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	Engineering and Design ENVIRONMENTAL ENGINEERING FOR COASTAL SHORE PROTECTION	
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**US Army Corps
of Engineers**

ENGINEERING AND DESIGN

Environmental Engineering for Coastal Protection

ENGINEER MANUAL

CECW-EH

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-1204

Engineer Manual
No. 1110-2-1204

10 July 1989

Engineering and Design

ENVIRONMENTAL ENGINEERING FOR COASTAL SHORE PROTECTION

1. Purpose. The purpose of this manual is to provide guidance in enviromental engineering for coastal shore protection projects.

2. Applicability. This manual applies to all field operating activities that have responsibility for environmental impact studies related to coastal shore protection projects.

3. Discussion. This manual summarizes research and field experience gained in the area of environmental engineering for coastal shore protection. It addresses both natural and human induced changes in the coastal zone; the structural and nonstructural measures that coastal engineers employ against these changes; and the desirable and adverse impacts of the measures. This manual is intended to be compatible and used in conjunction with other OCE engineering manuals and the coastal Engineering Research Center's "Shore Protection Manual." As new information becomes available the manual will be periodically revised.

FOR THE COMMANDER:

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CHAPTER 1

INTRODUCTION

1-1. Purpose. This manual provides guidance for incorporating environmental considerations into the engineering, design, construction, operation, and maintenance of coastal shore protection projects.

1-2. Applicability. The manual is applicable to all Corps field operating activities having civil works responsibilities in the area of coastal shore protection.

1-3. Scope. Selection of the best environmental and engineering solution to a specific coastal problem reguires a systematic and thorough study because of the complexity of coastal projects and the diversity of coastal environments. The prerequisites to such a study are a clear definition of the problem and cause of the problem and then a comprehensive review of potential solutions (alternatives). This manual addresses both natural and human-induced changes in the coastal zone; the structural and nonstructural measures that coastal engineers employ against these changes; and the beneficial and adverse impacts of these measures. Immediate and long-term impacts in the project area, as well as adjacent environments, are summarized. In addition, this manual emphasizes potential steps for obtaining desirable results and reducing adverse impacts. The manual focuses primarily on shore protection, i.e., coastal projects designed to stabilize the shore against erosion related principally to current and wave action: however, the material is also applicable to harbor and navigation channel improvements. The manual applies to both the Great Lakes and the coastal marine systems. It identifies the principal environmental factors that should be considered in design and construction and provides techniques for attaining environmental quality objectives. Proper techniques for collection, analysis, and interpretation of environmental data to use in planning and engineering are outlined. This manual is intended to be compatible and used in conjunction with other OCE engineering manuals and the Coastal Engineering Research Center's "Shore Protection Manual" (US Army Engineer Waterways Experiment Station 1984). As new information becomes available, this manual will be periodically revised.

1-4. <u>References.</u> The Corps references listed below provide guidance to field personnel concerned with planning, design, construction, operation, and maintenance of coastal shore protection projects.

a. ER 200-2-2, Procedures for Implementing NEPA.

b. ER 1105-2-10, Planning Programs.

c. ER 1105-2-20, Projects Purpose Planning Guidance.

d. ER 1105-2-35, Public Involvement and Coordination.

e. ER 1105-2-50, Environmental Resources.

f. ER 1110-2-400, Design of Recreation Sites, Areas, and Facilities.

g. ER 1110-2-1403, Hydraulic and Hydrologic Studies by Corps Seperate Field Operating Activities and others.

h. ER 1110-2-8102, Model Testing at Waterways Experiment Station.

i. ER 1110-2-1404, Deep-Draft Navigation Project Design.

j. ER 1130-2-307, Dredging Policies and Practices.

k. ER 1165-2-130, Federal Participation in Shore, Hurricane, Tide, and Lake Flood Protection.

l. EM 1110-1-400, Recreation Planning and Design Criteria.

m. EM 1110-2-1202, Environmental Engineering for Deep-Draft Navigation.

n. EM 1110-2-1614, Design of Coastal Revetments, Seawall, and Bulkheads.

o. EM 1110-2-2502, Retaining Walls.

p. EM 1110-2-2904, Design of Breakwaters and Jetties.

q. EM 1110-2-2906, Design of Pile Structures and Foundations.

r. EM 1110-2-3300, Beach Erosion Control and Shore Protection Studies.

s. EM 1110-2-5025, Dredging and Dredge Material Disposal.

t. EM 1110-2-5026, Dredged Material Beneficial Uses.

u. EP 1165-2-1, Digest of Water Resources Policies and Authorities.

1-5. Appendices.

a. Bibliography. Bibliographical. references are indicated throughout the text by last names of authors listed alphabetically in Appendix A. The WES reports referenced are available on loan from the Technical Information Center, US Army Corps of Engineer, Waterways Experiment Station, PO Box 631, Vicksburg, Mississippi 39180-0631.

b. Models. Appendix B contains information on both numerical and physical models available for environmental studies. The capability of each model is briefly discussed and its source is identified.

c. Regulations. Federal regulations related to implementing coastal shore protection projects are listed in Appendix C. All projects will also need to achieve compliance (most likely through the local sponsor) with state or territorial, county, and other local government statutes.

d. Species Profiles. A list of published and unpublished estuarine/marine species profiles is provided (Appendix D). The profiles give brief but conprehensive sketches of the biological characteristics and environmental and habitat requirement of coastal fish and invertebrates.

1-6. Glossary. Definitions of key terms frequently used are provided at the end of this manual.

CHAPTER 2

OVERVIEW OF COASTAL SHORE PROTECTION PROJECTS

2-1. Classification. Coastal shore protection projects are classified into four general categories in the "Shore Protection Manual:"

a. Shoreline stabilization.

b. Backshore protection (from waves and surge).

c. Inlet stabilization.

d. Harbor protection.

A coastal problem may fall into one or more categories.

2-2. Alternatives. Once the project is identified, various alternatives are available to the coastal engineer. These alternatives involve the placement or removal of sediment, rock, wood, or other material to create new structures, to modify existing structures, or to physically alter the shore in some manner. In this manual, potential alternatives have been grouped into three categories: protective beaches, dunes, and levees; man-made structures; and nonstructural alternatives (Table 2-1). While this manual primarily addresses these three action alternatives, information presented will also be useful in evaluating passive solutions such as coastal zoning and land-use management. Dredging, a potential solution to inlet stabilization problems, and environmental considerations for this activity are addressed in EM 1110-2-1202 (see para 1-4). Mitigation policy for Federal projects is summarized in ER 1105-2-50. Chapter 8 of this manual provides an additional discussion of mitigation.

2-3. Considerations.

a. Table 2-2 lists the factors that must be considered in analyzing each project category and its associated considerations. Hydraulic considerations include wind-generated waves, swells, currents, tides, storm surge or wind setup, and the basic bathymetry of the area. Sedimentation considerations include the littoral material and processes (i.e., direction of movement, net and gross rates of transport, and sediment classification and characteristics), and changes in shore alignment. Control structure considerations include the selection of the protective works by evaluating type, use, effectiveness, economics, and environmental impact. Navigation considerations include the design craft or vessel data, traffic lanes, channel depth, width, length, and alignment. In selecting the shape, size, and location of shore protection works, the objective should be not only to design an engineering work that will accomplish the desired results most economically, but also to consider effects on adjacent areas. An economic evaluation includes the maintenance and replacement costs, along with the interest on and the amortization of the first costs. If any plan considered would potentially increase the

TABLE 2-1

Classification of Coastal Engineering Solutions

Problems to Address	Solutions
Shore Stabilization	Beach & Dune
	Beach nourishment Sand bypassing
	Structures
	Bulkheads Revetments Seawalls Detached breakwaters Groins
	Nonstructural
	Marsh plants Seagrasses
Backshore Protection	Beach & Dune
	Protective beach Dune stabilization
	Structures
	Bulkheads Revetments Seawalls
Inlet Stabilization	Structures
	Jetties Dredging
Harbor Protection	Structures
	Breakwaters Jetties

TABLE 2-2

Classification of Coastal Engineering Considerations

PROJECT	HYDRAULICS	SEDIMENTATION	CONTROL STRUCTURE	MAINTENANCE	REPLACEMENT	MATERIAL SOURCES	LEGAL REQUIREMENTS	ECONOMICS	ENVIRONMENTAL IMPACT	NAVIGATION	BAY CIRCULATION
SHORE STABILIZATION	▨	▨	▨	▨	▨	▨	▨	▨	▨		
BACKSHORE PROTECTION	▨	▨	▨	▨	▨	▨	▨	▨	▨		
INLET STABILIZATION	▨	▨	▨	▨			▨	▨	▨	▨	▨
HARBOR PROTECTION	▨	▨	▨	▨		▨	▨	▨	▨	▨	

impact of a project to a larger coastal stretch or prevent an extension of the impacts, the economic effect of each such consequence should be evaluated. A convenient measurement for comparing various plans on an economic basis is the average annual cost over the evaluation period and the average annual benefit captured by each plan.

b. Effects on adjacent land areas are considered to the extent of providing the required protection with the least amount of disturbance to current and future land use, ecological factors, and aesthetics of the area. The form, texture, and source of material should be considered in the design, as well as how the material is used. Proper consideration must be given to the legal and social consequences where shore protection measures may result in significant effects on physical or ecological aspects of the environment.

c. Coordination between the design and environmental elements should begin early in the planning process to assure that environmental concerns, opportunities, and features are adequately considered.

CHAPTER 3

ENVIRONMENTAL RESOURCES

3-l. <u>Environmental Requirements</u>.

a. General. As noted in Table 2-2, the "Environment" is a consideration in each coastal shore protection project category. The environmental effects of all project alternatives must, by law as well as normal engineering considerations, be evaluated. Opportunities for incorporating environmental considerations and enhancements in coastal shore protection projects should be investigated.

b. Policies. The planning, design, construction, and operation and maintenance activities of coastal shore protection projects must be consistent with national environmental policies. Those policies require that such activities be done to the extent practicable in such a manner as to be in harmony with the human and natural environment, and to preserve historical and archaeological resources. Corps project development is documented by a series of studies, each being more specific than the previous study. The series of reports produced for a project varies by Corps District and Division and through time due to scientific judgment, the unique conditions specific to each project, and changing regulations. In general, an initial evaluation (or reconnaissance) report and a feasibility (or survey) report are prepared prior to congressional project authorization. Refer to ER 1105-2-10, for a description of this planning process. Environmental studies are included along with engineering, economic, and other types of analysis (ER 1105-2-50).

C. Statutes and Regulations. Complying with Federal statutes, executive orders and memoranda, and Corps regulations requires careful study of existing environmental conditions and those expected to occur in the future with and without shore protection. Principal environmental statutes/regulations that are applicable to Corps coastal shore protection projects arelisted in Appendix C.

d. Environmental Studies. During each stage of project planning, design and construction, major environmental concerns and corresponding information needs should be identified. Forecasting of information needs is necessary in order to schedule sufficient time for field data collection, physical or numerical modeling if needed, and other needs. Scheduling of field studies should allow for administrative time related to contract preparation, contractor selection, report and NEPA document preparation, review of findings, and coordination or consultation with concerned Federal agencies and the interested public.

(1) Checklist of studies. The following checklist consists of some of the environmental factors that should be considered for coastal shore protection projects. Environmental factors selected for study will depend upon the type project being considered. This checklist is not all inclusive and not all factors are appropriate for all projects.

(a) Determine the bounds of the project areas.

(b) Characterize existing environmental (physical, ecological, cultural, economic conditions at a project site.

(c) Be aware of other planned construction activities likely to be associated with the Federal project and evaluate their cumulative impacts.

(d) Evaluate project effects on long-shore sedimentation processes, circulation patterns, currents, and wave action.

(e) Evaluate project effects on water quality, including characterization and testing of sediments as required in Section 103 of the Ocean Dumping Act (PL 92-532) or Section 404 of the Clean Water Act (PL 92-500) evaluations.

(f) Evaluate the no action alternative and nonstructural solutions.

(g) Evaluate project effects on erosion and deposition.

(h) Evaluate all reasonable and practicable construction alternatives (construction equipment, timing, etc.).

(i) Evaluate effects of the final array of alternative plans on significant biological, aesthetic, cultural and recreational resources.

(j) Describe relationships of each plan to the requirements of environmental laws, executive orders, Federal permits and state and local land use plans and laws.

(k) Include feasibledesigns, operational procedures, and appropriate mitigation measures to reduce or avoid adverse environmental impacts in the preferred plan and alternatives evaluated.

(l) Coordinate with other agencies, the public, and private groups.

(m) Plan and design an environmental monitoring program as needed.

(2) Critical issues. Time and money constraints will generally dictate the level and scope of investigation and data collection for all environmental areas of interest. Therefore, the most significant environmental issues identified by the public and resource agencies during scoping should be investigated. It is essential that the issues investigated fully account for all significant effects of a project and that a realistic balance be achieved between the study requirements and funds available. The addition of factors determined at a later date will increase the time, cost, and expertise required for the study.

Chapters 4, 5, and 6 of this manual identify major environmental considerations associated with alternative shore protection solutions. Criteria for determining significant issues include statutory requirements, executive orders, agency regulations and guidelines, and other institutional standards of regional and local interest. (see Appendix C).

(3) Environmental monitoring. The Council on Environmental Quality regulations at 40 CFR 1505.3 state that agencies may provide for monitoring to assure that their decisions are carried out and should do so in important cases and upon request, make available to the public the results of relevant monitoring. The 40 CFR 1505.2 also states that a monitoring and enforcement program shall be adopted and summarized where applicable. The term "environmental monitoring" as defined in ER 200-2-2 is that oversight activity necessary to ensure that the decision, including required mitigation measures, is implemented. Environmental monitoring as discussed in Chapter 7 of this manual refers to the overall process of data collection, management, analysis and interpretation of short and long term changes over the life of the project and analysis are discussed in Chapter 7 of this manual.

(4) Each study must have well-defined, detailed objectives prior to field data collection. The study design should include a rationale for hypotheses to be tested, the variables to be monitored, techniques and equipment to be used, sample station locations and frequencies, and data storage and analysis. Monitoring may extend beyond water quality and ecological studies and include monitoring noise, emission from equipment engines, cultural resources, archeological resources, etc., if deemed appropriate.

(a) Environmental studies during early stages of project formulation should emphasize identification of resources, development of an evaluation framework, and collection of readily available information for all potential alternatives. Resources likely to be impacted should be investigated, and additional data needs should be identified.

(b) Detailed analysis of a project occurs after evaluations narrow the range of specific alternatives to the most feasible (usually three or four) which have been selected for study. Beneficial and adverse environmental effects of each alternative should be quantified where possible or qualified in adequate detail so they can be included with the economic and technical analysis to compare and select the plan that maximizes NED benefits. Although a preferred alternative can be identified at this stage, formal selection of an alternative for construction must await the completion and agency review of the Environmental Impact Statement or Environmental Assessments. In this way the Corps, the public, and outside agencies have the benefit of a full evaluation of all feasible alternatives and a comparison of them by the lead agency. Post-construction monitoring, if authorized, should also be done to verify the impact predictions made during without project analysis. Where monitoring reveals the presence of unexpected impacts, measures should be considered to minimize the impacts.

3-2. Environmental Resource Categories. The remainder of this chapter summarizes the environmental resource categories that should be considered in evaluating the coastal shore protection alternatives. The six categories are physical, water quality, biological, recreational, aesthetic, and cultural.

3-3. Physical.

a. General. The physical modifications of the environment from coastal shore protection projects can result in both desirable and undesirable impacts. Many adverse impacts can be avoided by evaluating alternatives for siting and design. Consideration of physical impacts must occur during both the design stage and impact assessment stage.

b. Physical Design Considerations. Structural and, to a lesser extent, nonstructural measures have the potential of altering the hydrodynamic regime (circulation) and the hydraulic and wave energy conditions of the project area. Furthermore, construction frequently alters the shoreline configuration and/or bathymetry at the project site and occasionally up or down coast, by modifying the littoral transport system. In many instances these modifications are the objective of the design process. The purpose of a shoreline breakwater project is to reduce wave energy entering a harbor, marina, or other facilities. Groin projects and jetty construction result in modification of the littoral transport regime. If the project is not properly designed, adverse physical impacts, such as changes in shoreline configuration (shore erosion) or changes in bathymetry (navigation channel infilling), my occur. These impacts should be identified during the impact assessment stage and, if necessary, the project redesigned or relocated to minimize unwanted effects, such as excessive maintenance dredging and beach nourishment.

c. Physical Impact Assessment. Physical impacts can occur on both a short-term and long-term basis. Short-term impacts are generally construction related (i.e., short sections of a beach may be temporarily restricted during the fill and grading operations). During a beach nourishment project or dune construction, sands can become compacted altering transport phenomena. Physical effects from construction of breakwaters, jetties, groins, piers, or other nearshore structures stem from rock placement, jetting or driving piles, dredging to a solid bed or required depth, and other on site construction activities. Following the completion of these activities, impacts usually diminish rapidly (Naqvi and Pullen 1982, Van Dolah et al. 1984). Long-term impacts may be more important and more difficult to predict. Several tools will help in assessing potential adverse impacts: interviews with long-time residents, review of old aerial photos, on site monitoring, case studies of similar projects numerical models, and physical models. Using any or all of these tools, an evaluation of potential changes in circulation patterns, flushing conditions, and sediment transport phenomena should be completed. Other studies of physical factors may be warranted on a case-by-case basis.

3-4. Water Qualitv.

a. General. Unlike physical impacts, water quality impacts involve changes in the water column's characteristics rather than changes in shoreline configuration or local bathymetry. Again the impacts are manifested on both a short-term and long-term basis.

b. Water Quality Design Considerations. The construction process is often responsible for increases in local turbidity levels, changes in salinity, releases of toxicants or biostimulants from fill materials, introduction of petroleum products, and/or the reduction of dissolved oxygen levels. These impacts can be minimized by modifying or selecting specific construction practices, carefully selecting fill materials, and in some instances by construction scheduling. These impacts are short-lived, and ambient water quality conditions will rapidly return unless long-term changes in the hydrodynamics and hydraulics have occurred. It is these long-tern impacts that must be identified during the design process. In addition to the general impacts of the selected alternatives (whether structural or nonstructural), the proposed design specifications of any selected alternative also have the potential for affecting water quality. For example, the design of an off-shore breakwater (length, height, water depth, spacing) will greatly influence its impact on circulation and flushing and thus its impact on water quality.

c. Water Quality Impact Assessment. The long-term impact on water quality of nonstructural alternatives, i.e., planting beach grasses for dune stabilization, marsh grasses for bank stabilization, and seagrasses for bottom sediment stabilization, is generally negligible, whereas structural alternatives have a range of potential impacts. The range is a function of the location, size, and type of structure. In general, groins have the least potential for water quality impacts. Because groins change local patterns of water circulation, some changes in specific water quality parameters may occur, but these impacts are minimal for most groin projects. The water quality effects of bulkheads and seawalls are similar in that both will reduce erosion of the backshore and decrease local levels of suspended solids. Revetments, similarly to bulkheads and seawalls, may promote erosion of the foreshore and increase levels of suspended solids but to lesser extent. On the other hand, these structures may reduce overall levels of suspended solids by preventing erosion of uplands and backshore materials. Jetties and breakwaters have the greatest potential impact on circulation and flushing. The placement of jetties my not only alter circulation patterns and flushing conditions, as well as erosion and deposition patterns, but may also alter both river outflow and tidal conditions. These impacts may be of consequence well into the estuary and may have widespread effects, such as changing salinity and circulation patterns. Breakwaters, by definition, are wave energy barriers designed to protect landforms or harbor- behind them. These off-shore structures also often influence circulation and flushing action in their lee. If the breakwater is constructed to form a semienclosed basin for use as a harbor or marina, the flushing conditions of the project area may be dramatically altered. Assessment and evaluation of water quality impacts must begin in the planning stage and continue at least through the design stage. Postconstruction monitoring may also be recommended to provide feedback for future projects.

d. Other Contaminants. Activities involving sediments or other construction materials known to contain chemical toxins should be conducted with special precautions to avoid unnecessary chemical release into the water body. Of particular concern would be potential introduction of chemical agents either during preparation, application, or cleanup of construction equipment. Chemical cleaning agents may also contain toxic compounds. Little is known about the potential affects of these compounds on aquatic organisms even in trace amounts. However, chemicals may acutely or chronically affect sensitive life history stages of fishes and shellfishes through: sorption onto eggs, causing reduced survival rates and hatching; impaired osmoregulatory ability, causing delayed development or mortality: or impaired sensory ability, affecting feeding, movement, or predator avoidance (Cairns 1968, Sindermann et al. 1982). Olsen (1984) provides a good general review of the literature on the availability and bioaccumulation of heavy metals, petroleum hydrocarbons, synthetic organic compounds, and radionuclides in sediments. Specific information on toxicity, sublethal effects and bioaccumulation of selected chemical compounds is given by Eisler (1985a-d, 1986a-b). Any release of potentially toxic chemical substances into the water should be particularly avoided during periods when the area is being utilized by migratory species and/or juvenile forms and during periods of harvest of nearby commercially important shellfishes.

3-5. Biological.

a. General. Nearshore marine and estuarine biological systems are diverse and complex. Shore protection projects may benefit one or more components of the biological system while adversely impacting others. Biological assessments of shore protection projects are used to predict the kind of ecosystem and importance, spatial extent, and severity of expected biological changes. In practice, analysis usually focuses upon species of commercial or recreational importance; rare, threatened, or endangered species; and sensitive or highly productive habitats.

b. Biological Design Considerations.

(1) The construction of shore protection measures usually produces short-term physical and water quality disturbances. These perturbations

directly impact biological communities and may result in long-term impacts. For example, some ecosystems damaged by construction or water quality degradation may recover slowly and take years to achieve preconstruction levels of development. Many of these impacts are unavoidable. However, construction activities can often be timed to avoid critical events such as fish or shellfish migrations or shorebird nesting. Construction activities also can often be located to avoid sensitive areas.

(2) Coastal structures alter bottom habitats by physical eradication and in some cases by deposition or scour. However, certain hard structures often create a highly productive, artificial reef type habitat. The type of material used to build a structure and the surface area of the structure will influence the quality of the newly created habitat.

(3) Some structures, which are connected to the shore and extend some distance seaward, may potentially interfere with the migration of certain fish and shellfish. To alleviate these concerns the structure. may be modified to include gaps or shortened in length, or located outside the path of the migrations.

(4) Following construction, some remedial measures can be used to minimize biological impacts. For example, plant communities such as seagrass, beachgrass, and marsh grasses can be replanted following construction.

(5) Noise pollution from dredging or other activities may also be a major concern when in the proximity of bird nesting sites (Buckely and Buckely 1977). However, breeding activities are seasonal, and disturbance can be avoided by scheduling the operations during nonusage periods.

C. Biological Impact Assessment. The assessment of biological impacts must begin very early in the planning process. Some types of biological studies tend to be time consuming and often require data collection over an extended period of time. Early identification of specific biological issues is critical. Chapter 7 provides valuable information on the conduct of biological studies when important issues have been established. Often a key issue is possible siting of a project in a valuable biological area. If the ecosystem can be located and mapped early, it might be possible to move the project elsewhere to avoid the impacts, or redesign the project to reduce impacts.

(1) Habitat modification. All shore protection projects result in some modification of coastal habitats. Beach nourishment results in smothered benthic communities, although the recovery of these communities following nourishment is reported to be generally rapid (Naqvi and Pullen 1982). Structures provide a permanent alteration of the bottom. In some cases, the tradeoff made in replacing "soft" (mud or sand) bottom habitat

with "hard" (rock, at least in rubble mound structures) bottom habitat has generally been viewed as a beneficial impact associated with coastal structures where diversity is desired (Van Dolah et al. 1984). Such habitat modification is typically not a major biological impact issue except when highly productive habitats such as coral reefs, seagrass beds, and spawning and nesting areas are involved.

(2) Fish migration. The impact of coastal structures on fish and shellfish larval migration has been raised as a biological issue. Early life history stages of many important commercial and sport fishes and shellfishes are almost entirely dependent on water currents for transportation between off-shore estuarine spawing grounds and nursery areas. Some coastal structures (inlet jetties in particular) may interfere with this migration process by modifying currents. However, the extent of a problem of this nature will depend upon a case-by-case evaluation of each site. Similar impacts have been associated with jetties and breakwaters on migrations of juvenile and adult fishes and shellfishes. This issue has been raised primarily in association with anadromous fishes in the Pacific Northwest. Conclusive evidence supporting these concerns has not been provided.

(3) Predation pressure. Coastal rubble mound structures provide substrate for the establishment of artificial reef communities. As such, jetties and breakwaters serve as a focal point for congregations of some types of fishes and shellfishes which feed or find shelter there. This condition has also generated a concern by resource agencies, again largely associated with projects in the Pacific Northwest, that high densities of predators in the vicinity of jetties and breakwaters pose a threat to egg, larval, and juvenile stages of important species. Conclusive evidence demonstrating the presence or absence of a significant impact is currently unavailable and will be extremely difficult to establish. It is unwarranted in any case to apply generalizations, and evaluations must be conducted on a site specific basis. For example, examination of existing similar structures nearby the proposed project site could provide clues on the type and extent of marine organism development on jetties, breakwaters, and other rubblemound structures.

3-6. Recreational.

a. General.

(1) Requirements. Recreation development requires cost sharing by a local sponsor. Refer to EP 1165-2-1 for cost-sharing policies. Additional basic requirements for recreation developmemts include:

(a) Sufficient demand to ensure utilization of the facility.

(b) Publicly controlled sites, including access routes.

(c) Provisions for prevention of vandalism.

Refer to ER 1105-2-20 and Appendix D of ER 1110-2-400 for a description of the types of recreation facilities eligible for Federal cost sharing. In general, eligible facilities are those not ordinarily provided by private enterprise or on a commercial or self-liquidating basis. In addition to these regulations, feature selection is also controlled by project site characteristics.

(2) Structures. The recreational potential of engineering structures such as jetties, groins, and breakwaters is generally limited, although in some cases slight modification of structures may increase their suitability for certain recreational activities. For example, jetties and groins often provide additional fish habitat and may become popular fishing spots and surfing areas. Provision for access, parking, and public safety can enhance their recreational potential. Modifications can be incorporated during the early design stage or retrofitted to existing structures.

(3) Lands. Project lands, whether purchased or created through disposal or accretion, have high and diverse recreation potential. They are especially attractive for shoreline recreation development such as swimming beaches, boat launching ramps, marinas, and fishing piers. Campgrounds, multiple-day use areas, and trail systems are appropriate where areas are of sufficient size. While high-intensity recreational use is generally dependent on facilities development, undeveloped project lands can support activities such as nature study, hunting, and beachcombing if sufficient access is provided. Where possible, recreational facilities should accommodate the handicapped. Table 3-1 outlines specific activities and required facilities for recreational use of Corps projects.

b. Recreation Design Considerations.

(1) Refer to EM 1110-1-400 and ER 1110-2-400 for guidance on design of recreation features. Additional information regarding land-based recreation and water-based activities is given by Nunnally and Shields (1985).

(2) Recreation facilities should be sized and located to avoid over utilization or underutilization, as well as conflicts with other authorized project purposes such as navigation. Refer to Urban Research and Development Corporation (1980) for methods to estimate carrying capacity. Over use often results in degradation of the natural resources. In addition, uncontrolled usage may impact the integrity of the shore protection project, particularly when dune or marsh vegetation is an integral part of that project. It is therefore necessary to assure adequate management to provide for optimum public use and maintain the natural characteristics and resource capabilities of the area.

3-7. Aesthetic.

a. General. Coastal shore protection projects affect aesthetic characteristics of the environment through changes caused by construction and maintenance activities, the presence of the coastal structures, and changes in public use patterns. Changes in public use patterns include the increased use of the coastal area for recreation or increased use of an area resulting from the protection afforded by the coastal structure. The aesthetic value of an environment is determined by the combination of landscape components, e.g., water resources, vegetation, and the perceptions and expectations for the resource user or visitor. Perceptions of aesthetic value encompass all of the perceptual stimuli in the environment, i.e., sight, scents, tastes, and sounds and the interaction of these. Visual perceptions are the most predominant of the senses, and visual changes are the major focus of aesthetic assessments. The visual environment for coastal shore protection includes terrestrial landscapes, shorelines, open-water channels, and waterways. Many coastal areas associated with coastal shore protection projects offer a high-value aesthetic experience.

b. Aesthetic Design Considerations. The assistance of a landscape architect should be sought for consideration of landscape design and aesthetic impact assessment. The landscape components of all environments can be manipulated, to some extent, to increase positive visual effects. The landscape components usually considered in water resource projects include landforms, water resources, vegetation, and use characteristics, e.g., recreation or navigation. Each of the landscape components has associated design elements that affect visual quality. The design elements are color, form, line, texture, scale, and spatial character. In considering the design elements, scale may be constrained more than the other properties because of its dependence on object size and the limitation on choice of size for most project features. Examples include the use of natural materials which possess colors, forms and textures that are more desirable than man-made materials, topographic modification of linear features to achieve a more irregular, natural appearing profile, and selection and placement of trees, grasses, and shrubs to improve compatibility of color, form, line, texture, and scale. Nonstructural alternatives, of course, provide high potential for maintaining or enhancing natural aesthetically pleasing conditions.

c. Aesthetic Impact Assessment. Potential visual impacts of proposed coastal projects or impacts at sites of existing projects can be assessed with a procedure such as the Visual Resources Assessment Procedures (VRAP) recommended to the US Amy Engineer Waterways Experiment Station by the Department of Landscape, State University of New York, Syracuse. Aesthetic impact assessment involves determining the changes to the landscape components caused by a proposed project. The potential changes caused by changes in vegetation and water resources can be determined by project plans. Evaluating the future visual appearance of a project is

TABLE 3-1

Recreational Activities and Facilities[1]

Activities	Facilities
Beachcombing	Beach
Bicycling	Trail or road
Boat launching	Ramp and parking areas
Boat mooring areas	Mooring buoys, boat slips, breakwaters, wake absorbers, jetties, dredged channels, aids to navigation, etc.
Camping	Campground, trash receptacles restrooms
Fishing	Water access
Hiking	Trails
Hunting	Sufficient area and habitat and access
Jogging/running	Jogging and running trails and paths
Nature study	Nature area
Outdoor games	Multiple play area
Picnicking	Tables, trash receptacles, fireplaces
Sunbathing	Beach
Swimming	Suitable water and shoreline
Sightseeing	Scenic overlook or viewing tower projects
Surfing	Water access, suitable wave climate and shoreline orientation, and/or sand bars
Snorkeling and scuba diving	Water access and marine recreational or park areas including navigational aids

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1/"Where possible, all facilities should accommodate handicapped and wheelchairs.

most appropriately done by visual simulations, such as drawings or rendering on a photograph. Districts have a number of graphic capabilities that can be used for visual simulations. Assistance of a landscape architect should be sought for the aesthetic impact assessments.

3-8. Cultural.

a. General. Guidance on the need for identification and protection of significant cultural resources in a project area is provided in ER 1105-2-50. Cultural resources are the physical evidence of past and present habitation that can be used to reconstruct or preserve human history. This evidence consists of structures, sites, artifacts, and objects that may best be studied to obtain relevant information. Cultural resources found in coastal shore protection project areas provide physical evidence of how the areas were used for commercial and game fishing, navigation, agriculture, and other activities during historic and prehistoric periods. Identification and interpretation of cultural resource sites clarify the relationship between present-day use and past use. Protection of these historic properties is in the broad public interest as declared by Congress and should be identified, evaluated, protected, preserved, and managed. Cultural resource preservation is an equal and integral part of resource management and should be given equal consideration along with other resource objectives.

b. Coordination Requirements. ER 1105-2-50 requires all actions involving unavoidable effects on Natural Register or eligible historic properties to be fully coordinated with the State Historic Preservation Officer (SHPO) and the Advisory Council on Historic Preservation (ACHP). It may also be desirable to establish and maintain coordination with state archaeologists, state and local archaeological or historical societies, and other state and federal agencies or institutions with special interests or expertise.

c. Cultural Resources Analysis. An analysis of the cultural resources of the project area is usually done during the planning phase to identify sites that require protection or mitigation due to their cultural significance. An analysis of cultural resources usually begins with a reconnaissance survey to determine whether sites are present and is later followed by an inventory of the cultural resource sites including their function and significance and an assessment of the potential losses or damages due to the project. Identification of sites is accomplished by professional archaeologists, often through interviews with local officials and residents, and by examination of archival materials such as the National Register of Historic Places, national architectural and engineering records, maps, and official records. The interviews and archival search delineate the density of sites and the types of sites present, i.e., prehistoric sites, historic sites, architectural elements, and engineering elements. The significance of each site is determined by criteria established by the National Register of Historic Places and by professional judgment. Loss or damage to sites from preliminary or potential project designs can be determined from an inventory and significance analysis, usually accomplished during the planning stage of the project as a result of an intensive archaeological survey. A management plan should be prepared for each applicable project consistent with current guidance to identify, evaluate, protect, preserve, and manage significant historic properties. A mitigation plan may be required when damage to significant resources is expected.

d. Cultural Resources and Design. Project designers should use the cultural resources analysis to develop designs that incorporate protection of the resources. compliance with historical preservation statutes is a significant determinant in developing the scope of studies and mitigation of impacts to significant resources. Preservation through avoidance of effects is preferable. Where avoidance of effects is impossible, protective measures incorporated in to project design must consider the nature and characteristics of the resource, site topography, and operation and maintenance requirements. Whenever a significant historic or archeological site is to be impacted, project design must proceed in consultation with the SHPO and ACHP in accordance with ER 1105-2-50 and 36 CFR Part 800. Project designers should consult Technical Report EL-87-3, Archaeological Site Preservation Techniques: A Preliminary Review (Thorne, Fay, and Hester 1987).

CHAPTER 4

PROTECTIVE BEACHES AND DUNES

4-1. Protective Beaches.

a. General.

(1) The sloping beach and beach berm are the outer line of defense in absorbing most wave energy; dunes are the last zone of defense in absorbing the energy of storm waves that overtop the berm. Beaches and dunes form a natural system of shore protection for coastal lowlands and associated development. When the natural protection system provides inadequate protection from large storms, the first solutions frequently chosen are quasi-natural methods such as beach nourishment or artificial sand-dune construction. Such solutions retain the beach as a very effective wave energy dissipater and the dune as a flexible last line of defense. Poorly conceived construction involving removal of berms and dunes or changes in long shore transport often aggravate shoreline erosion within and adjacent to the project area.

(2) Beach sediments on most beaches range from fine sands to cobbles. The size and character of sediments and the slope of the beach are related to the forces to which the beach is exposed and the type of material available on the coast. Much of the beach material originates many miles inland where weathering of mountains produces small rock fragments that are reduced to sand and gravel. When this sand and gravel reaches the coastal area, it is moved along shore by waves and currents. This longshore transport is a constant process, and great volumes may be transported. Beach material is also derived from erosion of nearby coastal beaches and dunes caused by waves and currents and, in some cases, by onshore movement of sediment from deeper water. In some regions, a sizable fraction of the beach material is composed of marine shell fragments, coral reef fragments, cobbles, or volcanic materials. Clay and silt do not usually exist on ocean beaches because the waves create such turbulence in the water along the shore that these fine particles are suspended and transported to low energy areas, either offshore into deeper water or into bays and estuaries.

(3) Beach characteristics are usually described in terms of average size of the sand particles that make up the beach, range and distribution of sizes of the sand particles, sand composition, elevation and width of berm, slope or steepness of the foreshore, the existence (or lack) of an offshore bar, and the general slope of the inshore zone fronting the beach (Figure 4-1). Generally, the larger the sand particles the steeper the beach slope. Beaches with gently sloping foreshores and inshore zones usually have a preponderance of the finer sizes of sand.

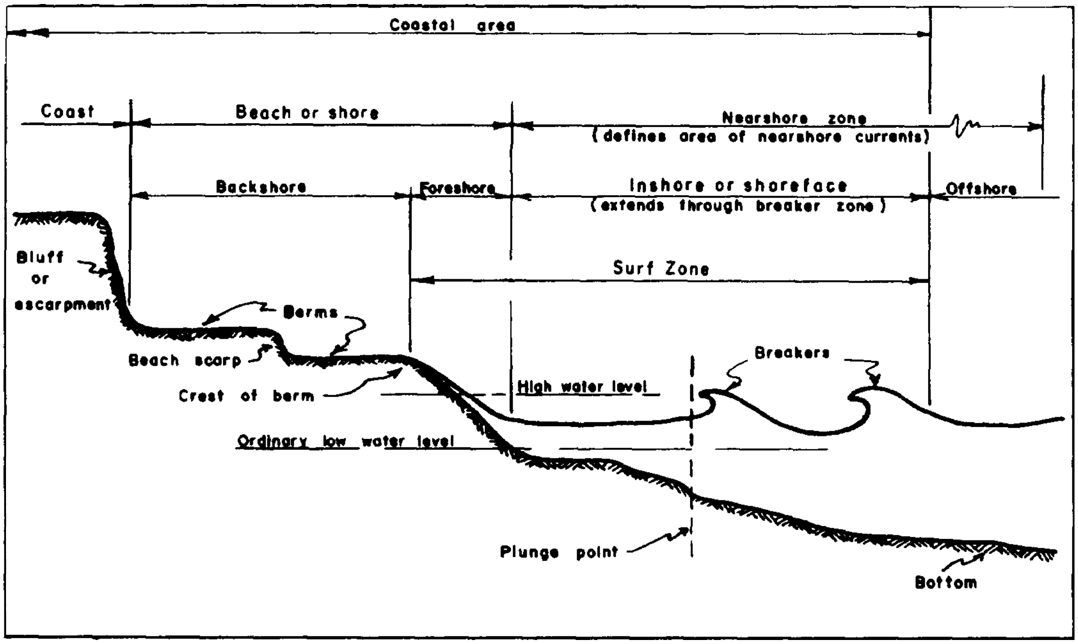


Figure 4-1. Visual definition of terms describing a typical beach profile (US Army Engineer Waterways Experiment Station 1984)

(4) Beaches can effectively dissipate wave energy and are classified as shore protection structures when maintained at proper dimensions. When beaches have narrowed because of long-term erosional trends or severe storms, beach restoration is often proposed. Beach restoration is the practice of mechanically or hydraulically placing sand directly on an eroding shore. However, it is important to remember that the replenishment of sand eroded from the beach does not in itself solve an ongoing erosion problem. Periodic replenishment will usually be required. Replenishment along an eroding beach segment can also be achieved by stockpiling suitable beach material at its updrift end feeder beach and allowing longshore processes to redistribute the material along the remaining beach. The establishment and periodic replenishment of such a stockpile is termed "artificial beach nourishment" (Figure 4-2). Artificial beach nourishment then maintains the shoreline at its restored position. When conditions are suitable for artificial nourishment, long reaches of shore may be protected by this method at a relatively low cost per linear meter of protected shore. An equally important advantage is that artificial nourishment directly but temporarily remedies a basic cause of most erosion problems--a deficiency in sand supply--and benefits rather than damages the adjacent shore. However, the use of feeder beaches may not be applicable in all cases. Thus, nourishment may be required along the entire length of an eroded beach. Feeder beaches are most often used after a beach has been restored to an acceptable alignment.

b. Role in Shore Protection. The shoreline, the interface between the land and the sea, is located where tides, winds, and waves attack the land, and where the land responds to this attack by a variety of "give and take" measures which effectively dissipate the sea's energy.

Figure 4-2. Beach nourishment operation, Mayport, Florida (courtesy of US Army Engineer District, Jacksonville)

(1) As a wave moves toward shore, it encounters the first beach defense in the form of the sloping nearshore bottom (Figure 4-3; Profile A). Along a gently sloping beach, when the wave reaches a water depth equal to about 1.3 times the wave height, the wave collapses or breaks. Thus, a wave 0.9 meter (3 feet) high will break in a depth of about 1.2 meters (4 feet). If there Is an increase in the incoming wave energy, the beach adjusts its profile to facilitate the dissipation of the additional energy. This adjustment is most frequently done by the seaward transport of beach material to an area where the bottom water velocities are sufficiently reduced to cause sediment deposition. Eventually enough material is deposited to form an offshore bar that causes the waves to break farther seaward, widening the surf zone over which the remaining energy must be dissipated. Tides compound the dynamic beach response by constantly changing the elevation at which the water intersects the shore and by providing tidal currents. Thus, the beach is always adjusting to changes in both wave energy and water level.

(2) During storms, strong winds generate high, steep waves. In addition, these winds often create a storm surge which raises the water level and exposes higher parts of the beach to wave action. The storm surge allows the large waves to pass over an offshore bar or reef formation without breaking. When the waves finally break, the remaining width of the surf zone is not sufficient to dissipate the increased energy contained in the storm waves. The remaining energy is spent in erosion of the beach, berm, and sometimes dunes which are now exposed to wave attack by virtue of the storm surge. The eroded

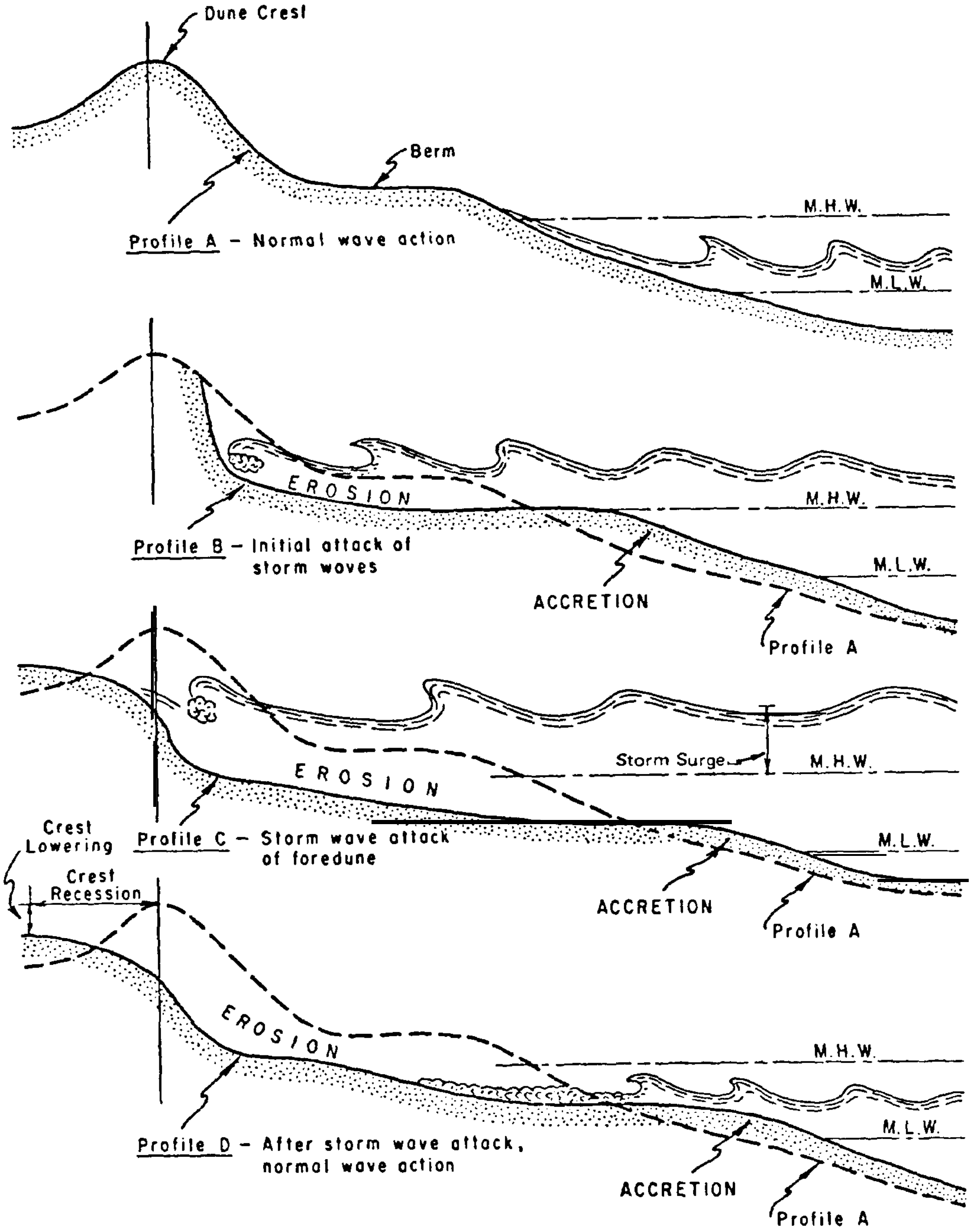


Figure 4-3. Schematic diagram of storm wave attack on beach and dune

material is carriedoffshore in large quantities where it is deposited on the nearshore bottom to form an offshore bar. This bar eventually grows large enough to break the incoming waves farther offshore, forcing the waves to spend their energy in the surf zone. This process is illustrated in Figure 4-3 (Profiles B, C, and D).

(3) Beach berms are built naturally by waves to about the highest elevation reached by average storm waves. When storm waves erode the berm and carry the sand off shore, the protective value of the berm is reduced and large waves can overtop the berm. The width of the berm at the time of a storm thus influences the amount of damage a storm can inflict. During extreme events, berm material can be carried landward and deposited, thus removing the material from the zone of littoral drift.

(4) Another dynamic feature of the beach and nearshore physical system is littoral transport, defined as the movement of sediments in the nearshore zone by waves and currents. Littoral transport is divided into two general classes : transport parallel to the shore (longshore transport), and transport perpendicular to the shore (onshore-offshore transport). The material that is transported is called littoral drift. Longshore transport results from the stirring up of sediment by the breaking waves and movement of this sediment by a longshore current generated by the breaking waves. The direction of longshore transport is directly related to the angle at which the wave breaks relative to the shoreline. Onshore-offshore transport is determined primarily by wave steepness, sediment size, and beach slope. In general, high steep waves move material offshore, and low waves of long period (low steepness) move material onshore.

C. Physical Considerations.

(1) Construction impacts.

(a) Three primary methods of placing sand on an eroding beach are land-hauling from a nearby borrow area, direct pumping of sand through a pipeline from an inlet or an offshore borrow area using a floating dredge, and transporting sand in a split-hull barge from a nearby area. Two basic types of floating dredges are used to remove material from the bottom and pump onto the beach. These two are the hopper dredge (with punp-out capability) and the hydraulic pipeline dredge (suction dredge). Hydraulic pipeline dredges are better suited to sheltered waters where wave height is less than one meter. A cutterhead is often used on the suction dredge. The action of the cutterhead agitates the substrate to a greater degree than a suction dredge without a cutterhead, creating a greater potential for elevated suspended sediment concentrations and turbidity. However, suspended sediments and turbidity are generally not a problem in sands. Studies have shown that very little material is resuspended from a properly operated cutterhead dredge. Desilting or sedimentationbasins are often needed to provide a controlled environment where pipeline slurry waters can be pumped and dewatered prior to placement of sand on the beach. These basins prevent the ecological and esthetic consequences of turbidity and sedimentation from pipeline discharges.

(b) Placement of equipment such as dredge anchors and pipelines can damage environmentally sensitive habitats such as coral reefs, seagrass beds, and dunes. Damage to coral reefs has been caused by dragging of anchors or other equipment across a reef (Maragos et al. 1977, Spadoni 1979, Courtenay et al. 1980). In addition, the operation of equipment on the beach can damage dune vegetation and may cause compaction. Narrow-tracked vehicles do not distribute the weight of the equipment as well as wider tracked vehicles and cause greater damage to the vegetation and increased sand compaction. Highly compacted beaches may have reduced numbers of burrowing organisms. Beach borrowing animals such as ghost crabs and sea turtles have difficulty digging in compacted beaches.

(2) Sediment modification.

(a) Sediments on most beaches range from fine sands to cobbles. The size and character of sediments and the slope of the beach are related to the natural forces to which the beach is exposed and the type of sediment available on the coast. The beach sediments may be in equilibrium due to the prevailing physical forces, or they may be eroding or accreting. When material is newly deposited on a high-energy beach, it modifies the beach sand/water interface and generally sand grain-size distribution, and may increase the suspended sediments of the adjacent nearshore waters depending on the type and particle size of sediments deposited. Waves and currents tend to winnow the finer sediments and to suspend them in the water column. Finer sediments are transported offshore and are deposited in the deeper, calmer offshore waters. These processes continue at a rather rapid pace until a more stable (flatter) beach profile is again achieved. Parr et al. (1978) observed at Imperial Beach, California, that fine sediments were rapidly sorted out of nourishment sediments and that sediment grain-size distribution after about four months was comparable to the beach sediments prior to nourishment. Generally, silts and clays in the fill material are suspended during placement, but after initial placement turbidity and suspended sediments are dissipated.

(b) Coincident with changes in grain size and shape in beach material, an increase in compaction of the beach can result from beach nourishment. A compact beach is less suitable for burrowing organisms. An increase in fine material, mineralization or the binding together of particles, and the layering of flat-shaped grains may contribute to an increase in compaction. However, a greater occurrence of increased compaction is likely when sand is pumped onto a beach in a water slurry. This sand-water slurry allows maximum crowding together of sand grains which results in a very dense, compact beach (Smith 1985). Increases in compaction may be a short-term effect since the beach will be softened by wave action, particularly during storms.

d. Water Quality Considerations. Problems related to water quality and turbidity in the nearshore zone of a high-energy beach do not appear to be a major concern because the fine sediments that contain high levels of organic material and other constituents are rapidly transported offshore and sulfides are oxidized (Naqvi and Pullen 1982). However, high turbidities resulting from prolonged beach nourishment and/or erosion degradation of nourishment material may indirectly affect light-sensitive plants and animals. The reduced sunlight penetration into the water may impact nearshore corals, associated algae, and submerged aquatic vegetation. It may also affect the migration and feeding of visually oriented adult and juvenile fishes and the recruitment of larval and juvenile animals to the beaches. Turbidity resulting from beach nourishment generally creates only minor impacts in the surf and the offshore zones except when light sensitive resources are involved (Naqvi and Pullen, 1982). Precautions should be taken to use only clean, uncontaminated material. While most dredged material is clean sand, concerns about the presence of toxins in the borrow material will have to be addressed.

e. Biological Considerations.

(1) Fish and other motile animals.

(a) Suspended solids in the water can affect fish populations by delaying the hatching time of fish eggs (Schubel and Wang 1973), killing the fish by abrading their gills, and anoxia (O'Connor et al. 1976). Fish tolerance to suspended solids varies from species to species and by age (Boehmer and Sleight 1975, O'Connor et al. 1976). This problem does not appear to be a major one along coastal beaches.

(b) Destruction of habitat rather than suspension of sediments seems to be the major hazard to beach and nearshore fishes. Most of these animals have the ability to migrate from an undesirable environment and return when disposal ceases (O'Connor et al. 1976, Courtenay et al. 1980). Species that are closely associated with the beach for part of their life cycle are most likely affected by beach nourishment. Parr et al. (1978) observed that beach nourishment did not prevent subsequent spawning of grunion (Leuresthes tenuis) at Imperial Beach, California. However, the dusky jawfish (Opistognathus whitehursti), a burrowing species with limited mobility and narrow sand grain-size requirements, was displaced by fine sediments on the east coast of Florida (Courtenay et al. 1980).

(c) The loss of a food source due to burial by nourishment sediments may also have some effect on motile populations. However, there is evidence that nourishment benefits some fish by suspending food material (Courtenay et al. 1972). Also, associated turbidities may provide temporary protection from predators (Harper 1973). Studies indicate that fishes may be attracted to dredging (Ingle 1952, Viosca 1958) or to sand mining operations (Maragos et al. 1977). Sherk et al. (1974) found that demersal fishes are more tolerant to suspended solids than filter-feeding fishes.

(d) Several long-term studies have shown that moderate to complete recovery of motile animal populations occurred within less than a year. Courtenay et al. (1972, 1980), Parr et al. (1978), Reilly and Bellis (1978), and Holland et al. (1980) described motile fauna recovery following beach nourishment. These studies have shown that motile animals generally temporarily depart an area disturbed by beach nourishment, but return when the physical disturbance ceased. Oliver et al. (1977) observed that demersal fishes moved into an area within the first day after a disturbance. Courtenay et al. (1980) noted that lobsters, crabs, shrimp, and fishes left disturbed areas, but reappeared within four months after the disturbance. The motile animals which have stringent environmental requirements, such as substrate preferences for spawning, foraging, or shelter, are most likely to be affected.

(2) Benthos.

(a) Species comprising marine bottom communities on most high-energy coastal beaches are adapted to periodic changes related to the natural erosion and accretion cycles and storms. Organisms adapted to unstable nearshore bottom conditions tend to tolerate perturbations better than those in more stable offshore environments (Thompson 1973, Oliver and Slattery 1976). Burial of offshore benthic animals by nourishment material has a greater potential for adverse impacts because the subtidal organisms are more sensitive to perturbation than those in the intertidal and upper beach zone (Naqvi and Pullen 1982). For that matter, any project which results in net deposition of sediment onto an offshore benthic community will tend to cause greater impacts. Direct burial of nonmotile forms with beach nourishment material can be lethal, whereas motile animals might escape injury. However, burial of animals is not generally significant at the population or community level, unless it is a sensitive resource such as corals. Some infaunal bivalves and crustaceans can migrate vertically through more than 0.3 meter (1 foot) of sediment (Maurer et al. 1978). Survival depends not only on the depth of deposited sediment, but also on rate of deposition, length of burial time, season, particle-size distribution, and other habitat requirements of the animals.

(b) Following dredging and burial of benthic animals, a short-term increase in diversity, accounted for by recruitment of opportunistic species, may occur (Clark 1969, Gustafson 1972, Parr et al. 1978, Applied Biology, Inc. 1979). These opportunistic species, which initially invade the disturbed area, are generally later replaced by species common to the original community. A similar response can also result from natural events such as storms, hurricanes, and episodes of "red tide" organisms (Saloman and Naughton 1977, Simon and Dauer 1977). The recovery rate of preproject resident species will vary from 5 weeks to 2 years (Hayden and Dolan 1974, Saloman 1974, Parr et al. 1978, Reilly and Bellis 1978, Taylor Biological Company 1978, Tropical Biological Industries 1979, Marsh et al. 1980). Reef corals tend to be among the slowest of recolonizers (15-50 years) and usually require hard substrates for larval settlement and attachment.

(c) Recovery will depend on the species affected, the season in which nourishment occurs, and the recruitment of larvae into the area. The ability of most macrofauna to recover rapidly is due to their short life cycles, their high reproductive potential, and the rapid recruitment of planktonic larvae and motile macrofauna from nearby unaffected areas. Shore zone animals are generally adapted to living in a high-energy environment; thus they can tolerate a high level of disturbance.

(3) Oysters. The turbidity and increased sedimentation that can result from beach nourishment in coastal bays and estuaries can be detrimental to oysters. Elevated turbidity can reduce oyster respiration and ingestion of food (Loosanoff 1962). Mature oyster reefs are more susceptible to elevated turbidity, sedimentation, and direct physical alteration than immature reefs because mature reefs are already stressed from crowding (Bahr and Lanier 1981). Even a moderate disturbance of a mature reef can destroy it. Immature reefs can undergo rapid growth and thus are more resilient to disturbance (Bahr and Lanier 1981).

(4) Seagrasses and mangroves. Burial, uprooting, elevated turbidity effects, and sedimentation as results of beach nourishment may damage coastal vegetation (Zieman 1982). Seagrasses may be slow to recover when rhizomes are severed and plants are uprooted (Godcharles 1971, Zieman 1975). Elevated siltation rates and turbidity can cause suffocation and reduce photosynthetic activity in seagrasses (Thayer et al. 1984). Covering of mangrove prop roots with dredged material can kill the plants (Odum et al. 1982).

(5) Corals.

(a) Corals are sensitive to covering by fine sediments (Figure 4-4). Hard corals (Scleractinians) are more sensitive than soft corals (Octocoralians) because they are not as capable of cleansing themselves of heavy sediment loads and are easily smothered. Sand or silt accumulation on reefs will foul and kill corals, algae, other invertebrates, and also displace other resident invertebrates and fish. The soft corals are better adapted for survival in the nearshore areas subject to beach nourishment.

(b) Coral damage as a result of beach nourishment is usually caused by elevated sedimentation rates and by direct physical damage (e.g. burial) to the reef. Sedimentation may inhibit the food-acquiring capability of the coral polyps and inhibit photosynthesis of symbiotic unicellular algae (Zooanthellae), eventually killing the coral (Goldberg 1970, Courtenay et al. 1972).

(c) Several studies have shown that coral reefs can withstand some sedimentation. Courtenay et al. (1974) examined the effects of beach nourishment on nearshore reefs at Hallandale Beach, Florida. They noted that the reefs sustained short-term damage caused by fine materials eroding from the nourished beach. A follow-up survey seven year later found no evidence of major reef damage (Courtenay et al. 1980, Marsh et al. 1980). Excessive sedimentation which buries a reef results in permanent destruction or replacement by soft bottom habitat and communities. Even for reefs where accumulated sediment is removed by later storms, recolonization by corals and other organisms on the dead surfaces may take decades to be complete.

(6) Sea turtles.

(a) Nourishment can affect the sea turtles directly by nest burial or by disturbing nest locating and digging behavior during the spring and summer

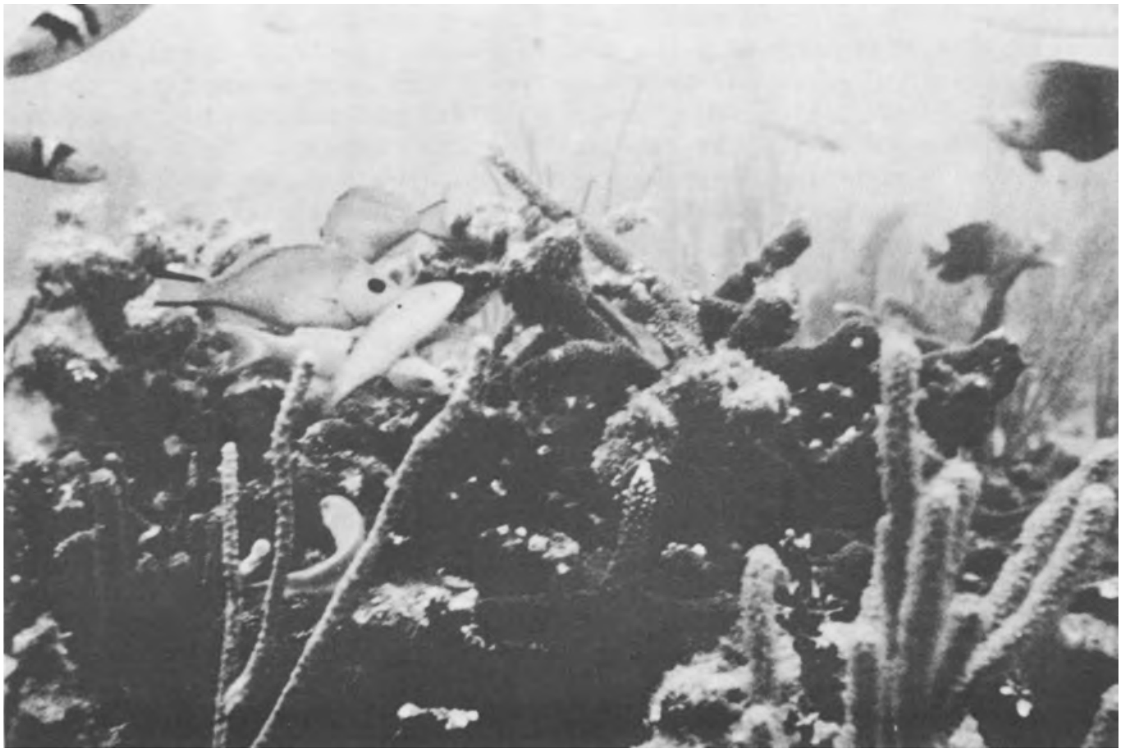


Figure 4-4. Reef fauna near outer edge of second reef off Golden Beach, Florida (Courtenay et al. 1980)

nesting season (Figure 4-5). Indirectly, beach nourishment or replenishment has the potential of affecting sea turtle nest site selection, egg clutch viability, and hatchling emergence by altering the physical makeup of the beach. Factors such as sand grain size distribution, grain shape, moisture content, color, temperature, and the density of the sand may be altered.

(b) Smaller grain size, flatter shaped grains, and greater density may cause compaction of the beach. A compacted beach will inhibit nest excavation by sea turtles (Fletemeyer 1980, Ehrhart and Raymond 1983) and impede emergence of hatchlings (Fletemeyer 1979). Mortimer (1981) and Schwartz (1982) reported that an optimum range of grain size for hatchling success was coarse to fine sand (2.5 to 0.125 millimeters). Even though sand particle size distribution varies greatly from one nesting beach to another (Hirth and Carr 1970, Hirth 1971, Hughes 1974, Stancyk and Ross 1978), when sands are too fine the gas diffusion rate required to support embryonic development may become inadequate (Ackerman 1977; Mortimer 1979, 1981; Schwartz 1982). If sands are too coarse, the nest collapses and the hatchling turtles are unable to emerge to the surface (Mann 1978, Sella 1981).

(c) Sand temperature may be affected by sand color, density, and grain size of borrow material. Nest site selection, incubation duration, sex ratio,

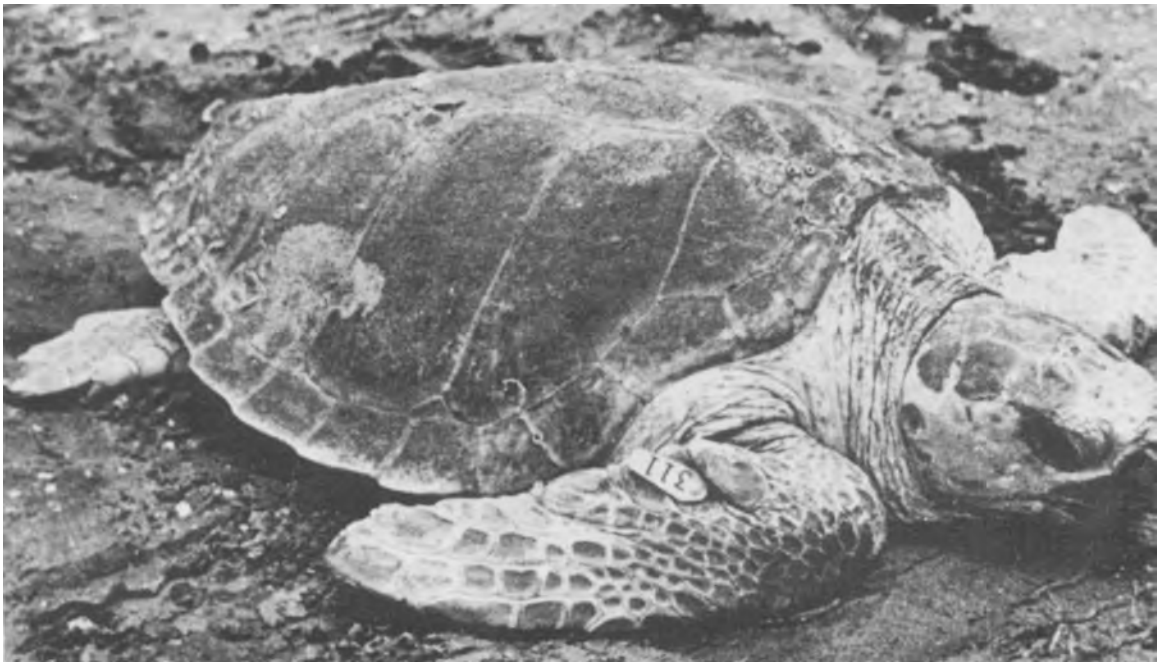


Figure 4-5. Nesting sea turtle

and hatchling emergence of turtles may be influenced by sand temperature (Mrosovsky 1980, 1982; Stoneburner and Richardson 1981). Stable nest temperature is a prerequisite for normal development of green and loggerhead turtles (Sella 1981, Geldiay et al. 1981). Lower ambient sand temperature increases incubation time (Harrison 1952, Hendrickson 1958, Mrosovsky 1982). Temperature is also an important determinant of hatchling sex ratios (Morreale et al. 1982). Incubation temperatures above 30" C result in more females hatchling, whereas below 30" C more males hatch (Yntema and Mrosovsky 1982). Morreale et al. (1982) also report that warmer temperatures inhibit emergence of hatchlings from the nest, presumably due to hatchlings cueing on cooler nighttime temperature6 for synchronization of nocturnal emergence.

(d) Sand moisture content may be affected by grain size, grain shape, pore space, compaction, density, and other factors. Moisture content can in turn affect hatching success of sea turtles (Ackerman 1977, Mortimer 1981). Too much moisture may decrease gas diffusion to the nest because of waterlogging of the sand (Ackerman 1977), while too little moisture may cause higher nest temperatures and egg desiccation (Mortimer 1981).

f. Recreational Considerations.

(1) Beach restoration and nourishment usually produce tangible recreation benefits by increasing the dry beach area. In general, the dry beach area determines the potential carrying capacity of the beach. Although there is no current formally established standard in the United States, EM 1110-1-400 recommends 50 square feet (4.6 square meters) of dry beach and 30 square

feet (2.8 square meters) of swimming area per bather as peak carrying capacity for optimal beach usage benefits (Figure 4-6). However, in resort areas with many visitors and limited beaches, densities may be much higher.

Figure 4-6. Recreational use of Delray Beach, Florida

(2) To the coastal engineer the dry beach is the "backshore" which consists of the "natural berm" and "storm berm." Increasing the width of the berm region is an important design criterion in beach restoration projects. Criteria for specifying berm width depend on several factors. If the purpose of the fill is to restore an eroded beach to protect backshore improvements from major storm damage, the width of the berm may be determined as the protective width of historical record which has been lost during storms plus the minimum required to prevent wave action from reaching improvements. Where the beach is used for recreation, the optimum width of the beach may be influenced by the recreational use. Estimated beach use is generally based on the prospective changes in population of the areas considered tributary to the beach and the beach-carrying capacity and availability of alternative sites. Federal participation in beach erosion control projects is limited to a part of the construction costs for restoration and protection of beach fills, based on public ownership and use of the shore frontage. For these projects, other recreation developments are entirely non-Federal responsibilities except on Federally owned shores (ER 1165-2-130).

g. Aesthetic Considerations.

(1) The alignment of a nourished beach segment generally parallels the existing shoreline but is offset seaward by the width of the fill. The

nourished segment can be thought of as a subtle headland that protrudes from the existing coast. Transition from the fill to the existing shoreline can be accomplished either by constructing 'hard' structures, such as groins and jetties, or by filling transition zones between the terminal ends of the beach fill and the unrestored beach. The use of containment structures often produces an abrupt transition at the limits of the project, and the structures themselves detract from the natural appearance of the beach. When transition fill is used in lieu of structural containment, the nourished beach is gradually merged with the natural shore and visual impacts are lessened or may be absent altogether. The orientation of the transition shoreline will differ from the natural shoreline alignment; however, for engineering reasons this difference is usually quite small.

(2) Locating borrow material that is visually compatible with the natural beach is often impractical and has generally not proven to be a necessary practice from the standpoint of aesthetics. Borrow sediments containing organic material or large amounts of the finer sand fraction have been used as beach fill since natural sorting and winnowing processes clean the fill material. This fact has been confirmed with fills containing fine sediments at Anaheim Bay and Imperial Beach, California, and Palm Beach, Florida. Also fill material darkened by organic material (Surfside and Sunset Beach, California) have been bleached quickly by the sun to achieve a more natural beach color. However, coastal engineers attempt to locate borrow materials that are texturally compatible with the natural beach. Textural properties of native sand are selected for the comparison because their distribution reflects a state of dynamic equilibrium between sediments and processes within the system. This process frequently leads to the selection of visually compatible borrow material (US Army Engineer Waterways Experiment Station 1984).

h. Cultural Considerations. As a shore protection measure, beach restoration will potentially protect onsite cultural resources. However, impacts on cultural sites associated with increased beach use and the impact of beach induced recreational or commercial development should be evaluated, In addition, when beach restoration is confined by "hard" structures, the impact of these structures on erosion rates in adjacent areas and possible erosion of cultural resources should be considered.

i. Environmental Summary.

(1) Environmental design.

(a) Equipment. A suction dredge with a cutterhead is less desirable than a dredge without a cutterhead for extracting beach nourishment material in the vicinity of live coral reefs or other light sensitive resources (Courtenay et al. 1975, Maragos et al. 1977). The suction dredge without a cutterhead is generally desirable because siltation is minimized and there is less potential for physical damage to the reef. To prevent sand compaction, wide-tracked vehicles should be used for moving equipment and beach nourishment material on the beach.

(b) Borrow material. The composition of sediment at the borrow sites should closely match that of the natural beach sediments (Thompson 1973, Parr et al. 1978, Pearson and Riggs 1981) and should be low in pollutants, silts, and clays. Minimum damage to the beach animals will occur when clean sand is placed on a sandy substratum. The damage may be great to the beach fauna if fine organic-rich sediments are used. In addition, fine sands exhibit greater density and thus greater potential for compaction. The vertical migration of infaunal animals may be inhibited when the particle size and composition of borrowed material differ from the original beach sediments (Maurer et al. 1978). To minimize siltation and consequently potential anoxic conditions following beach nourishment, the percentage of fine-grained sediments (smaller than 125 micrometers) should be kept to a minimum in the borrow material (Parr et al. 1978). Silt, which may be highly detrimental to corals and other beach and offshore benthic invertebrates, will be readily moved offshore if present in the material. Sedimentation can result in the reduction of species diversity. If a key specie (i.e., coral, seagrass, etc.) is affected adversely, the entire animal community of the area may be altered. Silt curtains may be used for containing silty sediments during construction. Silt curtains are not however, recommended for use in open water or in currents exceeding 1 knot. They are not effective for use in areas exposed to high winds or breaking waves or for preventing long-term elevated turbidity when silt is present in the material.

(c) Material placement. Nourishment material placed within the upper beach and the nearshore zone (intertidal) is best from an environmental standpoint. Organisms adapted to unstable nearshore bottom conditions tend to survive perturbations better than those in more stable offshore environments (Thompson 1973, Oliver and Slattery 1976). Burial of offshore benthic animals by nourishment material has a greater potential for adverse impacts because the subtidal organisms are more sensitive to perturbation than those in the intertidal and upper beach zone (Naqvi and Pullen 1982). In addition, by placing material into the intertidal portion of the beach, two benefits can be achieved. First, the maximum amount of existing beach is preserved. Second, the material is sorted and reworked by wave action, which reduces compaction.

(d) Time of placement. Most studies indicate that the optimal time for beach nourishment from a biological standpoint is during the winter (Saloman 1974, Oliver and Slattery 1976, Reilly and Bellis 1978, US Army Corps of Engineers 1979). Winter is typically the period of lowest biological activity. The spawning season for most nearshore and beach fauna occurs between the spring and fall. During winter adults have usually migrated out of the nearshore area and would be less concentrated in the shallow beach zone. Along most coasts, winter also has the most severe wave climate. This season makes it difficult to operate dredging equipment. It also may result in initial movement of large quantities of material offshore from the severe wave conditions.

(2) Environmental considerations. Though beach nourishment may be one of the most environmentally desirable and cost-effective shore protection alternatives, it is not without environmental consequences.

(a) Short-term impacts. During construction, the placement of equipment such as dredge anchors and pipelines can damage nearshore habitats and onshore earth-moving equipment can damage coastal vegetation. The dredging of material from the borrow area may cause locally elevated turbidity levels and increased sedimentation. However, few turbidity and sedimentation problems have ever been documented at the dredge cutterhead. Turbidity may impact motile animals while sedimentation can produce smothering of benthic fauna. The process of placing material on the beach will impact beach fauna. For a period following material placement, nearshore turbidity will be elevated because of the resuspension of fine sediments in the borrow material. The magnitude and duration of these impacts can be minimized through equipment selection, borrow material selection, the timing of construction, placement methods, and the use of dewatering, sedimentation or desilting basins.

(b) Long-term impacts. In general, beach restoration produces long-term recreational benefits and is seldom associated with long-term negative ecological impacts. Within a period of months, nourished beaches often visually and ecologically resemble undisturbed beaches. Potential long-term impacts are usually associated with sensitive habitats such as coral reefs and sea turtle nesting beaches. Under these circumstances special provision should be incorporated into the nourishment project to protect these resources. Many eroding shorelines do not provide sufficient surface area for nesting sea turtles. Restored beaches can provide additional nesting surface. Restored beaches require periodic replenishment. Therefore, impact assessments must consider that the short-term impacts will occur periodically over the life of the project. If a restored beach is confined by "hard" structures, the impact of these structures on the erosion rates in adjacent areas and possible erosion of cultural resources should be considered.

4-2. Dunes.

a. General.

(1) Foredunes are the dunes immediately behind the backshore. They are valuable, nonrigid shore protection structures created naturally by the combined action of sand, wind, and vegetation, often forming a continuous protective system.

(2) Dune building begins when an obstruction on the beach lowers wind velocity causing sand grains to deposit and accumulate. As the dune builds, it becomes a major obstacle to the landward movement of windblown sand. In this manner, the dune functions to conserve sand in the proximity to the beach system. Foredunes are often created and maintained by the action of the beachgrasses, which trap and stabilize sand blown from the beach.

(3) Foredunes may be destroyed by the waves and high-water levels associated with severe storms or by beach grass elimination (induced by drought, disease, excessive traffic by beach users, or overgrazing), which thereby permits local "blowouts." Foredune management has two divisions--stabilization and maintenance of naturally occurring dunes, and the creation and stabilization of protective dunes where they do not already exist.

(4) The creation of new barrier dunes or the rebuilding of damaged or incomplete foredunes may be done mechanically, by moving sand into place by truck, bulldozer, or pipeline dredge and grading it to suitable form, or by trapping blowing sand by means of sand fences or vegetation or a combination of these, where sand supply and wind pattern permit. The latter method utilizes natural forces to create dunes in the same way they develop in nature. It is usually the most economical method and tends to discourage the placement of dunes in unsuitable locations.

b. Beach Grasses For Beach and Dune Stabilization. The most common sand capture method is the use of dune vegetation, primarily beach grasses. Each coastal region has one or more beach grasses which are suitable for use in dune building. The most frequently used beach grasses are American beach grass (<u>Ammophila breviligulata</u>) along the mid-and upper-Atlantic coast and in the Great Lakes region: European beach grass (<u>Ammophila arenaria</u>) along the Pacific Northwest and California coasts; sea oats (<u>Uniola paniculata</u>) along the south Atlantic and Gulf coasts; and panic grasses (<u>Panicum amarum</u>) and (<u>Panicum amarulum</u>) along the Atlantic and Gulf coasts. Each of these grasses is easy to grow and plant, and all are efficient traps for sand. Stems of these plants are usually planted in early spring at one-half to one-meter (18- to 36-inch) centers in a band about 15 meters (50 feet) wide and parallel to the shore. If plantings are flooded with salt water during the growing season, the planting is usually destroyed. For this reason, a small elevated dune is often created prior to planting. Current dune construction methodology is described by Knutson (1977a-b) and Woodhouse (1978) and is summarized in the Shore Protection Manual (US Army Corps of Engineers 1984).

C. Other Herbaceous Vegetation for Beach and Dune Stabilization. There are a number of lesser known plant species that are very effective in stabilizing beaches and dunes. Some of these can be obtained commercially; however, most propagules of these species will be from such sources as donor beaches and sites. Grass species that can be effective in beach and dune stabilization include dune sandspur (<u>Canchrus tribuloides</u>), finger grasses (<u>Chloris spp.</u>), seaside paspalum (<u>Paspalum vaginatum</u>), coastal Bermuda grass (<u>Cynodon dactylon</u>), dropseeds (<u>Sporobolus spp.</u>), and others. Herbaceous plant species that can be effective for dune and beach stabilization include glass-worts (<u>Salicornia spp.</u>) which occur on all United States coasts, dune and beach morning glories (<u>Ipomoea spp.</u>), saltwort (<u>Batis maritima</u>), air potato (<u>Dioscorea</u>

bulbifera), sea purslanes (Sesuvium spp.), pepper grass (Lepidum virginicum), lead plants (Amorpha spp.), water pennywort (Hydrocotyle bonariensis), seaside evening primroses (Oenothera spp.), false mallows (Sida spp.), common nightshade (Solanum americanum), sea oxeye (Borrichia frutescens), dog fennel (Eupatorium capillifolium), camphor weed (Heterotheca subaxillaris), and a number of others. Detailed information concerning these plants and their propagation can be obtained in Landin (1978), Coastal Zone Resources Division (1978), US Army Engineer Waterways Experiment Station (1978), and EM 1110-2-5026.

d. Woody Vegetation for Beach and Dune Stabilization.

(1) In addition to salt meadow cordgrass (Spartina patens) and other grasses and herbaceous plant species that can be used to stabilize beaches and dunes, there are a number of woody plant species that also can be used for this purpose. Stabilization can be achieved in tropical and semitropical areas where native woody species such as mangroves grow into the water. Mangroves help break up wave action on shorelines, while at the same time they trap sediment and speed up development of fast land along the shore. In the tropics, especially on low coral islands vulnerable to erosion, are found several genera of strand trees and shrubs that can be of value in stabilizing beaches. These include species in the genera Messerschmidia, Casuarina, Scaevula, and Terminalia.

(2) In intertidal freshwater areas such as those found far inland in the Chesapeake Bay and in rivers such as the James, the Cape Fear, and the Columbia, woody vegetation that would be useful in shoreline and levee stabilization include a number of willows (Salix spp), alders (Alnus spp.), cotton-woods (Populus spp.), and such large trees as American sycamore (Platenus occidentalis) and willow oak (Quercus phellos). Black willow (Salix nigra) and sandbar willow (Salix interior) are pioneer species on beaches and dredged material deposits in freshwater/intertidal areas, and both can easily be planted on such sites to aid in stabilization. Plantings can be in the form of individual cuttings, wattling, matting, or willow fencing and can also be coupled with erosion control structures such as riprap or sandbags. Additional information on these techniques and plant species are available in EM 1110-2-5026, and in Allen and Klimas (1986), US Army Engineer Waterways Experiment Station (1986), and Schiechtl (1980).

(3) In intertidal saltwater areas such as those found in the Intra-coastal Waterway and along barrier islands and shorelines, the primary tree species that can be used for stabilization in North America are mangroves. It should be noted that mangrove species are not winter-hardy north of central Florida and south Texas. In those temperature zones, mangroves will establish naturally if wave conditions are suitable. In many cases where plant establishment is important to shoreline stabilization, such as on the fringes of dredged material

islands, mangrove establishment takes place by a unique planting method. First, smooth cordgrass (Spartina alterniflora) is planted in the intertidal zones, and mangrove propagules (seed pods) are planted between the Spartina sprigs. The Spartina is used to provide initial stabilization and to provide a protective substrate for the mangrove seedlings while they establish root systems. Eventually, the young mangroves overtop the Spartina, and the shade from the mangrove trees kills the Spartina. The primary mangrove used in this process is black mangrove (Avicennia germinans), since it is the mangrove usually found mixed with natural stands of Spartina in Florida and other tropical areas. White mangrove (Laguncularia racemosa) is the other mangrove which often grows in early successional stages with black mangrove. Red mangrove (Rhizophora mangle) is the climax in many areas and grows further out into the water than the other two species. Thus, for many years it was thought that red mangrove was the pioneer species until studies showed that black and white mangroves were actually the pioneers, followed by red mangroves (Lewis and Lewis 1978).

(4) Three other woody species which have been introduced to North America that will tolerate semiflooded conditions and that will provide shore-line stabilization are the punk tree (Melaleuca quinquenervia), tuart tree (Eucalyptus gomphocephalus), and Chinese tallow tree (Sapium sebiferum). However, it must be emphasized that these three species can very easily proliferate on their own and will quickly become pest species. Punk tree is a major problem in south Florida where it was introduced for shoreline stabilization in freshwater areas. It has spread on its own and has invaded the Everglades where it is displacing native species. These species are not recommended for Corps sites.

(5) There are a number of woody species that are common to coastal shorelines of North America that tolerate salt spray but do not tolerate saltwater conditions. They grow well from the mean high tide line up to dune or beach crests and establish well on beach slopes. Any of these species can be planted to hasten maritime forest development along beaches, but none can be relied upon to stop erosion in the intertidal zone. These plants, listed below in no particular order of importance or ability to colonize shorelines, are:

(a) Pinus maritima (maritime pine).

(b) Scaevola plumieri (scaevola).

(c) Tamarix aphylla (athel tamrisk).

(d) Tamarix gallica (French tamrisk).

(e) Schinus terebinthifolius (Brazilian pepper tree).

(f) Baccharis halimifolia (groundsel tree).

(g) Juniperus silicicola (Florida red cedar).

(h) Casurina equisetifolia (Australian pine).

(i) Sabel palmetto (cabbage palm).

(j) Myrica cerifera (wax myrtle).

(k) Atriplex arenaria (orach).

(l) Kostelelzkya virginica (salt marsh mallow).

(m) Forestiera segregata (Florida privet).

(n) Conocarpus erectus (buttonwood).

(o) Myricanthes fragrans(nakewood).

(p) Psidium guajava (guava).

(6) All of these species can be propagated readily, and in many cases, plants are available from nursery sources such as commercial businesses and US Department of Agriculture Soil Conservation Plant Material Centers. All of them should be transplanted as small trees or seedlings onto the site requiring stabilization rather than trying to use seeds for propagation (Landin 1978, US Army Engineer Waterways Experiment Station 1978, EM 1110-2-5026).

(7) The use of marsh or woody vegetation to stabilize shorelines and levees in lieu of or in conjunction with engineering features such as riprap can reduce costs of stabilization and will generally enhance the aesthetics of the eroding area. In areas where clean beaches are the desired result of the shoreline project, however, vegetation will not be readily accepted by users. Also, very heavy use of beach areas by recreationalists will retard or destroy any planted vegetation used for beach or dune stabilization, and such areas may have to be fenced or posted off-limits until plants are well established (EM 1110-2-5026).

e. Role in Shore Protection. Dune systems have two primary functions in shore processes. First, they act as a levee to prevent the inland penetration of waves and storm surges during some storm events. Second, they provide a reservoir of sand to nourish eroding beaches during storms.

(1) Overtopping. Assuming that the foredunes are not washed away, they prevent storm waters from flooding low interior areas (Figure 4-7). Large reductions in water overtopping are affected by small increases in the elevation of the foredune crest. For example, it has been estimated

that a l-meter (3-foot)-high dune on Padre Island, Texas, would prevent overtopping from water levels accompanying storms with an expected recurrence interval of five years (US Army Engineer Waterways Experiment Station 1984).

(2) Sand reservoir.

(a) During storm, erosion of the beach generally occurs and the shoreline recedes. In a sense, the dynamic response of a beach under storm attack is a sacrifice of some beach width to provide material for an offshore bar (Figure 4-8). This bar reduces the shoreline erosion. Dunes can reduce the amount of beach loss occurring during a particular storm event by contributing sand to the upper beach and offshore bar system.

(b) Recent investigations have estimated the volumes of sand eroded from beaches during storms. Losses from erosion during single storms on the shore of Lake Michigan, on Jones Beach, New York (Everts 1973), and on Mustang Island, Texas (Davis 1972), have been estimated to be as high as 14,000, 17,000, and 31,000 cubic meters per kilometer (29,000, 35,000, and 65,000 cubic yards per mile), respectively. These volumes are probably representative of temporary storm losses because much of the eroded sand usually is returned to the beach by wave action soon after the storm. Birkemeir (1979) studied poststorm changes on Long Beach Island, New Jersey. He found that about one half of the sand that eroded from the beach during the storm was returned to the beach within two days. Volumes of sediment equivalent to those eroded during the storm were trapped and stored by natural processes in foredunes adjacent to the beach at several locations. Foredunes constructed on Cape Cod, Massachusetts (Knutson 1980), Ocracoke Island, North Carolina (Woodhouse, Seneca, and Broome 1976), and Padre Island, Texas (Dahl et al. 1975), contained 60,000, 80,000, and 120,000 cubic meters of sand per kilometer 135,000, 185,000, and 275,000 cubic yards per mile) of beach, respectively.

f. Physical Consideration.

(1) Shore erosion.

(a) On an eroding coast, a stabilized dune will slow but not prevent erosion. Dunes can serve effectively as barriers to high-energy surf, but eventually storm waves will undermine or overtop the dunes with a subsequent net loss of sediment from the original dune. The life span of a particular foredune line is a function of the rate of shoreline erosion, dune height, and width. Large, well-developed dunes commonly withstand moderate storms and often relatively severe ones. But where beach erosion is rapid, artificial stabilization will result in dunes of limited size and short life span. Stabilization of dunes on such a coast will provide only temporary protection to backdune structures or facilities.

Figure 4-7. Dunes under wave attack, Cape Cod, Massachusetts (courtesy of Stephen P. Leatherman)

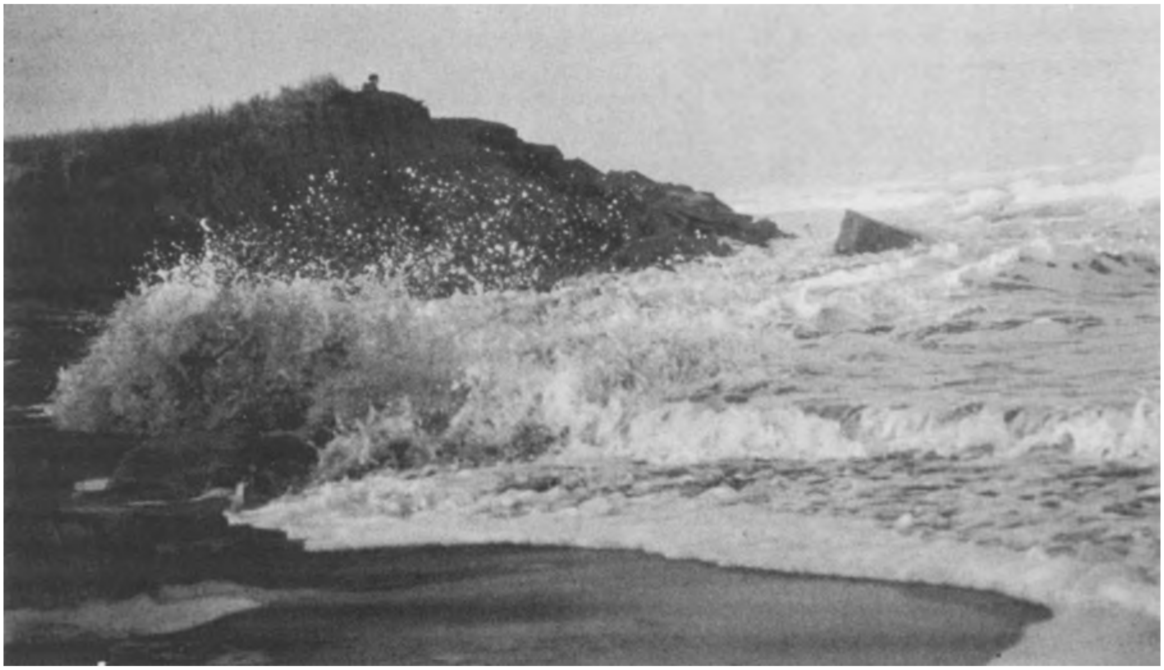


Figure 4-8. Dunes erosion during severe storm, Cape Cod, Massachusetts (courtesy of Stephen P. Leatherman)

(b) The impact of dunes on beach processes has been reviewed in detail by Leatherman (1979a-a). Leatherman concluded that much of the material removed from the dune and beach reforms as one or more nearshore bars. Wave reflection off the nearshore bars causes diminution of the incident waves and eventually reduces dune erosion. Seaward development of nearshore bars during high-wave storm events result in a dissipative surf zone (Figure 4-9) with shoreward decay of incident waves (Wright et al. 1979). The nearshore bar exhibits a cyclic behavior. During fair-weather conditions, the bar migrates landward and after several weeks may merge with the foreshore. Additional information on the process of onshore bar migration after a storm event due to decreasing wave power is provided by Short (1979). It should also be noted that major storms and high waves tend to flatten the foreshore profile rather than steepen it.

(c) Erosion of dunes by storms is a natural occurrence. This material provides a source of sand for the beach. As offshore sediments return to the foreshore to reestablish the original beach profile, onshore winds return sediment to the eroded dune. Whether or not the dunes revert to their former size depends on the local sand budget. If more sediment is leaving a local coastal zone than entering it, dunes will exhibit continual erosion. Where dunes are breached or undermined, dunes will reestablish naturally but usually landward of the original dune line. Sea-level rise may also cause dune erosion. If an adequate supply of sediment is available, the dune may migrate landward with the shoreline (Bruun 1983).

(d) High dunes, natural or artificial, reduce foreshore erosion during storms because much of the dunes and is transported seaward, ultimately to an outer bar and thereby further dissipating wave energy. This process does not appear to effect long-term erosional or depositional trends on the shoreline. Rather, stable dunes buffer rapid changes in the beach associated with the severe storm events.

(2) Barrier island migration.

(a) Barrier islands are elongated islands that mostly parallel the mainland shores of the Gulf of Mexico and Atlantic coasts. The coastal plain and continental shelf adjoining barrier islands are broad and gently sloping. In response to sea-level rise the coastal plain is being submerged. If barrier islands were to occupy a fixed position on the continental shelf, they eventually would be submerged by sea rise. It has been postulated that barrier islands migrate landward up the continental shelf maintaining a relatively constant elevation with respect to sea-level rise. Retreat of the seaward shore is accomplished by shore erosion, while the landward shore is extended by sediments transported between and around the island by tidal inlets and sediment transported over the islands by overwash and wind.

Figure 4-9. Dissipative surf conditions during Storm, Outer Banks, North Carolina

(b) Considering that the objective of most dune stabilization projects is to reduce the frequency of overwash and flooding, barrier island migration is an issue that should be addressed on a case-by-case basis. Though overwash processes have been shown to dominate some narrow barrier islands, most barrier islands appear to be too wide to migrate as a result of overwash. For example, the North Carolina barrier islands have narrowed, not migrated, over the past 130 years (Everts et al. 1983). Beach sands carried by overwash rarely reach the lagoonal side of most barrier islands, though after the barrier island narrows to a critical width, ovewash events may contribute to landward migration. Leatherman (1976) determined the critical maximum width for overwash based on an effective transport mechanism on Assateague Island, Maryland, to be between 100 and 200 meters (300 to 600 feet).

(c) The impact of small, localized dune-stabilization projects on barrier migration does not warrant extensive discussion. The beach grass planting techniques used to encourage dune growth mimic the natural dune building processes that are at work on all barrier systems. Typically, these techniques are used only when there is a need to protect existing man-made structures. Where such development exists, the absence of stable dune systems can often be attributed to human activities.

(d) The issue of barrier migration, however, may be raised when dune--stabilization efforts are employed to restabilize areas damaged by storm events. In this case, it should be recognized that the project, if successful, will accelerate dune establishment and will for a period of time reduce the frequency of overwash. The influence of this reduction in overwash, if any, on barrier island migration often will depend upon the type of barrier being stabilized. Upon relatively broad barriers, where the likelihood of an overwash traversing the entire barrier is remote, dune stabilization will have little impact on barrier migration. As noted earlier, most United States barriers are too broad for overwash to significantly effect their migration. On narrow, eroding barriers, overwash frequently will be critical to migration processes.

g. Water Quality Considerations. Dune sediments are composed of fine to coarse sands. Most coastal dune sediments are indirectly derived from reworked fluvial (river) and/or glacial material. Typically, dunes are nutrient poor and lack an organic component. Consequently, rainfall rapidly infiltrates the sediment, permitting little evaporation or surface runoff. Dune sands are a reservoir of fresh water and an aquifer for domestic water supply. Dune stabilization, by increasing the frequency and extent of dunes, can only enhance this resource.

h. Impacts of Human-Built Dunes.

(1) Dune vegetation. Human efforts to stabilize coastal dunes usually entail planting aggressive, perennial beach grasses in monospecific stands. These planted species remain dominant on the dune for many years after planting. Dahl and Goen (1977) found that when a dune forms naturally with the pioneering plants available to the area, some species remain from previous successional stages and a natural component of the mature dune plant community. However, planting of beach grasses bypasses some of the pioneering successional stages, resulting in rapid plant growth and dune development but in less plant diversity on the mature, planted dune. This lack of plant diversity is typically an unavoidable result of human-built dunes. Plant diversity is associated with slow and protracted dune development, which is contrary to the objectives of most dune stabilization projects. Cowan (1975) and others have conducted experiments on stabilizing dunes using a greater diversity of native species. However, because these native species are not commercially available and often require specialized treatment, such as hydromulching and irrigation, attempts to stabilize dunes in this manner are very costly.

(2) Secondary dune vegetation impacts.

(a) Some investigators have cautioned, based upon experiments conducted on the Outer banks of North Carolina, that dune stabilization projects may adversely impact coastal plant communities (Dolan, Godfrey, and Odum 1983, Godfrey and Godfrey 1973). They observed that high, continuous dunes form an effective barrier to stormwaves, reducing the amount of salt spray and preventing overwash. This protection of the secondary dune area can encourage the invasion and growth of shrub communities. At Cape Hatteras, North Carolina, continuous impenetrable thickets 3 to 5 meters (10 to 20 feet) high have formed in the lee of protective dunes. The National Park Service has resorted to controlled burnings to counter these changes. The excessive development of shrub communities in association with dunes is not an ecological issue in New England (Zaremba and Leatherman 1984) and has not been reported to be a problem in other regions. The shrubs do provide some benefit by providing storm erosion protection and wildlife habitat.

(b) The vegetative changes associated with artificial development of dunes are often considered ecologically beneficial. For example, plantings were made on Padre Island, Texas, following Hurricanes Carla and Beulah in 1967. Much of the island was unvegetated, hurricane-planed backshore and barren, migrating dunes. By 1976 the island's soil adjacent to the planted dunes was measurably less arid than other portions of this south Texas island (Figure 4-10). The mesic (moist) microclimate bayward of the planted dunes is believed to be due to the damming effect provided by the resultant dunes. These dunes retain rainwater in the mid-dune area, providing a more favorable habitat.

(c) The development of new dunes by planting or other means will change the microclimate of areas adjacent to the developing dunes. Whether or not these changes are viewed as ecologically positive or negative will depend upon the local importance and abundance of the habitats which are to be modified. Areas that are frequently stressed, by ovewash for example, either lack vegetation or are colonized by a limited number of grasses and forbs. Developing dunes provide a measure of stability to adjacent areas, reducing flooding and salt spray. This stability makes the environment suitable for a greater diversity of plant species. If stable for a sufficient length of time (10 to 50 years), shrubs will invade and later dominate the plant community (Dolan, Godfrey, and Odum 1973, Zaremba and Leatherman 1984). If stability continues, mature forests can develop in 50 to 100 years.

(d) The shrub and forest communities represent an improved habitat for terrestrial animals and many bird species, principally song birds, though herons and egrets also use coastal shrubs for nesting. Conversely, bare sand and grass areas on the coast are the primary nesting sites for many colonial nesting birds, particularly gulls and terns.

(3) Back barrier salt marsh impacts.

(a) The coastal salt marshes of the United States are considered to be a major environmental resource. They are important contributors to the primary production of the coastal zone and are essential nursery grounds for sport and commercial fishery species. Some researchers contend that

Figure 4-10. Vegetation landward (left on photo) of artificially stabilized dune, Padre Island, Texas (courtesy of Bill E. Dahl)

dune stabilization can impede the development of salt marshes on the back side of barrier islands (Godfrey and Godfrey 1973). This contention is related to sediment overwash providing substrate for the development extension of the marsh into the bay or sound. If overwash does not occur, the marshes slowly erode.

(b) Salt marshes are intertidal plant communities found on the Atlantic and Gulf coasts and, to a lesser extent, on the Pacific coast. Two processes are of particular importance in creating shallow, marine environments in which marshes may establish: flooding due to sea-level rise and/or subsidence of land, and sediment deposition. Salt marshes are often associated with deltas. The Mississippi River delta is a spectacular example of the constructive impact of sediment deposition on marsh development. This delta system represents nearly half of our nation's coastal marshes. Deltas also are responsible for the development of the majority of Pacific coast marshes.

(c) On much of the Gulf and Atlantic coasts, however, deposition of barrier island sediment is important to marsh development. Active and remnant flood-tidal deltas behind these barriers are commonly the focus of marsh development (Godfrey and Godfrey 1973) as shown in Figure 4-11. On some barriers, marshes are altogether absent except where there is evidence of inlet activity (Leatherman and Joneja 1980). Overwash may have either a negative or positive impact on marshes. When stable marshes are present landward of the barrier, overwash events may destroy the marsh through burial or change its ecological character by raising its elevation (Zaremba and Leatherman 1984). Conversely, overwash may widen a narrow eroding marsh or may encourage the growth of new marshes on barren areas by creating a broad, gradually sloping, intertidal plain (Godfrey and Godfrey 1974).

(d) To fully evaluate the potential impact of a particular dune stabilization project on marsh development, two factors must be considered. First, back-barrier marshes will only be impacted when the entire width of the barrier is traversed by overwash or the entire barrier is breached by an ephemeral inlet. Therefore, marsh impacts will be a concern only where events of this magnitude can be reasonably expected to occur within the anticipated life of the project. Second, the current condition of the marshes landward of the barrier should be evaluated. The impact on marsh development will be a project issue if barren shore or eroding marshes are present in the back–barrier area.

Figure 4-11. Salt marshes landward of barrier island system, Murrells Inlet, South Carolina

i. Recreational Considerations.

(1) In general, coastal dunes have a positive impact on recreational

use of the shore. Dunes enhance beach recreational experience by providing shelter from the wind and screening structures and facilities from the beach view. However, sometimes high dunes can obstruct the desirable view of the beach for people using inland facilities.

(2) Recreational use of dunes, however, can seriously impact dune stability. Pedestrian traffic to and from the beach often damages or destroys vegetation along frequently used paths. Knutson (1980) observed a dune crossover path on a developing dune over a five-year period. Although the dunes adjacent to the path increased in elevation by more than one meter (3 feet), the elevation of the path remained constant. Dune areas in which vegetation has been disturbed may deflate rapidly. Field surveys on Assateague Island, Maryland, documented pathway deflation rates of more than one-half meter (2 feet) per year (Leatherman 1979b). These weakened areas of the dune system are the first areas to be overwashed during severe storms. Beach dune walk-over structures can be placed to lessen the Impact of pedestrian traffic (Coastal Engineering Research Center 1981).

(3) Off-road vehicle (ORV) traffic can also severely impact developing dunes. The effect of ORV activity on American beach grass on Cape Cod showed that low levels of activity (less than 175 passes) were sufficient to cause maximum damage to plants (Brodhead and Godfrey 1979). Fewer than 50 passes were shown to preclude seaward growth and development of the foredune system in some cases.

(4) Sand fences are often used to lessen the impact of foot traffic on the dune. Fences can be used to confine and direct traffic to designated crossover areas. These crossovers can be relocated periodically and impact areas can be replanted with beach grass. If ORV traffic is present, wooden ramps should be built over dune lines. Maintenance and repair must be a continuing effort in these situations.

j. Aesthetic Considerations.

(1) There are several features of human-built dunes which make them visually different from natural dunes, at least during the early stages of dune development. Natural dunes are formed by a series of chance events. They begin as small individual hummocks, usually of assorted shapes and sizes. The hummocks may coalesce over time, and the resultant dune will be irregular in elevation and in its location with respect to the shore. Regardless of stabilization procedure, human-built dunes tend to be linear (Figure 4-12). Dunes can be designed with a zigzag or other patterns, but for practical and economical reasons they usually are not. First, straight dunes require the least effort and materials to construct. Second, if an irregular pattern were used on an eroding shoreline, the portion of the dune closest to the shore would be the first area to erode. The flood protection provided by a dune system is limited to the protection provided by the weakest portion of the system. The same line

of thinking can be used to discourage the use of an irregular dune crest elevation. Because of these considerations, human-built dunes typically will be more regular in appearance and more continuous than natural dunes.

(2) The human-built dunes can be made to conform to natural dune contours in other respects. The selection of stabilization technique may influence the final shape of the dune. Knutson (1980) observed in Cape Cod experiments that planted dunes produced lower and wider dunes than fence-built dunes. In North Carolina, researchers found that decreasing plant spacing both landward and seaward from the dune crest increased dune width and reduced the seaward slope of the dune from about one on ten to one on twenty (Savage and Woodhouse 1968).

Figure 4-12. Linear shaped, planted dune system, Outer Banks, North Carolina (courtesy of R. P. Savage)

k. Cultural Considerations. As a shore protection measure, dune stabilization will often protect onsite cultural resources. However, if dunes are created by mechanical methods, potential exists for onsite equipment and traffic damage to cultural resources. Because of the dynamic nature of beach and dune systems (cyclical erosion and deposition), cultural resources are not a common feature in dune stabilization project areas.

l. Environmental Summary.

(1) Environmental design. When beach grasses are used to create and

stabilize coastal dunes, human-built dunes can be developed which are aesthetically and biologically similar to natural dunes. Dune slope, alignment, and plant diversity can be controlled through the selection of an appropriate planting design. In most cases, the planted dune will have a greater diversity of both plants and animals than the unstable sand environment which preceded it. The use of construction equipment to build dunes will generally increase potential for environmental impacts. Vehicular traffic can damage or destroy coastal vegetation. Controlling equipment traffic patterns, constructing sand fences and walkovers, and replanting damaged areas can mitigate these impacts.

(2) Additional environmental considerations.

(a) Short-term impacts. During construction, coastal plant communities can be disturbed by equipment and human traffic.

(b) Long-term impacts. Small, localized dune-stabilization efforts, particularly the planting of dune vegetation, can usually be considered as conservation measures. Dune-building techniques are only used when there is a need to protect existing facilities. Where such development exists, the absence of stable dunes can often be attributed to human activities, hence dune building can be a restorative action. Environmental impacts are not likely to be a major consideration even for relatively extensive dune-stabilization projects in mainland coastal areas. However, major efforts to build continuous dunes on barrier islands to provide protection to mainland areas from major storms and hurricanes will require more serious consideration. Projects of this magnitude may potentially alter the geological and ecological characteristics of the barrier system. Major dune-stabilization projects along a barrier system should be preceded by an investigation of the role that the dunes and the physical processes modified by dunes play in the overall dynamics of the system.

CHAPTER 5

HUMAN-MADE STRUCTURES

5-1. Bulkheads, Seawalls, and Revetments.

a. General.

(1) Where beaches and dunes protect shore developments, additional protective works may not be required. However, when natural forces do create erosion, storm waves may overtop the beach and damage backshore structures. Human-made protective structures may then be constructed or relocated to provide protection. In general, measures designed to stabilize the shore attempt to either harden the shore to enhance resistance to wave action, prevent waves from reaching the shore (or harbor), prevent waves from overtopping an area, or attempt to retard the longshore transport of littoral drift. In this chapter, three types of human-made shore protection structures will be discussed:

(a) Bulkheads, seawalls, and revetments.

(b) Jetties and breakwaters.

(c) Groins.

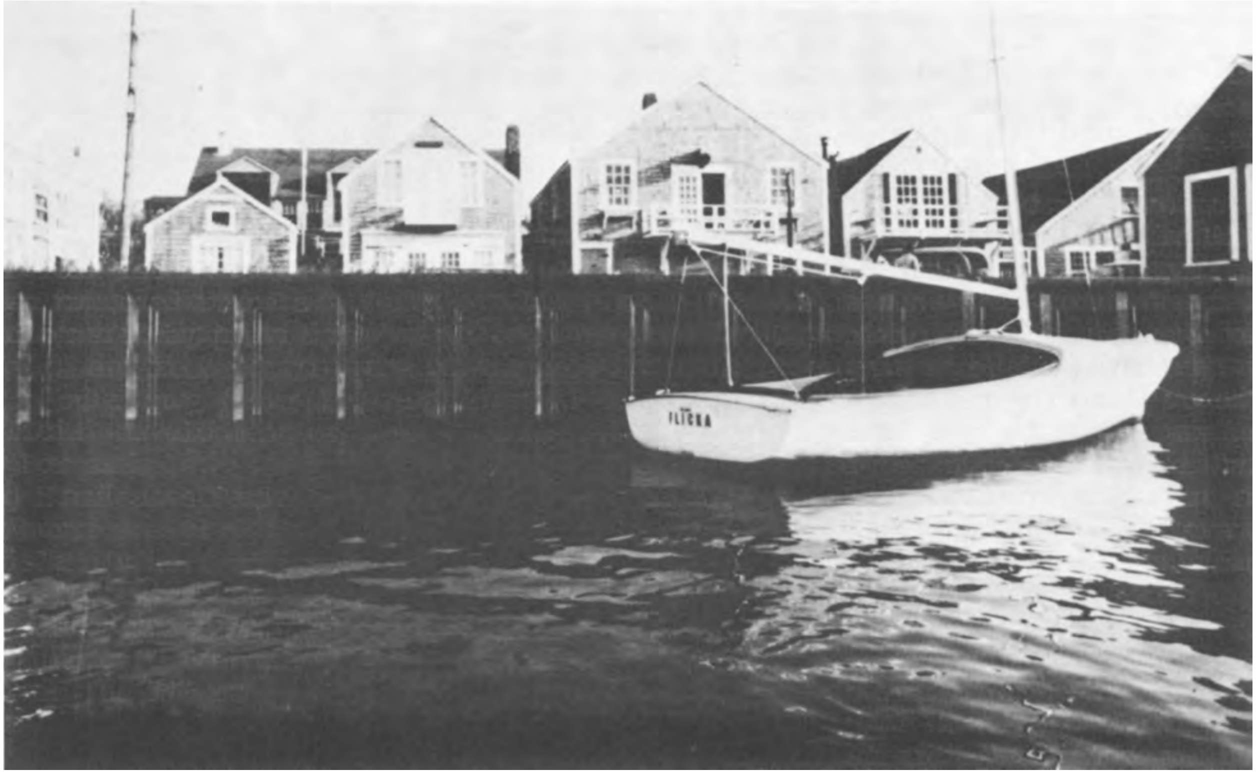
(2) Onshore structures, termed bulkheads, seawalls, and revetments, provide protection, based on their use and design, for the upper beach which fronts backshore development or erodible bluffs. Shorefront owners have resorted to shore armoring by wave-resistant walls of various types when justified by the economic or aesthetic value of the property to be protected.

b. Role in Shore Protection.

(1) Onshore structures are intended to protect the shore by reducing the rate of change in the shoreline. They slow the rate of change by protecting the shore from wave impact or by preventing overwash.

(2) Bulkheads and seawalls are similar in design with slightly differing purposes. Bulkheads are primarily soil-retaining structures which are designed to also resist wave attack (Figure 5-1). Conversely, seawalls are principally structures designed to resist wave attack, but also may retain some soil to assist in resisting wave forces. The land behind seawalls is usually a recent fill area. Bulkheads and seawalls may be built of many materials including steel, timber or concrete piling, gabions, or rubble-mound structures.

(3) For ocean-exposed locations vertical bulkheads alone do not provide a long-term solution because of foreshore erosion, toe scour, and flanking. Unless combined with other types of protection, the bulkhead must be enlarged into a massive seawall capable of withstanding the direct onslaught of the waves (Figure 5-2). Seawalls may have vertical, curved,



Nantucket Island, Massachusetts (1972)
(photo, courtesy of U.S. Steel)

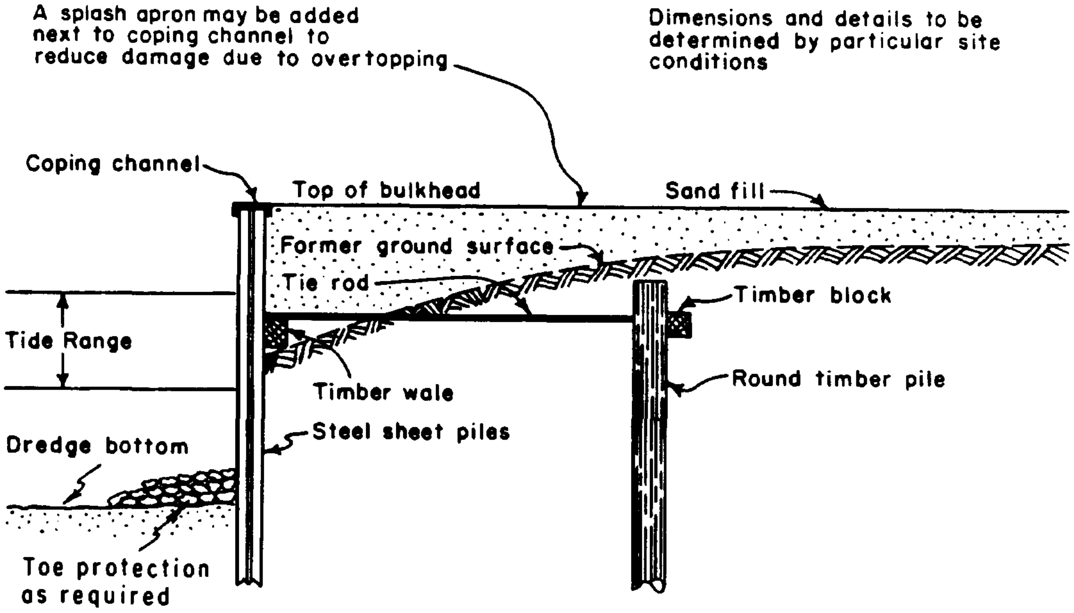


Figure 5—1. Steel sheet pile bulkhead

stepped, or sloping faces. Although seawalls protect the upland, they often create a local problem. Downward forces of water, produced by waves striking the wall, can rapidly remove sand from in front of the wall. A stone apron is often necessary to prevent excessive scouring and undermining.

(4) A revetment armors the existing slope face of a dune or embankment. It is usually composed of one or more layers of quarry stone or precast concrete armor units, with a filter layer overlaying a graded soil slope (Figure 5-3). Revetments are of little benefit if placed at the toe of a marginally stable slope since they are usually only a protective armor and not a retaining structure. Because the sloping face of the quarrystone revetment is a good energy dissipater, revetments have a less adverse effect on the beach in front of them than a smooth-faced vertical bulkhead.

c. Physical Considerations. The littoral system at the site of a structure is always moving toward a state of dynamic equilibrium where the ability of waves, currents, and winds to move sediment is matched by the available supply of littoral materials. When there is a deficiency of material moving within a system, the tendency will be for erosion at some location to supply the required material. Once a structure has been built along a shoreline, the land behind it will no longer be vulnerable to erosion (assuming proper design of the structure), and the contribution of littoral material to the system will be diminished along the affected shoreline. The contribution formerly made by the area must now be supplied by the adjoining areas. Therefore, though the structure provides a measure of stability to a portion of the shoreline, it may indirectly increase the rate of erosion along other reaches of the shoreline (Bellis et al 1975, Carstea et al. 197 5a-b, Georgia Department of Natural Resources 1975, Herbich and Schiller 1976, Pallet and Dobbie 1969, US Army Engineer District, Baltimore 1975, Mulvihill et al. 1980). In addition, some structures such as bulkheads may cause increased wave reflection and turbulence with a subsequent loss of fronting beach. Smooth, vertical structures will have the greatest impact on the beach and nearshore sediment loss.

d. Water Quality Considerations.

(1) The impacts of onshore structures on water quality result from increased suspended solids during construction and altered circulation patterns produced by the structure itself.

(2) Construction of onshore structures may require excavation, backfilling, pile driving, and material transport. These activities can result in increased suspended solid loads within the adjoining water body (Boberschmidt et al. 1976, Carstea et al. 197 5a-b and 1976, Environmental Quality Laboratory, Inc. 1977, US Army Engineer District, Baltimore 1975, Virginia Institute of Marine Science 1976, Mulvihill et al. 1980). The increased concentration of suspended solids is generally confined to the immediate vicinity of the construction activity and dissipated rapidly at the completion of the operation. Although these are generally short-term impacts, construction

Galveston, Texas (1971)

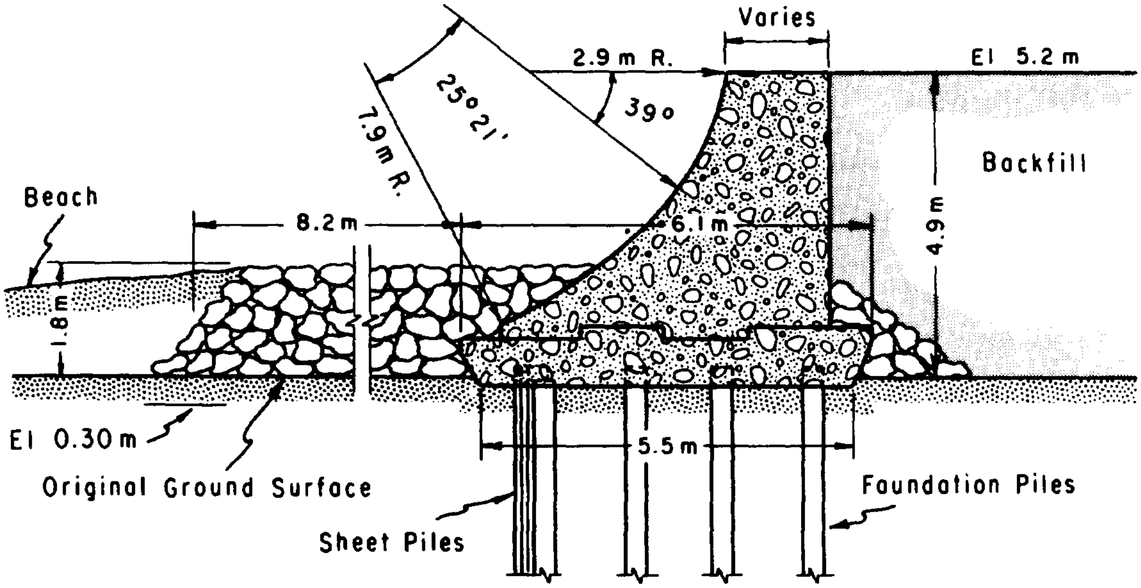


Figure 5-2. Concrete curved-face seawall

Chesapeake Bay, Maryland (1972)

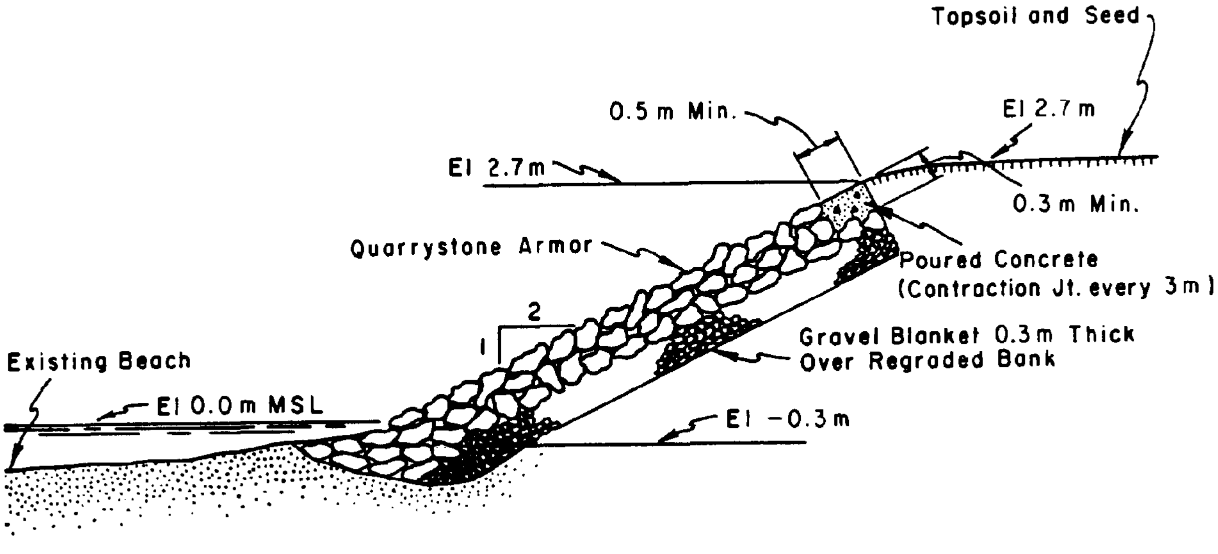


Figure 5-3. Quarrystone revetment

activities should be designed to minimize generation of suspended solids, for example, by the use of silt curtains in low-energy areas. See paragraph 4-11(1) (b) for a discussion of the limitation of silt curtains.

(3) Structures can influence water quality by altering circulation patterns. Modification in circulation can result in changes in the spatial distribution of water quality constituents, differences in the flushing rates of potential contaminants, and changes in the scour patterns and deposition of sediments (Bauer 1975, Carstea et al. 1975a-b, Georgia Department of Natural Resources 1975, Mulvihill et al. 1980). Environmental assessment of the effects on circulation should initially emphasize fundamental parameters such as salinity, temperature, and current velocity. If minimal changes occur in these parameters, then it can be assumed that the chemical characteristics of the system will not be significantly modified. Prediction of changes in circulation and its effect on the physical parameters can be achieved through comparison with existing projects, physical model studies, and numerical simulation (see Appendix B).

e. Biological Considerations. A wide variety of living resources is present in coastal shore protection project areas and includes species of commercial, recreational, and aesthetic importance. Because shore protection projects exist in arctic, temperate, and tropical climates, biological impacts will generally be highly site-specific and depend upon the nature and setting of the project.

(1) Short-term impacts. Short-term biological impacts are usually associated with the actual construction phase of the project. The actual time is typically short (measured in days and weeks) and therefore can be scheduled to minimize negative impacts. Transportation of material to the site, preparation and construction using heavy equipment, and backfilling and grading will cause temporary air and noise pollution close to the site. Nesting, resting, or feeding waterfowl, fish, and other wildlife may be disrupted. Projects should be timed, where possible, to avoid waterfowl and turtle nesting periods and fish spawning periods. Construction will also temporarily reduce water quality, generally by suspending sediments and generating turbidity. The environmental impacts on the benthic communities resulting from suspended solids in the water around shore protection construction are for the most part minor. Such impacts are particularly true in the surf zone on open coast beaches where rapid natural changes and disturbances are normal and where survival of the benthic community requires great adaptability. On rapidly eroding banks, construction impacts on suspended solids may be minimal when compared to the natural condition. However, sites with a high percentage of fine material and in proximity to seagrass beds or coral reefs (habitats sensitive to turbidity and siltation) will require special consideration and usually precautions such as silt curtains, where feasible. Temporary turbidity will also interfere with respiration and feeding, particularly of nonmotile bottom dwellers. Most motile organisms will avoid or flee the disturbed area.

(2) Long-term impacts.

(a) Long-term effects vary considerably depending upon the location, design, and material used in the structures. Placement of coastal shore protection structures requires an initial disturbance of the benthic substrate, but it results in the formation of a new substrate composed of structural material. In many locations the placement of these structures provides new habitat not available otherwise. The biological productivity of the area to be displaced is also important. The impact of a vertical steel sheet bulkhead located at mean low water in a coastal marsh (highly productive habitat) will be considerably different from a rubble-reveted bank in an industrialized harbor.

(b) Vertical structures in particular may accelerate erosion of the foreshore and create unsuitable habitat for many bottom species in front of the structure as the result of increased turbulence and scour from reflected wave energy. Bulkheads and revetments can reduce the area of the intertidal zone and eliminate the important beach or marsh habitat between the aquatic and upland environment. The result can be a loss of spawning, nesting, breeding, feeding, and nursery habitat for some species. On the other hand, rubble toe protection or a riprap revetment extending down into the water at a sloping angle will help dissipate wave energy and will provide hard-bottom habitat for many desirable species.

f. Recreational Considerations. Bulkheads can severely limit recreational use of the shoreline (Brater 1954, Mulvihill et al. 1980). In particular, they restrict public access to the water (Coastal Plains Center for Marine Development Service 1973, Snow 1973, Mulvihill et al. 1980). Revetments also hamper public access to the water for water contact activities. Seawalls are frequently designed to permit public access and to enhance beach usage (Figure 5-4). However, where beach erosion persists in the vicinity of the above onshore structures, the usable portion of the recreational beach is usually diminished.

g. Aesthetic Considerations. The transition between land and water on a natural shoreline is either gradually sloping, consisting of a beach or marsh, or is sharply defined by a bank or scarp. Onshore structures are more similar to the latter in that they often represent an abrupt visual change. Bulkheads and revetments can sometimes be designed to blend in with the surrounding shoreline. For example, their natural appearance can be enhanced with the use of vegetation. The use of unusual construction materials such as junk cars, tires, or recycled construction debris would produce the greatest negative aesthetic impacts. Because seawalls are frequently large concrete structures and are usually located in densely populated areas, particular attention should be paid to their visual impact. The design of a structure should be visually attractive as well as functionally sound.

h. Cultural Resource Considerations. By reducing erosion rates, onshore structures will generally preserve onsite cultural resources. However, this local protection can potentially increase the rate of erosion on adjacent

San Francisco, California (June 1974)

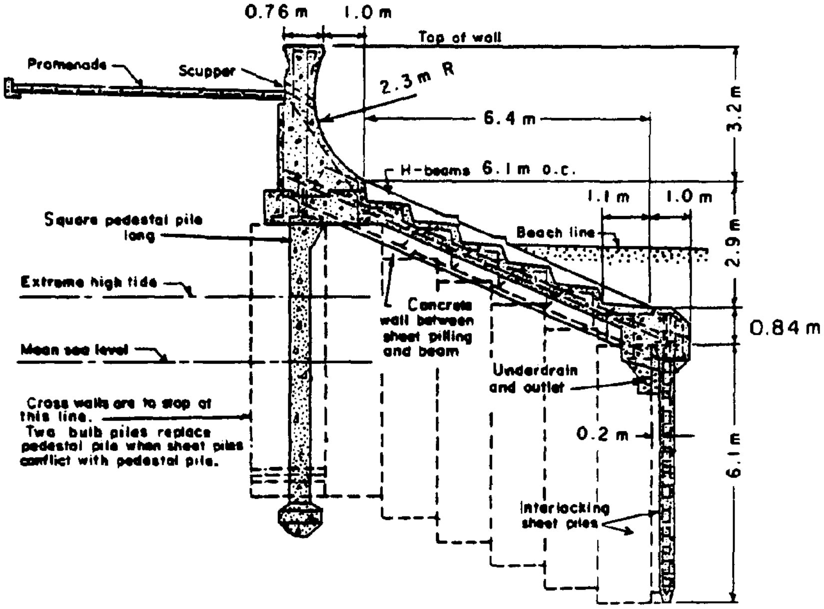


Figure 5-4. Concrete combination stepped- and curved-face seawall with public access points

shorelines. For this reason, cultural resources in the adjacent impact area must also be evaluated and projects designed so that erosion of adjacent areas is avoided.

i. Environmental Summary.

(1) Environmental design. Table 5-1 summarized potential design modifications that can be made to revetments, seawalls, and bulkhead projects in order to improve their environmental characteristics.

(2) Environmental assessment.

(a) Short-term impacts. Construction activities associated with onshore structures may include excavation, backfilling, and pile driving using both heavy equipment and hand labor. The impacts of this construction will be similar to the impacts associated with other land-based construction activities: vegetation damage, noise and air pollution, visual clutter, and other temporary impacts. Because this construction takes place on the shoreline, however, other impacts not usually associated with land-based construction activities are also possible. One of the short-term impacts of shoreline construction is the increased levels of suspended sediments in nearshore waters which accompany this disturbance. Suspended sediments and siltation can impact benthic communities and to a lesser extent life forms in the water column. Because of the local nature and short duration of this impact, it will be a primary consideration only in projects which are near sensitive habitats such as coral reefs and seagrass beds.

(b) Long-term impacts. The primary long-term impacts of onshore structures are associated with their effect on shore processes. Though these structures abate local erosion, they may indirectly accelerate erosion in adjacent shoreline areas. This accelerated erosion will be an important concern if potentially affected areas contain marsh vegetation, riparian vegetation, or other productive habitats. Wave reflection from exposed onshore structures may also produce deepening of the nearshore zone. Such losses may have recreational impacts and will alter biological habitats. Direct impacts of onshore structures include displacement of onsite habitats, modified public access, and aesthetic alterations.

5-2. Jetties and Breakwaters.

a. General.

(1) The distinction between jetties and breakwaters can be vague in that these structures are similar in many aspects of design and materials. They primarily differ with respect to function. Jetties are structures built at the mouths of rivers, estuaries, or coastal inlets to stabilize the position and prevent or reduce shoaling of entrance channels. A secondary function of a jetty is to protect an entrance channel from severe wave action or cross-currents, thereby improving navigational safety between harbors and deep water. Also, jetty construction can result in stabilization of the location

TABLE 5-1

Environmental Design Considerations for Revetments Seawalls, and Bulkheads

Factor	Design Consideration	Environmental Benefit
Location	Site structure above mean high water	Allows intertidal zone to remain
		Allows shoreline vegetation to remain
		Does not interfere with littoral drift
	Avoid wetland sites, spawning beds, shorebird and turtle nesting beaches, bird feeding and resting areas	
	Avoid nearby coral reefs and seagrass beds	Resource conservation
	Avoid archaeological sites	Preservation of historical information and features
Construction material	Rubble or riprap	Usually most desirable, natural, and durable
		Most reef-like surface area
	Treated wood and smooth concrete	Intermediate desirability and less surface area
	Steel sheet pile	Least desirable, least colonizable surface
	Armor stone, largest cost-effective	More stabile physical habitat
		More size diversity of openings

(Continued)

TABLE 5-1 (Concluded)

Factor	Design Consideration	Environmental Benefit
Design	Riprap or stair-step revetments on a slope of 45 degrees or less when structure is partially submerged	Dissipates wave energy, more habitat for fish and reef fish
	Toe protection on structures below mean low water	More diverse habitat, reef-like properties, dissipates wave energy on bottom
	Sloping structures that are partially submerged	Reduce wave reflection Less disturbance of intertidal habitat due to scour Less disturbance of fish nursery habitat
	Natural contours and lack of sharp angles	Aesthetically pleasing Less debris capture Reduces chance for rip current formation

of an inlet on a barrier beach coastline. In contrast, the primary function of a breakwater is to protect a harbor, water basin, or shoreline from destructive wave forces. Thus, breakwaters provide calm waters for safe anchorages, moorings, access points, and a host of other water resource uses. Some breakwaters may also serve to create sediment traps in the nearshore zone.

(2) There are no truly "typical" designs for jetty or breakwater structures. The multiplicity of physical, logistical, and economic factors considered during the planning, design, and construction phases ensure that each project will be unique. For example, the linear dimensions of a jetty structure will vary greatly from project to project, because the seaward extent of a jetty is determined largely by the distance offshore required to reach the design depth of the adjacent channel entrance. Physical factors, important from an environmental standpoint, include geomorphology of the project site, bottom topography, wave climate, sediment transport rates, and tide and current regimes, among others.

(3) Selection of construction materials has numerous alternatives, although jetties and breakwaters on open coastlines are predominantly rubble-mound structures. Other types of materials include vertical wood pile, steel sheet pile, caissons, sandbags, and, particularly in the Great Lakes, timber, steel, or concrete cribs. Rubble-mound structures consist of underlying layers of randomly shaped and placed stones that are overlaid by an armor (cover) layer of selectively sized stones or prefabricated concrete forms (Figure 5-5). Lateral toe-to-toe dimensions of rubble-mound structures, as well as the slope angles of their lateral faces, vary among projects based on design criteria for site-specific wave climates.

(4) Jetty or breakwater configurations follow basic patterns, but also demonstrate considerable variation to adapt to individual project conditions. Jetties generally extend seaward from the shore in a perpendicular fashion, but the actual angles vary from project to project. Updrift jetties may incorporate a weir section (submerged during some portion of the local tidal cycle) to allow littoral sand movement across the jetty and into a deposition basin (Figure 5-6). Sand bypassing can then be accomplished by periodic dredging of the basin. Breakwater configurations are somewhat more diverse than those for jetties, reflecting wider functional uses. Breakwaters can be categorized as either shore-connected or offshore (detached), and as either fixed or floating. Commonly the landward portion of a shore-connected breakwater lies perpendicular to the shoreline, and the seaward extension lies more or less parallel to the shore. Fixed breakwaters are constructed of materials placed on the bottom substrate, whereas floating breakwaters are buoyant structures held in position by anchors and tethers. Fixed breakwaters may be emergent or partially or totally submerged especially in the case of offshore designs.

b. Role in Shore Protection. Jetties and breakwaters are built to serve "stabilization" and "protection" functions. This fact infers that the

Santa Cruz, California (Mar. 1967)

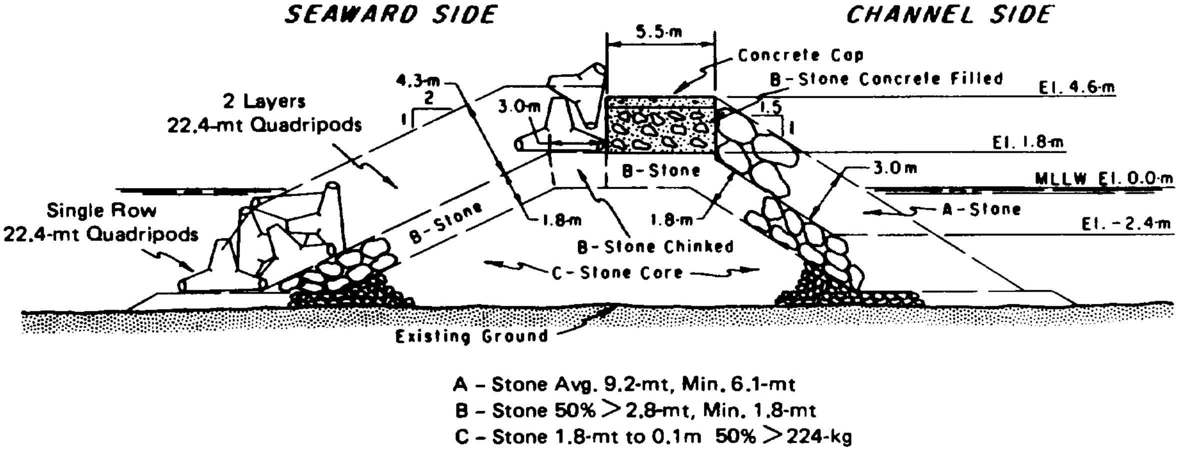


Figure 5-5. Quadripod and rubble-mound breakwater

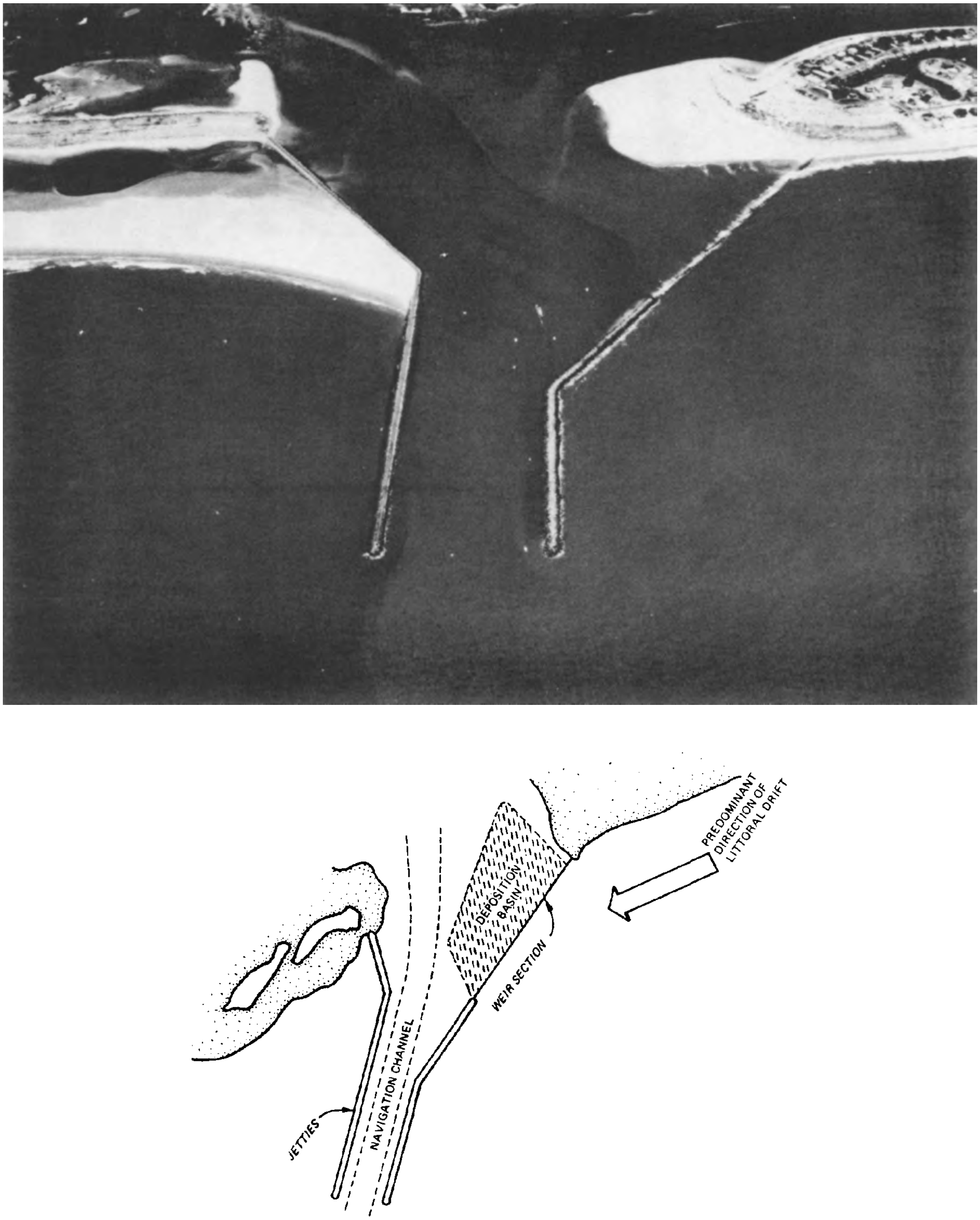


Figure 5-6. Sand bypassing, Murrells Inlet, South Carolina

environments in which they are built are characteristically dynamic and moderately to highly energetic.

(1) Jetties.

(a) Jetties are structures used at inlets to stabilize the position of the navigation channel, to shield vessels from wave forces, and to control the movement of sand along the adjacent beaches so as to minimize the movement of sand into the channel. The sand transported into an inlet will interfere with navigation depth. Because of the longshore transport reversals common at many sites, jetties are often required on both sides of the inlet to achieve complete channel protection. Jetties are built from a variety of materials, e.g., timber, steel, concrete, and quarrystone. Most of the larger structures are of rubble-mound construction with quarrystone armor and a core of less permeable material to prevent sand passing through. It is the impoundment of sand at the updrift jetty which creates the major physical impact. When fully developed, the impounded sand extends well updrift on the beach and outward toward the tip of the jetty.

(b) The jetty's major physical impact is the erosion of the downdrift beach. Before the installation of a jetty, nature supplies sand by intermittently transporting it across the inlet along the outer bar. The reduction or cessation of this sand transport due to the presence of a jetty leaves the downdrift beach with an inadequate natural supply of sand to replace that carried away by littoral currents.

(c) To minimize the downdrift erosion, some projects provide for periodically dredging the sand impounded by the updrift jetty and pumping it through a pipeline (bypassing the inlet) to the downdrift eroding beach. This pumping provides for nourishment of the downdrift beach and also reduces shoaling of the entrance channel. If the sand impounded at the updrift jetty extends to the head or seaward end of the jetty, sand will move around the jetty and into the channel causing a navigation hazard. Therefore, the purpose of sand bypassing is not only to reduce downdrift erosion, but also to help maintain a safe navigation channel.

(d) One design alternative for sand bypassing involves a low section or weir in the updrift jetty over which sand moves into a sheltered predredged, deposition basin. By dredging the basin periodically, channel shoaling is reduced or eliminated. The dredged material is periodically pumped across the navigation channel (inlet) to provide nourishment for the downdrift shore. A weir jetty of this type is shown in Figure 5-6. Environmental considerations of beach nourishment have been discussed in Chapter 4.

(2) Breakwaters.

(a) Breakwaters are wave energy barriers designed to protect any landform or water area behind them from the direct assault of waves. However, because of the higher cost of these offshore structures as compared to onshore structures (e.g. seawalls), breakwaters have been mainly used for harbor protection and navigational purposes. In recent years, shore-parallel, detached, segmented breakwaters have been used for shore protection structures.

(b) Breakwaters have both beneficial and detrimental effects on the shore. All breakwaters reduce or eliminate wave action in the lee (shadow). However, whether they are offshore, detached, or shore-connected structures, the reduction or elimination of wave action also reduces the longshore transport in the shadow. For offshore breakwaters, reducing the wave action leads to a sand accretion in the lee of the breakwater in the form of a cuspate sandbar (called a tombolo when a complete connection is made between the original beach and structure), which grows from the shore toward the structure.

(c) Shore-connected breakwaters provide protection to harbors from wave action and have the advantage of a shore arm to facilitate construction and maintenance of the structure.

(d) At a harbor breakwater, the longshore movement of sand generally can be restored by pumping sand from the side where sand accumulates through a pipeline to the eroded downdrift side.

(e) Offshore breakwaters have also been used in conjunction with navigation structures to control channel shoaling. If the offshore breakwater is placed immediately updrift from a navigation opening, the structure impounds sand in its lee, prevents it from entering the navigation channel, and affords shelter for a floating dredge plant to pump out the impounded material across the channel to the downdrift beach.

(f) While breakwaters have been built of everything from sunken ships to large fabric bags filled with concrete, the primary material in the United States is a rubble-mound section with armor stone encasing underlayers and core material. Some European and Japanese breakwaters use a submerged mound foundation in deeper water topped with concrete superstructure, thereby reducing the width and overall quantity of fill material necessary for harbor protection.

c. Physical Considerations.

(1) Jetty or breakwater construction is invariably accompanied by localized changes in the hydrodynamic regime, creating new hydraulic and wave energy conditions. The initial disruption of the established dynamic equilibrium will be followed by a trend toward a new set of equilibrium conditions. Rapid dynamic alterations in the physical environment may occur in the short-term time sale as the shore processes respond to the influence of the new structures. Slower, more gradual, and perhaps more subtle changes may occur over the long term.

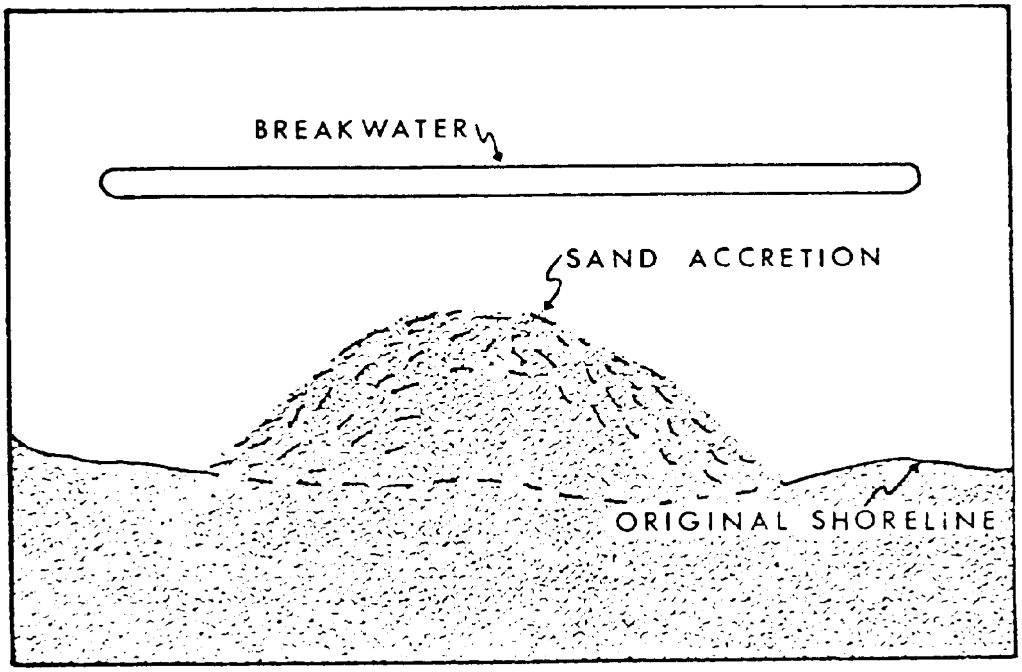
(2) In light of the dynamic character of shore processes, assessment of the effects of coastal engineering projects on shorelines is a difficult task.

Shoreline changes induced by the presence of a structure may be masked by wide annual or seasonal fluctuations in natural physical processes. Several events, however, can be predicted in response to jetty or breakwater construction with reasonable certainty. For example, by creating wave-sheltered areas, construction will result in changes in the erosional and depositional patterns along adjacent beaches, both inshore and offshore. A jetty or shore-connected breakwater will form a barrier to longshore transport if the structure extends seaward beyond the surf zone. In the particular case of a jettied inlet, sediment will tend to accrete on the seaward side (opposite the entrance channel) of the updrift jetty. Spatial extent of the ensuing shoreline alteration will depend on the structure’s effectiveness as a sediment trap, which is a function of its orientation to the inlet and to the prevailing wave climate. Updrift accretion of sediments will continue until the sink area is filled to capacity and the readjusted shoreline deflects longshore transport past the seaward terminus of the jetty. The volume of sediment trapped by the structure represents material removed from the natural sand bypassing process. Consequently, the downdrift shoreline will be deprived of this sediment and become subject to erosion. In circumstances where waves are refracted around the structures in a proper manner, accretion can occur along the seaward side of a downdrift jetty. Reflection of waves from a jetty may also cause erosion of adjacent shorelines. However, erosion further down the shoreline is not precluded. Planning for adequate sand bypassing is, in view of the above considerations, a critical requirement of coastal structure construction.

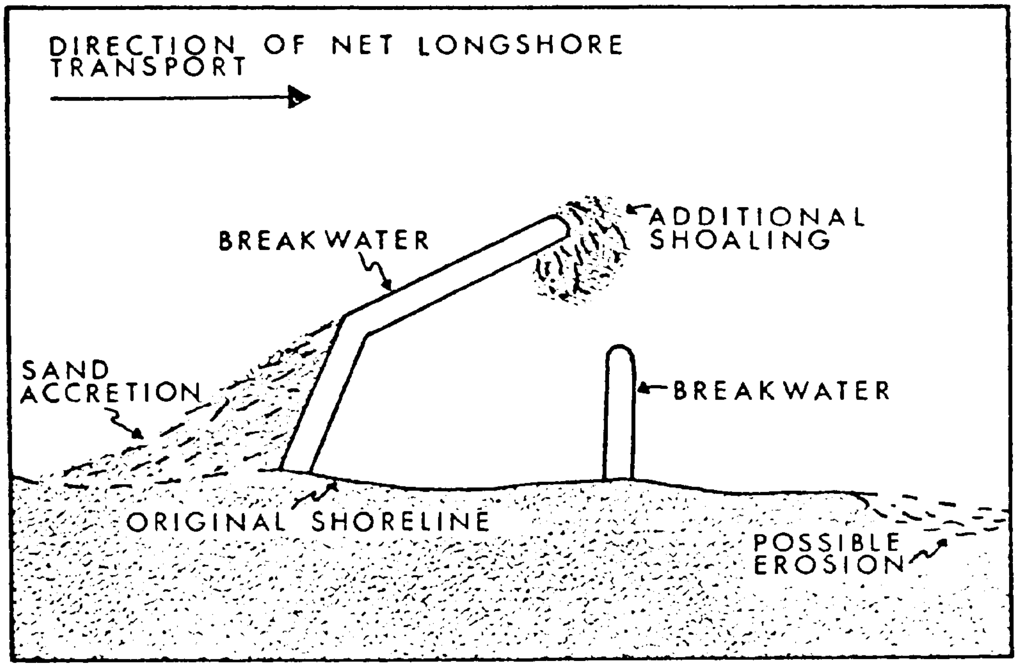
(3) Erosion at jetty project sites will not necessarily be limited to downdrift shorelines. Jetties redirect the course of the main ebb channel and confine ebb flows through an inlet such that current velocities are increased. An enhancement of ebb jet flows will result in displacement of sediments from between the jetties in a seaward direction to deeper waters. Also, sediments comprising the ebb-tidal delta will be shifted and redistributed, possibly leading to additional disruption of the natural sand bypassing process and exacerbation of downdrift erosion.

(4) Shore-connected breakwaters affect shorelines in much the same manner as jetties. Accretion occurs along the updrift junction of shore and structure and continues until longshore transport is deflected around the free end to the breakwater. Calm waters in the protected lee of the breakwater provide a depositional area which can rapidly shoal (Figure 5-7). Sediments trapped in the accretional area and terminal shoal are prevented from reaching downdrift beaches, and substantial erosion may result.

(5) Offshore breakwaters create depositional areas in their "shadows" by reflecting or dissipating wave energy. Reduction of wave energy impacting a shoreline in the lee of the structure retards the longshore transport of sediments out of the area and accretion ensues. The extent of accretion will depend on the existing balance of shore processes at a given project site. Generally, a cuspate spit will develop between the shoreline and the structure as the system approaches a new equilibrium (Figure 5-7). However, if the breakwater is situated in the littoral zone such that it forms a very



DETACHED EMERGENT BREAKWATER



ATTACHED BREAKWATER

Figure 5-7. Erosion and accretion patterns in association with detached and attached breakwaters effective sediment trap, a complete connection will eventually form, merging the shoreline with the structure. A tombolo associated with an offshore breakwater may present a severe obstruction to littoral transport and trap a significant volume of sediment. Extensive downdrift erosion may result.

(6) By modifying the cross-sectional area of an inlet, jetty construction potentially can alter the tidal prism, or volume of water entering or exiting through an inlet in one tidal cycle (usually excluding freshwater inflow). Enlarging an inlet can increase the tidal range within a harbor. In connection with channel deepening projects, seawater may intrude further into estuaries, embayments, or rivers than occurred under preproject conditions. Circulation patterns within a basin may be altered as a consequence of modified floodwater current conditions. Thus, the area physically affected by jetty construction might be extended appreciable distances from the actual project site. Conceivably, in systems with multiple connections to the sea, jetty construction at one inlet might elicit a response at a second inlet.

d. Water Quality Considerations.

(1) Suspended sediments. During the construction of a breakwater or jetty, suspended sediment concentration may be elevated in the water immediately adjacent to the operations. In many instances, however, construction will be occurring in naturally turbid estuarine or coastal waters. Plants and animals residing in these environments are generally adapted to, and are very tolerant of, high suspended sediment concentrations. The current state of knowledge concerning suspended sediment effects indicates that anticipated levels (generally less than 1,000 milligrams/l) generated by breakwater or jetty construction do not pose a significant risk to most biological resources. Limited spatial extent and temporal duration of turbidity fields associated with these construction activities reinforce this assessment. However, when construction is to occur in a clear water environment, such as in the vicinity of coral reefs or seagrass beds, precautions should be taken to minimize the amounts of resuspended sediments. Organisms in these environments are generally less tolerant to increased siltation rates, reduced levels of available light, and other effects of elevated suspended sediment concentrations. Potential negative impacts can be somewhat alleviated by erection of a floating silt curtain around the point of impact when current and wave conditions allow. However, the high-energy conditions usually associated with jetty and breakwater construction will generally preclude the use of silt curtains.

(2) Other water quality impacts. Indirect impacts on water quality may result from changes in the hydrodynamic regime. The most notable impact of this type is associated with breakwaters which form a semienclosed basin used for small boat harbors or marinas. If the flushing rate of the basin is too slow to provide adequate removal of the contaminants, toxic concentrations may result. Also, fluctuations in parameters such as salinity, temperature, dissolved oxygen, and dissolved organics may be induced by construction or due to altered circulation patterns. Anticipated changes in these parameters should

be evaluated with reference to the known ecological requirements of important biological resources in the project area.

e. Biological Considerations.

(1) Habitat losses. Measurable amounts of bottom habitat are physically eradicated in the path of fixed jetty or breakwater construction. If a rubble-mound structure with a toe-to-toe width of 50 meters (164 feet) is used as an example, one linear kilometer (0.6 mile) of structure removes approximately 5 hectares (12.5 acres) of preexisting bottom habitat. Once a structure is in place, water currents and turbulence along its base can produce a scouring action, which continually shifts the bed material. Scour holes may develop, particularly at the ends of structures. Scouring action may effectively prevent the colonization and utilization of that habitat area by sediment-dwelling organisms. Effects of scouring are largely confined to entrance channels and narrow strips of bottom habitat immediately adjacent to structures. Usually, only a portion of the perimeter of a structure will be subject to scouring, such as along the channel side of an inlet’s downdrift jetty. Generally, the amount of soft bottom habitat lost at a given project site will be insignificant in comparison with the total amount of that habitat available. Exceptions to this statement may exist, such as where breakwater construction and dredging of the total enclosed harbor area will displace large acreages of intertidal mudflats. Often such habitats serve critical functions as nursery areas for estuarine-dependent juvenile stages of fishes and shellfishes, and the availability of those habitats will be a determining factor in the population dynamics of these species. Additional habitat losses may occur when significant erosion of downdrift shorelines impact spawning or nesting habitats of fishes, shorebirds, or other organisms and when the tidal range of a harbor or bay is modified by entrance channel modification which in turn affects coastal habitat. Short-term impacts of this type may also occur during construction activities as heavy equipment gains access to the project site.

(2) Habitat gains.

(a) Losses of benthic (bottom) habitat and associated benthos (bottom-dwelling organisms) due to physical eradication or scouring will gradually be offset by the gain of new habitat represented by the structures themselves and the biological community, which becomes established thereon. The trade-off made in replacing "soft" (mud or sand) bottom habitat with "hard" (rock, at least in rubble-mound structures) bottom habitat has generally been viewed as a beneficial impact associated with jetty and breakwater projects. Submerged portions of jetties and breakwaters, including intertidal segments of coastal structures, function as artificial reef habitats and are rapidly colonized by opportunistic aquatic organisms. Over the course of time, structures in marine, estuarine, and most freshwater environments develop diverse, productive, reeflike communities. Detailed descriptions of the biota colonizing rubble-mound structures have been made for project sites on the Pacific (Johnson and De Wit 1978), Atlantic (Van Dolah et al. 1984), Gulf of Mexico (Hastings 1979, Whitten et al. 1950), and Great Lakes (Manny et al. 1985) coastlines.

In some geographical areas jetties and breakwaters provide the only nearshore source of hard-bottom habitat. Also, exposed portions of detached structures may be colonized by seabirds.

(b) The ultimate character of the biological community found on a jetty or breakwater will depend on the quality of habitat afforded by the construction materials used. Physical complexity (i.e., rough surfaces with many interstitial spaces and a high surface area to volume ratio) is a desirable feature of rubble-mound structures in comparison with the relatively smooth, flat surface of steel sheet pile or caisson structures. The sloping sides of rubble-mound structures also maximize the surface area of habitat created. Structures with sloping sides also provide more habitat within a given depth interval than structures with vertical elements. Where depths are sufficient, the biota on jetties and breakwaters exhibit vertical zonation, with different assemblages of organisms having discrete depth distributions. In general then, structures built in deep waters will support a more diverse flora and fauna than those in shallow waters. This pattern will be influenced by such factors as latitude and tidal range.

(c) Just as changes in shoreline configuration and beach profile can entail habitat loss, so can they represent habitat gain. Accretional areas, such as cuspate spits, tombolos, and exposed bars, and the above water portion of structures may be used, for example, by wading and shorebirds for nesting, feeding, and resting sites.

(3) Migration of fishes and shellfishes.

(a) Eggs and larvae. Early life history stages, namely eggs and larvae, of many important commercial and sport fishes and shellfishes are almost entirely dependent on water currents for transportation between offshore spawning grounds and estuarine nursery areas, A concern which has sometimes been voiced by resource agencies in relation to jetty projects is that altered patterns of water flow through coastal inlets may adversely affect the transport of eggs and larvae. Jetties displace the entrance to an inlet to deeper waters, perhaps forming a barrier to successful entry by eggs and larvae. Those eggs and larvae carried by longshore currents might be especially susceptible to entrapment or delay in eddies and slack areas formed adjacent to updrift jetties at various times in the tidal cycle. Even short delays in the passage of eggs and larvae to estuaries may be significant because of critical relationships between the developmental stage when feeding begins and the availability of their food items. All aspects of this potential impact remain hypothetical. Mechanisms of egg and larval transport across shelf waters and through inlets, as well as their retention within estuaries, have not been explained to date. No conclusive evidence exists to support either the presence or absence of impacts on egg and larval transport. This fact is true even where jettied inlets have been present for relatively long spans of time, such as along the Texas coast. The complexity of the physical and biological processes involved would render field assessments of this impact a long-term and expensive undertaking. Even if some degree of impacts in terms of numbers of eggs and larvae successfully transiting an inlet could be demonstrated to occur, the relative significance of the impact would be difficult to estimate. The results of hydraulic modeling studies related to this question have been inconclusive (US Army Corps of Engineers 1980). Future modeling studies combined with field verification studies may provide insight into resolving the validity of this concern.

(b) Juveniles and adults. Similar concern has been voiced regarding potential impacts of jetties and breakwaters on migrations of juvenile and adult fishes and shellfishes. These stages generally have well-developed swimming capabilities, such that physical barriers imposed by these structures are less of a concern than are behavioral barriers. This issue has been raised primarily in association with projects in the Pacific Northwest, and with anadromous fishes in particular. Anadromous fishes, including many salmonids, spend much of their adult life in the ocean, then return to fresh water to spawn. Early life history stages spend various lengths of time in fresh water before moving downstream to estuaries where the transition to the juvenile stage is completed. Specific concerns are that juveniles or adults will not circumvent structures that extend for considerable distances offshore. Juveniles in particular are known to migrate in narrow corridors of shallow water along coastlines and may be reluctant, due to depth preferences, to move into deeper waters. The State of Washington has developed criteria, whereby continuous structures that extend beyond mean low water (MLW) are prohibited. Designs of coastal structures there are required to incorporate breaches or gaps to accommodate fish passage.

(4) Increase predation pressure. Coastal rubble-mound structures provide substrate for the establishment of artificial reef communities. As such, jetties and breakwaters serve as a focal point for congregations of fishes and shellfishes which feed on sources of food or find shelter there. Many large predator species are among those attracted to the structures in numbers, as evidenced by the popularity of jetties and breakwaters as sites of intense sport fishing. Thus, there is concern, again largely associated with projects in the Pacific Northwest, that high densities of predators in the vicinity of jetties and breakwaters pose a threat to egg, larval, and juvenile stages of important species. For example, fry and smolt stages of several species of salmon are known to congregate in small boat harbors prior to moving to the sea. The concern raised is that these young fishes are exposed to numerous predators during their residence near the structures. As is the case with the concern for impacts on migration patterns, this concern remains a hypothetical one. Conclusive evidence demonstrating the presence or absence of a significant impact is unavailable and will be exceedingly difficult to obtain.

f. Recreational Considerations. The primary impact of breakwaters on recreational use of the beach depends largely upon the type of use the beach receives. Breakwaters reduce nearshore wave climate, which is generally beneficial to swimming, scuba diving, and wading activities. They may also cause a widening of the beach, which can result in increased recreational area. Figure 5-8 illustrates a wide beach accreted adjacent to a breakwater. Ownership of accreted beaches is determined by state law unless agreements are otherwise entered into prior to construction of the project. Diminished waves

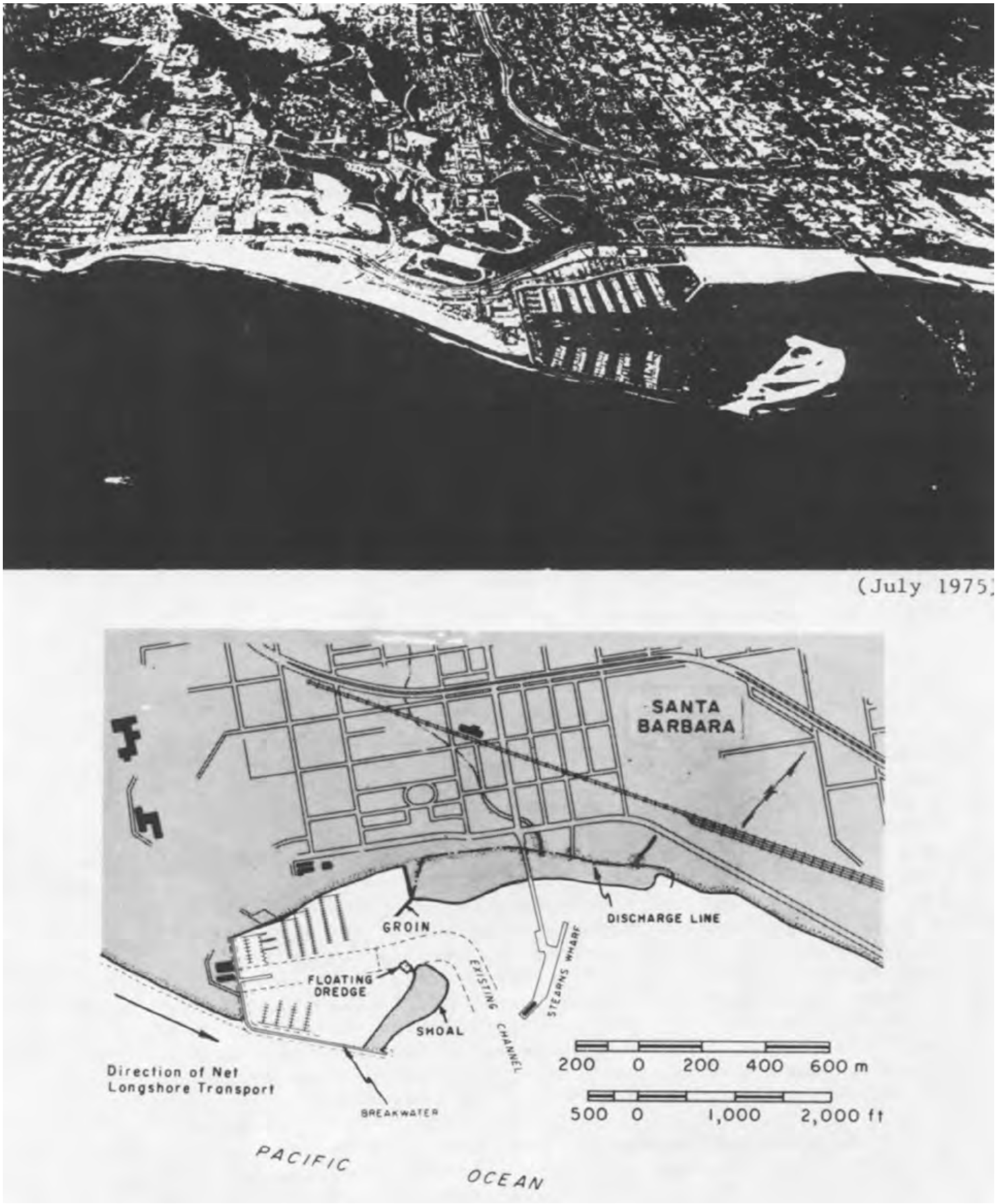

(July 1975)

Figure 5-8. Breakwater protecting recreational harbor, Santa Barbara, California will, however, reduce opportunities for body or board surfing activities. Special interest groups such as surfers may therefore vocally oppose detached breakwater projects. When breakwaters are used to shelter harbors or jetties are used to stabilize inlets, they benefit recreational boating (Figure 5-8). They may also act as fish attractors and may be used as fishing platforms. However, for safety reasons access to jetties for fishing is often prohibited. In other projects, walkways and handrails are provided to enhance fishing opportunities on these structures.

g. Aesthetic Considerations. Detached breakwaters are usually far enough from the beach that they do not produce visual impacts (Cole 1974). Jetties will visually alter shore views. The texture and shape of the jetty in relation to the overall shoreline scene should be considered in jetty design (Snow 1973).

h. Cultural Considerations. By reducing shore erosion or stabilizing inlet location, breakwaters and jetties will, generally, preserve onsite cultural resources. However, this local protection can potentially increase the rate of erosion on adjacent shorelines. For this reason, cultural resources in the adjacent impact area must also be evaluated. Lighthouses and other historically important structures are often found in close proximity to inlets.

i. Environmental Summary.

(1) Environmental design.

(a) Every jetty or breakwater project scenario should incorporate engineering design, economic cost-benefit, and environmental impact evaluations from the inception of planning stages. All three elements are interrelated to such a degree that efficient project planning demands their integration. Environmental considerations should not be an after thought. Structure design criteria should seek to minimize negative environmental impacts and optimize yield of suitable habitat for biological resources. Minimizing impacts can best be achieved by critical comparisons of a range of project alternatives, including the alternative of no construction. From an environmental perspective, site selection is perhaps the single most important decision in the planning process. However, various engineering design features can be incorporated to optimize an alternative from an ecological viewpoint. For example, opting for a floating rather than fixed breakwater design might alleviate most concerns related to impacts on circulation, littoral transport, and the migration of fishes, because passage is allowed beneath the structure. Floating breakwaters are also excellent fish attractors and still provide substrate for attachment and shelter for many other organisms.

(b) In planning breakwaters for small boat harbors, configurations which minimize flushing problems should be examined. Rectangular basins which maximize the area available for docks and piers characteristically have poor water circulation, particularly in the angular corner areas. Designs with rounded corners and entrance channels located so that flood tidal jets provide adequate mixing throughout the basin are desirable. Selection of a less steep rubble-mound sideslope angle will maximize the availability of intertidal and subtidal habitat surface areas. The size class of stone used in armor layers of rubble-mound structures is another engineering design feature that has habitat value consequences. Selection of large-size material results in a heterogeneous array of interstitial spaces on the finished structure. Heterogeneity rather than uniformity enhances the quality of the structure in terms of refuge and shelter sites for diverse assemblages of fishes and shellfishes.

(2) Environmental assessment.

(a) Short-term impacts. Actual construction activities for jetties and breakwaters entail a number of potential impacts of durations generally less than several days or weeks. These impacts will vary in type and frequency from project to project. For example, temporary or permanent access roads may have to be built to allow transportation of heavy equipment and construction materials to the site. Grading, excavating, backfilling, and dredging operations will generate short-term episodes of noise and air pollution and may locally disturb wildlife such as nesting or feeding shorebirds. Project activities should be scheduled to minimize disturbances to waterfowl, spawning fishes and shellfishes, nesting sea turtles, and other biological resources at the project site. Precautions should also be taken to reduce the possibility of accidental spills or leakages of chemicals, fuels, or toxic substances during construction activities. Effort should be expended to minimize the production and release of high concentrations of suspended sediments, especially where and when sensitive biological resources such as corals or seagrasses could be exposed to turbidity plumes and increased siltation rates. Dredging of channels in conjunction with jetty or breakwater projects presents a need for additional consideration of short-term impacts in relation to suspended sediments.

(b) Long-term impacts. Long-term impacts of jetty or breakwater construction are less definitive or predictable. Ultimate nearfield effects on littoral sediment transport can be expected to become evident within several seasonal cycles. These effects will vary according to a given project’s environmental setting and specific engineering design. For example, periodic maintenance dredging will be required for catch basins adjacent to weir jetties. Consequences of constructing coastal structures on farfield shore processes are presently understood only qualitatively.

5-3. Groins.

a. General.

(1) Groins are barrier-type structures that extend from the backshore into the littoral zone. Although single groins are constructed on occasion, groins are generally constructed in series, referred to as a groin field or system, along the entire length of beach to be protected.

(2) Groins have been constructed in various configurations which are classified as high or low, long or short, permeable or impermeable, and fixed or adjustable. A high groin, extending through the surf zone for ordinary or moderate storm waves, initially entraps nearly all of the longshore moving sand within that intercepted area, until the accumulated sand fills the entrapment area and the sand passes around the seaward end of the groin to the downdrift beach. Low groins (top profile no higher than that of desired beach dimensions or natural beach elevation) trap sand like high groins. However, some of the sand also passes over the top of the structures. Permeable groins permit some of the wave energy and movement of sand through the structure.

(3) A number of factors are taken into consideration in the design of groins. As with other coastal structures, the prevailing wave climate at a project site is of paramount importance. Wave energies and the angle of wave approach onto a beach are critical factors in predicting the response of a shoreline to groin construction. The direction and rate of littoral drift will also determine design specifications. Additional factors include the existing pattern of water currents and the spatial distribution of accretional and depositional areas. These factors are essentially identical to those considered in the previous section on jetties and breakwaters. Indeed, the major differences between groins and these structures are in terms of function rather than form. In general, groins are smaller, less massive structures than jetties or breakwaters. An example of rubble-mound groin design is depicted in Figure 5-9. The length or seaward extent of a groin will largely determine the initial effectiveness of the structure as a barrier to littoral transport, so that the design length will vary from project to project. In most cases, a groin will be built out to the distance at which incoming waves exert their maximum force on bottom sediments. The length of a groin will determine the ultimate rate of sediment passage around the end of the structures (end passing), whereas the design height of the groin will largely determine the rate of sediment movement over the structure (overpassing). Overpassing can be augmented by incorporation of one or more weir sections into the groin or groin field design. The shoreward terminus of a groin is generally set sufficiently far inshore that abnormally high tides will not flank the structure, thereby preventing possible scouring, undercutting, and failure.

(4) As in the case of jetties and breakwaters, a wide variety of materials are used in the construction of groins. Impermeable groins can be constructed of stone (rubble-mound), sheet piles (concrete, timber, or steel), or asphalt. Often these materials are used in combination; for example, concrete may be set as a grout or cap in rubble-mound groins. In addition to the above materials, permeable groins can be made of sand bags, large stones, and earth, or by slots created in sheet-pile structures, although these are not commonly employed. Selection of construction materials depends on foundation characteristics of the seabed as well as cost and availability factors.

b. Role in Shore Protection. The basic purpose of groins is to modify the longshore movement of sand and to either accumulate sand on the shore or retard sand losses. Trapping of sand by a groin is done at the expense of the adjacent downdrift shore unless the groin or groin system is artificially

Westhampton Beach, New York (1972)

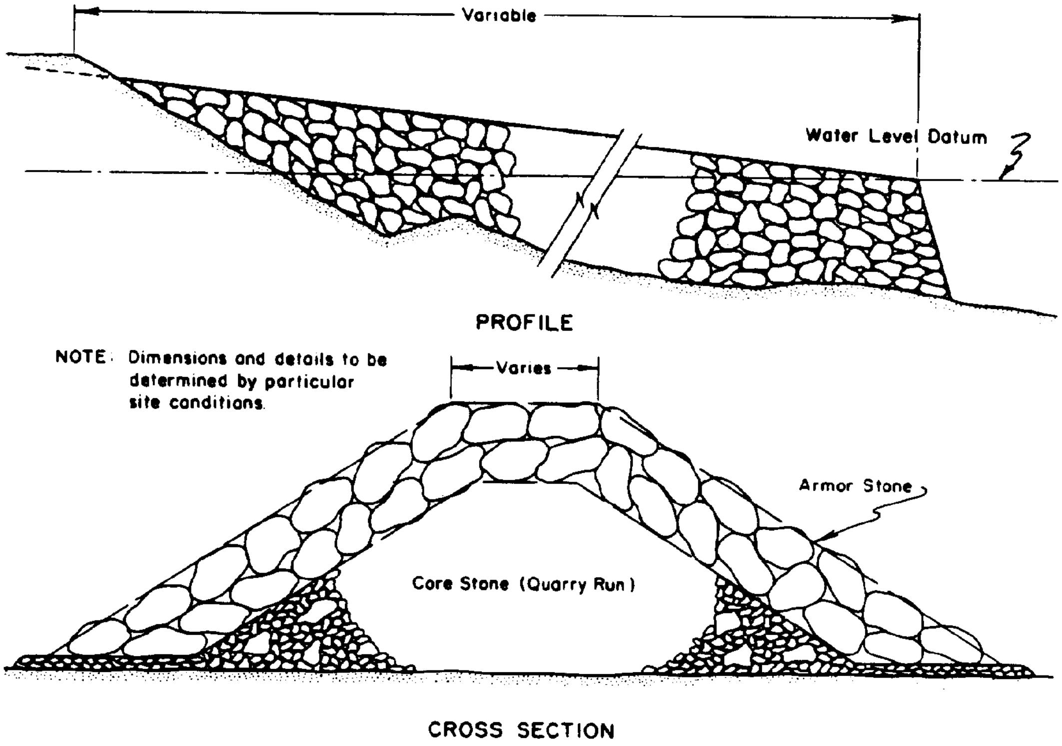


Figure 5-9. Rubble-mound groin

filled with sand to its entrapment capacity from other sources. To reduce the potential for damage to property downdrift of a groin, some limitation must be imposed on the amount of sand permitted to be impounded on the updrift side. It is desirable, and frequently necessary, to place sand artificially to fill the area between the groins, thereby ensuring an uninterrupted passage of the sand to the downdrift beaches. When fill is used, the groin functions to anchor the fill material. In either instance, groins provide shore protection by modifying longshore sand transport.

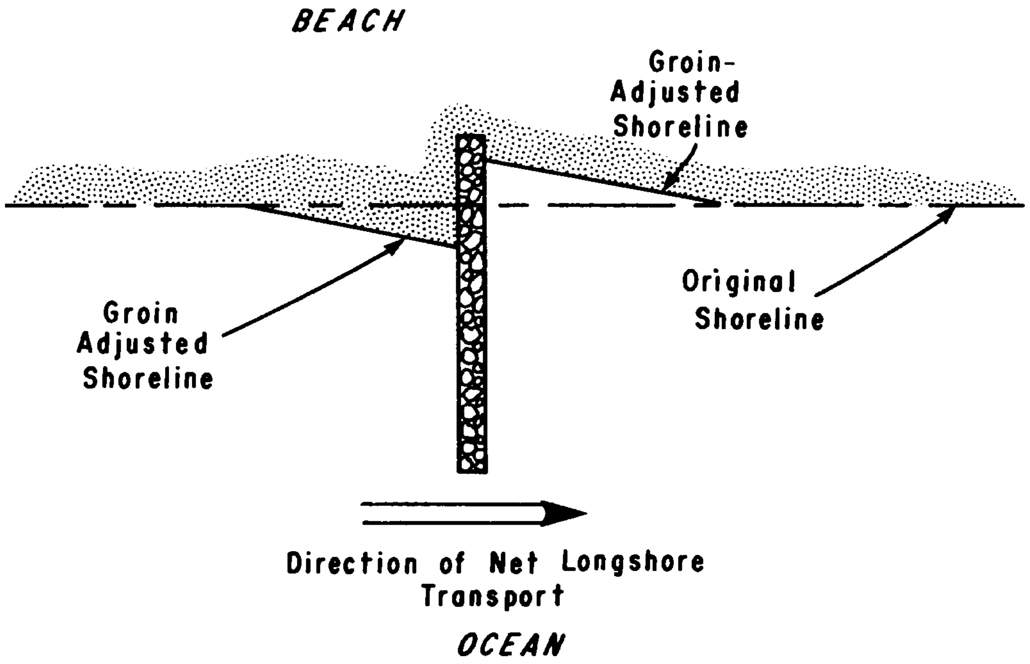
c. Physical Considerations.

(1) The effects of groins on shore processes are very similar to those discussed in reference to jetties and breakwaters. Groin construction will initially disturb the balance or equilibrium between physical processes at a given project site. With the passage of time, the system will tend to develop some new set of equilibrium conditions. The reader is referred to the discussion of physical impacts in the preceding section on jetties and breakwaters.

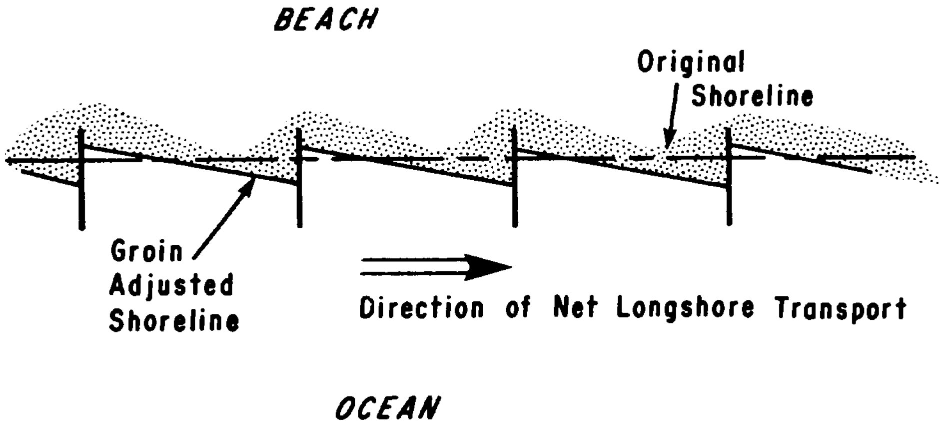
(2) By creating a barrier to littoral transport, groins cause changes in both shorelines and beach profiles. Entrapment of littoral drift results in the gradual buildup of a fillet on the updrift side of a groin. The fillet will grow until the volume of the available sediment sink reaches capacity and the rate of littoral drift is accommodated by endpassing or overpassing of the structure. Accretion of the updrift beach also shifts the location of the breaker zone offshore. Downdrift shorelines, however, will be deprived of that volume of sand accreted updrift of the groin and become susceptible to erosion. The overall displacement of both updrift and downdrift shorelines will reflect the groin’s relative effectiveness as an obstruction to littoral transport (Figure 5-10). In turn, effectiveness as a transport barrier will largely be determined by the orientation of the groin to the direction of approaching waves. Adjustment of the shorelines within the influence of a groin or groin field will tend toward achieving normality, i.e., shorelines perpendicular to the direction of wave approach. Net littoral longshore transport is reduced to zero when waves move onto shore in a normal or perpendicular manner, thus expending their energy equally in both lateral directions.

(3) Changes in beach profiles in response to groin construction can be substantial. Growth of the updrift fillet alters the locations and slopes of the foreshore and nearshore zones. The alteration may also cause selective settlement of sediments of different size categories along the beach profile and result in graded rather than uniform substrate conditions.

(4) Groins may interfere with the onshore-offshore transport process by displacing the position of longshore currents and rip currents. Rip currents within groin compartments (the area between two consecutive groins in a groin field) may displace sediments from the shallow beach areas, carry them by jetting action, and deposit them in deeper offshore areas, thus preventing them from being carried to downdrift sections of the beach. Rip currents can be generated as the longshore movement



a. Single groin



b. Multiple groins

Figure 5-10. General shoreline changes associated with single or multiple groins of water is deflected seaward by the presence of a groin.

d. Water Quality Considerations.

(1) Groin construction operations may induce short-term episodes of elevated suspended sediment concentrations in the water column. This impact will usually be limited to the water immediately adjacent to the structure. Historically, concerns have been raised in connection with potential detrimental impacts of high suspended sediment loads on biological resources. However, the present state of knowledge on this topic allows an assessment that concentrations of suspended sediments found at groin construction projects pose minimal risk to lost flora and fauna likely to occur at these sites. Most estuarine and coastal marine organisms are highly tolerant to elevated suspended sediment concentrations for moderate to extended periods of time. As was stated in the discussion relevant to jetties and breakwaters, however, precautions such as the installation of silt curtains should be considered when feasible, where sensitive resources such as coral reefs and seagrass beds are located in the vicinity of a project.

(2) Because groins change local patterns of water circulation, sane changes in water quality parameters may also be anticipated. Slight fluctuations in temperature, dissolved oxygen, and dissolved organics may occur in the sheltered waters in the lee of groins. These impacts should be insignificant for most groin project scenarios.

e. Biological Considerations.

(1) Habitat alterations, both losses and gains, associated with groin construction projects are analogous to those discussed for jetty and breakwater projects. Because groins are generally smaller structures by comparison, these habitat changes are usually on a smaller scale. Construction operations will physically displace existing bottom habitat covered by the placement of structural materials, particularly in the case of rubble-mound groins. This habitat loss will be supplemented by scouring effects of water movement along the base of the structures. The amounts of bottom habitat involved will be dependent upon the number, location, and size of groins in relation to the total available habitat. Exceptional cases, such as tidal flats, do exist and should be examined on a project by project basis. Initial bottom habitat losses are later offset at least in part by the habitat represented by the structures themselves. Often the local diversity of bottom habitats, including the presence of scour holes, will be enhanced by groin construction. Where scouring effects would represent unacceptable habitat loss, they can be minimized by proper design of the groin, for example, by inclusion of a weir section.

(2) Habitat gains are evidenced by the biota which becomes established upon groin structures, although due to the shallow nature of groins, these biological communities are somewhat less diverse than those on larger jetties and breakwaters built of similar materials. Nevertheless, groins provide

substrate which serves as artificial reef habitat in the nearshore zone. Rubble--mound groins especially afford a physically complex habitat in support of productive invertebrate and fish assemblages.

(3) Habitat losses and gains can also take place on shorelines influenced by groin structures. Where the shoreline response occurs along the periphery of a fringing marsh or other wetland, downdrift erosion or updrift accretion can result in significant adverse impacts. These impacts must be weighed against the eventual habitat losses incurred if stabilization by groins or other alternatives is not accomplished. Groin associated accretional areas may provide substrate for the establishment of beach vegetation. Shoreline responses to groins may also represent loss or gain of wildlife or fishery habitat in the form of nesting, spawning, nursery, resting, feeding, or shelter areas.

(4) Small groins have not been documented or implicated to have effects on the movements or migration patterns of fishes and shellfishes. Groins are very effective fish attractors and provide excellent sport fishing sites. Predation effects, as discussed under the biological impacts of jetties and breakwaters, have not been a significant topic of concern in relation to groin projects. These structures, particularly those of rubble-mound construction, may provide beneficial protective cover, as well as feeding and resting areas for both juvenile and adult fishes and shellfishes during coastal migrations.

f. Recreational Considerations. By increasing beach width, groins increase beach area available for use. However, they can be a safety hazard to nearshore recreation activities such as swimming, wind surfing, board surfing, and shallow-water diving. Potentially dangerous conditions can be created where the waves first encounter the structure or where rip currents are created between groins. Scour holes adjacent to groins also constitute safety hazards to nonswimmers. Also, some groin structures may impede lateral movement of beach users.

g. Aesthetic Considerations. One common feature of natural beaches is the presence of long, straight stretches of sand. Groin fields usually alter beach topography into a series of abrupt indentations (Figure 5-10). In addition, the materials used to construct groins and their linear configuration substantially alter the scenic character of the beach (Figure 5-11).

h. Cultural Considerations. Groins can protect onsite cultural resources by reducing shore erosion. However, the downdrift erosion usually associated with groins can potentially threaten cultural resources in adjacent areas. For this reason, cultural resource losses in the adjacent impact areas must also be considered. Cultural resource surveys should be conducted prior to construction. Placement of groins should accommodate cultural resource protection in so far as practical, while accomplishing the primary purpose of the project.

Presque Isle, Pennsylvania (Oct. 1965)

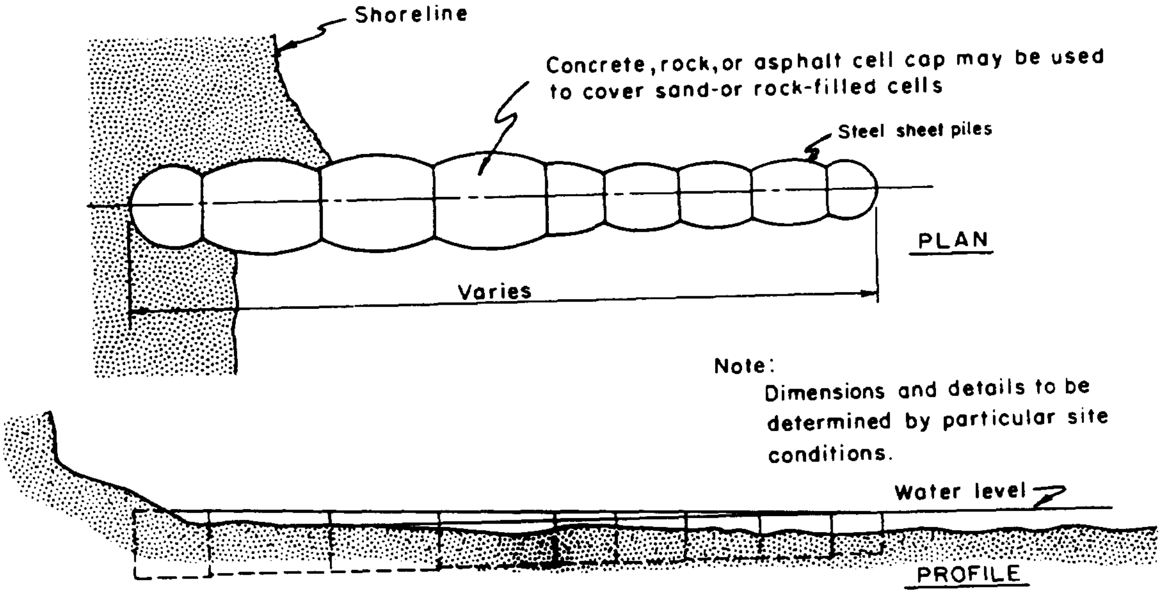


Figure 5-11. Irregular beach formed by cellular steel sheet-pile groin

i. Environmental Summary.

(1) Environmental design. Downdrift erosion will often be an important environmental consideration. Downdrift erosion can be ameliorated by providing beach fill, reducing groin height (overpassing) and length (endpassing), or incorporating permeability. The selection of construction materials can also be important to the overall impact of the project. Because rubble-mound structures provide a variety of living spaces and a firm surface for attachment, they are often considered beneficial habitats.

(2) Environment assessment.

(a) Short-term impacts. Construction operations are a source of several types of short-term impacts. Transportation of construction materials and operation of heavy equipment at the project site will generate localized incidences of air and noise pollution. Flexibility in the scheduling of these activities should be exercised to minimize disturbance of coastal biological resources, especially during critical spawning and nesting periods. Short-term events of elevated turbidity induced by groin construction or associated beach fill will occur. As discussed under water quality impacts, proper precautions should be taken to reduce suspended sediment effects if sensitive organisms or habitats are present.

(b) Long-term impacts. Long-term impacts of groin construction, as for jetty and breakwater construction, are difficult to assess. Downdrift erosional problems are by far the major topic of concern, and these will vary in magnitude among different projects. Deprivation of downdrift shorelines appears to be a cumulative impact in that large groin fields may take extended periods to attain their sediment entrapment capacities. Therefore, the downdrift erosional process, if not mitigated by nourishment or sand bypassing, could be both severe and prolonged. Such erosion may produce recreational impacts (loss of downdrift beach area), cultural resource impacts (erosion of cultural sites), and biological impacts (erosion of biologically productive habitats).

CHAPTER 6

NONSTRUCTURAL ALTERNATIVES

6-1. Salt Marshes.

a. General. Shore erosion is a common problem in the bays, sounds, and estuaries of the coastal United States. A wide variety of structures have been developed and used to control this erosion. However, due to environmental objections and economic limitations it is often impractical to use even the most innovative of these structures. This fact is particularly true for relatively low wave-energy areas where erosion may be costly but has not yet reached catastrophic proportions. Low-cost, nonstructural techniques are available for controlling erosion in salt and brackish water, low wave-energy areas of contiguous United States using native marsh plants. Vegetation, where feasible, is usually lower in cost than structures and may be more effective.

(1) Coastal marsh vegetation.

(a) A coastal marsh is an herbaceous (plants lacking woody stems) or grassy plant community found on the part of the shoreline which is periodically flooded by salt or brackish water. A number of species in the grass family (Poaceae), sedge family (Cyperacae), and rush family (Juncaceae) commonly form coastal marshes.

(b) Coastal marshes occur naturally in the intertidal zone of moderate- to low-energy shorelines along tidal rivers and in bays and estuaries. These marshes may be narrow fringes along steep shorelines but can extend over wide areas in shallow, gently sloping bays and estuaries. Historically, such lands were extensive and widely distributed along the Atlantic, Florida peninsula, Gulf, and Pacific coasts of the United States before development by man.

(c) There are two major groups of coastal salt marshes in the United States, based on physiographic differences--marshes of the Atlantic, Florida peninsula, and Gulf coasts (the eastern region) and those characteristic of the northern and southern Pacific coasts (the western region). The eastern marshes usually form on a gently sloping coast with a broad continental shelf, under conditions of a sea slowly rising relative to the land. Western marshes are mostly formed in relatively narrow river mouths which drain almost directly onto a steeply sloping continental shelf along a slowly emerging coastline (Cooper 1969). Consequently, the western estuaries and their marshes are more limited in development than those of the east and tend to mature more rapidly. There are two types of coastal salt marshes: the regularly flooded low marsh, which is considered to be the most valuable and usually the most essential to erosion control; and the irregularly flooded high marsh.

(2) Erosion control plantings.

(a) With the use of agricultural techniques, plants can often be established on shorelines where natural processes of invasion have failed to produce plant cover. Marshes established in this manner may greatly improve the shore's stability and resistance to erosion. This erosion control alternative has been used successfully for many years in the United States. For example, in the winter of 1928, a property owner on the eastern shore of Chesapeake Bay planted smooth cordgrass (*Spartina alterniflora*) along more than 1 kilometer (0.5 mile) of shoreline in an attempt to reduce erosion. This shoreline has remained stable for more than 50 years and is the oldest reported example of shore stabilization with salt marsh vegetation in the United States (Knutson et al. 1981) as shown in Figure 6-1. Similarly in 1946, a landowner on the Rappahannock River in Virginia graded an eroding shoreline and planted several varieties of salt-tolerant plants. This planting has prevented erosion for 40 years (Phillips and Eastman 1959, Sharp and Vaden 1970, Sharp et al. 1981).

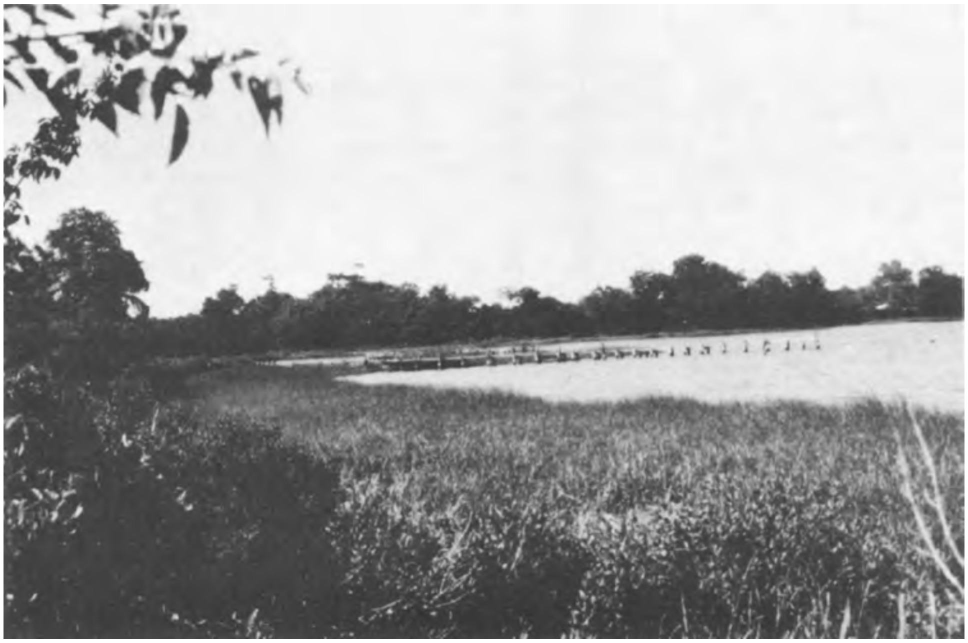


Figure 6-1. Oldest reported salt marsh planting in the United States

(b) Researchers in other coastal regions have found that shoreline stabilization with plants can be successful--Garbisch et al. (1975) in Chesapeake Bay; Webb and Dodd (1978) in Galveston Bay, Texas; Allen et al. (1986) in Mobile Bay, Alabama; Newcombe et al. (1979) in San Francisco Bay, California; and Newling and Landin (1985) at Corps sites in a number of coastal Districts. Based on these studies, design criteria for vegetation stabilization projects were developed (Knutson 1976 and 1977a-b, Knutson and Woodhouse 1983, Allen and Webb 1983, Allen et al. 1984, Webb et al. 1984). The US Army Engineer

Waterways Experiment Station (1978) conducted a nationwide study program on marsh establishment on dredged material in the mid-1970's as part of the Dredged Material Research Program, which resulted in design criteria for marsh development. This program has continued to the present under the Dredging Operations Technical Support Program to include all types of wetland development as well as erosion control in moderate wave energies using vegetation (Landin 1986).

(c) Hall and Ludwig (1975) evaluated the potential use of marsh plants for erosion control in the Great Lakes. They concluded that there were few natural areas suitable for this method of shore protection because there are few sheltered shorelines. Marsh plantings are also subject to winter icing conditions and fluctuating lake levels in this region. Marsh vegetation can be established behind protective structures in the Great Lakes (Landin 1982). However, vegetation can be used to stabilize upland areas (Hunt et al. 1978, Pennington 1986). The roots of terrestrial plants add stability to the soil, retard seepage, and reduce surface runoff (Great Lakes Basin Commission 1978, Gray 1974 and 1975, Dai et al. 1977). Information on surface erosion and various techniques for its control (dewatering, slope grading, and planting ground cover species) are available from EM 1110-2-5026, US Army Engineer Waterways Experiment Station (1986), the US Soil Conservation Service, or from county agriculture extension agents.

(d) In Alaska, a relatively short-growing season, broad tidal ranges, high-energy conditions, and icing prevent the use of salt marsh vegetation for erosion control, and only one site is known to exist. This alternative has not been used in the bays and estuaries of Hawaii.

(3) Planting guidelines.

(a) For erosion control projects, the intertidal zone is the most critical area to be planted and stabilized. If a healthy band of intertidal marsh can be established along a shore, revegetation of the slope behind it will occur through natural processes. Four species of pioneer plants have demonstrated potential in stabilizing the part of the intertidal zone which is in direct contact with waves: smooth cordgrass (Spartina alterniflora) along the Gulf and Atlantic coasts, Pacific cordgrass (Spartina foliosa) on the Pacific coast from Humboldt Bay south to Mexico, and Lyngbye’s sedge (Carex lyngbyei) and tufted hairgrass (Deschampsia caespitosa) in the Pacific Northwest (Smith 1978). A number of wetland plants colonize the freshwater/intertidal zone (Landin 1978, Lunz et al. 1978).

(b) The width of the substrate at an elevation suitable for plant establishment will determine in part the relative effectiveness of the erosion control planting. A practical minimum planting width for successful erosion control is 6 meters (20 feet) (Knutson et al. 1981). On the Atlantic and Gulf coasts, marsh plants will typically grow in the entire intertidal zone in microtidal areas and to mean tide where tidal ranges are broader. Marsh plants seldom extend below the elevation of mean tide on the southern Pacific coast or below lower high water in the Pacific Northwest. Because of these elevational constraints, the more gradual the shore slope, the broader the potential planting width. On steeply sloping shores, there may be little area suitable for planting. If the potential planting area is not 6 meters (about 20 feet) in width, the shore must be sloped or backfilled to extend it. Backfilling must be done enough in advance of planting to allow for settling and firming of the soil.

(c) Salt marsh plants rely heavily on exposure to direct sunlight and will not grow in shaded areas. Therefore, any overstory of woody vegetation present at a site should be cleared above the planting area and landward to a distance of 3 to 5 meters (10 to 15 feet). However, should the woody overstory be desirable wetland plants such as mangroves, they should not be cleared, but worked around to prevent their loss.

(d) Vegetative transplants are used for erosion control planting instead of seeding which is not likely to be effective on sites subject to erosion. Vegetative transplant types include: sprigs, stems with attached root material; pot-grown seedlings; or plugs, root-soil masses containing several intact plants dug from the wild. Sprigs are the least expensive to obtain and easiest to handle, transport, and plant. They may be obtained from field nurseries, planted at least a year in advance, or collected from young marshes or the edges of expanding established marshes. Pot-grown seedlings are expensive to grow and plant, more awkward to handle and transport, but relatively easy to produce and transplant. They are superior to sprigs for late season planting. Plugs are the most expensive to obtain, difficult to transport, and probably used only when no other sources are available. The Soil Conservation Service may be helpful in locating and obtaining plant materials. A conservationist for the State Soil Conservation Service is located in all the state capitals.

b. Role in Shore Protection.

(1) Marsh plants perform two functions in abating erosion. First, their aerial parts form a flexible mass which dissipates wave energy. As wave energy is diminished, both the offshore transport and the longshore transport of sediment are reduced. Dense stands of marsh vegetation may even create a depositional environment, causing accretion rather than erosion of the shoreface. Second, many marsh plants form dense root-rhizome mats which add stability to the shore sediment. This protective mat is of particular importance during severe winter storms when the aerial stems provide only limited resistance to the impact of waves.

(2) Wave attenuation in marshes has not been studied extensively. Wayne (1975) measured small waves passing through a smooth cordgrass marsh at Adams Beach, Florida, and Webb et al. (1984) measured wave attenuation in a human-made marsh in Mobile Bay, Alabama. Knutson et al. (1982) conducted a series of field experiments measuring wave attenuation in natural salt marshes. Knutson found that a 15-cm (0.5-foot) wave experienced a 72 percent energy loss while traversing 5 m (15 feet) of coastal marsh. As the wave energy impacting the shore is reduced, there is increased potential for sediment

deposition and decreased potential for erosion. Woodhouse et al. (1974) measured sediment deposition resulting from marsh plantings and reported the deposition at 15 to 30 cm (0.5 to 1 foot) of sediment along three planted profiles at Snow's Cut, North Carolina, during a 30-month period.

(3) Studies have shown that plant roots do significantly increase soil stability (Gray 1974), In these studies the shear strength of vegetated soils was as much as two and three times greater than unvegetated soils. In addition, the shear strength of soils was higher when the volume fraction or weight density of the root system was greater.

c. Physical Considerations. The planting of shore vegetation is accomplished with a minimum of equipment and physical disturbance. When erosion control plantings are successful, they create a region of sediment deposition along the shoreline and reduce erosion.

d. Water Quality Considerations.

(1) Salt marshes have substantial absorptive capacities for potential pollutants such as nitrogen, phosphorus, and heavy metals (Williams and Murdock 1969, Woodhouse et al. 1974). Increased growth of salt marsh species in response to nutrients has been noted at several locations. Apparent recovery of applied nitrogen may be as high as 40 to 60 percent in shoot growth alone (Woodhouse et al. 1974 and 1976), a value that compares favorably with upland field crops. The potential for substantial recycling of nutrients between salt marshes and estuaries exists. The absorption, conversion, and recycling capabilities of marsh plants offer potential opportunities for water purification (Woodhill 1977).

(2) There has been concern expressed that intertidal marshes planted on polluted sediments may be a source for release of potentially toxic heavy metals to estuarine systems and the ocean. This matter is a subject of extreme complexity. In general, the release of heavy metals is not a major concern for shore stabilization projects unless sediments with high levels of heavy metals are used to grade the site prior to planting (Gunnison 1978). In this case, the issue of heavy metal release should be resolved on a case-by-case basis. However, it is also advisable to consider this issue when sizable shore stabilization projects are proposed for areas with highly polluted sediments.

e. Biological Considerations.

(1) Marsh ecology.

(a) Salt marshes are valued as sources of primary production (energy), as nursery grounds for sport and commercial fishery species, and as a system for storing and recycling nutrients. Once established, erosion control plantings function as natural salt marshes and gradually develop comparable animal populations (Cammen 1976, Cammen et al. 1976, Newling and Landin 1985).

(b) Only about five percent of the biomass of a given salt marsh is consumed while the plant material is still living. Grasshoppers and plant hoppers graze on the grass and are, in turn, eaten by spiders and birds, Direct consumption of rhizomes and culms of marsh grasses by waterfowl may be significant locally near waterfowl wintering grounds (Lunz et al. 1978). Periwinkles graze on algae growing on the grass. The pathway of energy flow is believed to move through the detrital food chain. Dead grass is broken down by bacteria in the surrounding waters and on the surface of the marsh. This process greatly decreases the total energy content but increases the concentration of protein, thereby increasing the food value. Some detrital particles and microalgae are eaten by a variety of deposit and filter feeders such as fiddler crabs, snails, and mussels; these organisms are, in turn, eaten by predators such as mud crabs, fish, rails, and raccoons. The remaining detritus, augmented by the dead matter from the primary and secondary consumers, is washed from the marsh by tidal action. This exported detritus, with material from submergent aquatic plants and the plankton, feeds the myriad of larvae and juvenile fish and shellfish which use estuaries, bays, and adjoining shallow waters. Marsh grasses may account for most of the primary production of the system in waters where high turbidity reduces light penetration, thereby reducing phytoplankton and submergent aquatic production.

(c) The rigorous environment of the salt marsh controls the number of animals living there. These areas are used by fur-bearing animals, such as the muskrat, nutria, and raccoon, and by birds such as herons, egrets, rails, shorebirds, raptors, waterfowl, and some songbirds. A much larger population of animals lives in or on the mud surface. The more conspicuous inhabitants are fiddler crabs, mussels, clams, and periwinkles. Less obvious but more numerous are annelid and oligochaete worms and insect larvae. In addition, larvae, juveniles, and adults of many shellfish and fish are commonly found in the marsh creeks.

(2) Introducing nuisance species.

(a) Although most coastal marsh species are highly regarded as ecologically beneficial, some are not. Common reed (Phragmites communis) particularly has a reputation in United States coastal areas as a nuisance plant. More literature is available on eradicating common reed than on planting it. It is purported to be of little direct value to wildlife and aggressively crowds out other desirable species. It grows in dense monotypic stands often to a height of about 10 feet (3 meters), which can interrupt views of the water and preclude public access. Because of these considerations common reed is usually not planted for shore stabilization in coastal areas even though it has demonstrated potential for this use (Benner et al. 1982). It is, however, planted at interior United States reservoirs and lakes for erosion control in drawdown zones (Allen and Klimas 1986).

(b) The introduction of nonnative species may also have negative impacts. Most marsh plants are aggressive colonizers. When introduced to regions where they do not occur naturally, they may spread rapidly in the absence of the diseases and predators which act as biological controls in their native environments. Introduced nonnatives may displace species which have ecological or agricultural significance. For this reason, careful consideration must be given before marsh plants are planted outside their natural ranges.

f. Recreation Considerations. Vegetative stabilization discourages certain recreational activities. Vegetation discourages public access for water-oriented activities such as swimming, wading, and sunbathing. In addition, vegetation discourages fishing from the shore; other shore protection structures often provide a platform for fishing use, and wave reflection may increase nearshore depths. Marshes may substantially increase the number of fish and wildlife in an area. As a result, nonconsumptive wildlife oriented recreational activities such as photography, observation, and nature study and consumptive uses such as fishing, bird hunting, and trapping are benefited.

g. Aesthetic Considerations. Marshes are a visual transition between land and water and a natural feature of the landscape adding form, color, and texture to the shore. Unlike other forms of shore protection, once plants are established no visible evidence remains to indicate that there has been a human effort to reduce erosion (Figure 6-2). In addition, the unique assemblage of birds and mammals associated with marshes are interesting subjects of photographic and illustrative art forms. Standard structural methods of shore protection may visually alter the shoreline (Figure 6-2), creating a barrier rather than a transition between land and water.

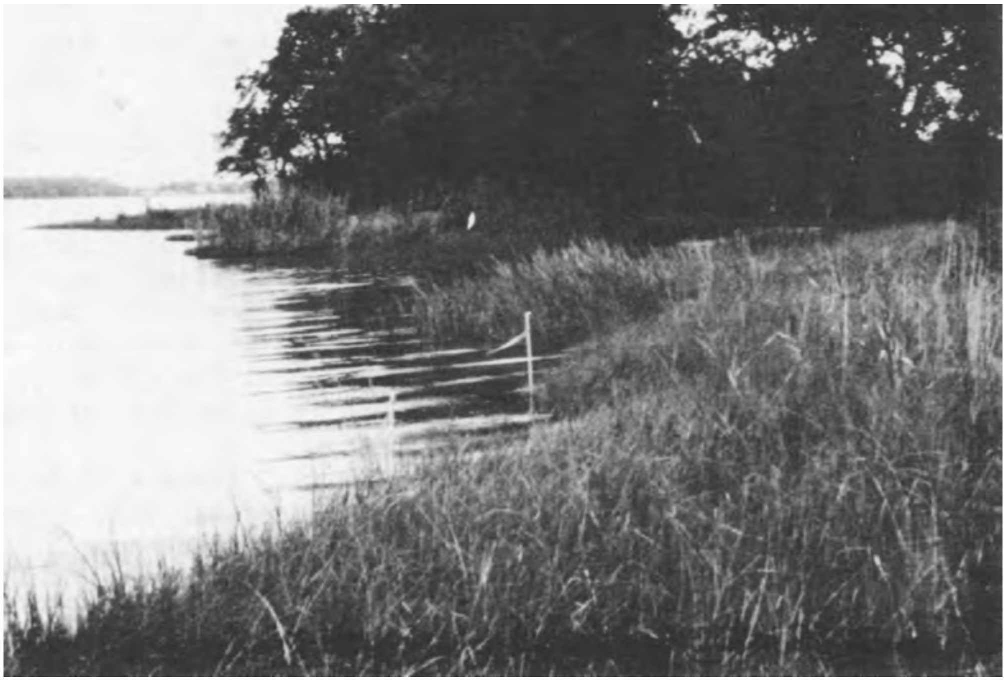
h. Summary.

(1) Establishing marsh plants to abate shore erosion generally will be considered as an environmental improvement. Positive water quality, biological, recreational, and aesthetic benefits are typically associated with vegetative stabilization projects. In addition, vegetative stabilization is the least costly of all erosion control measure. A 33-foot-wide, (10-meter-wide), (landward to seaward) shoreline planting requires an investment of only about $12 per linear yard (linear meter) to hand plant sprigs and about $28 per linear yard to hand plant nursery seedlings (based on labor costs of $15 per hour plus 100 percent overhead). Costs for structural alternatives will range from $50 to $1,000 per linear yard (Figure 6-3).

(2) Due to associated environmental benefits and low cost, this alternative should always be considered when shore protection is planned in sheltered bays and estuaries. However, this alternative is effective only within a limited range of wave climates and never on open, exposed coastlines, unless it is done in conjunction with energy-reducing structures. Refer to Knutson et al. (1981) for information on a simple method for evaluating site suitability on a "case-by-case" basis.

6-2. Seagrasses.

a. General. The establishment of seagrass meadows to aid in shore protection has only recently been recognized as a potential nonstructural



a. Vegetative erosion control project (Maryland)

b. Erosion control structure (Maryland)

Figure 6-2. Aesthetic comparison of nonstructural (salt marsh planting) and structural (revetment) measures

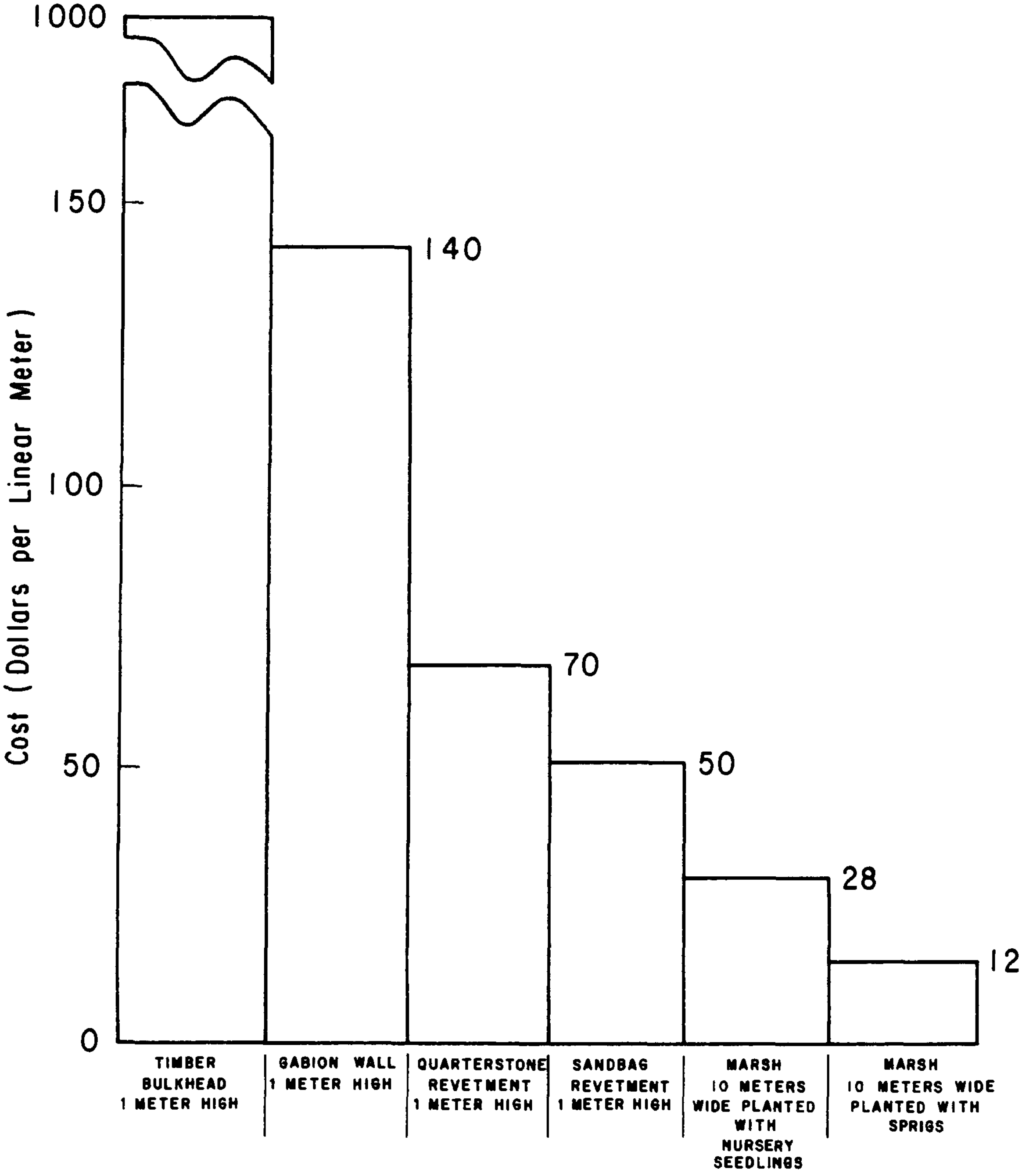


Figure 6-3. Cost comparison of alternative erosion control measures (after Knutson and Woodhouse 1983)

alternative. Restoration of seagrass for sediment stabilization and habitat enhancement is now possible due to recent developments in seagrass planting technology (Phillips 1980, Fonseca et al. 1982 and 1985).

(1) Seagrass meadows. Seagrasses are underwater marine vascular plants occurring primarily in shallow soft-bottom habitats and frequently forming extensive meadows. The plants can generally be characterized as having long, flat, grass-like leaves anchored to the sediment by extensive root and rhizome systems. Five species are common to the marine coasts of the United States--eelgrass (_Zostera_ _marina_), widgeongrass (_Ruppia_ _maritima_), shoalgrass (_Halodule_ _wrightii_) manateegrass (_Syringodium_ _filiforme_), and turtlegrass (_Thalassia_ _testudinum_). Seagrasses normally occur in sediments ranging from sand to mud in relatively protected environments. Depth is limited to generally less than 10 feet (3 meters) by light attenuation in the water column. Salinity tolerance ranges from 20 to 40 parts per thousand (ppt), except for widgeongrass (0-15 ppt).

(2) Planting guidelines.

(a) Methods for transplanting seagrasses and guidelines for determining initial densities of transplants have been developed for most of the common species of seagrasses. Recommended procedures involve four relatively simple steps: obtain seagrass shoots from healthy donor beds by digging sods containing shoots, roots, and rhizomes; gently wash sediment out of sod; attach 5-15 shoots to wire anchors (Figure 6-4); and replant shoot bundles at designated site.

(b) Initially a seagrass transplant will consist of an array of shoot bundles arranged in a grid fashion with the individual bundles separated by areas of bare sediment. Coverage of the sediment will occur through lateral growth of the plants as new shoots develop runners in a similar fashion to plant spreading in strawberry patches. Depending on initial spacing, complete coverage may take one or more years.

(c) It should be noted that candidate locations for seagrass transplanting are limited by certain physical factors (i.e., large waves or low salinity). It is recommended that a monitoring survey be conducted before a decision to transplant is made. This survey should include measurements of depth, light penetration, salinity, temperature, erosion and deposition rates, currents, and wave conditions. Surveys should be conducted as frequently as possible and should encompass seasonal variation (Fredette et al. 1986). If the project is large, then it is prudent to establish and monitor pilot plantings before the full-scale project is begun.

b. Physical Considerations. Seagrasses are capable of dampening waves and currents, decreasing sediment transport, and protecting low-energy shorelines for erosion. These plants influence their physical environment by binding sediments with dense mats of roots and rhizomes and absorbing current energy via their flexible strap-shaped leaves (Figure 6-5). For example,

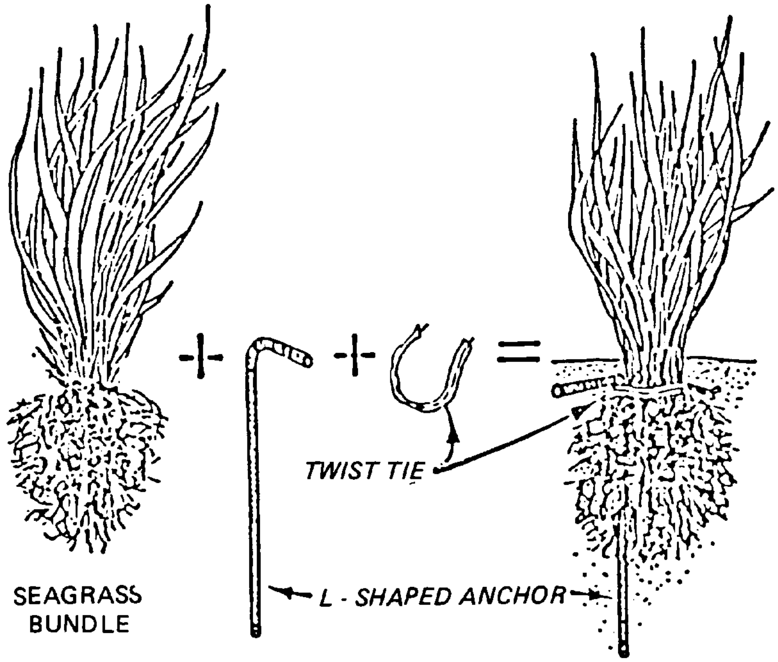


Figure 6-4. Typical seagrass and generalized method of making transplant unit.

Fonseca et al. (1982) report nearly 118 cubic yards (90 cubic meters) per hectare (2.5 acres) of sediment capture in a two-year old eelgrass planting.

c. Biological Considerations. Seagrass meadows serve as nursery sites and primary habitat for numerous fish and invertebrate species of both commercial and ecological importance and as feeding sites for wading birds and over-wintering water fowl. Seagrasses are an important part of the food chain base, influencing estuarine and nearshore production well beyond the physical boundaries of the meadows.

d. Summary. Though seagrass meadows dampen waves as they approach the shore and capture sediments, seagrass plantings alone are seldom considered an adequate shore protection alternative. However, plantings can be a viable alternative when used in conjunction with other shore protection measures. Seagrass planting technology can also be used for the repair or replacement of seagrass meadows that have been damaged or displaced by the construction of other erosion control alternatives.

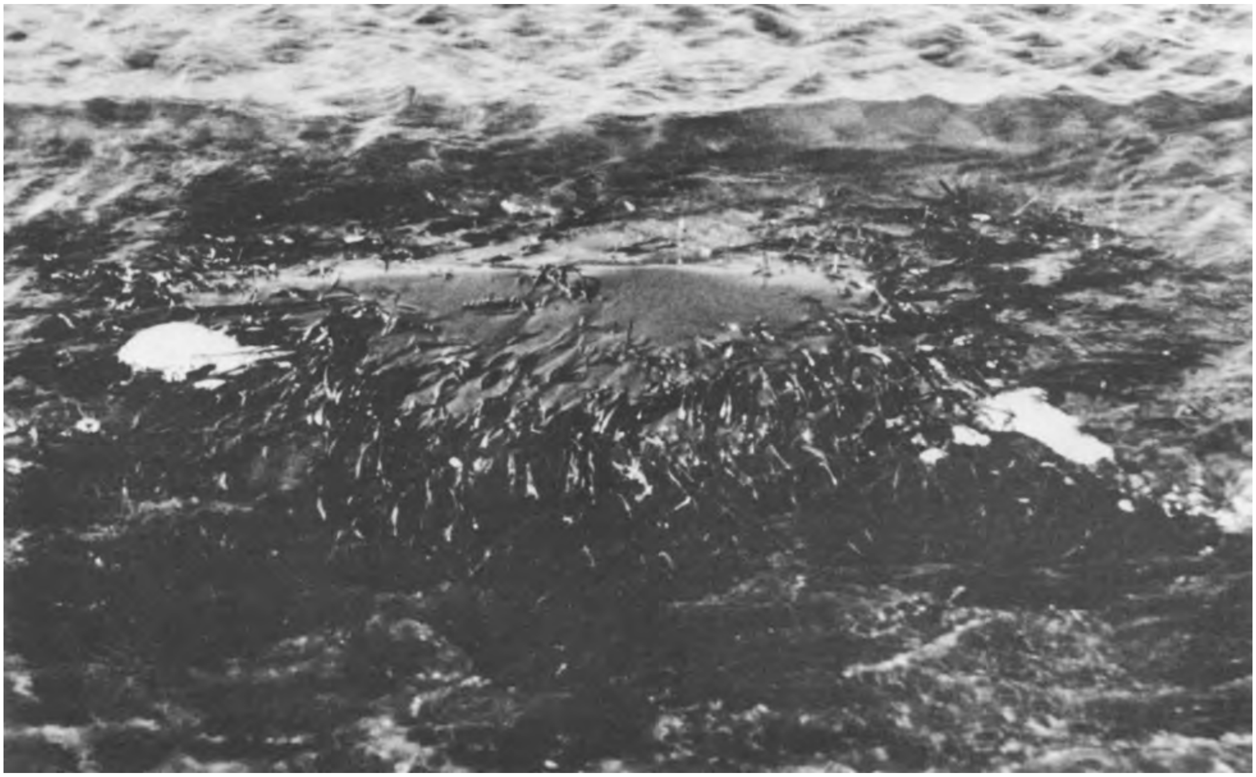


Figure 6-5. Sediment capture in seagrass meadow

CHAPTER 7

ENVIRONMENTAL MONITORING

7-1. Monitoring Program.

a. General.

(1) Monitoring refers to the overall process of data collection, analysis, and interpretation of either short-term, immediate impacts, or long-term changes over the life of a project. This chapter covers only the coastal aquatic/marine habitat. Readers should refer to EM 1110-2-5026, Chapter 16, if interested in monitoring wetland/terrestrial birds and mammals. Environmental monitoring is usually conducted for several purposes as described below.

(2) Monitoring activities are used to document compliance with standards, control the impacts of construction and operation of projects, evaluate predictions from the planning phase, and guide any necessary remedial work. These predictions are found in the environmental effects section of the project Environmental Impact Statement or environmental assessment, and relate to changes expected to result from the project. Before and after measurements are then compared to establish the accuracy of project predictions. Predictions may be either qualitative, such as a change in fish stomach content, or quantitative, such as a 20 percent reduction in crustacean biomass. Quantitative predictions are of greater value in that threshold levels can be set at which an impact (reduced crustacean biomass) can be deemed significant. If a predicted change does not occur, or if an unexpected changed does occur, either is an indication that the predictor model) is faulty. However, the model may not be totally at fault because of the dynamic system it is attempting to predict. Although the monitored predictions cannot be redone for the existing project or activity being monitored, predictive procedures can be improved for future projects.

(3) Monitoring is also used to determine if project operation meets water quality or other environmental standards. Coordination with other agencies or groups and examination of the Environmental Impact Statement and legal requirements (consent decrees, stipulations, rules and regulations, etc.) will usually reveal areas in which monitoring may be desirable. Monitoring should be limited to parameters that provide information about issues of genuine concern and should produce information (data) that can be compared against environmental quality criteria that exist either in Federal or State regulations or that are negotiated and established for the specific project.

(4) Project operations may also be monitored to assess their effects on cultural resources. This monitoring, if appropriate, should include, but not be limited to, soil erosion and accretion rate in, on, and around cultural resource sites, water table increases or decreases, and vandalism. Vandalism protection devices such as cover, fencing, and masking devices should be evaluated for effectiveness. Such monitoring must be tailored to specific site requirements.

b. Setting Objectives.

(1) The most essential part of an environmental data collection and analysis effort is the establishment of clear and concise objectives. If not done, the net result is often a mass of data that defies rational analysis, an inability to solve the problem for which the data were generated, and a waste of money and effort. Without good objectives, any data collection/analysis effort faces a high probability of failure or the collection of unnecessary or worthless data. Phenicie and Lyons (1973) present a logical and complete approach to setting objectives; the approach is applicable to all fields of study.

(2) A good objective is a specific action or activity, not a goal or wish. It places bounds on the work to be done, excluding nonapplicable or unnecessary efforts. Wording of an objective should be clear, concise, and simple. An objective must be <u>realistic</u> and therefore <u>attainable</u>, and <u>measurable</u> to allow evaluation of results and development of conclusions.

(3) Because of different objectives and environmental circumstances, scopes of monitoring programs need to be carefully developed on a case-by-case basis and are rarely identical for different projects.

c. Controls.

(1) Monitoring program design should provide for adequate controls. Data on baseline conditions serve as a temporal reference, and reference site data serve as a spatial reference.

(2) A set of baseline data is required to measure change. By definition, baseline data must be collected prior to the construction, dredging, or other environmental disturbance of interest. Depending upon study objectives, these data may or may not need to be collected over a multiyear period to lessen the statistical impact of the variability in natural systems. The use of a "typical year" may not be a valid approach because "typical years" may not be definable. The changes that occur in a system may not occur in a single annual cycle but may require several years to detect. However, data collected over any given year may still be valuable compared to the collection over part of a year or no collection at all.

(3) Reference sites representative of without-project conditions should be included in the monitoring program if at all possible. The purpose of reference sites is to evaluate changes that occur through time but are not related to the project. Without reference sites it is often very difficult to establish that observed changes are project related, and a question may remain as to whether natural variability or other perturbations were responsible for observed changes. In some cases, it may be possible to control for other perturbations by establishing more than one reference site. Reference stations may also be used to ensure that changes which occur within some designated boundary around an activity remain restricted within that boundary. Stations

may be situated in such a way that those nearer the activity would be impacted if the boundary was exceeded.

d. Quantitative Data. If the study objectives call for scientifically and legally defensible conclusions, baseline monitoring and reference data should be quantitative and the experimental design such that hypotheses concerning change can be statistically tested. Quantitative data sufficient for application of statistical tests are often expensive to obtain, a fact which underlines the prerequisite for well-defined objectives and importance of careful selection of parameters for measurement.

e. Remedial Action. The monitoring program design should include consideration of potential remedial action either during or following construction. If a desirable change does not occur or if an undesirable change is detected, this information is of little value unless a remedy is provided. The only positive result would be the lesson learned if a remedy is not provided. Of course, should a predicted change not occur or an unexpected change be observed, it is an indication that the predictive procedure was not accurate. In many cases, environmental processes are complex, and their interactions sometimes are not well understood. In such a case, understanding of the processes and interactions can serve as a useful feedback mechanism indicating a need for more environmental data and a need to modify and improve the predictive procedure.

7-2. <u>Data Collection</u>. This section provides general guidance necessary to plan an environmental monitoring program that will meet stated objectives of the study design. The most critical aspect of data collection is selecting proper parameters to sample and measure in order to address identified problems.

a. Primary Consideration. The quality of the information obtained through the sampling process is dependent upon these factors: collecting representative samples, using appropriate sampling techniques, protecting the samples until they are analyzed (sample preservation and handling), accuracy and precision of analysis, and correct interpretation of results. Other factors impacting on the sampling process are time, cost, and equipment constraints, which will limit the amount of information that can be gathered. Under such conditions, careful tailoring of the monitoring program is required. It will often be necessary to focus on a single basic objective rather than dilute available effort on tangential questions such that none are completely resolved.

b. Representative Sampling. The purpose of collecting samples is to acquire the basis for adequate representation and definition of the cultural, physical, chemical, or biological characteristics of the project area environment. To do so requires that sampling be conducted or samples be taken in locations which are typical of ambient conditions found at the project site. Failure to obtain samples that are truly representative of a given location will result in inaccurate data and misinterpretations.

c. Sampling Site Selection and Location. The following factors should be considered in sampling site selection:

(1) Objectives of the study.

(2) Accessibility of the site.

(3) Physical characteristics such as tides (consider extremes in amplitude, duration, and velocity), currents (mixing processes), salinity (means and extremes), and presence of vegetation.

(4) Available personnel and facilities.

(5) Cost or funding limitations.

(6) Past history and past studies conducted at or near the site.

(7) Type sampling proposed (random, stratified, or systematic).

d. Number of Stations. If reference areas, control areas, or former study sites are to be sampled for comparative purposes, multiple stations should be sampled. Sample composition from these areas will also be variable and cannot be defined based on single samples. If habitats or cultural horizons to be sampled are known to be heterogeneous, then stations should be allocated to strata (area of uniformity, such as depth, substrate type, and vegetated versus unvegetated) in proportion to spatial coverage of each stratum (e.g., stratified sampling). Therefore, more stations would be required to monitor impacts in physically, ecologically, or culturally complex environments.

e. Number of samples.

(1) Guidance in this section is limited to general concepts. First, the greater the number of samples collected, the better the sampled parameters will be defined. Second, on the other hand, the greater the number, the larger the cost; hence some reasonable compromise must be defined. Third, the mean of a series of replicated measurements is generally a better estimate of actual site conditions than any individual measurement. Fourth, statistics generally require calculation of two characteristics, usually a mean and a standard deviation, because single measurements are inadequate to describe a sample. Fifth, the necessary number of samples is proportional to the source heterogeneity.

(2) Consideration of the above factors suggests that replicate samples should be collected at each station location and that a minimum of three replicates are required to calculate standard deviations. Beyond the replication at a single point, the factors listed above do not limit the number of samples needed since the number of samples depends on site-specific heterogeneity (distribution pattern) and the desired level of source definition (degree of precision). The total number of necessary samples is controlled by the type

of dispersion pattern displayed by the organisms or habitat units to be sampled (random, aggregated, uniform) (Figure 7-1) and the level of precision desired. Additional information regarding "number of samples" can be found in Elliott (1977), Green (1979), and Snedecor and Cochran (1967).

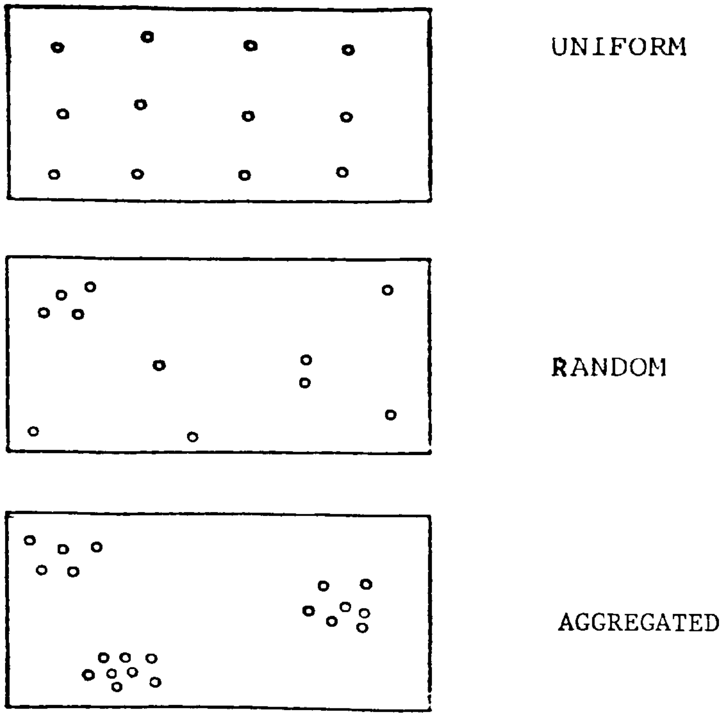
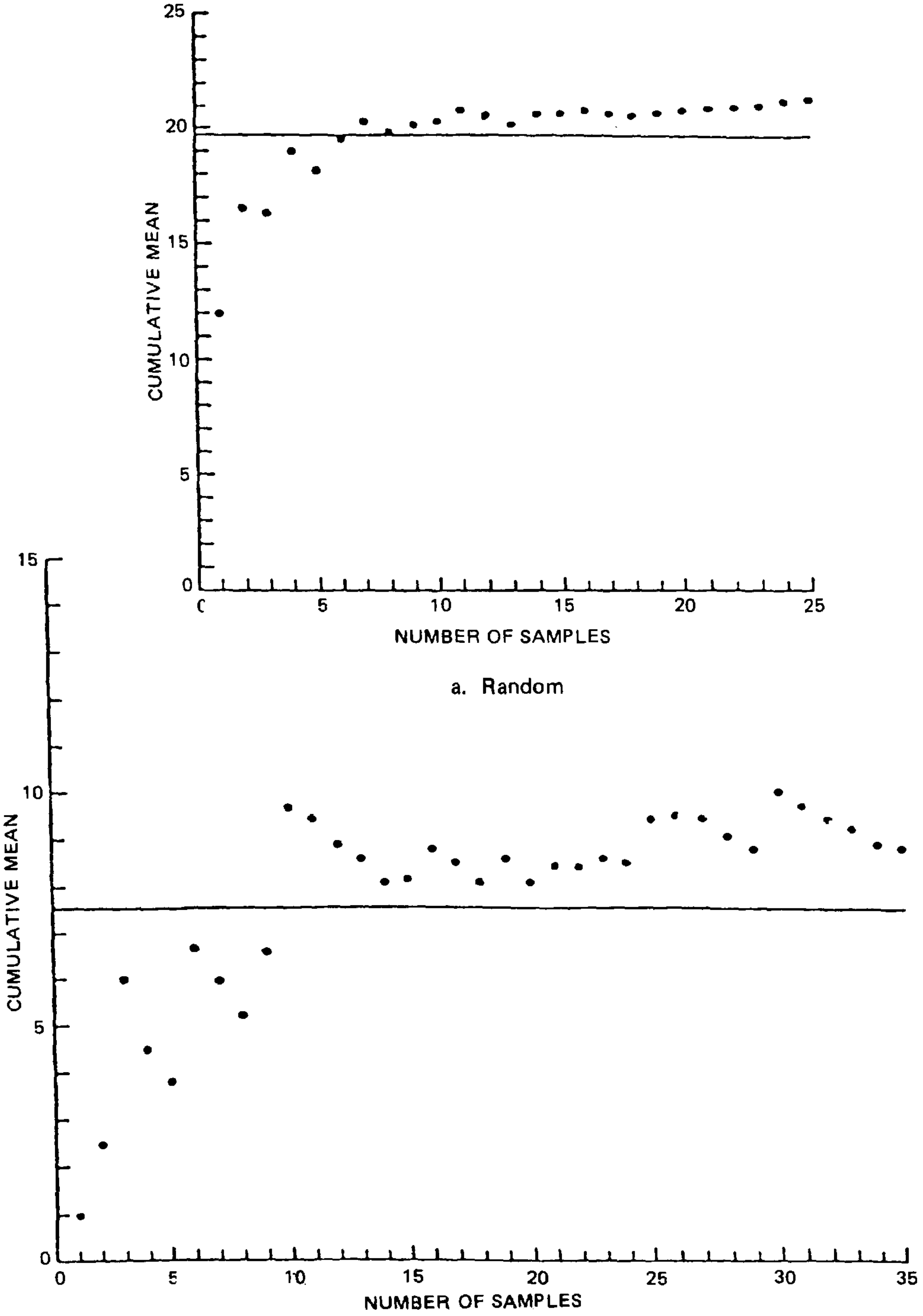


Figure 7-1. Three possible distribution patterns

(3) A rapid method for determining number of samples necessary when investigating a biological population is to calculate the cumulative mean of a few samples obtained in a pilot survey. A cumulative mean (or running average) consists of taking the average of samples 1 and 2; then of samples 1, 2, and 3 (first, second, and third, etc.); then of samples 1, 2, 3, and 4 (and so on), until all samples have been included. If the results are displayed (Figure 7-2), the plot of mean values will stabilize as more and more samples are included. In a population with a uniform distribution (when the variability is low), the mean stabilizes more quickly and in random populations less quickly. In the cluster distribution pattern, the cumulative mean value stabilizes most slowly and never stops fluctuating, although as can be seen in Figure 7-2, after about 15 samples the data begin to stabilize. In the illustrated examples, 8 to 10 samples would be minimally adequate to describe the randomly distributed population, whereas at least 15 to 20 samples would be required for the clustered population.

(4) A more sophisticated technique for estimating the number of samples is described by Green (1979). A preliminary or pilot survey is taken from the



a. Random

b. Aggregated

Figure 7-2. Cumulative means calculated for a random and a cluster distribution population, and individual counts are made from each collection to calculate the sample mean and standard deviation. The following formula is then used:

$$\bar{X} \pm t_{1-(1/2)\alpha} \frac{s}{\sqrt{n}}$$

where x̄ is the sample mean, t is the t statistic, " is the significance level, s is the standard deviation, and n is the number of samples. For example, assume that an investigator wishes to estimate the mean density of a species in a population within 10 percent of the actual number and with a 1-in-20 chance of being wrong (0.95 confidence limits). The t value is unknown and is a function of n-1 degrees of freedom; however, for large sample sizes, t is a weak function of n and is approximately 2. If it can be estimated, then the formula can be solved for n . Refer to Green (1979) for an additional explanation.

(5) An additional factor which will serve to limit the number of samples is financial resources. For example, the number of samples upon which bioassays can be performed is determined by the ratio of available dollars and cost per sample:

$$\textbf{Maximum number of samples} = \frac{\textbf{Dollars available}}{\textbf{Cost per sample}}$$

This approach will provide one method of estimating the number of samples that can be collected and analyzed. However, should the calculated number of samples not be sufficient to establish an adequate sampling program (i.e., the number of samples is insufficient to allow replicate sampling at all locations indicated in para 7-2e) one of the following options will have to be considered. The first option is to reduce the replicate sampling at each station. This option will allow the distribution of a parameter within the project area to be determined, but variability at a single sampling station location could not be calculated. The second option is to maintain replicate sampling but reduce the number of sampling stations. This option will result in the project area being less well-defined, but sampling variability can be calculated. The consideration of these two options should be based on project-specific goals. If the first option is used (more stations but fewer replicates), the results will provide a better indication of distribution patterns in the project area, but it will be difficult to compare individual stations. If the second option is used (fewer stations but more replicates), the results will provide a better indication of variability at a given station and will improve comparison between sampling stations. However, the project area will be less well-defined. A third option is, of course, to increase the financial resources available for sample analysis. This option will increase the number of samples that can be collected and analyzed in order to establish an adequate sampling program.

(6) It is suggested that consideration be given to collecting samples (stations and numbers) in excess of that determined by the above process. The

samples do not have to be analyzed and may even be discarded later without analysis. Should sample analysis indicate abnormal results, it is easier and ultimately less expensive to analyze additional samples on hand rather than to remobilize a field crew. Also, the additional and potentially confounding variable of different sampling times is avoided with this approach.

f. Frequency of Sampling. Frequency of sampling will depend on the original objectives of the monitoring program, the availability of resources, and the size of the project. Seasonal fluctuations of physical and biological parameters may be or may not be suspected or known; therefore, seasonal sampling may be required. A sampling frequency of once per year may be sufficient for an annual maintenance project, unless there is a reason to believe otherwise (e.g., some major change in point sources or basin hydrology). If subtle impacts are to be detected, then long-term quarterly or more frequent sampling may be required to overcome the masking effect of wide seasonal and annual variation in the natural system.

g. Sampling Equipment. Sampling equipment should be selected based on the reliability and efficiency of the equipment and on the habitat to be sampled. Several types of water and sediment samplers used in the coastal zone are described in Table 7-1. The water column and sediments are frequently stratified vertically as well as horizontally, and this source of variability should be considered when choosing a method of sampling (i.e., grab versus corer). Additional techniques and equipment available to meet the particular needs of beach and rubble structure sampling are discussed in the following sections.

h. Sample Preservation.

(1) The importance of sample preservation between time of collection and time of analysis cannot be overemphasized particularly for water quality parameters. The purpose of collecting samples is to gain an understanding of the source (point of origin) of the sample; any changes in sample composition can invalidate conclusions regarding the source of the samples. Results based on deteriorated samples negate all efforts and costs expended to obtain reliable data.

(2) The most effective way to ensure a lack of sample deterioration is to follow instructions in the appropriate manuals or to analyze the samples immediately. However, this method may not be practical, and preservations may have to be used to assure the integrity of the samples until the analyses can be completed. In taking this approach, it must be remembered that complete stabilization is not possible and no single preservation technique is applicable to all parameters.

(3) Preservation is intended to retard biological action, hydrolysis, and/or oxidation of chemical constituents, and reduce volatility of constituents. Refrigeration in an airtight container is the only acceptable method to preserve sediments for bioassays. The elapsed time between sample collection and sample preservation must be kept to an absolute minimum.

TABLE 7-1

Sediment Sampling Equipment

Sampler	Weight	Remarks
Peterson	39-93 lb	Samples 144-in, area to depth of up to 12 in., depending on sediment texture
Shipek	150 lb	Samples 64-in. area to a depth of approximately 4 in.
Ekman	9 lb	Suitable only for very soft sediments
Ponar	45-60 lb	Samples 81-in. area to a depth of less than 12 in. Ineffective in hard clay
Reineck box	1,650 lb	Samples 91.3 in. to a depth of 17.6 in.

(4) The effects of transportation and preservation of sediment samples have not been fully evaluated. However, it is suggested that sediment samples should be sealed in airtight glass containers to preserve the anaerobic integrity of the sample and maintain the solid phase-liquid-phase equilibrium.

(5) Animals stored in the field should be preserved with a buffered 10 percent formalin-seawater solution stained with rose bengal. If stored for a period of time greater than three months, the benthic samples should be transferred to 70 percent isopropyl alcohol. After identification and enumeration, voucher specimens should be archived in 70 percent isopropyl alcohol. Reference collections should be maintained for reasonable postproject periods for quality control insurance (e.g., cross checking of taxonomic identifications should questions arise).

i. Sampling Beaches and the Nearshore Zone.

(1) Sampling methods.

(a) There have been few quantitative studies of the communities along high-energy coastal beaches because these areas are difficult and hazardous to sample. The Coastal Engineering Research Center (CERC) published a report that provided a standardized system for sampling macroinvertebrates on high-energy sand beaches (Hurme, Yancey, and Pullen 1979). This report suggests that samples on the upper beach be taken by excavating 0.1-square-meter quadrats with a trenching shovel and sieving the samples through a 0.5-millimeter mesh soil sieve. Compaction of the upper beach sediments can be measured in situ as a function of penetrability with a cone penetrometer. In the surf zone, a coring device generally provides a better and more consistent sample of the infauna (living in the sediments) than grabs or dredges. Beyond the surf zone, in deeper water, cores, grabs, and dredges may be used. Cores taken by a diver applying the quadrat techniques yield the most consistent quantitative samples (Figure 7-3). Trawls and beach seines are less quantitative, but they provide samples that are useful in interpreting biological changes in nektonic and epibenthic communities.

(b) When working in the surf, divers should use a transect line to stay on station (Figure 7-4); range markers on the beach are also helpful for keeping divers on station. Samples are generally collected along lines or transects perpendicular to the beach or parallel to the depth contours, depending upon objectives, and are stored in plastic bags, labeled, and preserved. Sorting of the animals from the sediments is done on the beach or in the laboratory. The animals preserved are later identified and counted.

(c) In clear water beyond the surf zone, diver observations and underwater photographs provide additional information on the epifauna (living on the surface of the bottom) that supplements core samples (Figure 7-5). Divers can observe and count attached reef animals, burrowing and reef fish which tend to be territorial, and pelagic fish.

(2) Sampling design. Sampling plans for a specific area depend on the nature and magnitude of the project, the use and purpose of the data, and the animals to be evaluated. The animals may be sessile or motile with populations that vary seasonally and distributions that are random or clustered. Refer to paragraph 7-2 for sampling design. In most cases, quantitative studies of the beach and nearshore will concentrate on the benthic community, especially the infauna. Epifauna and flora are usually not conspicuous on beaches. The following are general sampling design guidelines for the beach and nearshore zone.

(a) The infaunal sampling device should be reliable and accurate. It should ensure consistent substrate penetration, no loss of sample during retrieval, and minimal variation between sample sizes. Refer to Table 7-1 for typical benthic sampling devices.

(b) Sieve size for processing benthic (infauna) animals should be selected to ensure complete retention of macrofauna (Reish 1959, Hurme, Yancey, and Pullen 1979). By convention, a 0.5-millimeter mesh sieve is recommended for quantitative macrobenthic collections.

Figure 7-3. Core sampling at sandy-bottom stations

Figure 7-4. Diver using transect line in the surf

Figure 7-5. Quadrat sampling of epibiota at reef stations

(c) The number and the locations of stations should be chosen carefully before the project begins. Addition and deletion of stations should be avoided as much as possible. The number of stations should be adequate to address spatial variability of the infauna.

(d) Replications should be adequate to account for variability within station fauna and to collect the majority of the species inhabiting the study site. Refer to paragraph 7-2e on replicate sampling.

(e) There should be a sufficient temporal frequency of sampling to address seasonal variations in the physical and biological parameters.

(f) Sampling methods for "pre," "during," and "post" construction should be consistent and comparable.

(g) Because taxonomic identification is one of the costliest exercises in a monitoring program, level of identification of animals should be no greater than required by the stated objectives.

(h) Consistency in all procedures (sampling methods, sample processing, sample preservation, and sample analysis) should be maintained.

(3) Manpower requirements. Manpower estimated for collecting, processing, and analyzing benthic data varies depending on the location of sampling, site conditions and areal extent, number and type samples to be taken, the size of animals collected (macrobenthos or meiobenthos), and the level of taxonomic identification. As a general rule, project time for an assessment can be prorated as follows: field time - 10 to 25 percent; sample processing - 50 to 75 percent; data analysis - 5 to 10 percent; and preparation of an assessment document - 10 to 20 percent. Picking (separating benthos from sediments and debris) and sorting macrobenthic samples generally takes 1 to 4 hours per sample depending on whether or not the sediment is fine or coarse and whether the benthos are rare or abundant. Processing time, which includes taxonomic identification, counting, and weighing varies from 1 to 4 hours for beach samples with 25 to 75 species and 6 to 10 hours for nearshore samples with 200 to 300 species.

j. Sampling rubble structures. Although they provide excellent habitat for many fishes and shellfishes, rubble structures present difficulties in assessing these resources. The exposed armor layer of rubble structures creates an extremely rough and irregular surface such that obtaining biological samples of standardized volume, surface area, or other unit of habitat measure becomes a distinct problem. Specific biological sampling methods of potential application to rubble structure assessment are recommended below.

(1) Sampling epibenthic communities.

(a) Line transects. Van Dolah et al. (1984) used the following procedures to estimate the percent coverage of sessile biota on jetties at Murrells Inlet, South Carolina. Their methodology was adapted from line transect techniques described by Loya and Slobodkin (1971), Porter (1972a-b), and Loya (1972, 1978). A clear plastic strip with 15 inscribed marks at 2.5-centimeter intervals along its edge is placed against the rock surface. All organisms found directly under each mark (point) are identified and recorded. To accommodate the patchy distribution of many organisms on the same rock as related to the rock's orientation, assessments are made on each of the seaward, landward, outer, inner, and top surfaces of structure quarrystone at a station. The transect strip is always positioned horizontally on sloping or vertical rock faces. Ideally, the strip should be placed randomly upon each rock face rather than selecting areas of high-organism density. Nonrandom placement would introduce bias into the sampling. If more than one species is present under a point, all are recorded. At each station on the structure, samples are taken at predetermined elevations, including subtidal, intertidal, and supratidal levels. Percent cover estimates are then calculated based on the percentage of points each species occupied at a level or at a station. Because this procedure may result in estimates of total biota coverage of over 100 percent (more than one species can contribute to coverage at any given point), total biota coverage is adjusted by subtracting the estimated percent of unoccupied space from 100. For in situ observations, individual rocks can often be removed from the appropriate depth and brought to the surface for examination. Organisms unidentifiable in the field should be preserved and taken to the laboratory for identification.

(b) Scrape sampling. Manny et al. (1985) documented periphyton colonization of a rubble-mound jetty in Lake Erie. Samples were obtained with a bottle-brush sampler as described by Douglass (1958). Each sample covered 12.56 square centimeters (5.0 square inches) of rock surface. At a given station replicate samples can be taken and dedicated to separate analyses such as biomass estimation, taxonomic identification, and chlorophyll content determination.

(c) Quadrat sampling. Johnson and Dewit (1978) used randomly placed quadrats to characterize the biomass and densities of macrobenthic species assemblages on a rubble-mound island at Punta Gorda, California. Samples from subtidal and lower intertidal elevations were taken by using a 0.25-square meter (10.0-square-inch) quadrat, whereas samples in the upper intertidal zone were taken with duplicate 0.1-square-meter (40.0-square-inch) quadrats. Numbers drawn from a random numbers table, used as vertical and horizontal distances from fixed points on the structure, determined the location of each sample. Divers measured the specific distances along a steel tape measure, then dropped the quadrat behind them in order to minimize sampling bias in placement. To arrive at estimates of density, numbers of percent coverage (estimated visually) were recorded for each species in each quadrat. All detachable biota were removed and placed in labeled plastic bags for weighing in the laboratory. Subsamples of encrusting biota were scraped off rock surfaces with a steel chisel and hammer, then collected with a slurp gun (suction apparatus consisting of a plastic tube plunger system) fitted with a collecting chamber lined with plankton netting. Contents of the chamber were then processed with the biomass samples. Quadrant sampling can be adapted to other habitat types, including coral reefs, seagrass beds, and epibenthic communities that may occur in project areas.

(d) Suction samples. Motile epifauna can be sampled with devices such as slurp guns (Van Dolah et al. 1984) and pumps (Manny et al. 1985). Replicate or pooled samples can be taken with slurp guns by standardizing the number of pulls of the plunger rod. A flexible gasket around the opening of the slurp gun barrel can improve the fit of the device when placed against an uneven rock surface. Holes drilled in the base of the barrel and covered with fine mesh netting allow water to enter as the plunger is pulled, creating suction through venturi action. The volume of water and surface area of rock sampled can be calculated from the internal volume of the device and the barrel opening diameter, respectively. The pump sampler used by Manny et al. (1985) consisted of a gasoline-powered centrifugal pump fitted with a 5-centimeter-ID (inside diameter) hose. Incoming water passed through a screen head with 9-millimeter openings. Replicate three-minute pump samples were taken at each station, then filtered through standard mesh-size sieves. Samples were obtained by placing the intake hose in the interstices among the rock rubble. Thus, data were compared on a catch per unit effort basis because the absolute amount of surface area sampled was unknown.

(2) Sampling nekton. Assessment of fish and shellfish populations near rubble structures requires care to avoid the hazards of fouled nets and traps on the structures themselves.

(a) Nets and traps. If the bottom type is suitable, conventional trawling techniques can be used to sample demersal (bottom dwelling) fishes and shellfishes in the vicinity of rubble structures. Trawling would not, however, adequately sample nekton above the bottom and in the immediate area of the structures. Baited traps can be set directly on the rock surfaces but suffer from inherent selectivity in catch and susceptibility to loss during turbulent wave conditions or due to vandalism. Traps may be useful for assessment of specific target species (e.g., of commercial or recreational value) such as crabs or fishes intimately associated with the rubble substratum. In many cases, an appropriate gear type would be gill nets. Properly set, gill nets can be used to sample the water column immediately adjacent to a structure (generally set perpendicular to the axis of the structure) and can be set either high or low in the water column. Gill nets are less useful in deep water because the proportion of the water depth range sample of the net is less. Ideally, the same gear should be used at all sampling locations to avoid problems in comparing catch per unit effort data.

(b) Diver observations. Where water clarity conditions allow, underwater visual census techniques can be applied to assessments of rubble structure fish populations. A number of standard transect or point count techniques can be modified for use by swimmer-observers (Jones and Thompson 1978, Clarke 1986). Detailed studies of the fish fauna associated with rubble structures have been accomplished by divers (Hasting 1979, Stephens and Zerba 1981, Lindquist et al. 1985).

7-3. Habitat Assessment. In resource management decision making, questions that arise in the environmental review process can differ in specifics but have a fundamental theme: Will a project result in unacceptable changes in the functional "value" of the habitat involved? Two habitat assessment techniques and a series of marine and estuarine species profiles are available to assist in answering this important question.

a. Habitat Evaluation Procedures.

(1) Habitat-based evaluation procedures are designed to document the quality and quantity of habitat available for aquatic and terrestrial animals. These procedures can be used to compare the relative value of different areas at the same time (baseline studies) and/or the relative value of one area at different points in time (impact assessment), e.g., present conditions to future conditions. The effect of a project or environmental disturbance on animals can thus be quantified and displayed. One such procedure, the Habitat Evaluation Procedure (HEP), has not been applied frequently in estuarine! marine settings, although Cordes et al. (1985) provided one published example for Mobile Bay, Alabama. The limited application of HE? in coastal environments is primarily due to the small number of Habitat Suitability Index (HSI) models available for estuarine species (zero for marine species), and concerns over the sensitivity of HSI models in documenting impacts of Corps of Engineers activities on estuarine/marine species (Nelson 1987).

(2) HEP is computerized for use in habitat inventory, planning, management, impact assessment, and mitigation studies. The method consists of a basic accounting procedure that outputs quantitative information for each species evaluated. The information can pertain to all life stages of a species, to a specific life stage, or to groups of species. A HEP analysis includes the following (Refer to US Fish and Wildlife Service 1980b, Armour et al. 1984, and O'Neil 1985 for guidance and suggestions on conducting a HEP analysis.):

(a) Scoping. Scoping includes defining study objectives, delineating the boundary of the study area, and selecting aquatic evaluation species. The selection of evaluation species can be based on ecological importance, importance for human use (e.g., sport or commercial fishing), or other factors, including legal protection status.

(b) Development and use of Habitat Suitability Index models. An HSI model can be in one of several forms, including equations for standing crop or harvest, mathematical and nonmathematical mechanistic models that involve aggregations of variables that affect life requisites of a species, pattern recognition models, or narrative (word) models. The mechanistic model (Figure 7-6) is a commonly used model and requires development and use of Suitability Index (SI) curves (Figure 7-7). The tree diagram in Figure 7-6 illustrates the relationship of habitat variables and life requisites to the HSI for juvenile Atlantic croaker (Diaz and Onuf 1985). The value of each variable (V_n) is determined from a suitability curve as shown in Figure 7-7. HSI models published by the US Fish and Wildlife Service (Schamberger et al. 1982)

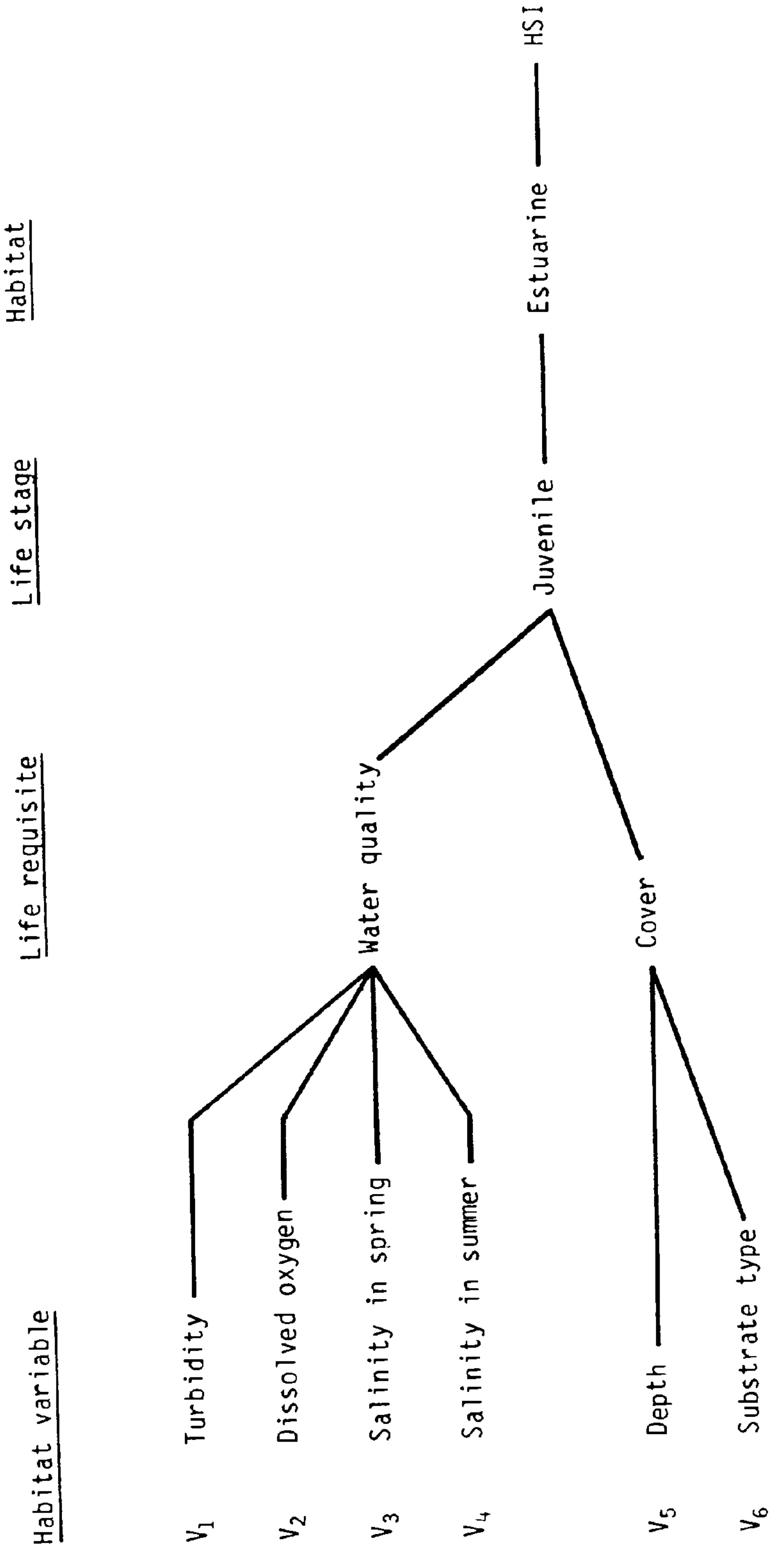


Figure 7-6. Example of a mechanistic Habitat Suitability Index model

V_6 Dominant substrate type:

1) >75% mud.

2) 25% to 75% mud.

3) >75% sand, shell, or other hard material.

4) Seagrass beds or mostly rock and shell; no soft material.

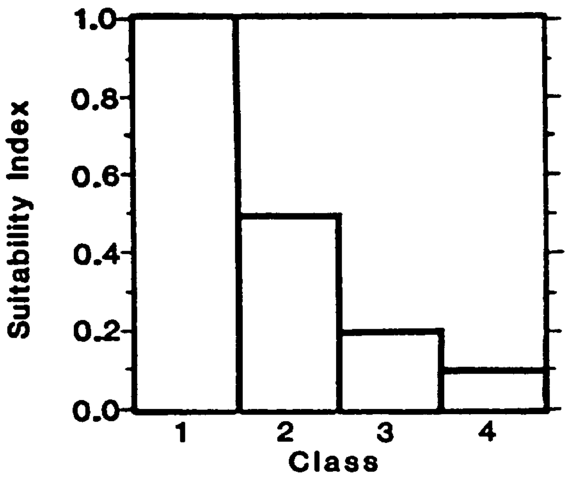


Figure 7-7. Suitability index curve for substrate type for juvenile Atlantic croakers Habitat Suitability Index model (Diaz and Onuf 1985)

should be evaluated by users to determine if they meet site-specific requirements. If the requirements are not met, the models can be modified or the user can develop new models for application. Guidance for developing HEP models is presented in "Standards for the Development of Habitat Suitability Index Models" (US Fish and Wildlife Service 1981). Availability of models is regularly updated in an instruction report by O’Neil (1985).

(c) Baseline assessment. Existing or baseline HU’s are quantified within the study area for each evaluation species. HU’s are derived by delineating the area of each habitat type for each evaluation species and then multiplying the area by its average HSI (HSI x area = HU). The number of HU’s in the study area for an evaluation species is derived by summing the individual HU’s for all habitat types and locations that provide habitat for the species for a particular life stage within the study site (Armour et al. 1984).

(d) Impact assessment. Target years are designated at specific points in time throughout the lifespan of the proposed project or study. A target year is defined as a specific year for which habitat conditions can be predicted and evaluated. Target years should be selected for points in time when rates of loss or gain in HSI, or area of available habitat, are predicted to change. The values for habitat variables for evaluation species must be predicted for each target year. Therefore, the planning agency must be able to predict habitat conditions for each alternative at each target year.

(e) Mitigation. Because HEP can be used to quantify losses resulting from proposed projects or construction activities, it can be used in mitigation studies. Habitat losses are determined, and the areas or measures designated for compensation are evaluated for various management alternatives to determine habitat gains. Partial or full compensation or enhancement to fish and wildlife habitat can be quantified. The analyses can be for in-kind compensation (one HU is provided for each HU lost for an evaluation species), equal replacement (a gain of one HU for a species to offset the loss of one HU for another, equally important, species), and relative trade-off.

(f) Decision on course of action. After the HEP analysis is completed, information is prepared for evaluation and use by decision makers and should include complete and clear documentation.

b. Benthic Resources Assessment Technique.

(1) Procedures have been developed at the US Army Waterways Experiment Station that use benthic characterization information to produce semiquantitative estimates of the potential trophic value of soft-bottom habitats. These procedures are called the Benthic Resources Assessment Technique (BRAT). As presently configured, BRAT can be applied under any circumstances in which the pre- or post-project fishery value of an unvegetated soft bottom is an important issue. Although developed primarily for application to subtidal estuarine and coastal marine systems, it may be feasible to apply the BRAT to evaluations on unvegetated intertidal or shallow subtidal bottoms as foraging habitat for wading birds and some waterfowl.

(2) In essence, BRAT estimates the amount of the benthos at a given site that is both vulnerable and available to target fish species that occur at the site. Here "vulnerable" and "available" are the key words. Different species of bottom-feeding fishes, by virtue of their particular morphological, physiological, and behavioral adaptations, can detect, capture, and ingest only a portion of the total benthos present. According to optimal foraging theory, fishes should feed on those food items which afford the greatest net nutritional/caloric benefit for the required energy expenditure for search, capture, and handling of prey. Thus, the optimal diet will depend on the abundance of the prey item, its size relative to the predator, its spatial and temporal distributions, and its defensive adaptations (camouflage, burrowing behavior, etc.). Bottom-feeding fishes will consume different prey at different locations and during different seasons, reflecting those vulnerable prey items that happen to be situated where they are available for capture. In the BRAT, vulnerability is taken to be a function of the depth of the prey’s location below the sediment-water interface. Both factors, vulnerability and availability, are estimated by examination of the diets of target predatory fishes.

(3) The overall BRAT approach is quite simple. Figure 7-8 depicts a flow chart of the major steps of the BRAT up to the point at which statistical and numerical analyses come into play. Benthos and fishes are collected simultaneously at the project site. Benthos are retrieved using a modified box-corer which enables the obtained sediment core to be partitioned into vertical depth intervals. The benthos are then removed and segregated according to their respective depth intervals. After separation from the sediments, the benthos from individual depth intervals are sorted into major taxonomic

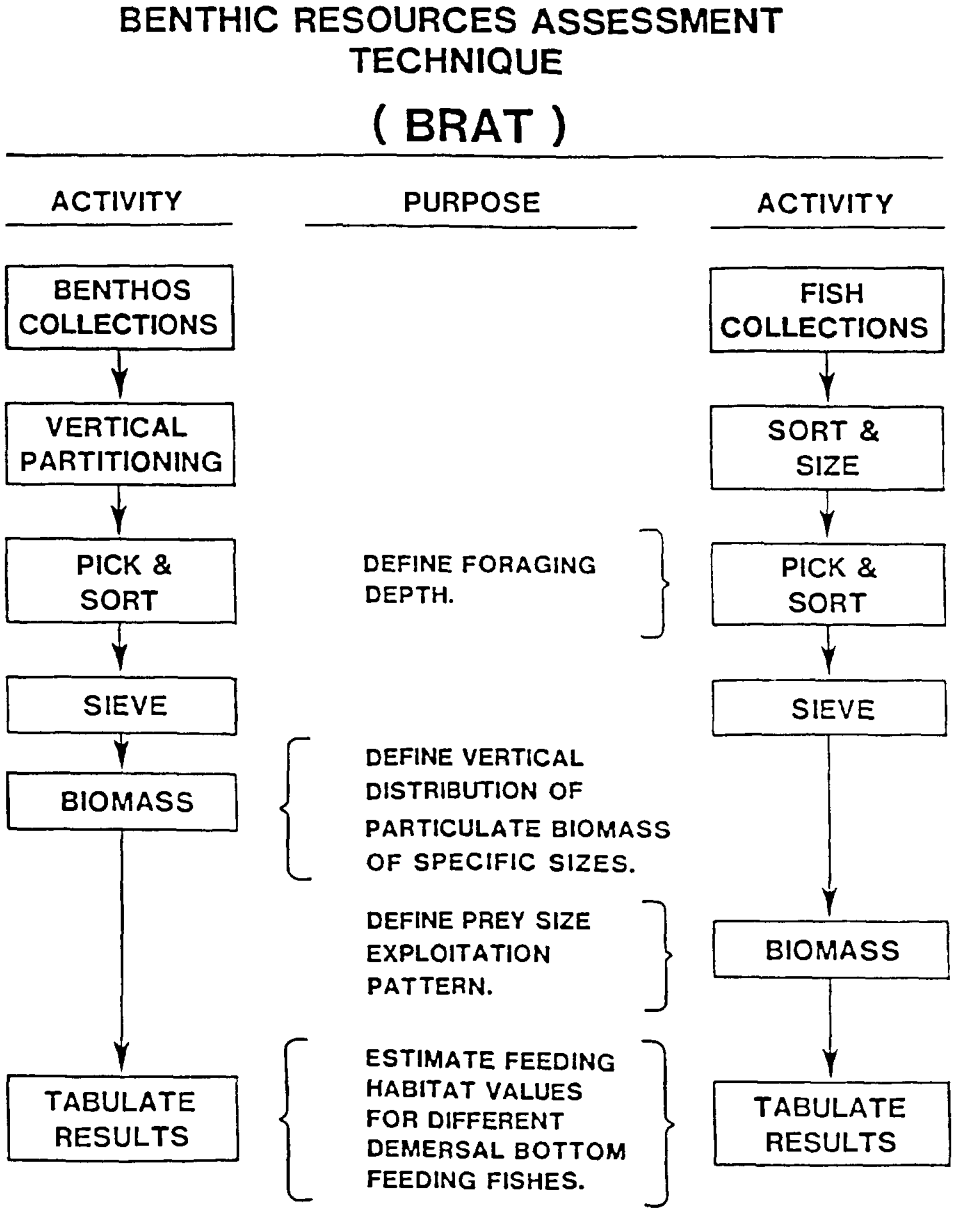


Figure 7-8. Benthic resources assessment technique (BRAT)

categories, then passed through a series of standardized mesh-size sieves. Each size fraction is then wet-weighed. At this point, the vertical distribution by size and weight of all potential food items has been established.

(4) Fishes that have been collected by conventional trawling methods are measured (standard length) and separated into size classes. Stomach content samples for fishes within each size class are pooled, then treated in a manner identical to the benthic samples. First, the food items are sorted into major taxonomic categories, then sieved into standardized size classes, and finally wet-weighed. Thus, there is a record of the size of prey items and the relative proportions of prey items utilized by bottom-feeding fishes in a project area at a given time. There is also a record of the locations of those utilized prey in the sediment column. What follows is simply a means of comparing the two records (actual food items eaten and food item size/depth distribution) to arrive at an estimate of the potential trophic support represented by a specified area of bottom habitat.

(5) Each size class of fish species will exhibit a particular prey exploitation pattern, i.e., its diet will be composed predominantly of prey items in a certain size range. This size range may be either narrow or broad. For projects at which there are multiple target fish species, and multiple size classes of each species, it will be necessary to use cluster analysis to assign each predator species size class to a prey exploitation pattern. Cluster analysis, also known as ordination, is a multivariate statistical technique which objectively sorts entities (in this case fish species size classes) into groups based on their attributes (sized-sorted prey items as used here). Cluster analysis is not an end in itself but rather an exploratory tool that assists in the recognition of patterns in large or complex data sets. The output in the BRAT is in the form of fish species size classes sorted into groups having similar prey exploitation patterns, or feeding strategies.

(6) Next, a second component of prey exploitation to be evaluated is the vertical foraging capability within the sediment column for each fish species size class. Qualitative examination of each food habitats sample provides evidence of the kinds of prey and their relative abundances. Comparison of this information with the vertical distribution patterns of these prey in the sediment column (derived from published reports or from the vertically partitioned box-core samples) gives an indication of the sediment depth to which a particular fish species or guild of species can forage. For example, hypothetical group A fish species size classes may eat prey less than 1 millimeter in size (vulnerable prey size) and be limited to foraging in the upper 5 centimeters of sediment (available foraging zone). The total amount of benthic biomass potentially exploitable by group A predators can be calculated as the cumulative biomass of all food items less than 1 millimeter in size for all sediment intervals down to 5 centimeters. Because the original box-core samples represented a standardized surface area of bottom habitat, an estimate of the total amount of food potentially available to group A predators in a project area can be extrapolated. By repeating this process for all bottom-feeding predator groups found in the project area, and taking the sum of their

exploitable prey biomasses, an estimate of the potential trophic support for all target fish species can be obtained. An example of BRAT data tabulation is presented in Table 7-2. In this example, the potential food value of the sampled bottom habitat was found to be 12.3 grams per square meter of vulnerable available biomass. The tabulation would be repeated for each benthic feeding predator group.

TABLE 7-2

An Example of a BRAT Data Tabulation

Benthic Community Analysis						
Prey Taxa	**Vulnerable Size**	**Proportion of Biomass in Available Zone**		**Biomass/ Productivity**		**Potential Food Value**
1	+	100%	×	10 g/m^2	=	10 g/m^2
2	-	0%	×	3.1 g/m^2	=	0 g/m^2
3	+	50%	×	1.4 g/m^2	=	0.7 g/m^2
o	o	o	o	o	o	o
o	o	o	o	o	o	o
o	o	o	o	o	o	o
n	+	70%	×	2.3 g/m^2	=	1.6 g/m^2
				Total food value	=	**12.3 g/m^2**

NOTE: The food value in grams per square meter (g/m^2) can be converted to units of energy to compute potential fish production or to a suitability index (actual/optimum) value for input to a HEP analysis.

The analysis would be conducted separately for each predator guild (guild = n species).

(7) The utility of the BRAT lies in the ability to provide meaningful information relevant to value decisions by the resource manager. The BRAT does not provide an assessment of the overall status of the habitat but can be viewed as an in-depth assessment of a single habitat variable, that of trophic support. As such it may potentially contribute semiquantitative input to habitat-based assessments such as the Habitat Evaluation Procedures.

c. Species Profiles. A series of 126 profiles on marine and estuarine animals are being prepared for seven United States coastal biogeographic regions (Appendix D). The profiles are designed to provide coastal managers, engineers, and biologists with a brief but comprehensive sketch of the biological characteristics and environmental and habitat requirements of coastal species. They will assist the planners in predicting how populations of coastal species may react to environmental modifications resulting from engineering projects. The profiles are jointly developed by the US Army Corps of Engineers and the US Fish and Wildlife Service and may be acquired by contacting the Coastal Ecology Group at the Waterways Experiment Station in Vicksburg, Mississippi.

7-4. Data Analysis, Interpretation, and Presentation.

a. Data Analysis Plan and Presentation. A preliminary idea of the data analysis and presentation techniques to be used should be formulated during the study design stage. Green (1979) has outlined principles important to planning successful study design and data analysis. Several techniques are readily available for data analysis and presentation.

(1) Qualitative analysis. Results of qualitative analyses are generally prose statements based on visual observations and perhaps a few measurements.

(2) Maps and graphical analysis. Patterns inherent in data can often be revealed by mapping or graphing the data. Maps are used to show two- and three-dimensional spatial patterns, whereas graphical approaches are most useful for showing temporal relationships or variations with a single dimension such as distance or depth. In general, variables can be divided into two types-continuous and discontinuous (or discrete)--and appropriate map and graphical techniques vary, depending on how variables are measured and distributed.

(a) Phenomena to be mapped may be distributed in a continuous or discrete manner. Discrete distributions are composed of individual elements that are countable or measurable (individual fish, species of fish, etc.), whereas with continuous distributions there are no recognizable individuals (dissolved oxygen concentration, turbidity, etc.). Symbols such as dots may be used to map discrete distributions to reveal patterns. Discrete data are often converted into densities by dividing counts of individuals (frequencies) by the areas of the spatial observation units. The results (animals per square meter, biomass per square meter, etc.) may be plotted on maps. Patterns are often enhanced by grouping all values into five or six classes and mapping each class with a separate tone or color. Data representing continuous distribution are usually plotted and contoured to reveal patterns.

(b) Graphic techniques specialized for certain disciplines or types of data are too numerous to describe. As with maps, however, graphic techniques vary with the type of data. Discrete data are often graphed as frequency histograms (or by graphs), with frequencies on the vertical axis and classes or categories on the horizontal axis. Continuous data are usually plotted as curves, with the spatial or temporal dimension on the X-axis. Logarithmic scales are often used when the data to be graphed vary over more than one order of magnitude. Patterns or trends in irregular curves may be more evident if the data are smoothed with a moving average or by fitting generalized mathematical functions to the plotted points. Schmid and Schmid (1979) provide a thorough review of graphs and charts. Tukey (1977) provides a discussion of graphical smoothing techniques. Tufte (1983) is an excellent source of ideas on clearly and accurately displaying quantitative data.

(c) More complex maps and graphs such as three-dimensional contour plots, trend surfaces, and perspective plots are also useful but more difficult to comprehend. Various mapping and geographical display options are available as part of most data management systems.

(3) Statistical analysis. Statistical analysis can be used to summarize or describe complex data bases. Statistics can also be used as a formal decision-making tool to decide whether measured temporal or spatial differences between samples are real or whether they may be the result of sampling variability. Commercially available data management systems have options for computing and displaying several types of statistics.

(a) Large amounts of data can be summarized by calculating statistics such as measures of central tendency (mean, median, and mode) and dispersion (standard deviation and range). Statistics can be used to compare sets of data to determine if differences exist among them and, if so, whether the differences are significant.

(b) Formulas are available for determining if observed differences between sample data sets are real, or if they may have occurred by chance because of insufficient sample size used in calculating the statistics. These techniques are called significance tests, and theories and formulas for their use are given in basic texts on statistics and experimental design. Users should be cautioned, however, that observed differences may be statistically significant and yet not be very meaningful. Special techniques have been developed or modified for analysis of biological data, particularly benthic biota data, e.g., Boesch (1977).

(c) Relationships among variables may be explored using correlation and regression analyses. For example, the relationship between the density of a certain benthic species and certain physical (water depth, temperature, sediment grain size, etc.) and chemical (dissolved oxygen, salinity, etc.) parameters might be explored using correlation and regression. Basic theory and formulas for correlation does not imply cause and effect relationships. Kenney (1982) discusses spurious self-correlations that result when two or more variables have a common term. The use of correlation and regression with several variables should be accompanied by a good understanding of the basic assumptions that must be met in order to use the techniques effectively. Mather (1976) presents a thorough discussion of the basic assumptions of multiple correlation and regression and of some of the mathematical and data constraints that influence results.

(d) Most data management systems contain programs for a variety of advanced statistical techniques. Pattern recognition techniques, such as cluster or character analysis, are powerful procedures for describing patterns and complex relationships when employed by individuals with sufficient training to understand the statistical and mathematical constraints to proper use of the technique.

b. Data Interpretation.

(1) Editing. Data checking and editing should precede analysis. Extreme errors may be detected by computer programs that check for boundary conditions and ensure that data values are within reasonable limits. Quality work requires human judgment. Simple computer plots of the raw data should be generated and examined for unreasonable values, extreme values, trends, and outliners. More detailed editing should include checking all or random samples of the computer data base values against data sheets from the lab or field.

(2) Analysis. The next step in data interpretation is to ensure that the assumptions on which the data analysis plan is based are still valid. New information or failure to collect all the data required in the original analysis plan may necessitate modification. Data analysis should then proceed according to plan, and a decision should be made to accept or reject the tested hypothesis. Following this step, an effort should be made to identify additional quantitative or qualitative conclusions that may be warranted, and additional hypotheses that may be tested using the data base. If resources permit, this additional analysis may be completed prior to formulation of final conclusions. Final conclusions should not be limited to acceptance or rejection of hypotheses but should extend to clear, verbal expression of the implications of the observed results. Decision makers who are not technical specialists may fail to grasp these implications unless they are clearly communicated.

(3) Maps and Graphs. When using maps and graphical techniques, one must be careful not to draw conclusions that depend on either interpolation between data points or extrapolation beyond the range of the data, unless such interpolation or extrapolation can be justified. Quantitative statements should not be based solely on map and graphical analysis. A choice of scales or coordinate axes that unduly exaggerate or minimize point scatter or differences should be avoided.

CHAPTER 8

MITIGATION DECISION ANALYSIS

8-1. Policy. Care must be taken to preserve and protect environmental resources, including unique and important ecological, aesthetic, and cultural values. The Fish and Wildlife Coordination Act of 1958 (Public law 85-624, 16 U.S.C. 61 et seq.) requires fish and wildlife mitigation measures when appropriate and justified. The National Historic Preservation Act of 1966 (Public Law 89-665, as amended, 16 U.S.C. 470 et seq.) does the same for cultural resources. The Water Resources Development Act of 1986 (Public Law 99-662) and implementing guidance provide further policy on fish and wildlife mitigation, including cost-sharing provisions. Specific Corps mitigation policy on fish and wildlife and historic and archaeological resources is included in ER 1105-2-50, Chapters 2 and 3, and current Engineering Circulars. All actions related to planning and implementing mitigation should incorporate appropriate Engineer Regulations and Engineer Circulars.

8-2. Definition.

a. Mitigation. The Council on Environmental Quality (CEQ), in its Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (40 CFR Part 1508.20), published a definition of mitigation that has been adopted by the Corps (ER 1105-2-50) and includes:

(1) Avoiding the impact altogether by not taking a certain action or parts of an action.

(2) Minimizing impacts by limiting the degree or magnitude of the action and its implementation.

(3) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment.

(4) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.

(5) Compensating for the impact by replacing or providing substitute resources or environments.

These will be referred to as the five elements of mitigation.

b. Significant Resources and Effects. Significance includes meanings of context and intensity. Context refers to the degree of technical, institutional, and/or public recognition accorded to a resource at local, regional, or national levels. Intensity refers to the severity of impacts as measured in duration, location, and magnitude of effects. The criteria for determining the significance of environmental resources and effects are provided in ER 1105-2-50, Appendix A, Section 1.7.3, and subsections 3.4.3, and 3.4.12. Significance of historic resources is further defined as a property listed or determined to be eligible for listing in the National Register of Historic Places (ER 1105-2-50, Chapter 3).

8-3. Key Concepts for Mitigation.

a. General.

(1) Significant resources are to be identified and specifically considered in all phases of a project. If significant losses to those resources will occur because of the project or action, then those losses must be mitigated.

(2) Mitigation consists of avoiding, minimizing, rectifying, reducing, or compensating for the impacts. The five elements of mitigation are logically stepwise, i.e., it is better, easier, and often cheaper to avoid an impact than to compensate for it. The elements are iterative in that the results from one step may require reexamination of previous actions. The first elements of mitigation can often be accomplished through the use of good engineering practices, e.g., changes in project design.

(3) Impacts resulting from coastal shore protection projects are largely on coastal and Great Lakes bottoms, shorelines, wetlands, submerged aquatics, coral reefs, and other tropical and subtropical ecosystems. These areas will usually be composed of or are considered to be significant resources. Chapters 4-6 of this EM discuss potential impacts on some of these resources.

b. Early and Continuous Coordination and Public Involvement. Planning for mitigation must occur concurrently and proportionally with overall project planning activities and with the involvement of personnel from all appropriate state and Federal agencies (ER 1105-2-35). An integrated planning effort assures that the significant resources are correctly identified, significant impacts are determined, all the elements of mitigation are considered, and the mitigation actions taken or recommended are appropriate and justified.

c. Monetary and Nonmonetary Concerns. Both monetary and nonmonetary aspects of significant resources and effects will be considered. Monetary aspects are quantified using dollars, and nonmonetary aspects are quantified using one of several appropriate measures such as Habitat Units, acres, population data, Visual Impact Assessment Units, parts per million, and use-days.

d. Mitigation Framework. A useful framework for describing mitigation has two of four conditions:

(1) In kind - resources physically, biologically, and functionally the same or similar to those being altered.

(2) Out of kind - resources physically, biologically, and/or functionally dissimilar to those being altered.

(3) Onsite - occurring on, adjacent to, or in the immediate proximity of the impact.

(4) Offsite - occurring away from the site of the impact.

The first four elements of mitigation in paragraph 8-2a generally take place onsite, the fifth one may be onsite or offsite. Mitigation in kind and onsite requires no trade-offs, while the out of kind and offsite conditions show that relative values have been assigned.

e. Mitigation Objectives. Mitigation objectives should be stated as a quantification of the amount of compensation required for significant losses to significant resources. Both the identity and character of the significant resources and the amount of losses to them should be clearly documented. Significant resources should be placed in a priority list or category, accompanied by any stipulations such as the weightings to be used in trade-off analysis, trade-offs not allowed, or mitigation to be onsite.

f. Incremental Cost Analysis. Incremental or marginal cost analysis is a process used in designing a compensation plan that meets the mitigation objectives. It investigates and characterizes how the cost of a unit of output increases as the level of output changes, e.g., change in dollars per Habitat Unit with increasing Habitat Units. An analysis will result in an array of implementable mitigation actions, ranked from most to least cost-effective. A mitigation measure such as beach nourishment or placement of a sand fence becomes an increment when it is combined with other measures into a plan and analyzed to determine the most cost-effective solution.

g. Justification for Mitigation. Justification for mitigation must be based on the significance of the resource losses due to a project, compared to the costs necessary to carry out the mitigation (ER 1105-2-50, paragraph 2-4c(1)). Endangered and threatened species and designated critical habitats will be given special consideration (Public Law 93-205, as amended, 15 U.S.C. 1531-1543).

8-4. Examples. Throughout the text of this EM are measures that can serve one or more of the mitigation elements. Example measures of each of the elements are listed below:

a. Avoid -- Time construction activities to avoid periods of fish migration or shorebird nesting; preserve a public access point.

b. Minimize -- Disturb an immature reef instead of a mature one; use rough surface-facing materials on a structure.

c. Rectify -- Replace a berm; restore flow to former wetlands.

d. Reduce -- Control erosion; place restrictions on equipment and movement of construction and maintenance personnel.

e. Compensate -- Use dredged material to increase beach habitat; construct an artificial reef.

APPENDIX A

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APPENDIX B

MODELS

Section I. Numerical Models

B-1. Introduction. Numerical models use computational methods to solve mathematical expressions describing physical, chemical, and biological phenomena. Computational methods such as approximation and iteration performed by high-speed digital computers allow solution of complex equations that cannot be solved by analytical methods.

a. Numerical modeling provides much more detailed results than analytical methods and may be substantially more accurate, but it does so at the expense of time and money. However, once a numerical model has been formulated and verified, it can quickly provide results for different conditions. In addition, numerical models are capable of simulating some processing that cannot be handled in any other way. They are also limited by the modeler's ability to derive and accurately solve mathematical expressions that truly represent the processes being modeled.

b. The four types of numerical models that are pertinent in the investigation of the environmental impact of coastal shore protection projects include:

(1) Hydrodynamic models describe the velocity components, water surface elevations, and salinity (or any other conservative passive constituent) distributions within the study area.

(2) Sediment transport models predict the shoreline response (erosion or accretion) to man-made engineering structural or dredged channel modifications, and estimate the ultimate fate (resuspension, transport, and deposition) of dredged material disposed in an aquatic dredged material disposal site.

(3) Water quality models predict physical characteristics and chemical constituent concentrations of the water at various locations within the study area.

(4) Ecological models predict the interactions between water quality and the aquatic community.

c. The information derived from hydrodynamic models forms part of the data base for sediment transport, water quality, and ecological models, and the data from sediment transport and water quality models, in turn, form part of the data base for ecological models. Hence, it is essential that these foundation modeling activities be accomplished with adequate accuracy. The various described models require input data which may be classified as:

(1) Initial conditions. The data describe the initial state of the system prior to numerical modeling.

(2) Boundary conditions. The data specify the system geometry and the quantity and constituent concentrations of freshwater inflows or other depositions.

(3) Verification requirements. Any other data considered necessary for the verification (or calibration) of the numerical models.

B-2. Field Data.

a. Because no numerical model study can be more accurate than the information on which it is based, the importance of adequate field data cannot be overemphasized. The first steps in any numerical model study must be the specification of objectives: an assessment of the geophysical, chemical, and biological factors involved; and collection of data essential to describe these factors. Assessment and data collection should include:

(1) Identification of freshwater inflow sources, including their average, range, and time history distribution of such inflow.

(2) Assessment of the tides and tidal currents that exist within the region of interest.

(3) Evaluation of wind effects and other geophysical phenomena that may be peculiar to the specific study and that may contribute to aeolian sediment transport within or beyond the study boundary limits.

(4) Complete understanding of wave climate throughout the region of interest, including seasonal and annual distribution with frequencies of occurrence by height, period, and direction of approach.

(5) Knowledge of the resulting wave-induced currents.

(6) Evaluation of the effects of simultaneous occurrence of unidirectional flow (tidal currents or freshwater river inflow) and oscillatory currents (wave-induced particle motion).

(7) Assessment of effects and probability of occurrence of aperiodic extreme meteorological events such as severe storms or hurricanes.

(8) Identification of the sources of sedimentation and of the sediment types for development of a sediment budget analysis of the system under evaluation.

(9) Determination of sources and expected quantities and composition of industrial and municipal effluents, nonpoint contaminants, and tributary constituent concentrations.

(10) Identification and census of the aquatic community of the region, and the chemical, physical, and biological factors which influence its behavior.

(11) Archive of all available hydrographic, bathymetric, topographic, and other geometric data pertinent to preparation of numerical models.

b. The purpose of the preliminary assessment of pertinent and available data is to provide a basis for the selection of the models needed and for planning field data acquisition programs. The most satisfactory procedure is to plan the numerical modeling and field data acquisition program together. If possible, the basic hydrodynamic model should be operational during the period in which field data are being acquired. One major reason for concurrent model simulation and data acquisition is that anomalies in field data frequently occur, and the numerical model may be useful in identifying and resolving any such anomalies.

B-3. Data Analysis.

a. In conjunction with the field data acquisition program and the projected numerical modeling activity, a program of data analysis must be undertaken. For the data analysis program to be as efficient as possible, the field data should be recorded on media that can be automatically read by the computer equipment to be used for such data processing.

b. Data analysis includes isolation of the astronomical tide from the tidal record and for an identification of the decomposition of the constituents of the astronomical tide. The purpose of separating the astronomical tide from the observed tide is two-fold:

(1) This separation allows one to examine the residual and, by using statistical methods, to investigate the extent to which other geophysical phenomena, such as wind, influence the observed flow.

(2) The astronomical tide is deterministic and may be used in synthesizing tidal records for hypothetical events or during periods for which tide records are not available.

c. Three fundamental observations regarding data analysis should be considered:

(1) The astronomical tide is somewhat dependent on freshwater inflows into the study region, and the amplitude of the tidal constituents therefore tends to vary seasonally in many coastal areas.

(2) Past experience in the analysis of tidal data in conjunction with model studies has shown that a minimum of about 30 days of record for tidal elevation, velocity, and salinity data is essential for satisfactory analysis.

(3) Data should be synoptic, with all data stations being monitored during the same time period in order to properly verify the numerical models.

B-4. Hydrodynamic Models. Numerical models of hydrodynamic processes, sediment transport, and water quality processes are said to be coupled if they are applied simultaneously and interactively on a digital computer. The codes use the same spatial and temporal grid. If, conversely, the hydrodynamic model is run and the output from it used as input to the sediment transport or water quality model, the two models are said to be uncoupled. With uncoupled codes, the hydrodynamic output may be spatially and/or temporarily averaged and subsequently used as input to the water quality model. In many instances, it is more economical to run uncoupled models. Uncoupled models are unacceptable where thermal gradients or the concentration of dissolved or suspended material causes a large enough variation in the fluid density to substantially affect the flow.

a. General. The various numerical models may be classified as one-, two-, or three-dimensional. The one-dimensional models treat the system by averaging over a succession of cross sections. One-dimensional models are well suited to geometric situations such as channels with relatively uniform cross-sectional shape and with center lines whose radius of curvature is relatively large compared to the width, provided the water density is uniform over the cross section. Two-dimensional depth-averaged models are the type most commonly employed and are well suited to studies in areas such as shallow estuaries where the water column is relatively well mixed. Laterally averaged models are used in studies of relatively deep and narrow bodies of water with significant variation of density vertically through the water column. Three-dimensional hydrodynamic models are relatively new and have been applied to only a limited number of practical studies. In general, two-dimensional models are substantially more expensive to operate than one-dimensional models, and three-dimensional models are more complex and more expensive than two-dimensional models. Hence, in situations where it is known a priori that one of the simpler models will produce satisfactory results, the simpler model should be employed for economy.

b. Two-Dimensional Depth-Averaged Models. Two-dimensional depth-averaged models are most commonly employed in the investigation of tidal flows in inlets, bays, and estuaries. The two distinctly different formulations that have been employed are finite difference and finite element. Models currently being used at the Waterways Experiment Station (WES) include the finite difference model WIFM (WES Implicit Flooding Model), which evolved from early work by Leendertse (1967, 1973). The model and its application have been refined and significantly improved at WES, and have been described at different stages of development by Butler (1980). The finite element flow model of Research Management Associates (RMA-2V) (Ariathurai and Arulanadan 1978) evolved rom work by Norton et al. (1973) sponsored by US Army Engineer District, Walla Walla. The WES version of this model and a companion sediment transport model, STUDH, and their application to project studies have been described by McAnally et al. (1983). A user's manual for these finite element models and support programs (TABS-2) has been prepared by Thomas and McAnally

(1985). Most existing finite difference models employ cartesian coordinates which, even with variable grid spacing capabilities, may lead to undesirable approximations in schematization of complex study areas. Recent work by Johnson (1980) has resulted in a finite difference model VAHM (Vertically Averaged Hydrodynamic Model) for flow and transport which employs a generalized coordinate transformation technique called boundary-fitted coordinates to overcome this limitation. Development of this approach is continuing.

c. Two-Dimensional Laterally Averaged Models. Laterally averaged models are applicable in studies of relatively deep, narrow channels with small radius of curvature in which lateral secondary, currents of appreciable magnitude do not develop. Since fewer systems meet this criterion, work on models of this type has been more limited than on the depth-averaged models. However, work performed during the last few years has produced a useful model CE-QUAL-W2 (Environmental Laboratory, Hydraulics Laboratory 1986). CE-QUAL-W2 was originally developed as a two-dimensional laterally averaged free surface and heat conducting model (LARM) for computing reservoir flow patterns (Edinger and Buchak 1979). In more recent developments, the water density was allowed to be a function of both temperature and salinity, and estuarine boundary conditions were incorporated. This version was called LAEM (Edinger and Buchak 1981). LARM and LAEM were combined with multiple branching capabilities and renamed GLVHT (Buchak and Edinger 1983). WES included water quality algorithms and named the resulting code CE-QUAL-W2. These codes have been used to investigate the effect of navigational channel deepening on salinity intrusion in the Lower Mississippi River and the Savannah River estuary.

d. Three-Dimensional Models. Depth- and laterally averaged two-dimensional models obviously lack the ability to predict secondary flows involving the plane that has been averaged. In some instances, these secondary currents may be appreciable and affect such things as salinity intrusion, sediment transport, thermal distribution, and water quality. Leendertse et al. (1973) pioneered the development of one of the early three-dimensional models of an estuary. Leendertse ' s model employed cartesian coordinates. A three-dimensional model that utilizes stretched coordinates in both the horizontal and vertical directions has been developed and applied in studies of the Mississippi Sound (Sheng and Butler 1982, Sheng 1983). This model CELC3D (Coastal, Estuarine, and Lake Currents; Three-Dimensional) may be used to provide detailed computations of the currents within several tidal cycles or time scales of a storm event. For a scenario of repeatable hydrodynamics, CELC3D may be combined with the sediment transport algorithm for long-term computations on the order of weeks, months, or longer. Three-dimensional versions of the finite element flow and sediment models have also been developed and have been applied to several field sites (Ariathurai 1982, King 1982). Improvements in the efficiency of computational equipment and modeling technology are increasing the feasibility of applying three-dimensional models.

B-5. Sediment Transport Models. The transport of noncohesive and cohesive sediments under the simultaneous action of waves and currents takes place along natural beaches, coastlines, bays, estuaries, and elsewhere when waves become superposed upon currents. The currents may be wave-induced, wind-driven, tidal, and stream, or may originate from some other less cause.

a. CIP (Coastal and Inlet Processes Numerical Modeling System). Coastal processes of tides, waves, wave-induced currents, and sediment transport can be modeled by using the numerical modeling system CIP (Coastal and Inlet Processes). The system utilizes the WES Implicit Flooding Model (WIFM) for tides, the Regional Coastal Processes Wave Propagation Model (RCPWAVE) for waves, the model CURRENT for wave-induced currents, and a sediment transport model for transport of sediment due to the combined action of tides, waves, and wave-induced currents. All four models generally use the same computational grid for a given set of conditions.

(1) WIFM is a general, long-wave model which can be used for simulation of tides, storm surges, tsunamis, etc. It allows flooding and drying of land cells near the shoreline. It is a depth-averaged model so that variations in the vertical direction are averaged in the model. It is used to determine tidal elevations and velocities in the two horizontal coordinate directions.

(2) RCPWAVE is a linear, short-wave model which considers the transformation of surface gravity waves in shallow water, including the processes of shoaling, refraction, and diffraction due to bathymetry, and allows for wave breaking and decay within the surf zone (the region shoreward of the breaker line). Unlike traditional wave-ray tracing methods, the model uses a rectilinear grid so that model output in the form of wave height, direction, and wave number is available at the centers of the grid cells. This method is highly advantageous since the information can be used directly as input to the wave-induced current and sediment transport models, and the problem of caustics due to crossing of wave rays is avoided.

(3) CURRENT computes the wave-induced currents that result when wave breaks and decay in the surf zone. In general, such breaking induces currents in the longshore and cross-shore directions with resulting changes in the mean water level. These currents play a major role in the movement of sediment in the nearshore region.

(4) The sediment transport model predicts the transport, deposition, and erosion of sediments in open coast areas as well as in the vicinity of tidal inlets. It accounts for both tides and wave action by using for input the results of WIFM, RCPWAVE, and CURRENT in terms of tidal elevations and currents, wave climate information, wave-induced currents, and setups at the centers of grid cells. The model computes transport separately for straight open coast areas, and areas in the vicinity of tidal inlets. In the case of straight open coast areas, transport inside and outside the surf zone is treated separately.

(a) Transport inside the surf zone. Inside the surf zone, it is the wave-breaking process that is primarily responsible for the transport of sediment. This process is quite complex and not entirely understood. There is even disagreement on the primary mode (bed load or suspended load) of sediment transport in the surf zone. Thus, a model that determines transport in the surf zone must be empirical to some degree in its formulation. The surf zone transport model is based upon an energetics concept which considers that the wave orbital motion provides a stress that moves sediment back and forth in an amount proportional to the local rate of energy dissipation. Although there is no net transport as a result of this motion, the sediment is in dispersed and suspended state so that a steady current of arbitrary strength will transport the sediment. Thus, breaking waves provide the power to support sediment in a dispersed state (bed and suspended load), while a superposed current (littoral, rip, tidal, etc.) produces net sediment transport.

(b) Transport beyond the surf zone. Beyond the surf zone, waves are not breaking. Currents (tidal, littoral, rip, etc.) still transport sediments, but the sediment load is much smaller than the load in the surf zone. Waves still assist in providing power to support sand in a dispersed state. However, there is little turbulent energy dissipation, and frictional energy dissipated on the bottom represents most of the energy dissipation. Bed load is the primary mode of sediment transport beyond the surf zone. Since beyond the surf zone it is the tractive forces of currents (including wave orbital velocity currents) that produce sediment movement, an approach is applied which considers sediment transport by such currents which may exist in the area. Again, since the complete physics of the problem is not entirely understood, a semiempirical approach must be undertaken. To model this zone, the approach of Ackers and White (1973) is followed, after appropriate modification for the influence of waves.

(5) The CIP (Coastal and Inlet Processes Numerical Modeling System) has been applied by WES to the entrance region of Kings Bay Naval Submarine Base, Georgia. The sediment transport model was verified by comparing computed erosion and deposition rates in the navigation channel with those obtained from field surveys. There was good agreement both with respect to trends and magnitudes.

b. Shoreline Change Model. A numerical model for predicting shoreline evolution has been developed by Le Mehaute and Soldate (1980), which evaluates long-term three-dimensional beach changes. The combined effects of variations of sea level, wave refraction and diffraction, loss of sand by density currents during storms, by rip currents, and by wind, bluff erosion and berm accretion, effects of man-made structures such as long groins or navigation structures, and beach nourishment are all taken into account. A computer program has been developed with various subroutines which permit modifications as the state-of-the-art progresses. The program has been applied to a test case at Holland Harbor, Michigan.

c. N-Line Sediment Transport Model. An implicit finite-difference, N-Line numerical model has been developed by Perlin and Dean (1983) to predict bathymetric changes in the vicinity of coastal structures. The wave field transformation includes refraction, shoaling, and diffraction. The model is capable of simulating one or more shore-perpendicular structures, movement of offshore disposal mounds, and beach fill evolution. The structure length and location, sediment properties, equilibrium beach profile, etc., are user-specified along with the wave climate. The N-Line model has been used to simulate sediment transport of dredged material disposal in the vicinity of Oregon Inlet, North Carolina.

d. CELC3D Sediment Transport Model.

(1) The most recent advance in the area of mathematical modeling of coastal currents and sediment dispersion (resuspension, transport, and deposition), as well as the state of the art at the present time has been conducted by Sheng and Butler (1982) and Sheng (1983). An efficient, three-dimensional, and comprehensive numerical model of coastal currents, CELC3D (Coastal, Estuarine, and Lake Currents; Three-dimensional), has been developed and is operational. The authors have provided a thorough quantitative analysis of the role of turbulence in affecting the deposition, entrainment, and transport of cohesive sediments. Detailed dynamics within a turbulent boundary layer, under pure wave or wave-current interaction, has been studied by means of a turbulent transport model. Model predictions compare well with prototype data and are more accurate than simpler parametric models. Dispersions of sediment due to tidal currents, wind-driven currents, and waves have been studied. Waves were found to be generally more effective in causing entrainment (resuspension) of sediments.

(2) Physical models, field studies, and laboratory investigations were utilized to aid in the ultimate construction of CELC3D. Special features of CELC3D include:

(a) A "mode-splitting" procedure which allows efficient computation of the vertical flow structures (internal model).

(b) An efficient alternating direction implicit (ADI) scheme for the computation of the vertically-integrated variables (external mode).

(c) An implicit scheme for the vertical diffusion terms.

(d) A vertically and horizontally stretched coordinate system.

(e) A turbulence parameterization which requires relatively little tuning.

(3) Slowly varying currents and wave orbital velocities generally both contribute to the generation of bottom shear stress in shallow or intermediate waters. To remove empiricism from CELC3D simulation, Sheng (1983) used a dynamic turbulent model to predict the wave-current interaction within the bottom boundary layer. Calibration data were collected at a 90-meter water depth site about 1 kilometer off the California coast during the Coastal Ocean Dynamics Experiment (CODE-1) program. Due to the relatively long fetch from the north, high seas (6-8 feet) were typical, and wavelengths were sufficiently long for the wave to feel the bottom. Velocity profiles (averaged over 6-minute intervals) at this site showed typical logarithmic variation

with height above the bottom. The values of the frictional velocity, u_*, were typically between 0.22 and 0.66 centimeter per second. Using reference velocities at 1 meter, these u_* values correspond to drag coefficients of 0.019 and 0.026, respectively. Corresponding values of the effective roughness height, z_o , in the presence of waves are 1.3 and 3.0 centimeters, respectively. These values are an order of magnitude greater than the z_o based on physical roughness alone.

B-6. Water Quality Models. Historically, the analysis of water quality has concentrated on the dissolved oxygen (DO) and biochemical oxygen demand (ROD). The balance between DO and BOD concentrations was the result of two processes: the reaeration of the water column, and the consumption of DO in oxidation of BOD. Later emphasis has been on extending and refining the Streeter-Phelps formulation by using a more generalized mass balance approach and by the inclusion of additional processes such as benthic oxygen demand, benthic scour and deposition, photosynthesis and respiration of aquatic plants, and nitrification. The more comprehensive water quality models have been developed to include the nitrogen and phosphorus cycle and the lower trophic levels of phytoplankton and zooplankton. A number of investigations have modeled the algal nutrient silica. Selected chemical constituents have been modeled by assuming thermodynamic equilibrium. The fate of toxicants such as pesticides, metals, and PCB’s is very complicated, for they involve adsorption-desorption reactions, flocculation, precipitation, sedimentation, volatilization, hydrolysis, photolysis, microbial degradation, and biological uptake. Selection of a water quality methodology requires consideration of Water Quality Constituents and Dimensional and Temporal Resolution.

a. Water Quality Constituents. The water quality constituents most frequently simulated include salinity, light, temperature, DO, ROD, coliform bacteria, algae, nitrogen, and phosphorus. Each of these constituents interacts with the others, but the significance of their dependencies varies among constituents, and their inclusion in a numerical water quality model depends upon the study objectives and the water body under consideration. The environmental impact analysis of most coastal shore protection projects can use salinity and DO as indices of environmental change. Salinity plays a dominant role in physio-chemical phenomena such as flocculation of suspended particulates, is used as a variable to define the habitat suitability for aquatic organisms, and is frequently employed as a conservative tracer to calibrate mixing parameters. Dissolved oxygen is a respiratory requirement for most organisms and is used as a measure of the "health" of aquatic systems. Dissolved oxygen can be used to evaluate the environmental significance of stratification resulting from channel deepening and realignment of deep-draft navigation projects, or most other coastal shore protection projects.

b. Dimensional and Temporal Resolution.

(1) In a numerical water quality model the choice is between a one-dimensional model and one that incorporates two or three spatial dimensions.

A long, narrow, and vertically well-mixed water body may be represented by a one-dimensional model consisting of a series of segments averaged over the cross section. Where there is pronounced vertical stratification, it is likely that a laterally averaged two-dimensional model will be needed. In other situations where there are marked lateral inhomogeneities that are accompanied by pronounced stratification, a three-dimensional model may be required. Most existing water quality models are one-dimensional, Practical application of two-dimensional laterally and depth-integrated models has been made and is feasible. The Corps has recently developed and applied three-dimensional water quality models.

(2) The basis of all water quality models is a velocity field either specified by empirical measurements or computed by numerical hydrodynamic models. The current trend in hydrodynamic modeling is toward development of three-dimensional models with increased spatial and temporal resolution in order to resolve important scales and minimize the need for parameterization. As a result, modern time-dependent hydrodynamic models normally have time steps on the order of minutes to 1 hour. The chemical and biological equations of water quality models have characteristic time scales determined by the kinetic rate coefficients. These time scales are usually on the order of 1 to 10 days. The phenomena of interest, such as depletion of DO and excessive plant growth, occur on time scales of days to several months. Direct coupling of hydrodynamic and water quality models may provide unnecessary spatial and temporal resolution, and the high resolution water quality model results cannot be effectively interpreted or verified. Present field sampling programs resolve constituent concentrations on the order of a kilometer to tens of kilometers in the horizontal, meters in the vertical, and days to weeks in time. In addition, the kinetic rate coefficients presently used in water quality models resolve dynamics on the order of days to weeks.

c. Numerical Water Quality Models. Linkage of the hydrodynamics and water quality using the same spatial and temporal grid is practical with one-dimensional and some two-dimensional models even for long-term simulations. However, long-term water quality simulations are computationally very expensive when water quality is directly coupled to two-dimensional vertically averaged and three-dimensional hydrodynamic models. Therefore, the Environmental Laboratory has developed not only one-dimensional and two-dimensional laterally averaged numerical water quality models that use the same spatial and temporal grid used by the hydrodynamic driver but also a method for averaging fine scale hydrodynamic data to drive a coarser scale water quality model for two-dimensional depth-averaged and three-dimensional applications.

(1) CE-QUAL-RIVI is a dynamic, one-dimensional (longitudinal) hydrodynamic and water quality model originally developed for flows in streams. Recent enhancements included provision for tidal boundary conditions and reversing flows. The hydrodynamic and water quality codes are separate but use the same spatial and temporal grid. Simulated water quality constituents include temperature, DO, CBOD, organic nitrogen, ammonia nitrogen, nitrate nitrogen, orthophosphate phosphorus, coliform bacteria, dissolved iron, and dissolved manganese.

(2) CE-QUAL-W2 is a two-dimensional laterally averaged hydrodynamic and water quality model developed for reservoirs and estuaries (Environmental Laboratory, Hydraulics Laboratory 1986). The water quality coding is arranged into hierarchial levels of complexity, allowing the user to select the level of water quality detail desired for a particular study. The first level of complexity deals with conservative and noninteractive constituents (e.g., conservative tracer and coliform bacteria), the second level with DO-BOD or DO-nutrient-phytoplankton dynamics, the third with PH and carbonated species, and the fourth level with reduced chemical species.

(3) The MULTIPLE-BOX model method consists, of driving a finite segment, box-type water quality model with temporally and/or spatially averaged hydrodynamic output. The box model segment sizes, time step, and dispersion coefficients are adjusted to assure that transport with the box model adequately reproduces that of the finer scale hydrodynamic/transport model. The EPA’s multiple-box model WASP (Water Quality Analysis Simulation Program) was selected as the transport framework for a versatile water quality model that could be interfaced with hydrodynamic model (Ambrose et al. 1986). WASP contains a variety of water quality kinetic algorithms that the user may select, including toxic substances. The WASP code may be applied in one-, two-, or three-dimensional configurations. The code does not compute hydrodynamics; the use of the WASP code requires hydrodynamic input. A methodology for spatially and temporally averaging hydrodynamic output is being developed by WES.

B-7. Ecological Models. Ecological models include numerous biological species and emphasis food chain and species interactions. No general ecological model exists. Existing ecological models are site-specific and dependent upon the local aquatic community. The Environmental Laboratory at WES serves as a clearinghouse for Corps inquiries and is becoming an active participant in ecological model application.

B-8. Modeling Systems.

a. Consideration has been given to some of the more important aspects of numerical model selection and application. Hydrodynamic, sediment transport, water quality, and ecological models may not be considered as individual entities. The various models must be coupled, or the output of one model must be used as input to a subsequent model. If the applicable models are to be used efficiently and economically, the data transfer between the models must be considered and steps must be taken to ensure output-to-input compatibility. In modeling there are, in addition to the modeling itself, data to be collected, analyzed, and put into appropriate data bases. Each of these activities requires substantial data processing, and the aggregate cost of these activities may far exceed the cost of the actual modeling exercise. Also associated with most studies are other requirements, such as reports, which lead to additional data processing for such activities as computer graphs. The development of the models and other programs requires a broad spectrum of technical talents, and the execution of a comprehensive study may require the interaction of several individuals.

b. A comprehensive, integrated system of modeling and utility programs, which are documented to the extent that the system may be understood and used by the various individuals participating in the study, is essential to an effective study. Such systems are emerging. The WES Hydraulics Laboratory has developed a system for Open Channel Flow and Sedimentation (TABS-2) that uses depth-averaged finite element models to predict hydrodynamics, salinity, and sediment transport. The WES Environmental Laboratory has developed the one-dimensional (CE-QUAL-RIVI), the two-dimensional laterally averaged (CE-QUAL-W2) (in conjunction with the Hydraulics Laboratory), and the arbitrarily dimensioned multiple-box model. The WES Coastal Engineering Research Center has developed and made operational an efficient, comprehensive, and three-dimensional numerical model system of coastal currents and sediment transport, CELC3D, which provides for the resuspension, transport, and deposition of coastal sediments where sediment particle dynamics is modeled by a consideration of particle groups and coagulation processes. The emergence of such comprehensive systems is a significant aspect of the advancement of numerical modeling of the environmental engineering aspects of coastal shore protection projects.

Section II. Physical Models

B-9. Physical Coastal Models.

a. Earlier sections of this EM discuss specific considerations that must be addressed to evaluate the impacts of coastal shore protection projects on hydrodynamics, sediment transport, water quality, biological, or ecological conditions. One of the tools that often is applied to make the necessary predictions of these conditions is the physical coastal model. This section provides a brief description of physical coastal modeling and its relation to other models. It is intended to familiarize engineers and scientists with the use of this technique in preparing impact studies. The relative strengths and weaknesses are discussed so that, depending on the specific situation, physical coastal models might be considered in a modeling strategy. The basis and methods used in physical coastal modeling are also briefly described.

b. For projects in which dependable, accurate results warrant the additional expense, a physical coastal model study is recommended. This approach is especially recommended if the system is partially mixed or stratified in vertical salinity structure, or if it has a complicated geometry. Guidance for initiating physical (hydraulic) models studies is given in ER 1110-2-8102, ER 1110-2-1403, and related ER’s. The Coastal Engineering Research Center’s comprehensive report by Hudson et al. (1979) discusses physical models to assist in the solution of complex coastal engineering problems. This report provides information for use by both the laboratory research engineer and the field design engineer on the capabilities and limitations of coastal hydraulic modeling procedures. The report is intended to provide sufficient information to document the state of the art of scale modeling practiced by WES. It is also intended for field design engineers and other laboratory research engineers to better understand the principles of scale models and the application of these principles in the design, construction, and operation of scale hydraulic coastal models in the solution of problems involving the interaction of waves, tides, currents, and related sediment movements in estuaries, coastal harbors, coastal erosion, and stability of coastal structures and inlets. Estuarine and coastal physical hydraulic model studies performed at WES usually require from 18 to 48 months, and cost approximately $20 per square foot of model to build, and approximately $20,000 per month to operate (1986 dollars).

c. Physical coastal models are scaled representations of a coastal problem area under study. Seawater supply, tide generators, wave generators, and gaged freshwater inflows are necessary appurtenances. The models are often molded in concrete between closely spaced templates, although many coastal models are constructed with movable-bed boundaries. Instrumentation may be mounted on the models or experimental samples may be withdrawn from the models to measure such attributes as water surface elevation, current speed and direction, salinity, and tracer concentrations. Water surface tracers and dye patterns are often photographed to qualitatively and quantitatively examine their behavior or patterns of flow.

d. Boundaries and features of models should be carefully planned. A physical coastal model is designed and constructed to include the region of interest and any other areas necessary so that boundary data or conditions can be satisfactorily applied. If the effects of assimilative capacity on the area of interest are to be tested, effluent outfalls or diffusers are included in model design and construction. If all the modifications to be tested in the model study are anticipated at the time of model design, provisions can be made to make them quickly and much less expensively.

B-10. Similarity Criterion.

a. In any coastal model study, the physical phenomena observed in the model should represent those phenomena occurring in the prototype, so that the prototype action can be predicted by operating the model. The general theory of model design is based on the fundamental principle that a functional relationship exists among all the variables associated with the system. Further, the number of variables can be significantly reduced by forming a complete set of dimensionless variables for which a new function expressing the relationship between the dimensionless terms exists. If the model is designed so that each of the dimensionless terms of the complete set is the same in the model as in the prototype, then the nature of the unknown function is identical for the model and the prototype. If all these conditions are satisfied, the model is considered a "true" model which provides accurate information concerning the behavior of the prototype.

b. Although space limitation for the construction of the model may sometimes dictate that the model be distorted, a physical model can usually be operated with the same linear scale in all three dimensions (i.e. an undistorted-scale model). This undistorted-scale model dictates that geometric similarity exists, as the ratios of all homologous dimensions on the model and prototype are equal. In addition to geometric similarity, a true undistorted-scale model requires that kinematic similarity and dynamic similarity also exist. Kinematic similarity exists when the ratios of all homologous velocities and accelerations are equal in the model and prototype. Dynamic similarity requires that the ratios of all homologous forces be the same in the model and prototype. Since force is related to the product of mass and acceleration, dynamic similarity implies the existence of kinematic similarity which, in turn, implies the existence of geometric similarity.

c. For dynamic similarity, the ratio of the inertial force between model and prototype must be the same as the ratio of the individual force components between the model and prototype. The ratios of the inertial force to the other component forces must also be the same between model and prototype. These ratios have developed a reference to specific names, such as the ratio of the inertial force for the pressure force as:

$$E_n = \frac{F_i}{F_{pr}} = \frac{p}{\rho V^2} \text{ (Euler No.)} \tag{B-1}$$

$$F_n = \frac{F_i}{F_g} = \frac{V}{(gL)^{1/2}} \text{ (Froude No.)} \tag{B-2}$$

$$R_n = \frac{F_i}{F_\mu} = \frac{VL\rho}{\mu} \text{ (Reynolds No.)} \tag{B-3}$$

$$W_n = \frac{F_i}{F_{st}} = \frac{\sigma}{\rho V^2 L} \text{ (Weber No.)} \tag{B-4}$$

Since only three of these equations are independent, the Euler number will automatically be equal. in the model and prototype if the other numbers are equal. For the remaining three equations,

$$\left[\frac{V}{(gL)^{1/2}}\right]_r = \left(\frac{VL\rho}{\mu}\right)_r = \left(\frac{\sigma}{\rho V^2 L}\right)_r = 1 \tag{B-5}$$

It can be demonstrated that no single model fluid will permit all of these equations to be satisfied at once. Therefore, absolutely true dynamic and kinematic similarity apparently cannot be achieved between a model and the prototype. However, one or more of the specific forces are often found to be negligible, and the number of equations to be satisfied can be reduced accordingly. In fact, the phenomena in a particular instance often involve the effect of only one force ratio, and the others are negligible.

d. The use of water as a model fluid is usually necessary in physical coastal models. Surface tension, the least important term if the depths of the fluid are not excessively small, will have a negligible effect on the flow of water more than 0.25 foot deep, or on waves with lengths exceeding about 1 foot in the same water depth. By ensuring that the flow and waves exceed these limiting values, the effect of surface tension can be neglected.

e. When both viscous and gravity forces are important, the Froude and Reynolds numbers should both be satisfied simultaneously. This requirement can only be met by choosing a special model fluid. Since water is the only practical model fluid, an approximate similarity requirement may be used, based on empirical relationships which include the major effects of frictional forces (such as Manning's equation). Since fairly high Reynolds numbers are usually associated with tidal flows through coastal models, the shear stresses are primarily determined by form drag. The use of Manning's formula as a similarity criterion requires that the flow be fully rough turbulent in both the model and prototype. When a bulk Reynolds number, defined as $Vd/<$, is greater than about 1,400 (where d is the depth of flow and < is the kinematic viscosity), fully rough turbulence will normally exist. A surface gravity wave is essentially a gravitational phenomenon; therefore, the controlling criterion of similitude is the Froude number, and waves may be represented correctly in undistorted-scale coastal models.

f. There are several physical interpretations that may be given the Froude number, but fundamentally it is the ratio of inertial to gravitational forces acting on a particle of fluid. It can be shown that this ratio reduces to $V/(gL)^{1/2}$, where V is a characteristic velocity, and L is a representative length. Here the velocity is taken to be a horizontal length divided by the time parameter. However, any representative velocity and any representative length can be used in the Froude number as long as dynamic similarity is maintained and corresponding regions are considered in the model and prototype. The Froude number, defined as $V/(gd)^{1/2}$, is related to the vertical scale (depth), so that the velocity ratios are equal to the square root of the depth ratios. The pertinent ratios required for geometric, kinematic, and dynamic similarity, based on the Froudian similarity criterion, are developed in Table B-1.

B-11. Physical Coastal Model Design.

a. After the purpose of the coastal model study has been defined, the actual design of the model can proceed. The significant steps are acquisition of prototype data to assure model accuracy, establishment of model limits, and definition and acquisition of model appurtenances.

TABLE. B-1

Froude Criteria Scaling Relationships for Physical Coastal Models

	Undistorted-scale model	Distorted-scale model
	Geometric similarity	
Length	L_r	
(horizontal)		$(Lh)_r$
(vertical		$(Lv)_r$
Area	L_r^2	
(horizontal)		$(Lh)_r^2$
(vertical)		$(Lh)_r(Lv)_r$
Volume	L_r^3	$(Lh)_r^2(Lv)_r$
	Kinematic similarity	
Time	$L_r^{1/2}$	$(Lh)_r/(Lv)_r^{1/2}$
Velocity	$L_r^{1/2}$	$(Lv)_r^{1/2}$
Acceleration	1	1
Discharge	$L_r^{5/2}$	$(Lh)_r(Lv)_r^{3/2}$
Kinematic viscosity	$L_r^{3/2}$	$(Lv)_r^{3/2}$

(Continued)

TABLE B-1 (Continued)

	Undistorted-scale model	Distorted-scale model
	Dynamic similarity	
Mass	L_r^3	$(Lh)_r^2(Lv)_r$
Force	L_r^3	
(horizontal)		$(Lh)_r^3$
(vertical)		$(Lh)_r^2(Lv)_r$
Dynamic viscosity	$L_r^{3/2}$	$(Lv)_r^{3/2}$
Surface tension	L_r^2	$(Lh)_r^2$
Pressure intensity	L_r	$(Lv)_r$
Impulse and momentum	$L_r^{7/2}$	$(Lh)_r^2(Lv)_r^{3/2}$
Energy and work	L_r^4	$(Lh)_r^2(Lv)_r^2$
Power	$L_r^{7/2}$	$(Lh)_r(Lv)_r^{5/2}$

b. The importance of accurate prototype data cannot be overemphasized in model operation. The accuracy of the model is dependent on the use of proper field data. Although the similitude of fixed-bed, undistorted-scale models indicated that good approximation of bed-form losses can be derived in the model, assurance of accurate model results can only be achieved through a comparison of model and prototype results. To assure that the model is a geometric reproduction of the prototype, hydrographic and bathymetric surveys must include the pertinent bay and ocean approaches that influence the study region.

c. The final proof of model effectiveness is a comparison of current velocities and water surface elevations in both the model and the prototype. The requirements for a particular coastal model can vary extensively; however, a limited number of critically placed tide gages and wave gages, along with carefully located velocity stations, can provide enough information for confidence in the model operation.

d. The appurtenances required for an effective model study include:

(1) A tidal reproducing system for the ocean.

(2) A tide reproducing system for the bay if the bay is not completely modeled.

(3) Wave generator or generators.

(4) Tidal height measuring and recording system.

(5) Velocity measuring and recording system.

(6) Wave measuring and recording system.

(7) Photographic capabilities.

(8) Specialized equipment appropriate to the specific study under evaluation.

Each of these systems requires proper planning in designing the model as construction of the model depends on advanced knowledge of the specific requirements of each system.

B-12. Physical Coastal Model Construction.

a. Among the details that must be planned in model construction are the various modifications (plans) which will be evaluated during the model study. If, for example, the effects of dredging a feature (navigation channel, harbor, turning basin, etc.) are evaluated, the construction of the model should be based on this information. The templates prepared from detailed hydrographic and bathymetric maps to assure that the model is a true representation of the prototype should be modified to include the deepest possible navigation channel, deposition basin, turning basin, etc. This modification would allow the study of these features in later stages of the model testing program. A second set of templates can then be installed in the molded model to allow features of lesser depth to be incorporated into the model. Tests can then be conducted with the conditions of lesser depth in the model; when tests are completed, conversion of the model to evaluate a proposed change can be easily accomplished.

b. The construction of the coastal model requires the proper planning and sequencing of:

(1) Basic site preparation.

(2) Installation of buried features (i.e., pipelines, required bases for instrumentation support systems, etc.).

(3) Installation of control templates.

(4) Installation of base material.

(5) Placement of material (concrete, sand, etc.,) forming the model.

(6) Finishing the model for the desired surface texture.

(7) Fabrication and installation of tide-generating capabilities.

(8) Installation of wave generators, velocity recording systems, tide recording systems, wave recording systems, and photographic capabilities.

(9) Installation of other specialized monitoring equipment necessary to evaluate effects of proposed coastal projects on specific environmental or ecological parameters.

B-13. Fixed-Bed, Undistorted-Scale Coastal Models.

a. For coastal studies not concerned with the movement of sediments, fixed-bed models can often be easily developed to provide kinematic and dynamic responses indicative of the prototype conditions. Specifically, fixed-bed models reveal information regarding velocities, discharges, flow patterns, water surface elevations, and energy losses between points in the prototype. In the superposition of surface gravity waves on the fixed-bed flow conditions, an undistorted-scale model ideally provides greater insight at less effort into the refraction and diffraction phenomena associated with the wave passing the underwater topography and around coastal features. Accordingly, the fixed-bed, undistorted-scale model can be effectively used for the analysis of kinematic and dynamic conditions associated with waves, current intensities and patterns, discharges, and forces existing along coasts and in bays or estuaries.

b. A fixed-bed model (although not is primary purpose) may also be useful in studying shoaling of entrance and interior inlet channels. Saltwater intrusion and the effects thereon of proposed changes in the physical or hydraulic regimes of the system can be effectively studied by fixed-bed models. The diffusion, dispersion, and flushing of wastes discharged into coastal regions, as well as the hydraulics as related to location and design of channels suitable for navigation, can be expediently studied. Tidal flooding by hurricane surges or other tidal phenomena can also be readily analyzed.

(1) Model verification.

(a) The verification of a fixed-bed, undistorted-scale coastal model consists basically of conducting sufficient tests in the model to reproduce model boundary conditions (i.e., ocean tides, ocean waves, bay tides, and current velocities). The model data are then compared with prototype data for duplicate locations in the model and prototype to define the accuracy with which the model reproduces the prototype. If reproduction of the prototype is not achieved, the differences are evaluated for possible sources of error. Frequently, the differences are a result of either incorrect location of roughness in the model or improper magnitude of model roughness. If the comparison shows isolated stations to differ, the differences are usually caused by incorrect model results or erroneous prototype data collection. Repeating the model test will clearly indicate which of these causes produced the difference between the model and prototype information. If it is concluded that the model data were in error, then new model data can be quickly obtained.

(b) Model verification can also include definition of the model operating characteristics required to achieve reproduction of fixed-bed shoaling patterns throughout the coastal model. This procedure consists of a trial-and-error operation until the model operating conditions required to reproduce known changes in prototype shoaling are developed.

(2) Model tests.

(a) Tests in undistorted-scale, fixed-bed models can provide useful information on not only the hydrodynamics of a coastal region but also the expected changes to the hydrodynamics due to changes in the region. An effective model test program should include initially a complete set of tests to define the conditions that exist in the model for hydrographic, bathymetric, topographic, and hydraulic conditions for which the model was verified. These data then form the base conditions to which all future tests can be compared to evaluate the effects of changes to the coastal area under consideration.

(b) The data obtained from the model for the base conditions should include: detailed current velocities at critical locations throughout the model for a complete tidal cycle, detailed surface current patterns of the entire area of interest at incremental times throughout the tidal cycle, detailed wave characteristics throughout the inlet for an array of expected prototype conditions, and a complete documentation of tidal elevations throughout the area of interest. The evaluation of a particular proposed change in the model duplicates the procedure followed in obtaining a base set of data and compares the results of each set of data.

B-14. Fixed-Bed Distorted-Scale Coastal Models.

a. Physical coastal models are frequently distorted for various reasons. Many regions of interest are large and flood and ebb tidal deltas may be quite shallow, leading to large model energy attenuation and viscous friction scale effects on waves. These effects can be minimized through distortion and at the same time decrease model costs. Reproduction of the entire tidal estuary in the model is often desirable, since inclusion of the tidal estuary results in the flexibility to study the effects of proposed improvements on the tidal prism, tidal circulation, tidal flushing, and salinity of the estuary. Inclusion also results in the correct nonlinear energy transfer from various tidal constituents to higher order harmonics. Deletion of a major part of the estuary leaves reproduction of this phenomenon more uncertain.

b. Distorted-scale models for use in the study of coastal harbors, inlets, etc., have generally been universally accepted. The horizontal scale ratio is often dictated by the size of the facility in which the model is placed or the construction cost. The vertical scale ratio needs not be larger than the ratio of model measurement accuracy to prototype measurement accuracy. The accuracy of laboratory measurements of water surface is generally on the order of 0.001 foot; the accuracy of prototype measurements varies with equipment and field conditions but is generally within 0.1 foot. Thus, a vertical scale ratio, model-to-prototype, of 1:100 will fully utilize the capabilities of the model in simulating the prototype. Models of larger vertical scale are often used to simplify operational techniques and to assure model depths larger enough that surface tension does not affect flow.

c. A second factor to be considered in the selection of scales is the "distortion." Distortion is the ratio of the horizontal scale to the vertical scale, and its value relates the order that all slopes of the prototype are steepened in the mode. In the study of coastal regions, particularly with movable-bed models, efforts are made to design models with distortion values of five or less. Otherwise, the slopes required in the movable-bed model for accurate reproduction of the prototype may be steeper than the angle of repose of the model material, thus creating a difficult scale effect to overcome. This point is emphasized because coastal models are often constructed with both a fixed bed and a movable bed, and with a distorted scale. Vertical scale ratios, model-to-prototype, are generally in the order of 1:40 to 1:100; horizontal scale ratios are generally in the order of 1:100 to 1:500.

d. Distorted-scale coastal models are frequently constructed for multiple purposes, e.g., an investigation of an inlet may be necessary where a jetty is to be installed. A prediction will be required of the effects of the jetty on tidal currents and water levels near the inlet and also the degree to which the jetty interrupts the littoral drift and affects deposition patterns near the inlet. Other water quality and biological questions may also be addressed in such a coastal model study at the same time. In this case, a multipurpose model is needed. This model would first be built with a distorted-scale, fixed-bed design and then adjusted and tested to determine the effects of the jetty on tidal heights and currents. A segment of the fixed part of the model surface would then be carefully removed and replaced with a movable material to evaluate the effects of the jetty on the littoral drift or other phenomena of interest.

e. Model verification and testing in a distorted-scale, fixed-bed model follow essentially the same procedures as for an undistorted-scale, fixed-bed model. However, because of distortion effects, the transference equations from the model to a prototype situation are, in general, completely different.

B-15. Movable-Bed Coastal Models.

a. Theoretical Aspects of Movable-Bed Modeling.

(1) The movement of loose bed material is governed by the inertial forces of the particles and of the water against them, by the weight of the particles, and by the viscous forces acting between the water and the particles. Three physical laws have evolved from an analysis of these forces: Newton's law of inertia, the law of gravitation, and the viscous friction law of Newtonian fluids. These laws have provided two well-known dimensionless terms which must be equated between the model and the prototype for kinematic and dynamic similarity to prevail; i.e., the Reynolds Number, R_n, and the Froude Number, F_n, expressed as

$$R_n = \frac{Vd}{\nu} \qquad \text{(B-6)}$$

and

$$F_n = \frac{V}{(gd)^{1/2}} \qquad \text{(B-7)}$$

where V is the fluid velocity, d is the depth of flow, < is the fluid kinematic viscosity, and g is the acceleration of gravity.

(2) The simultaneous conformation of the model and prototype to both the Reynolds number and Froude number yields the familiar problem that the length-scale factor becomes a function of the scale factor of the kinematic viscosity. This function determines that no readily available fluid possesses the kinematic viscosity to make a useful model fluid. Schuring (1977) reasons that since the same fluid for model and prototype provides less than perfect similarity but probably must be used, design requirements can be relaxed if the inertial forces of the sediment are much smaller than the rest of the forces and, therefore, can be neglected. Then Newton's law of inertia must only be applied to the fluid. A further simplification, without loss of

generality, is achieved by restricting the law of gravitation to the weight difference of water and sediment. With these two modifications, a qualified Froude number evolves, often referred to as a densimetric Froude number, and the length-scale factor is freed from its dependence on kinematic viscosity:

$$F_* = \frac{V}{\left[\left(\frac{\rho_s}{\rho_w} - 1\right) gd\right]^{1/2}} \qquad \text{(B-8)}$$

The penalty for this simplification is a restriction of the particles to a state of rolling or sliding with small or no inertial forces acting upon them. The model becomes invalid when the particles begin to leave the bed and are carried upward, such as in the surf zone or in relatively shallow water affected by surface gravity waves. Very good correlation between variables was achieved in flume experiments with unidirectional flow (Schuring 1977).

(3) A different approach, advanced by Gessler (1971), assumes that both the prototype sediment and the material used as model sediment are given, and the model geometric scales are determined to fit the requirements of these materials. In this approach, supplemental information should be used in the form of the Shields parameter regarding the critical tractive force necessary to produce incipient motion. However, model scales based on the principles of unidirectional motion may not be strictly applicable to the case of oscillatory wave motion, but a first approximation is probably permissible. By setting a lower limit to the model Reynolds number and computing the prototype Reynolds number, the ratio of the prototype-to-model Reynolds number will determine the scale of the characteristics length used in the vertical direction of the model. In this procedure, it is assumed that the ratio of model-to-prototype velocity is a function only of the depth ratio, as determined by the Froude law.

(4) If the model sediment material has not been selected beforehand, a revised approach can be developed (Gessler 1971). To have similarity in incipient motion and bedload transport, the bed mobility in the model and prototype should be the same at homologous points. This mobility is determined by the ratio of the actual Shields parameter to the critical Shields parameter. The reason for this modification in approach is that the critical Shields parameter depends somewhat on the grain Reynolds number for values below about 150. For ordinary model materials (fine-grained sands), the grain Reynolds number is on the order of 5 to 10. The Shields diagram is poorly verified in this range, so the grain Reynolds number should not be smaller than about 15. This grain Reynolds number can be achieved by using a coarser bed material in the model than in the prototype, but one that is less dense. The Shields parameter is

$$\tau_* = \frac{\gamma_w dS}{(\gamma_s - \gamma_w)D_s} \tag{B-9}$$

where S is the bed slope and d is the particle size. By using this definition and evaluating the ratio of the prototype-to-model Shields parameter, a generalized criterion will evolve which can be solved for the specific weight (submerged) of the bed material to be used in the model. The reason for using a lightweight material refers to the idea that the grain size is relatively too large in the model. The final selection of the model material will depend on the materials available; however, a slight adjustment in the desired grain size may be necessary.

(5) The analyses of Gessler (1971) are applicable only to unidirectional flow at one specific discharge; thus highly unsteady flow processes like surface gravity waves cannot adequately be modeled by this process. Changes in discharge require that the time scale of the discharges be modeled according to the time scale associated with the sedimentation process to obtain similarity in bed-forming processes. The considerable discrepancy between the hydrodynamic and sedimentological time scales means that the sedimentation processes are advancing too rapidly in the model. Gessler (1971) concludes that no matter how carefully the design is done, it remains absolutely essential for distorted-scale as well as undistorted-models to be verified against field data.

(6) When studying problems of scour and deposition, it becomes necessary to add the critical shear stress and sublayer criteria to the gravity and frictional criteria, as developed by Graf (1971). Introducing the empirical relationship between the bed particle diameter and Manning’s n value produces

$$(d_r)^{1/6} = n_r = (R)_r^{2/3} \left(\frac{1}{L_{h_r}}\right)^{1/2} \tag{B-10}$$

where d is the bed particle diameter and R is the hydraulic radius. When model and prototype fluids are identical, four independent variables are found, and three equations provide a solution. The problem is determined if one of the four parameters is chosen, and the remaining three variables are found from the equation solutions. A distorted-scale model was assumed in this analysis. Various researchers have stated that some model laws can be relaxed with little harm to the overall investigation. Einstein and Chien (1954) suggested that the friction criterion, the Froude criterion, or the sublayer criterion might absorb further distortions. Under certain circumstances, small deviations from the exact similarity may be allowed, making it possible to arbitrarily select more than one single variable.

(7) For the application of strictly coastal sediment modeling problems, Migniot et al. (1975) have stated that since all of the similitude conditions involved cannot be satisfied, the model scales, the material size and density, and the current exaggeration cannot be determined by straightforward computations but must be chosen to obtain the most favorable balance between all relevant phenomena. In many respects, movable-bed physical modeling is more an art than a science. A feeling of the problem, previous experience, and a perspective of the relative importance of each factor are of paramount value in applying the method. The sedimentological time scale can be derived from general transport formulas. When sand is simulated with a lightweight material such as plastic with a density of 1.4, the sedimentological time scale will be in the range of 1:1,000 which means that a year will correspond to some 8 hours of model time. Although it is disquieting to note that so much empiricism prevails in the design of coastal movable-bed models, the model is only fit for predictive use when it has successfully reproduced past evolution. While the various similitude conditions may not all be satisfied, the conditions do not differ too much from each other, so fairly satisfactory compromises can usually be found. For instance, model material density required to satisfy these various prototype conditions may typically vary from 1.3 to 1.6, while size exaggeration may vary from 1.0 to 1.7.

(8) The movable-bed coastal model by Kamphuis (1975) is a wave model incorporating coupled wave motion and sediment motion relationships which have been determined experimentally. The unidirectional flow phase is then added to the basic wave model and adjusted to yield correct results for different situations. This philosophy is basically different from Le Méhaute (1970) who assumed that a coastal movable-bed model is a unidirectional flow model modified by waves. The difference in scale laws is quite evident when the results of their models are compared.

(9) According to Kamphuis (1975), the movable-bed phase of the model study is subjected to four relaxed basic scaling criteria: the particle Reynolds number, the densimetric Froude number, the relative density, and the relative length-scale relating water motion to sediment size. Ideally, all of these basic scaling criteria must be satisfied simultaneously but cannot be satisfied in practice. As more of these criteria are ignored, the model will perform successively less like the prototype, and scale effects (nonsimilarity between model and prototype) increase. Only a lightweight material can be used to keep the model and prototype particle Reynolds number identical. Any deviation from unity is rather small (in all cases) and is not considered to limit the model seriously. Similarity of the densimetric Froude number is considered to be the most important of the four modeling criteria. If the model densimetric Froude number is less than some critical value and the prototype number is greater than this critical value, the model is useless. The model and prototype densimetric Froude numbers should be equal, or incorrect scaling will result in considerable distortion of the sediment motion parameters with exaggerated time scales for sediment motion, and the model will take longer to move the material than it theoretically should. Thus, the sediment motion will start later in the model (in shallow water), but in the area where material moves freely, the nonsimilarity of the densimetric Froude

numbers will manifest itself in adjustment of the time scale for sediment motion. The time scale also varies with depth, and moreover, if initial motion and depositional patterns are important, it is necessary to model the densimetric Froude number correctly.

(10) The nonsimilarity of the model and prototype ratios of sediment particle density to water density affects the process in two distinct ways. The acceleration of the particle is changed, and the particle becomes relatively too heavy when no longer submerged. For a lightweight material, the individual particles are relatively heavier in the surf zone than if sand were used. Therefore, the beach material has a tendency to pile up immediately past the surf zone, and the particles will remain in this location because they become relatively heavier when not submerged. As a result, there is a highly distorted version of sediment transport in the surf zone. It is very difficult to duplicate prototype conditions in the littoral zone using lightweight materials.

(11) Coastal movable-bed models suffer from various scale effects when the particle sizes are not scaled down geometrically. Since this fact is true for most coastal movable-bed models, the prediction of bed morphology time scales is virtually impossible. Thus, verification using historical survey data remains a necessary step. Because of the variety of scale effects, coastal movable-bed modeling continues to be as much an art as an exact science.

b. Prototype Data Requirements.

(1) Perhaps the most important aspect of the design phase of a movable-bed coastal model study is to assure the adequacy of the prototype data. The model is constructed to conform to prototype surveys; adjustment of the model to accurately reproduce prototype hydraulics or sedimentation patterns is based on prototype measurements. Any errors or insufficiencies in prototype information will result in inadequate and incorrect performance of the model.

(2) Prototype information required for a movable-bed coastal model study includes geometry and sediment properties, adjacent beach configuration, wave measurements, littoral drift estimates, water surface time histories, and synoptic tidal currents in the ocean, bay, inlets, and harbors. The occurrence of storms of low-return frequency should be noted, since large volumes of sand can be displaced during these activities. Hydrographic and wave observations should also be made frequently enough to detect seasonal and yearly fluctuations.

(3) A longer data collection period is needed for a movable-bed study than for a fixed-bed model. The period length also varies with the data type; e.g., longer term wave data are needed than tide level and current data to calibrate a movable-bed model. Prototype observations for several consecutive years before the model study will allow an evaluation of both short- and long-term tendencies of the coastal region -and the selection of a typical period on which to base the model verification. A three-year documentation period is

probably the minimum length, since major trends cannot usually be detected in shorter time periods.

c. Model Verification.

(1) The verification phase of a coastal movable-bed model study is perhaps the most important. A well-accomplished verification will minimize or eliminate the effects of small errors in construction and will allow the evaluation of the effects of poorly understood variables on the coastal region during the testing phase. Verification requires the adjustment of model boundary conditions to recreate or correct conditions that were altered in the scaling process. Sedimentation verification is based on prototype observations and is accomplished by selecting an appropriate model sediment and developing the necessary model operating technique to reproduce the observed scour and fill patterns. Verification of a coastal movable-bed model is, theoretically, more difficult than for a fixed-bed model. The purpose of a movable-bed model is to simulate the evolution of the coastal bathymetry. This evolution takes place in response to many factors, but primarily to the sediment washed from adjacent beaches by wave action, to erosion of the inlet channels by tidal currents, and to entrapment of material at the bars on the ocean and bay sides of the tidal inlets. Coastal harbors also accumulate littoral drift and shoal material. These same factors must be included in the model to simulate degree as well as type of bathymetry evolution.

(2) Since a movable-bed coastal model simulates shoaling and scouring patterns, the requirement that the model also simulate the basic hydraulic quantities (tidal heights, tidal phases, velocities, etc.,) is somewhat relaxed. In practice, the verification of a movable-bed coastal model is a little easier than for a fixed-bed model, since the experimenter has more variables available with which to work to achieve the desired verification. The validity of tests of proposed improvement plans in movable-bed model is based on the following premise: if model reproduction of the prototype forces known to affect movement and deposition of sediments (tides, tidal currents, waves, etc.) produces changes to model bed configuration similar to those observed in the prototype under similar conditions, then the effects of a proposed improvement plan on the movement and deposition of sediments will be substantially the same in both model and prototype.

(3) One of the most important reasons for the verification of a movable-bed coastal model is the establishment of the time scale with respect to bed movement. The model-to-prototype time scale for bed movement cannot be computed from the linear scale relations because the interrelation of the various prototype forces affecting movement and deposition of sediments is too complicated for accurate definition. Therefore, the time scale is determined empirically during the model verification; i.e., the actual time required for the model to reproduce certain changes that occurred in a given period of time in the prototype is used to determine the model time scale for bed movement.

d. Model Tests.

(1) The actual testing phase of a coastal movable-bed model is perhaps the easiest of all phases to accomplish. The model has been carefully designed and built based on measurements obtained from the prototype. The model has performed similarly to the prototype by responding to events to which it was subjected during verification in the same manner the prototype was observed to response when similar events occurred in its history. The model may now be justifiably expected to respond as the prototype would respond to an event or sequence of events, which has not yet occurred to the prototype at the particular point being investigated, for the same hydrography and operating conditions. This response of the model is termed the "predictive capability" of the model, since the behavior of the prototype under similar conditions can be inferred from that response.

(2) A model test series always involves at least two separate tests. The first test is a "base" test, which studies the existing coastal region and provides a basis for comparison with later tests that have alternative plans. The next test or tests in the series are the "plan" tests, so-called because the plan or plans for improving the coastal region are installed in the model and tested. The plan tests are always conducted with model conditions identical to those of the base test. This test procedure allows straightforward interpretation of the test results, as differences in results are attributable to the plan under investigation although some differences may occur because similitude criteria have not been completely satisfied.

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APPENDIX C

ENVIRONMENTAL PROTECTION STATUTES AND OTHER ENVIRONMENTAL REQUIREMENTS

C-1. Federal Statutes.

Clean Air Act of 1963, as amended, 42 U.S.C. 7401, et seq.

Clean Water Act of 1977, as amended (Federal Water Pollution Control Act), 33 U.S.C. 1344, et seq.

Coastal Barrier Resources Act of 1982, (16 U.S.C. 3501 Public Law 97-348).

Coastal Zone Management Act of 1972, as amended, 16 U.S.C. 1451, et seq.

Deep Water Port Act of 1974, as amended, 33 U.S.C. 1501, et seq.

Endangered Species Act of 1973, as amended, 16 U.S.C. 1531, et seq.

Estuary Protection Act, 16 U.S.C. 1221, et seq.

Federal Water Project Recreation Act, as amended, 16 U.S.C. 460-1(12), et seq.

Fish and Wildlife Coordination Act of 1958, as amended, 16 U.S.C. 661, et seq.

Historic Site Act of 1935, as amended, 16 U.S.C. 461, et seq.

Land and Water Conservation Fund Act, as amended, 16 U.S.C. 4601-4601-11, et seq.

Marine Mammal Protection Act of 1972, as amended, 16 U.S.C. 1361-1907, 86 stat, 1027.

Marine Protection, Research and Sanctuaries Act of 1972, 33 U.S.C. 1401, et seq.

Migratory Bird Conservation Act, 16 U.S.C. 715-715d, 715e, 715f-715k, and 715n-715r (1970 and Supp. IV 1974).

National Environmental Policy Act of 1969, as amended, 42 U.S.C. 4321, et seq.

National Historic Preservation Act of 1966, as amended, 16 U.S.C. 470a, et seq.

Preservation of Historic and Archaeological Data Act of 1974, as amended, 16 U.S.C. 469, et seq.

River and Harbor Act, 3 March 1899, 30 stat, 1151, 33 U.S.C. 401 and 403, and 30 stat, 1152, 33 U.S.C. 407, et seq.

Watershed Protection and Flood Prevention Act, as amended, 16 U.S.C. 1001, et seq.

Wild and Scenic Rivers Act of 1968, as amended, 16 U.S.C. 1271 ,et seq.

Water Resources Development Act of 1986 (Public Law 99-662).

C-2. Executive Orders and Memoranda.

Protection and Enhancement of Cultural Environment, 13 May 1971 (E.O. 11593).

Floodplain Management, 24 May 1977 (E.O. 11988).

Protection of Wetlands, 24 May 1977 (E.O. 11990).

Protection and Enhancement of Environmental Quality (E .0. 11514, amended by EO 11991, 24 May 1977).

Environmental Effects Abroad of Major Federal Actions (E .0. 12114).

Analysis of Impacts on Prime and Unique Farmlands (CEQ Memorandum, 11 Aug 80).

Interagency Consultation to Avoid or Mitigate Adverse Effects on Rivers in the Nationwide Inventory (CEQ Memorandum, 11 Aug 80).

Guidance on Applying Section 404 (r) of the Clean Water Act to Federal Projects Which Involve the Discharge of Dredged or Fill Materials into Waters of the U.S. Including Wetlands (CEQ Memorandum, 17 Nov 80).

C-3. Agency Regulations.

US Environmental Protection Agency:

Ocean Dumping Regulations and Criteria	(40 CFR 220-229)
Guidelines for Specifications of Disposal Sites for Dredged or Fill Material	(40 CFR 230)

Council on Environmental Quality:

Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act of 1969	(40 CFR 1500-1508)

Appendix D

Estuarine/Marine Species Profiles

D-1. Species Profiles: Published.

Biological Report (*)	Title	Date Published	
	Gulf of Mexico		
82/11.4	Spotted Seatrout	February	1983
82/11.3	Atlantic Croaker	February	1983
82/11.2	Gulf Menhaden	February	1983
82/11.1	Brown Shrimp	February	1983
82/11.14	Bay Anchovy and Striped Anchovy	October	1983
82/11.5	Sea Catfish and Gafftopsail Catfish	October	1983
82/11.20	White Shrimp	September	1984
82/11.29	Sheepshead	March	1985
82/11.30	Southern Flounder	April	1985
82/11.26	Pinfish	September	1984
82/11.31	Common Rangia	April	1985
82/11.35	Grass Shrimp	March	1985
82/11.36	Red Drum	June	1985
82/11.51	Black Drum	April	1986
82/11.55	Blue Crab	June	1986
82/11.64	American Oyster	July	1986
82/11.71	Pigfish	March	1987
82/11.72	Sand Seatrout and Silver Seatrout	March	1987
82/11.83	Red Snapper	August	1988
	South Florida		
82/11.16	Snook	October	1983
82/11.17	Pink Shrimp	October	1983
82/11.21	Stone Crab	March	1984
82.11.34	Striped Mullet	April	1985
82.11.39	White Mullet	May	1985
82.11.42	Florida Pompano	April	1986

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* All Biological Reports are published under Technical Report EL-82-4, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

82/11.58	King and Spanish Mackerel	June	1986
82/11.52	Gray, Lane, Mutton, and Yellowtail Snapper	June	1986
82/11.54	Southern, Gulf and Summer Flounder	July	1986
82/11.61	Spiny Lobster	August	1986
8/11.43	Spotted Sea Trout	August	1986
82/11.73	Reef-Building Corals	August	1987
82/11.77	Long-Spined Black Sea Urchin	August	1987

South Atlantic

82/11.11	Atlantic Menhaden	October	1983
82/11.15	Summer Flounder	October	1983
82/11.19	Blue Crab	March	1984
82/11.25	Atlantic Sturgeon	July	1984
82/11.24	American Eel	July	1984
82/11.27	White Shrimp	September	1984
82/11.45	American Shed	April	1986
82/11.57	American Oyster	July	1986
82/11.75	Hard Clam	August	1987
82/11.91	Spot	January	1989
82/11.90	Brown Shrimp	January	1989

North Atlantic

82/11.7	White Perch	October	1983
82/11.18	Hard Clam	October	1983
82/11.23	American Oyster	July	1984
82/11.22	American Salmon	July	1984
82/11.33	American Lobster	April	1985
82/11.38	Atlantic Herring	April	1986
82/11.66	Sand Lance	June	1986
82/11.53	Softshelled Clam	June	1986
82/11.56	Alewife/Blueback Herring	July	1986
82/11.59	American Shad	July	1986
82/11.67	Sea Scallop	August	1986
82/11.76	Atlantic Tomcod	August	1987
82/11.74	American Eel	August	1987
82/11.80	Sandworm and Bloodworm	April	1988
82/11.87	Winter Flounder	January	1989

Mid-Atlantic

Ref. No.	Title	Date Published	
82/11.8	Striped Bass	October	1983
82/11.9	Alewife/Blueback Herring	October	1983
82/11.10	Atlantic Silverside	October	1983
82/11.12	Bay Scallop	October	1983
82/11.13	Surf Clam	October	1983
82/11.41	Hard Clam	February	1985
82/11.37	American Shad	April	1985
82/11.40	Mummichog and Striped Killifish	June	1985
88/11.65	American Oyster	July	1986
82/11.68	Softshell Clam	August	1986
82/11.94	Bluefish	February	1989
82/11.97	Bay Anchovy	February	1989
82/11.98	Spot	February	1989

Pacific Northwest

82/11.6	Chinook Salmon	October	1983
82/11.48	Coho Salmon	April	1986
82/11.63	Dungeness crab	August	1986
82/11.62	Steelhead Trout	August	1986
82/11.69	Amphipods	August	1986
82/11.78	Common Littleneck Clam	August	1987
82/11.81	Chum Salmon	March	1988
82/11.85	Pacific Oyster	September	1988
82/11.86	Sea-Pun Cutthroat Trout	January	1989
82/11.88	Pink Salmon	January	1989
82/11.89	Pacific Razor Clam	January	1989
82/11.93	Ghost Shrimp and Blue Mud Shrimp	January	1989

Pacific Southwest

82/11.28	California Grunion	February	1985
82/11.32	Black, Green, and Red Abalone	March	1985
82/11.44	California Halibut	April	1986
82/11.46	Common Littleneck Clam	April	1986
82/11.47	Spiny Lobster	April	1986
82.11.49	Chinook Salmon	April	1986
82/11.50	Northern Anchovy	April	1986
82/11.61	Steelhead	June	1986
82/11.70	Coho Salmon	August	1987

82/11.79	Pacific Herring	February 1988
82/11.82	Striped Bass	March 1988
82/11.84	California Sea Mussel and Bay Mussel	September 1988
82/11.95	Pismo Clam	February 1989
82/11.92	Amphipod	January 1989

D-2. <u>Species Profiles: Unpublished.</u>

<u>South Florida</u>

Ladyfish and Tarpon
Reef-Building Tube Worm
Black, Red and Nassau Grouper

<u>South Atlantic</u>

Bluefish
Black Sea Bass
Alewife/Blueback Herring
Fiddler Crab
Striped Bass

<u>North Atlantic</u>

Rainbow Smelt
Blue Mussel
Tautog/Cunner

<u>Mid-Atlantic</u>

Summer and Winter Flounder
Atlantic Menhaden
Blue Crab
Weakfish
Atlantic and Shortnose Sturgeon
Blue Mussel
Mud Fiddler Crab

<u>Pacific Southwest</u>

Crangonid Shrimp
Pile Perch and Striped and Rubberlip Seaperch
Dungeness Crab

Brown, Copper, and Black
Rockfishes
Pacific and Speckled Sanddabs
Rock Crabs: Brown, Red,
  and Yellow Crab

Pacific Northwest

Sockeye Salmon
English Sole
Pacific Herring
Geoduck
Dover and Rock Soles
Lingcod

GLOSSARY

TERMS

Accretion: May be either natural or artificial. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of water or airborne material. Artificial accretion is a similar buildup of land by reason of an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.

Algae: Any of a group of nonvascular plants with chlorophyll, lacking true stems, leaves, and roots.

Anadromous: A life cycle in which maturity is attained in the ocean and adults ascend rivers and streams to spawn in fresh water (e.g., salmons, shad, etc.).

Anaerobic: An oxygen-independent type of respiration.

Backshore: That zone of the shore or beach lying between the foreshore and the coastline comprising the berm or berms and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

Baseline data: Data used as a temporal control, collected prior to the environmental disturbance of interest.

Basin: A naturally or artificially enclosed or nearly enclosed harbor area for small craft.

Bathymetry: The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements.

Bay: A recess in the shore or an inlet of a sea between two capes or headlands, not so large as a gulf but larger than a cove.

Beach: The zone of unconsolidated material that extends landward from the low-water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves).

Benthic: Pertaining to the subaquatic bottom or organisms that live on the bottom of water bodies.

Benthos: A collective term describing (1) bottom organisms attached or resting on or in the bottom sediments, and (2) community of animals living in or on the bottom.

Berm: A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms; others have one or several.

Biomass: The amount of living material in a unit area for a unit time.

Biota: The living part of a system (flora and fauna).

Breaker: A wave breaking on a shore, over a reef, etc.

Breakwater: A structure protecting a shore area, harbor, anchorage, or basin from waves.

Bulkhead: A structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the upland against damage from wave action.

Carrying capacity: The maximum number of individuals or biomass that any particular area can support over an extended period of time.

Channel: (1) A natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. (2) The part of a body of water deep enough to be used for navigation through a body of water otherwise too shallow for navigation.

Coast: A strip of land of indefinite width (may be several kilometers) that extends from the shoreline inland to the first major change in terrain features.

Continental shelf: The zone bordering a continent and extending from the low-water line to the depth (usually about 180 meters) where there is a marked or rather steep descent toward a greater depth.

Coral: (Biology) Marine coelentrates (Madreporaria), solitary or colonial, which form a hard external covering of calcium compounds or other materials. The corals which form large reefs are limited to warm, shallow waters, while those forming solitary, minute growths may be found in colder waters to great depths. (Geology) The concretion of coral polyps, composed almost wholly of calcium carbonate, forming reefs and tree-like and globular masses. May also include calcareous algae and other organisms producing calcareous secretions, such as bryozoans and hydrozoans.

Current: A flow of water.

Delta: An alluvial deposit, roughly triangular or digitate in shape, formed at a river mouth.

Demersal: Organisms (usually fish) that live on or slightly above the bottom.

Dissolved oxygen (DO): The amount of oxygen dissolved in water.

Dredge: An apparatus used in the removal of substrate usually to deepen water passages.

Dunes: Ridges or mounds of loose, wind-blown material, usually sand.

Ebb current: The tidal current away from shore or down a tidal stream; usually associated with the decrease in height of the tide.

Ebb tide: The period of tide between high water and the succeeding low water; a falling tide.

Eddy: A circular movement of water formed on the side of a main current. Eddies may be created at points where the main stream passes projecting obstructions or where two adjacent currents flow counter to each other.

Epibenthic: Organisms that attach themselves to structures (e.g. rocks) which lie on the aquatic bottom.

Erosion: The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

Escarpment: A more or less continuous line of cliffs or steep slopes facing in one general direction which are caused by erosion or faulting (also scarp).

Estuary: (1) The part of a river that is affected by tides. (2) The region near a river mouth in which the fresh water of the river mixes with the salt water of the sea.

Fauna: The entire group of animals in an area.

Flora: The entire group of plants found in an area.

Forage: Food for animals especially when taken by browsing or grazing.

Foreshore: The part of the shore, lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low-water mark, that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall.

Geomorphology: That branch of both physiography and geology which deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of landform.

Groin: A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore.

Harbor: Any protected water area affording a place of safety for vessels.

Hydrolysis: A chemical process of decomposition involving splitting of a bond and addition of the elements of water.

Hypothesis: A tentative conclusion made in order to draw out and test its logical or empirical consequences.

Inlet: (1) A short, narrow waterway connecting a bay, lagoon, or similar body of water with a large parent body of water. (2) An arm of the sea (or other body of water) that is long compared to its width and may extend a considerable distance inland.

Inshore: The zone of variable width extending from the low-water line through the breaker zone.

Intertidal zone: See littoral zone.

Jetty: On open seacoasts, a structure extending into a body of water, which is designed to prevent shoaling of a channel by littoral materials and to direct and confine the stream or tidal flow. Jetties are built at the mouths of rivers or tidal inlets to help deepen and stabilize a channel.

Lee: Shelter, or the part or side sheltered or turned away from the wind or waves.

Levee: A dike or embankment to protect land from inundation.

Littoral transport: The movement of littoral drift in the littoral zone by waves and currents.

Littoral zone: The zone from high-tide level to edge of continental shelf.

Longshore: Parallel to and near the shoreline.

Macrofauna: Those animals equal to or larger than 0.5 millimeter in size.

Marsh: An area of soft, wet, or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

Mean high water (MHW). The average height of the high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All high-water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high-water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water.

Mean low water (MLW): The average height of the low waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All low-water heights are included in the average where the type of tide is either semidiurnal or mixed. Only lower low-water heights are included in the average where the type of tide is diurnal. So determined, mean low water in the latter case is the same as mean lower low water.

Meiofauna: Generally those interstitial animals below 0.5 millimeter.

Mitigation: Avoiding the impact of a certain action or part of an action; minimizing impacts by limiting the degree of magnitude of an action; rectifying an impact by repairing, rehabilitating, or restoring the affected environment; reducing an impact over time by preserving and maintaining operations during the life of the action; compensating the impact by replacing or providing substitute resources or environments.

Nearshore: An indefinite zone extending seaward from the shoreline well beyond the breaker zone.

Nekton: Those aquatic animals able to swim efficiently, and not mainly at the mercy of currents.

Onshore: A direction landward from the sea.

Osmoregulatory: The maintenance of constant osmotic pressure in the body of a living organism.

Overwash: That portion of the uprush that carries over the crest of a berm or of a structure.

Pelagic: All ocean waters covering the benthic region.

Periphyton: Any organism attached or clinging to stems, leaves, or other surfaces of plants under the water.

Plankton: Those organisms passively drifting or weakly swimming in marine or fresh water.

Primary production: The rate at which energy is stored by photosynthesizing organism (chiefly green plants) in the form of organic substances.

"Red Tide" organism: Planktonic organism that produces toxic substances that can contribute to killing of great numbers of marine animals.

Revetment: A facing of stone, concrete, etc., built to protect a scrap, embankment, or shore structure against erosion by wave action or currents.

Riprap: A protective layer or facing of quarrystone, usually well-graded within wide size limit, randomly placed to prevent erosion, scour, or sloughing of an embankment or bluff; also the stone so used. The quarrystone is placed in a layer at least twice the thickness of the 50 percent size, or 1.25 times the thickness of the largest size stone in the gradation.

Rubble: (1) Loose angular waterworn stones along a beach. (2) Rough, irregular fragments of broken rock.

Rubble-mound structure: A mound of random-shaped and random-placed stones protected with a cover layer of selected stones or specially shaped concrete armor units. (Armor units in a primary cover layer may be placed in an orderly manner or dumped at random).

Salt marsh: A marsh periodically flooded by salt water.

Scour: Removal of underwater material by waves and currents, especially at the base or tow of a shore structure.

Seagrass: Members of marine seed plants that grow chiefly on sand or sand-mud bottom. They are most abundant in water less than 9 meters deep.

Seawall: A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action.

Sessile: Any organism which usually is fixed but may move infrequently or may be permanently attached.

Sheet pile: A pile with a generally slender flat cross section to be driven into the ground or seabed and meshed or interlocked with like members to form a diaphragm, wall, or bulkhead.

Shellfish: Any aquatic invertebrate with a hard external covering; more commonly mollusks and crustaceans.

Shoreline: The intersection of a specified plane of water with the shore or beach (e.g., the high-water shoreline would be the intersection of the plane of mean high water with the shore or beach). The line delineating the shoreline on National Ocean Survey nautical charts and surveys approximates the mean high-water line.

Sorption: The process of being taken up and held by either adsorption or absorption.

Sound: A relatively long arm of the sea or ocean forming a channel between an island and a mainland or connecting two larger bodies, as a sea and the ocean, or two parts of the same body; usually wider and more extensive than a strait.

Subtidal: The region extending below the intertidal to the edge of the continental shelf.

Supratidal: The zone immediately adjacent to the mean high-water level; commonly called the splash zone.

Surf zone: The area between the outermost breaker and the limit of wave uprush.

Tide: The periodic rising and falling of the water that results from gravitational attraction of the moon and sun and other astronomical bodies acting upon the rotating earth.

Tombolo: A bar or spit that connects or "ties" an island to the mainland or to another island.

Topography: The configuration of a surface, including its relief and the positions of its streams, roads, buildings, etc.

Toxicant: A poisonous agent.

Turbidity: A condition where transparency of water is reduced. It is an optical phenomenon and does not necessarily have a direct linear relationship to particulate concentration.

Volatile: The tendency of a substance to erupt violently or evaporate rapidly.

Wave: A ridge, deformation, or undulation of the surface of a liquid.

Weir: A low section in an updrift jetty over which littoral drift moves into a predredged deposition basin which is dredged periodically.