by improving the environmental quality of other degraded areas in the region (e.g., establishing or improving coastal wetlands, providing new material for beach nourishment, or enhancing aquatic habitats).

Environmental Quality

Coastal engineers now play an important role in coastal environmental management, and this involvement is expected to increase in the future (NRC, 1994). They are generally involved in the areas of dredging and managing dredged material, beach nourishment, addressing water quality issues, and wetlands restoration.

The loss of coastal marshlands and degraded water quality in estuaries and bays has resulted in a significant decline in environmental quality (NRC, 1990). Coastal marshes are important for marine and upland biotic communities, and the effects of degraded water quality and loss of habitat on marine systems have created major problems. When some species flourish while others die off, the result is an unbalanced ecosystem and a significant loss of diversity. Marine nurseries and protected habitats are necessary to sustain the marine fisheries industry, as well as to meet the growing demand for recreational fishing and nature-based ecotourism.

The development of hydrodynamic and water quality models will require an understanding of tidal and freshwater discharges, nutrient loadings, point and nonpoint discharges, and pollutant loadings to the system. Storm water runoff and water quality degradation continually stress marine and terrestrial ecosystems. Degraded water quality in rivers, estuaries, and bays presents challenges to coastal engineers to design inlets and channels that can improve flushing of degraded water. Innovative design strategies will be necessary for site-specific solutions, as well as monitoring to ensure that these solutions restore water quality in estuaries and wetlands and biodiversity to marine ecosystems.

Environmental Preservation

Early coastal engineering projects were conducted without regard to their adverse environmental impacts. In light of new concerns about the environmental quality and integrity of coastal zones, projects in the past 20 years have been required to show minimal adverse impacts and, wherever possible, positive environmental impacts (NRC, 1994). Examples of environmentally sensitive projects include the creation of wetlands and the use of dredged material for beach nourishment that provides habitats for endangered species, including nesting habitats for sea turtles and piping plovers. Remediation is often necessary to reverse the adverse impacts of former practices.

The environmental concerns and mitigation requirements of the past few decades have led to widespread, sophisticated restorations of coastal wetlands, such as salt marshes and mangroves that line estuaries, barrier islands, and other shoreline environments. Restoration projects require an understanding of intertidal conditions, including tidal channels. In many ways, the nonbiotic design of wetland restoration projects is similar to the design of beach restoration projects. The most successful restorations and enhancements are designed by teams of coastal engineers and environmental scientists.

Public Education

Ecosystem protection and biological resource management are often seen as competing with coastal engineering projects. A major public education program would show how successful coastal engineering projects could be environmentally sensitive and mindful of ecosystem health. Urban and regional planners and public administrators in coastal areas would also benefit from courses in coastal processes and dynamics and inlet and beach management.

NATIONAL DEFENSE[4]

During the Cold War period, much oceanographic research and development was related to deep water. As the plans for national defense are being adjusted to accommodate post-Cold War conditions, operational oceanography is also changing. The Navy is now focusing on coastal regions, and better characterizations of the littoral zone are of major importance to national defense. The Navy's concerns are focused on the challenges of understanding and predicting natural coastal environments that change more rapidly in time and space than deep-ocean environments.

The Navy needs local environmental information on relatively small spatial scales, short time scales, with coast-related parameters (e.g., surf conditions, water clarity, atmospheric visibility, wind and current vectors, the nature of the coastline, the variability and stability of the seabed, high-resolution bathymetric data, and concentrations of local marine life). Hybrid platforms with different types of sensors for local and regional observations will have to be developed and deployed to address these parameters. The capability of measuring, understanding, and predicting variations in these parameters will require the development of new research and engineering techniques, as well as new modeling concepts and programs.

Coastal engineering is a significant part of defense-related planning, operations, and the development of innovative technologies. In many ways, the research, development, and educational needs of the Army overlap those of the Navy and the Marines. In some areas, however, the Army has unique needs based largely on providing sustained logistical support over long periods of time, which could involve moving and storing large amounts of materiel (this unique issue is referred to as logistics-over-the-shore [LOTS]).

Planning

The Army considers the selection of potential LOTS sites to be extremely important. The site must have natural environmental characteristics (e.g., waves,

[4] This section draws heavily on a recent National Research Council (NRC) report based on a symposium convened by the NRC's Ocean Studies Board with the support of the Office of Naval Research and the Office of the Oceanographer of the Navy. This report, *Oceanography and Naval Special Warfare: Opportunities and Challenges* (NRC, 1997), focuses on the U.S. Navy's activities in nearshore regions and identifies the Navy's needs in this area.

water levels, currents, and beach and bar movements) that allow sustained, rarely interrupted throughput. At the present time, open-coast LOTS operations are highly sensitive to wave conditions. Selected beaches must have topographical and other characteristics that allow for easy movement. For operations that involve existing harbors, the important questions are the maintenance or improvement of navigation to support large ships and the rapid repair or enhancement of port facilities.

Operations

Once a LOTS site has been selected and operations begin, coastal engineers must be able to forecast critical events that could disrupt operations or destroy critical facilities. Forecast technologies will be much the same as the technologies necessary for Marine or Navy SEAL operations on beaches (i.e., accurate forecasts of waves, water levels, currents, sediment transport, and beach morphology). The Army will also need information on the shoaling of navigation channels and short and long wave conditions in harbor areas. These forecasts will require sensor systems that can monitor natural environmental parameters.

2

Status of Education and Research in the United States

INTRODUCTION AND BACKGROUND

Coastal construction early in the nation's history was primarily to provide harbors and navigation. Breakwaters and jetties were built by civil engineers to provide safe havens for ships and to protect navigational channels. Along the shoreline, groins and sea walls were built to protect property, and marshes were drained and filled to provide habitable or arable land and to reduce mosquito populations. Trade, shipbuilding, and fishing were major industries along the coast, and towns and cities grew up to support these industries.

Coastal structures were designed and built using time-tested methods that protected navigational channels and harbors from waves and sand infilling. The erosion of shorelines caused by sand being trapped or diverted offshore was frequent. However, the long-term welfare of adjacent beaches and the conservation of the sand resource were not design considerations at that time, as beaches were considered to have little intrinsic value. The breakwater for Santa Barbara, California, built between 1927 and 1930, is a classic example of the unintended consequences of building a harbor without concern for coastal processes, causing beach erosion for many miles downdrift.

As the nation became more affluent, people began to seek out beaches for recreation, and the value of beaches increased. Some beaches were even created to meet the public demand, such as the 2,400-acre Jones Beach[1] in New York

[1] Jones Beach was the creation of Robert Moses, who was responsible for many of the public works in New York City and Long Island. The construction of Jones Beach on top of a low-lying spit required 40 million cubic yards of fill material (Caro, 1974).

City, which was created in 1929 by dredge fill and which still serves the recreational needs of New Yorkers. Coastal communities and towns grew in size to meet the needs of beachgoers for amenities and services. They later attracted new residents, particularly retirees and those who could afford vacation homes. Ancillary erosion caused by the increased number of coastal structures led to the establishment of the Beach Erosion Board in 1930 to begin research into coastal processes and design procedures for protecting the shoreline from erosion and from inappropriately designed structures. The Beach Erosion Board became the Coastal Engineering Research Board in 1963, an advisory board to USACE.

The recognition that engineering at the shoreline required specialized knowledge of coastal processes gave rise to research projects at universities, such as those undertaken at the University of California, Berkeley, beginning in the late 1940s, under the direction of M.P. O'Brien. Eventually graduate programs in coastal engineering were established at several universities, with the first program being established in 1967 at the University of Florida. Today, more than 20 institutions around the nation offer graduate education in coastal engineering.

The number of trained coastal engineers has increased over the past 30 years, along with the awareness of problems caused by the lack of attention to coastal processes during the design and construction of coastal projects. Coastal engineers now assist, or have sometimes supplanted, civil engineers on many coastal construction projects.

The state of Florida can be considered a bellwether in terms of the growing demand for expertise in coastal engineering. Florida is a prime tourist destination for beachgoers. It is also an area that is highly susceptible to hurricanes. As a result, state and local agencies have developed elaborate construction setback requirements to ensure appropriate development along the shoreline. Florida has more than 1,300 kilometers of sandy shorelines, with 56 inlets (not counting the Keys), which account for much of the beach erosion in the state.

The number of graduates of the University of Florida with M.S. and Ph.D. degrees in coastal engineering has grown steadily since the program's inception in 1967 (Mehta, 1996). By 1995, more than 110 M.S. and 50 Ph.D. degrees had been granted. There has been a concomitant growth in the number of coastal engineering firms in the state: one new coastal engineering firm has been founded in Florida every two years since 1975, while the state's population grew from 8 million to 13 million (Mehta, 1996).

Coastal engineers in Florida are working at the state, county, and federal levels. The state of Florida now employs about 20 people who are practicing coastal engineering in the Department of Environmental Protection (Bureau of Beaches and Coastal Systems). Coastal county governments also have coastal engineers on staff: Martin County has two, and Indian River, Palm Beach, Sarasota, Broward, and Dade counties have one each. USACE employs 8 to 12 trained coastal engineers in the Jacksonville District. The U.S. Geological Survey employs three coastal engineers in their coastal office in St. Petersburg. Altogether, about 140 coastal engineers are working in Florida, about half of whom are civil engineers working as coastal engineers. Nationally, the number of coastal engineers is small, but growing.

At the federal level, USACE has hired coastal engineers in its district offices around the country and at the Coastal Engineering Research Center (now Coastal and Hydraulics Laboratory [CHL]) at the Waterways Experiment Station (WES) in Vicksburg, Mississippi. In 1985, the shortage of qualified coastal engineers and the small amount of funds for research and development prompted the chief of engineers at the 44th meeting of the Coastal Engineering Research Board to call for USACE to train its own coastal engineers (Heiberg, 1986). These remarks led to the establishment of two educational programs at USACE's WES to provide graduate education for USACE personnel. At the time, Dr. C.C. Mei, a member of the Coastal Engineering Research Board, suggested that joint research projects with academic institutions would provide an alternative means of educating students and developing research capabilities in the country (Mei, 1986).

As the complexity and importance of coastal engineering problems has increased, the education of coastal engineers has become increasingly important to the nation, as has the amount of funding available for research to develop a better understanding of coastal processes and to provide innovative solutions to coastal problems. In this chapter, the state of coastal engineering education and research are examined.

EDUCATION

The committee conducted a survey of individuals and universities to assess academic programs and research capabilities in coastal engineering. The survey included questions about the content of relevant programs, the numbers of students and faculty, teaching and research facilities, and employment opportunities. The answers were average figures for the last five years. A copy of the survey and the tabulated responses are included in Appendix B. The survey was sent to individuals and distributed over "coastal_list,"[2] an email list specifically for coastal engineers and scientists, which has more than 800 members worldwide. Individuals from 19 institutions in the United States responded to the survey.

The first courses in coastal engineering in the United States were offered at the University of Florida, the University of California, Berkeley, and Texas A&M University. Over the next 30 years, both graduate and undergraduate programs were developed at about 20 institutions across the country, most of which evolved from civil engineering programs. Some schools have combined coastal and ocean engineering into a single program, while others have focused on one or the other.

[2] www.coastal.udel.edu/coastal/coastal_list.html

Undergraduate Programs

Coastal engineering is predominantly a graduate degree program. Only four institutions have undergraduate programs: the United States Naval Academy, Texas A&M University, Stevens Institute of Technology (New Jersey), and Florida Institute of Technology. At all of these institutions, coastal engineering is an option in the ocean engineering program; none of them offers an undergraduate degree specifically in coastal engineering. An average of 75 students per year graduate from the four institutions combined. The graduates of the Naval Academy, who make up more than 50 percent of the total, typically go on to military careers and rarely appear in the coastal engineering civilian sector after completing their service obligation.

The undergraduate courses include wave mechanics, coastal processes, the design of coastal structures, ocean engineering, geology, tidal hydrodynamics, and complementary courses in engineering and oceanography. Nonmilitary graduates are employed by private engineering firms, industry (typically offshore), and state and federal agencies. The remaining students continue their studies in graduate school.

Graduate Programs

All 19 institutions that responded to the survey indicated that they offer graduate programs in coastal engineering. However, only the University of Florida offers a degree that specifically refers to coastal engineering (coastal and oceanographic engineering). The other institutions offer degrees in ocean, civil, or environmental engineering. On an average annual basis, these institutions reported that they confer a total of 65 M.S. and 22 Ph.D. degrees from their designated coastal engineering programs. The survey indicated that about 30 percent of the graduating masters students enter doctoral programs at other institutions. About 30 percent of M.S. and Ph.D. graduates are employed in private engineering practice. The rest are employed by state or federal agencies. USACE also has two programs for training coastal engineers, one at WES, in Vicksburg, Mississippi, and a cooperative program with Texas A&M University.

Providing financial support for graduate students is an important element in maintaining a viable degree program. Although the numbers vary considerably from one institution to another, approximately 80 percent of the masters degree students and more than 90 percent of the doctoral students receive financial support, mostly through research contracts.

With fewer than 90 students earning graduate degrees annually, coastal engineering is one of the smallest engineering disciplines in the United States. By way of comparison, the number of graduate degrees in civil and environmental engineering is estimated to be approximately 6,000 per year (Engineering Workforce Commission, 1997).

Graduate courses in coastal engineering include wave theory, coastal processes, the design of coastal structures, ocean engineering, estuarine mechanics, tidal hydrodynamics, the dynamics of offshore structures, water quality modeling, sediment transport, ocean acoustics, coastal geology, and marine geotechnology. The committee noted that in spite of an established need for coastal engineers with a background in port and harbor design, these subjects are not included in the curriculum of any of these programs. Furthermore, despite the growing need for coastal engineers to deal with a complexity of environmental issues, no courses in wetlands ecology, coastal geology, environmental management, or assessing environmental impacts are being offered.

Faculty

The 19 institutions that responded to the survey have approximately 50 full-time faculty positions, either in coastal engineering or in related programs. Generally, each institution has one or two coastal engineers on the faculty. Only four institutions (the University of Florida, Texas A&M University, the University of Delaware, and Stevens Institute of Technology) had more than three full-time faculty positions in coastal engineering, accounting for 40 percent of the total.

According to the survey, only three institutions have plans to add new or replacement faculty in the near future. The allocation of faculty positions is based partly on available research support, which limits the number of graduate students that can be supported. Thus, maintaining sufficient faculty to meet national needs in coastal engineering is closely linked to budgets supporting academic research. The figures suggest that the natural attrition of the present faculty is likely to lead to a decrease in the number of faculty positions, a decrease in graduate enrollments, and eventually, a loss of degree granting programs.

The orderly growth of this national educational capability will be complicated by the advanced age of present faculty. In the four largest coastal engineering programs, with a total of 21 faculty members, only one is an assistant professor, and there are no associate professors. The committee believes that these numbers are representative of the entire community. Although retirement is not mandated at a given age, a substantial number of faculty will be leaving the profession in the near future, and replacements for them are uncertain. Unless there is more support for research and for research and teaching facilities, scarce university resources are likely to be allocated to other programs.

Continuing Education

Only a few of the institutions that responded to the survey have made significant commitments to continuing education in coastal engineering. Texas A&M has a well established program in dredging that is offered on a regular schedule. Annual enrollments average 45 students. Other programs offer occasional extension courses.

In general, coastal engineering lags behind other engineering disciplines in the area of continuing education. This may reflect the small number of engineers working in the field and, hence, the absence of a critical mass of students at any one location. This obstacle could be overcome as distance learning improves. Many universities are actively exploring new technologies for distance learning, including closed circuit TV, satellite, and web-based education. Thus, in the future, coastal engineers may have access to continued education without having to leave their places of employment. Improvements in distance-learning technologies may also benefit students in small academic programs by making courses available from universities with more comprehensive programs.

RESEARCH SUPPORT

Coastal engineering is an evolving field, and many aspects of coastal processes are still unknown. Research in coastal processes leads to, among other things, better designs of coastal structures at the shoreline and to better predictions of the future of shorelines. One of the goals of coastal engineering is to predict the behavior of the coast as a function of time, from a timescale of hours and days (as in response to a coastal storm) to a timescale of years (as in response to coastal structures or other shoreline modifications, such as beach fill). Two examples of the benefits of research are described below.

The prevailing method of treating coastal erosion is beach nourishment, which involves placing new sand on beaches. The amount of material to be used and the lifetime of a project depend on the design of the beach-fill geometry. Research to date has shown that the lifetime of the beach is increased with larger fills and by using sand that is similar to or coarser than the native sand. Appropriate fills can substantially reduce the cost to the public (NRC, 1995).

Post-storm reconnaissance surveys taken after hurricanes Elena, Gilbert, and Hugo, which struck in Florida, Mexico, and South Carolina, respectively, showed that structures designed to modern coastal engineering standards resisted major structural damage (Dean, 1991b).

Benefits of research could accrue in many other areas in the future. For example, based on the immense volume of material dredged annually, any significant reduction in the cost per cubic meter of dredged material will result in large savings. Also, a better understanding of the currents and waves in the nearshore zone will ensure a safer environment for amphibious landings and for LOTS. These benefits would also accrue to the general public. Finally, better designs for sand-bypass systems could substantially reduce the costs of erosion downdrift of tidal inlets.

Throughout its history, the backbone of coastal engineering in the United States has been academic research. Much of the fundamental science and many of the models used by practicing coastal engineers were developed in national and international academic institutions. However, funding for research in coastal engineering in the United States is poorly coordinated.

Most federal support for coastal engineering research and education comes from three agencies, USACE, the Office of Naval Research (ONR), and Sea Grant. NSF also provides minor support. Although USACE has the largest budget for research, most of its funds are spent internally; only about 10 percent is used to support education. Funds from ONR are almost entirely devoted to academic research, as are all of the Sea Grant and NSF funds. The preponderance of ONR funding is for coastal sciences. The U.S. Geological Survey supports academic research in coastal science but not coastal engineering as defined in this report. On occasion, other agencies, such as the U.S. Department of Energy, the U.S. Department of Transportation, the Army Research Office, and the Federal Emergency Management Agency, have supported research for specific coastal engineering projects, but none of these agencies provides significant ongoing support.

The USACE, ONR, Sea Grant, and NSF provided the committee with dollar amounts of their support for academic research in coastal engineering since 1985, and the committee's assessment of the level of support for academic research is based on these figures.[3] Overall support for coastal engineering research by the federal government since 1985 is shown in Figure 2-1. The USACE (the leading government agency) budget for coastal engineering is also shown, for comparison. (These support levels have been adjusted to constant 1996 dollars.)

Support for academic research in coastal engineering and coastal sciences by the four principal funding agencies (ONR, NSF, Sea Grant, and USACE) from 1985 through 1998 is shown in Figure 2-2. This figure shows that ONR is now the most important source of funding for academic research, having surpassed Sea Grant in the early part of this decade, and that NSF provides the least funding. Figure 2-3 shows the cumulative funding for academic research (the total of funds shown in Figure 2-2). As Figure 2-3 shows, the underlying level of federal support (in constant dollars) for academic research has decreased from $5 million to $3 million per year since 1985. Note that a substantial portion of these funds is for coastal engineering-related activities, such as nearshore oceanography and marine geology, rather than for research on coastal engineering.

The federal government provides approximately $11 million per year for all research on coastal engineering—academic and nonacademic. Of this, USACE receives about two-thirds of the total, including about $1 million for the Field

[3] Since the release of the report in a prepublication version (April 13, 1999), corrected data has been provided by the U.S. Army Corps of Engineers to replace previous data, which included funding for internal agency activities that should not have been included in the research budget. All the data has now been adjusted to 1996 dollars and is reflected in Figures 2-1, 2-2, and 2-3. Text describing the figures has been revised accordingly.

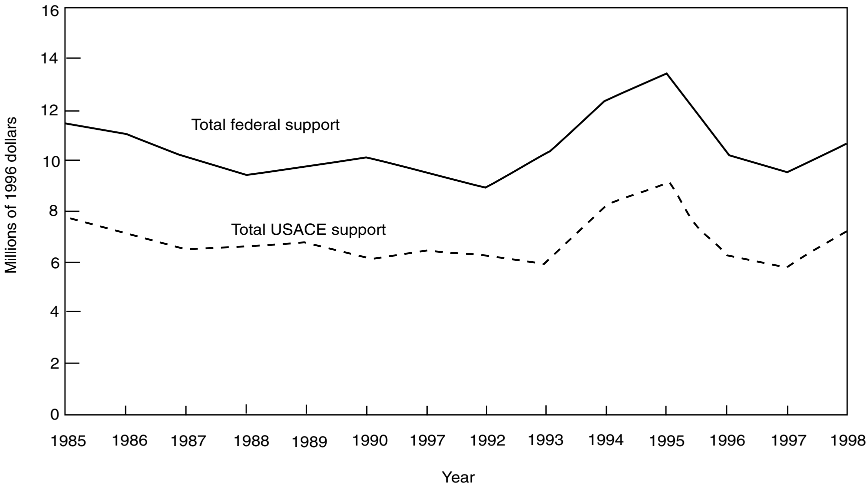

FIGURE 2-1 Total federal support for research in coastal engineering.

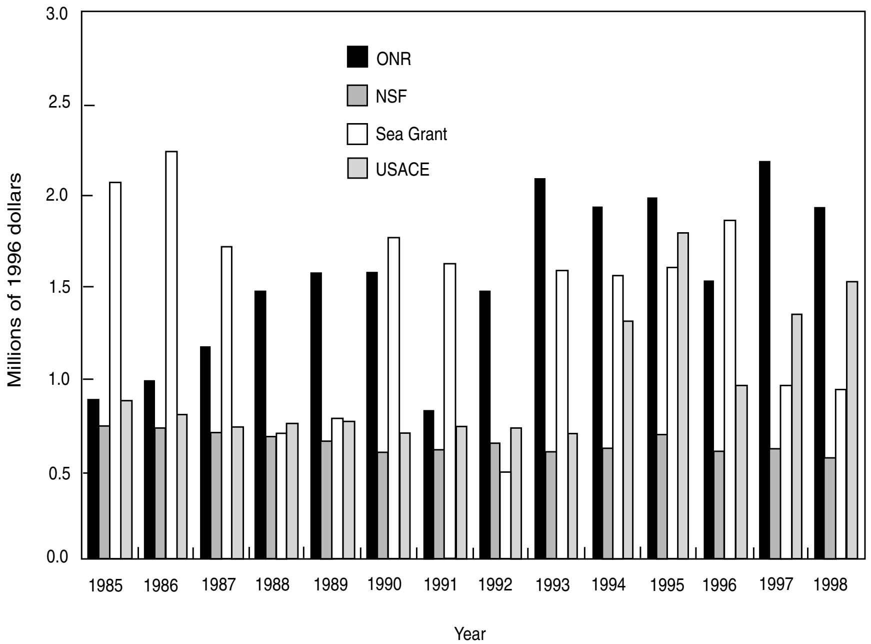

FIGURE 2-2 Major funding for academic research.

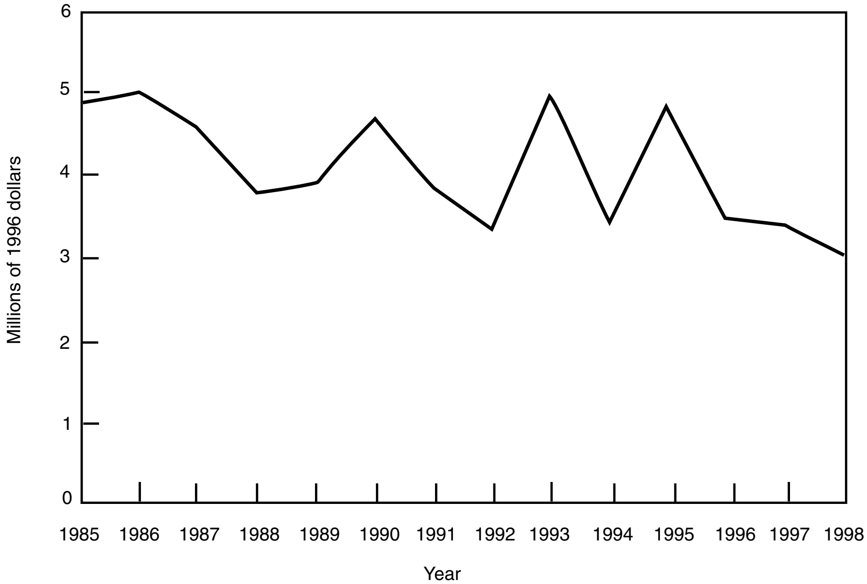

FIGURE 2-3 Total support for academic research.

Research Facility (FRF) at Duck, North Carolina. The amount available for USACE's research is about $7 million, about twice the national total for academic research.

INTERNATIONAL COMPARISONS

It is interesting to compare the funding for research in coastal engineering in the United States to funding in the European Common Market, which created the Marine Science and Technology Program (MAST) in 1989. The present MAST III[4] receives 240 million ECU (about $266 million) per year. Approximately 20 percent of these funds (about $50 million per year) is spent on research in coastal engineering at academic institutions in the Common Market countries. This level of financial support is more than 12 times the current level of support for academic research in the United States. Research topics include the mechanics of sediment transport, the mechanics of surf and swash zones, modeling of coastal evolution, beach nourishment, wave forces on structures, and the probabilistic design of breakwaters.

[4] http://europa.eu.int/comm/dg12/marine/mast3-pr.html.

Each MAST project[5] is carried out by a consortium of European universities and laboratories, which provides a mechanism for pooling talent and spreading expertise across national boundaries. As a result of MAST funds, scientific capability all across the European Union and research equipment at these institutions has improved significantly.

Another feature of European coastal engineering has been the close collaboration of universities with large, now-private laboratories. Two prominent examples are the collaboration between the Technical University of Delft (T.U. Delft) and Delft Hydraulics, whose team of coastal engineers has made significant contributions to the development of coastal engineering. Their success is partly attributable to their connection with T.U. Delft, where many of the engineers were trained. Several of the engineers from Delft Hydraulics have academic appointments at T.U. Delft.

The second example is the Danish Hydraulic Institute (DHI) and the Technical University of Denmark (T.U. Denmark). DHI is a major consulting company that competes successfully worldwide for major coastal engineering projects. The company has close ties with T.U. Denmark, hiring their graduates and working collaboratively with the faculty. Much of the scientific base of their suite of coastal engineering numerical models was developed in conjunction with faculty from T.U. Denmark.

The success of Delft Hydraulics and the DHI is clearly related to their collaboration with leading academic programs in coastal engineering research. There are no equivalent collaborations in the United States.

RESEARCH FACILITIES

Academic Facilities

Based on the survey of academic institutions, 19 schools have teaching facilities in coastal engineering, but only a few have extensive research-type facilities: the University of Delaware (Center for Applied Coastal Research, Department of Civil and Environmental Engineering); the University of Florida (Department of Coastal and Oceanographic Engineering); Texas A&M University (Department of Civil Engineering); and Oregon State University (O.H. Hinsdale Wave Research Laboratory, Department of Civil Engineering). These facilities include two- and three-dimensional wave basins and harbor modeling facilities,

[5] One project, SCARCOST (scour around coastal structures), deals with the flow and sediment transport in the vicinity of coastal structures. The participants are the Technical University of Denmark, NR Wallingford Ltd., The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF), Universitet Joseph Fourier (France), The University of Liverpool, Institute of Marine Research (Portugal), International Center for Coastal Research (Spain), Oxford University, and Norges Teknisk-Naturvitenskapelige Universitet (Norway).

dredging-simulation capabilities, and sediment-transport tanks. Several other institutions have smaller facilities. None of these facilities can be described as state of the art in terms of instrumentation and/or experimental capabilities.

Sophisticated laboratories and field resources are indispensable to high quality education and research in coastal engineering. However, the costs of advanced research facilities, including the cost of regular maintenance and full-time staff support, have prevented many institutions from acquiring and maintaining these facilities. Laboratory facilities should include wave tanks and basins, as well as the sensors and data-acquisition systems required to support them. Most of the institutions that responded to the committee's survey have small wave tanks or basins, but only a few have made substantial investments in the large facilities necessary for most current research. Twelve of the 19 programs have wave tanks longer than 30 meters, and eight have wave basins wider than 10 meters. Oregon State University is the only one with a very large wave tank (more than 100 meters long).

The University of Florida's coastal engineering laboratory was the first in the world to include a wave tank with an air-sea capability and the first in the United States with a broad range of facilities to address a variety of coastal problems. These facilities included a "snake"-type wave generator in a wave basin that can generate waves from a single but arbitrary direction. Of the 56 inlets in Florida, engineering solutions to more than 12 inlets have been developed in this facility. Nevertheless, because minimal investments have been made in this laboratory over the past two decades, it has now become outdated. Modernization of the facility is required for basic research and for investigations of current coastal engineering problems.

In addition to wave tanks and basins, both teaching and research activities require sophisticated measurement and data-acquisition systems. These devices are expensive to acquire and maintain, and, because of the rapid evolution of measurement technologies, they often become outdated in a relatively short time. Flow-measurement equipment, for example, has evolved from propeller meters and hot film/wire to acoustic and laser Doppler and particle-image velocimetry in just a few years. These more sophisticated technologies provide much better results but are more difficult to use and more expensive to buy and maintain (often requiring dedicated computers).

Several of the institutions surveyed have limited field-research capabilities, but only a few (such as the University of Florida) have made a substantial investment in vessels and field-measurement systems. In several cases, this equipment is either shared with, or borrowed from, oceanography programs at the same institutions. The lack of field-observation capability limits most academic programs to theoretical and laboratory research.

Large wave tank at the O.H. Hinsdale Wave Research Laboratory of Oregon State University (104.24 m long, 4.57 m deep, and 3.66 m wide). Used with permission from Charles K. Sollitt, Oregon State University.

Federal Facilities

All of the significant federal research facilities are operated by USACE, two by the CHL, an organization that incorporates the former Coastal Engineering Research Center at Vicksburg, Mississippi, and FRF at Duck, North Carolina. The Vicksburg facilities are used mostly by USACE for internal research and for reimbursable studies, although cooperative research with academia and industry is being encouraged. The facilities at Vicksburg include significant computing and communication equipment that can support numerical modeling, as well as outstanding physical modeling capabilities. The physical modeling facilities are used for research in waterways engineering, dredging, ports engineering, and coastal protection. The replacement value of the USACE coastal engineering research facilities in Vicksburg would be tens of millions of dollars, and they represent the largest and most comprehensive single site in the United States devoted to this discipline.

The substantial field facilities at the FRF are used to study nearshore waves, currents, and sand transport. The FRF has data-gathering and computing facilities with hundreds of channels of data capable of supporting cooperative field experiments involving large numbers of investigators from academia and commercial interests. The research pier supports the use of instrumentation across the surf zone during high-energy events, and the coastal research amphibious buggy (CRAB) permits rapid, high-resolution measurements of seafloor contours over large areas and during high-wave events. The FRF provides base support for academic research and USACE researchers who are cooperatively investigating a broad range of coastal phenomena in field experiments that have recently been held once every two or three years. These collaborative investigations are funded by a variety of agencies, such as ONR and the U.S. Geological Survey.

USACE's Inland Waterways Research Facility, used for waterways engineering, includes the exact-scale modeling of navigational channels; the ship/tow simulator facility, a computerized simulator of navigation conditions, used for realistic, real-time piloted evaluations of proposed improvements to navigation; dredging research supported by the draghead test facility for modeling hopper-dredge draghead performance and the eductor loop facility for the evaluation of dredging pumps, piping, and instrumentation. Port engineering is supported by a number of large-scale hydraulic models of port systems, in which the effects of tides, currents, ocean waves, and internal oscillations can be studied. Coastal-protection research is supported by a number of basins, flumes, and channels for fixed and moveable bed modeling of nearshore dynamics.

Commercial Facilities

At this time, the committee knows of no commercial laboratory facilities in the United States that are available for research in coastal engineering, although there were at least two a decade ago. Commercially funded testing and applied research are done either through contracts with a few academic institutions or overseas.

3

Findings, Conclusions, and Recommendations

OVERALL FINDINGS

As population densities and investments along the nation's shorelines increase, so do incomes and the quality of life. Fifty percent of the nation now lives within 75 kilometers of a coast, and this number is expected to increase to 60 percent by 2010. One out of every three jobs is now generated in a coastal county; 95 percent of our foreign trade passes through coastal ports; and 33 percent of our GNP (gross national product) is produced in the coastal zone. Ninety percent of foreign tourist dollars, an estimated $80 billion annually, is spent in coastal states, most of it at beach resorts (Houston, 1996).

As the population of coastal regions increases, so does the need for transportation, recreation, waste disposal, and other services. Growing populations also increase the risks of damage from natural coastal hazards, as well as the effects of human development on this fragile environment. Recent hurricanes along the Atlantic coast caused billions of dollars in damage. Eighty-six percent of the coastline of California is eroding, and the last two El Niño events along the Pacific coast caused significant damage. Beaches, upon which most coastal tourism depends, are eroding nationwide as a result of a combination of reductions in sand supply, interventions in natural littoral drift systems, and the continually rising sea level. Ports must be dredged to keep up with the requirements of modern vessels and to control natural shoaling processes, but environmental constraints on dredging and the disposal of dredged materials have led to serious unresolved conflicts.

Because specific knowledge of coastal processes is necessary for designs at the shoreline, the field of coastal engineering is now a separate discipline. More and better research will lead to better coastal designs, and as the ongoing debate about erosion mitigation (retreat, nourish, or armor) shows, there is much more to be learned about coastal processes. In the future, coastal engineers will have to be knowledgeable in fields that were not originally part of the coastal engineering curriculum, such as the Earth and environmental sciences and public policy.

The United States faces many problems that could be solved, or at least mitigated, by well trained coastal engineers. Solving these problems will require new approaches and greater attention to environmental considerations than in the past. Only a few academic programs, however, are training coastal engineers, and very few students are educated in port engineering or environmental sciences. In addition, funding for academic research is limited, reducing the likelihood that innovative solutions to problems will be developed. The committee believes universities should have stronger incentives for maintaining and building coastal engineering programs, which would be provided by the establishment of a division within a federal agency responsible for supporting academic research and education in this field. A substantial increase in research funding would ensure the long-term survival and health of the coastal engineering discipline.

Institutions with programs in coastal engineering have a preponderance of full professors and very few assistant professors on their faculties. New junior-level appointments would ensure the continuity of these programs and bring new energy to solving multidisciplinary problems. Currently, there are about 50 coastal engineering faculty nationally. The danger today is that because of limited research funds, existing positions may be eliminated as senior professors retire; in other words, university administrators may decide to fill academic vacancies with faculty in fields that are more generously funded or that have larger student enrollments. Thus, increasing the number of faculty in coastal engineering will depend on substantial increases in research funding.

Faculty could be increased rapidly in several different ways. First, a national fellowship program for coastal engineering graduate students could be established to ensure that the number of graduates increases significantly in 10 years. Fully qualified professors could be drawn from the pool of trained coastal engineers who have gone into environmental, civil, or ocean engineering because of the limited funding for research in their own field.

The Engineering Division of the NSF is devoted to single-discipline basic research. Although coastal engineering is inherently multidisciplinary, many of the difficult fundamental problems, such as those related to hydrodynamics, turbulence in nearshore waters, and the transport of sediment and pollutants, are well suited to NSF's peer-reviewed, basic research approach. The committee believes a separate program in coastal engineering should be established in NSF's Engineering Directorate. Support may be small at first and increased regularly for several years. An Ad Hoc Committee for the Civil and Environmental Engineering Division of NSF made essentially the same recommendation almost 15 years ago (see Box 3-1).

USACE has congressionally mandated responsibilities in every phase of the practice of coastal engineering and, therefore, has a strong interest in the success of coastal engineering research and education. USACE is also the largest single employer of coastal engineers and already has the expertise in place to administer applied engineering research contracts in this field. At present, the USACE

BOX 3-1
Recommendations of the Ad Hoc Committee for the Civil and Environmental Engineering Division, National Science Foundation

1. A research program should be identified within the NSF for coastal and ocean engineering research. A first-year budget of $3 million is suggested to cover the costs of administration; analytical, laboratory, and modest field research studies; and planning studies for important new construction of research facilities. The second-year funding should be $6 million to cover the same subjects as the first year's funding, plus a start on facilities improvements. The third and succeeding years should probably be $10 million per year to supply funds for the accelerated research program and ongoing improvement of facilities. Reports that follow will more carefully break down costs into detailed areas.

2. The program should be administered by the Civil and Environmental Engineering Division of NSF. Peer review of proposals should be done predominantly, but not entirely, by coastal and ocean engineers. The director of the program should be a coastal and ocean engineer and serve in a two-year chairmanship, after which time another professional in the field should be selected.

3. Initially, the funded research should be directed toward hurricanes and winter storms, long-term sea level rise, tsunamis, ice and other phenomena characteristic of cold regions, biofouling and corrosion, and the ways in which these natural hazards influence beach erosion, breakwater stability, silting of harbors, wave forces on structures, flooding of lowlands, capsizing of small vessels, loss of aids to navigation, ice abrasion in the Arctic, accumulation of biological growths on structures, and large submarine mudflows.

4. It is possible that a long-term sea level rise is in progress which will create severe losses within the next 100 years. It is imperative that we promote a concerted effort to make sophisticated measurements of mean sea level over the next 10-year period to identify changes in sea level.

Source: NSF, 1984, p. 52.

research program is almost entirely internal, is often closely linked to the immediate needs of specific projects, and provides only limited support for academic research and education.

Sea Grant, which has a very diffuse regional management structure, has a broad mandate that involves almost every aspect of applied oceanography and ocean engineering. Although Sea Grant programs in some states actively support coastal engineering, programs in other states do not. Without major restructuring (which would substantially disrupt its remaining programs) or the establishment of a new national plan for coastal engineering (such as the National Sediment Transport Study, which was conducted over a five-year period in the 1970s), Sea Grant could not administer the national coastal engineering research program described in this report.

ONR funds basic and applied research related to coastal engineering, but the Navy's research needs cover only a small part of the broad area of coastal engineering as defined here. ONR has been, and is expected to continue to be, a major supporter of coastal sciences that interact synergistically with coastal engineering, and the committee encourages ONR to continue providing this support.

Many coastal engineering research facilities have the potential to support the research described by the committee. However, the major capabilities are clustered at a few institutions, and support for maintaining both laboratory and field facilities at these institutions, including technical, data-collection, and instrument capabilities, has been inadequate. No practical arrangements are in place for investigators to use these facilities, as there are for oceanographic research vessels, for example.

CONCLUSIONS AND RECOMMENDATIONS

Coastal engineering is important to the vitality of the nation's shorelines and ports. However, academic research in coastal engineering is poorly funded, and the level of funding has not increased in the last decade, which has affected the competitiveness of the United States. The lack of sufficient funds has affected the availability and quality of laboratory facilities and the ability to conduct extensive field experiments. Unlike several other countries, the United States does not have a central government agency that is responsible for the field. The following recommendations are intended to address these problems.

Academic Consortium

Recommendation 1. The committee recommends that the coastal engineering academic community establish a consortium to improve research and education through cooperative arrangements for leveraging major research facilities and educational capabilities. This consortium should assess the available facilities and determine which ones are critical to meeting the national needs. Budgets for maintaining these facilities should be prepared and proposals submitted to the U.S. Army Corps of Engineers and the National Science Foundation under the funding programs recommended in this report, along with a plan for ensuring fair and equitable access to these facilities for researchers whose projects are funded under these programs. The consortium should be responsible for scheduling the use of these facilities.

The consortium should provide academic leadership in coastal engineering education at all levels, from elementary school through postgraduate continuing education. It should also provide guidance to academic programs concerning the evolution of graduate curricula to include courses in port engineering, environmental issues, and public policy. The consortium should also provide leadership in educating the general public about coastal processes.

National Science Foundation

Recommendation 2. The committee recommends that the National Science Foundation establish a program in its Engineering Division to fund fundamental research on coastal engineering. This program should be separately identified and should be directed by a highly qualified coastal engineer. The 1984 Ad Hoc Committee for the Civil and Environmental Engineering Division recommended that funding for this program be gradually increased to $10 million dollars per year. This committee agrees that a comparable level of funding is still appropriate. Funds in this program should also be allocated to the support and maintenance of large experimental coastal facilities.

U.S. Army Corps of Engineers

Recommendation 3. The committee recommends that the U.S. Army Corps of Engineers establish a substantial program to fund applied research in academic coastal engineering programs. The level of support should be comparable to the funding level for basic research. Most of this funding should be used for extramural grants, with a small percentage (less than 5 percent) for administering the program. The committee believes these grants would encourage stronger partnerships with the academic community in coastal engineering, which would strengthen all research and applied programs, as well as the pool of candidates from which the Corps of Engineers recruits coastal engineers.

A review board for academic research should be charged with overseeing the research-funding process. Half of the members should be agency representatives, and half should be qualified external individuals. (The civilian members of the Coastal Engineering Research Board could serve in this capacity, along with academics and others from outside of academia.) The review board would establish research priorities, oversee the solicitation of proposals, and review the external/internal peer-review processes. Matching funding by coastal states could be used to bolster this program.

SUMMARY

The nation's needs in coastal engineering are becoming increasingly urgent to the economy and to our quality of life. However, these needs have far outstripped financial support for research and education in coastal engineering, and the United States is falling behind other coastal nations in its support of research and laboratory facilities. In response to developmental pressures on our coastlines and the international demand for coastal engineering services, the United States must maintain a healthy and vigorous program in coastal engineering education and research.

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Appendices

APPENDIX A

Biographical Sketches of Committee Members

Robert A. Dalrymple (chair) is the Edward C. Davis Professor of Civil and Environmental Engineering at the University of Delaware, where he has been on the faculty since 1973. He also has served as assistant dean of the College of Engineering and acting department chair. Dr. Dalrymple's research has focused on wave mechanics, including wave-propagation modeling and wave-current interaction, littoral processes, and tidal inlets. His publications include many peer-reviewed articles and several books, including *Water Wave Mechanics for Engineers and Scientists* (with R.G. Dean) and *Physical Modeling in Coastal Engineering and Coastal Hydrodynamics* (editor). He currently serves on editorial boards of *Coastal Engineering* and the *Journal of Hydraulic Research.* A registered professional engineer in Delaware, Dr. Dalrymple is a fellow of the American Society of Civil Engineers (ASCE) and a member of the American Geophysical Union and the American Shore and Beach Preservation Society. He is a member of the ASCE Coastal Engineering Research Council and the Advisory Committee of COPEDEC (Coastal and Port Engineering in Developing Countries). He received the 1996 John G. Moffatt-Frank E. Nichol Harbor and Coastal Engineering Award from the ASCE and the 1999 Coastal Engineering Award from the American Society of Civil Engineers. He was a member of the Marine Board's Committee on Engineering Implications of Changes in Sea Level. He has an A.B. in engineering science from Dartmouth College, an M.S. in ocean engineering from the University of Hawaii, and a Ph.D. in civil and coastal engineering from the University of Florida. Dr. Dalrymple received the 1999 International Coastal Engineering Award from the American Society of Civil Engineers.

Richard A. Davis is Distinguished Research Professor in the Department of Geology and former director of the Environmental Science and Policy Program at the University of South Florida. Dr. Davis has specialized in coastal and marine geology (especially beaches, inlets, and barrier-island systems); sedimentology of tide-dominated environments; coastal management, with an emphasis on beaches and inlets; environmental geology; and modern and ancient depositional systems. His research has focused on process and response systems at work along beaches, inlets, and barrier islands and the Holocene history of these coastal systems. He is currently conducting research on the history and development of the barrier-island system of Florida's gulf coast, along with multiple beach-monitoring projects. He is the author or editor of 14 textbooks and monographs. Dr. Davis received a B.S. from Beloit College, an M.A. from the University of Texas, and a Ph.D. from the University of Illinois, all in geology. He is a former Fulbright Scholar and a member of Sigma Gamma Epsilon.

Robert G. Dean, NAE, is graduate research professor of coastal and ocean engineering at the University of Florida, a position he has held since 1982. Previously, he held faculty positions at the University of Delaware, the University of Washington, and the Massachusetts Institute of Technology. He also has served as a consultant on coastal and ocean engineering to private industry and government clients. He is a past member of the Marine Board and chaired the Committee on Engineering Implications of Sea Level Rise. Dr. Dean is an expert in wave mechanics and coastal engineering problems, and he has published many papers on wave theory, beach erosion, tidal inlets, and coastal structures. He is a past recipient of the John G. Moffatt-Frank E. Nichol Harbor and Coastal Engineering Award and International Coastal Engineering Award, both administered by the ASCE. Dr. Dean has a B.S. in civil engineering from the University of California (UC), Berkeley, an M.S. in physical oceanography from the Agricultural and Mechanical College of Texas, and a Sc.D. in civil engineering from the Massachusetts Institute of Technology.

Billy L. Edge is the W.H. Bauer Professor of Dredging Engineering at Texas A&M University. An internationally recognized expert in coastal engineering and dredging technology, Dr. Edge has had a distinguished career as a senior researcher in the physical sciences with the U.S. Army Corps of Engineers (USACE), a member of the faculty at Clemson University and Texas A&M, and a consultant with Dames and Moore, Cubit Engineering, and Edge & Associates. He has served as secretary of the Coastal Engineering Research Council of the ASCE, editor of the ASCE's *Proceedings of the International Conferences on Coastal Engineering*, and chair of the biennial international coastal zone conferences. He is a recipient of the American Shore and Beach Preservation Association's Morrough P. O'Brien Award and the ASCE's International Coastal Engineering Award. A registered professional engineer in South Carolina, Florida, and

Virginia, Dr. Edge has B.S. and M.S. degrees from Virginia Polytechnic Institute and a Ph.D. from the Georgia Institute of Technology, all in civil engineering.

Karyn E. Erickson is vice president of Applied Technology & Management, Inc., of Gainesville, Florida, where she has served as a project director for coastal engineering projects and services, including the design and engineering of coastal structures and beach-nourishment programs, emergency beach and dune protection and recovery, inlet management planning and implementation, and financing. She has managed numerous highly visible recreational beach-restoration projects in Florida, South Carolina, North Carolina, and the Caribbean, and has published and presented many related papers. Ms. Erickson is a registered professional civil engineer in Florida, South Carolina, and North Carolina and a member of the ASCE and the Florida Shore and Beaches Preservation Association. She has an M.E. degree from the University of Florida.

John S. Fisher is director of the Center for Transportation and the Environment at North Carolina State University, where he is also a professor. Previously, he held teaching and research positions at the University of Virginia and Clemson University and positions in private industry. Dr. Fisher's research has focused on coastal engineering and shoreline processes, such as beach erosion and nourishment, storm effects, structures, shoreline changes over time, and barrier-island dynamics. He has conducted research for the National Park Service, U.S. Army Research Office, USACE, National Sea Grant College Program, National Science Foundation, North Carolina Department of Transportation, and Federal Emergency Management Agency and has published numerous journal articles and technical reports. Among other professional activities, he served on the Publications Committee of the *Journal of the Waterway, Port, Coastal, and Ocean Division, ASCE* and on the Board of Directors of the American Shore and Beach Preservation Association. He has a Ph.D. in civil engineering from the Massachusetts Institute of Technology.

Gary B. Griggs is director of the Institute of Marine Sciences at UC, Santa Cruz, where he is also a professor of Earth sciences. His research has included coastal hazards, such as shoreline erosion, littoral sand budgets (including sources, transport, storage, and sinks), and the effectiveness and impacts of coastal engineering structures. A former Fulbright fellow and National Science Foundation graduate fellow in oceanography, Dr. Griggs is a fellow of the Geological Society of America and a member of the American Geophysical Union. He serves on the editorial boards of the *Journal of Coastal Research* and *Geology* and on the Board of Directors of the American Shore and Beach Preservation Association. He has a B.A. in geology from UC, Santa Barbara, a Ph.D. in oceanography from Oregon State University, and is a registered geologist and certified engineering geologist in California. He has published many journal articles and technical reports and has written four books, including *Living with the California Coast, California's Coastal Hazards: A Critical Look at Existing Policies and Practices*.

Orville T. Magoon, president of the Coastal Zone Foundation, has experience in coastal planning; coastal-zone management; and the design, construction, and rehabilitation of coastal structures. Mr. Magoon conceived and chaired major conferences on coastal-zone management and coastal processes, an achievement for which he received the National Oceanic and Atmospheric Administration's Benchmark Award in 1983. He was the organizer and co-chair of California and the World Oceans '97, a conference on California's new long-range planning document covering coastal protection, development, and management. Mr. Magoon is the author of numerous technical publications on coastal engineering and has received many awards for his activism in the field. He is a member of the Advisory Council of the California Academy of Sciences. Mr. Magoon has a B.S. from the University of Hawaii and an M.S. from Stanford University, both in civil engineering.

Marvin K. Moss is provost and vice chancellor for academic affairs at the University of North Carolina at Wilmington, a position he has held since 1992. His career has included positions as associate vice chancellor for marine sciences at UC, San Diego, deputy director of the Scripps Institution of Oceanography, director and technical director of the Office of Naval Research, and associate director for energy research at the U.S. Department of Energy. His research interests include ocean physics, global warming, and environmental issues, and he is the author of numerous science and policy publications. He is a member and former chair of the federal interagency Strategic Environmental Research and Development Program and a member of the Board of Governors for the Consortium of Oceanographic Research and Education. He also has served on numerous professional review panels and study groups. Dr. Moss has a Ph.D. in physics from North Carolina State University.

Robert D. Nichol has been president of Moffatt & Nichol Engineers of Long Beach, California, since 1975. He is in charge of projects and operations for the company, which has provided consulting services for the U.S. Navy, USACE, U.S. Air Force, U.S. Maritime Administration, and U.S. Department of State, as well as many other government, foreign, and private-sector clients. Mr. Nichol contributes his engineering and management expertise to waterfront, industrial, commercial, military, and public works projects, such as harbor channel deepening for the Port of Los Angeles, infrastructure development and lakeshore land reclamation, and coastal erosion control in Malaysia. A registered civil engineer in 10 states, Mr. Nichol is a member of the ASCE, National Society of Professional Engineers, Chi Epsilon, National Honor Civil Engineering Fraternity, and the Board of Directors of the California Marine Affairs and Navigation

Conference. He has a B.S. degree in civil engineering from the University of Minnesota.

Anthony P. Pratt is environmental program manager for the Delaware Department of Natural Resources and Environmental Control in the Division of Soil and Water Conservation. He oversees numerous programs related to beach construction, dune building and maintenance, and the National Flood Insurance Community Assistance Program. His career in public service has included managing the Delaware Coastal Management Program, which oversees coastal projects involving wetlands, beaches, reducing storm hazards, land use, and public access. Mr. Pratt is a member of the Board of Directors of the American Coastal Coalition and the American Shore and Beach Preservation Association. He chaired the Ad Hoc Committee on Beach Management/Sea Level Rise for Delaware's Environmental Legacy and was lead staff member for the Beaches 2000 Planning Group. He has a B.S. degree from Hampshire College.

Fredric Raichlen, NAE, is professor of civil engineering at the California Institute of Technology. His experience encompasses fundamental and applied research, teaching, and consulting in coastal engineering. He is an expert in the wave defense of structures, surges and oscillations in harbors, and the dynamics of tsunamis. He served on the USACE Coastal Engineering Research Board and helped integrate USACE's physical modeling with numerical calculations and field observations. Dr. Raichlen is a fellow of the ASCE and the recipient of the ASCE 1994 John G. Moffatt-Frank E. Nichol Harbor and Coastal Engineering Award. He is also a member of the International Association for Hydraulic Research, Permanent International Association of Navigation Congresses, Sigma Xi, and numerous industry advisory committees. He has a B.E. from Johns Hopkins University and S.M. and Sc.D. degrees from the Massachusetts Institute of Technology.

Richard J. Seymour is director emeritus of the Offshore Technology Research Center and emeritus professor of civil engineering at Texas A&M University, where he also held the Wofford Cain Chair in Ocean Engineering. Currently, he is head of the Ocean Engineering Research Group at Scripps Institution of Oceanography. An ocean and coastal engineer, Dr. Seymour has had a broad range of experience in industry, state government, and academic research. His research specialty is ocean wave spectra and the application of knowledge of waves and related ocean conditions to the design and operation of structures in, on, under, and adjacent to the sea. Dr. Seymour was a member of the Marine Board from 1984 through 1990 and board chair from 1994 through 1996. He chaired the Committee on Information for Port and Harbor Operations and the Committee on Beach Nourishment. Dr. Seymour has a B.S. in engineering from the U.S. Naval Academy and a Ph.D. in oceanography from the Scripps Institution of Oceanography, UC, San Diego.

Appendix B

Survey of Academic Institutions

The committee undertook a survey of universities known to have faculty involved in coastal engineering to document the status of coastal engineering education today. The survey included questions on program contents, the numbers of students and faculty, teaching and research facilities, and employment opportunities. The survey asked that answers be based upon average figures for the past five years. A copy of the survey is reprinted below. Of the 32 institutions invited to participate, 19 responded. A compilation of responses follows.

SURVEY OF EDUCATION PROGRAMS

Background

The Marine Board of the National Research Council has formed the Committee on Coastal Engineering Research and Education Needs to examine the national needs and to assess the adequacy and effectiveness of existing institutions in meeting those needs. An important element in the committee's study is a survey of current educational and research programs. The following questions are being asked of all of the academic programs known to be involved in coastal engineering education. Your cooperation in this survey is greatly appreciated.

Committee on Coastal Engineering Research and Education Needs

Robert Dalrymple, *chair*
Billy Edge, Richard Davis, Robert Dean, Karyn Erickson, John Fisher, Gary Griggs, Orville Magoon, Marvin Moss, Robert Nichol, Anthony Pratt, Fredric Raichlen, Richard Seymour

Survey Questions

Name of your institution:

Name of respondent:

1. Does your institution have an undergraduate degree concentration, track, or specialty in coastal engineering?

1.a. If so, what is the average number (per year) of coastal graduates over the past 5 years?

1.b. What are the core coastal engineering courses/topics in this program?

linear wave theory
non-linear wave theory
coastal processes
design of coastal structures
ocean engineering
estuarine mechanics
tidal hydrodynamics
other courses

1.c. Where do these students go after graduation? (percent)

graduate school
consulting
off shore industry
state agency
federal agency (COE) or other
other

1.d. Are you making plans to add this program in the future?

2. Does your institution have a masters degree concentration, track, or specialty in coastal engineering?

2.a. If so, what is the average number (annual) of coastal graduates over the past 5 years?

2.b. What are the core coastal engineering courses/topics in this program?

linear wave theory
non-linear wave theory
coastal processes
design of coastal structures
ocean engineering
estuarine mechanics
tidal hydrodynamics
other courses

2.c. Where do these students go after graduation? (percent)

graduate school (PhD)
consulting
off shore industry
state agency
federal agency (COE) or other
other

2.d. Are you making plans to add this program in the future?

2.e. What percent of your MS students are supported?

3. Does your institution have a PhD degree concentration, track, or specialty in coastal engineering?

3.a. If so, what is the average number (annual) of coastal graduates over the past 5 years?

3.b. What are the core coastal engineering courses/topics in this program?

linear wave theory
non-linear wave theory
coastal processes
design of coastal structures
ocean engineering

estuarine mechanics
tidal hydrodynamics
other courses

3.c. Where do these students go after graduation? (percent)

consulting
off shore industry
state agency
federal agency (COE) or other
other

3.d. Are you making plans to add this program in the future?

3.e. What percent of your PhD students are supported?

3.f. Do you have any Post Docs in your program?

4. Does your institution and or your faculty offer continuing education courses in coastal engineering, planning, or systems?

4.a. What is the average number of students taking these courses over the past 5 years?

4.b. What are these continuing education courses?

wave theory
coastal processes
structural design
dredging
computer modeling of coastal processes
tidal hydrodynamics
other

4.c. Where do these students come from?

private practice
government
other

5. If your institution does not offer a degree concentration, track, or specialty in coastal engineering, does it nonetheless offer coastal engineering courses?

5.a. What are these courses? (graduate and/or undergraduate)

wave theory
coastal processes
structural design
dredging
computer modeling of coastal processes
tidal hydrodynamics
other

6. What coastal engineering laboratory research or teaching facilities does your institution have?

depth (>100cm)	sediment	tides	currents

wave flume
wave basin
other

7. What coastal engineering field research capabilities does your institution have? Please itemize
vessels
equipment

8. How many coastal engineers are there on your faculty?

full time
other, non-full time
adjunct

8.a. Do you expect to hire coastal engineering faculty in the near future?

9. Does your program engage in coastal engineering research?

If yes, is the average over the past 5 years:

a. less than $250,000
b. between $250,000 and $500,000
c. between $500,000 and $1,000,000
d. greater than $1,000,000

10. Who are some of the principal sponsors of your research support? What percent is private, state, or local?

SUMMARY OF RESPONSES

Undergraduate Programs

Most coastal engineering programs are on the graduate level. Only three institutions have undergraduate programs, Texas A&M University, the Stevens Institute of Technology, and the Florida Institute of Technology. Table B-1 is a summary of the responses about these programs.

Graduate Programs

The 19 institutions that responded to the survey indicated that they offer graduate programs in coastal engineering. However, only the University of Florida continues to offer a degree specifically called coastal engineering (actually coastal and oceanographic engineering). All of the other institutions offer degrees in ocean, civil, or, in one case, environmental engineering. Table B-2 is summary of the average number of M.S. and Ph.D. degrees awarded annually in the past five years from each of these institutions.

Research Support

The survey asked the respondents to indicate where graduates had found employment in the past year. These results are summarized in Table B-3.

Annual funding for research varied among the respondents. Table B-4 summarizes the responses.

TABLE B-1 Undergraduate Programs

Average Number of Degrees Awarded	
Texas A&M University	22
Florida Institute of Technology	8
Stevens Institute of Technology	5
Student Placement (percentage)	
Graduate school	25
Private practice	25
Industry (typically offshore)	25
State and federal agencies	25

TABLE B-2 Degrees Awarded

	M.S.	Ph.D.
California Institute of Technology	0	<1
Clemson University	1	<1
Cornell University	1	1
Drexel University	7	<1
Florida Institute of Technology	4	<1
Johns Hopkins	2	<1
Lehigh University	1	0
North Carolina State University	2	<1
Naval Post-Gradate School	n/a	n/a
Massachusetts Institute of Technology	2	2
Old Dominion University	5	3
Oregon State University	7	1
Stevens Institute of Technology	6	<1
Texas A & M University	12	4
University of California, Berkeley	3	2.5
University of Delaware	3	2.5
University of Florida	6	3
University of Hawaii	3	1
University of Rhode Island	3	1
University of Washington	1.5	1
Total	66	22

TABLE B-3 Employment of Recipients of Graduate Degrees

	Percentage of Graduates	
	M.S.	Ph.D.
Graduate school	30	n/a
Private practice	35	35
Industry	19	16
State or federal agencies	16	19
Academic	n/a	30

TABLE B-4 Levels of Research Funding

Number of Institutions	Funding
5	less than $250,000
7	$250,000 to $500,000
2	$500,000 to $1,000,000
1	more than $1,000,000