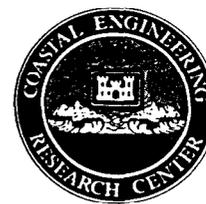




Coastal Engineering Technical Note



DESIGN ASPECTS OF CORPS BEACH NOURISHMENT PROJECTS

PURPOSE: To provide an overview of the process employed by the U.S. Army Corps of Engineers in designing beach nourishment projects.

BACKGROUND: Beach nourishment has become a preferred method for shore protection along the coasts of the United States, and many projects have been designed and constructed in the past several years. Based upon a detailed review of several beach nourishment project studies recently performed by the U.S. Army Corps of Engineers (USACE), a general framework for beach fill design has been developed.

This Technical Note provides an overview of the framework and a description of the major design elements. Engineering tools and procedures that can be employed in the design process are referenced. The design framework presented herein forms the basis of development of the Beach Fill Module (BFM). The BFM is an integrated system of analysis programs that incorporates major engineering and planning functions required in beach fill design as performed by the U.S. Army Corps of Engineers.

SUMMARY OF THE BEACH NOURISHMENT PROJECT DESIGN PROCESS: The beach nourishment design process begins with identification of need and definition of project objectives, constraints, and performance criteria. Site characterization is performed to gain an understanding of the problem and to obtain information required to develop potential solutions. Alternative designs are identified and evaluated based on expected physical performance, project economics, environmental impacts, and local concerns to select a preferred alternative which meets project objectives. Final design optimization and construction of the selected alternative are followed by project monitoring, maintenance, and periodic renourishment. The flowchart shown in Figure 1 summarizes the beach nourishment design process. Depending on the level of study (e.g., reconnaissance, feasibility, or preconstruction engineering design), project design may include some or all of the major steps performed at varying levels of detail. Often, project design involves overlap and iteration of the design steps, and specific design elements may be emphasized or de-emphasized depending on the purpose and scope of the project. Thompson et al. (1995) provide additional details on the general design process for coastal projects. Major elements of the design framework presented in Figure 1 are discussed below.

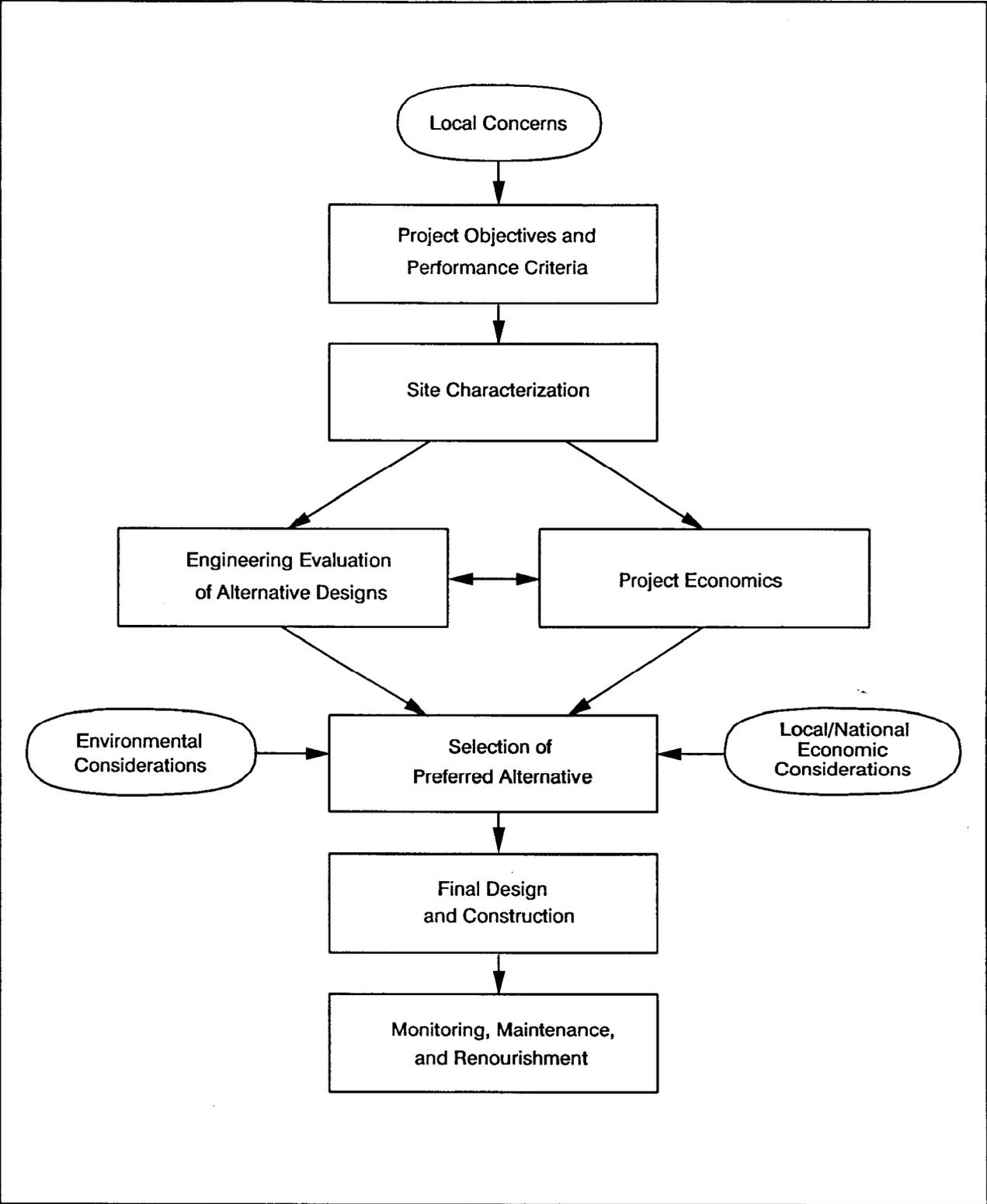


Figure 1. Beach nourishment project design framework

PROJECT OBJECTIVES AND PERFORMANCE CRITERIA: *Identification of beach fill project objectives and physical criteria and constraints under which the project must perform satisfactorily.*

- a. **Local Concerns:** A U.S. Army Corps of Engineers beach nourishment project study is initiated by a congressional authorization typically developed in response to local concerns about loss of protective beach, threat of or actual damage to structures, and dune erosion or breaching. The local sponsors or other local governments and interests often have a wide range of positive and negative opinions regarding the potential beach nourishment project. It is useful to identify as many of these concerns as possible early in the planning process to clearly define the objectives of and constraints on the project.
- b. **Statement of the Problem:** A problem statement must be clearly formulated to communicate the problem to be addressed by the U.S. Army Corps of Engineers, the objectives of the project, and the areas of project responsibility. Project objectives may involve one or a combination of the following: hurricane and storm damage reduction, beach erosion control, recreation, placement of dredged material from navigation projects, and prevention or mitigation of shore damages resulting from Federal navigation works (USACE 1994).
- c. **Performance Criteria:** Performance criteria for Corps beach fill projects typically involve providing protection from erosion, wave, and inundation damages during a statistically defined storm condition and mitigation of long-term shoreline recession over a specified period of time. Economic performance is also a primary consideration, as project designs are often selected to maximize net average annual benefits to the nation while providing a solution to the stated problem. In some cases additional criteria or limitations are placed on a project, based upon environmental constraints or other local concerns.

SITE CHARACTERIZATION: *Description of past and present conditions at the project site and the parameters under which the beach fill project will be designed.*

- a. **Historic Shoreline Change:** Historic shoreline change data are used to estimate long-term shoreline erosion rates and volumetric changes. Shoreline change analysis is typically based on digitized historic shoreline maps, beach profile and offshore bathymetry data, and/or aerial photography. Geographic Information System (GIS) tools can be used to facilitate organization and analysis of shoreline change information (e.g., Byrnes, McBride, and Hiland 1991).
- b. **Profile Shape and Variability:** Beach profile data are used for short-term temporal beach change analysis and modeling. A knowledge of the spatial and temporal (storm and seasonal) variability of profile shape and response alongshore (e.g., Larson and Kraus 1994) is essential to developing a comprehensive design. Beach profile analysis tools such as the Interactive Survey Reduction Program (ISRP) (Birkemeier 1984) and the Beach Morphology Analysis Package (BMAP) (Sommerfeld and Wise 1995) provide automated routines for processing and analyzing beach profile data.

- c. **Depth of Closure:** The seaward limit of significant sediment movement is a critical parameter for beach fill volume calculations and sediment transport modeling. Depth of closure can be estimated analytically (e.g., Hallermeier 1981, Birkemeier 1985, Houston 1994) or from field data (e.g., Stauble et al. 1993). Kraus and Larson (1995) provide guidance on use of the depth of closure in beach fill design.
- d. **Offshore Bathymetry:** Details of the offshore bathymetry beyond the depth of closure area may be required for wave transformation modeling and/or identification of potential offshore borrow source areas.
- e. **Coastal Oceanography:** A knowledge of wave and water level conditions along the project area is needed to assess and model sediment transport and coastal flooding under existing conditions and for alternative beach fill designs. Long-term and short-term (i.e., storm) conditions need to be quantified. Sources of wave and water level information include gauge data (e.g., McGehee 1993, McAneny 1993), numerical model hindcasts (e.g., Hubertz 1992, McAneny and Jones 1993), and statistical estimates of average and peak parameters.
- f. **Sediment Budget:** A sediment budget quantifies erosion, deposition, and sediment transport into and out of an area of interest on a variety of time scales. Sediment budgets provide information on littoral transport which can be used to estimate long-term renourishment requirements and to evaluate potential updrift and downdrift impacts of a beach fill project. The *Shore Protection Manual* (1984), USACE (1992), Jarrett (1991), and Meisburger (1993) discuss sediment budget calculation procedures. Identifying net direction and magnitude of littoral transport are key elements of a sediment budget analysis. Stauble and Morang (1992) provide guidance for using morphologic indicators to determine littoral drift direction. Gravens (1989) presents a method for estimating longshore transport rates using hindcast wave information.
- g. **Sediment Characteristics:** Characteristics of the native beach and fill sediments are needed to evaluate suitability of fill material and to predict profile shape and response of the fill. Sediment size, color, gradation, and environmental compatibility are typically considered. Stauble (1991a) discusses techniques for assessing sediment characteristics relevant to beach fill design.
- h. **Potential Sediment Borrow Sources:** Onshore and offshore sources of sediment for beach fill must be identified and evaluated in terms of sediment quality, quantities available, cost of transportation to and placement on the beach, and physical and environmental impacts of borrow operations.
- i. **Topography and Structure Inventory:** Detailed mapping of the existing shoreline topography is required to identify beach and inland features, buildings, roads and utilities, erosion control structures, and end-of-project transitions. Structure inventories are of particular importance in economic analysis of beach fill project benefits.

- j. **Regulatory and Local Concerns:** The interests and concerns of local regulatory agencies, municipalities, local interest groups, and adjacent property owners need to be considered in relation to potential project impacts such as changes in transport patterns at the ends of a project and compatibility with wildlife habitats. The impacts of a beach fill project on local residents and tourism need to be considered including factors such as ocean views, beach access, sand characteristics (texture and color), and local cost sharing.

ENGINEERING EVALUATION OF ALTERNATIVE DESIGNS: *Examination of reasonable potential engineering options to provide a solution to coastal erosion, storm damage, and flooding problems, and other concerns identified as project objectives.*

- a. **Selection of Feasible Alternative Designs:** Initially, several engineering design options are considered for a given project. Alternative designs are selected based on an understanding of the problem, a knowledge of coastal processes affecting the project site, and engineering experience regarding design and physical performance of design options in comparable coastal environments. Economic and regulatory constraints, environmental effects, and local preferences must be considered when selecting feasible alternative designs.

In developing specific alternative designs for beach fills, several fill cross sections (including different beach berm widths and dune geometries) are considered. In some cases, structural measures such as groins, breakwaters, or seawalls are included to stabilize the fill or to provide supplemental storm protection. Design cross sections, fill characteristics, and structures often vary along the project based on physical and economic considerations.

Alongshore project boundaries and end effects are also considered in selecting beach fill design alternatives. Beach fills often terminate along an open coast at a political (municipal or state) boundary, either due to changes in jurisdiction or changes in the level of development of the shoreline. In such cases, beach fill projects are transitioned into the neighboring boundaries to minimize effects on adjacent beaches, loss of material from the project, and project cost. Alternatively, project boundaries may coincide with physical boundaries (such as an inlet or headland) and may involve terminal structures, in which case downdrift impacts must be considered.

- b. **Detailed Design Evaluation of Feasible Alternatives:** Following identification of feasible design alternatives, a detailed coastal engineering analysis of each alternative is conducted to further evaluate expected physical performance. Engineering evaluation is performed within a planning framework that includes analysis of project economics. Because the without-project configuration provides the basis of the economic analysis, the response of the shoreline without project improvements in place is examined at the same level of detail as for the various alternatives. A number of engineering analyses need to be performed including, but not limited to, the following:

(1) *Equilibrium Beach Profile Shape*: The equilibrium shape of the beach profile, which develops after the fill is placed and reshaped by waves, determines the volume of fill needed to achieve a specified dry beach width. The equilibrium profile shape is also required to define the initial condition in storm-induced profile erosion modeling. The adjusted profile shape of the fill is often assumed to be similar to historic or existing profiles at the site; however, the analysis must consider factors that may modify the shape such as differences in grain size, changes in sediment supply, and presence of structures. Dean (1991) discusses characteristics and applications of equilibrium beach profiles, and Houston (1994) provides guidance for estimating fill volume requirements using equilibrium profile concepts. BMAP (Sommerfeld and Wise 1995) includes automated routines for calculating equilibrium beach profile shapes.

(2) *Long-Term Shoreline Recession Rates*: Annual shoreline erosion/accretion rates and alongshore variability of the rates are estimated based upon analysis of historic shoreline change data and sediment budget information. Estimates are used to assess the long-term performance of the existing shoreline condition and to evaluate renourishment needs for alternative beach fill designs.

(3) *Storm-Induced Beach Erosion Modeling*: Storm-induced beach erosion is calculated using a numerical cross-shore sediment transport model such as the Storm-induced BEach CHange (SBEACH) model (Rosati and Wise 1994). SBEACH simulates beach profile change produced by varying waves and water levels, and is used to predict the response of the existing beach profile and alternative design configurations to a range of storm conditions. Erosion, wave, and water level parameters generated by the model are utilized in economic analyses to determine storm damages. SBEACH can be applied to evaluate the effects of different beach fill cross-section geometries (e.g., dune height and berm width) and sediment grain sizes on storm-induced profile response.

(4) *Shoreline Change Modeling*: Long-term evolution of the beach planform is estimated for existing conditions and the project alternatives using a numerical shoreline change model such as the GENERalized model for SIMulating Shoreline change (GENESIS) (Gravens 1990). GENESIS can be applied to evaluate planform geometries, project boundaries (e.g., terminations or transitions), shore protection structures, and renourishment requirements. The Shoreline Modeling System (SMS) (Gravens 1991) includes a collection of computer programs developed to facilitate GENESIS applications.

PROJECT ECONOMICS: *Analysis of the economic benefits and costs associated with each project design alternative, resulting in the determination of the most cost-effective design which also meets the performance objectives of the project.*

a. **Damages:** Damage estimates for coastal structures are generated using damage function tables or curves which relate the percent damage to a structure to various possible damage mechanisms. Damage mechanisms which are typically considered include long-term shoreline recession and storm-induced erosion, wave impact, and flooding.

(1) *Shoreline Recession Damages*: Long-term erosion damages are determined for the

without-project condition with the assumption that the average historic rate of shoreline erosion will continue over the design lifetime, resulting in damage to structures as the shoreline recedes. Long-term erosion damages are normally not considered for the without-project alternatives because the designs include periodic renourishment to mitigate long-term shoreline recession.

(2) *Storm Damages*: Storm-induced economic damages are calculated for the without-project condition and each design alternative based on structure damage caused by storm-induced beach erosion, wave impacts, and flooding. Typically all three damage mechanisms are considered in the analysis. To avoid double counting of damages, only damage produced by a single mechanism (that which produces the most damage) is counted for each structure. Structure failure during storms may be partial or complete and the degree of damage is a function of structure type and the damage mechanism. Dollar values of all partial and complete structural failures are totalled to provide the storm-induced economic damage that is expected to occur for a given storm.

- b. **Benefits**: The total economic benefit of a given project design alternative is the sum of the damages prevented plus additional economic benefits including added recreational opportunities, reduction of land losses, damage reduction in the project transition areas, and downdrift benefits.
- c. **Project Costs**: The cost for each alternative is calculated by estimating volumes and unit costs for construction, and adding other project costs for items such as planning, engineering and design, construction management, environmental mitigation, lands and right-of-ways, interest on construction monies, renourishment costs, maintenance and storm damage repairs, and project monitoring.
- d. **The NED Plan**: The National Economic Development (NED) plan is the alternative which maximizes the net average annual benefits while meeting project objectives. The net average annual benefits are calculated as the difference between annual costs and annual benefits. Net average annual benefit is calculated for each alternative. The alternative with the greatest net annual benefit is the optimal economic solution to the problem. The benefit/cost ratio for each alternative is also calculated.

SELECTION OF PREFERRED ALTERNATIVE: *Ranking and selection of the design alternative which best meets project objectives and satisfies local and national interests.*

Results of the engineering and economic analyses are evaluated to select the preferred project design alternative. Project economics is a central consideration in the ranking process, and often the NED plan is selected. However, because of other concerns such as environmental impacts, another economically viable alternative may be selected. Local concerns also influence the final selection. For example, the local sponsors may object to the NED plan, or prefer another alternative for reasons such as aesthetics, impact on tourism, etc. In such a case, another alternative may be selected for construction provided that the project has a benefit/cost ratio

greater than one. Generally, Federal participation in the project is limited to the amount authorized for the NED plan.

FINAL DESIGN AND CONSTRUCTION: *Development of final design plans and specifications and construction of the project.*

Many of the design calculations, including project cross-section geometry and volume estimates, will have been completed as part of the alternative design evaluation. During final design, the project design parameters are modified and refined as required to optimize the design. Project plans, specifications, and construction schedules are developed. Project specifications include boundaries of the fill placement and borrow source areas; requirements on excavation, transport, and placement of fill material; environmental protection measures; construction templates and tolerances; method of determining fill volume for payment; etc. Jarrett (1981) presents a method for developing construction profile templates for beach fills.

After completion of final plans and specifications, bids are solicited and contracts awarded for construction of the project. Prior to construction, required real estate and right-of-ways must be obtained. The local sponsor will often provide real estate and right-of-way acquisition as part of the non-federal cost sharing. In addition to beach construction easements and access, dredge pipeline right-of-ways will often be required.

Construction monitoring plays a vital role in ensuring that sufficient volumes and dimensions of fill material are placed by the contractor. Because wave action often spreads the placed material over a wide area, disagreements can arise regarding how much material has actually been placed on the beach. The best protection against such disputes is to conduct frequent and accurate profile surveys during construction. Grosskopf and Kraus (1993) present guidelines for performing beach profile surveys of beach nourishment projects.

MONITORING, MAINTENANCE, AND RENOURISHMENT: *Collection of information on project condition and response, performance of maintenance operations, and continuation of construction to maintain project functionality over the design lifetime.*

Following construction, beach fills are monitored to evaluate project performance and to regularly assess the condition of the project. Profile surveys, beach sediment sampling, aerial shoreline photography, and wave and water level monitoring provide an accurate and objective measure of project response. Without physical monitoring data, it is difficult to estimate how well a project is performing in comparison to the design. Comparing actual performance to predicted performance provides useful information for modification and refinement of renourishment plans to improve project effectiveness and cost efficiency. Most monitoring programs involve an early phase of more intensive data collection to evaluate project performance. After project performance is established, data collection is scaled back to focus on monitoring project condition. Wise (1995) presents a recommended base-level physical monitoring plan for beach fills. Stauble (1991b) discusses additional elements of beach nourishment project monitoring including borrow area monitoring and biological impact assessment.

Periodic inspection, maintenance, and renourishment are performed over the project lifetime to ensure that project functionality is preserved. Maintenance refers to actions taken to maintain the design beach configuration (short of adding new fill material) such as reshaping the beach profile after a storm. Renourishment refers to placement of additional sediment on the beach to replace material lost from the project. Renourishment is performed periodically based on average annual losses and may be required following major storms to replenish material eroded from the project. Maintenance and renourishment needs must be assessed regularly throughout the life of the project. While maintenance is typically the responsibility of the local sponsors, renourishment is considered continuing construction and is included in Federal cost share arrangements.

SUMMARY: A framework for designing beach nourishment projects is presented. The framework can be followed using increasing levels of detail, depending upon the level of study and stage of project development. A summary of the major elements of beach fill design is provided and acceptable approaches and methods are discussed.

ADDITIONAL INFORMATION: This technical note was developed by Mr. Daniel Behnke, P.E. and Mr. William Grosskopf, P.E., Offshore & Coastal Technologies, Inc., East Coast, and Mr. Randall Wise, Coastal Processes Branch, Coastal Engineering Research Center. For more information contact Mr. Wise at (601)-634-3085.

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