US Army Corps of Engineers
Philadelphia District

DELAWARE BAY COASTLINE -
DELAWARE AND NEW JERSEY

DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL

Broadkill Beach, DE
Interim Feasibility Study

FINAL
FEASIBILITY REPORT
AND
ENVIRONMENTAL IMPACT
STATEMENT

September 1996

DISTRICT ENGINEERS STATEMENT OF TECHNICAL REVIEW

COMPLETION OF TECHNICAL REVIEW

The District has completed the final Feasibility Report and Environmental Impact Statement of the Delaware Bay Coastline: Delaware and New Jersey - Broadkill Beach, Delaware. Certification is hereby given that an independent technical review has been conducted that is appropriate to the level of risk and complexity inherent in the project, as defined in the Quality Control Plan. The technical review team is provided in the following table.

TECHNICAL REVIEW TEAM		
TECHNICAL ELEMENT	**STUDY TEAM MEMBERS**	**REVIEW TEAM MEMBERS**
PLANNING DIVISION		
Planning Division	----------------------------	Robert L. Callegari John A. Burnes, Ph. D., P.E.
Project Development Branch	----------------------------	Lee Ware, P.E.
Basin Planning Section	Wendy Jones	----------------------------
Environmental Resources Branch	Barbara Conlin, Mike Swanda	Jerry Pasquale
Economics Branch	Gene Senycz, Chris Bethke	Robert Selsor
ENGINEERING DIVISION		
Civil Project Management Branch	Dwight Pakan	Gary Rohn, P.E.
Design Branch	----------------------------	Leonard J. Lipski, P.E.
Geotechnical Section	Brian Murtaugh	Scott Fritzinger, P.E.
Civil/Structural Design Section	Tom Heary	Gus Rambo, P.E.
Hydrology & Hydraulics Branch	Keith Watson	George Sauls, P.E.
Cost Engineering Branch	Bill Welk	Jose Alvarez, P.E.
OTHER OFFICES		
Office of Counsel	Barry Gale	Mark Dolchin
Real Estate	Mike Hewitt	Sue Lewis

FINDINGS AND RESPONSE

During the technical review, compliance with clearly established policy principles and procedures, utilizing clearly justified and valid assumptions, were verified. This included assumptions; methods, procedures, and material used in analyses; alternatives evaluated; the appropriateness of data used and level of data obtained; and the reasonableness of the results, including whether the product meets the customer's needs consistent with law and existing Corps policy. There were no significant concerns identified in the technical review of the final Feasibililty Report and Environmental Impact Statement.

CERTIFICATION OF TECHNICAL REVIEW

As noted above, there were no significant concerns resulting from the technical review of the project. The report and all associated documents required by the National Environmental Policy Act, has been fully reviewed and is approved as sufficient. The project may proceed to the Preconstruction Engineering and Design phase.

for John A Burner
Robert L. Callegari
Chief, Planning Division

13 Sept 96
Date

FOR
Dennis J. Kamper, P.E.
Chief, Engineering Division

9/13/96
Date

James S. Turkel
James S. Turkel
Chief, Real Estate Division
Baltimore District

9-12-96
Date

CENAP-OC September 13, 1996

MEMORANDUM FOR CENAP-PL

SUBJECT: Delaware Bay Coastline - Delaware and New Jersey, Broadkill Beach, Sussex County, Delaware Final EIS

1. Office of Counsel has reviewed Civil Works and NEPA compliance documents for the subject project.

2. The selected plan identified in the Feasibility Study has the potential to become legally sufficient if the Corps obtains the requisite Section 401 Water Quality Certification prior to construction of the project.

3. The Final EIS is legally sufficient.

Barry Gale

BARRY GALE
Office of Counsel

Delaware Bay Coastline, Delaware & New Jersey

BROADKILL BEACH, DE
INTERIM FEASIBILITY STUDY

SYLLABUS

This report presents the results of a feasibility phase study to determine an implementable solution and the extent of Federal participation in a storm damage reduction project for the community of Broadkill Beach, Delaware. This feasibility study was conducted based on the recommendations of the Delaware Bay Coastline - Delaware and New Jersey Reconnaissance Study completed in 1991, which identified a possible solution to the storm damage problems facing the Broadkill Beach area. The reconnaissance study also determined that such a solution was in the Federal interest and identified the non-Federal sponsor. The feasibility study was cost shared between the Federal Government and the State of Delaware through the Delaware Department of Natural Resources and Environmental Control (DNREC), and was conducted under the provisions of the Feasibility Cost Sharing Agreement executed in December 1992. This interim feasibility study was initiated in January 1993.

Broadkill Beach is an unincorporated bayfront community located in Sussex County approximately three miles northwest of Lewes and extends along approximately 3 miles of bay frontage. The area has been subject to major flooding, erosion, and wave attack during storms resulting in damage to structures. Continued erosion in recent years has resulted in a reduction in the height and width of the beachfront. In addition, the lack of a continuous dune system, the proximity of roads to the shoreline, and the concentration of homes on the bay side of Bayshore Drive can result in significant economic damages in the event of a major storm.

This feasibility study evaluated alternative plans of improvement formulated on hurricane and storm damage reduction. The NED plan identified for Broadkill Beach is a 100 foot berm at an elevation of +8 ft. NGVD, and a dune at an elevation of +16 feet NGVD and a crest width of 25 feet. The selected plan includes dune grass, dune fencing and suitable beachfill with periodic nourishment to ensure the integrity of the design. The plan requires 1,305,000 cubic yards of initial fill to be placed from a designated offshore borrow site and subsequent periodic nourishment of 358,400 cubic yards every 5 years for 50 years.

The economic analysis indicates that the selected plan will provide annual benefits of $1,741,000, which when compared to the annual cost of $1,303,000, yields a benefit to cost ratio of 1.34 with $438,000 in net benefits.

The total initial project cost of construction is currently estimated to be $8,409,000 (at October 1995 price levels). The Federal share of this first cost is $5,258,000, and the non-Federal share is $3,151,000. Periodic nourishment is estimated at $2,852,000 on a 5-year cycle and will be similarly cost shared for the life of the project.

The proposed plan is technically sound, economically justified, and socially and environmentally acceptable. However, the current Administration's budgetary policy precludes further Federal participation in the design and construction of hurricane and storm damage reduction projects. This means that the feasibility phase of study will be completed, but Federal funds will not be budgeted for future construction of this project.

Delaware Bay Coastline, Delaware & New Jersey

BROADKILL BEACH, DE
INTERIM FEASIBILITY STUDY

DESCRIPTION OF SELECTED PLAN

Project Title: Delaware Bay Coastline - Delaware and New Jersey, Broadkill Beach Interim Feasibility Study

Description: The proposed project provides a protective beach with a dune system to reduce the potential for storm damage in the community of Broadkill Beach, DE.

Beach Fill	
Volume of Initial Fill	1,305,000
Volume of Renourishment Fill	358,400
Interval of Renourishment	5 yrs.
Length of Fill	14,600 lf
Width of Beach Berm	100 ft.
Width of Dune Crest	25 ft.
Elevations	
Dune Crest	+16 ft.
Beach Berm	+8 ft.
Slopes	
Dune (Landward & Seaward)	1V:5H
Beach Berm to Existing Bottom	1V:15H
Dune Appurtenances	Grass Planting Sand Fencing Vehicle Access Pedestrian Access
Project Cost	
Initial Cost	$8,409,000
Annualized (Discounted 7.625%)	$1,303,000

Average Annual Benefits	
Storm Damage Reduction	$1,741,000
Benefit/Cost Ratio	1.34
Cost Apportionment	
Federal	$5,258,000
Non-Federal	$3,151,000

NOTE: All elevations referenced to the National Geodetic Vertical Datum (NGVD)

Delaware Bay Coastline, Delaware & New Jersey

BROADKILL BEACH, DE
INTERIM FEASIBILITY STUDY
Final Feasibility Report

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INTRODUCTION

1. The Delaware Bay Coastline Feasibility Study is an ongoing study of the shore protection problems facing a number of areas in both Delaware and New Jersey. Due to the extent of the study area, the feasibility study was divided into seven interim studies. In Delaware, the interim study areas include Broadkill Beach, Roosevelt Inlet/Lewes Beach, and Port Mahon. The interim study areas in New Jersey include Maurice River, Cape May Villas, Reeds Beach to Pierces Point, and Oakwood Beach.

2. This feasibility report for the Broadkill Beach Interim Feasibility Study provides recommendations for future actions and programs to reduce storm damage and shoreline erosion. It also provides valuable information to coastal planners and engineers. This feasibility report presents existing conditions, without-project analyses, plan formulation and the National Economic Development Plan (NED) for this interim study of the Delaware Bay Coastline - Delaware and New Jersey Feasibility Study.

STUDY AUTHORITY

3. Authorization to undertake this study was established by a resolution adopted by the Committee on Public Works and Transportation, United States House of Representatives, on October 1, 1986. The resolution states:

> "RESOLVED BY THE COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION OF THE UNITED STATES HOUSE OF REPRESENTATIVES, that the Board of Engineers for Rivers and Harbors is hereby requested to make a comprehensive review of the existing reports on communities within the tidal portion of the Delaware Bay and its tributaries with a view to developing and updating a physical and engineering data base as the basis for actions and programs to provide shoreline protection or to provide up-to-date information for state and local management of this coastal area and to determine whether any modifications of the conclusions and recommendations contained in the previous reports of the Chief of Engineers that pertain to the Delaware Bay Coasts of Delaware and New Jersey are advisable at the present time. Such modifications to previous conclusions and recommendations shall be cognizant of, and incorporate where feasible, the findings of the final report of the Chief of Engineers on the Shoreline Control Demonstration Program, Section 54, of Public Law 93-251."

STUDY PURPOSE AND SCOPE

4. The Feasibility Study is the second of the Corps of Engineers two-phase planning process. The purpose of the Feasibility Study is to investigate and recommend solutions to problems identified in the Reconnaissance Study and further defined herein. This Feasibility Report will accomplish the following:

a. Provide a complete presentation of the existing conditions, without project analyses and plan formulation analyses for Broadkill Beach.

b. Indicate compliance with applicable statutes, executive orders and policies.

c. Provide a sound and documented basis for decision makers at all levels to judge the recommended solution(s).

5. This document was prepared in accordance with ER 1105-2-100 (Civil Works Planning Guidance Notebook), ER 1110-2-1150 (Engineering and Design for Civil Works Projects), ER 1165-2-130 (Federal Participation in Shore Protection) and other applicable guidance and regulations. The guidelines for planning water and related resources activities as contained in the ER 1105-2-100 require that Federal water resources activities be planned for achieving the NED objective. The NED objective is to increase the value of the Nation's output of goods and services and improve national economic efficiency consistent with protecting the Nation's environment pursuant to national environmental statutes, applicable executive orders, and other Federal planning requirements.

6. The principal focus of this report is on the problems associated with the persistent erosion of the Delaware Bay shoreline at Broadkill Beach. The erosion has caused significant economic losses, particularly during storm events. This report includes detailed engineering and economic appendices, including cost estimates, to compare alternative plans of protection. Ultimately the goal of this study is to identify the NED plan to reduce the storm damage potential in Broadkill Beach.

STUDY AREA

7. The Delaware Bay study area extends from the C&D Canal to Cape Henlopen in Delaware, and from the Salem River to Cape May Point in New Jersey for a total of approximately 130 miles of shoreline (Figure 1). In Delaware, the study area includes three counties: Sussex, Kent and New Castle as well as two National Wildlife Refuges (Bombay Hook and Prime Hook). Broadkill Beach is a bayfront community located in Sussex County approximately three miles northwest of Lewes and extends along approximately 15,200 ft. of bay frontage (Figures 2 and 3).

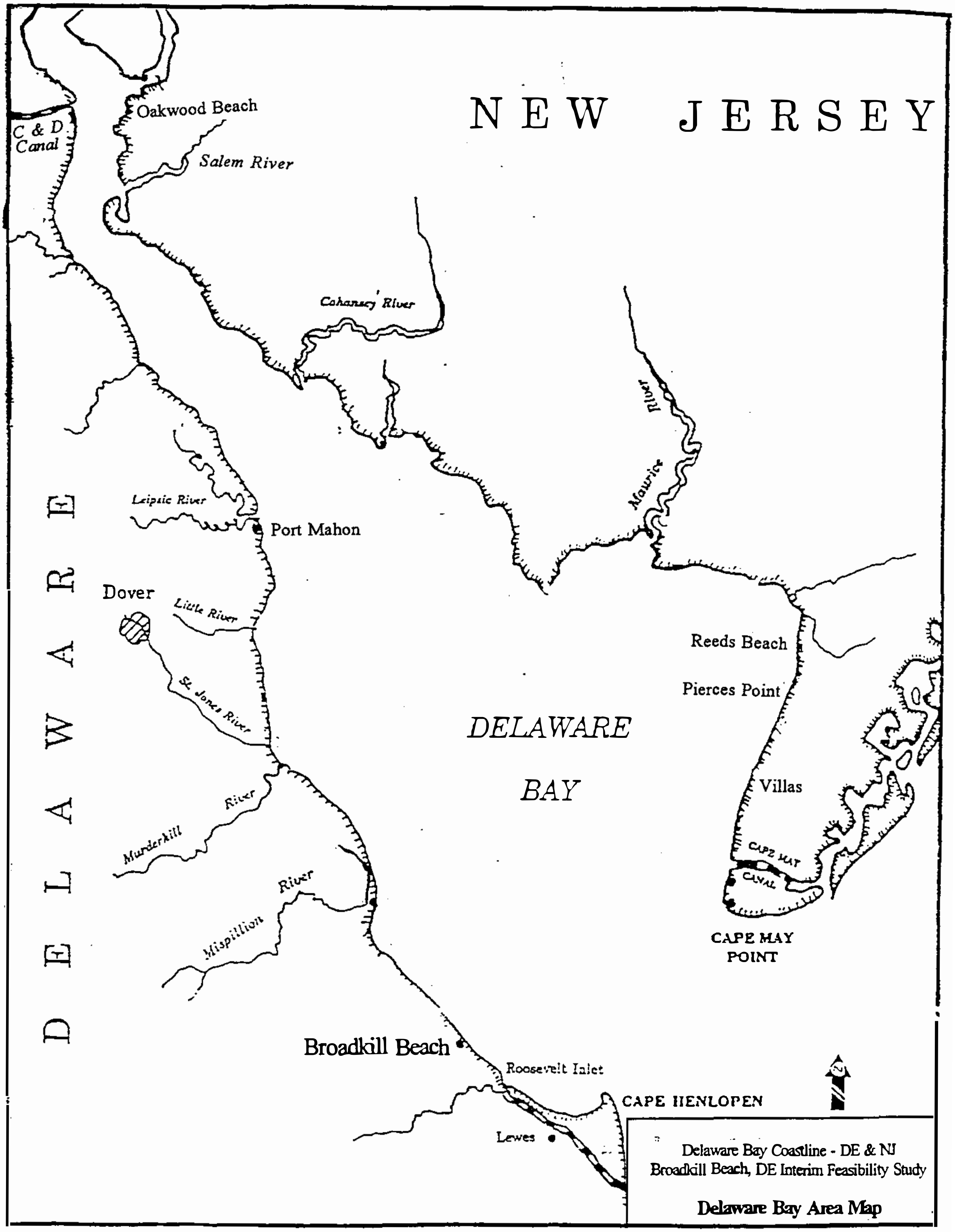
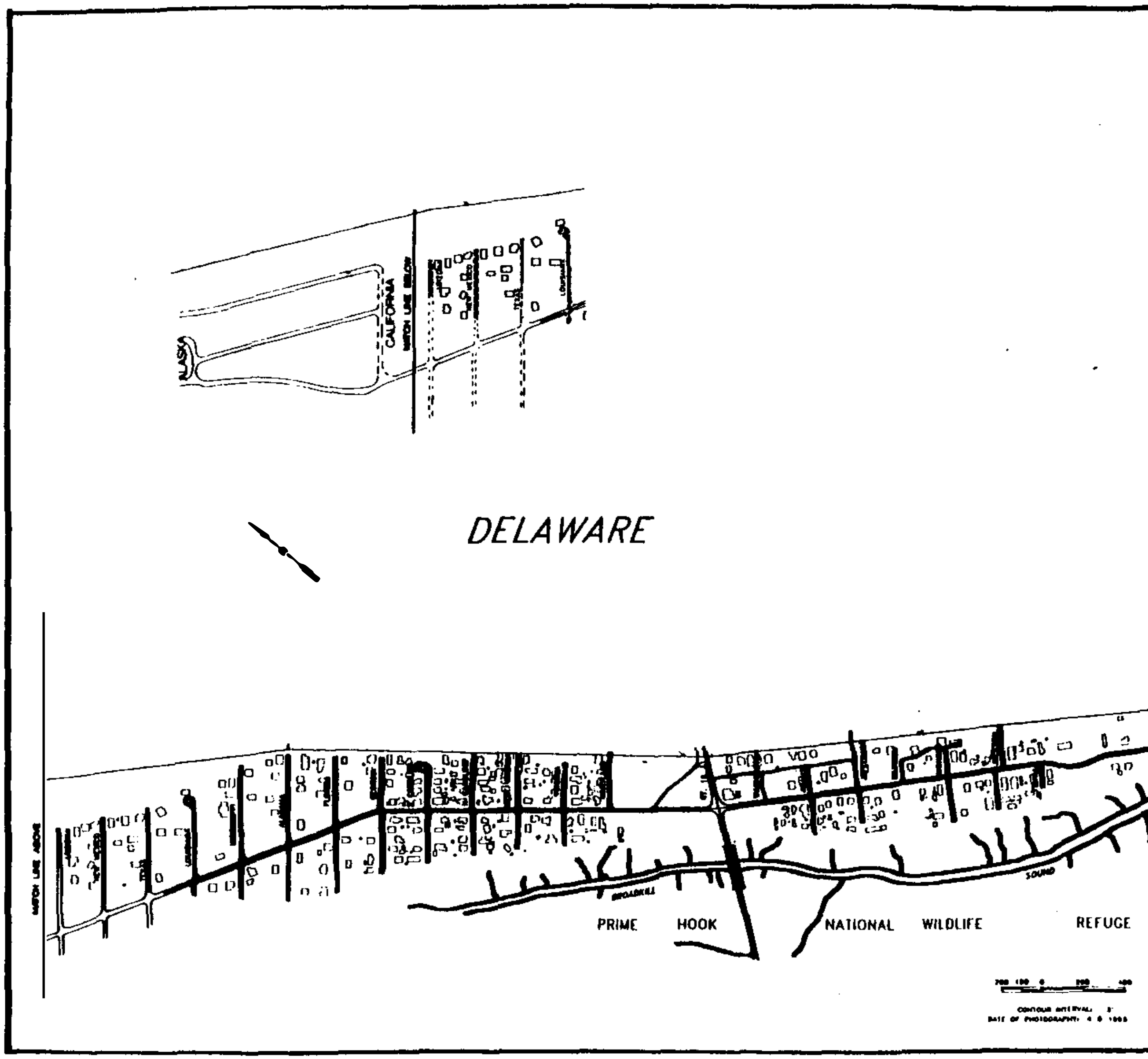

NEW JERSEY
DELAWARE
Oakwood Beach
C & D Canal
Salem River
Cohansey River
Maurice River
Leipsic River
Port Mahon
Dover
Little River
St. Jones River
Murderkill River
Mispillion River
DELAWARE BAY
Reeds Beach
Pierces Point
Villas
CAPE MAY CANAL
CAPE MAY POINT
Broadkill Beach
Roosevelt Inlet
CAPE HENLOPEN
Lewes
Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study
Delaware Bay Area Map

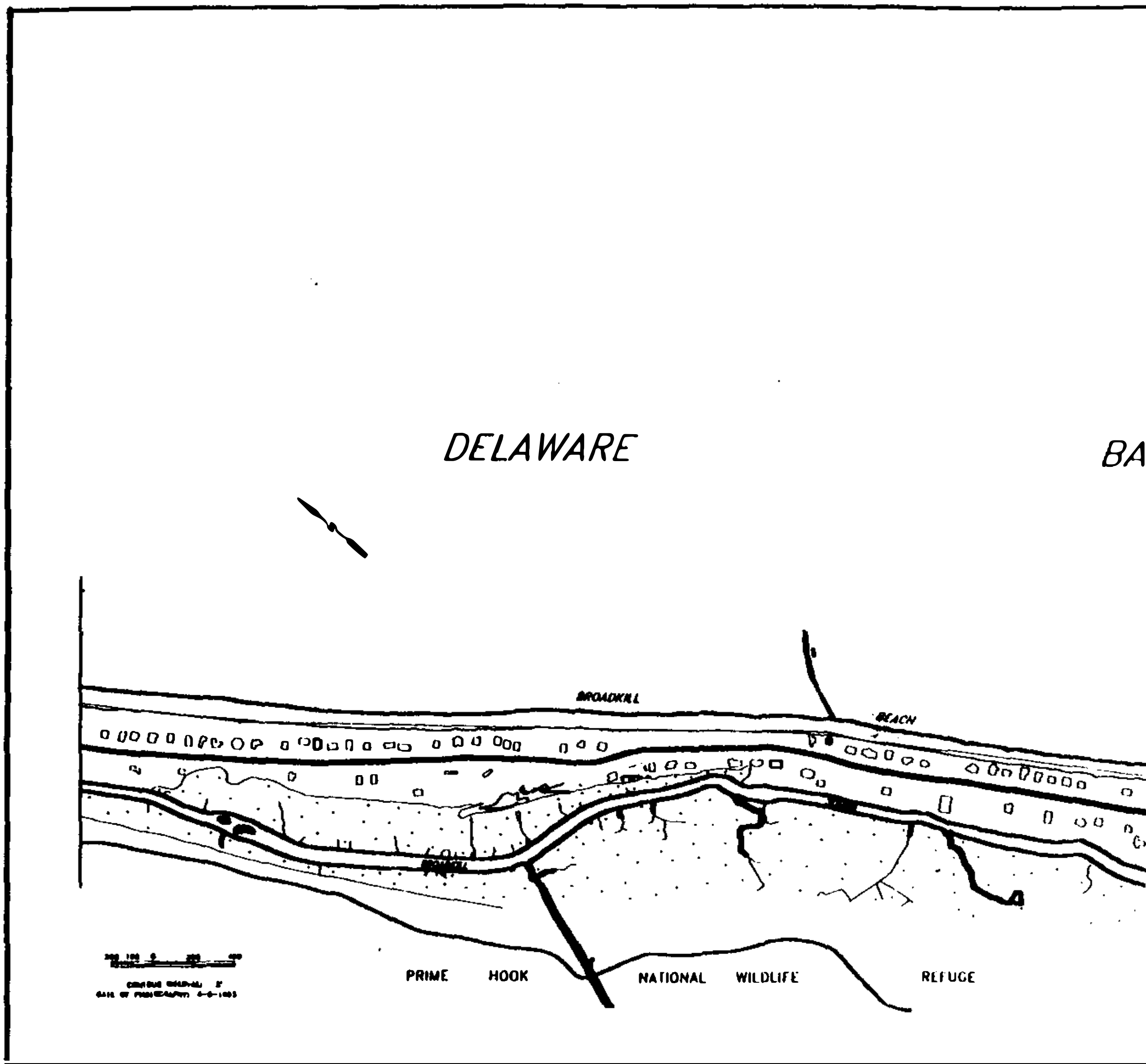
FIGURE 1



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Broadkill Beach Study Area
(North)

FIGURE 2



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Broadkill Beach Study Area (South)

FIGURE 3

PRIOR STUDIES AND REPORTS

8. There are several published and unpublished reports by the Corps of Engineers with regard to Broadkill Beach. Reports which are applicable to the study area are listed in chronological order in Table 1.

Table 1
Prior Reports

Publication and Date	Recommendations
H.D. 56, 74th Congress, 1st Session, 1935 Broadkill River, Delaware Bay Harbor of Refuge, Rehoboth Bay.	Entrance channel from Rehoboth Bay to Delaware Bay near Lewes; widening canal from Broadkill River to Lewes: 15 ft. deep channel from Harbor of refuge to Lewes was recommended and constructed.
H.D. 216, 85th Congress, 1st Session, 1957 Beach Erosion Control Report on Cooperative Study, Delaware Coast from Kitts Hummock to Fenwick Island.	Protective measures for selected sites along the Delaware Bay and ocean coast were recommended but never constructed.
H.D. 348, 88th Congress, 2nd Session, 1964 Delaware River and Bay, Pennsylvania, New Jersey, and Delaware.	Hurricane and tidal flood protection improvements were not recommended.
H.D. 90, 9th Congress, 2nd Session, 1968 Delaware Coast Beach Erosion Control and Hurricane Protection.	Federal shore protection projects along Delaware Bay communities not economically justified at this time.
Small Beach Erosion Project - Broadkill Beach, DE Detailed Project Report, 1972	Widening beach by sand placement and a 50 ft wide berm at an elevation of 10 ft above mean low water (MLW) recommended and partially constructed.
Low Cost Shore Protection - Final Report on the Shoreline Erosion Control Demonstration Program (section 54), 1981.	Structural devices placed at Pickering Beach, Kitts Hummock, and Slaughter Beach; Monitoring of beachfill performance at Broadkill Beach, Lewes Beach, and Bowers Beach.

RELATED PROJECTS

9. Federal projects developed in the vicinity of Broadkill Beach are listed below.

Beach Erosion Control Projects

Constructed & Completed

* Broadkill Beach, Delaware

Navigation Projects

Active

* Broadkill River, Delaware

10. **Section 54--Low Cost Shore Protection**. Another array of projects originated from a program conducted by the U.S. Army Corps of Engineers. The program's objectives were to develop and demonstrate low cost methods of shore protection in accordance with the provisions of Section 54, Public Law 93-251, 93rd Congress, approved 7 March 1974. Broadkill Beach was one of six locations along the Delaware Bay named in the authorizing legislation as project sites for the program. Low cost shore protection measures were installed and monitored for effectiveness by the Corps. Other aims of the program were:

1. to provide a data base that could be used for the logical selection of devices or combinations of devices to protect inland or sheltered shorelines in any given region of the United States.

2. to develop techniques for making selections.

3. to disseminate this information. The devices selected for the projects were chosen from a large listing of low cost shore protection devices, including vegetation, which had been tried or proposed in the past.

11. Three sites were chosen for demonstration projects utilizing a variety of structural devices and materials. Three additional sites were selected as monitoring projects. The projects on these sites, principally beachfill, were constructed prior to the initiation of the Section 54 Program. No shore protection devices were added to these sites under the program.

12. At Broadkill Beach, the monitoring project examined a 50 ft. wide berm constructed in 1976 to an elevation of +10 ft. MLW and a foreshore slope of 1 on 10. An initial fill in 1976 consisted of 40,300 cubic yards of material.

RELATED INSTITUTIONAL PROGRAMS

13. **National Estuary Program - Delaware Estuary Program.** The National Estuary Program (NEP) was established by Congress under the Water Quality Act of 1987, section 317. The purposes of the NEP are: (1) to identify nationally significant estuaries threatened by pollution, development, or overuse; (2) promote comprehensive planning, conservation and management of nationally significant estuaries; and (3) encourage the preparation of management plans and enhance coordination of estuarine research. These goals are to be achieved for the estuaries in the NEP by a Comprehensive Conservation and Management Plan (CCMP) developed in a management and study effort called a Management Conference.

14. The NEP is managed by the United States Environmental Protection Agency (EPA). The Administrator of the EPA selects estuaries for the program in response to nominations by State Governors, or, in the case of interstate estuaries, at the initiative of the EPA. Selection is based on issues of significant national concern regarding water quality, biological diversity, and recreational activities.

15. The Delaware Estuary Program (DELEP) is a five-year Federally funded program which has been undertaken by the States of Delaware, New Jersey, and Pennsylvania and the EPA. The DELEP was included into the NEP in 1988. The goals of the DELEP are: (1) evaluate the Delaware Estuary; (2) define its environmental management needs; and (3) develop a Delaware Estuary CCMP. This plan will recommend solutions to guide future management of the Estuary's resources that will be implemented through existing and possibly new institutions and agencies.

16. The DELEP study area includes: (1) the Delaware River and Bay from Morrisville, Pennsylvania and Trenton, New Jersey, to Lewes Delaware and Cape May, New Jersey; (2) all tidal tributaries to these waters; and (3) the surrounding land areas.

17. **North American Waterfowl Management Plan**. The North American Waterfowl Management Plan (NAWMP) was established on 14 May 1986 by the United States Fish and Wildlife Service and the Canadian Wildlife Service. The purpose of the plan is to reverse the decline of wetlands and waterfowl by establishing goals for conserving wetland habitats and for restoring waterfowl populations. Broad guidelines are provided for habitat protection and management through the year 2000. Each country, state, province, and territory will need to establish specific plans for habitat preservation and management in the respective jurisdictions. The implementation of the NAWMP takes place through "Joint Ventures", coalitions of State and Federal agencies, conservation groups, and landowners.

18. About ten to twenty million shorebirds from over 48 species migrate annually from South America to Canada along the Atlantic Flyway, relying upon strategically placed habitats for food and rest. The Delaware Estuary is the largest staging site in the eastern United States for shorebirds migrating along the Atlantic Flyway. It is also the second largest staging site in North America. The conservation of the Delaware Estuary through the

NAWMP is critical to the survival of the various species of migrating shorebirds as well as the Estuary's unique resources.

19. **Western Hemisphere Shorebird Reserve Network.** The Western Hemisphere Shorebird Reserve Network (WSHRN) was created in 1985 by the International Association of Fish and Wildlife Agencies. The Network is an inclusive, multi-organizational effort. The objectives of the WSHRN are: (1) to promote the conservation of Western Hemisphere Shorebirds; and (2) the sustenance of natural ecological processes in wetlands and other critical habitats upon which they depend. The member sites or "Sister Reserves" are Hemispheric, International, Regional, and Endangered Species sites. Throughout the Western Hemisphere, fifteen sites have been dedicated as of 1991.

20. The lower 25 miles of the Delaware Bay shore of New Jersey and Delaware has been established as a "Sister Reserve" through a joint resolution by then Governors Thomas H. Kean of New Jersey and Michael M. Castle of Delaware. The objective of the joint resolution is to recognize and protect the critical migrating and feeding habitat for over one million shorebirds which utilize the Delaware Bay during spring migration between April and June.

EXISTING CONDITIONS

SOCIO-ECONOMIC RESOURCES EVALUATION

21. **Population and Land Use**. Broadkill Beach is a small bay-side community consisting of 3 miles of beaches along the Delaware Bay with a permanent population slightly under 500. Due to the relatively small size of Broadkill Beach the community has remained unincorporated and is governed under the jurisdiction of Sussex County.

22. Sussex County is the largest of the three counties in Delaware, encompassing 950 square miles of the state's 1982 square miles. It is the second most populated county with approximately 17% of the state's permanent population. In 1990 Sussex County had a population of 113,229 residents, almost 1/4 of New Castle County's population, and an increase of 9.5% since 1985.

23. Unlike the majority of shoreline communities in Delaware, Broadkill Beach has remained a small residential community with very little tourism. There are approximately 430 single family homes and only 1 commercial lot within the town's boundaries, the Broadkill Store. The store is located at the corner of Route 16 and Bayshore Drive, the only marked intersection within Broadkill Beach.

24. Bayshore Drive is the primary road in Broadkill Beach and Route 16 is the only access road which leads into the community. Because Route 16 is the only evacuation route it is very important that the road remains accessible. In attempts to prevent flooding, the road was slightly raised almost 20 years ago. However, despite this effort the road still remains vulnerable to overflow in major storms. When the road becomes inundated with flood waters, access to Broadkill becomes virtually impossible.

25. Within the town itself there is only one main road, Bayshore Drive, which runs parallel with the bay. There are also a few roads which run perpendicular to Bayshore Drive, but most are small dirt roads with limited access. Even Bayshore Drive becomes a dirt road at the southern end of the community. Very few homes are built on these side roads, instead most homes line the bay-side of Bayshore Drive, with less than 1/4 of the homes on the west side of the road.

26. Development within Broadkill Beach is limited due to the nature of the land. To the west of Broadkill Beach is the Primehook National Wildlife Refuge, and to the far south, lies the state owned Beach Plum Island. There are only a few available lots in the northern section of Broadkill Beach. As a result, most new construction is occurring on the southern end of Bayshore Drive. These homes are newer and more expensive than the cottages which are located in the center of town. Construction is expected to continue due to the abundance of vacant lots as well as the existence of water hookups already pre-installed.

27. In 1990 the median value of a single family home in Sussex County was $79,800, almost 20% less than the State's median value. Less than half of the homes in Sussex County are owner occupied with 12.6% renter occupied and 41.2% vacant. Median rent for single family homes in Sussex County is approximately $278, more than 65% of Delaware State's median rent. Table 2 shows the housing occupancy for the State of Delaware and Sussex County. Unlike Sussex County, residents of Broadkill Beach permanently occupy about 25% of the homes year round and the majority of homes are owner occupied rather than renter occupied .

Table 2
Housing Unit Occupancy

	Total Households	Total Housing Units	% Owner Occupied	% Renter Occupied	% Vacant
Delaware	247,497	289,919	60.0	25.4	14.6
Sussex County	43,681	74,253	46.2	12.6	41.2

Source: Upclose U.S. Data Book 1993

28. Because of the expected continual development in both Broadkill and Sussex County, the U.S. Census Bureau has projected that both the State of Delaware and Sussex County's population will continue to increase over the next twenty years, but at a decreasing rate of growth. Table 3 contains estimates of population by the Delaware Population Consortium, University of Delaware, College of Urban Affairs and Public Policy for the next fifteen years.

Table 3
Year Round Population

	1985	1990	1995	2000	2005	2010
Delaware	625,950	682,700	738,150	784,850	820,500	845,000
Sussex County	107,450	113,229	132,400	142,700	151,700	162,350

29. **Economic Development**. In 1990 Sussex County's labor force was projected to be 62,750, with an unemployment rate of 4.2%, just above the state's unemployment rate of 4.0%. The study area is similar to the rest of Sussex County and Delaware in its reliance on the agriculture and manufacturing/processing industry. In Sussex County, 1/3 of the work force is employed in retail or services, while another 1/3 are in manufacturing.

30. Table 4 contains 1990 income information for the State of Delaware and Sussex County. The estimated per capita income in 1990 for Sussex County was $12,723, slightly lower than the state of Delaware which had a per capita income of $15,584. Although the study area is similar in nature to the county as a whole, it differs greatly from most coastal areas. Since most coastal communities have come to rely heavily on tourism, they are not affected by economically hard times caused by poor agricultural crops or a recession in the manufacturing industry. However, because Broadkill has a strictly agricultural and manufacturing industry the economy tends to fluctuate greatly from year to year.

Table 4
Income For 1990

	Per Capita Income	Median Household Income	Median Family Income
Delaware	15,854	34,875	40,252
Sussex County	12,723	26,904	31,112

Source: The Upclose U.S. Data Book 1993

ENVIRONMENTAL RESOURCES EVALUATION

31. **General Setting**. The land on which the Broadkill Beach community is located was formed from sand carried northwestward along the bay shore by the littoral transport system. Sand was carried along the shore from Breakwater Harbor by flood tide currents and wave refraction around the tip of Cape Henlopen (Kraft and Caulk, 1972). As accretion continued in the Lewes Beach area, a sand spit grew northwestward. By 1882 it had advanced to the Broadkill Beach area, deflecting the mouth of the Broadkill River to the northwest. As the Cape Henlopen spit continued building northward toward the inner breakwater, flood tidal currents were deflected northward into deeper water of Delaware Bay, and the sediment supply that had previously flowed onto Lewes Beach was cut off. As a result, the net littoral drift at Broadkill Beach shifted to the southeast beginning an erosional period. Eventually, a new inlet broke through the barrier beach to the southeast, and Broadkill Beach was cut off from its former source of sand (Kraft, et al., 1975).

32. **Terrestrial Ecosystems**.

33. Beaches. The narrow sandy beach is flanked by a discontinuous dune system, the result of development and erosion. The predominant plant species on the dunes is American beach grass (Ammophila breviligulata). This species is adapted to harsh conditions such as low fertility, temperature extremes, and high energy from the bay and wind, conditions typical

of sand dunes. Beach grass is valued as a beach binder. The plants spread by long rhizomes and stolens which form a fibrous network to keep the sand from blowing away. The plants also have the ability to grow even partly buried in the sand. The upper portions of the dune system are colonized by seaside goldenrod (Solidago sempervirens) and cocklebur (Xanthium echinatum).

34. To a limited extent, the dune system grades into a zone of shrubby vegetation where development is not present. This is observed directly to the north and south of the community. This scrub-thicket zone is typically populated by dwarf trees and shrubs such as wax-myrtle (Myrica cerifera), bayberry (Myrica pensylvanica), dwarf sumac (Rhus copallina), poison ivy (Toxicodendron radicans), groundsel bush (Baccharis halimifolia), loblolly pine (Pinus taeda), pitch pine (Pinus rigida), and Virginia creeper (Parthenocissus quinquefolia).

35. Many species of gulls and shorebirds inhabit the beach. Gulls forage on components of the beach wrack such as carrion and plant parts. The more common species include laughing gull (Larus atricilla), herring gull (L. argentatus), and ring-billed gull (L. delawarensis). Shorebird numbers along the lower bay coast are particularly noticeable during spring and fall migrations. The Delaware Bay ranks as the largest spring staging site for shorebirds in eastern North America. Staging sites serve to link wintering areas with breeding grounds and are critical to the survival of hundreds of thousands of migrating shorebirds.

36. Burger (1983) documented over 400,000 shorebirds, representing 21 different species during surveys conducted from May through October 1982. The birds arrive to the shores of the bay in early May from the coast of Brazil, Patagonia, Tierra del Fuego, Chile, Peru, Suriname, Venezuela, and the Guyanas. They reach the bay depleted of their energy reserves after several days of nonstop flight, traveling up to 5,000 miles. The birds feast on horseshoe crab eggs which fuel their northward migration from Delaware Bay to their Arctic nesting grounds. Common species include sanderling (Calidris alba), dunlin (C. alpina), semipalmated sandpiper (C. pusilla), red knot (C. canutus), western sandpiper (C. mauri), willet (Catoptrophorus semipalmatus), ruddy turnstone (Arenaria interpres), and short-billed dowitcher (Limnodromus griseus). In 1985, Delaware Bay became a charter member of the Western Hemisphere Shorebird Reserve Network. The network was established by the combined efforts of governmental and private organizations to encourage protection for internationally significant staging areas.

37. A number of non-marine mammals, reptiles, amphibians, and birds are associated with beach habitat along the Delaware Bay coastline. These species include Fowler's toad (Bufo woodhousei fowleri), eastern hognose snake (Heterodon platyrhinos), box turtle (Terrapene carolina), raccoon (Procyon lotor), eastern cottontail (Sylvilagus floridanus), red fox (Vulpes fulva), white-footed mouse (Peromyscus leucopus), meadow vole (Microtus pensylvanicus), white-tailed deer (Odocoileus virginianus), savannah sparrow (Passerculus sandwichensis), song sparrow (Melospiza melodia), mourning dove (Zenaida macroura), gray catbird (Dumetella carolinensis), northern mockingbird (Mimus polyglottos), and brown thrasher (Toxostoma rufum).

38. Wetlands. Wetlands have long been recognized as providing essential habitat to wildlife and are now recognized for their economic and other environmental values. Fish and wildlife utilize wetlands in a variety of ways. Some spend their entire lives in wetlands while others use wetlands for specific life stages, such as nursery or feeding areas. Wetlands are also essential for the majority of endangered plants and animals. Coastal and inland wetlands are critical as fish habitat and coastal wetlands are essential for shellfish. Approximately two-thirds of the major U.S. commercial fishes depend on estuarine saltmarshes for nursery and spawning grounds. Broadkill Beach is surrounded with 8,818 acres of wetlands/forested uplands which make up the Prime Hook National Refuge, which lies directly west and north of the beach community. The saltmarshes surrounding Broadkill Beach have a typical salinity range from 20 to 30 parts per thousand and the area is generally flooded twice daily by the tides. The dominant plant species in these highly productive areas is smooth cordgrass (Spartina alterniflora). The high marsh, which is flooded less frequently, is located above the tall cordgrass zone and inhabited with salt hay grass (Spartina patens), spike grass (Distichlis spicata), and common reed (Phragmites australis). Other floral species associated with a cordgrass marsh are big cordgrass (S. cynosuroides), black grass (Juncus gerardii), and switch grass (Panicum virgatum).

39. Species which inhabit the wetlands include snails (Melampus bidentatus), fiddler crab (Uca sp.), ribbed mussel (Modiolus demissus), blue mussel (Mytilus edulis), marsh crab (Sesarma sp.), snapping turtle (Chelydra serpentina), and the diamond back terrapin (Malaclemys terrapin). When flooded, the marshes become host to several species of fish including mullet (Mugil cephalus), mummichog (Fundulus heteroclitus), red drum (Scianops occelatus), sheepshead minnow (Cyprinodon variegatus), and striped killifish (Fundulus majalis). The wildlife habitat of these areas is excellent, and migratory waterbird management is particularly emphasized. Hunting, trapping, boating, fishing, and wildlife observation are important recreational activities.

40. Avian use of wetlands is extensive. Saltmarshes are used for nesting by many birds, including the laughing gull (Larus atricilla), sharp-tailed sparrow (Ammospiza caudacuta), seaside sparrow (Ammospiza maritima), clapper rail (Rallus longirostris), black duck (Anas rubripes), blue-winged teal (Querquedula discors), willet (Catoptrophorus semipalmatus), and marsh hawk (Circus hudsonius). Wading birds like the great blue heron (Ardea herodias), little blue heron (Florida caerulea), black-crowned night heron (Nycticorax nycticorax hoactli), glossy ibis (Plegadis falcinellus), common egret (Casmerodius albus), and snowy egret (Egretta thula) feed in the salt marshes and nest in adjacent woody vegetation. The bay's coastal marshes are also important feeding and stopover areas for migrating greater snow geese (Chen caerulescens), black duck (Anas rubripes), Canada geese (Branta canadensis), and mallard (Anas platyrhynchos).

41. Over a dozen raptor species are known to migrate through the lower Delaware Bay on an annual basis, including the sharp-shinned hawk (Accipiter striatus), Cooper's hawk (Accipiter cooperii), and red-tailed hawk (Buteo jamaicensis). In addition, many owls migrate through the area on an annual basis. Typical species include the common barn owl (Tyto

alba), northern saw-whet owl (Aegolius acadicus) and long-eared owl (Asio otus). During their migration through the project area, owls generally utilize the forested areas of the Refuge.

42. **Aquatic Ecosystems.**

43. Intertidal Zone. The upper marine intertidal zone is primarily barren. Organic inputs are derived from the bay in the form of beach wrack, which is composed of drying seaweed, tidal marsh plant debris, decaying marine animals, and miscellaneous debris that is washed up and deposited on the beach. The beach wrack provides a cooler, moist microhabitat suitable to crustaceans such as the amphipods: Orchestia spp. and Talorchestia spp., which are commonly referred to as beach fleas. Beach fleas are important prey to ghost crabs (Ocypode quadrata). Various foraging birds and some mammals are attracted to the beach fleas, ghost crabs, carrion and plant debris found in this zone. The intertidal zone contains more biological activity that the upper intertidal zone. Frequent inundation with water provides suitable habitat for benthic infauna.

44. The horseshoe crab (Limulus polyphemus) is a notable inhabitant of the intertidal zone of Delaware Bay sandy beaches. This arthropod migrates into shallow water in late spring to spawn in the upper tidal zone. Spawning activity peaks in May and June. The lower bay region ranks as one of the largest migratory shorebird staging areas as a result of the seasonal abundance of horseshoe crabs eggs. Adult horseshoe crabs are a minor component in commercial fisheries and are harvested for medical use, fertilizer, and animal feed.

45. Nearshore Zone. A benthic habitat assessment study revealed a productive benthic assemblage off Broadkill Beach. Invertebrate phyla occurring along the coastline are represented by Cnidaria (jellyfish), Platyhelminthes (flatworms), Nemertinea (ribbon worms), Nemathelminthes (Nematoda), Bryozoa, Mollusca (chitons, clams, mussels), Echinodermata (sea urchins, sea cucumbers, sand dollars, sea stars), and the Urochordata (tunicates). Benthic invertebrate species are discussed below in more detail.

46. Water Quality. Other than ocean input, water that flows into Delaware Bay comes primarily from two sources: indirect runoff, which comes through the rivers of the drainage system; and direct runoff, which enters from the land or marshes. The water column is well mixed throughout most of the year. As a result of high concentrations of suspended sediment and strong tidal and wind generated currents, turbidity is relatively high. The concentration of oxygen in the water is typically high as a result of high rates of mixing by the tidal currents and wind. Large amounts of nutrients enter the bay as runoff from the land. The Bay owes its productivity to these large amounts of nutrients and the extensive recycling that occurs between the overlying water and the biologically active bottom sediments. Vertical mixing with surface water permits the phytoplankton to utilize this nutrient source.

47. Phytoplankton. Phytoplankton growth depends on temperature, light, nutrients, and trace elements such as metals and vitamins. These factors that affect phytoplankton populations are crucial to the health of the Bay and its food web. Several hundred species of phytoplankton have been observed in Delaware Bay. The most predominant are diatoms which are well suited for growth in the spring when temperatures are low and nutrient concentrations high. The spring diatom bloom supports the growth of larval and juvenile shellfish and fish species. Small green algae and brown algae make up much of the summer phytoplankton population in the lower Bay.

48. Zooplankton. During productive periods, phytoplankton are grazed upon by zooplankton, which range in size from microscopic single-celled organisms to larger jellyfish. Populations of zooplankton in the lower Bay reach a peak in April and another lower peak building from June through August. Zooplankton provide an essential trophic link between primary producers (phytoplankton) and higher organisms (larger invertebrates and fish). Sampling in the lower Bay by Watling and Maurer (1976) revealed the presence of 60 species representing the following Phyla: Protozoa, Cnidaria, Ctenophora, Ectoprocta, Annelida, Mollusca, Arthropoda, Chaetognatha, and Chordata. Three copepod species dominate the lower bay's zooplankton community: Acartia tonsa, Eurytemora hirundoides, and Eurytemora affinis, constituting approximately 84% of all zooplankton (Pennock and Herman, 1988).

49. Macrobenthos. Benthic macroinvertebrates are those dwelling in the substrate (infauna) or on the substrate (epifauna). Benthic organisms provide an important food source for fishes and humans. The following benthic species were found to be most abundant in a benthic assessment study conducted in July 1994 by Battelle for this project: the bivalves Gemma gemma, Nucula annulata, and Tellina agilis; 5 crustaceans Protohaustorius wigleyi, Tanaissus psammophilus, Corophium tuberculatum, Ampelisca verrilli, and Neomysis americana; 8 annelids Oligochaeta spp., Parapionosyllis longicirrata, Sabellaria vulgaris, Spiophanes bombyx, Brania wellfleetensis, Polydora cornuta, Spio setosa, and Mediomastus ambiseta; and 1 urochordate Ascidiacea spp. In January 1994, the Greeley Polhemus Group completed an assessment of the benthic habitat at a 500 acre site 1,000 yards offshore of Broadkill Beach for this study. Fifty-one species, mostly crustaceans and polychaete worms were collected from 40 samples. The crustaceans Ampelisca sp., the bivalve mollusk Mulinia lateralis, the crustacean Cerapus tubularis, and the bivalve mollusk Nucula proxima were most abundant in descending order.

50. Fisheries. The Delaware Bay is home to over 100 species of finfish, many of which are commercially or recreationally important. This great diversity is the result of the overlap between northern and southern species in the mid-Atlantic coastal region. Many species use the Bay as a breeding ground and nursery area for their young. Surveys of finfish in Delaware's coastal waters have been conducted by Maurer and Tinsman (1980), and annually for several years by the National Marine Fisheries Service. Abundant finfish species include: red hake (Urophycis chuss), northern sea robin (Prionotus carolinus), spot (Leiostomus xanthurus), windowpane flounder (Scopthalmus aquosus), silver hake (Merluccuns bilinearis), bluefish (Pomatomis saltatrix), summer flounder (Paralichthys dentatus), clearnose skate (Raja

eglanteria), hogchoker (Trinectes maculatus), and weakfish (Cynocion regalus).

51. In terms of its abundance and value to the recreational and commercial fisheries, the weakfish ranks as one of the most important species in Delaware Bay. It is a seasonal resident from April through October. The area between Mispillion River and Lewes is a major spawning area. Spawning primarily occurs during June and July. The larvae are transported to the middle and upper estuary where they develop into juveniles. By the fall, they have reached a length of 4 to 6 inches. Then they migrate to spend the winter in warmer waters off Virginia and North Carolina.

52. The surf clam (Spisula solidissima) was once harvested from Delaware's coastal waters for commercial purposes. Commercial harvesting ceased in 1975 and surveys conducted by the State in 1982, 1986, and 1992 confirmed that no significant populations of surf clams exist within Delaware's territorial zone. Despite the lack of commercially harvestable densities of surf clams, juvenile forms have been recorded in increasing numbers in recent years. In the benthic assessment, one to seven individuals were collected from each sample grab.

53. The blue crab Callinectes sapidus) is an important commercial component of the bay. Blue crabs seasonally migrate into the bay. In early spring and summer, the crabs are caught nearshore in the lower bay. As temperatures increase, the crabs are caught further upbay. The crabs return to the lower bay as temperatures decline in the fall to burrow under the sediment to overwinter (Schuster, 1959). Blue crab populations are considered healthy and sustainable despite the annual fluctuations in catch. Over two million pounds a year are commercially harvested by dredge in the fall (Price et al., 1983). The recreational catch for the bay approximates about 10% of the commercial catch.

54. Threatened and Endangered Species. Several threatened and endangered species are known to occur in the bay region. The American peregrine falcon (Falco peregrinus anatum) and Arctic peregrine falcon (Falco peregrinus tundrius) migrate through the project area but are not known to nest there. Bald eagles (Haliaetus leucocephalus) have been observed nesting in Prime Hook National Wildlife Refuge. In Delaware Bay, bald eagles stay loosely associated with their nests year round and do not migrate out of the area (pers. comm. Lisa Gelvin-Invaer, Delaware Fish & Wildlife). Pairs bond in December/January and begin egg incubation as early as February.

55. Piping plovers (Charadrius melodus) have previously nested on Beach Plum Island, immediately south of Broadkill Beach, but haven't in recent years. Piping plovers begin nesting in March/April. The Delmarva fox squirrel (Sciurus niger) is a forest dweller and may occur in the forested areas of the Prime Hook National Wildlife Refuge, but does not approach the project area. Sea turtles, the Federally-listed threatened loggerhead (Caretta caretta) and green turtle (Chelonia mydas) as well as the Federally-listed endangered Kemp's Ridley (Lepidochelys kempii), leatherback (Dermochelys coriacea), and hawksbill (Eretmochelys imbricata imbricata) have been observed offshore.

56. The northern diamondback terrapin (Malaclemys terrapin) is a federal candidate species found in the marshes and tidal flats of Delaware Bay. The terrapin breeds in vegetated dunes above the high tide line. The harbor porpoise (Phocoena phocoena) typically feeds at river mouths and have been known to become entangled in gillnets in the project area. Dead specimens have been found washed up on Broadkill Beach. The harbor porpoise is currently a candidate for threatened status.

57. Six species of endangered whales that have been observed migrating along the Atlantic coast and occasionally spotted in the lower bay include the sperm whale (Physeter catodon), fin whale (Balaenoptera physalus), humpback whale (Megaptera novaeangliae), blue whale (Balaenoptera musculus), sei whale (Balaenoptera borealis), and black right whale (Balaena glacialis). All marine mammals are protected by Federal laws.

58. The shortnose sturgeon (Acipenser brevirostrum), an endangered species within the purview of the National Marine Fisheries Service migrates through the project area in the spring from the sea to spawn in the upper estuary. Although most of the recorded occurrences have been from the upper tidal freshwater area of the Delaware River, the fish also utilize Delaware Bay, especially during the winter months (Brundage and Meadows, 1982).

59. One plant species, the sea beach pigweed (Amaranthus pumilus), a Federally-listed species, typically does not occur north of Indian River. However, propagation on Beach Plum Island could result from a major storm event when propagules are carried north or existing dormant seeds are exposed as a result of erosion.

CULTURAL RESOURCES

60. The prehistoric occupation of Delaware and the Delmarva Peninsula has been categorized by archaeologists into three general periods of cultural development: Paleoindian (15,000 years before present (B.P.) - 8,500 B.P.), Archaic (8,500 B.P. - 5,000 B.P.), and Woodland (5,000 B.P. - 400 B.P.). Few Paleoindian sites have been located in the Delaware region of the Delmarva Peninsula. This is partly due to the low population density and nomadic lifestyle of the people from the period, as well as from the inundation of sites by sea level rise and burial under thick layers of alluvium and modern cultural deposits. Archaic period sites tend to be relatively small, suggesting short-term and intermittent occupations. Archaeological investigations have traditionally focused on Woodland period sites. Many Early Woodland period base camps have been located along brackish rivers. By the Late Woodland period, there is evidence of a further sedentary lifestyle with an increasing reliance on agriculture. Woodland sites have been identified on both the coastal marshes and in the mid-drainage areas in the region.

61. The first documented exploration of the Delaware Coast was accomplished by Giovanni de Verranzo (1524) and Estevan Gomez (1525). The first Dutch explorers came to the Delaware Bay from New Amsterdam (New York City) in 1614 and soon set up trading stations and settlements at various locations along the banks of the bay and river. In 1631, the Dutch established a small whaling community and settlement near Cape Henlopen that was named "Zwaanendael." The Swedes and Dutch co-existed in the Delaware Valley until 1664 when the British, under the command of Sir Robert Carr, assumed command of the region. King Charles II deeded a substantial portion of the territory to William Penn in 1682 and subsequently established an English colony on the Delaware with Philadelphia as its capital.

62. The first comprehensive navigation chart of the Delaware Coast vicinity was not completed until 1756 when Joshua Fisher charted the Delaware Bay and provided the first bottom contours based on soundings. Standardized charting of the coast was not initiated until the first United States Coast Survey was completed in the middle of the nineteenth century. The earliest known aid to navigation in Delaware was the 1767 Cape Henlopen Light. A second lighthouse was constructed on Fenwick Island in 1858 to further aid mariners traversing the Delaware coastal waters. Two breakwaters creating a Harbor of Refuge were constructed inside Cape Henlopen between 1869 and 1901 to provide vessels protection from storms and ice at the mouth of the bay. By the middle of the nineteenth century the U.S. Coast Guard had established a series of lifesaving stations at Lewes, Cape Henlopen, Rehoboth Beach, Indian River Inlet, Bethany Beach and Fenwick Island. Historic maritime activity within the project areas was almost exclusively transient, with vessels crossing the area on coastal networks linking the Delaware River Ports and New York with other ports from Maine to Texas and the Caribbean to Central and South America.

63. Over the years, many types of ships and vessels have wrecked while enroute up and down the coast. Many vessels were lost along the coast in an attempt to reach the Harbor of Refuge. Coastal storms, treacherous northeast winds and swift tidal currents coupled with historically heavy coastal traffic has caused the loss of dozens of documented sailing vessels, steamships, barges, tugs and large modern ships off the Delaware Coast. A variety of potential submerged cultural resource types in the project vicinity could date from the first half of the seventeenth century through the Second World War.

64. Broadkill River, known until 1889 as Broadkiln River and then Broadkill Creek, rises in the neighborhood of Georgetown. Milton, the historic head of navigation on the waterway lies approximately 12.5 miles above the mouth. Milton had three shipyards producing sailing vessels. Larger vessels were often towed to Philadelphia to complete their masting, rigging and outfitting. Vessels registered from Broadkill include the 10-ton shallop "Broad Kill", built in 1737. Between 1815 and 1915, local shipyards produced 271 vessels. A regular steamboat service was established between Milton and Philadelphia during the second half of the nineteenth century. The steamer "Mary M. Vineyard" carried a wide variety of general merchandise and passengers on a regular schedule. In addition to steamers, freight boats, steam barges, and two- and three-masted schooners were actively engaged in transporting

farm produce, piling and brick, fertilizer and coal from Broadkill River to Philadelphia. Lack of water depth and the winding course of the river adversely effected Broadkill navigation. By the twentieth century, commercial maritime activity on the river declined and ceased to operate by the 1930's.

65. In 1872, the U.S. Government inaugurated an improvement project on the Broadkill. By 1907, a curved jetty was constructed to create a new river mouth to the south. A five-foot deep channel was cleared and maintained to Milton. In 1909, the jetty was repaired and reinforced with additional stone filling. However, a major storm breached a new opening from Delaware Bay through to the Broadkill River. The new opening, which was south of the jetty, diverted water flow and the former river mouth at the jetty eventually closed when additional improvements did not occur. By 1953, the Federal project which provided for an entrance channel from the bay to the river was abandoned. In addition, the Federal Government constructed a series of groins at Broadkill Beach in 1950.

66. Two offshore remote sensing surveys have been completed in the Broadkill Beach area. The Delaware Division of Soil and Water Conservation conducted a Phase 1 survey of a potential offshore borrow area located adjacent to Broadkill Beach in 1985. The study results, presented in a report entitled Offshore Cultural Resources Survey Between Pickering Beach and Broadkill Beach, Delaware (Tidewater Atlantic Research, 1985), identified three magnetic targets exhibiting shipwreck signature characteristics in a location lying outside of, but adjacent to, the present study area. The Philadelphia District completed a remote sensing investigation of the present project borrow areas in 1994. The survey results, discussed in a draft report entitled A Phase 1 Submerged and Shoreline Cultural Resources Investigation, Broadkill Beach, Broadkill Hundred, Sussex County, Delaware (Dolan Research, Inc./Hunter Research, Inc., 1994), identified one remote sensing target displaying shipwreck characteristics. No significant cultural resources were identified along the project area shoreline. No prehistoric sites have been documented in the vicinity.

SHORELINE CONDITIONS

67. **Historic Shoreline and Beach Changes.** Historic shoreline position data for Broadkill dates back to the late 1800's. The chronology of events affecting the Broadkill shoreline from that period to the late 1900's has been documented in the reference reports (USACE, 1972; Dalrymple, 1982; French, 1990).

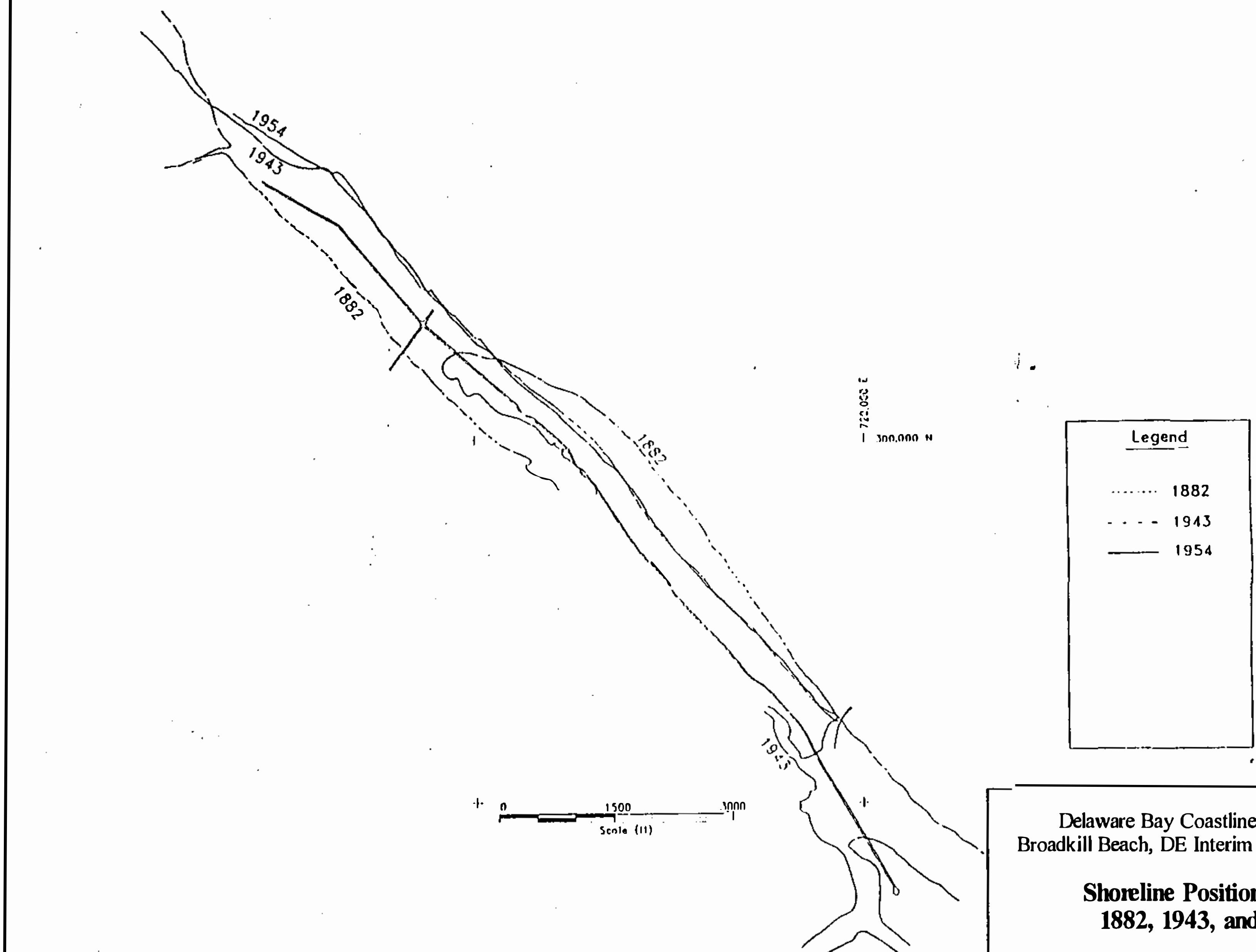
68. Briefly, the history of the Broadkill Beach shoreline is closely tied to the northerly advance of the Cape Lewes spit from the late 1800's up to about 1900 (Dalrymple, 1982). At this time the bayward migration of the Cape Henlopen spit, the completion of the inner breakwater at Breakwater Harbor, and the cutting of a new inlet to the Broadkill River had a significant impact to the shoreline changes in the lower western shores. The new inlet shoaled and in 1908 the Army Corps of Engineers cut another inlet about 1500 feet to the northwest and stabilized it with a timber and stone jetty. Over time the spit remnant welded

onto the beach to form what is presently Broadkill Beach. The jettied inlet again experienced high shoaling and in 1953 the Congress authorized to abandon this project.

69. Gross shoreline change rates were markedly reduced approximately after 1954, compared to the period from the late 1880's to the early 1950's. Figure 4 shows the remarkable changes in shoreline positions for the years 1882, 1943, and 1954. Assuming that major events such as the opening or closing of an inlet or any significant changes to the breakwaters at Breakwater Harbor will not occur over the lifetime of any proposed alternatives, the more recent (1950's) temporal baseline should be adopted for the present study. Considering the availability of historic shoreline position data and the approximate onset of existing littoral conditions, 1950 was chosen as the base year for shoreline and beach profile change analysis. This is the year groins were first constructed at Broadkill. The first beach profiles were surveyed in 1954. The first beach fill was placed in 1957.

70. Much of the available shoreline position data for Broadkill Beach was assembled by French (1990). That study utilized two data sources: National Ocean Survey (NOS) "T" sheets and aerial photographs. The T-sheets are coastal maps which were produced by the U.S. Coast and Geodetic Survey (presently NOS) and date back to the 1840's. The shoreline delineated on the T-sheets is a debris line. It is therefore dependent on the wave conditions and water elevation during the high tide that preceded the survey used to develop the map. The aerial photographs used were obtained from the U.S. Department of Agriculture (USDA) and the Delaware Department of Natural Resources and Environmental Control (DNREC). The shoreline position for these dates was determined by digitizing the wet/dry sand interface which is usually discernable on the photographs. The shoreline determined in this way can be taken as an approximation of the MHW position. The details of the procedures used on these two sources are described in French (1990).

71. In addition to these data, additional shoreline positions were obtained by digitizing other aerial photographs. The dates of these additional photographs are April 1964, March 1979, April 1990, and April 1993. The April 1993 shoreline position was taken as the MHW line (+2.6 foot NGVD) from the Broadkill Beach topographic map (Greenhorn and O'Mara, 1994). The topographic map was prepared using an aerial photograph taken in April, 1993. This topographic map was available in a digital file which allowed additional aerial photos to be registered to it using common physical landmarks such as road intersections.



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Shoreline Positions From 1882, 1943, and 1954

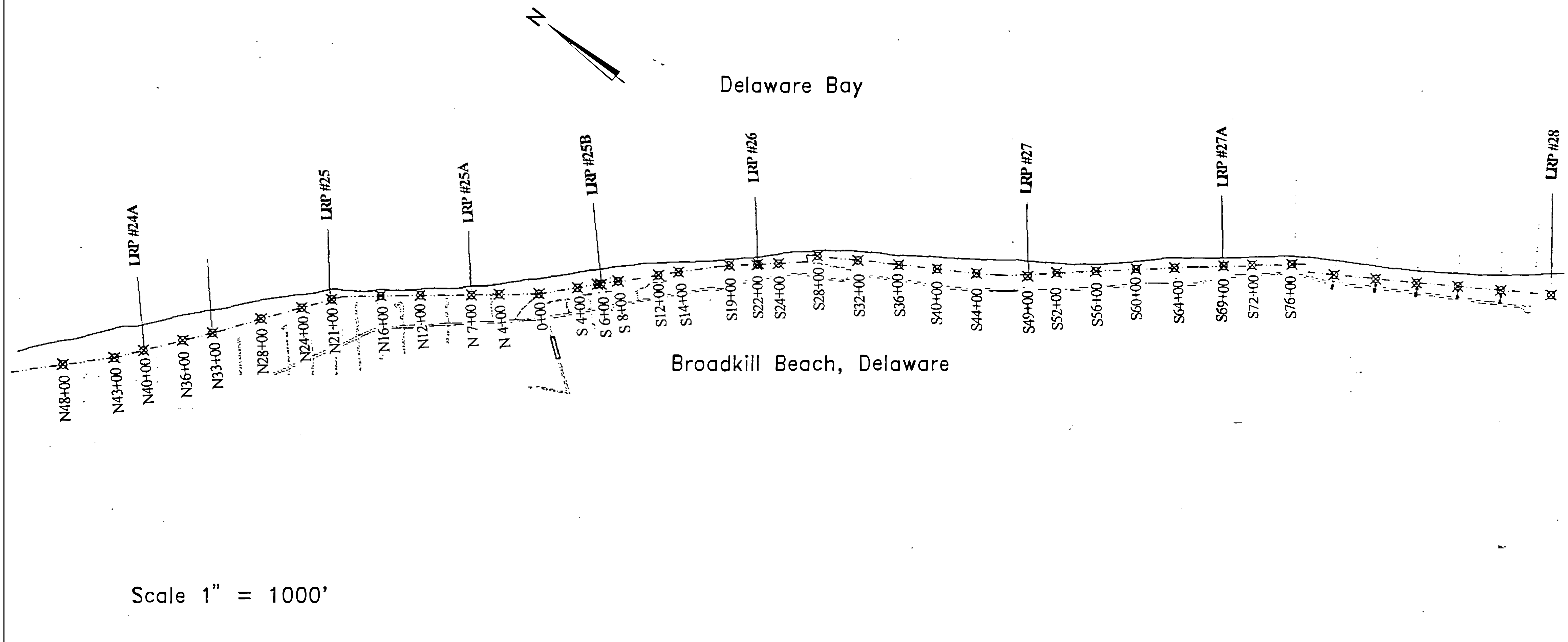
FIGURE 4

72. Table 5 provides a listing of the dates for which shoreline positions were compared. The University of Maryland data were prepared based on the NAD27 coordinate system. The COE's coordinate conversion program CORPSCON (USACE, 1990) was used to convert the NAD27 to NAD83 coordinates.

Table 5
Historic Shoreline Position Summary

Date	Source
Jul 1954	USDA aerial
Apr 1964	USDA aerial
Aug 1971	NOS T-sheet
May 1977	DNREC aerial
Mar 1979	USACE aerial
Nov 1980	USACE aerial
Jun 1989	Unknown
Apr 1990	USDA aerial
Apr 1993	USACE survey

73. The transect locations at which shoreline positions were measured were chosen to coincide with the locations of beach surveys. Both DNREC and the Philadelphia District (CENAP) have conducted profile surveys over the years. These beach profiles will be analyzed in the following sections. The baseline used to reference MHW positions was the survey baseline established by DNREC. The beach profile and transect locations are shown in Figure 5. A more detailed discussion of the historic shoreline data is presented in Appendix A, Section 2.



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Beach Profile and Transect Locations

FIGURE 5

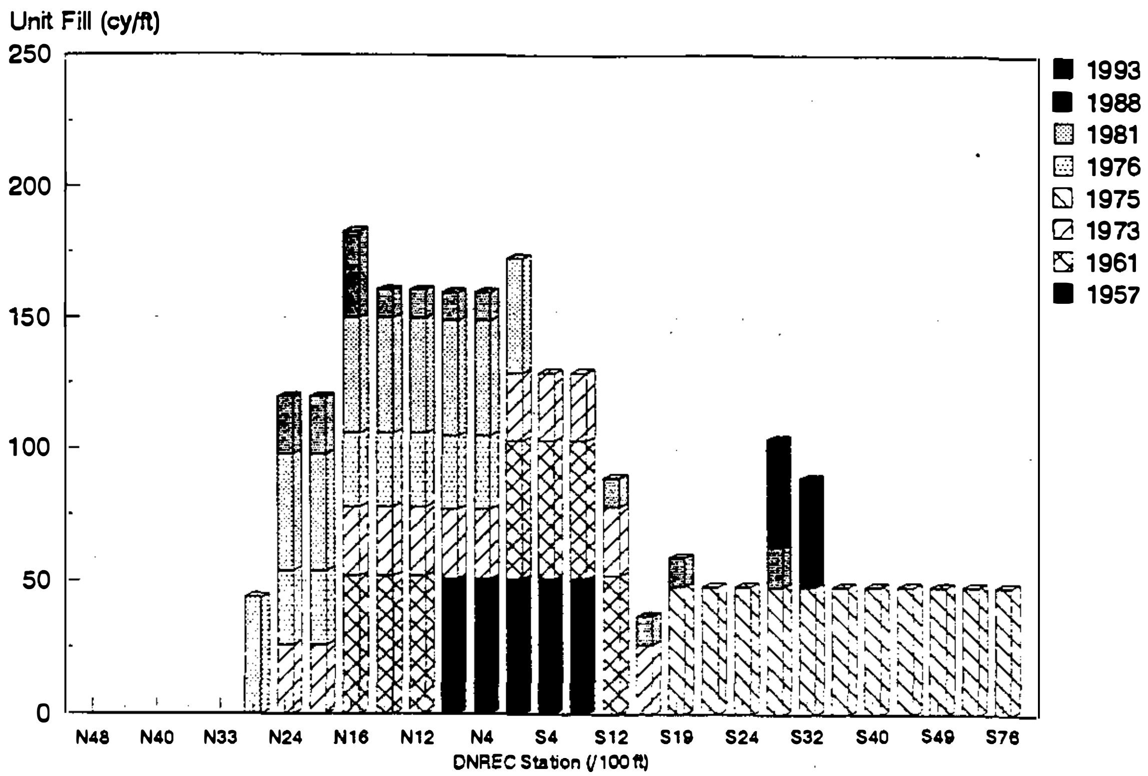
74. **Beachfill History**. Based on recommendations contained in a 1956 COE study, the Delaware State Highway Department placed the first beachfill at Broadkill in 1957 and again in 1961. In 1972 the state authority for beach maintenance passed from the highway department to DNREC who placed the next several beachfills. The first Federal involvement in beach maintenance at Broadkill occurred in 1976 with the cost sharing of that year's beachfill operation. According to the USACE (1981), a 50 foot wide berm was constructed at Broadkill Beach in 1976.

75. Table 6 presents a summary of the beachfill project history at Broadkill Beach. USACE (1972) mentions a 1962 placement of 180,000 cy. This could not be verified by a DNREC official who regards that reference as an error (personal communication, 1994).

Table 6
Beachfill History at Broadkill Beach

Built (yr/mo)	Volume (cy)	Limits (ft)	Unit volume (cy/ft)
1957	76,800	N 7+50 - S 7+50	51
1961	120,000	N19+00 - N12+00	52
		N 2+00 - S14+00	52
1973/11-12	118,000	N27+00 - S18+00	26
1975/2-6	295,000	S18+00 - S79+00	48
1976/8-9	59,700	N25+00 - N 4+00	28
1981/10-3('82)	127,700	N28+00 - S 1+00	44
1987/6-12	21,700	N17+00 - N 3+00	11
	30,900	S 8+00 - S21+00	11
1988/6-10	19,600	N24+00 - N16+00	22
	8,900	S25+00 - S31+00	15
1993	37,000	S25+00 - S34+00	41

76. The unit volumes reported in Table 6 are simple averages considering the total volume placed and the total length of placement. These data were supplied by DNREC. Figure 6 plots the cumulative unit beach fill volumes vs alongshore station location.



1987 fill data included in 1988 data.

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Cumulative Beachfill Volumes

FIGURE 6

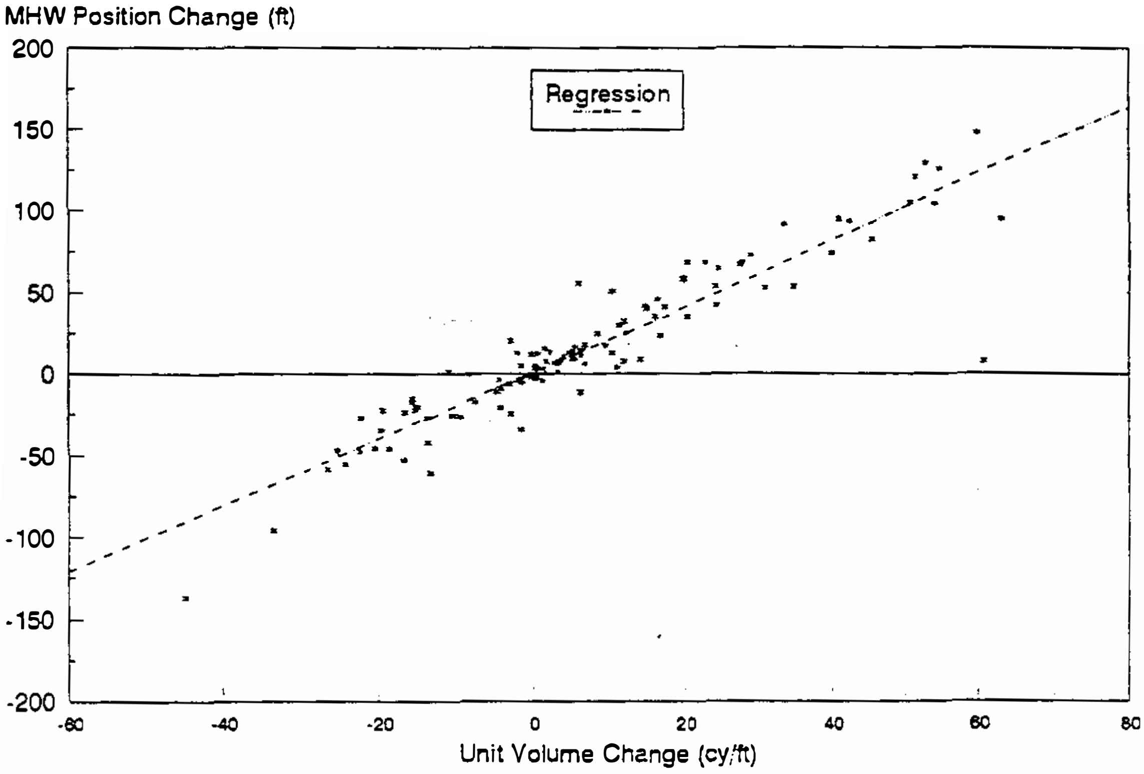
77. Figure 6 shows that the greatest amount of fill has been placed between stations N24+00 and 0+00, with a total unit volume in one area of approximately 180 cy/ft. No fill has been placed north of N24+00 although this area has certainly benefitted from the placements to the south, considering the variable directions of wave approach. Areas to the south of station S76+00 also received no direct placement of beach fill. The areas south of Route 16 were affected primarily by the 1975 placement of 48 cy/ft with the exception of a small section between S25+00 and S34+00 which has received additional attention in the form of a modest fill in 1988 (15 cy/ft) and more substantially in 1993 (41 cy/ft).

78. **Beach Profile VS Shoreline Change Data** For coastal planning and design purposes, volumetric profile change rates are more meaningful than linear shoreline change rates. Linear change rates are sensitive to seasonal profile variations due to changing wave regimes. Also, for an eroding beach apparent shoreline changes are sensitive to changes in profile shape which can be significant for a sand supply deficit condition. In both cases, the MHW position change analysis may exaggerate the actual erosion considering the entire active profile from dune crest to depth of closure. For a storm erosion analysis, the unit volume in the beach profile and the volumetric change rate are important quantities for planning purposes. During a severe storm it is the total quantity of sand eroded which results in contour movements.

79. In order to plan a beach fill project, profile shape, unit volume and volumetric erosion rates provide a basis for estimating the amount of fill required to provide a given level of storm protection or recreational high tide beach width. In addition, an estimate of the alongshore variation in volumetric erosion rates provides an important check on the results of a longshore transport analysis.

80. Although extensive beach profile data are best for determining historic beach change trends, sufficient quantities of such data with the necessary spatial and temporal extent are often not available. The relatively extensive amount of beach profile data at Broadkill Beach make the examination possible. In areas where the profile data are inadequate, the shoreline change data should be used instead.

81. To do this, unit volume changes were plotted vs MHW shoreline changes. The profile volumes were computed from the dune crest to the apparent depth of closure as indicated on plots of the beach profiles. The changes in these quantities were plotted instead of the computed values so that the results would not be biased by the choice of starting and ending distance along the profile. The results are plotted in Figure 7 with the least squares best fit line drawn through the data. The correlation coefficient, r, has a value of 0.92 indicating a strong linear relationship between the unit volume and MHW change at Broadkill Beach. The relationship from the regression analysis is 1 cy/ft volume loss = 2.0 ft MHW recession.



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Linear Regression Plot

FIGURE 7

82. **Volumetric Profile Analysis**. Available beach profile data for Broadkill Beach were obtained from DNREC. The data from DNREC spanned the period from the early 1970's to the late 1980's. The profiles are referenced to the survey baseline shown in Figure 5. The alongshore distances are referenced to a starting point at State Route 16 in the central portion of the beach. The DNREC profiles are spaced at 100 foot intervals. Based on a site visit in April 1994 and a review of the shoreline change history, a spacing of 400 feet is considered to be sufficient for estimating volumetric beach changes.

83. In addition to DNREC profiles, the Philadelphia District has eight Line Reference Point (LRP) stations within the Broadkill Beach study area. Their locations are shown in Figure 5. In addition to one 1990 and two 1993 surveys, LRP stations 25, 25A, 25B, and 26 were surveyed in 1954 and 1964. The report on Broadkill Beach (USACE, 1972) presents plots of the 1954 and 1964 profiles. These profiles were digitized from the plots to create a set of (distance, elevation) pairs for comparison with the more recent data.

84. For plotting and unit volume computations, the DNREC baseline was used as the reference baseline. The transects used were chosen so that they would coincide as closely as possible with the LRP stations and maintain a profile spacing of 400 feet. The LRP data were referenced to the DNREC baseline so they could be compared directly with the DNREC data. The set of transects chosen for analysis are given in Table 7. Transect locations are the same as those used to determine historic shoreline changes.

85. Both the Philadelphia District data for the LRP transects and the DNREC data were in the USACE's Interactive Survey Reduction Program (ISRP) format. Each set of transect profiles were analyzed for apparent errors and in-consistencies. Unit volumes were calculated for discrete vertical profile lenses. The lenses chosen were dune crest to +2.5 ft, +2.5 to -1.5 ft, and -1.5 to -10.0 ft NGVD. These lenses approximately represent the above-tide, tidal, and below-tide elevation ranges, respectively. Starting distances were chosen to match the most landward common limit or the dune crest. Ending distances were chosen to match the apparent depth of closure for the toe of the beach face, beyond which the profiles slopes become extremely mild.

Table 7
Transect Stations for Volume Profile Analysis

DNREC Station	LRP Station
N48+00	
N43+00	
N40+00	#24A
N36+00	
N33+00	
N28+00	
N24+00	
N21+00	#25
N16+00	
N14+00	
N12+00	
N 7+00	#25A
N 4+00	
0+00	
S 4+00	
S 6+00	#25B
S 8+00	
S12+00	
S14+00	
S19+00	
S22+00	#26
S24+00	
S28+00	
S32+00	
S36+00	
S40+00	
S44+00	
S49+00	#27
S52+00	
S69+00	#27A
S76+00	
	#28

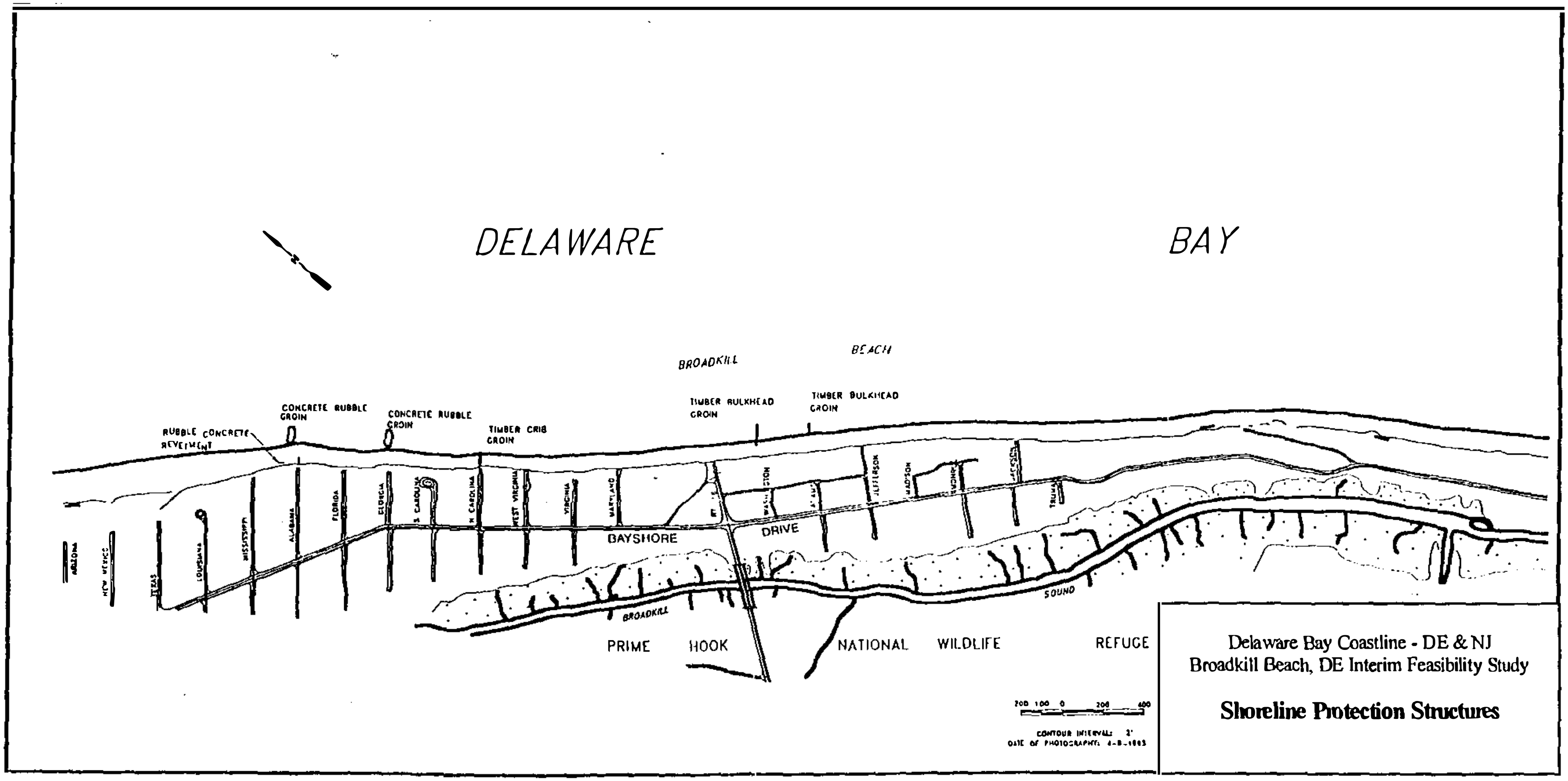
86. The data has not been adjusted for beachfills. The unit volumes themselves are sensitive to the selection of the starting and ending distances and the vertical lens limits. In most cases the ending distance was chosen to coincide with the apparent closure limit. In most open-coast settings there is a definite dune system and a well-defined depth of closure with a significant profile slope change. At Broadkill, however, there are areas where there is no definite dune system or depth of closure considering the very mild profile slopes adjacent to the bay slopes. As a result, alongshore unit volume variations may be dependent on the cross-shore extent of the survey data.

87. The unit volumes for the LRP profile lines are presented in Appendix A, Section 2 as Figures 40 through 43. Examination of the data shows that there are many coverage gaps. Of the transects considered, less than 40% have been surveyed in the 1990's. For nearly 30%, the most recent survey was conducted in the 1970's. The remainder were last surveyed sometime in the 1980's. The alongshore coverage for any given survey date is also sporadic.

88. It is probable that the trends indicated for most transects do not adequately describe the beach history at Broadkill Beach due to the incompleteness of the data. The most reliable volumetric trends should result from those transects having the greatest temporal coverage (i.e. transects combining the LRP and DNREC survey data). These data along with the shoreline change data and information on the history of groins and beach fills will be evaluated carefully to determine representative shoreline and beach profile change rates.

89. **Shore Protection Structures**. In September 1994, a site inspection of the existing beachfront was conducted. The only coastal structures present in Broadkill Beach are five beach groins that were constructed in the 1950's and a dumped concrete rubble revetment built in 1964. The groins are located at Washington, Adams, North Carolina, Georgia, and Alabama Avenues; the coastal revetment is in the vicinity of Alabama Avenue. The location of the existing structures in Broadkill Beach are shown in Figure 8.

90. The groins located at Washington and Adams Avenues are timber bulkhead construction type. The groins are in fair condition, are approx. 20'-30' long (exposed section) and the exposed sections are at an elevation below mean high water. A small amount of sand appears to be building on the west side of the groins at Adams and Washington. In addition, it seems that the groins are being maintained; relatively new steel bolts were visible in the structures. The groin located at North Carolina Avenue is a timber crib-stone filled construction type. The groin is approx. 40' long (exposed section) and is only visible on the upper end of the beach berm. The groin appears buried beyond the high water line. The condition is extremely poor. The wood is rotted and there is almost no stone left in the cribbing structure. The groins located at Georgia and Alabama Avenues are made of dumped concrete rubble. The groins are in poor condition and do not appear to be functioning at all. The concrete rubble extends approximately 15' to 20' into the water and at most 10' onto the beach at low tide. There are no existing construction plans for these groins.



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Shoreline Protection Structures

FIGURE 8

91. The other type of shore protection structure located within the study limits is a concrete rubble revetment. The revetment extends from North Carolina Avenue to approximately 700' just north of Alabama Avenue. Only 30 l.f. of the revetment is visible just north of Alabama Avenue at the present time, the rest is buried under existing dune. The revetment is very low in height, approximately 3' from top to toe, and is in poor condition. The revetment is constructed of broken up concrete rubble, and does not appear to be designed or engineered specifically for the site. Instead, it appears as randomly dumped. A complete structure inventory of the study area including color photographs is included in Appendix A, Section 6.

92. The continual erosion of the protective beach face within the study area causes more deterioration of the existing groins and revetment. Since there are no protective structures such as bulkheads, the continued erosion of the land will eventually cause damage to utilities and private property. Increased maintenance costs will be incurred to repair damaged utilities and street ends. In addition, home owners will find their bay front property shrinking unless they continually backfill eroded areas.

93. **Analysis of Shoreline and Profile History**. Available historic data on shoreline and beach profile change has been presented in earlier sections. However, these data were unadjusted for the effects of beach fills and groins constructed at Broadkill. By considering the magnitude of these effects and their chronological occurrence in the known sequence of shoreline and profile changes, realistic values of background change rates might be determined. These rates can then be used to estimate likely shoreline positions for planning purposes.

94. Besides the effects of beach fills and groins on the apparent profile changes, the available records of storm effects indicate that they can significantly affect the beach profile in a matter of days or even hours. These extreme events can significantly alter the average rates of profile change, depending on the period of record considered. Since storms are a natural part of coastal processes, albeit an unpredictable one, their effects should be included in an assessment of background profile change rates. To obtain the most realistic estimates possible, the longest possible period of record should be used.

95. Profile change indicates that historically the central portion of Broadkill Beach has experienced the greatest amount of erosion. The placement of the three groins in 1950 at stations S7+40, S2+65, and N2+00 stabilized the beach in this area (USACE, 1972). Erosion to the north prompted the construction of two more in 1954 at stations N6+70 and N11+70. By the early 1970's these groins were still in good condition and the erosion problem had proceeded again to the north. The fact that the areas immediately north of the groin group were eroding suggests that net longshore transport was directed to the north and the groins were benefitting the area they occupied at the expense of downcoast areas to the north. However, the 1950's were a period of frequent storm activity and the erosion north of the groin group may have been storm-induced with the area occupied by groins stabilized.

96. Table 8 summarizes the adjusted background shoreline and volumetric change rates for areas represented by selected survey profiles. These rates are recommended for planning purposes. In addition to the adjusted rates, the apparent rates for each profile were also determined using the slopes of the linear regression lines from the shoreline positions in Figures 30 to 37, Appendix A, Section 2. A complete explanation of Table 8 is presented in Appendix A, Section 2.

Table 8
Background Erosion Rates - 1954 through 1993

Profile	Apparent Linear (ft/yr)	Annual Fill (cy/ft)	Adjusted Volumetric (cy/ft/yr)	Adjusted Linear (ft/yr)
LRP #24	8.0	0	stable	stable
N33+00	5.3	0	stable	stable
LRP #25	-1.5	4.6	-4.0	- 9.6
LRP # 25A	1.7	3.9	-5.4	-10.8
LRP # 25B	2.2	2.4	-1.9	- 3.8
LRP # 26	-2.0	2.3	-4.9	- 9.8
LRP #27	-3.9	2.8	-6.5	-13.0
LRP #27A	-2.0	2.7	-7.8	-15.6
LRP #28	1.7	0.4	stable	stable

HYDRAULIC ANALYSIS

97. **Previous Reports and Studies.** All available relevant reports and studies concerning Delaware Bay in general and Broadkill Beach in particular were reviewed. Below is a listing of the publications relevant to Broadkill Beach and a summary of the key findings and/or recommendations they contain.

Reconnaissance Report, Small Beach Erosion Control Project, Broadkill Beach, Delaware. (USACE 1966)

- o Identified central 2600 foot beach area as having an erosion problem with adjacent areas stable.
- o Estimated unit erosion rate at 4 cy/ft/yr based on comparison of beach profile data from 1954 and 1964.

- o Recommended construction of 2 groins at Georgia and Alabama Avenues, 51,000 cy of beach fill along 2600 foot problem area, and renourishment of 42,000 cy every 4 years.

Detailed Project Report, Small Beach Erosion Control Project, Broadkill Beach, Delaware. (USACE, 1972)

- o Found problem at Broadkill Beach to consist of erosion due to wave action during storms and determined that erosion was episodic rather than continuous.
- o Recommended additional 110,000 cy beach fill along central 4500 ft of beach followed by renourishment every 4 years of approximately 40,000 cy.

Broadkill Beach, An Assessment of an Erosion Problem. (Dalrymple, 1982)

- o Explained that localized high erosion rates in vicinity of station S23+00 as due to temporary effects of offshore borrow pits and response of beach fill materials to nearshore wave climate.

- o Recommended continued use of beach fill but with wider alongshore placements to reduce apparent angle of wave attack at shoreline and therefor reducing longshore transport potential.

Historical Shoreline Changes in Response to Environmental Conditions in West Delaware Bay. (French, 1990)

- o Compared historic shoreline positions for West Delaware Bay shorelines. Found Broadkill Beach area to be accretional but did not take beach fill quantities placed there into account.

98. **Tides and Tidal Currents**. The tides at Broadkill Beach are semi-diurnal with a mean tide range of 4.1 feet. Table 9 presents the mean tide statistics at nearby Breakwater Harbor.

Table 9
Tide Statistics at Breakwater Harbor

Stage	Elevation[1] (ft MLLW)	Elevation[2] (ft NGVD)
MHHW	4.7	3.0
MHW	4.3	2.6
MLW	0.2	-1.5
MLLW	0.0	-1.7

[1] Source: NOS Chart 12304, Jan 1994
[2] NGVD is 1.69 ft above MLLW, Source: Harris (1981)

99. Tidal currents for stations in Delaware Bay were predicted over the course of an average tidal cycle using a hydrodynamic computer model (NOAA, 1987). The model results were verified with 14 months of field observations of tide elevations, currents, and environmental conditions. The tidal current results are presented as a series of vector plots at one hour intervals at locations throughout the bay. The closest location to Broadkill Beach is approximately 3500 feet offshore. The results predict maximum flood and ebb tidal currents of approximately 0.6 ft/sec. USACE (1972) reports normal flood and ebb tides at Broadkill having velocities of 3 ft/sec. The average values from the NOAA hydrodynamic model are considered the best available estimates.

100. **Sea Level Rise**. Sea level rise is generally considered to be a contributing factor to log-term coastal erosion and increased potential for coastal inundation. Because of the large variability and uncertainty of the climactic factors that affect sea level rise, predicting future trends with any certainty is difficult. Corps of Engineers guidance EC-1105-2-186 states that, until substantial evidence indicates otherwise, local regional history of sea level changes will be used to forecast a change in sea level for a specific project area. Based on historical gauge records at Breakwater Harbor, sea level has been rising 0.0102 feet per year Hicks and Hickman, 1986). The ocean-stage frequency analysis, historic shoreline analysis, and required nourishment rate estimates incorporate the effects of sea level.

101. **Average Offshore Wave Conditions**. Hindcast wave data for the Delaware Bay and entrance are available from several sources. The U.S. Army Waterways Experiment Station, Coastal Engineering Research Center has developed a set of hindcast data for stations in the Atlantic ocean including the Delaware Bay entrance area for the 1956-1975 period (Hubertz et al. 1993). Work is under way to extend these data from 1975 to the early 1990's (R. Hoban, personal communication, 1994).

102. A recent COE study (USACE, in preparation) includes a wave hindcast study for the Delaware Bay and vicinity for the period November 1987 to October 1993. These data were utilized in the present study for the classification of average offshore wave conditions. They were also used to develop longshore transport (Q_l) estimates, as input to the shoreline change model GENESIS, and for the storm-induced beach erosion analysis.

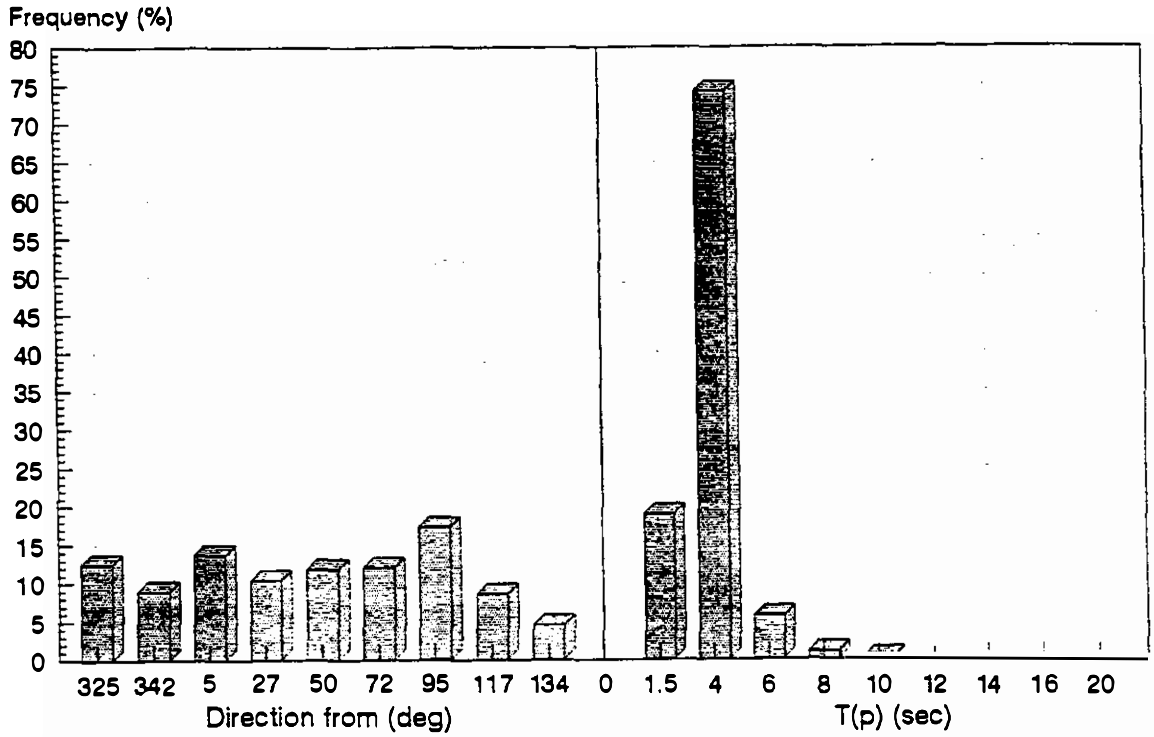
103. Wave hindcast results are saved on a 5 minute grid spacing throughout Delaware Bay. Two stations for which data were applied in the present study are located at 38° 55' 00" latitude, 75° 10' 00" longitude and 38° 50' 00" latitude, 75° 10' 00" longitude. The first station is located approximately 7 miles from Broadkill Beach. The water depth at this hindcast station is approximately 60 feet (NGVD). The second station is located approximately 2 miles from Broadkill Beach with a water depth of approximately 15 feet.

104. The mean orientation of the shoreline including Broadkill Beach from Cape Henlopen to the Mispillion River is 319.8° Azimuth. This leaves Broadkill Beach open to waves approaching from 319.8° to 139.8° Az. The time series was processed to determine the frequency distribution of wave characteristics for those waves traveling onshore. Offshore

traveling waves occur 49.7% of the time annually. Only those waves traveling onshore were counted so the total frequency of wave events would sum to 100%.

105. Direction bands of 22.5° were chosen so that shore-normal would coincide with a mid-band direction. Wave period bands of 2 seconds (except for the lowest 0-3 second band), and wave height bands of 1.6 feet were chosen. Frequency distributions were prepared annually and seasonally. Figure 9 presents the average direction and period distribution of wave events for the 6 year hindcast period.

106. **Storm Wave Conditions and Extreme Estimates**. Broadkill Beach is affected both by tropical (hurricanes) and extra-tropical (northeasters) storms. Both can cause severe beach erosion and damage to coastal structures. Hurricanes are associated with extreme low pressure systems and can result in large increases in water level. Coupled with a high tide condition and with waves superimposed on the flood profile, a hurricane can result in significant flooding and damage. Northeasters cause their damage principally through wave attack of the beach and adjacent structures. They can be as damaging or more damaging than hurricanes depending on their duration which can extend over several tidal cycles. During successive high tides, higher and steeper waves caused by the persistence of winds over a nearly unlimited fetch can cause extensive beach erosion. Since the 1950's the significant storms of record have been chronicled (USACE, 1966, 1977; Dalrymple, 1982; French, 1990, USACE, in preparation). Table 10 presents a summary of some of the more severe storms. The data are compiled from previous reports and the Delaware Bay hindcast study.



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Wave Average Direction and Period Distribution

FIGURE 9

Table 10
Summary of Significant Storms

Date	Type	Significant features
Aug 1933	Hurricane	75 mph onshore winds; flooding; moved inland S of Broadkill; minor residential damage
Sep 1936	Hurricane	Wind=46 mph; H=9.6 ft; TWL=4.0 ft
Sep 1938	Hurricane	Passed 75 mi offshore at low tide; minor damage
Sep 1944	Hurricane	Passed 50 mi E of DE coast; extensive damage
Nov 1950	Northeaster	Strong E wind at high tide (7.2 MSL); loss of beach
Aug 1953	Hurricane	Wind=37 mph; H=8.6 ft; TWL=7.6 ft
Nov 1953	Northeaster	60 mph winds; 5.4 MSL tide; minor damage
Aug 1954	Hurricane	Wind=32 mph;H=5.3 ft;TWL=6.3 ft
Sep 1954	Hurricane	Wind=32 mph;H=5.9 ft;TWL=5.3 ft
Jan 1956	Northeaster	High water levels and some beach loss
Aug 1958	Hurricane	Wind=40mph;H=7.9 ft;TWL=5.3 ft
Sep 1960	Hurricane Donna	Weak winds of 110 mph
Mar 1962	Northeaster	Strong winds over 5 tide cycles; tide of 7.9 SLD; 20-30 ft. wave heights; extensive beach damage; cut an inlet to sound at ~S42+50
Jan 1964	Northeaster	Wind=43 mph;H=10.6 ft;TWL=7.3 ft
Oct 1965	Northeaster	Significant beach erosion in central Broadkill
Jan 1966	Northeaster	Wind=47 mph;H=8.9 ft;TWL=6.3 ft
Sep 1967	Hurricane	Wind=43 mph;H=8.9 ft;TWL=6.3 ft
Dec 1973	Northeaster	Wind=39 mph;H=7.9 ft;TWL=6.6 ft
Dec 1974	Northeaster	Wind=38 mph;H=6.3 ft;TWL=6.9 ft; SR 16 flooded in Broadkill.
Aug 1976	Hurricane	Wind=47 mph;H=7.3 ft;TWL=5.6 ft
Mar 1977	Northeaster	Wind=46 mph;H=7.3 ft;TWL=3.0 ft
Oct 1977	Northeaster	Wind=45 mph;H=6.6 ft;TWL=6.9 ft
Feb 1978	Northeaster	Wind=43 mph;H=7.6 ft;TWL=5.6 ft
Oct 1980	Northeaster	Wind=46 mph;H=8.6 ft;TWL=6.3 ft
Mar 1984	Northeaster	H=8.5 ft; TWL=6.8 ft
Sep 1985	Hurricane	Wind=46 mph;H=7.9 ft;TWL=7.3 ft
Oct 1991	Northeaster	Wind=39 mph;H=7.3 ft;TWL=6.6 ft
Jan 1992	Northeaster	Wind=53 mph;H=11.6 ft;TWL=6.9 ft
Dec 1992	Northeaster	Wind=40 mph;H=9.6 ft;TWL=6.6 ft
Feb 1994	Northeaster	(NO DATA AVAILABLE)

107. The extreme wave analysis conducted in 1994 (USACE, in preparation) includes wave and water level calculations for 15 northeasters and 15 hurricanes. A probability analysis was conducted for the two sets of storms and for the combined 30 storms. The Hs , Tp, Tm and the peak surge still water level (SWL) values for each storm were ranked and a regression analysis conducted for an assumed Gumbel type distribution. The results for the station located at 38° 50' 00" latitude, 75° 10' 00" longitude are shown in Table 11.

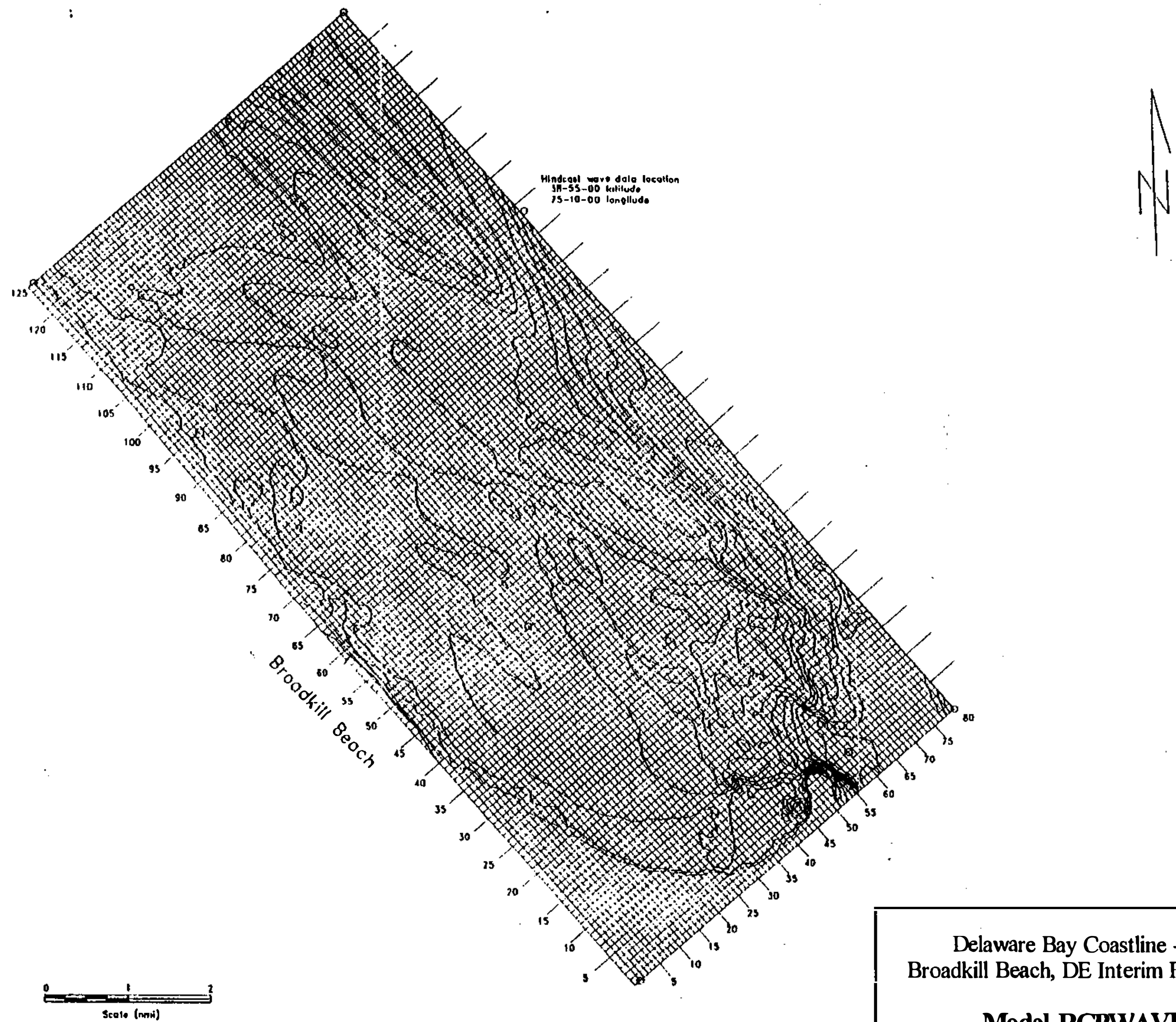
Table 11
Extreme Wave and Water Level Estimates

Return Period (year)	Hs (ft)	Tp (sec)	Tm (sec)	SWL (ft) NGVD
5	7.9	9.2	5.6	6.2
10	8.9	10.3	6.5	7.5
20	9.8	11.2	7.8	8.0
50	11.2	12.2	9.7	9.5
100	12.1	12.7	11.5	10.5
200	13.1	14.0	13.0	11.2
500	15.4	16.0	16.0	12.4

108. **Wave Transformation Model - RCPWAVE.** To estimate the potential longshore transport rates, nearshore wave characteristics are required. The finite difference model, Regional Coastal Processes Wave Transformation Model (RCPWAVE), developed by CERC (Ebersole et al., 1986) was used to calculate nearshore wave characteristics as a function of deep water wave characteristics and the regional bathymetry.

109. The model grid limits were chosen based on the range of directions of wave approach, the location of the offshore wave data, regional bathymetry and shoreline orientations, and model capabilities. RCPWAVE uses rectangular grid elements which should be oriented so the smaller dimension is parallel with the offshore grid axis. The grid should be oriented so that the offshore axis is parallel to the dominant direction of wave approach. For Broadkill Beach where the directional distribution is fairly uniform, the grid was oriented so the offshore axis was shore-perpendicular. Considering the bathymetric change and the model's element number limitations, a grid array of 125 x 80 was chosen for the alongshore and offshore directions, respectively. Grid element dimensions are 543 ft x 382 ft in the alongshore and cross-shore directions, respectively.

110. The model grid for the study area is shown in Figure 10. The numbering along the grid axes is consistent with the numbering scheme used by RCPWAVE. The bathymetry was generated by an interpolation program using a subset of sounding data from the National Ocean Services Hydrographic Data Base. Only a subset of the available sounding data could be used due to the extremely high density of data locations. For the area within the grid



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Model RCPWAVE Grid

FIGURE 10

boundaries there were over 47,800 soundings from the years 1970, 1971 and 1972 with 89% from 1971. This file was then used in the interpolation program to determine representative water depths at each grid element center and to plot the bathymetric contours. The bathymetric contours plotted were verified using NOS nautical chart 12304.

111. RCPWAVE uses one set of H, T, and α values for each transformation. It is unrealistic and unnecessary to run RCPWAVE for every set of H, T, and α contained in the offshore time series. Rather, a finite set of condition combinations can be used which will adequately describe the range of offshore conditions for the purposes of estimating Q_l and shoreline modeling. The mid-band direction and period combinations run in RCPWAVE are reported in Table 12. All model runs were conducted for MSL water depths.

Table 12
Input Wave Conditions

Direction (° Az)	**Period (sec)**
325.4	3,6
342.4	3,6
4.8	3,6
27.4	3,6
49.8	3,6
72.4	3,6,8,10,12
94.8	3,6,8,10
117.4	3,6,8
134.2	3,6,8

112. RCPWAVE calculates output for each element in the grid. Wave height, water depth, wave direction, breaker index, and wave phase function are reported at each cell. The breaker index indicates whether the wave has broken. Wave phase function is related to wave length and is described in greater detail in Ebersole et al. (1986).

113. The RCPWAVE elements along Broadkill Beach generally have water depths between 8-9 feet MSL. Although internal calculations are performed over the entire grid, only elements 1-40 along the cross-shore axis and elements 25-84 along the shore-parallel axis were output. Broadkill Beach is located approximately within the RCPWAVE model elements 68-42. The results from each of the 25 input conditions were saved for calculating potential longshore transport rates and for the shoreline modeling. The results were verified for physical sensibility and errors by inspecting output vector plots with a program written for that purpose.

114. The program displays the water depth, wave direction, and relative wave height at each element center. Figure 11 shows the RCPWAVE results for an incident wave angle of 324.6° Az and period of 6 seconds. The cross-shore element numbers shown are 1-40 and the alongshore elements shown are 40-69. The asterisks plotted indicate land. The direction of the arrows correspond to the output wave direction and the arrow length is proportional to the wave height. When viewed on a color monitor the arrows are colored according to their depth to reveal the bathymetric contours and aid in error checking of the input depth file. A complete set of graphical output is presented in Appendix A, Section 2.

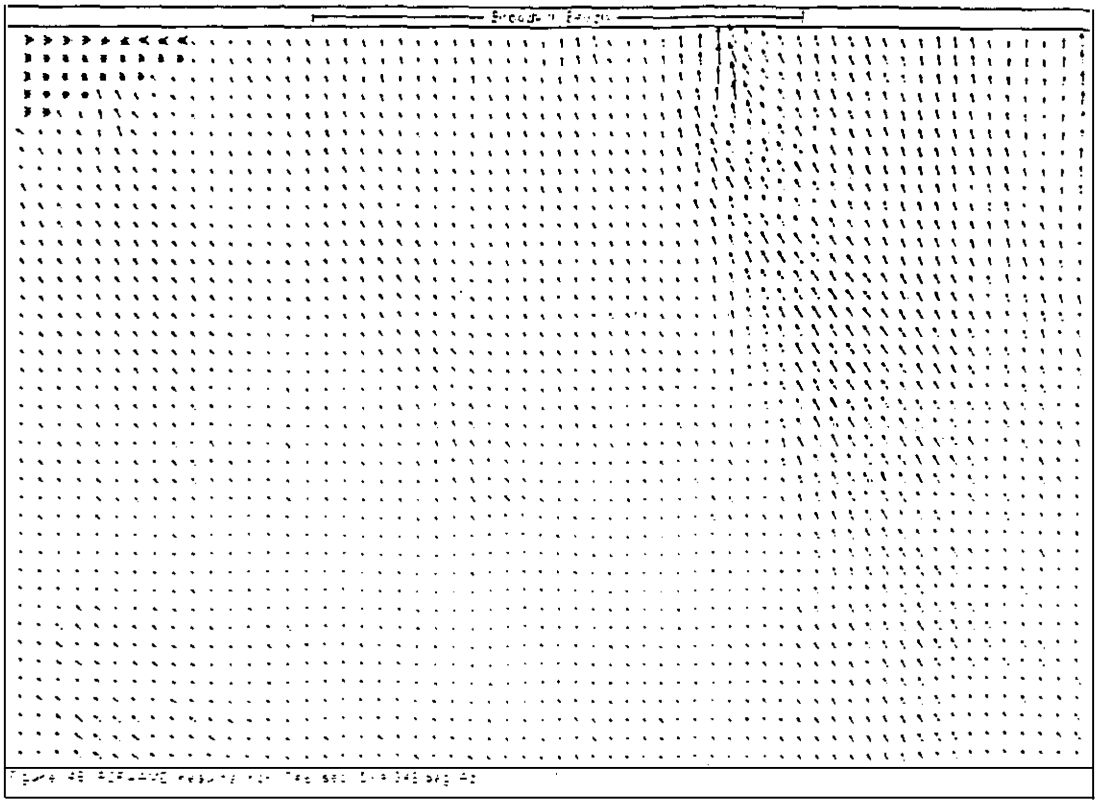
115. RCPWAVE's internal calculations proceed best when the input wave direction is shore-perpendicular. For highly oblique cases the computations become unstable. Several instances of this instability are indicated in the output by very large wave heights. For these cases, the nearshore results from the closest T,α input combination was substituted for subsequent longshore transport rate calculations.

116. **Longshore Transport Rates**. Estimates of the gross and net potential transport rates are one the most important variables in a coastal processes analysis. Appropriate estimates of transport rates and alongshore patterns can determine whether a coastal engineering project involving a beach fill, groin field, or detached breakwater will be successful.

117. The gross transport rate is the sum of both upcoast and downcoast rates for the shoreline of interest. The net transport rate is the difference between the upcoast and downcoast rates.

118. An important consideration in the calculation of Q_l is the difference between potential transport rate and actual transport rate. The potential rate is that which is calculated based on recognized empirical relationships developed by comparing measured transport rates with a measure of longshore energy for areas where there is no deficit of sand supply. In this case, actual and potential rates will be equal. However, when the upcoast sediment supply is deficient due to a lack of sand on the beach and in the surf zone, or there is some sort of sediment sink, actual transport rates will be less than potential rates. The amount by which actual rates lag potential rates for such a case is usually difficult to estimate.

119. Calculation of Potential Transport Rates. Empirical relationships between measures of the longshore wave energy and transport rates have been developed from measured longshore transport rates (directly and indirectly) and nearshore wave processes. The empirical equation used in this study relates the wave-energy flux factor (P_{ls}) for incipient breaking conditions to the transport rate. The basis for the relationship is described in the Shore Protection Manual (SPM) (USACE, 1984). A program included as part of the Shoreline Modeling System (SMS) (Gravens, 1992) was used to calculate Q_l in the nearshore elements off Broadkill Beach in 8-9 feet of water (MSL). The input required were an offshore wave time series, nearshore wave conditions (RCPWAVE), and the water depths for the relevant RCPWAVE elements. The files required can subsequently be used in the GENESIS model.



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RCPWAVE Results

FIGURE 11

120. The total 6 year hindcast period was used. The program determines which set of nearshore transformation conditions to use for the particular offshore event using "keyed" data in the nearshore wave file. Waves are then transformed to incipient breaking conditions using linear wave theory. The breaking conditions are used to calculate P_{ls}, Q_l, and direction for each time step in the time series. The procedure is repeated at every time step, the results are summed and reported on an annual basis in an output file.

The empirical equation used to determine Q_l is:

$$Q_l = 7500\ (\gamma/16)(H_s^2 C_g)_b \sin(2\alpha_b) \qquad (1)$$

where: Q_l = longshore transport rate (cy/yr)
γ = unit weight of water (64lbs/cf)
C_g = wave group celerity (fps)
α_b = angle between wave crest and shoreline

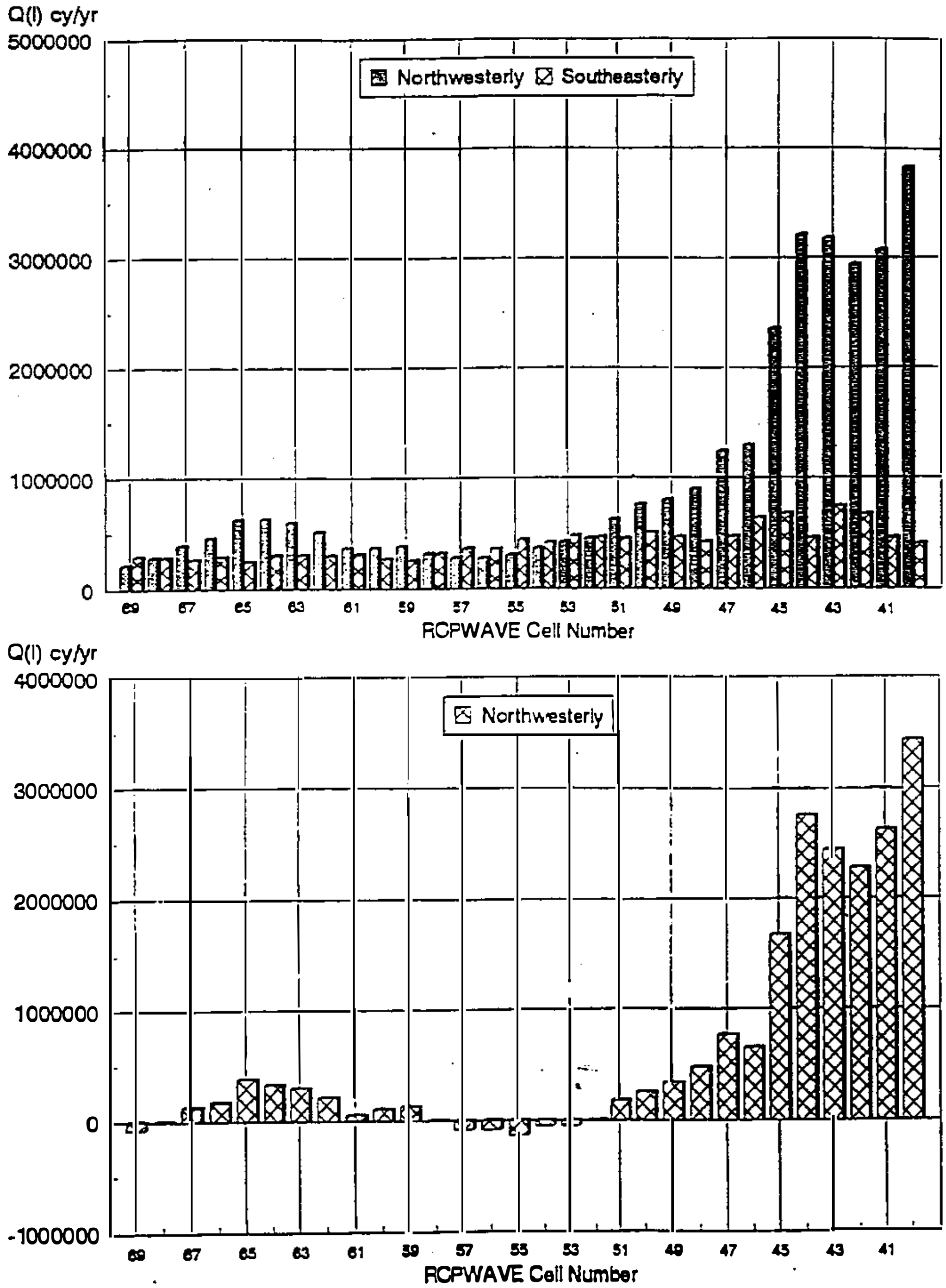
121. The "b" subscript refers to breaking conditions. Numerous investigators have provided criticism and modification to the above equation to account for the effects of longshore gradient of wave height, sediment characteristics, and bed slope (e.g.,Bailard, 1984; Hanson and Kraus, 1989; Kamphuis and Sayao, 1982), but without changing the essence of the relationship.

122. The gross and net transport rates are presented in Figure 12. A net transport budget can be performed on each grid element to indicate whether erosion or accretion is predicted for a particular area. Such a budget for RCPWAVE element 65 near profile LRP #25 indicates a potential transport rate of approximately 51,000 cy/yr to the northwest. The element width is 543 ft, yielding an average unit erosion rate of 94 cy/ft/yr. An examination of the unit volume change data for this area reveals that such a value is an entire order of magnitude too high.

123. The transport rates and transport rate gradients for the grid elements at the southeast portion of Broadkill are completely unrealistic. For example, at RCPWAVE element 46, the net Q_l gradient predicts accretion of over 1800 cy/ft/yr. There are several reasons why the predicted potential Q_l rates might be so high:

- o The rates are potential values and in general are higher than actual rates.

- o The model is not capable of directly accounting for the sheltering effect of the breakwaters at Breakwater Harbor. The difference in nearshore wave heights off Broadkill for incident waves from the Atlantic should be significant. The modeling of this sheltering was attempted by mixing the time series data for a station at 38-50 lat, 75-10 along with the data at the bayward edge of the grid. However, the sheltering may still have been only partially accounted for considering the relationship of the nearshore station to the breakwaters for waves approaching from the E-NE.



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Gross (Top) and Net (Bottom) Transport Rates

FIGURE 12

- The use of a unit wave height as input to RCPWAVE runs resulted in unnaturally high wave heights since actual wave heights would have broken. This should not effect the results significantly since in the Q_l calculating algorithm wave heights are restricted to be no larger than 78% of the water depth.

- The input wave period and direction bands recommended in the SMS guidance are too wide for use at Broadkill. For example, the program which calculates Q_l recognizes as one band period values from 0 to 5 seconds. At Broadkill nearly 75% of waves approaching shore have 3-5 second periods. When the 0-3 second period waves are included, over 90% of shore-directed waves are accounted for. With the period distribution being so tight, more low period RCPWAVE runs should be used to represent the distribution.

- RCPWAVE is an open coast model and Broadkill Beach is not an open coast location. Open coast sites typically experience a much wider range of incident period waves and as a result the period band widths recommended in the SMS guidance are acceptable.

- The orientation of the Broadkill shoreline relative to the incident waves originating in the Atlantic may result in unreasonable results which are manifest in the Q_l results. Ideally, the majority of incident wave angles should not be highly oblique. At Broadkill, the range of incident wave directions might best be handled with two or even three grids.

124. **Cross-Shore Transport and Storm-Induced Beach Erosion**. In addition to moving alongshore, sediment also is moved under the action of waves and currents across the beach profile. Cross-shore transport occurs as a result of changing water level and wave energy flux in the surf zone. The concept of an equilibrium beach profile has been used to describe beach profile changes from cross-shore transport resulting from a relative change in surf zone energy. Research has shown that beach profile slope is a function of sediment characteristics, wave energy, and wave steepness (Bascom, 1951; Bruun, 1954; Dean, 1977). When one of these environmental characteristics is changed the existing beach profile is no longer in dynamic equilibrium and cross-shore transport occurs until a new equilibrium profile is established.

125. Under relatively mild storm conditions sediment eroded from the upper beach profile is later recovered under the action of longer low-steepness waves. However for severe storms, eroded upper profile sediments can be deposited in water depths at which prevailing bottom wave-generated stresses are too low to transport the sediments back up the profile. In this case the eroded sediments are permanently lost. For Broadkill Beach-type coasts characterized by low closure depths and nearly flat bottom slopes beyond the beach face toe having normal low-energy nearshore wave climates, this type of storm-induced erosion can be the dominant erosion mechanism.

GEOTECHNICAL EVALUATION

126. **Physiography**. Delaware encompasses segments of two regional physiographic-geologic provinces. The extreme northern portion of the state lies within the Appalachian Piedmont province, an area characterized by an exposed bedrock complex consisting of metamorphic and igneous rocks. The eroded surface of this complex slopes south and east to the sea, forming the depositional basement for the wedge-shaped mass of essentially unconsolidated sediments commonly referred to as the Atlantic Coastal Plain Province. This wedge, believed to reach a thickness of approximately 7,800 feet at Fenwick Island, extends eastward beyond the edge of the continental shelf which is considered a part of the Coastal Plain. As a result, this province can be divided into two sections: a submerged portion, commonly referred to as the continental shelf and a subaerial or emerged portion, with the present Atlantic Coast shoreline forming the boundary between the two. The area under investigation lies totally within the Coastal Plain physiographic province approximately 60 miles southeast of the Fall Line (the exposed edge of the Piedmont) and encompasses segments from both the submerged and emerged portions of the province.

127. The nearly continuous beaches bordering the Delaware Bay are generally narrow with an average width of 10 to 50 feet at high water. At many locations, the water reaches the foot of the low dunes behind the beach during periods of storm waves or unusually high tides. A belt of grass-covered dunes ranging from 50 to several hundred feet in width and from 8 to 12 feet in height separates the beach from extensive salt marshes. At many places, the dune crest is only 3 to 4 feet above the high water line. Salt marshes 0.5 to 2 miles in width separate the dunes from the headlands. Narrow bands of marsh follow the stream channels several additional miles inland.

128. The St. Jones, Murderkill, Mispillion and Broadkill Rivers, which empty into the Delaware Bay, are the principal streams draining the bay shore area between Pickering Beach and Lewes. Except for the St. Jones, they are all less than 15 miles in length with low gradients. The lower courses of these streams meander through extensive salt marshes and are tidal for several miles inland. Although these streams flow through a region composed of sand and silt, the stream velocities are insufficient to transport any appreciable amount of sediment. What little material is carried, is deposited in the marshes, and practically none reaches the littoral zone to serve as a source of beach building material. The Lewes and Rehoboth Canal enters Delaware Bay at Roosevelt Inlet just west of Lewes and terminates about 1.5 miles south of Rehoboth in Rehoboth Bay. Several minor creeks and drainage ditches empty into this canal. Practically no sediment is furnished by this canal to nourish the beaches.

129. **Surficial Deposits**. The sedimentary formations comprising the surface of the coastal plain of Delaware outcrop in successive belts having a northeast-southwest trend. The oldest, of Cretaceous age, outcrops at the western edge of the coastal plain, and the succeeding overlapping formations are progressively younger as the shoreline is approached. Comparative mineral studies indicate that the original source of material comprising these

sediments was derived through erosion of older rock formations in the Piedmont and Appalachian Mountain provinces to the west. Sedimentary formations of both marine and fluvial origin are represented. They were formed when sediments from the area to the west were deposited in the shallow waters overlying the coastal plain during periods of submergence, and along the stream valleys. In general, these sedimentary deposits are composed of unconsolidated and semi-consolidated material of Cretaceous, Eocene, Miocene and Quaternary age. The cretaceous beds include sands, clays and glauconitic marls: while the Eocene sediments are composed of glauconitic marls, lime sand, glauconitic quartz, sand and clay. Fine micaceous sands and quartz sands with local beds of clay and gravel comprise the Miocene sediments. Quaternary formations, which are the most recent in age, are chiefly sands and gravels. The Quaternary can be further subdivided into the Pleistocene, or glacial period, and the Recent, or present day. Sedimentary deposits of Pleistocene age, particularly those occurring along the shores of the Delaware estuary, contain glacial debris transported there by melt waters, which flowed down the Delaware River valley, from the continental glaciers to the north. Recent sediments are represented by beach and dune sands and deposits of peat in the marshy areas. Only three sedimentary geologic units are exposed at the surface of the coastal plain within the drainage limits of the study area. Since these formations are possible sources of beach material, they are described in detail.

130. The Wicomico formation of Pleistocene age is exposed at elevations above 25 feet. This includes the materials ranging in elevation from 25 to 42 feet, which are designated as the Talbot formation by some geologists. The sediments comprising the Wicomico formation range in size from clay and silt to sand and gravel. Although the upper courses of the streams draining the study area are cut in material of this formation, it is doubtful that their velocities are sufficient to transport a significant amount of material of a size greater than silt. Material that is carried is probably deposited in the marshy areas bordering the lower courses of the streams.

131. The Pamlico formation, also of Pleistocene age, forms the surface between sea level and the 25-foot elevation. This formation, of fluvial and estuarine origin, is primarily gravel, sand and silt. Its maximum thickness probably does not exceed 30 feet. The lower courses of the streams are cut in material of this formation. Sluggish stream velocities and fringing tidal marsh prevent any appreciable amount of beach-building sized material from reaching the shore. Overlying the Pamlico formation are deposits of recent age. These are chiefly tidal marsh, and beach and dune sands. The latter are presently being reworked by littoral forces and redistributed along the shore.

132. **Geological History**. The geological history of the Delaware area indicates that from Cretaceous time to the present, there has been continuous transgression and regression of ocean waters across the Coastal Plain province. At times, the shoreline has been located west of Chesapeake Bay, and at other times, it has been far to the east on the continental shelf. During periods of transgression, materials which eroded from the higher lands to the west were deposited in the shallow ocean waters overlying the coastal plain, in the estuaries which formed as river valleys became flooded, and in lagoons which formed behind barrier beaches.

During periods of emergence, the newly deposited sediments were exposed to erosion. Later they were submerged again, and overlapped and buried by younger sediments.

133. The dominant physiographic features of the coastal plain, the long narrow lowland bordering the Piedmont province and the high ground of the "Eastern Shore" of Maryland and northwestern Delaware, were probably initiated during a period of erosion prior to Miocene time. During the Miocene period, these features were nearly covered by a deposit of marine sediment, only to be uncovered and developed almost to their present form by post-Miocene erosion. In Pliocene time, several broad areas of alluvium were deposited on the Coastal Plain by southeastwardly flowing streams, particularly the Delaware, Susquehanna and Potomac Rivers. The distribution of these sediments suggests that material was first deposited along the pre-existing valleys, and as the valleys filled up, the alluvium spread over the intervalley areas forming a coalescent, nearly continuous alluvial plain sloping seaward. During a succeeding period of emergence, this Pliocene surface between the Delaware and Potomac Rivers was maturely eroded, and the large valley that now constitutes the estuary of the Delaware River was formed. Some of the alluvial material deposited during the Pliocene time was reworked and redistributed, and today constitutes the Wicomico formation.

134. The succeeding Pleistocene epoch is notable for the extensive continental glaciers, which alternately advanced southward from the northern polar regions and the retreated. During the glacial periods when the ice sheet advanced, sea level was lowered considerably as large quantities of water which normally would have returned to the ocean remained on the land as snow and ice. During the interglacial stages, sea level rose as the glaciers melted, and the melt-water flowed to the ocean. This oscillation in the level of the sea caused the shoreline to migrate back and forth across the Coastal Plain.

135. **Formation of the Present Shoreline.** During the Wisconsin, or latest glacial stage, it is estimated that the level of the ocean reached a maximum low of between 230 and 300 feet below the present sea level. This would place the shoreline about 60 miles east of the present Delaware coast. Recent time began with the end of the Wisconsin glacial stage, the gradual return of melt water to the ocean from the receding glaciers, and a consequent rise in sea level. This was caused by a progressive migration of the shoreline across the continental shelf and the formation of barrier beaches, bays and lagoons. Evidence of these are found in the physiography of the surface of the continental shelf, particularly in the elongated shoals with a northeast-southwest trend, which suggests the location of former barrier beaches and bars. The glacial debris, which was spread over the continental shelf and the Delaware Valley, furnished abundance of material from which sand dunes were formed. Inland of the barrier beaches, lagoons formed, which eventually became marshes as they filled with sediment. As the sea level continued to rise, the beaches were driven landward over the marshes.

136. This trend is still continuing. The shoreline follows the contour of the flooded land, the lower reaches of the stream valleys are flooded, and many low areas have been converted into tidal marsh through the accumulation of silt and the growth of water plants. Barrier

beaches have formed where the coast of the coastal plain is too gentle to afford a profile of equilibrium for shore processes. Exposed tree stumps, in the position of growth, in front of the large dune on Cape Henlopen and exposed marshes along the foreshore of many Delaware Bay beaches indicate that the migration of the beaches is still continuing. Recent studies indicate that sea level is continuing to rise at a very slow rate with respect to the land. The rise in sea level along with the scarcity of an adequate source of material for beach nourishment will effect a continued landward migration of the beaches.

137. **Offshore Borrow Area Investigation**. The Reconnaissance Study report identified several possible borrow areas for Broadkill Beach. In order to specifically identify sources of sand borrow for the Broadkill Beach Feasibility Study, a subbottom acoustic survey was performed by the U.S. Army Corps of Engineers Waterways Experiment Station Hydraulics Laboratory (WES). A series of vibracores was also taken along the subbottom profiling lines in order to calibrate the WES model to actual field conditions.

138. **Acoustic Subbottom Profile.** A hydrographic acoustic impedance survey of the Delaware Bay coasts of New Jersey, from Cape May Point to Egg Island Point, and Delaware from Lewes to Port Mahon were conducted by WES aboard their research vessel named the *Waterways Explorer*, a shallow draft tri-pontoon vessel. Multiple low frequency acoustic systems were deployed to provide data across the frequency spectrums between 500 and 5000 Hz. Both digital and analog reflection data were collected. A differential global positioning system (DGPS) was used for survey control and positioning. High frequency bathymetric information was also collected. The field work associated with the acoustic survey was completed in October 1993.

139. The hydrographic acoustic impedance survey system was developed jointly by the Geotechnical and Hydraulics Laboratories of WES through the Dredging Research Program. The acoustic survey was chosen for the following reasons:

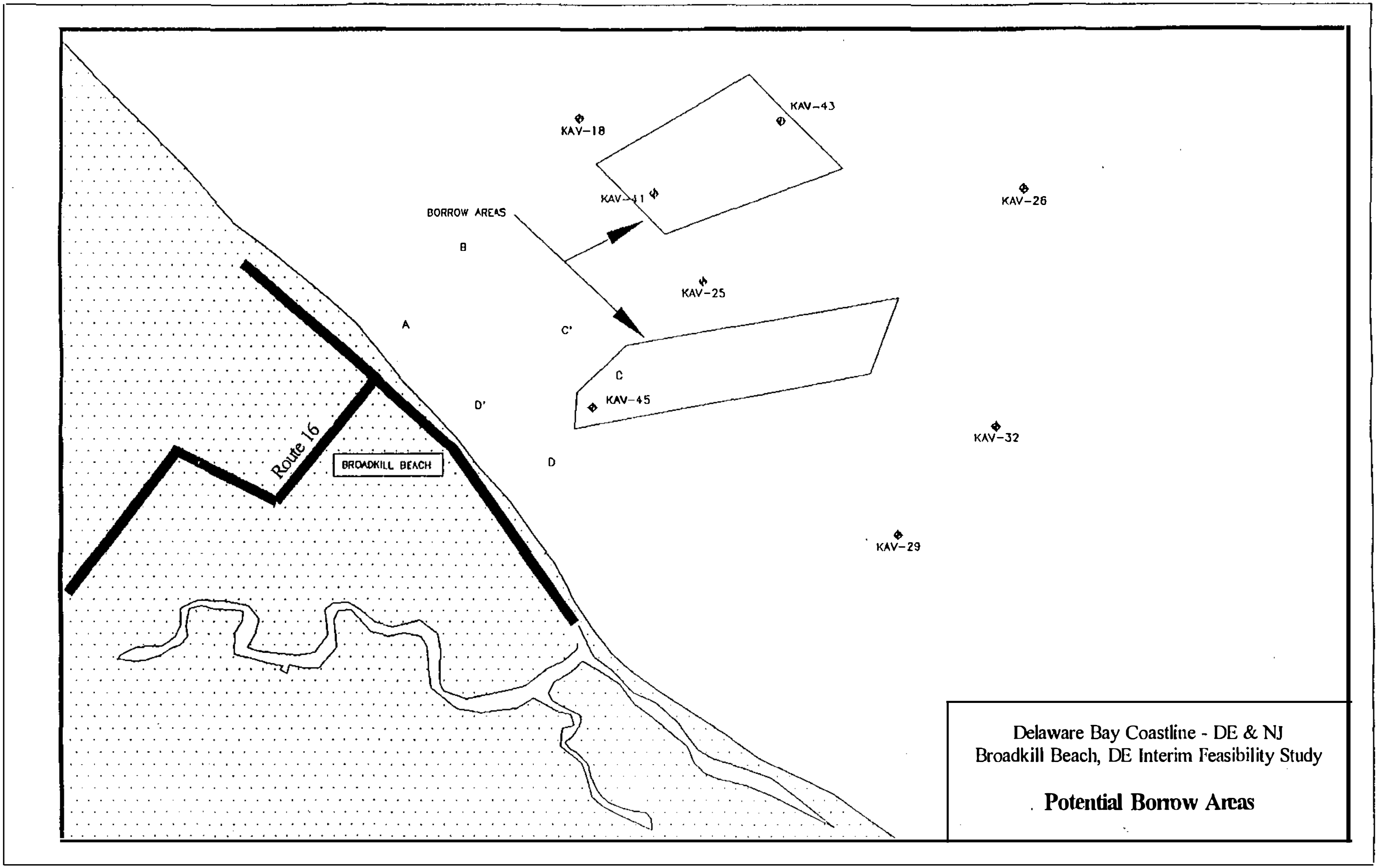
- Acoustic impedance is the product of the material's density and the sound velocity through that material.
- Relates seismic reflectivity and adsorption to material type and density.
- Provides continuous coverage of bottom and subbottom conditions.
- Provides guidance for optimal location of borings.
- Eliminates needless borings.

140. **Offshore Vibracore Investigation**. A series of 46 vibracores were collected by Alpine Ocean Seismic Survey, Inc. along the Delaware and New Jersey coasts of the Delaware Bay, along the acoustic subbottom profile lines. The samples were collected in July and August 1994 to depths of 20 feet below the bottom. The field work included positioning the vessel, obtaining continuous core samples by pneumatic vibration, field logging of the samples and obtaining penetrometer records. The field work was conducted aboard the 110-foot research vessel *Atlantic Twin*. The vibracores were retrieved using a model 271B Alpine pneumatic vibracorer, with an air-driven vibratory hammer. The geotechnical analysis (including

classification testing, specific gravity testing and density determination) of the vibracores was conducted by the South Atlantic Division Geotechnical Laboratory of the Army Corps of Engineers. Data from the vibracore investigation was used to calibrate and confirm data collected in the acoustic survey

141. **Beach Sampling**. The State of Delaware conducted a beach sampling program for this study. Beach samples were obtained from two survey lines in the project area (LRP-25 and LRP-27) in September 1993. Sampling points along the lines were: dune base, mid-beach, high tide, mid-tide, low tide, -5 ft., -10 ft. Both lines were composited individually and together using the Automated Coastal Engineering System (ACES) computer program, which was developed by the Coastal Engineering Research Center (CERC) and the Waterways Experiment Station of the Army Corps of Engineers. Geotechnical analysis of the beach samples and the subsequent compositing give the following characteristic parameters for Broadkill Beach: Mean Grain Size=1.42 phi (0.374 mm) and a Standard Deviation=0.70 phi.

142. **Borrow Area Identification**. WES has analyzed their data and has identified two areas that contain sufficient quantities of suitable beachfill material (Figure 13). These two areas lie in 9 to 13 feet of water and are approximately 312 acres (northern site) and 349 acres (southern site) in plan view. The northern area lies approximately 1.5 to 2.5 miles offshore while the southern area is approximately 0.5 to 2.5 miles offshore.


KAV-43
KAV-18
KAV-41
KAV-26
BORROW AREAS
B
KAV-25
A
C'
C
KAV-45
D'
KAV-32
Route 16
BROADKILL BEACH
D
KAV-29
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Potential Borrow Areas

FIGURE 13

WITHOUT PROJECT CONDITIONS

PROBLEM IDENTIFICATION

143. Water resources problems associated with the main study objectives are identified below. The problems which exist in the study area were identified during site visits, literature review, public and interagency coordination, surveys and aerial reconnaissance flights.

144. **Problem Analysis**. The problem categories are 1) long term shoreline erosion and 2) storm damage vulnerability with a high potential for storm-induced erosion, inundation and wave attack which is exacerbated by long term erosion.

145. **Long Term Shoreline Erosion**. Progressive and constant erosion is evident in certain areas of the coastline. In an attempt to prevent further erosion of the shoreline, the State has performed a number of beachfills over the years on an as-needed basis. In addition, the groins and revetment were installed in the 1950's and 60's. However, sections of Broadkill Beach are continuing to erode despite these efforts.

146. It should be noted that simply because areas may have relatively stable or low background erosion rates does not preclude the need to fully address options for additional shore protection. In the case of Broadkill Beach which has a variable beach width, much of the existing beachfront lacks a continuous dune system. In areas where dunes are present, they have been significantly eroded by recent storms.

147. **Flooding and Storm Damages**. Long term erosion of the beachfront along the Delaware Bay has resulted in a persistent reduction in storm damage protection. The lack of a continuous dune system, proximity of roads to the shoreline, and the concentration of homes on the bay side of Bayshore Drive can result in significant economic damages in the event of a major storm.

148. The highest elevation of water recorded for Lewes, DE was 7.9 feet (NGVD) for the March 1962 northeaster. Damage from inundation was heavy in the tidal section of the bay. The hurricane of August 1993 also caused great damage in the tidal portion of the bay. The stage at Philadelphia during the hurricane was 8.8 feet MSL.

RESULTS OF STORM ANALYSES

149. A site visit was conducted in mid-April 1994. Spot measurements of beach width were made to compare with the most recent detailed survey data of April 1993. A series of northeasters in the winter of 1993 resulted in an estimated 25-35 feet of dune erosion in the vicinity of State Route 16 (discussion with beachfront property owner). Recent scarping was

evident. A comparison of the dune widths with those indicated on a topographic map of the April 1993 condition confirmed this estimate.

150. Spot observations during the site visit indicated that the berm sand is fairly clean medium sand and is well-graded. There are some grain size distribution (GSD) statistics reported in USACE (1972) for beach samples taken along the LRP survey lines. The Delaware Department of Transportation sampled and performed GSD analyses on surface samples taken along LRP transects #25 and #27 in Oct 1993. Samples were collected at various cross-shore locations from the dune base to the -10 foot (NGVD) contour. Table 13 presents the d_{50} values for the sampled locations. The anomalous values for the MHW and MLW positions at transect LRP #25 may be due to a deposit of shell hash or other coarse relic material from previous beach fills. These two values should be neglected since the spatial extent they represent is unknown. Furthermore, grain size statistics from beach samples should not be considered true "native" samples due to the beach fill history of the area.

Table 13
Median Grain Size (mm) for 1993 Beach Samples

Location	**LRP #25 (N21+00)**	**LRP #27 (S49+00)**
dune base	0.52	0.40
mid-beach	0.37	0.62
MHW	1.80	0.27
MSL	0.80	0.37
MLW	7.80	1.00
-5' NGVD	0.20	0.18
-10' NGVD	0.90	(NO DATA)

151. **Storm-Induced Erosion**. Based on examination of the shoreline change history over the last 40 years at Broadkill Beach, it is likely that shoreline and profile erosion is largely storm-related. From Table 10, there were 18 northeasters and 8 hurricanes between 1950 and 1994 which affected area shorelines. The average frequency for this period is one severe northeaster every 2.5 and one hurricane every 5.5 years, or an average of one severe storm every 2 years.

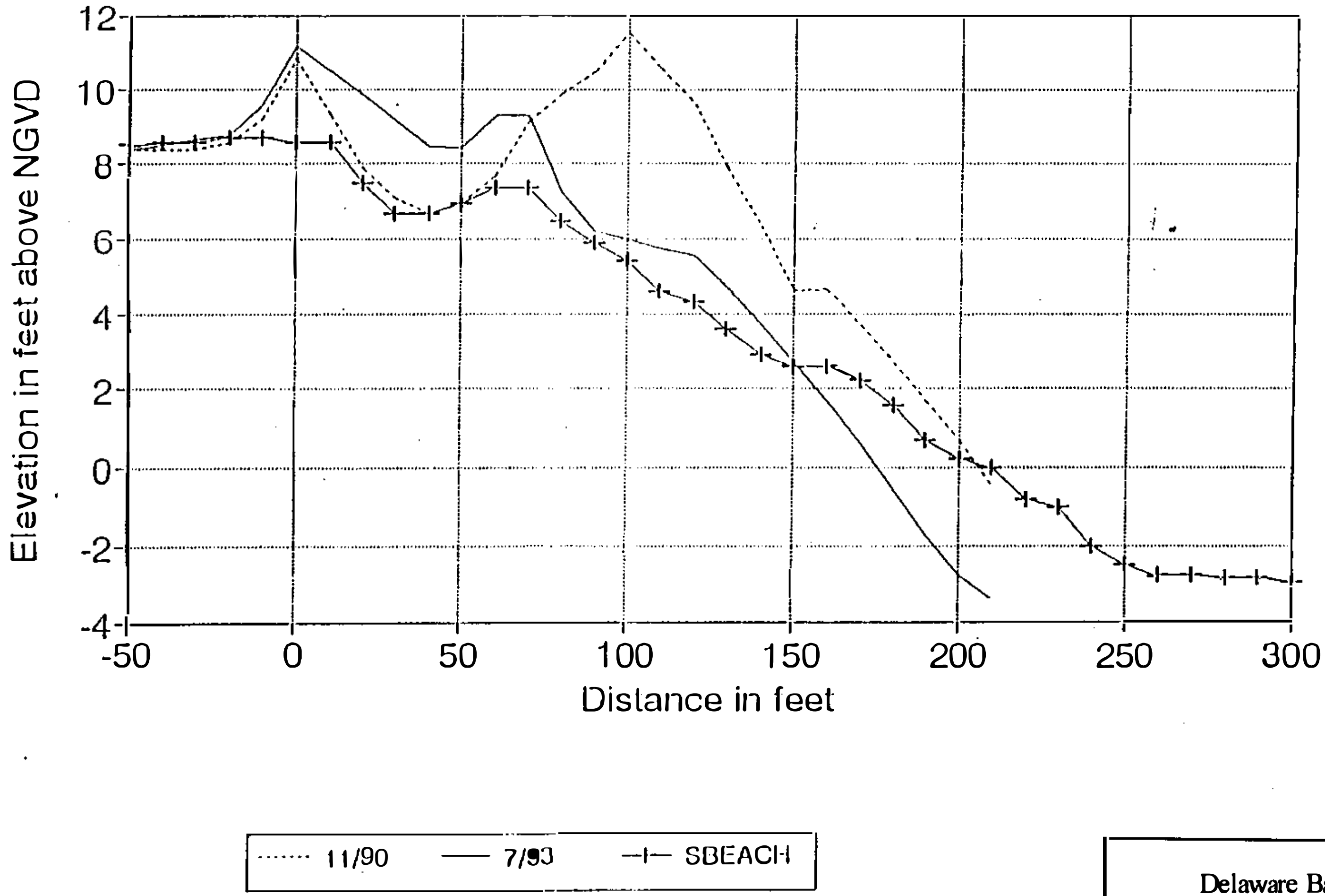
152. Two approaches can be taken to estimate storm-induced beach erosion: the "design-storm" and the "storm-ensemble" approach. For the storm-ensemble approach, erosion rates are calculated from a large number of historical storms and then ranked statistically to yield an erosion frequency curve. In the design-storm approach, the modeled storm is either a hypothetical or historical event that produces a specific storm surge hydrograph and wave condition of the desired frequency. The design-storm approach is used to analyze storm induced erosion at Broadkill Beach. A comparison of the two approaches is presented in Appendix A, Section 2.

153. The Storm Induced Beach Change Model (SBEACH) (Rosati et. al., 1992) was used to estimate storm-induced erosion at Broadkill Beach. SBEACH is a geomorphic-based model utilizing large wave tank profile change data and high quality field data. Breaking waves and a variable water level are the major driving forces in SBEACH that produce sediment transport and beach profile changes. It is a two-dimensional model in that only cross-shore processes are considered. SBEACH was designed to predict and analyze short-term, storm-induced erosion.

154. Due to the empirical foundation of SBEACH and the natural variability that occurs alongshore during storms, the model should be tested and calibrated. Pre- and post-storm beach profiles together with wave and water level time series data for the storm are required to calibrate the model. Since these data are not available at Broadkill, the calibration parameters were first adopted from nearby Dewey Beach study.

155. From 1991 to 1992, three northeasters attacked the study area (January 1991, January 1992, and December 1992). Beach profiles were surveyed two months prior to the January 1991 storm and seven months after the December 1992 storm. These profiles along with the computer simulated wave and water stage conditions for these storms were used to test the SBEACH model. This is not a model calibration or verification but to test the SBEACH model using available information. In order to calibrate the model, it is necessary to have accurate field wave and water level data, and pre- and post-storm beach profile survey.

156. The November 1990 beach profile at LRP #25B was used as the initial profile. The stage hydrograph and wave conditions for the January 1991 storm simulated in the Delaware Bay wave and surge study were used for model input. The eroded profile was then used as the initial profile for the January 1992 northeaster. The wave and stage time series for that storm was then used to compute a second eroded profile. The procedure was then repeated for the December 1992 storm. Figure 14 shows a comparison between the initial measured profile (November 1990), the calculated profile, and the final measured profile (July 1993).



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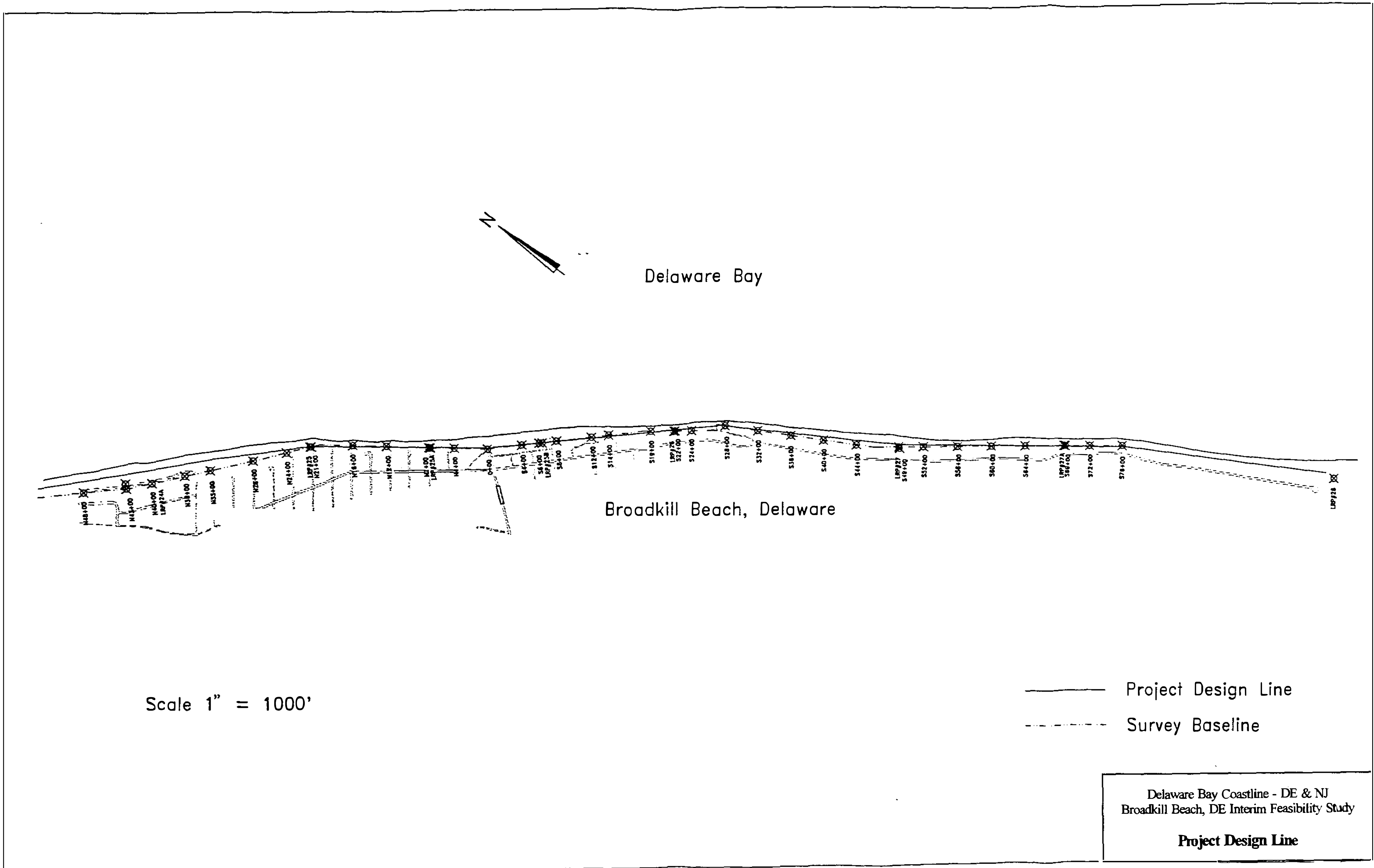
SBEACH Profile Comparison

FIGURE 14

157. Since the SBEACH simulation indicated that the rear dune was eroded as the result of the January 1991 storm, subsequent model testing was done only for the 1991 storm. During the process, it was determined that a smaller value of the Eps parameter should be used to produce a profile similar to the July 1993 profiles. Also, reducing the profiles' landward extent behind the rear dune resulted in less erosion of the second dune and produced a receded dune profile more like the measured final profile.

158. Twelve beach profiles were surveyed at Broadkill Beach in September 1993. These profiles are used as the project's base condition. For erosion and wave inundation analyses, a project design line was chosen as shown in Figure 15. All profile distances were adjusted relative to the design line. Table 14 presents the transects selected for the analysis, dune crest locations relative to the design line, and the dune crest elevations. Tables 15-23 present the SBEACH results for select return periods. Figures 16-24 present the initial beach profiles and the 100-year eroded profiles.



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Project Design Line

FIGURE 15

Table 14
Existing Dune Crest Location and Elevation

Profile Station	Design Line To Crest (ft)	Dune Crest (ft, NGVD)
LRP #24A	0	12
N33+00	90	12
LRP #25	- 3	12
LRP #25A	0	13
LRP #25B	- 4	11
LRP #26	10	11
LRP #27	25	13
LRP #27A	6	15
LRP #28	20	12

- bayward + landward

Table 15
Without Project Erosion Results - LRP #24A

Return Interval	Dune Crest Erosion Position (feet from design line)	Volume Eroded Above NGVD (cu yd/ft)
Original Dune Crest Location = 0 feet		
500	14	17.1
200	14	15.5
100	10	14.4
50	10	12.8
20	0	12.1
10	0	10.8
5	0	8.8

Table 16
Without Project Erosion Results - N33+00

Return Interval	**Dune Crest Erosion Position (feet from design line)**	**Volume Eroded Above NGVD (cu yd/ft)**
Original Dune Crest Location = 90 ft		
500	114	17.5
200	110	16.3
100	110	15.9
50	110	13.2
20	90	13.2
10	90	12.8
5	90	10.8

Table 17
Without Project Erosion Results - LRP #25

Return Interval	**Dune Crest Erosion Position (feet from design line)**	**Volume Eroded Above NGVD (cu yd/ft)**
Original Dune Crest Location = -3 ft		
500	112	19.1
200	88	16.9
100	88	15.5
50	82	14.4
20	75	12.4
10	42	10.8
5	10	7.6

Table 18
Without Project Erosion Results - LRP #25A

Return Interval	Dune Crest Erosion Position (feet from design line)	Volume Eroded Above NGVD (cu yd/ft)
Original Dune Crest Location = 0 ft		
500	82	22.3
200	72	19.4
100	72	18.7
50	59	16.7
20	42	14.4
10	32	13.2
5	6	10.4

Table 19
Without Project Erosion Results - LRP #25B

Return Interval	Dune Crest Erosion Position (feet from design line)	Volume Eroded Above NGVD (cu yd/ft)
Original Dune Crest Location = -4 ft		
500	53	21.5
200	23	18.7
100	23	16.7
50	16	14.8
20	7	12.8
10	0	11.2
5	-4	8.4

Table 20
Without Project Erosion Resnlts - LRP #26

Return Interval	Dune Crest Erosion Position (feet from design line)	Volume Eroded Above NGVD (cu yd/ ft)
Original Dune Crest Location = 10 ft		
500	74	20.3
200	64	18.3
100	61	16.7
50	61	15.5
20	55	13.2
10	51	12.0
5	35	9.2

Table 21
Without Project Erosion Resnlts - LRP #27

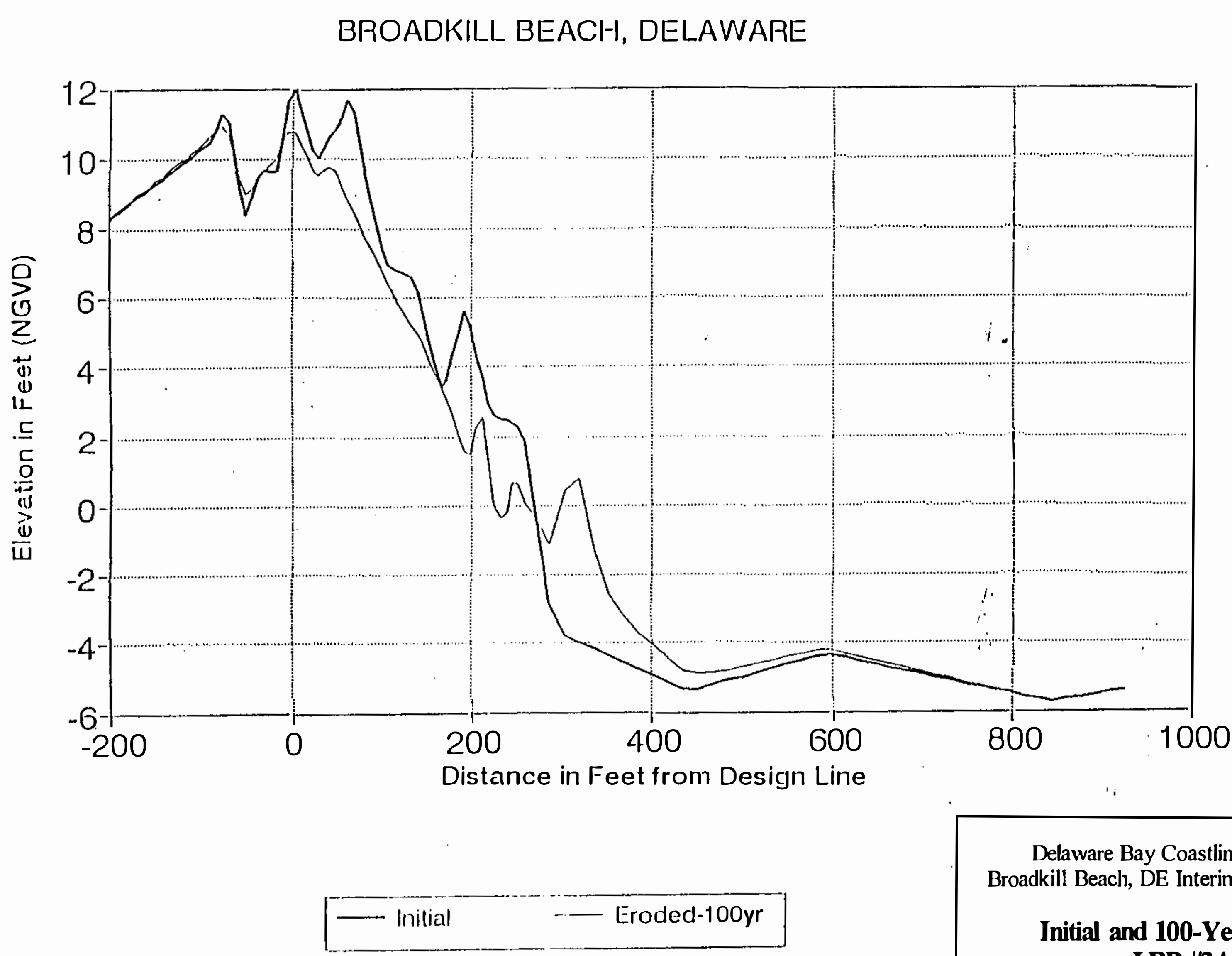
Return Interval	Dune Crest Erosion Position (feet from design line)	Volume Eroded Above NGVD (cu yd/ ft)
Original Dune Crest Location = 25 ft		
500	122	17.5
200	83	14.0
100	76	12.8
50	76	10.8
20	37	8.0
10	34	8.0
5	25	8.0

Table 22
Without Project Erosion Results - LRP #27A

Return Interval	Dune Crest Erosion Position (feet from design line)	Volume Eroded Above NGVD (cu yd/ ft)
Original Dune Crest Location = 6 ft		
500	102	19.1
200	98	17.9
100	92	17.1
50	92	15.9
20	79	14.4
10	36	12.8
5	20	10.4

Table 23
Without Project Erosion Results - LRP #28

Return Interval	Dune Crest Erosion Position (feet from design line)	Volume Eroded Above NGVD (cu yd/ft)
Original Dune Crest Location = 20 ft		
500	107	16.3
200	90	15.2
100	84	14.8
50	77	14.0
20	67	12.0
10	64	10.4
5	38	8.8



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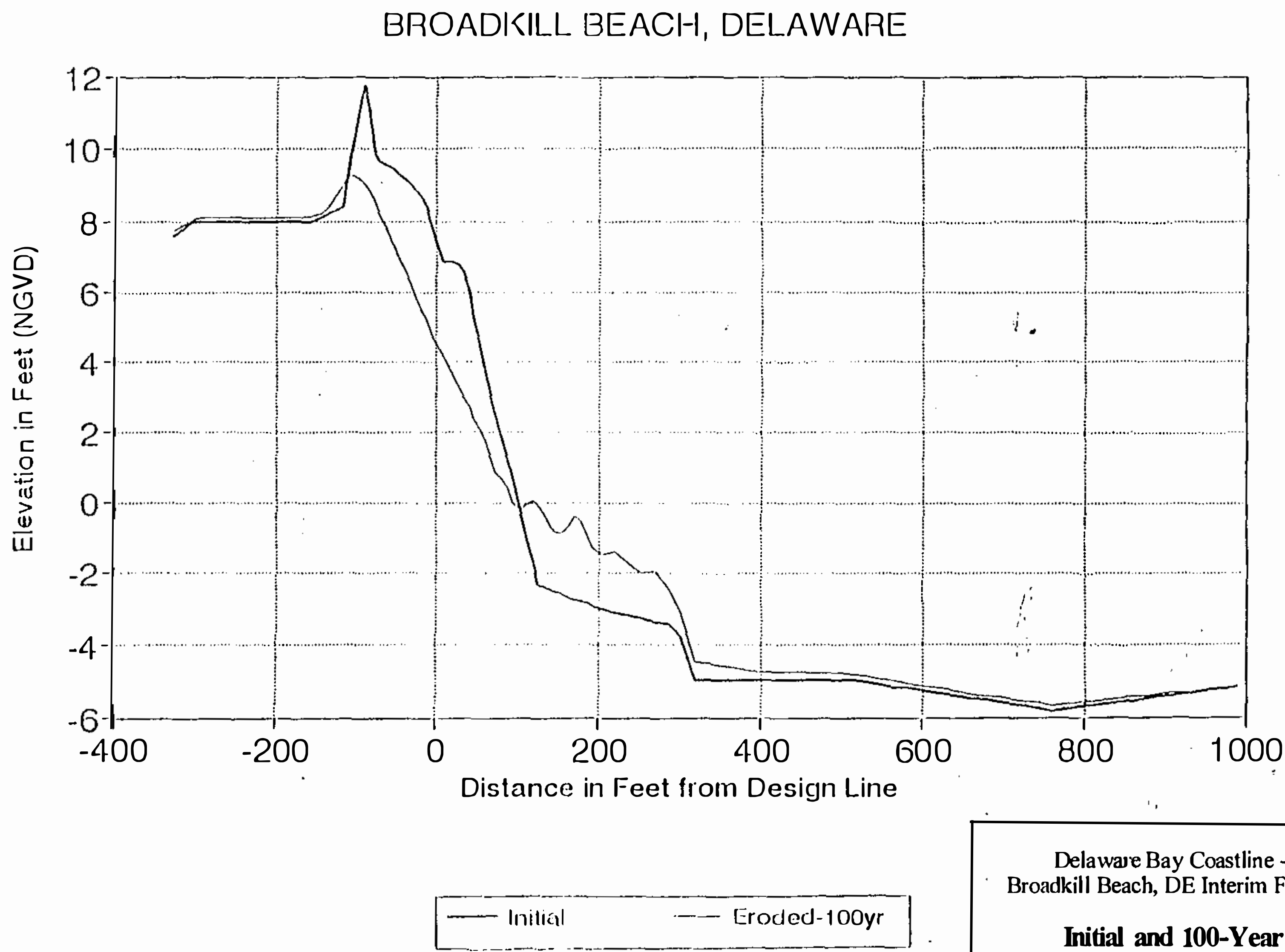
Initial and 100-Year Profiles
LRP #24A

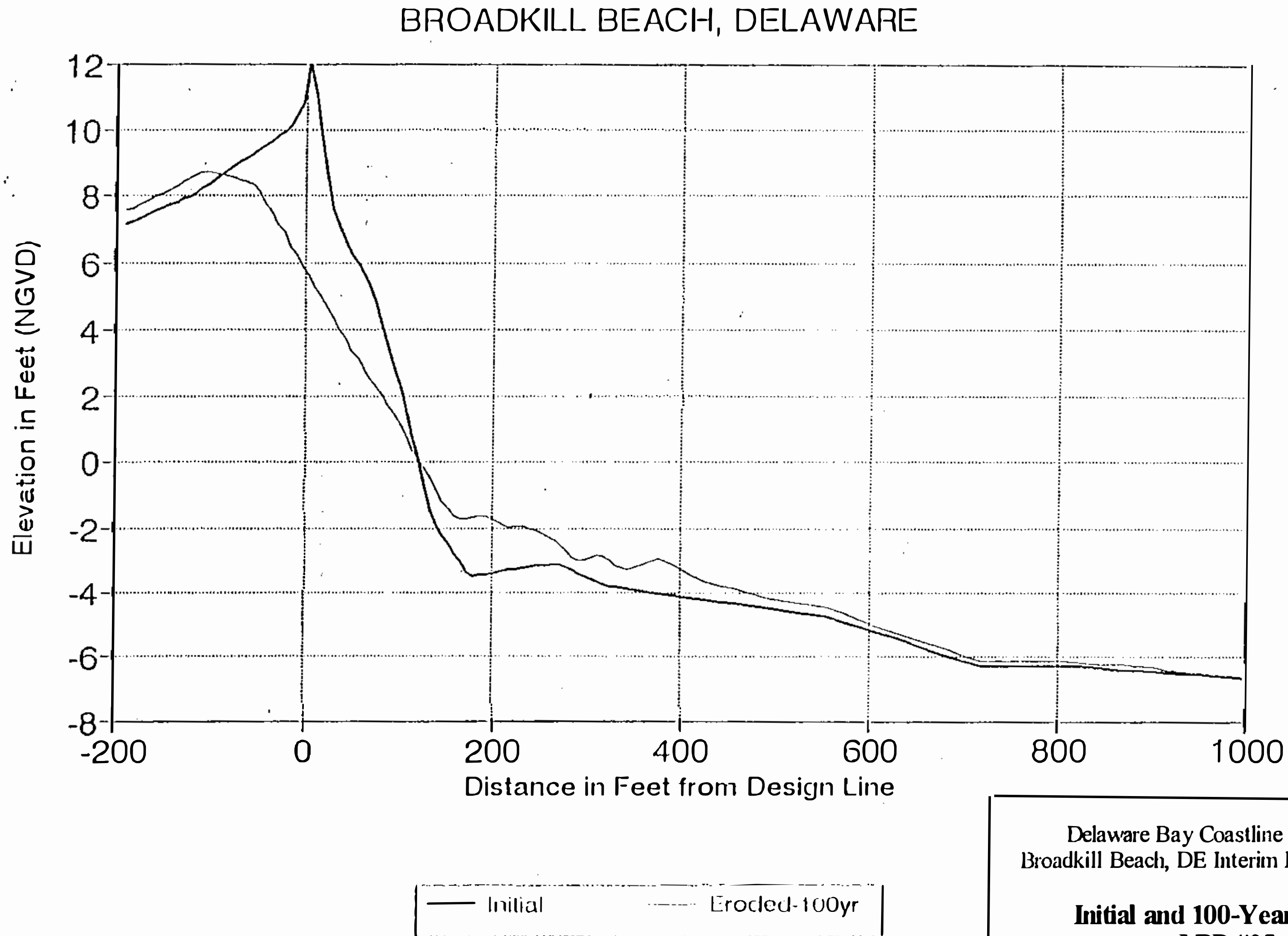
FIGURE 16



Delaware Bay Coastline - De & NJ
Broadkill Beach, DE Interim Feasibility Study

Initial and 100-Year Profiles
N33+00

FIGURE 17



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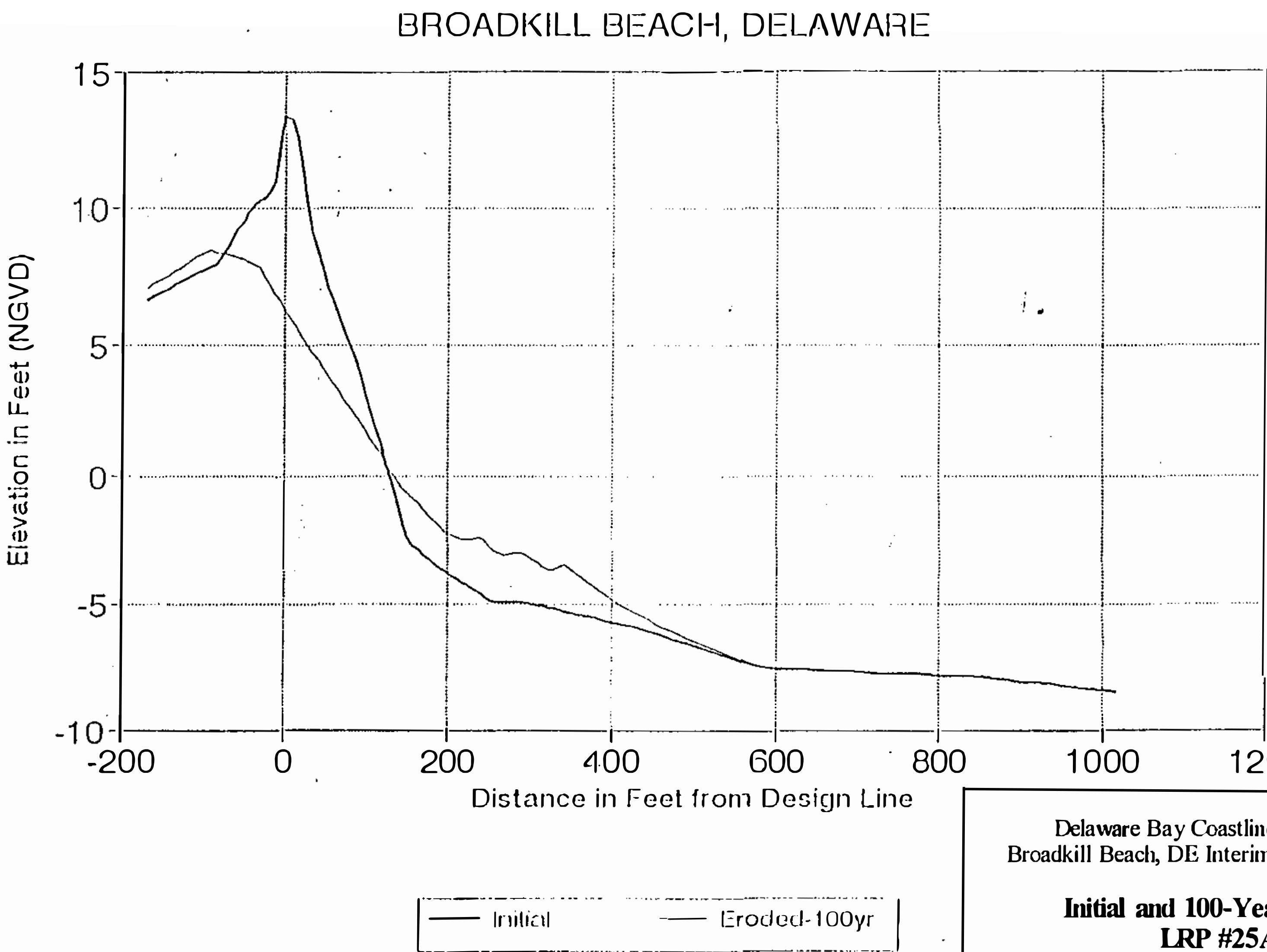
Initial and 100-Year Profiles
LRP #25

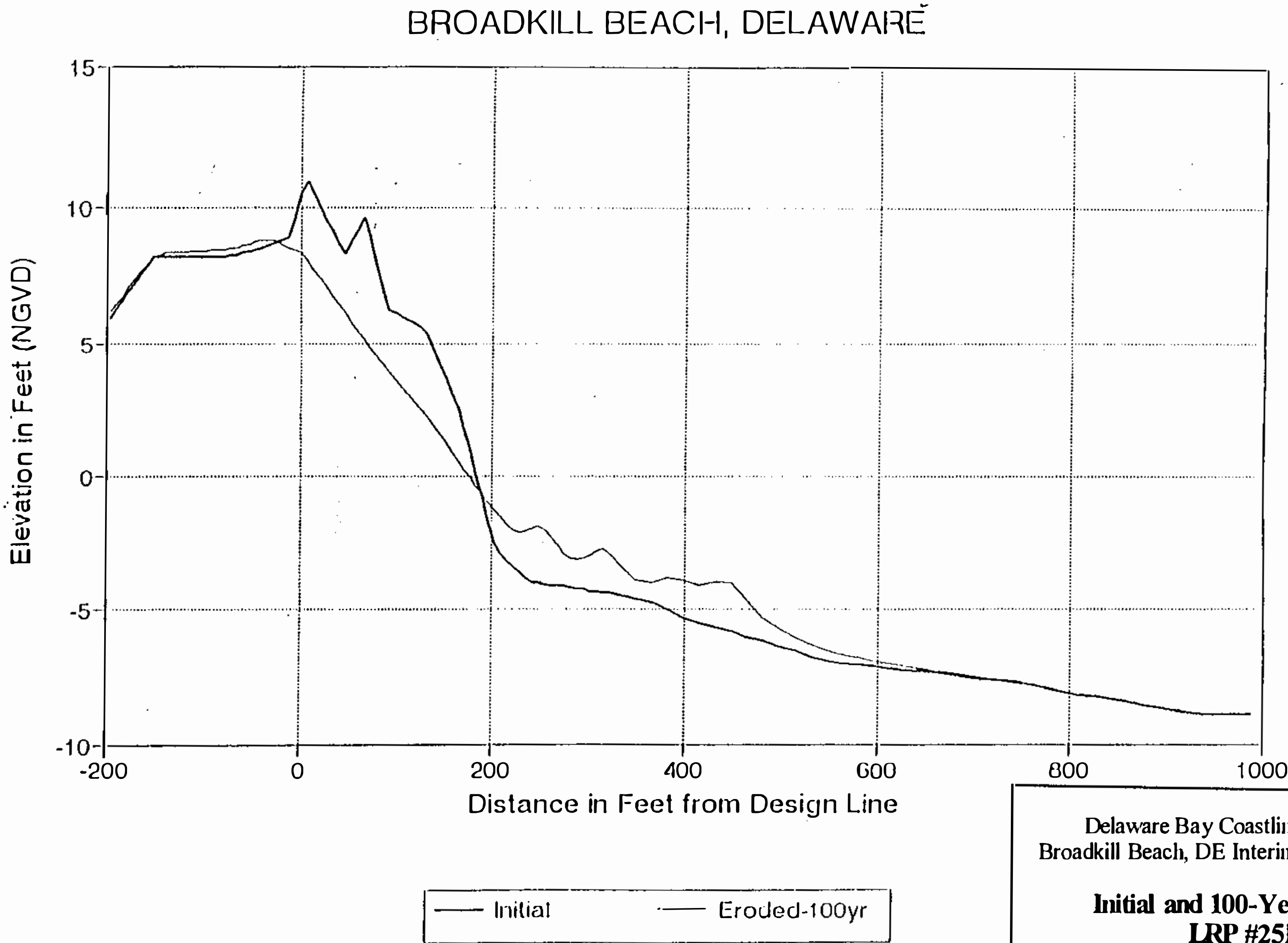
FIGURE 18



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Initial and 100-Year Profiles
LRP #25A

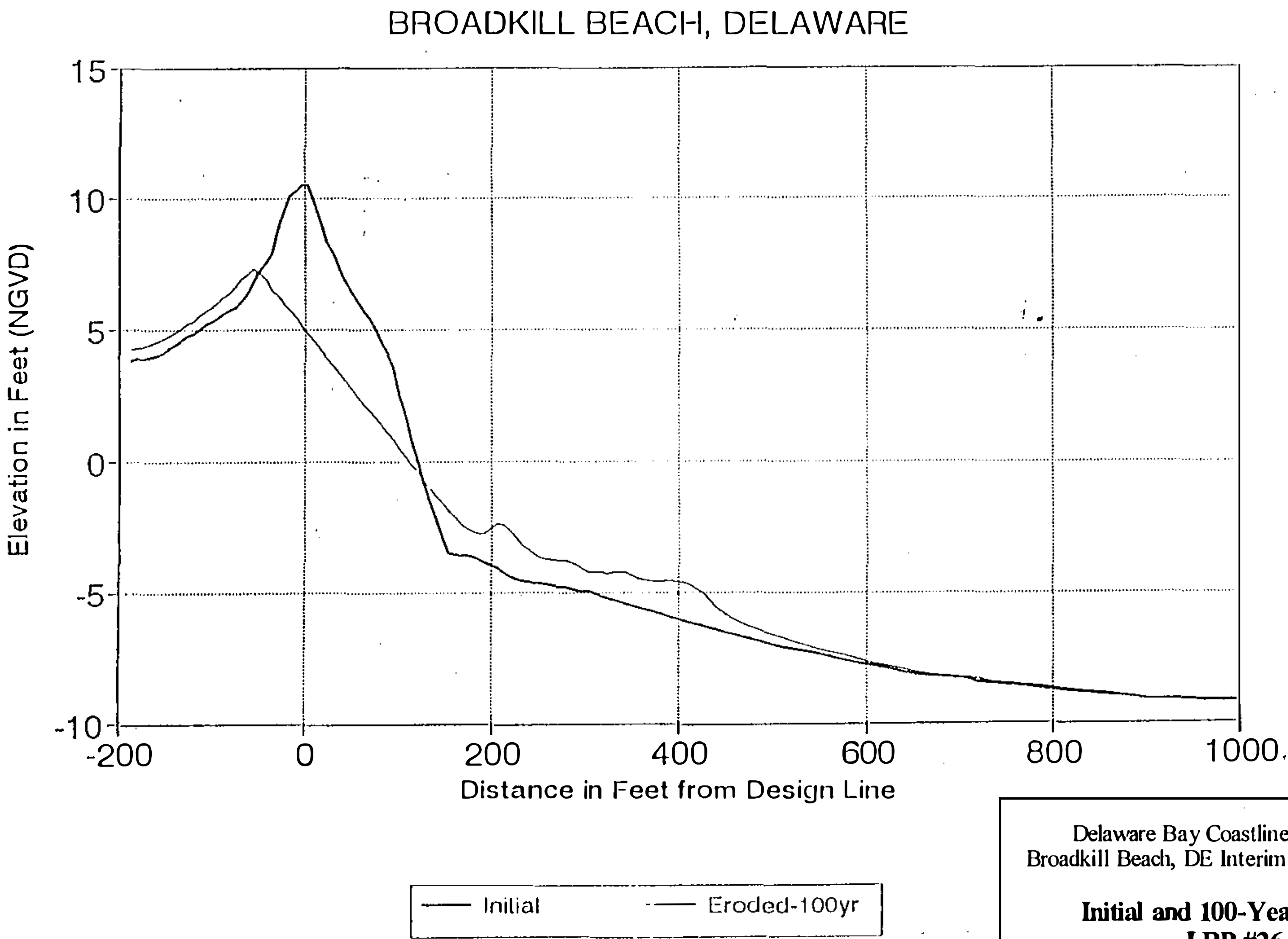
FIGURE 19



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Initial and 100-Year Profiles
LRP #25B

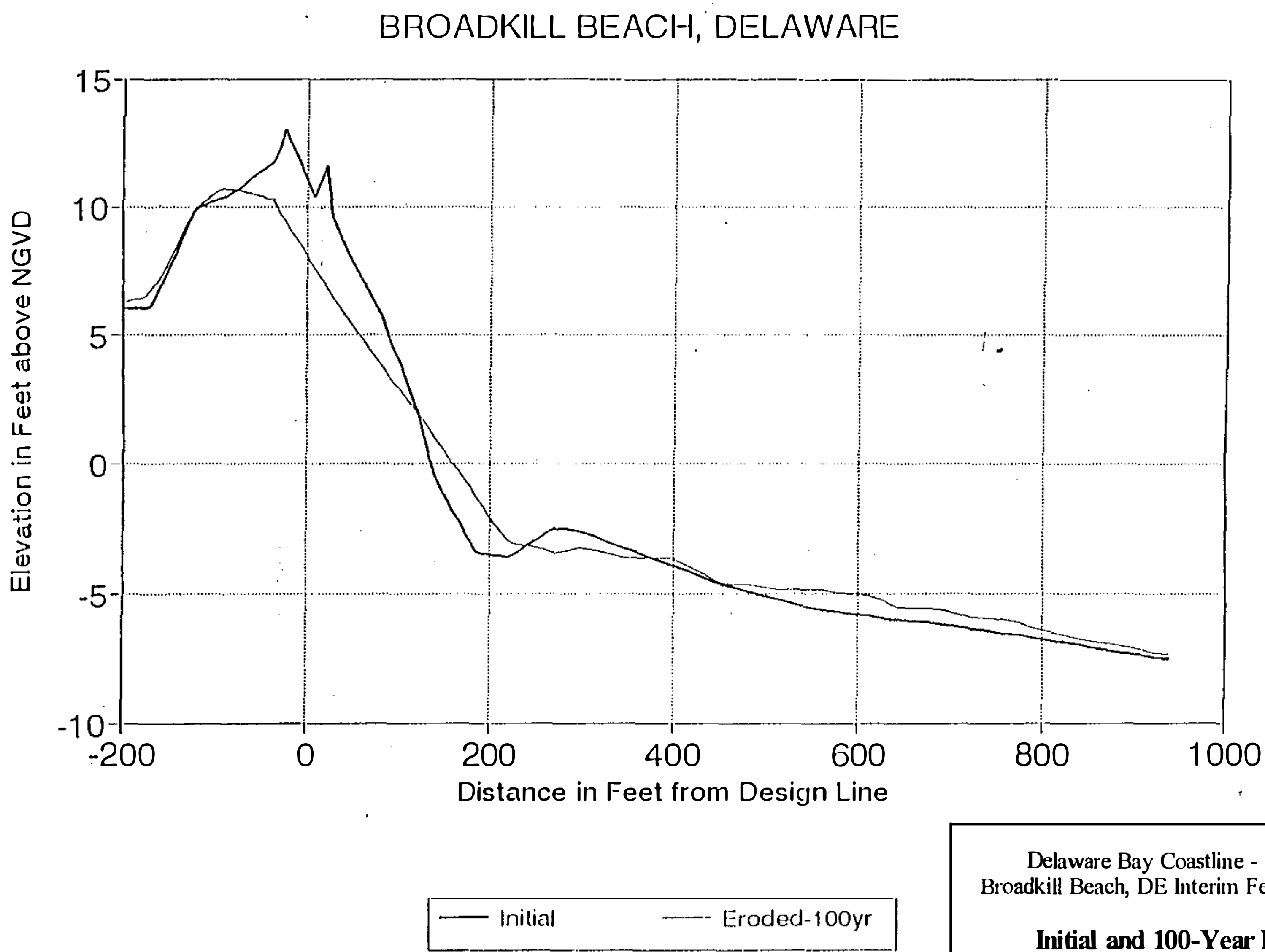
FIGURE 20



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Initial and 100-Year Profiles
LRP #26

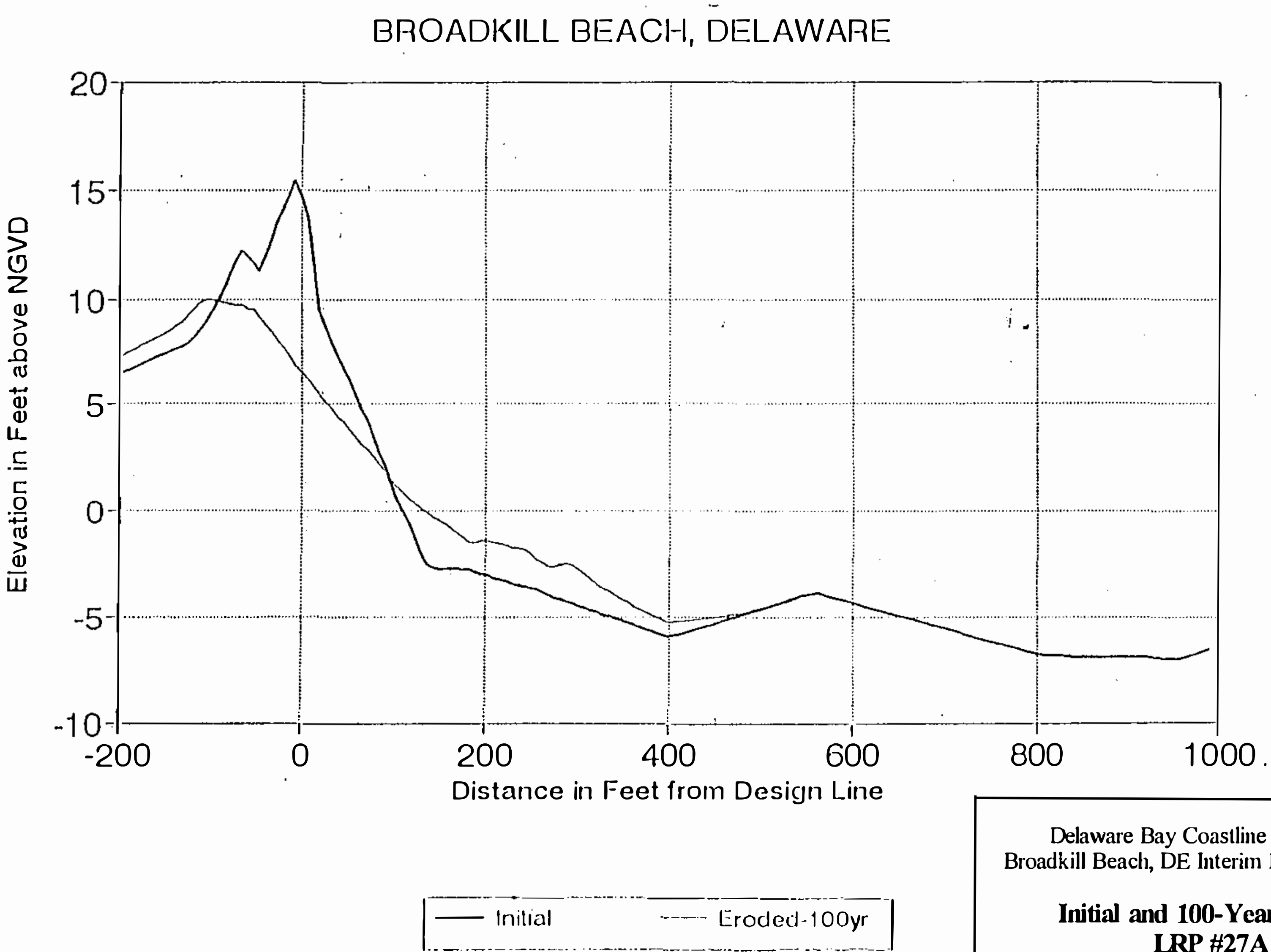
FIGURE 21



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Initial and 100-Year Profiles
LRP #27

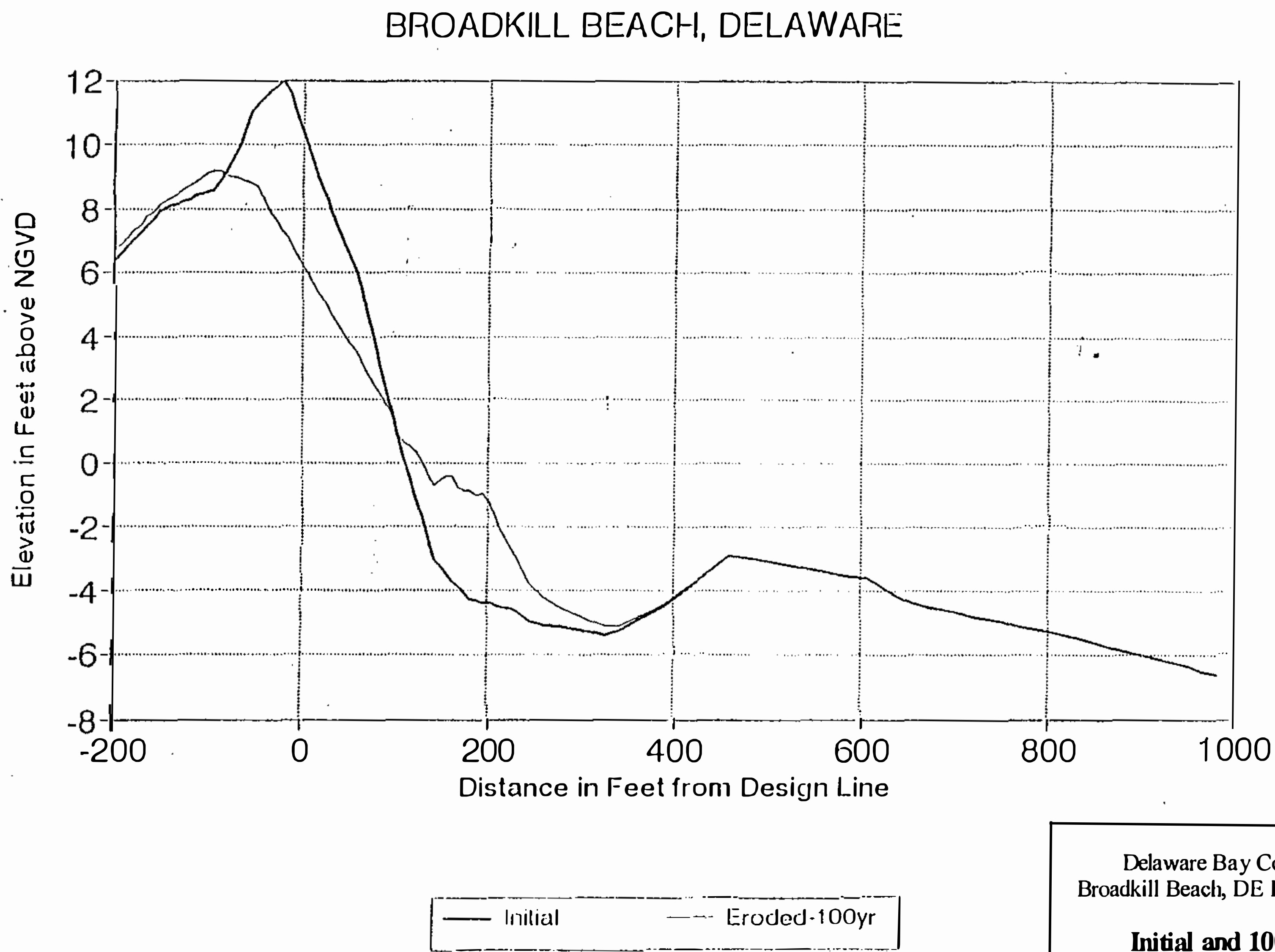
FIGURE 22



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Initial and 100-Year Profiles
LRP #27A

FIGURE 23



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Initial and 100-Year Profiles
LRP #28

FIGURE 24

159. **Wave Attack and Inundation**. The project area is subject to inundation from several sources including waves overtopping the dune and flooding from Broadkill Sound. Inundation can be categorized as two separate phenomena: (1) Static flooding due to the superelevation of the water surface (storm surge and wave setup), and (2) Wave attack, the direct impact of waves and runup on the dunes.

160. Wave setup has long been recognized as an important component in the design of coastal projects. The U.S. Army Corps of Engineers, Shore Protection Manual (1984), defines setup as the superelevation of the mean water level caused by wave action alone. As wave trains approach the coast, non-linear wave breaking in the surf zone causes the water level at the shoreline to increase. Depending on the wave characteristics and nearshore bottom slope, this accumulation of water will continue until the slope of the water surface results in head which balances the forces driving the water onto the shoreline.

161. In order to quantify the effects from flooding and wave attack, all inundation events are based on the stage frequency analysis in the recently developed Delaware Bay surge study. To estimate the setup during storm events, the techniques presented in the SPM (1984) were used. The wave heights and periods used for setup calculations at each frequency event were also obtained from the Delaware Bay wave study. The stage-frequency adopted at Broadkill Beach and the water stage with wave setup are presented in Table 24.

Table 24
Stage Frequency Data

	Elevation in ft. (NGVD) at given recurrence interval (yr)						
	5	10	20	50	100	200	500
Stage+setup	7.5	9.2	10.1	11.2	12.5	13.5	14.6
Stage	6.2	7.5	8.0	9.5	10.5	11.2	12.4

162. To evaluate the added potential for structural damage, the boundaries of the wave attack were estimated along each survey profile. The analysis estimates the location of a wave attack line and the associated zones of high energy stages. The wave attack line is the most landward position in the swash zone where the force due to waves exceeds the force required to damage typical coastal structures. A 3-foot wave height is adopted as the minimum wave that would cause damage to typical structures.

163. The methodology applied to estimate the wave attack is outlined in the FEMA report "Guidelines and Specifications for Wave Elevation Determination and V-Zone Mapping" (1989). The analysis is done for each of the selected profiles, and it should be noted that variability exists which cannot be modeled at this level of detail.

164. A potential wave is transmitted across the eroded profiles. The total water level (wave crest elevation) is computed by adding 70% of the maximum sustained wave height to the inundation stage. The first seaward estimate starts at the design line. If the wave zone location is seaward of the design line, the estimate begins at the wave zone. Seaward of the dune, the total water level is the higher of the breaking wave crest elevation or the maximum runup elevation. At the dune crest, the maximum total water level again is either from runup or from breaking waves. The maximum runup level is limited to the dune crest elevation plus 3 feet. In this case, the wave zone is at the dune crest if the still water level cannot support a three foot wave across the dune. If the still water level is over 3.8 feet higher than the dune crest, the wave zone can be further landward. Landward of the dune crest, it is assumed that the total water level drops at the rate of 1 foot every 50 feet.

165. Tables 25-33 present the wave inundation results for each profile for the without project condition. The total water level in these tables is the combined height (relative to NGVD) of surge, setup and wave height.

Table 25
Without Project Wave Inundation Results - LRP #24A

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 50 100-river	16.5 15.5 14.5	0
200	0 50 80-river	15.0 14.0 13.5	0
100	-40 10 60 110-river	14.0 13.5 12.5 10.5	-40
50	-50 0 50 200-river	13.5 12.5 11.5 9.5	-50
20	-80 -60 0 50 120-river	13.0 13.0 12.0 11.0 7.0	-80
10	-90 -70 -20-river	11.0 11.0 5.5	- 90
5	-150 - 90 -40-river	9.0 9.0 4.5	-150

Table 26
Without Project Wave Inundation Results - N33+00

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 50 100 130 180-river	20.0 19.0 18.0 17.5 16.5	entire area in wave zone
200	0 50 110 160-river	18.5 17.0 16.0 15.5	entire area in wave zone
100	0 50 100 180 200-river	17.5 15.0 14.5 13.0 12.5	130
50	0 50 100 150 200 250-river	14.5 14.0 13.5 12.5 11.5 9.5	100
20	0 90 150 200-river	13.0 12.5 9.0 7.0	60
10	0 90 140-river	12.0 11.5 5.5	40
5	0 80 130-river	9.5 9.5 4.5	20

Table 27
Without Project Wave Inundation Results - LRP #25

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 90 140 170-river	20.0 18.0 17.0 16.5	entire area in wave zone
200	0 40 120-river	18.0 17.0 15.5	entire area in wave zone
100	0 60 120 270-river	16.5 15.0 14.5 11.5	entire area in wave zone
50	0 70 120 170 240-river	14.0 13.0 12.0 11.0 9.5	70
20	0 40 90 140 190 240-river	12.0 12.0 11.0 10.0 9.0 7.0	40
10	0 10 60 110 210 240-river	11.0 11.0 10.0 9.0 7.5 5.5	10
5	-30 20 70 120-river	10.5 10.5 6.2 4.5	-30

Table 28
Without Project Wave Inundation Results - LRP #25A

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 100 130 180-river	20.0 18.0 17.0 16.5	entire area in wave zone
200	0 70 120-river	18.0 16.5 15.5	entire area in wave zone
100	0 70-river	16.5 14.5	entire area in wave zone
50	0 20 60 110 160 210-river	14.0 13.0 12.5 11.5 10.5 9.5	60
20	0 70 120 170 270 370-river	12.5 12.5 11.5 10.5 8.5 7.0	20
10	0 40 90 140-river	11.0 11.0 7.5 5.5	0
5	-60 -20 30 80-river	9.5 9.5 6.2 4.5	-60

Table 29
Without Project Wave Inundation Results - LRP #25B

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 50 100 130-river	19.0 18.0 17.0 16.5	entire area in wave zone
200	0 30 50-river	16.5 16.0 15.5	entire area in wave zone
100	0 50-river	15.0 14.5	entire area in wave zone
50	0 30 80 130 150-river	12.5 12.0 11.0 10.5 9.5	30
20	0 50 100 150 230-river	12.5 11.5 10.5 9.5 8.0	0
10	-45 0 50-river	11.0 11.0 7.5	-45
5	-70 -20 -30-river	9.5 9.5 6.2	-70

Table 30
Without Project Wave Inundation Results - LRP #26

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 80 130 180 200-river	20.5 19.0 18.0 17.0 16.5	entire area in wave zone
200	0 70 120 150-river	18.5 17.0 16.0 15.5	entire area in wave zone
100	0 70 120-river	17.0 15.5 14.5	entire area in wave zone
50	0 70 120 170 220 270-river	15.0 13.5 12.5 11.5 10.5 9.5	70
20	0 50 100 150 180 280-river	12.5 11.5 10.5 9.5 8.0 7.0	50
10	0 50 100 150 200 280-river	11.0 11.0 10.0 9.0 8.0 5.5	50
5	-20 30 80 130-river	9.5 9.5 6.0 4.5	-20

Table 31
Without Project Wave Inundation Results - LRP #27

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 50 100-river	18.5 17.5 16.5	entire area in wave zone
200	0 50 80 100 150-river	16.5 15.5 15.0 14.5 13.5	80
100	0 40 70 170 250-river	15.0 14.0 13.5 12.5 10.5	70
50	0 50 100 150 200 250-river	13.0 13.0 12.0 11.0 10.0 9.5	30
20	0 50 100 150 200 250 300-river	13.0 13.0 12.0 11.0 10.0 9.0 7.0	10
10	-30 20 70 130-river	11.5 11.5 7.5 5.5	-30
5	-70 -30 20 100-river	9.5 9.5 6.0 4.5	-50

Table 32
Without Project Wave Inundation Results - LRP #27A

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 50 100 150-river	19.0 18.0 17.5 16.5	entire area in wave zone
200	0 50 100 150 200-river	17.5 16.0 15.5 14.5 13.5	100
100	0 50 150 200 250-river	16.0 15.0 13.0 11.5 10.5	80
50	0 50 100 150 200 230-river	13.5 12.5 12.0 11.0 10.0 9.5	50
20	0 70 170 270 320-river	12.5 12.5 10.5 8.5 7.5	20
10	0 20 70 120-river	12.0 12.0 7.5 5.5	0
5	-20 0 50 100-river	11.0 11.0 6.0 4.5	-20

Table 33
Without Project Wave Inundation Results - LRP #28

Return Interval (years)	Distance (ft landward of design line)	Total Water Level (ft NGVD)	Wave Zone Location (ft from design line)
500	0 100 150 200-river	20.0 18.0 17.0 16.5	entire area in wave zone
200	0 50 150-river	17.5 16.5 15.5	entire area in wave zone
100	0 100 150 250 300-river	16.0 14.5 13.0 11.5 10.5	110
50	0 40 140 190 220-river	14.0 12.5 11.5 10.0 9.5	90
20	0 80 130 180 230 280-river	12.0 12.0 11.0 10.0 9.0 7.0	30
10	0 70 120 170 220 270-river	11.5 11.5 10.5 9.5 8.0 5.5	20
5	-30 20 70 120 -river	10.0 10.0 6.0 4.5	-30

WITHOUT PROJECT ECONOMICS ANALYSIS

166. The purpose of this section is to describe the information and methods used in the economic analysis of storm damage reduction and erosion protection benefits for the developed area along the Delaware Bay Coastline in Broadkill, Delaware.

167. **Conditions.** An October 1995 price level, 50 year project life, and a base year of 2000 were used in the economic analysis. Damages were converted to an annual equivalent time basis using a 7.75% discount rate as applicable to public works projects. The final table for the selected plan applied the FY 96 discount rate of 7.625%.

168. **Methodology and Assumptions.** Without project conditions damages were calculated for seven frequency storm events (5, 10, 20, 50, 100, 200 and 500 year) for erosion, wave and inundation damages to structures, infrastructures and improved property. Values for infrastructures and property were estimated using standard engineering criteria. The assumption was made that all infrastructures damaged in Broadkill would be replaced in-kind. This assumption also applies to older residential structures on slab. For more frequent events, which are weighted more heavily in computing average annual damages, the structure will be replaced in kind since damage will not be total but only partial. Only for the rare events will structures that incur total damage be faced with the choice of replacement in kind or conversion from slab to pile construction. The average structural replacement valuation of older slab foundation houses, in the study area, is approximately $100,000 versus $200,000 for the newer pile foundation structures. If structures were to be converted from slab to pile construction, the overall damage potential and benefits would actually increase due to the higher replacement valuation of recent pile construction. This has been the case not only at Broadkill Beach but also other coastal communities where older less valuable structures have been replaced even without storm damage with higher value structures on piles. Since frequency events by nature are uncertain to their timing it is nebulous as to what would be replaced and when it would occur. Therefore replacement in kind for both construction and replacement cost was utilized as a conservative basis for future damages. Once damage was calculated for all infrastructures they were placed into EAD to calculate the Expected Annual Damages.

169. Damage calculations for structures were performed using COSTDAM. COSTDAM is a Fortran program originally written by the Wilmington District and updated for the Philadelphia District. COSTDAM reads an ASCII "Control" file which contains storm frequency parameters and an ASCII "Structure" file.

170. A structure inventory survey was undertaken to gather data pertaining to the structural characteristics of all residential, commercial and public structures in the study area. The information was then placed in the Marshall & Swift Residential and Commercial Estimator programs, where the structural value was determined through the manipulation of such data as the number of stories, square footage, quality and condition (worn out, badly worn, average, good,very good, and excellent). Depreciation is therefore implicit in the replacement cost of

the structure. The associated content value of each structure is assumed to be 35% of the structural replacement cost. This assumption is based on interviews with locals as well as through field observations. Interviews with local realtors also confirmed estimated structural replacement costs. Affluence was evaluated and found not to be significant, and therefore not claimed. Table 34 displays the values for both structures and contents at Broadkill Beach for each frequency zone.

Table 34
Without Project Conditions - Value of Structures and Contents
October 1995 Price Levels
Values are in $000s

	5		10		20		50		100		200		500	
	Structure	Content	Structure	Content	Structure	Content	Structure	Content	Structure	Content	Structure	Content	Structure	Content
Wave	0	0	0	0	0	0	532	187	8611	3041	15127	5295	23437	8202
Erosion	648	227	2449	857	3523	1236	5974	2088	4642	1616	4412	1543	7059	2472
Flood	0	0	1337	469	8040	2817	10262	3591	7197	2453	9633	3413	12286	4340
Total	648	227	3786	1326	11563	4053	16768	5866	20450	7110	29172	10251	42782	15014

171. Once the information was placed in COSTDAM, the program was able to calculate damages. COSTDAM initially examined a structure for damages caused by wave attack, based on the relationship between a structure's first floor elevation and the total water elevation that sustains a wave. COSTDAM then determined if the structure had undergone any erosion damage. If the water elevation was higher than the first floor elevation (based on FIA depth-damage curves adjusted by increased salt water damagibility) the program calculated damages caused by inundation. To avoid double counting, if damage occurs by more than one mechanism, COSTDAM took the maximum damage of any given mechanism (wave, erosion, inundation) and eliminated the remaining damages from the structure's total damages. Average annual damages were then calculated and aggregated for the study area.

172. **Erosion Damages**. This analysis evaluated the expected storm erosion losses and the subsequent damage caused by a range of storm events. In order to estimate the extent of erosion damage produced by a certain horizontal retreat of the shoreline, the position of each structure in relation to the shoreline had to be determined. The erosion points were calculated by measuring the distance between the reference (design) line and the front and bask walls of each structure in AutoCAD, using a georeferenced map of the area in the Map & Image Processing System (MIPS) format. Based on engineering input, it was determined that if the structure was not on a pile foundation, it was destroyed at the point that the land below the structure was eroded halfway through the structure. If the structure was on piles, erosion needed to retreat entirely through the footprint before the total damage was claimed. Before

total failure, for both foundation types, the percent damage claimed was equal to the proportion of erosion under the structure's footprint compared to the total footprint. The total damages were calculated by COSTDAM and entered directly into an Excel file to annualize all damages accrued.

173. **Loss of Improved Property and Infrastructures**. Loss of improved property and infrastructure damage due to erosion was also calculated. EAD was used to calculate the damages to both land and infrastructures. The land value was determined by comparing market value of the developed land compared to the cost of filling in the eroded land for reutilization, and using the least expensive of the two values. The cost of filling/restoring the land is based on a typical 100' x 50' lot for the different depths, widths and cubic yards of erosion produced by the storms. The cost of filling/restoring the eroded developed land was determined to be the cheaper of the two, and the cost of fill was prorated for the width of the study area to estimate total damages. The cost of fill and the replacement of roads was not a fixed value. It decreased with greater quantities eroded, therefore reflecting economies of scale. The total annual damages for developed land and infrastructures are $262,000 and $38,000 respectively.

174 **Loss of Landscaping.** Loss of landscaping was calculated by estimating the value of landscaping for the study area. Houses were individually placed into two categories of landscaping: fair and low. Once the individual structures were assigned a rating, the study area received a general rating based on the overall ratio of homes within each category. "Fair" landscaping was estimated to have a replacement cost of $300 per linear foot of recession for a 50' x 100' lot, while "low" was estimated to be $200. Landscaping damages use a frequency-damage relationship. Measurement for the purpose of calculating land loss begins at a structure's property line. The damage per foot of recession was based on erosion rates for each storm frequency and statistically weighted using the Expected Annual Damage (EAD) computer program. Damages corresponding to each frequency of erosion was weighted by the percent chance of each foot of recession occurring (damage caused by rare events is weighted less). Therefore, landscape loss was computed using a frequency-damage relationship.

175. **Wave-Inundation Damages**. Beachfront structures are subject to damage as a result of direct wave impact. However damage was not claimed for a structure from both wave attack and erosion for the same event to avoid double counting. Also, any structure sustaining total damage in the wave attack or erosion analysis at a particular event was not included in the inundation model for that event. A structure was considered to be damaged by a wave when there was sufficient force in the total water elevation to destroy a structure. Partial wave damages are not calculated; instead the structure was subjected to inundation damages.

176. The percentages of total replacement cost used to calculate damages by the depth-damage function curves for inundation damages reflect various characteristics of a structure. The depth-damage curves display the percent damaged at various depths relative to the first floor. These depth-damage curves used to estimate the damage of structures were derived

from previous studies of saltwater areas and FIA (Federal Insurance Administration) curves. The distinguishing characteristics were construction type (frame, concrete block, or masonry), the number of stories in a structure as well as the presence of a basement. These curves were modified based on historical information from the December 1992 storm which was obtained from interviews with local officials and residents. Depth-damage results under the without project conditions were calibrated to this empirical data and were determined to be valid based on this reported historical information.

177. **Future Development.** The structure file also includes future development. Available lots were determined through tax maps as well as field observation. Lots were assumed to be developed over the life of the project at approximately the same rate as historical development has occurred. Structures were developed with similar characteristics as existing adjacent homes. If the vacant lot is surrounded by two story homes on piles worth $150,000, then the future development was expected to be a house around $150,000. However all houses were assumed to be built on piles with a first floor elevation at the 100 year storm level +1 foot, in accordance with FEMA regulations. Table 35 shows estimated future development.

Table 35
Number of Structures by Decade

Year	1994	2000	2010	2020	2030	2040	2050
Number of Structures	426	473	552	623	668	668	668

178. Once the structural characteristics were determined for future development, the data was then placed in COSTDAM and future damages incurred over the 50 year project life were calculated. To prevent over stating damages, each new structure was given a "voodoo number" which told what year the lot was expected to be developed, after the base year of 2000. For example, if the lot was to be developed in 2010 the voodoo number would be 10. COSTDAM then began calculations for that structure in the year 2010 and disregarded any prior damages. The structure damages are based on a total of 668 structures, 242 of which are vacant lots expected to be developed by the year 2050 (Table 35). The expected annual damages for future development is $194,000 compared to $831,000 for existing development. The total average annual damages to structures is $1,025,000.

179. **Local Beach Nourishment Costs**. The State has been involved in maintaining the beach at its pre-storm state , and this involvement is expected to continue. Based on the erosion occurring in Broadkill, the estimated amount of material required to maintain the beach is 44,000 cy/yr. This will cost the State approximately $573,000 annually. Without this expenditure by the State, the without project damages estimated in this report would have been significantly higher.

180. **Without Project Damages Summary**. Average annual damage results for structures, improved property, local costs forgone, and infrastructure were combined to provide total annual damages. These combined without project damages are displayed in Table 36.

Table 36
Without Project Total Average Annual Damages
(in $000s)

Development Type	Avg. Annual Damages
Structures	$1,025
Improved Property	$262
Local Costs Forgone	$573
Infrastructure	$38
TOTAL	**$1,898**

PLAN FORMULATION

181. The purposes of the Plan Formulation section are (1) to provide background on the criteria used in the formulation process, (2) to present the procedures followed in evaluating plans, and (3) the subsequent designation of plans selected for further analysis in Cycle 3. The formulation process involved the establishment of plan formulation rationale, identification and screening of potential solutions, and assessment and evaluation of detailed plans which are responsive to the identified problems and needs.

PLANNING OBJECTIVES

182. General planning objectives for the Delaware Bay study area are to take an integrated approach to the solution of erosion and inundation problems and storm vulnerability. Specific objectives include the following:

a. Provide shore protection measures to reduce shoreline erosion, potential storm damages, and damage from inundation for Broadkill Beach.

b. Minimize degradation of the natural environment in areas impacted by such shore protection measures and protect fish and wildlife resources. Where possible, the environmental character of the areas under study will be preserved and maintained. This will include such considerations as aesthetic, environmental, and social concerns, as directly related to plans formulated for implementation by the Corps.

PLANNING CONSTRAINTS

183. The formulation and evaluation of alternative plans are constrained by technical and economic considerations, environmental awareness and institutional policies. The formulation of all alternative shore protection designs will be conducted in accordance with all Federal laws and guidelines established for water resources planning.

184. **Technical Criteria.** These constraints include physical or operational limitations. The following criteria, within a planning framework, were adopted for use in plan formulation:

a. Natural berm elevations and foreshore beach slopes, including marsh/wetland locations and elevations, should be used at least as a preliminary basis for the restoration of beach profiles. Protective measures should be constructed to adequate dimensions to minimize the effect of shoreline erosion processes. A beach berm, if included in the plan of protection, should have height and width dimensions adequate to dissipate the storm wave energy and resist erosion.

b. Several potential sand source areas should be investigated for the purpose of identifying feasible and suitable beachfill.

c. If a dune is included in the plan of protection, the dune profile should provide protection from the storm surge, wave height, and run-up accompanying the design storm.

185. **Economic Criteria** Economic constraints limit the range of alternatives considered. The following items constitute the economic constraints foreseen to impact the formulation of alternative plans.

a. Analyses of project benefits are conducted in accordance with Corps of Engineers' guidelines and must assure that any plan is complete within itself, efficient and safe, and economically feasible in terms of current prices.

b. Tangible benefits should exceed project economic costs. Assessment shall be based on the NED benefit/cost ratio being greater than 1.0

c. The benefits and costs are expressed in comparable quantitative economic terms to the maximum practicable extent. The costs for alternative plans of development are based on preliminary designs and investigations, estimates of quantities, and October 1995 price levels. Annual charges are based on a 50-year amortization period and an interest rate of 7.75 percent. The annual charges also include the cost of maintenance and replacement.

d. Economic evaluations of project modifications must assume that authorized dimensions are maintained and will evaluate the incremental justification of modifications.

186. **Institutional Criteria** According to the Planning Guidance Notebook (ER 1105-2-100), Section IV--Shore Protection, "Current shore protection law provides for Federal participation in restoring and protecting publicly owned shores available for use by the general public". Typically, beaches must be either public or private with public easements/access to allow Federal involvement in providing shoreline protection measures. Private property can be included, however, if the "protection and restoration is incidental to protection of publicly owned shores or if such protection would result in public benefits". Items which can affect the designation of beaches as public include the following:

a. A reasonable beach user fee, uniformly applied to all, may be established to offset the local share of project costs.

b. Sufficient parking facilities for the general public (including non-resident users) must be available within a reasonable walking distance on free or reasonable terms. Public transportation may substitute for, or compliment, local parking.

Street parking may only be used if it will accommodate existing and anticipated demands.

c. Federal aid to private shores owned by beach clubs and hotels is not compatible with the law if the beaches are limited to use by members or paying guests.

d. Reasonable public access must be furnished to comply with the planned recreational use of the area.

e. Publicly owned beaches which are limited to use by residents of the community are not considered to be open to the general public and cannot be considered for Federal involvement.

187. **Environmental Criteria.** Appropriate measures must be taken to ensure that any resulting projects are consistent with local, regional, and State plans, and that necessary permits and approvals are likely to be issued by the regulatory agencies. The following environmental and social well-being criteria were considered in the formulation of alternative plans.

a. Consideration should be given to public health, safety, and social well-being, including possible loss of life.

b. Wherever possible, provide an aesthetically balanced and consistent appearance.

c. Avoid detrimental and social effects, specifically eliminating or minimizing the following where applicable:

* Air, noise, and water pollution.
* Destruction or disruption of man made and natural resources, aesthetic and cultural values, community cohesion, and the availability of public facilities and services.
* Adverse effects upon employment as well as the tax base and property values.
* Displacement of people, businesses and livelihoods.
* Disruption of normal and anticipated community and regional growth.

d. Maintain, preserve, and where possible and applicable, restore the following in the study area:

* Water quality.
* The beach and dune system together with its attendant fauna and flora.

* Wetlands, if any.
* Sand as a geological resource.
* Commercially important aquatic species and their habitats.
* Nesting sites for colonial nesting birds.

CYCLE 1 - INITIAL SCREENING OF MEASURES

188. Alternative measures considered for implementation in the study area are classified as nonstructural and structural. Non structural measures are those measures which control or regulate the use of land and buildings such that damages to property are reduced or eliminated. No attempt is made to reduce, divert, or otherwise control the level of erosion. Structural measures are generally those which act to block or otherwise interfere with erosive coastal processes or which restore or nourish beaches to compensate for erosion.

189. Measures were evaluated individually and in combination on the basis of the suitability, applicability, and merit in meeting the specific objectives of the study.

190. The alternative measures considered are as follows:

a. Nonstructural
   * No Federal action
   * Permanent Evacuation

b. Structural
   * Berm Restoration
   * Berm Restoration with Dune
   * Groin Field (with Berm Restoration)
   * Offshore Detached Breakwater (with Berm Restoration)
   * Perched Beach
   * Seawall
   * Seawall with Berm Restoration

191. The initial screening was done based on engineering experience within the Philadelphia District. The following paragraphs contain the objectives and evaluation of each of the alternatives listed above.

192. **No Federal Action.** The no action alternative involves no Federal measures to provide erosion control, recreational beach, or storm damage protection to structures landward of the bayfront. The State of Delaware has placed beachfills in the past on an as-needed basis, and has expressed its intent to continue this action if a Federal project is not implemented. However, even with the State's efforts to maintain the current shoreline, the without project

analysis demonstrates that Broadkill Beach will incur significant damages (Table 36). This alternative would not check the continuing erosion of the beach, nor would it prevent property from being subjected to high storm damages from beach recession, flooding, and wave attack. This plan fails to meet the objectives of the study. Therefore, this alternative will not be considered in Cycle 2.

193. **Permanent Evacuation**. Permanent evacuation of existing development areas subject to inundation involves the acquisition of lands and structures either by purchase or through the exercise of powers of eminent domain, if necessary. Following this action, all commercial and industrial developments and residential property in areas subject to erosion are either demolished or relocated to another site. Roads, railroads, water supply facilities, electric power, telephone and sewerage facilities would also need to be relocated. Lands acquired in this manner could be used for undeveloped parks, or other purposes, that would not result in material damage from erosion. However, Broadkill Beach has been developed steadily over the years, and this development is expected to continue until the presently available lots are occupied. Development inland is limited by the Primehook National Wildlife Refuge, which lies to the west of Broadkill Beach. Since the majority of homes lie along the bayfront, the community is more vulnerable to damages from relatively low to average strength storms which occur more frequently. It is estimated that 120 structures (28 percent of the structures in Broadkill Beach) will be damaged at a 20-year storm event. Relocating all or only the most vulnerable structures in Broadkill Beach, along with utilities and infrastructure, to another site would be prohibitively expensive. Therefore, this alternative will not be considered in Cycle 2.

194. **Berm Restoration**. This alternative involves the placement of sand directly onto the eroded beach. Usually, the sand is pumped onto the existing shore using a dredge and an offshore borrow source. An appropriate design uses borrow material that has similar properties to the existing beach sand. In addition, the restored beach is graded to a specific design elevation and width to provide the desired level of storm protection. This alternative requires renourishment on a periodic basis to maintain the design berm width and elevation. Berm restoration has a relatively low cost and is technically feasible to address the erosion problem. In addition, the beachfill project which was implemented in the area during the 1970's functioned well. For these reasons, this alternative will be considered further in Cycle 2.

195. **Berm Restoration with Dune**. This alternative provides the berm restoration described above with additional beachfill material to create a dune at a specific elevation and width. The dune will provide storm surge protection in addition to the erosion protection. The berm restoration and dune meets the study objectives, is technically feasible and has a relatively low cost. Therefore, this alternative will be considered further in Cycle 2.

196. **Groin Field with Berm Restoration and Dune**. This alternative provides the berm restoration and dune described above with a groin field along the bayfront of Broadkill Beach. Groins are structures built perpendicular to the shoreline that extend from the upper beach

face into the surf zone. In many instances, groins are made up of a timber bulkhead type structure at the landward end and a rubble mound stone structure at the outer end extending into the water. A properly designed groin field will reduce erosion by trapping some of the littoral drift, thereby reducing the need for renourishment. However, a groin field built on an eroded beachface will not necessarily provide adequate storm surge protection, unless it is combined with a properly designed beach restoration with dune. Because this alternative meets the study objectives, is technically feasible and has a relatively low cost, it will be considered further in Cycle 2.

197. **Offshore Detached Breakwater with Berm Restoration and Dune**. A breakwater is an offshore structure which reduces the wave energy impacting the beaches landward. The reduced wave energy reduces beach erosion. Breakwaters have been constructed using a variety of materials. Concrete filled nylon bags were used in Kitts Hummock as part of the Section 54 Program. However, the structure was determined to be ineffective after the bags deteriorated and the structure settled. Sand filled bags have also been considered. However, there is the potential for the bags to topple over during a storm. A series of rubble mound breakwaters is more appropriate for the Broadkill Beach area. Constructing breakwaters at open ocean coasts can be difficult, requiring additional equipment which increases costs. However, the lower energy environment and relatively shallow profile of the Delaware Bay coast can make breakwater construction less costly. The berm restoration with dune described above provides the needed storm protection in eroded areas and maintains the littoral drift. Because this alternative meets the study objectives, has a moderate cost, and is technically feasible, it will be considered further in Cycle 2.

198. **Perched Beach with Berm Restoration and Dune**. This alternative provides the berm restoration with dune described above with a perched beach. The perched beach consists of a submerged structure or sill, usually rubble mound, which is used to trap sediment carried by incoming waves. This eliminates the outer part of the beach profile near its closure with the ocean bottom included in the berm restoration alternative. A perched beach was installed in Slaughter Beach, Delaware as part of the Section 54 Program but it was ineffective. The sill did not fill with sand as expected due to the lower wave energy and limited sediment transport of the Delaware Bay. In addition, the angled swell scours in front of and behind the sill, resulting in frequent maintenance. Because the perched beach is unsuitable for the Delaware Bay environment, and the expense of high maintenance, this alternative will not be considered in Cycle 2.

199. **Seawall**. This alternative consists of the construction of a "Galveston type" seawall with a top elevation of +20 NGVD placed along the entire 15,200 foot length of the study area, replacing all of the existing dunes. The structure includes fronting toe scour stone protection, pile supports, and underlying sheeting to reduce underseepage. This alternative would provide storm damage protection consistent with other structural alternatives. However, the relative cost for such a project would be prohibitively high. For this reason, this alternative will not be considered in Cycle 2.

200. **Seawall with Berm Restoration**. This alternative consists of the berm restoration plan with the addition of the "Galveston type" seawall, both described above. This alternative is eliminated from Cycle 2 for the same reasons that the seawall alternative above has been eliminated.

201. The Cycle 1 screening process is summarized in Table 37.

Table 37
Cycle 1 - Initial Alternative Screening

Alternative	**Meet Objectives? (Y/N)**	**Technical Feasibility**	**Consider for Cycle 2? (Y/N)**
No Federal Action	N	N/A	N
Permanent Evacuation	Y	N	N
Berm Restoration	Partial - provides erosion protection but no storm damage protection.	Y	Y
Berm Restoration with Dune	Y	Y	Y
Groin Field with Berm Restoration and Dune	Y	Y	Y
Offshore Detached Breakwater with Berm Restoration and Dune	Y	Y	Y
Perched Beach with Berm Restoration and Dune	N	N	N
Seawall	Y	Y	N
Seawall with Berm Restoration	Y	Y	N

CYCLE 2 - EVALUATION OF ALTERNATIVES

202. The objective of Cycle 2 screening is to evaluate and compare alternatives resulting from Cycle 1 screening. Evaluations are based on environmental, socio-economic, and institutional factors as well as preliminary cost comparisons. In each case, moderate scale plans were evaluated using typical cross-sections as a basis for assessing preliminary costs per linear foot of shoreline, and were generalized as follows:

a. Low Cost - Less than $100/lf
b. Moderate Cost - $100 to $200/lf
c. High Cost - Greater than $200/lf

203. **Berm Restoration**. This alternative involves the placement of sand from an offshore source over a length of approximately 15,000 feet. The sand was assumed to be borrowed from one of two possible offshore sources (see Geotechnical Evaluation and Figure 13). Table 38 shows that this alternative will be considered further in Cycle 3.

204. **Berm Restoration with Dune**. This alternative combines the beachfill alternative described above with dunefill. Lengths of placement and sand source location are the same as above. Table 38 shows that this alternative will be considered further in Cycle 3.

205. **Groin Field with Berm Restoration and Dune**. New groins would be constructed of timber bulkhead at the landward end and quarry stone at the seaward end. A beachfill and dune was also included in this alternative. Table 38 shows that this alternative will be considered further in Cycle 3.

206. **Offshore Detached Breakwater with Berm Restoration and Dune**. This alternative includes the construction of rubble mound breakwater segments along the study area. The top elevation of the breakwater was assumed to coincide with the mean high tide level. A beachfill and dune was also included. Table 38 shows that this alternative will not be considered in Cycle 3.

Table 38
Cycle 2 Evaluation of Alternatives

Description	Environmental Considerations	Socio-Economic Considerations	Institutional Considerations	Relative Cost	Further Consideration in Cycle 3?	Remarks
Berm Restoration	Temporary destruction of benthic habitat in borrow area. A minor increase in turbidity in construction area.	Provides useable beach area and reduces erosion damages.	State preferred plan.	Low	Y	Adverse environmental impacts may be minimized through coordination with environmental agencies
Berm Restoration with Dune	same as above with the addition of dune habitat.	Same as above but dune may obstruct some bayfront view of the Delaware bay. Provides storm protection in addition to erosion protection.	State supports further study.	Low	Y	Can provide aesthetic value by planting of dune grass.
Groin Field with Berm Restoration and Dune	In addition to above, groins may disrupt benthic environment. However they may provide habitat for sessile organisms.	In addition to above, aesthetics would be reduced.	Same as above.	Low to Medium	Y	Costs of groins may be offset by the reduction in periodic nourishment requirements.
Offshore Detached Breakwater with Berm Restoration and Dune	Same as berm restoration and dune.	Same as berm restoration and dune with the addition of possible navigation hazard.	Navigation hazard is a concern of the State.	High	N	Warning bouys may be placed at segment locations.

RECOMMENDED PLANS FOR CYCLE 3 ANALYSIS

207. The Cycle 1 and 2 screening processes eliminated most of the measures considered in this interim study. The alternative projects recommended for further study in Cycle 3 for Broadkill Beach include:

a. Berm Restoration
b. Berm Restoration and Dune
c. Groins with Berm Restoration and Dune

208. In Cycle 3, the projects listed above will be formulated and optimized to develop the NED plan for the area between DNREC stations N33+00 near California Avenue and S76+00 near the remains of the old jetty. As previously described in the Shoreline Conditions section, this area has been the focus of beachfills in the past by the State of Delaware. The Cycle 3 evaluation will examine berm width, dune height, and area of sand placement. In addition, groin spacing, length and elevation will be investigated as well as the effect of these structures on periodic nourishment requirements.

BORROW AREA ANALYSIS

209. **Borrow Area Suitability Analysis**. Ideally, borrow material should be the same size, or slightly coarser than the native material on the beach to be nourished. If the borrow material has a significantly smaller grain size, the profile will be out of equilibrium with the local wave and current environment, and will therefore be quickly eroded either offshore or alongshore. This analysis compares the native sediment characteristics to the borrow material characteristics. The analysis was completed using the methodology put forth in the Shore Protection Manual. Overfill factors (Ra) and renourishment factors (Rj) were calculated for each potential borrow area.

210. The overfill factor estimates the volume of initial fill material needed to produce one cubic yard of stable beach material after equilibrium (when the beachfill and native beach materials are compatible) is reached. Consequently, overfill factors are greater or equal to one. For example, an overfill ratio of 1.2 would indicate that 1.2 cubic yards of borrow material would be required to produce 1.0 cubic yards of stable beach material. This technique assumes that both the native and composite borrow material distributions are nearly log-normal. The renourishment factor is a measure of the stability of the placed borrow material relative to the native beach sand. Desirable values of the renourishment factor are those less than or equal to one. For example, a renourishment factor of 0.33 would mean that renourishment using the borrow material would be required one third as often as renourishment using the same type of material that is currently on the beach.

211. Vibracores located in the vicinity of the selected borrow areas, which were done in conjunction with the subbottom profiling effort, indicate that their overfill factors are 1.4. It is estimated that a total quantity of 7.3 million cubic yards of suitable beach building material lie in the two borrow areas previously described in the Existing Conditions section (Figure 13).

CYCLE 3 - OPTIMIZATION OF THE SELECTED ALTERNATIVE SOLUTIONS

212. The initial alternative evaluations are focused on the berm restoration and berm restoration with dune plans with an assumed nourishment cycle of 3 years. Upon selection of the NED plan, consideration is given to the placement of groins and periodic nourishment requirements.

213. **Design Template Parameters**. The alternative of beach nourishment requires optimization of the berm width and the dune height. The methodology followed to optimize these features is accomplished by varying parameters between a set of boundary conditions established at the beginning of the analysis. Design of the beach restoration alternatives was done in accordance with CETN-II-5, the Shore Protection Manual, and accepted engineering practice.

214. Design Baseline. A design baseline was established along the length of the study area in order to determine the alignment of the proposed beach restoration alternatives. In Broadkill Beach, the design baseline was located to follow as close as possible to the landward edge of the existing dune line or private property line (Figure 15). For each option analyzed, the seaward edge of the proposed berm was located by offsetting the beach width from the design line. For those options that included a dune, the design baseline was used to locate the toe of the dune.

215. Berm Elevation. Design berm heights for each alternative have an elevation set at the natural berm elevation as determined by historical profiles. The average berm elevation for Broadkill Beach is +7 to +8 ft. NGVD. Therefore, a berm elevation of +8 ft. NGVD was used to analyze all alternatives.

216. Berm Width. The minimum design berm width considered is approximately the average width of the without project condition along the length of the study area. This design alternative requires beachfill for some locations to establish a consistent berm height, and includes advance nourishment along the entire area to ensure a constant design template between nourishment cycles. The minimum berm width is 50 ft.

217. An interval between berm widths is chosen so that the optimum berm width can more easily be identified. This interval is set wide enough to discern significant differences in costs and benefits between alternatives, but not so great that the NED plan cannot be accurately determined. In order to satisfy these criteria, a 50 ft. interval is used.

218. Beachfill Slope. The slope of the proposed beachfill was determined to be 15H:1V down to the Mean Low Water elevation. This slope matches closely with the existing beaches in the study area. Below Mean Low Water, the slope follows that of the existing profile down to the elevation of closure.

219. Beachfill Taper. All beachfill alternatives include a taper at each project terminus to transition the constructed project into the existing beaches outside the project area. For the optimization analysis, a 1000 ft. taper was used at the northern and southern limits of the project area to terminate the beachfill options.

220. Dune Height and Width. Dune elevations in the vicinity of Broadkill Beach vary from +12 ft. to +15 ft. NGVD. For the optimization analysis, dunes with top elevations of +14 ft., +16 ft., and +18 ft. NGVD were used. Dune top width was 25 ft. for all alternatives. The side slopes chosen for the dune were 5H:1V, which is the average for naturally occurring dunes in the area.

221. Dune Alignment. The landward toe of the dune was located as close as possible to the design baseline, at the landward edge of the berm. Where feasible, the proposed dunes tie into existing dunes to take advantage of conditions that reduce required quantities.

222. Beachfill Quantities. To determine quantities for each alternative, the proposed design templates were drawn on the existing beach survey cross sections. Average end area methods were used to compute volumes. Initial construction volumes presented in this report include quantities required to attain the design profile and advanced periodic nourishment.

223. Periodic Nourishment. In order to maintain the design profile, an advanced nourishment fill is placed in addition to the initial design beachfill. The nourishment volume is sacrificial and protects the design beachfill. Nourishment quantities include an overfill factor of 1.4 (previously discussed in the Borrow Area Investigation).

224. **Preliminary Screening of Beach Restoration Alternatives**. Based on the boundary condition assumptions discussed above, 12 combinations of berm widths and dune heights was generated. A preliminary evaluation was performed to reduce the total number of hydraulic (SBEACH) and economic model runs utilized during the optimization to identify the NED plan.

225. Some berm and dune alternatives were quickly identified as virtually non-constructible considering the footprint requirements of the various dune options and toe protection required for dune stability. For example, the smallest dune (at +14 NGVD top elevation) requires a base width of 85 feet which would significantly exceed the 50 foot berm (at +8 NGVD). This eliminated all dune options on the 50 foot berm. In addition, placing a dune with a +18 NGVD top elevation on the 100 foot berm is not feasible because the dune base requires 125 feet. As a result, a total of 4 combinations were eliminated from the matrix. The remaining alternatives were then subjected to a screening consisting of limited model runs and quantity

calculations. This initial screening was used to assess the performance of the alternatives in the study area, and provide a basis for progression to the full analysis of benefits and costs.

226. The results of the initial screening eliminated the berm-only alternatives from the matrix. The majority of the Broadkill Beach study area contains dunes which have an average top elevation of +12 ft NGVD (Table 14). The without project analysis shows that, even with an average elevation of +12 NGVD, significant damages occur due to erosion and inundation. Alternatives which include a dune with a higher top elevation prevented considerably more damages than berm-only alternatives. This finding would point to the conclusion that a much larger amount of fill is required for a berm-only alternative to achieve the same level of damage reduction provided by a higher dune. As a result, three alternatives were eliminated from further consideration. Table 39 summarizes the full matrix of alternatives and the recommendations of the preliminary screening.

Table 39
Matrix of Initial Cycle 3 Alternatives

Dune Elevation (Feet NGVD)	Berm Width (Feet)		
	50	100	150
0	E	E	E
+14	X	R	R
+16	X	R	R
+18	X	X	R

E = Eliminated in the preliminary screening analysis
R = Recommended for further analysis
X = Inappropriate design template

227. Based on this initial screening, 5 alternatives remained in the matrix and were recommended for further analysis. These alternatives are listed in Table 40.

Table 40
Alternatives Recommended for Optimization

Alternative	Dune Elevation (Feet NGVD)	Berm Width (Feet)
Plan 1	+ 14	100
Plan 2	+ 16	100
Plan 3	+ 14	150
Plan 4	+ 16	150
Plan 5	+ 18	150

OPTIMIZATION OF ALTERNATIVE PLANS

228. **General**. Benefits and costs for Broadkill Beach were developed for the alternative plans discussed above to optimize the NED plan in the study area. This was accomplished using the same numerical modeling techniques utilized in the without-project analysis, coupled with engineering and technical assessments to interpret model results as applied to the various alternatives. Reduced damages based on the predicted reduction in storm impacts due to the with-project alternatives, were compared to the without-project results to generate project benefits. Costs for each alternative were estimated based on standard construction practices and District experience in the construction of beach nourishment projects.

229. **Storm Impacts**. The with-project conditions are the conditions that are expected based on the predicted impacts of storm events on the various project alternatives. The periodic nourishment associated with the project is designed to ensure the integrity of the project design. In the case of beachfill, this ensures the project design cross-section will be maintained and the elimination of shoreline recession due to long-term erosion. However, coastal processes will continue to impact the shoreline along the project area. Storm-induced erosion, wave attack and inundation were evaluated for the with-project conditions using the same methodologies utilized in the without-project analyses. The following sections describe the coastal processes which were used to estimate the with-project damages.

230. Storm Induced Erosion. The numerical model SBEACH was applied to predict storm-induced erosion for the with-project conditions for the study area. All SBEACH input variables were identical to the without-project runs except the input profiles were modified to include the alternative beachfill designs. As in the without-project condition, storm events

from 5- to 500-year frequency were analyzed on the with-project alternatives. Model results were reviewed and analyzed for reasonability as applied to the with-project alternatives. A summary of the with-project erosion results is presented in Appendix A, Section 2.

231. Storm Inundation. The post-storm recession profiles generated by SBEACH were used to analyze flooding and wave/run-up attack using the same methodology described in the without project analysis. The wave height frequency and stage-frequency data utilized to assess the alternative designs was identical to that used for the without-project conditions. Appendix A, Section 2 lists the 3 foot damaging wave/run-up impact zones for the beachfill alternatives in the study area for the 5- through 500-year event as well as the total water elevation profile. Similar inundation profiles were computed in order to determine the total water level across the beach profile and into the community.

232. **Periodic Nourishment** In order to maintain the integrity of the design beachfill alternatives, beachfill nourishment must be included in the project design. If periodic nourishment is not performed throughout the life of the project, longshore and cross shore sediment transport mechanisms will act to erode the design beach. This erosion will reduce the protection from storm damage afforded by the project. The nourishment quantities are considered sacrificial material which acts to protect the design fill volume. Various coastal processes were analyzed to develop an estimate of the required annual nourishment fill volumes.

233. The nourishment rates for design were developed considering long term historic erosion losses using shoreline recession rates developed for the sediment budget, volumetric analysis of recent beach fills and profiles, beachfill losses due to the predicted rate of sea level rise, and losses due to storm induced erosion. The results of these analyses were compared and the volumetric requirements were combined to obtain the total nourishment needs for each of the alternatives.

234. Sea Level Rise. Using the current sea level rise rate of 0.0102 feet per year, as described earlier in this report, and the Bruun method, the distance of shoreline retreat over the 50 year project life was determined. This retreat rate was added to the longterm erosion losses to develop the project nourishment estimates.

235. Long Term Losses. The GENESIS model developed in the without project phase of study was refined and calibrated to estimate long-term shoreline changes within the project area. The model shows generally good agreement throughout the proposed project reach. Using the GENESIS model to estimate longterm erosion rates at the Broadkill Beach produced the same results for existing conditions as those derived from analysis of historic beach profiles. It has been concluded that the GENESIS model can be a useful tool for evaluating shoreline change under various project conditions. The model calibration and simulation procedures are described in Appendix A, Section 2 .

236. To estimate the required nourishment quantities for various intervals due to long term shoreline change, the GENESIS model was used to predict the shoreline position out to 7 years from the project base year. The initial shoreline within the project limits is either 100 or 150 feet from the project design line. The beach fill is tapered at both ends of the project to the predicted 2001 shoreline. As the duration of the nourishment cycle is increased, from 2 to 7 years, the incremental quantity predicted by the model plus sea level rise requirements lessens. This method of analysis will yield a result based upon the largest storm which occurred during the wave record used.

237. However, this analysis does not take into account the evident risk of a large storm or storms occurring between nourishments nor the risk of a higher wave energy year occurring outside of the representative envelope in the current modeling. These risks grow larger with every year the nourishment cycle is increased. At the present time, there is no generally accepted method to quantify this risk and apply it to the economic optimization of nourishment cycle, but common sense dictates that the increase in this risk will diminish returns as the nourishment interval is lengthened.

238. Nourishment Rates. In order to account for the inherent risk involved with extending replenishment intervals, beachfill losses due to storm-induced erosion for various nourishment cycle time periods are considered. It was assumed that the nourishment volume required for storm-induced erosion must be calculated to withstand the losses for the event which has a 50% chance of being exceeded during each nourishment cycle, from 2 to 7 years.
To develop the total project nourishment volume required for each cycle, the volumetric losses from the three processes, losses due to long term erosion, losses due to the predicted rate of sea level rise, and losses due to storm induced erosion were combined.

239. **Major Rehabilitation**. Major rehabilitation quantities were developed in accordance with ER 1110-2-1407 to identify erosional losses from the project due to high intensity(low frequency) storm events. The nourishment rates developed for the project alternatives include losses due to storms that have occurred within the analysis period. Storms of approximately 50 year return period and more frequent are encompassed in those rates. Major rehabilitation losses are computed as the losses that would occur from the 50% risk event over the project life. The event having a 50% risk over the 50 year economic project life is 1.37%. The method used to determine major rehabilitation quantities is described in detail in Appendix A, Section 2. It is estimated that 210,000 cubic yards of material would be required to perform major rehabilitation in response to the 50% risk event over the project life.

240. **Economic Evaluation of Alternative Plans**. Damages for the with project alternatives were calculated using the same methodologies and databases previously detailed for the without project conditions. The benefits for any given project are the difference between the without project and with project damages.

241. Reduced Maintenance Benefits. In addition to storm damage reduction benefits, reduced maintenance benefits accrue under the with-project scenario. As discussed in the without project analysis, the State of Delaware has provided beachfill material to Broadkill Beach on an as-needed basis. This expenditure will not accrue under the with project condition. The estimate for local cost forgone for beach maintenance in Broadkill Beach is $573,000 annually.

242. Economic Optimization. Optimization of the alternatives is based on the priority benefit category of storm damage reduction (including reduced maintenance) indexed to an October 1995 price level. A periodic nourishment cycle of 3 years was chosen to screen the alternatives. The initial construction and periodic nourishment costs for the with project alternatives are presented in Table 41. Initial construction and periodic nourishment costs for the with-project alternatives are annualized for comparison to the average annual benefits for specific project alternatives. Initial construction and periodic nourishment costs are annualized over a 50 year project life at 7.75%. The average annual costs are subtracted from average annual benefits to calculate net benefits. The NED plan is the plan which maximizes net benefits. The final table for the selected plan applied the FY 96 discount rate of 7.625%.

Table 41
Alternative Project Costs

INITIAL COSTS		
Option (Dune Elevation and Berm Width)	Total Quantity + Adv. Nourishment (cubic yards)	Total Cost
+14' + 100'	854,000	$6,483,000
+16' + 100'	943,000	$6,820,000
+14' + 150'	1,183,000	$7,567,000
+16' + 150'	1,271,000	$7,889,000
+18' + 150'	1,354,000	$8,227,000
PERIODIC NOURISHMENT COSTS (3 YR CYCLE)		
Option (Berm Width)	Quantity (cubic yards)	Total Cost
100'	235,200	$2,052,000
150'	247,800	$2,141,000

243. A summary of the reduction in with-project storm damages for each project alternative is listed in Table 42. Table 43 identifies the optimized plan for Broadkill Beach including average annual benefits and costs, net benefits and the benefit-cost ratio. Plan 2 which provides a 100 ft. berm and dune with a top elevation of +16 ft. NGVD is the optimal plan.

Table 42
Storm Damage Reduction Benefits by Alternative

Alternative Plan	Berm Width (ft)	Dune Elevation (ft NGVD)	Without Project Storm Damages	With Project Storm Damages	Storm Damage Reduction Benefits	Percent Reduced
1	100	14	$1,898,000	$380,000	$1,518,000	80
2	100	16	$1,898,000	$309,000	$1,589,000	84
3	150	14	$1,898,000	$271,000	$1,627,000	86
4	150	16	$1,898,000	$259,000	$1,639,000	86
5	150	18	$1,898,000	$243,000	$1,655,000	87

Table 43
Benefit/Cost Matrix
($000's)

Dune Elevation (ft. NGVD)		100' Berm	150' Berm
		Alt. 1	Alt. 3
14	Average Annual Benefits Average Annual Costs Benefit-Cost Ratio Net Benefits	1,518 1,146 1.32 372	1,627 1,259 1.29 367
		Alt. 2	Alt. 4
16	Average Annual Benefits Average Annual Costs Benefit-Cost Ratio Net Benefits	**1,589** **1,173** **1.35** **416**	1,639 1,285 1.28 354
			Alt. 5
18	Average Annual Benefits Average Annual Costs Benefit-Cost Ratio Net Benefits		1,655 1,312 1.26 343

244. **Periodic Nourislunent Cycle**. Once the selected plan was detennined, an attempt was made to economically optimize the periodic nourishment cycle. Required quantities were obtained for 3 to 7-year nourishment cycles and are shown in Table 44. Initial construction and periodic nourishment costs were computed for the cycles. Table 45 shows the economic comparison of the nourishment cycles including average annual costs, average annual benefits, net benefits and BCR. The 5-year cycle is identified as the optimal nourishment cycle. This interval of nourishment is also in agreement with the historical beachfill frequency at Broadkill Beach.

Table 44
Periodic Nourishment Quantities - 3 Through 7 Year Cycles
(Cubic Yards)

Nourishment Cycle (Years)	Initial Construction	Periodic Nourishment
3	898,000	190,400
4	947,000	239,400
5	1,066,000	358,400
6	1,255,000	547,400
7	1,514,000	806,400

Table 45
Benefit-Cost Comparison - 3 Through 7 Year Cycles
(Oct 1995 Price Level, 7.75% Discount Rate)

Cycle (Years)	Avg. Annual Benefits	Avg. Annual Costs	Net Benefits	BCR
3	$1,589,000	$1,099,00	$642,000	1.58
4	$1,589,000	$1,053,000	$688,000	1.65
5	$1,589,000	$1,046,000	$695,000	1.66
6	$1,589,000	$1,174,000	$567,000	1.48
7	$1,589,000	$1,320,000	$421,00	1.32

245. **Groin Analysis.** Following the selection of the optimized beachfill alternative and appropriate nourishment cycle, groins were analyzed to determine whether the cost to construct them is offset by the savings in periodic nourishment reduction. Reduced nourishment rates were estimated for a groin field consisting of 16 timber groins spaced 720 feet apart (Appendix A, Section 2).

246. The annualized cost of the proposed groin field is $372,000. The annualized savings (benefits) from reduced periodic nourishment associated with construction of the groin field is $159,000. Therefore, the placement of a groin field in combination with Plan 2 is not justified.

247. **Project Design Line.** Consideration was also given to structures which may be impacted by the location of the design line. During a site visit, two adjacent structures located near Polk Avenue appeared to lie further bayward in relation to other bayfront structures in the community. If the design baseline only followed the general location of the existing dune line, its location would have been through the two structures. The design baseline was relocated bayward of these structures in order to avoid potentially higher real estate costs resulting from property acquisition. An analysis was performed to ensure that the cost associated with the relocation (such as potentially higher beachfill quantities) offset the cost to acquire the two properties.

248. The adjustment of the design line required an additional 48,000 cubic yards of beachfill material to be placed. The addition of this quantity resulted in a project cost increase of $196,000. The costs associated with the acquisition of the two properties is $357,000. These results confirm that the placement of the design line is cost effective.

249. **Project Length.** As described earlier, the focus area for the optimization analysis was conservatively defined by the community's beachfill history. During the optimization analysis, the Sponsor requested that the District examine extending the project southward of DNREC station S76+00. It was also requested that the taper should not extend into Beach Plum Island State Park. The area south of station S76+00 has not received beachfill material in the past, and was much less developed than the northern and central areas of Broadkill Beach. However, substantial development has occurred in recent years. In order to provide protection to as much of the community as possible, the project length was extended approximately 1,500 feet. The southern taper itself was examined to establish the minimum reasonable length. The southern taper was then reduced to 500 feet, with the taper ending at the boundary between Broadkill Beach and Beach Plum Island State Park. An analysis was performed on the optimized plan and nourishment cycle for a total project length of approximately 13,100 feet (excluding tapers). Table 46 compares the average annual benefits, average annual costs, and net benefits of both plans at the updated discount rate of 7.625%. The plan suggested by the State has higher total net benefits, and is therefore the NED plan.

Table 46
Benefit Cost Comparison - Selected Plan and State Plan
(Oct 1995 Price Level, 7.625% Discount Rate)

Plan	Average Annual Benefits	Average Annual Costs	Net Benefits	BCR
Selected Plan (13,500 ft total length)	$1,592,000	$1,039,000	$533,000	1.53
State Plan (14,600 ft total length)	$1,741,000	$1,136,000	$605,000	1.53

SELECTED PLAN

250. **Identification of the NED Plan**. The National Economic Development (NED) plan is defined as that plan which maximizes beneficial contributions to the Nation while meeting planning objectives. The NED plan for Broadkill Beach is beachfill with a berm width of 100 ft and a dune with an elevation of +16 ft NGVD.

251. **Description of the Selected Plan**. Total quantities for the selected plan are presented in Table 47. Figures 25 and 26 show the limits of the selected plan including taper areas, and a typical cross-section is presented in Figure 27.

* A berm with an elevation of +8 ft NGVD extending seaward 100 ft. from the design line. The beachfill extends from Alaska Avenue southward for 13,100 linear feet. Tapers of 1,000 feet and 500 feet, respectively, extend from the northern and southern limits of the main project bring the total project length to 14,600 linear feet.

* On top of the berm lies a dune with a top elevation of +16 ft NGVD and a top width of 25 ft.

* A total initial volume of 1,305,000 cubic yards of sand fill will be placed along the area. This fill volume includes initial design fill requirements and advanced nourishment.

* Periodic nourishment of 358,400 cubic yards of sand fill will be placed every 5 years.

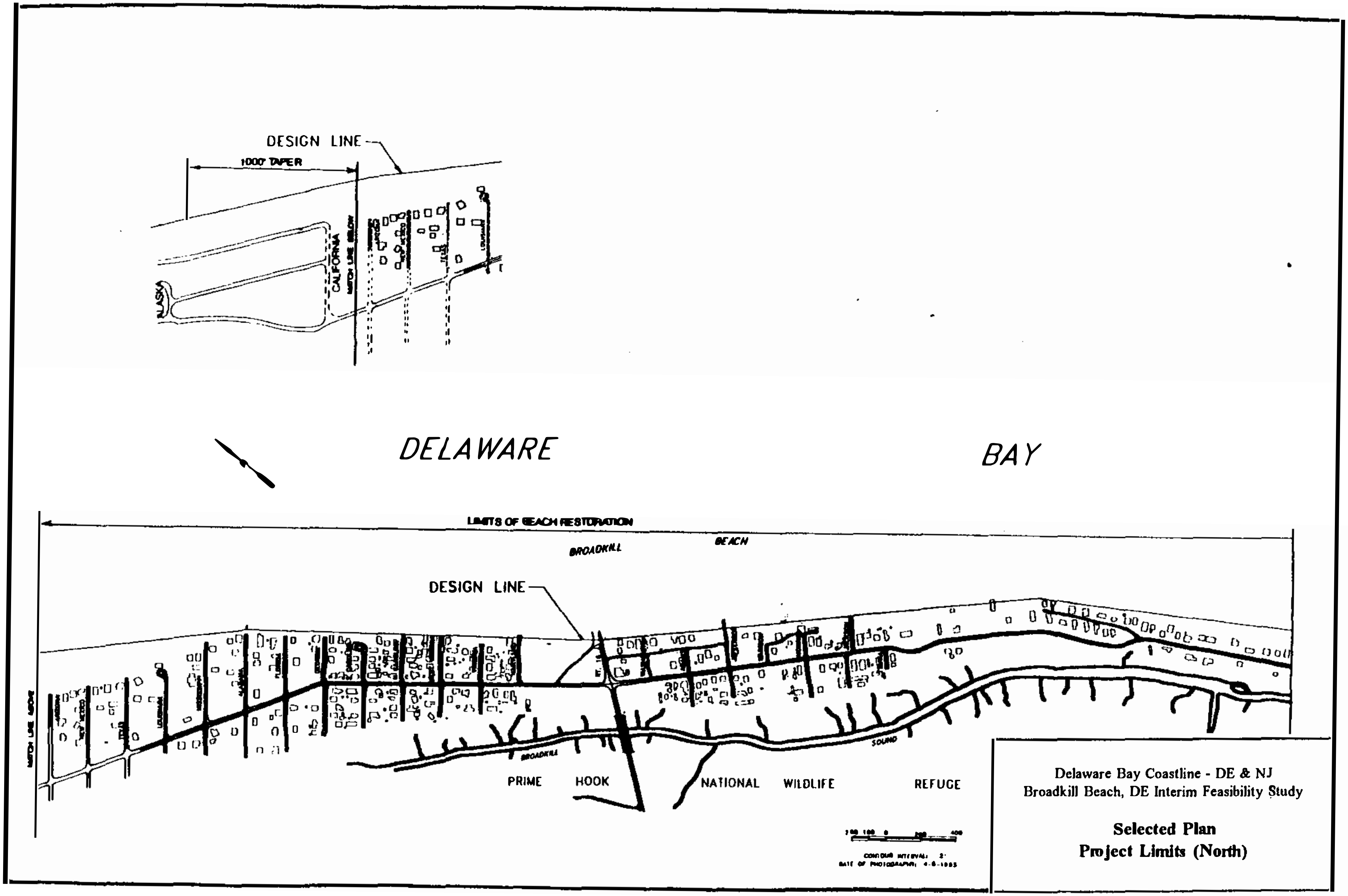
* Planting of 174,800 s.y.of dune grass and 21,800 l.f. of sand fence are included for dune stability.

* Vehicular access to the beach will be provided at Route 16 in the center of Broadkill Beach. Sand fence will be used to create a path 12 ft. wide along both sides of the dune at a skewed angle to the dune alignment. This would allow vehicles to climb along the side of the dune at a flatter slope than 5H:1V.

* Pedestrian access paths will be located at each street end in a similar fashion as the vehicular access. However, the access path will be smaller in width and at a somewhat steeper slope.

Table 47
Total Quantities for Selected Plan

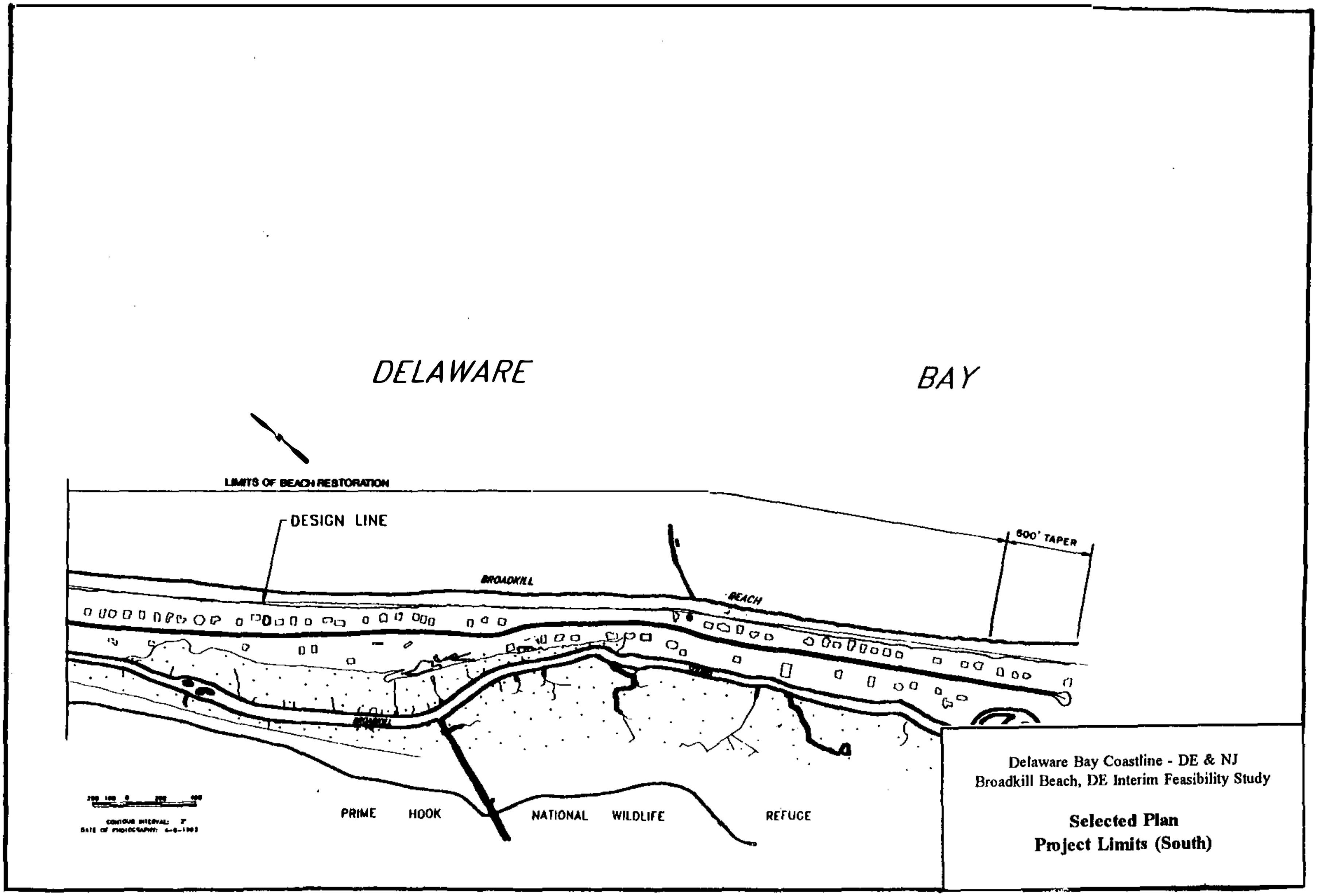
Feature	Quantity
Beachfill (c.y.)	
Berm	685,600
Dune	261,000
Advanced Nourishment	358,400
Total Initial Quantity	1,305,000
Periodic Nourishment (c.y.) 5-Year Cycle	358,400
Sand Fence (l.f.)	21,800
Dune Grass (s.y.)	174,800



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Selected Plan
Project Limits (North)

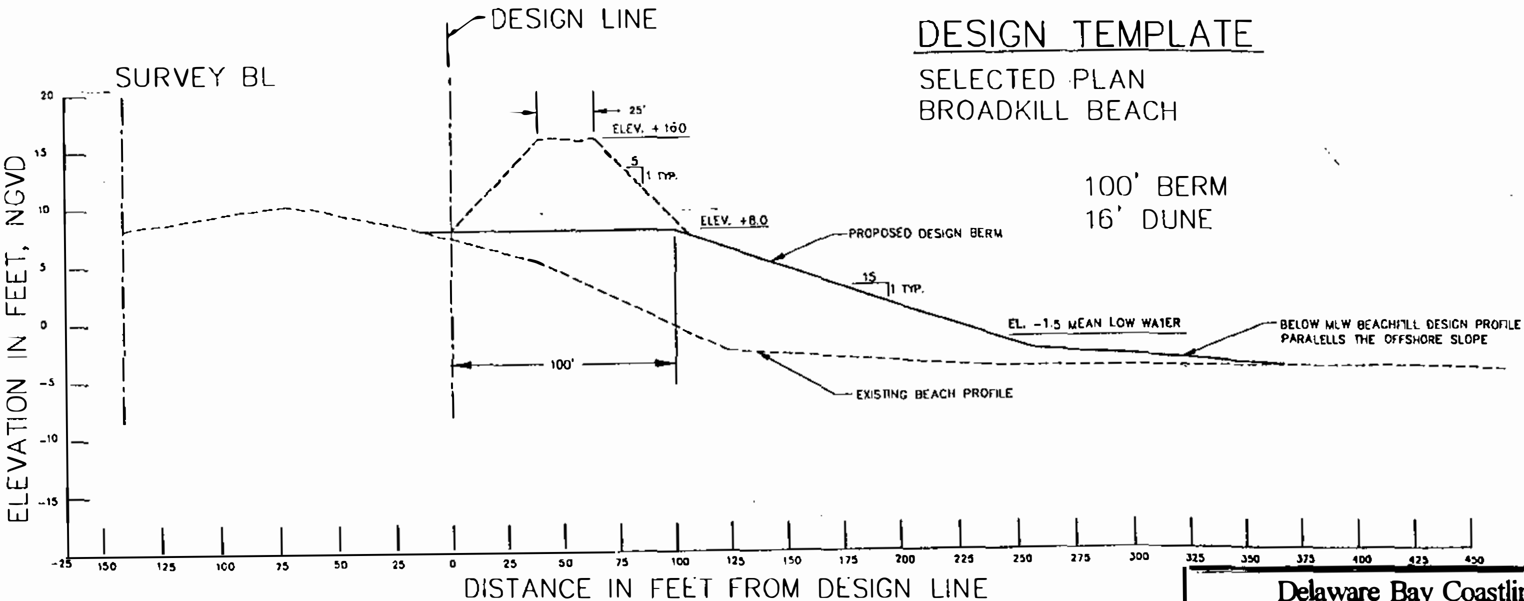
FIGURE 25



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Selected Plan
Project Limits (South)

FIGURE 26



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Typical Section of Selected Plan

FIGURE 27

252. **Beachfill Monitoring Plan**. The project monitoring plan will document beachfill performance and determine conditions within the borrow areas. Periodic assessments will assist in determining renourishment quantities. The program was developed in accordance with ER-1110-2-1004, ER-1110-2-1407, CETN-II-26, and the draft CETN dated 3/13/95 entitled "Recommended Base-level Physical Monitoring of Beach Fills". The following items are to be included in the project monitoring plan: Pre- and post-construction beach profile surveys, sediment sampling of beach and borrow areas, aerial photography, and tidal data collection. The field data collection will be followed up by lab and data analyses. The proposed monitoring program will begin at the initiation of pre-construction efforts and will continue throughout the project life. The monitoring program is further described in Appendix A, Section 2.

253. **NED Benefits Summary**. Table 48 presents a summary of the average annual benefits associated with the NED plan.

Table 48
Average Annual Benefits of NED Plan
(October 1995 Price Level)
7.625% Discount Rate

Benefit Category	Without Project Damages	With Project Damages	Benefits
Structures	$1,086,000	$292,000	$794,000
Improved Property	$314,000	$14,000	$300,000
Infrastructure	$28,000	$11,000	$27,000
Local Cost Forgone	$620,000	$0	$620,000
Total	$2,057,000	$317,000	$1,741,000

PROJECT IMPACTS

254. **Impacts to Environmental Resources.**

255. Impacts of Dredging. The primary impact of dredging the borrow area will be the removal of the existing benthic community through entrainment into the dredge. A secondary disturbance results from the increased turbidity and deposition of sediments on the benthic community adjacent to the borrow area. However, these impacts are only temporary, and recolonization of the borrow area is expected to occur within one year. The existing benthic community is adapted to dynamic conditions and is capable of rapidly recovering from the disturbance caused by dredging.

256. From June through November, Delaware's coastal waters may be inhabited by transient sea turtles, especially the loggerhead (Federally-listed threatened) or the Kemp's ridley (Federally-listed endangered). Coordination with the National Marine Fisheries Service (NMFS) in accordance with Section 7 of the Endangered Species Act has been undertaken on all Philadelphia District dredging projects that may pose an impact to Federally threatened or endangered species. Sea turtles have been known to be adversely impacted by dredging operations that utilize a hopper dredge. Shallow water depths in the Broadkill Beach project area preclude the use of a hopper dredge, thus the potential impacts to sea turtles will be minimized..

257. Impacts of Beachfill Placement. The initial effect of dredging and beachfill placement will be increased turbidity, resulting in the smothering and destruction of existing benthic organisms within the nearshore (littoral) zone. Beach nourishment may also temporarily inhibit the return of adult intertidal organisms from their overwintering refuges, reduce organism density on adjacent beaches, and inhibit pelagic larval recruitment. However, recovery of macrofauna is usually rapid after pumping operations cease, possibly occurring within one or two seasons when grain sizes are compatible with the existing beach. The present species inhabiting the beach are capable of surviving under adverse conditions, and most are able to temporarily migrate out of the impacted area.

258. The piping plover, which is state and Federally listed as a threatened species, is an inhabitant of Delaware's beaches. Although nesting sites have not been observed within the study area in recent years, the lack of human disturbance on Beach Plum Island to the south makes the study area suitable habitat. If a piping plover or nest is discovered within the project area prior to maintenance activities, coordination will be undertaken with the Delaware Department of Environmental Control, Division of Fish and Wildlife and the U.S. Fish & Wildlife Service. Protection measures for the piping plover may include establishing a buffer zone around the nest, and requiring that construction be conducted outside of the nesting period (1 April to 1 September).

259. **Impacts to Cultural Resources.** On the basis of the current project plan, the Corps is of the opinion that proposed dredging operations at borrow areas and fill placement along the shoreline and within adjacent nearshore underwater locations will have no adverse effect on significant cultural resources.

260. The remote sensing investigation of the borrow areas, previously described in the Existing Conditions section, identified one underwater target exhibiting shipwreck characteristics. Proposed sand borrowing activities would adversely impact this target location, which may represent a significant cultural resource. Therefore, in order to eliminate construction impacts at this location, the Philadelphia District proposes to completely avoid this target during sand borrowing operations by delineating a buffer of at least 200-feet around the target. Nearshore underwater project areas were not investigated for cultural resources. Remote sensing survey within the high-energy surf zone is dangerous and extremely difficult. The likelihood for intact and undisturbed cultural resources in such an unstable and shifting coastal environment is very minimal.

261. A low-tide pedestrian survey conducted along the shoreline did not identify any prehistoric or historic archaeological sites within the project boundaries. Proposed construction will have no impact on historic architectural resources, since buildings within the settlement of Broadkill Beach lie inland from the beach itself and outside the zone of impact.

262. The Philadelphia District coordinated Section 106 project review with the Delaware Historic Preservation Office (DESHPO). The draft cultural resources investigation report prepared by Cox and Hunter in November, 1994 was submitted to the DESHPO for review on January 4, 1995. Based on the results of this investigation and consultation with the DESHPO, the District found that the proposed project, as detailed in the Feasibility Report, will have no adverse effect on significant cultural resources. The DESHPO concurred with this finding in a letter dated September 10, 1996 (see Pertinent Correspondence, Appendix D).

263. **Hazardous, Toxic and Radiological Waste Assessment** In accordance with ER 1165-2-132 entitled Hazardous, Toxic and Radioactive Wastes (HTRW) Guidance for Civil Works Projects, dated 26 June, 1992, the Corps of Engineers is required to conduct investigations to determine the existence, nature and extent of hazardous, toxic and radioactive wastes within a project impact area. Hazardous, toxic and radioactive wastes are defined as any "hazardous substance" regulated under the Comprehensive Environmental Response, compensation and Liability Act (CERCLA), 42 U.S.C. 9601 et seq, as amended. Hazardous substances regulated under CERCLA include "hazardous wastes" under Section 3001 of the Resource Conservation and Recovery Act (RCRA), 42 U.S.C. 6921 et seq; "hazardous substances" identified under Section 311 of the Clean Air Act, 33 U.S.C. 1321, "toxic pollutants" designated under Section 307 of the Clean Water Act, 33 U.S.C. 1317, "hazardous air pollutants" designated under Section 112 of the Clean Air Act, 42 U.S.C. 7412, and imminently hazardous chemical substances or mixtures" that EPA has taken action on under Section 7 of the Toxic Substance Control Act, 15 U.S.C. 2606.

264. Preliminary Assessment. An HTRW literature search was conducted for this study area by Environmental Risk Information and Imaging Services (ERIIS). The literature search identified no documented or potential HTRW sites in the project area. An additional search by the Philadelphia District Army Corps of Engineers of the DERP-FUDS database identified the Broadkill Beach Fire Control Station as a site of potential concern.

265. Potential for Contamination at Broadkill Beach. The Broadkill Beach Fire Control Station inventory project report was completed in 1991. Although the potential for ordnance, unexploded waste and chemical surety materials is unknown, the possibility for a project at Broadkill Beach to encounter HTRW or to degrade the existing environmental conditions is low.

266. Potential for Borrow Area Contamination. Two offshore borrow areas have been identified for the study area. These two borrow areas lie approximately 0.5 to 2.5 miles offshore of Broadkill Beach (Figure 13). The Broadkill Beach Fire Control Station had the potential to impact the borrow areas in that ordnance may have been directed into the borrow areas by this station. A freedom of information record search was requested from the U.S. Coast Guard, but as of this time no response has been received. However, consultation with knowledgeable officials and examination of NOAA charts indicate that there is no potential for OEW contamination of the borrow areas.

PROJECT COST ESTIMATE

267. The estimated first cost for the selected plan is $8,409,000 (October 1995 price level) which includes real estate acquisition costs (including administrative costs), engineering and design (E&D), construction management (CM) and associated contingencies. E&D costs include preparation of plans and specifications, environmental, cultural and pre-construction monitoring and the development and execution of the Project Cooperation Agreement (PCA). A summary of the first cost is shown in Table 49.

268. Periodic nourishment is expected to occur at 5 year intervals subsequent to the completion of initial construction. Based on a volume of 358,400 cubic yards for each nourishment cycle, the total cost per operation (or cycle) is estimated to be $2,852,000 (October 1995 price level).

Table 49
Total First Cost Summary
October 1995 Price Levels

Description of Item	Quantity	Unit	Unit Price	Estimated Amount	Contingency	Total Amount
Lands and Damages						
Post Authorization Planning				0	0	0
Required Easements Including Surveys Appraisal and Administration		Job	LS	$59,165	$11,236	$70,401
Total Lands and Damages				$59,165	$11,236	$70,401
Beach Replenishment						
Mobilization, Demobilization and Preparatory Work		Job	LS	$448,616	$53,834	$502,450
Beachfill	1,305,000	CY	$3.81	$4,972,050	$745,808	$5,717,858
Dune Grass	174,800	SY	$4.73	$826,804	$165,361	$992,165
Sand Fence	21,800	LF	$2.59	$56,462	$11,292	$67,754
Planning, Engineering and Design (PE&D)		Job	LS	$520,000	$78,000	$598,000
Construction Management (S&A)		Job	LS	$400,000	$60,000	$460,000
Total Beach Replenishment				$7,223,932	$1,114,295	$8,338,227
Project Total						
Total Project First Cost				$7,283,097	$1,125,531	$8,408,628
Total Project First Cost (Rounded)				$7,283,000	$1,126,000	$8,409,000

269. **Economics of the NED Plan**. The selected plan provides total average annual benefits of $1,741,000 at a total average annual project cost of $1,303,000. Interest during construction is estimated to be $279,000. Total average annual benefits and costs are displayed by category in Table 50. The result is a benefit-cost ratio of 1.34 with $438,000 in annualized net benefits.

270. In accordance with ER 1105-2-100, the parameters and variables considered critical were varied in a sensitivity analysis. The amount of variation is reasonable since the techniques and methodology used in the analysis were refined to an effort to reduce uncertainty. The sensitivity analysis increased the discount rate by 2.375 percentage points to 10%. The base year for the project is in 4 years. Review of the trend in discount rates shows that the rate has not increased by more than 1 percentage point in any 4 year period since 1974. Most recently, the discount rate has actually decreased every year since 1990. Additional runs varied depth-damage curves and replacement cost values. However, plan sensitivity to depth-damage and replacement cost values was less critical.

271. The results of the sensitivity analysis are displayed in Appendix B.

Table 50
Benefit-Cost Summary for the NED Plan

Discount Rate	7.625%
Project Life	50 Years
Price Level	Oct 1995
Base Year	2000
Average Annual Benefits	
Storm Damage Reduction	$1,741,000
Benefits During Construction	$0
Total AAB	**$1,741,000**
Total Project Costs	
Initial Construction	$8,339,000
Interest During Construction	$279,000
Real Estate	$70,400
Periodic Nourishment (per cycle)	$2,852,000
Major Rehabilitation (annualized)	$76,000
Project Monitoring (annualized)	$60,000
Total AAC	**$1,303,000**
Benefit-Cost Ratio	1.34
Net Benefits	$438,000

COST APPORTIONMENT

272. The cost apportionment between Federal and non-Federal total first cost of the selected plan is shown in Table 51. The selected plan has been shown to be economically justified on benefits associated with storm damage reduction. There are no separable recreation features included with this project.

273. In accordance with Section 103 of the Water Resources Development Act of 1986 and appropriate Federal regulations, such as ER-1165-2-130, Federal participation in a project formulated for hurricane and storm damage reduction is 65 percent of the estimated total project first costs for developed shoreline, including Lands, Easements, Rights-of Ways, Relocations and Dredged Material Disposal Areas (LERRD). The estimated market value of LERRD provided by non-Federal interests is included in the total project cost, and they shall receive credit for the value of these contributions against the non-Federal cost share. The cost to provide protection to undeveloped private land is 100 percent non-Federal.

274. **Undeveloped Land**. There are a total of 32 privately-owned undeveloped bayfront parcels in Broadkill Beach. Four of these parcels are expected to be developed prior to the project base year of 2000. Through coordination with the Sponsor and local interests, an additional 18 parcels are expected to be developed by the project base year. The remaining 10 parcels comprise about 500 linear feet of shoreline, which is 3 percent of the total project length of 14,600 linear feet.

275. Shoreline Ownership and Public Access. All beachfront property which lies between the existing high water line and the natural and/or artificial dune line are subject to the direct jurisdiction of the State of Delaware, Department of Natural Resources and Environmental Control. The beaches are managed by Sussex County and the local municipalities, and the restrictive dune line is under the direct control of the State of Delaware.

276. Full public access is available for the general public along the project area. There are no operative restrictions for public use of the beaches, except for the restrictive dune for which general public access is restricted. The dune walkovers will provide the necessary public access (see the Public Access Plan, Appendix F).

277. **Operation and Maintenance**. Coordination has been accomplished with DNREC, the non-Federal sponsor, and they are fully aware of their obligations concerning Operation and Maintenance of the Federal project. The operation and maintenance of the project includes maintaining the sand fence and replanting dune grass as needed. The annual cost for these repairs is estimated to be $5,000, and is based on operation and maintenance experience for similar beachfill projects within the Philadelphia District.

278. The cost sharing for the selected plan is based on a total first cost of $8,409,000 and does not include interest during construction, which is used only for economic justification purposes.

Table 51
Cost Sharing for the NED Plan
(Oct 1995 Price Level)

Project Feature	Federal Cost	Non-Federal Cost	Total
Initial Project Cost - Developed Land (Cash Contributions)	$5,258,000	$2,831,000	$8,089,000
Initial Project Cost - Undeveloped Land (Cash Contributions)	$0	$250,000	$250,000
LERRD	$0	$70,000	$70,000
Total Initial Cost	$5,258,000	$3,151,000	$8,409,000
Periodic Nourishment (50 years) Developed Land (includes major replacement)	$17,942,000	$9,661,000	$27,603,000
Periodic Nourishment (50 years) Undeveloped Land (includes major replacement)	$0	$854,000	$854,000
Monitoring (50 Years) Developed Land	$1,706,000	$918,000	$2,624,000
Monitoring (50 Years) Undeveloped Land	$0	81,000	$81,000
Operation and Maintenance (50 Years)	$0	$250,000	$250,000
Total Project Cost (50 Years)	$24,906,000	$14,915,000	$39,821,000

279. **Construction and Funding Schedule**. The NED project will be constructed over six months, with an additional two months before and after construction for mobilization and demobilization. The Project Management Plan (PMP) describes activities leading to, through and after construction of the selected plan. An estimated schedule of expenditures by year is shown in the PMP.

LOCAL COOPERATION

280. In accordance with Section 105 (a)(1) of WRDA 1986, the Broadkill Beach interim feasibility study was cost shared 50%-50% between the Federal Government and the State of Delaware. The contributed funds of the local sponsor, the Delaware Department of Natural Resources and Environmental Control (DNREC), has shown intent to support a project for Broadkill Beach, Delaware.

281. **Coordination**. In an effort to keep the Sponsor informed of study progress, coordination through telephone conversations, formal and informal meetings continued throughout the feasibility phase. These efforts will continue, including coordination of this report with other State and Federal agencies.

282. **Project Cooperation Agreement**. A fully coordinated Project Cooperation Agreement (PCA) package, including the Sponsor's financing plan and reflecting the recommendations of this interim feasibility study, will be prepared subsequent to the approval of the feasibility phase. In the PCA the non-Federal sponsor will:

* Provide 35 percent of total project costs assigned to hurricane and storm damage reduction plus 50 percent of total project costs assigned to recreation, plus 100 percent of total project costs assigned to privately owned shores (where use of such shores is limited to private interests), and as further specified below:

* Provide all lands, easements, and rights-of-way, including suitable borrow and dredged or excavated material disposal areas, and perform or ensure the performance of all relocations determined by the Federal Government to be necessary for the initial construction, periodic nourishment, operation, and maintenance of the Project.

* Provide all improvements required on lands, easements, and rights-of-way to enable the proper disposal of dredged or excavated material associated with the initial construction, periodic nourishment, operation, and maintenance of the project. Such improvements may include, but are not necessarily limited to, retaining dikes, wasteweirs, bulkheads, embankments, monitoring features stilling basins, and dewatering pumps and pipes.

* Provide, during construction, any additional amounts as are necessary to make its total contribution equal to 35 percent of total project costs assigned to hurricane and storm damage reduction plus 50 percent of total project costs assigned to recreation, plus 100 percent of total project costs assigned to privately owned shores (where use of such shores is limited to private interests).

* For so long as the Project remains authorized, operate, maintain, repair, replace, and rehabilitate the completed Project, or functional portion of the Project, at no cost to the Federal Government, in a manner compatible with the Project's authorized purposes and in accordance with applicable Federal and State laws and regulations and any specific directions prescribed by the Federal Government.

* Give the Federal Government a right to enter, at reasonable times and in a reasonable manner, upon property that the Non-Federal Sponsor, now or hereafter, owns or controls for access to the Project for the purpose of inspection, and, if necessary after failure to perform by the Non-Federal Sponsor, for the purpose of completing, operating, maintaining, repairing, replacing, or rehabilitating the Project. No completion, operation, maintenance, repair, replacement, or rehabilitation by the Federal Government shall operate to relieve the Non-Federal Sponsor of responsibility to meet the Non-Federal Sponsor's obligations, or to preclude the Federal Government from pursuing any other remedy at law or equity to ensure faithful performance.

* Hold and save the United States free from damages arising from the initial construction, periodic nourishment, operation, maintenance, repair, replacement, and rehabilitation of the Project and any Project-related betterments, except for damages due to the fault or negligence of the United States or its contractors;

* Keep and maintain books, records, documents, and other evidence pertaining to costs and expenses incurred pursuant to the Project in accordance with the standards for financial management systems set forth in the Uniform Administrative Requirements for Grants and Cooperative Agreements to State and Local Governments at 32 Code of Federal Regulations (CFR) Section 33.20.

* Perform, or cause to be performed, any investigations for hazardous substances as are determined necessary to identify the existence and extent of any hazardous substances regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Public Law (PL) 96-510, as amended, 42 U.S.C. 9601-9675, that may exist in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for the initial construction, periodic nourishment, operation, and maintenance of the Project. However, for lands that the Federal Government determines to be subject to the navigation servitude, only the Federal Government shall perform such investigations unless the Federal Government provides the Non-Federal Sponsor with prior specific written direction, in which case the Non-Federal Sponsor shall perform such investigations in accordance with such written direction.

* Assume complete financial responsibility, as between the Federal Government and the non-Federal sponsor for all necessary cleanup and response costs of any CERCLA regulated materials located in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be necessary for the initial construction, periodic nourishment, operation, or maintenance of the Project.

* As between the Federal Government and the non-Federal sponsor, the non-Federal sponsor shall be considered the operator of the project for the purpose of CERCLA liability. To the maximum extent practicable, operate, maintain, repair, replace and rehabilitate the Project in a manner that will not cause liability to arise under CERCLA.

* Comply with the applicable provisions of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, Public Law 91-646, as amended by Title IV of the Surface Transportation and Uniform Relocation Assistance Act of 1987 (Public Law 100-17), and the Uniform Regulations contained in 49 CFR Part 24, in acquiring lands, easements, and rights-of-way, required for the initial construction, periodic nourishment, operation, and maintenance of the Project, including those necessary for relocations, borrow materials, and dredged or excavated material disposal, and inform all affected persons of applicable benefits, policies, and procedures in connection with said Act.

* Comply with all applicable Federal and State laws and regulations, including, but not limited to, Section 601 of the Civil Rights Act of 1964, Public Law 88-352 (42 U.S.C. 2000d), and Department of Defense Directive 5500.11 issued pursuant thereto, as well as Army Regulation 600-7, entitled "Nondiscrimination on the Basis of Handicap in Programs and Activities Assisted or Conducted by the Department of the Army".

* Provide 35 percent of that portion of total historic preservation mitigation and data recovery costs attributable to hurricane and storm damage reduction that are in excess of one percent of the total amount authorized to be appropriated for hurricane and storm damage reduction.

* Provide 50 percent of that portion of total historic preservation mitigation and data recovery costs attributable to recreation that are in excess of one percent of the total amount authorized to be appropriated for recreation.

* Provide 100 percent of that portion of total historic preservation mitigation and data recovery costs attributable to privately owned shores (where use of such shores is limited to private interests) that are in excess of one percent of the total amount authorized to be appropriated for privately owned shores (where use of such shores is limited to private interests).

* Participate in and comply with applicable Federal flood plain management and flood insurance programs.

* Not less than once each year inform affected interests of the extent of protection afforded by the Project.

* Publicize flood plain information in the area concerned and provide this information to zoning and other regulatory agencies for their use in preventing unwise future development in the flood plain and in adopting such regulations as may be necessary to prevent unwise future development and to ensure compatibility with the protection provided by the Project.

* For so long as the Project remains authorized, the Non-Federal Sponsor shall ensure continued conditions of public ownership and use of the shore upon which the amount of Federal participation is based.

* Provide and maintain necessary access roads, parking areas, and other public use facilities, open and available to all on equal terms.

283. **Local Support**. The community of Broadkill Beach and DNREC have expressed strong support for a potential project. Their cooperation indicates a strong willingness to proceed with a potential solution to the storm damage problems facing the community of Broadkill Beach. Coordination efforts with the Sponsor will continue regarding project financing and identification of any locally preferred plan.

Final
ENVIRONMENTAL IMPACT STATEMENT

Delaware Bay Coastline - Delaware and New Jersey
Broadkill Beach
Sussex County, Delaware

September 1996

U.S. Army Corps of Engineers
Philadelphia District
100 Penn Square East
Philadelphia, Pennsylvania
19107 3390

Final
Environmental Impact Statement
Delaware Bay Coastline - Delaware and New Jersey
Broadkill Beach
Sussex County, Delaware

The responsible lead agency is the U.S. Army Corps of Engineers, Philadelphia District.

Abstract:

This study evaluates existing conditions and shore protection problems facing Broadkill Beach along the coast of Delaware. Significant beach erosion has left the area vulnerable to storm damages. Severe storms in recent years have caused a reduction in the overall beach height and width along the study area, which, along with the absence of a significant dune system, leaves the residential community of Broadkill Beach vulnerable to catastrophic damages from flooding. The selected plan for storm damage and erosion control is beach nourishment utilizing sand obtained from two offshore borrow areas. Beach nourishment will consist of berm and dune restoration along 13,500 linear feet of the bayfront. The plan will require 1,305,000 cubic yards of sand for initial beachfill placement with 358,400 cubic yards for periodic renourishment every 5 years over a 50 year project life. The proposed beach nourishment will result in a 100 foot minimum design width berm with a top elevation of +8 feet NGVD and 15H:1V sideslope. The dune will be 11,500 feet long and have a top elevation of +16 feet NGVD and a 25 foot wide top width and a foreshore slope of 5H:1V. Dune grass will be planted on 174,800 square yards with 21,800 linear feet of dune fencing.

A Section 404 (b)(1) evaluation has been prepared and is included in the Draft Environmental Impact Statement. This evaluation concludes that the proposed action would not result in any significant environmental impacts relative to the areas of concern under Section 404 of the Federal Clean Water Act.

PLEASE SEND YOUR COMMENTS TO
THE DISTRICT ENGINNER,
LTC ROBERT B. KEYSER:

For further information on this statement
please contact: Ms. Barbara Conlin
Environmental Resources Branch
Telephone: (215) 656-6555

U.S. Army Engineer District, Philadelphia
Wanamaker Building, 100 Penn Square East
Philadelphia, Pennsylvania 19107-3390

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1.0. SUMMARY

1.1. Major Conclusions and Findings

The purpose of the Delaware Bay Coastline, Broadkill Beach Study was to evaluate existing conditions and shore protection problems facing the shoreline of the community of Broadkill Beach, Delaware. Several nonstructural and structural erosion controls alternative plans were evaluated. Based on an environmental and economic analysis, the preferred plan for storm damage and erosion control is beach nourishment, utilizing sand obtained from two offshore borrow areas. Beach nourishment will consist of berm and dune restoration along 13,100 linear feet of the bayfront. The plan will require 1,305,000 cubic yards of sand for initial beachfill placement, with 358,400 cubic yards for periodic nourishment every 5 years over a 50 year project life. The beach nourishment will result in a 100 foot minimum design width berm with a top elevation of +8 feet NGVD, and a 15H:1V sideslope. The dune will be 11,500 feet long and have a top elevation of +16 feet NGVD and a 25 foot wide top width, and a foreshore slope of 5H:1V. Dune grass will be planted on 174,800 square yards, with 21,800 linear feet of dune fencing.

Implementation of the recommended plan of improvement would not result in any significant long-term adverse impacts on the environment. Appropriate consideration was given to environmental concerns during the plan formuation phase to avoid environmentally valuable and sensitive habitats. Impacts to the aquatic environment, as a result of dredging operations, would be avoided or minimized through the application of appropriate dredging procedures. Established time-of-year dredging restrictions would be employed to avoid significant disturbances to fisheries during important life history periods. A benthic biological assessment was conducted in the vicinity of the borrow areas to rule out the presence of unique benthic populations. Chemical testing of the borrow sediments was conducted to ensure grain-size compatibility and the absence of contamination. Dredging operations have the potential to impact submerged cultural resources, principally shipwrecks. In order to minimize or avoid any adverse impacts, remote sensing and underwater investigations were undertaken to locate submerged resources and avoid them.

1.2. Areas of Controversy

Areas of controversy include the destruction of benthic organisms at the borrow area, suffocation of benthic organisms at the placement site, the potential for sea turtles to become entrained in the dredge, and the potential for storm damage and flooding to homes on the bay front. Although the benthic assessment did not find the benthic community to be unique in composition, 69 acres of aquatic habitat will be impacted by beachfill placement and result in the burial of less mobile benthic species in the shallow nearshore zone. In the borrow areas, the recolonized benthic community may differ considerably from the original community.

Dredging will be conducted during fall and winter months when horseshoe crab spawning and shorebird migrations are not taking place and turtle activity in the study area is at a minimum. Dredging will be conducted using a hydraulic cutterhead so as to eliminate entrainment of turtles that is associated with the use of a hopper dredge.

The continued erosion of the protective beach face on Broadkill Beach will continue to cause deterioration of the existing groins and revetment. There are no protective structures, such as bulkheads or dunes, on most of the beach face. Continued erosion will eventually cause damage to utilities and property.

1.3. Relationship to Environmental Statutes

Preparation of this Final Environmental Impact Statement (FEIS) has included several coordination/scoping meetings with appropriate Federal and State resource agencies. After public review of this DEIS, concurrence of Federal consistency with the Delaware Coastal Zone Management Program, in accordance with Section 307(c) of the Coastal Zone Management Act, was obtained from the Delaware Department of Natural Resources and Environmental Control. A Water Quality Certificate, in accordance with Section 401 of the Clean Water Act has been waived by the Delaware Department of Natural Resources and Environmental Control pending receipt of plans and specifications and favorable review of a subaqueous lands permit application in the next phase of study. A Section 404(b)(1) evaluation has been prepared and is included as Section 8.0 of the FEIS. This evaluation concludes that the proposed action would not result in any significant environmental impacts relative to the areas of concern under Section 404 of the Clean Water Act. In accordance with the Fish & Wildlife Coordination Act (FWCA), a planning aid report was obtained and is provided in the pertinent correspondence section of the main report. A section 2(b) FWCA report was obtained after circulation of the DEIS and is included in the correspondance section of the main report.

Compliance has been met for all environmental quality statutes and environmental review requirements with distribution of the Final Environmental Impact Statement (FEIS) with the exception of the Clean Water Act of 1977. Full compliance for the Clean Water Act of 1977 will be achieved upon favorable review of a subaqueous lands permit application and plans and specifications and subsequent receipt of the Water Quality Certificate in the next phase of study. Table 1 provides a list of Federal environmental quality statutes applicable to this statement, and their compliance status relative to the current stage of project review.

TABLE 1
COMPLIANCE WITH ENVIRONMENTAL QUALITY PROTECTION STATUES AND OTHER ENVIRONMENTAL REVIEW REQUIREMENTS

FEDERAL STATUTES	COMPLIANCE WITH PROPOSED PLAN
Archeological - Resources Protection Act of 1979, as amended	Full
Clean Air Act, as amended	Full
Clean Water Act of 1977	Partial
Coastal Barrier Resources Act	N/A
Coastal Zone Management Act of 1972, as amended	Full
Endangered Species Act of 1973, as amended	Full
Estuary Protection Act	Full
Federal Water Project Recreation Act, as amended	N/A
Fish and Wildlife Coordination Act	Full
Land and Water Conservation Fund Act, as amended	N/A
Marine Protection, Research and Sanctuaries Act	Full
National Historic Preservation Act of 1966, as amended	Full
National Environmental Policy Act, as amended	Full
Rivers and Harbors Act	Full
Watershed Protection and Flood Prevention Act	N/A
Wild and Scenic River Act	N/A
EXECUTIVE ORDERS, MEMORANDUM, ETC.	
EO 11988, Floodplain Management	Full
EO 11990, Protection of Wetlands	Full
EO 12114, Environmental Effects of Major Federal Actions	Full

Full Compliance	Requirements of the statute, E.O., or other environmental requirements are met for the current stage of review.
Partial Compliance	Some requirements of the statute, E.O., or other policy and related regulations have been met.
Noncompliance	None of the requirements of the statute, E.O., or other policy and related regulations have been met.
N/A	Statute, E.O., or other policy and related regulations are not applicable.

2.0. NEED FOR AND OBJECTIVES OF ACTION

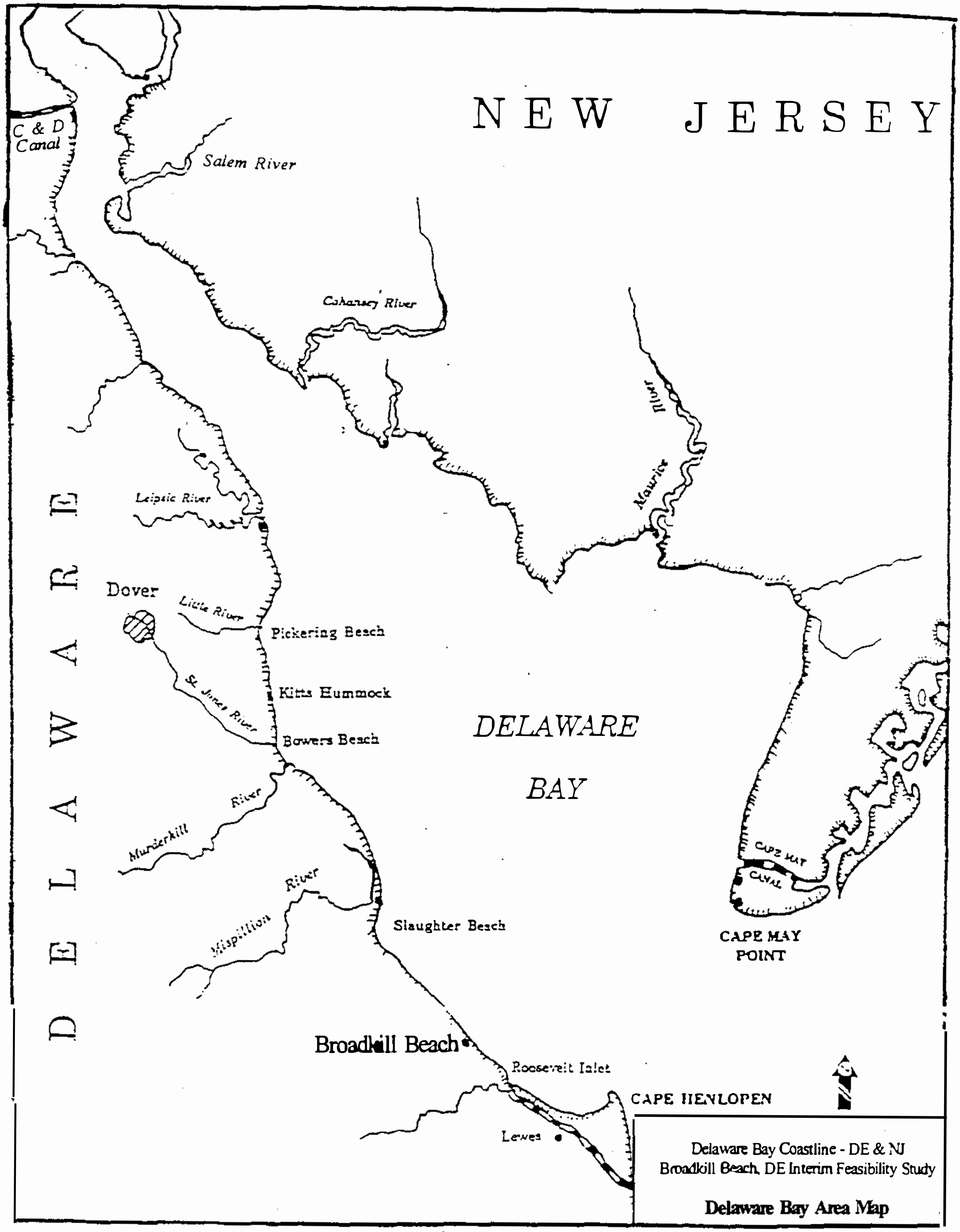
Broadkill Beach is a small coastal community located five miles from the mouth of the Delaware Bay (Figure 1). Broadkill Beach encompasses a three-mile stretch of shoreline along the bay and lies entirely within Sussex County, Delaware (Figure 2). The area is generally a strip of land ranging in width from 100 yards (91 meters) to 350 yards (320 meters), and is bordered by the bay on the northeast and marshland on the southwest. A discontinuous dune system lies along the shoreline.

2.1. Need

The land on which the Broadkill Beach community is located was formed from sand carried northwestward along the bay shore by the littoral transport system. Sand was carried along the shore from Breakwater Harbor by flood tide currents and wave refraction around the tip of Cape Henlopen (Kraft and Caulk, 1972). As accretion continued in the Lewes Beach area, a sand spit grew northwestward. By 1882 it had advanced to the Broadkill Beach area, deflecting the mouth of the Broadkill River to the northwest. As the Cape Henlopen spit continued building northward toward the inner breakwater, flood tidal currents were deflected northward into deeper water of Delaware Bay, and the sediment supply that had previously flowed onto Lewes Beach was cut off. As a result, the net littoral drift at Broadkill Beach shifted to the southeast beginning an erosional period. Eventually, a new inlet broke through the barrier beach to the southeast, and Broadkill Beach was cut off from its former source of sand (Kraft, et al., 1975).

Historic shoreline position data for Broadkill dates back to the late 1800's. The chronology of events affecting the Broadkill shoreline from that period to the late 1900's has been documented in the reference reports (USACE, 1972; Dalrymple, 1982; French, 1990). A combination of the northerly advance of the Cape Lewes spit, the bayward migration of the Cape Henlopen spit, completion of the inner breakwater at Breakwater Harbor, and the cutting of a new inlet to the Broadkill River all played a significant role in the shoreline changes in the lower western shores. The new inlet shoaled, and in 1908 the Army Corps of Engineers cut another inlet about 1500 feet to the northwest and stabilized it with a timber and stone jetty. Over time, the spit remnant welded onto the beach to form what is presently Broadkill Beach. The jettied inlet again experienced high shoaling, and in 1953 Congress deauthorized maintenance of the project.

A site inspection of the existing beachfront was conducted in September 1994. There are presently 5 beach groins located on Broadkill Beach, which were constructed in the 1950's. They are located at Alabama, Georgia, North Carolina, Washington, and Adams Avenues (Figure 3). There is also a dumped concrete rubble revetment near Alabama Avenue, which was built in



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Delaware Bay Area Map

FIGURE 1

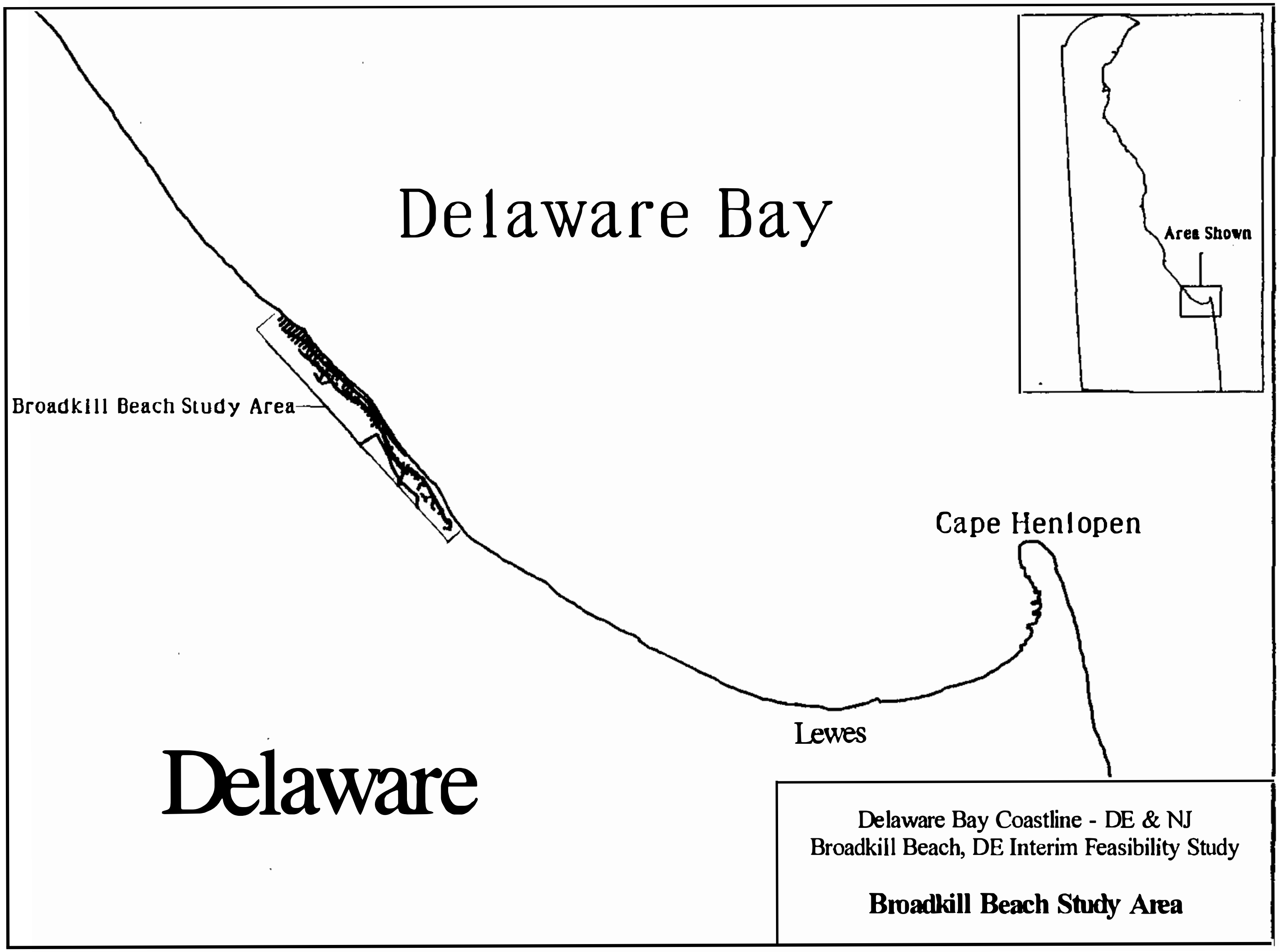
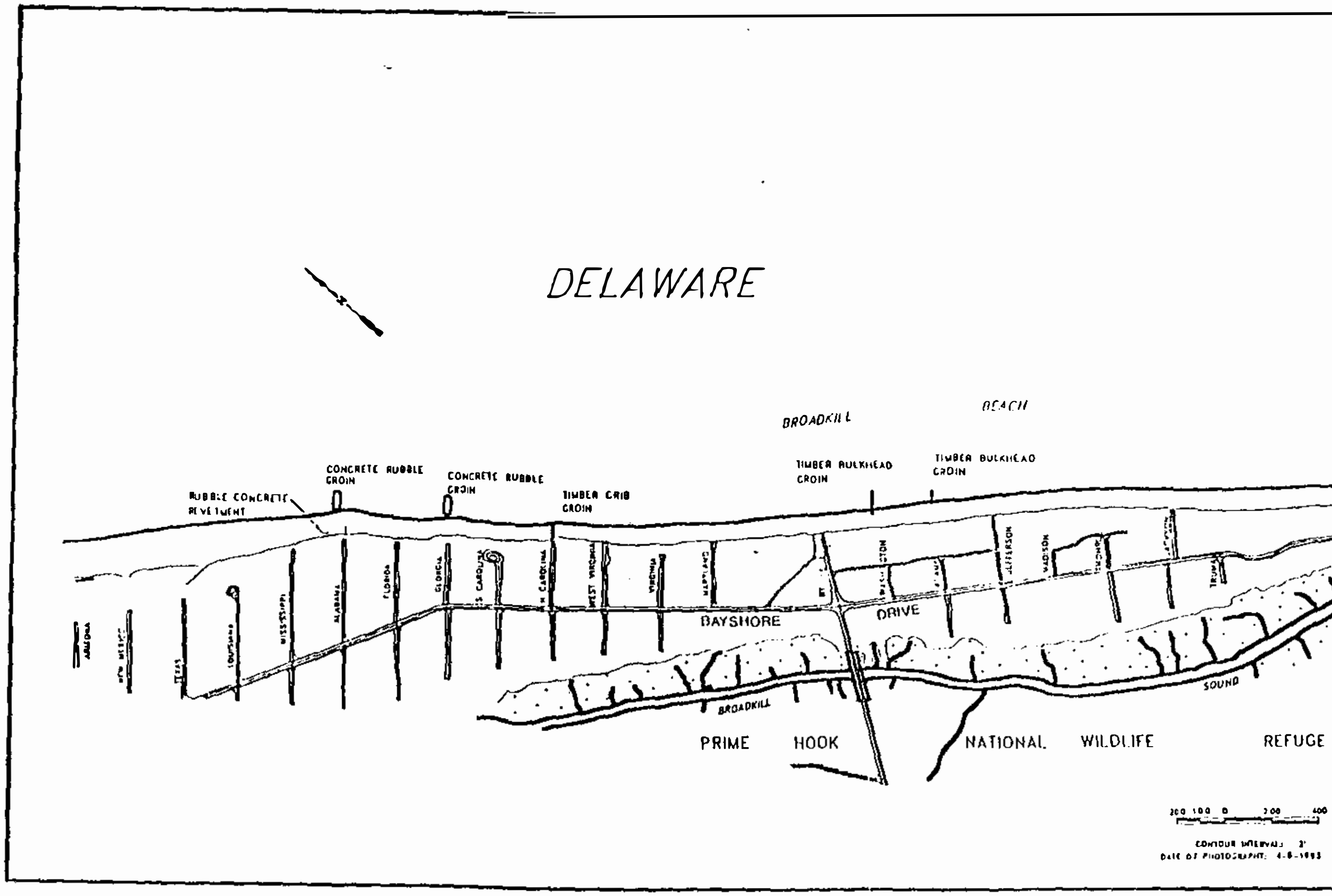

Delaware Bay
Area Shown
Broadkill Beach Study Area
Cape Henlopen
Lewes
Delaware
Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study
Broadkill Beach Study Area

FIGURE 2



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Shoreline Protection Structures

FIGURE 3

1964. The groins at Georgia and Alabama Avenues are made of dumped concrete rubble and are in poor condition. The concrete rubble extends approximately 15 to 20 feet into the bay and at most, 10 feet on the beach at low tide. The groin at North Carolina Avenue is a timber crib-stone filled construction type in poor condition. It is approximately 40 feet long and is located entirely on the upper end of the beach berm. The groin does not extend into the water at low tide. The groins located at Washington and Adams Avenues are timber bulkhead construction in fair condition, approximately 20 to 30 feet in length. The concrete revetment extends from North Carolina Avenue to approximately 700 feet north to Alabama Avenue. Only 30 feet of the revetment is visible, the rest is buried under existing dune.

The continual erosion of the protective beach face within the study area causes more deterioration of the existing groins and revetment. There are no protective structures such as bulkheads, and dunes are lacking in many areas of Broadkill Beach. The continued erosion of the land will eventually cause damage to utilities and private property. Increased maintenance costs will be incurred to repair damaged utilities and street ends. In addition, home owners will find their bay front property shrinking unless they continually backfill eroded areas.

2.2. Objectives

Broadkill Beach is affected both by tropical (hurricanes) and extra-tropical (northeasters) storms. Both can cause severe beach erosion and damage to coastal structures. Hurricanes are associated with extreme low pressure systems, and can result in large increases in water level. Coupled with a high tide condition and with waves superimposed on the flood profile, a hurricane can result in significant flooding and damage. Northeasters cause damage principally through wave attack of the beach and adjacent structures. They can be as damaging or more damaging than hurricanes depending on their duration which can extend over several tidal cycles. During successive high tides, higher and steeper waves caused by the persistence of winds over a nearly unlimited fetch can cause extensive beach erosion.

Broadkill Beach was chosen for study because it was identified as a representative beach community known to have erosion problems and the potential for storm damages. In addition to its historical erosion problems, Broadkill also has continuing economic growth and public access. These criteria, along with current Federal and non-Federal sponsor participation in the funding of the project, made it a successful candidate for a shoreline protection study.

This Final Environmental Impact Statement (FEIS) has been prepared to assess the potential environmental impacts associated with the renourishment of Broadkill Beach. The study evaluates the impacts of increased shoreline protection through beach nourishment and erosion control. An additional objective of the study is to provide up-to-date information for state and local management of this coastal area. Information gathered from the two-phase planning process will guide the design of this renourishment project.

This FEIS includes a general environmental inventory for the project area, and the conclusions of specific surveys conducted for water and sediment quality, aquatic biota, habitat value, and cultural resources.

2.3. Study Authority

Authorization to undertake this study was established by a resolution adopted by the Committee on Public Works and Transportation, United States House of Representatives, on October 1, 1986. The Resolution states:

> "RESOLVED BY THE COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION OF THE UNITED STATES HOUSE OF REPRESENTATIVES, that the Board of Engineers for Rivers and Harbors is hereby requested to make a comprehensive review of the existing reports on communities within the tidal portion of the Delaware Bay and its tributaries with a view to developing and updating a physical and engineering data base as the basis for actions and programs to provide shoreline protection or to provide up-to-date information for state and local management of this coastal area and to determine whether any modifications of the conclusions and recommendations contained in the previous reports of the Chief of Engineers that pertain to the Delaware Bay Coasts of Delaware and New Jersey are advisable at the present time. Such modifications to previous conclusions and recommendations shall be cognizant of, and incorporate where feasible, the findings of the final report of the Chief of Engineers on the Shoreline Erosion Control Demonstration Program, Section 54, of Public Law 93-251."

In addition, separate authority has been established to undertake investigations in the vicinity of Port Mahon, Delaware by a resolution adopted by the Committee on Public Works, United States Senate, on September 30, 1974. The resolution states:

> "RESOLVED BY THE COMMITTEE ON PUBLIC WORKS OF THE UNITED STATES SENATE, created under Section 3 of the Rivers and Harbors Act approved June 13, 1902, be, and is hereby requested to review the reports of the Chief of Engineers on the Mahon River, Kent County, Delaware, published as House Document Numbered 72, 56th Congress, reports dated 24 October 1888 and 25 June 1940, and other pertinent reports, with a view to determining the advisability of improvements in the interest of navigation, recreation, fish and

wildlife, environmental enhancement and protection, and shoreline erosion control along the Mahon River in the vicinity of Port Mahon, Delaware, and along the Delaware Bay shore of Delaware including Kelly Island in the Bombay Hook National Migratory Waterfowl Refuge and other areas in the vicinity of the confluence of the Delaware and Mahon Rivers, and other purposes."

2.4. The Report and the Planning Process

Prior to the development of an EIS, a two-phase study process is conducted. The Federal government first conducts a reconnaissance study to evaluate whether a Federal project can solve local and regional water problems. This phase is 100% Federally funded.

Based on the first phase, the Federal government and the non-Federal sponsor jointly determine whether a full feasibility study is needed. The second, or feasibility phase is only initiated upon the execution of a cost-sharing agreement between the Federal government and the sponsor.
Cost sharing however, is not required for inland navigation improvements.

The reconnaissance phase specifically identifies and defines problems and opportunities related to water resources. This phase then also presents possible solutions to the problems identified. This step is followed by an estimation of benefits and costs of the solutions to determine the prospects of implementing the project, and federal interest in the potential solutions is appraised. Feasibility phase costs are then estimated, and it is determined whether further studies are appropriate. For the feasibility phase to proceed, the Army Corps of Engineers, the Federal government agency, and the non-Federal sponsor must agree to equally share in the expense of the feasibility phase.

The feasibility phase encompasses further planning and evaluation of alternative solutions to water resources problems. In this phase, detailed estimations of benefits and the cost of alternatives are conducted to determine which plans merit Federal participation. A Detailed Project Report (DPR) is prepared to recommend solutions to water resources problems, and to seek Congressional authorization. A letter is prepared by the state or local entity concerning their intent to financially participate in implementation of the recommended plan. This phase then requires the coordination of the DPR with Federal, state, and local agencies.

In summary, the two-phase planning process is made up of six steps:

1) Problem Perception
2) Request for Federal Action
3) Study Problem and Report Preparation
4) Report Review and Approval

5) Congressional Authorization
6) Project Implementation

2.5 Prior Reports and Studies

There are several published and unpublished reports by the Corps of Engineers with regard to Broadkill Beach. Reports which are applicable to the study area are listed in chronological order in Table 2.

2.6. Related Projects

There have been numerous Federal projects developed along the Delaware Bay. A list of the projects is provided below.

Beach Erosion Control Projects

Constructed & Completed
* Broadkill Beach, Delaware
* Lewes Beach, Delaware

Authorized but Never Constructed
* Cape May Point, New Jersey

Active Navigation Projects
* Broadkill River, Delaware
* Cedar Creek, Delaware
* Cohansey River, New Jersey
* Delaware River, Philadelphia to the Sea: PA, NJ, DE
* Harbor of Refuge, Delaware Bay
* Inland Waterway - Chesapeake and Delaware Canal
* Inland Waterway - Chincoteague Bay, VA to Delaware Bay, DE
* Inland Waterway - Rehoboth Bay to Delaware Bay
* Little River, Delaware
* Maurice River, New Jersey
* Mispillion River, Delaware
* Murderkill River, Delaware
* Salem River, New Jersey
* Smyrna River, Delaware
* St. Jones River, Delaware

Inactive Navigation Projects
* Alloway Creek, New Jersey
* Dennis Creek, New Jersey
* Goshen Creek, New Jersey
* Leipsic River, Delaware

TABLE 2
BROADKILL BEACH
PRIOR REPORTS

PUBLICATION AND DATE	RECOMMENDATIONS
H.D. 56, 74th Congress, 1st Session, 1935 Broadkill River, Delaware Bay Harbor of Refuge, Rehoboth Bay.	Entrance channel from Rehoboth Bay to Delaware Bay near Lewes: widening canal from Broadkill River to Lewes: 15 ft. deep channel from Harbor of Refuge to Lewes was recommended and constructed.
H.D. 216, 85th Congress, 1st Session, 1957 Beach Erosion Control Report on Cooperative Study, Delaware Coast from Kitts Hummock to Fenwick Island.	Protective measures for selected sites along the Delaware Bay and ocean coast were recommended but never constructed.
H.D. 348, 88th Congress, 2nd Session, 1964 Delaware River and Bay, Pennsylvania, New Jersey, and Delaware.	Hurricane and tidal flood protection improvements were not recommended.
H.D. 90, 9th Congress, 2nd Session, 1968 Delaware Coast Beach Erosion Control and Hurricane Protection.	Federal shore protection projects along Delaware Bay communities not economically justified at this time.
Small Beach Erosion Project - Broadkill Beach, DE Detailed Project Report, 1972	Widening beach by sand placement and a 50 ft. wide berm at an elevation of 10 ft. above mean low water (MLW) recommended and partially constructed.
Low Cost Shore Protection - Final Report on the Shoreline Erosion Control Demonstration Program (section 54), 1981.	Structural devices placed at Pickering Beach, Kitts Hummock, and Slaughter Beach: Monitoring of beachfill performance at Broadkill Beach, Lewes Beach, and Bowers Beach.

Another series of projects originated from a project conducted by the U.S. Army Corps of Engineers. The objectives of the program were to develop and demonstrate low cost methods of shore protection in accordance with the provisions of Section 54, Public Law 93-251, 93rd Congress, approved 7 March 1974. Broadkill Beach was one of the six locations along the Delaware Bay named in the authorizing legislation as project sites for the program. Low cost shore protection measures were installed and monitored for effectiveness by the Corps. Other aims of the program were:

1. to provide a data base that could be used for the logical selection of devices or combinations of devices to protect inland or sheltered shorelines in any given region of the United States;

2. to develop techniques for making selections; and

3. to disseminate this information.

The devices selected for the projects were chosen from a large listing of low cost shore protection devices, including vegetation, which had been tried or proposed in the past.

Three sites were chosen for demonstration projects utilizing a variety of structural devices. The demonstration project at Pickering Beach consisted of two types of floating tire breakwaters and was completed in 1978. At Kitts Hummock, three types of fixed offshore breakwaters: rubble mound, nylon sandbags, and precast concrete box were installed in 1979. The project at Slaughter Beach consisted of a perched beach with three types of sill devices: concrete boxes, wood sheet piling, and large nylon sandbags. The Slaughter Beach project also included supplementary planting of vegetation and was completed in 1979.

Three additional sites were selected as monitoring projects. Devices on these sites (principally beachfill) were constructed prior to the initiation of the Section 54 Program, and no shore protection devices were added to these sites under the program. The monitoring project at Bowers and South Bowers evaluated a beach berm built by the State of Delaware with beachfill in 1973 and 1974, and two nylon Dura-Bag groins to retain the fill. A beach berm was also monitored at Lewes with an initial beachfill in 1975 of 86,710 cubic yards.

At Broadkill Beach, the monitoring project examined a 50 ft. wide berm constructed in 1976 to an elevation of +10 ft. MLW and a foreshore slope of 1 on 10. An initial fill in 1976 consisted of 40,300 cubic yards of material.

2.6.1. Related Institutional Programs

National Estuary Program - Delaware Estuary Program. The National Estuary Program (NEP) was established by Congress under the Water Quality Act of

1987, Section 317. The purposes of the NEP are: (1) to identify nationally significant estuaries threatened by pollution, development, or overuse; (2) promote comprehensive planning, conservation, and management of nationally significant estuaries; and (3) encourage the preparation of management plans and enhance coordination of estuarine research. These goals are to be achieved for the estuaries in the NEP by a Comprehensive Conservation and Management Plan (CCMP) developed in a management and study effort called a Management Conference.

The NEP is managed by the United States Environmental Protection Agency (EPA). The Administrator of the EPA selects estuaries for the program in response to nominations by state governors, or, in the case of interstate estuaries, at he initiative of the EPA. Selection is based on issues of significant national concern regarding water quality, biological diversity, and recreational activities.

The Delaware Estuary Program (DELEP) is a five-year, Federally funded program which has been undertaken by the States of Delaware, New Jersey, and Pennsylvania, and the EPA. The DELEP was included into the NEP in 1988. The goals of the DELEP are: (1) evaluate the Delaware Estuary; (2) define its environmental management needs; and (3) develop a Delaware Estuary Comprehensive Conservation Management Plan (CCMP). This plan will recommend solutions to guide future management of the Estuary's resources that will be implemented through existing and possibly new institutions and agencies.

The DELEP study area includes: (1) the Delaware River and Bay from Morrisville, Pennsylvania and Trenton, New Jersey, to Lewes, Delaware and Cape May, New Jersey; (2) all tidal tributaries to these waters; and (3) the surrounding land areas.

North American Waterfowl Plan. The North American Waterfowl Management Plan (NAWMP) was established on 14 May 1986 by the United States Fish and Wildlife Service (USFWS) and the Canadian Wildlife Service. The purpose of the plan is to reverse the decline of wetlands and waterfowl by establishing goals for conserving wetland habitats and for restoring waterfowl populations. Broad guidelines are provided for habitat protection and management through the year 2000. Each country, state, province, and territory will need to establish specific plans for habitat preservation and management in the respective jurisdictions. The implementation of the NAWMP takes place through "Joint Ventures", coalitions of state and Federal agencies, conservation groups, and landowners.

About ten to twenty million shorebirds comprising over 48 species migrate annually from South America to Canada along the Atlantic Flyway, relying upon strategically placed habitats for food and rest. The Delaware Estuary is the largest staging site in the Eastern United States for shorebirds migrating along the Atlantic Flyway. It is also the second largest staging site in North

America. Conservation of the Delaware Estuary through the NAWMP is critical to the survival of various species of migrating shorebirds, as well as the Estuary's unique resources.

Coastal Barrier Resources Act. The Coastal Barrier Resources Act (CBRA) was enacted on 18 October 1982 (Public Law 97-348), and was amended on 16 November 1990. The purpose of the CBRA was to protect undeveloped barrier islands, and to restrict future Federal expenditures and financial assistance which encourage development of coastal barriers. Through CBRA, the Secretary of the Interior is empowered to implement a Coastal Barrier Resources System (CBRS) consisting of undeveloped coastal barriers on the Atlantic and Gulf Coasts.

Limitations on Federal spending are enumerated in Section 5 of the CBRA. These limitations prohibit expenditures for:

1. construction or purchase of any structure, appurtenance, facility, or related infrastructure;

2. construction of roads, airports, boat landing facilities or bridges or causeways to any System Unit; and

3. carrying out of any shoreline stabilization (erosion) projects except where an emergency threatens life, land, and property immediately adjacent to the unit.

The Act also stipulated that the Secretary of the Interior should submit a report to Congress by 18 October 1985 containing (1) recommendations for conservation of the fish, wildlife, and other natural resources of the system, and (2) recommendations for additions to, or deletions from, the CBRS and for modifications to boundaries of existing System Units. Two major changes to the CBRS which have been proposed by the USFWS are: (1) to include public lands (protected lands) such as State and Federal Parks, wildlife refuges, and National Seashores, and (2) to include secondary barriers. In order to further expand the System, the 101st Congress amended the CBRA in 1990. Nearly 788,000 acres along the Atlantic and Gulf coasts were added to the CBRS, including secondary barriers in the Delaware Bay. There are no CBRS Units located in the immediate vicinity of the study area.

Western Hemisphere Shorebird Reserve Network. The Western Hemisphere Shorebird Reserve Network (WHSRN) was created in 1985 by the International Association of Fish and Wildlife Agencies. The Network is an inclusive, multi-organizational effort. The objectives of the WHSRN are: (1) to promote the conservation of Western Hemisphere Shorebirds; and (2) the sustenance of natural ecological processes in wetlands and other critical habitats upon which they depend. The member sites or "Sister Reserves" are Hemispheric, International, Regional, and Endangered Species sites. Throughout the Western Hemisphere, fifteen sites have been dedicated as of

1991.

The lower 25 miles of the Delaware Bay shore of New Jersey and Delaware has been established as a "Sister Reserve" through a joint resolution by then Governors Thomas H. Kean of New Jersey and Michael M. Castle of Delaware. The objective of the joint resolution is to recognize and protect the critical migrating and feeding habitat for over one million shorebirds which utilize the Delaware Bay during spring migration between April and June.

Coastal America Program. The Coastal America Program was established in 1991. The goal of the program is to preserve, restore, and protect national coastal resources. The program is managed through the combined efforts of the U.S. Department of the Interior, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration.

These agencies provide the foundation for reaching the goal of the program by: (1) quickly responding to coastal management needs at the state and local level; and (2) assisting local governments and states obtain public participation in coastal management through educational programs.

Coastal America provides support for both short-term and long-term coastal management projects using a three-level strategy which consists of: (1) preventive measures applied to all coastal areas; (2) site-specific restoration; and (3) long-term plans for containing or removing pollutants in highly contaminated areas. The future status of the Coastal America Program is in question however, due to lack of Congressional support.

3.0. ALTERNATIVES

3.1. No Action

The no action alternative involves no measures to provide erosion control, recreational beach, or storm damage protection to structures landward of the bayfront. This alternative would not check the continuing erosion of the beach, nor would it prevent property from being subjected to high storm damages from beach recession, flooding, and wave attack. This plan fails to meet the objectives of the study. The State of Delaware has placed beachfill in the past on an as-needed basis and has expressed intent to continue this action if a Federal project is not implemented. However, even with the State's efforts to maintain the current shoreline, the without-project analysis demonstrates that Broadkill Beach will incur significant damages (refer to Table 35 in the Main Report).

3.2. Nonstructural Alternatives

3.2.1. Permanent Evacuation

Permanent evacuation of existing development areas subject to inundation involves the acquisition of lands and structures either by purchase or through the exercise of powers of eminent domain, if necessary. Following this action, all commercial and industrial developments and residential property in areas subject to erosion are either demolished or relocated to another site. Roads, water supply facilities, electric power, telephone and sewage facilities would also need to be relocated. Lands acquired in this manner could be used for undeveloped parks or other purposes that would not result in material damage from erosion. However, Broadkill Beach has been developed steadily over many years and this development is expected to continue until the presently available lots are occupied. In addition, Broadkill is bounded by Prime Hook National Wildlife Refuge to the west and the Beach Plum Island State Park to the south. Development in these areas is prohibited. Finally, relocating all of the structures, or even the most damageable structures, in Broadkill Beach to another site would be prohibitively expensive. Therefore, this alternative was not considered further.

3.3. Structural Alternatives

3.3.1. Berm Restoration

This alternative involves the placement of sand directly on the eroded beach. The sand is typically pumped onto the existing shore using a dredge and an offshore borrow source. An appropriate design uses borrow material that has similar physical properties to the existing beach sand. In addition, the restored beach is graded to a specific design elevation and width to provide the desired level of storm protection. This alternative requires renourishment on a periodic basis to maintain the design berm width and elevation. Berm restoration is technically feasible, and has a relatively low cost. In addition, a beachfill project, implemented in the 1970s, functioned well. Therefore, this alternative was considered further.

3.3.2. Berm Restoration with Dune

This alternative provides the berm restoration described above with additional beachfill material to create a dune at a specific elevation and width. The dune can be vegetated, and provides storm surge protection in addition to the erosion protection. The berm restoration with dune meets the study objectives, is technically feasible, and has a relatively low cost. Therefore, this alternative was considered further.

3.3.3. Groin Field with Berm Restoration and Dune

This alternative provides the berm restoration and dune described above with a groin field along the bayfront of Broadkill Beach. Groins are structures built perpendicular to the shoreline that extend from the upper beach face into the surf zone. In many instances, groins are made up of a timber bulkhead type structure at the landward end, and a rubble mound stone structure at the outer end extending into the water. A properly designed groin field will reduce erosion by trapping some of the littoral drift, thereby reducing the need for nourishment. However, a groin field built on an eroded beachface will not necessarily provide adequate storm surge protection, unless it is combined with a properly designed beach restoration with dune. This alternative meets the study objectives, is technically feasible, and has a relatively low cost. This alternative was considered further.

3.3.4. Offshore Detached Breakwater with Berm Restoration and Dune

A breakwater is an offshore structure which reduces the wave energy impacting the beaches landward. The reduced wave energy reduces beach erosion. Breakwaters have been constructed using a variety of materials. Concrete filled nylon bags were used at Kitts Hummock as part of the Section 54 Program. However, the structure was determined to be ineffective after the bags deteriorated and the structure settled. Sand-filled bags have also been considered. However, there is the potential for the bags to topple over during a storm. A series of rubble mound breakwaters is more appropriate for the Broadkill Beach area. Constructing breakwaters at open ocean coasts can be difficult, requiring additional equipment which increases costs. However, the lower energy environment and relatively shallow profile of the Delaware Bay coast can make breakwater construction less costly. The berm restoration with dune described above provides the needed storm protection in eroded areas, and maintains the littoral drift. This alternative meets the study objectives, has a moderate cost, and is technically feasible. This alternative was considered further.

3.3.5. Perched Beach with Berm Restoration and Dune

This alternative provides the berm restoration with dune described above with a perched beach. The perched beach consists of a submerged structure or sill, usually rubble mound, which is used to trap sediment carried by incoming waves. This eliminates the outer part of the beach profile near its closure with the bay bottom, included in the berm restoration alternative. A perched beach was installed at Slaughter Beach as part of the Section 54 Program, but was found to be ineffective. The sill did not fill with sand as expected, due to the lower wave energy and limited sediment transport of the Delaware Bay. In addition, the angled swell scoured in front of and behind the sill, resulting in frequent maintenance. The perched beach alternative involves high maintenance expense and is considered unsuitable for the Delaware Bay environment. Therefore, it was not considered further.

3.3.6. Seawall

This alternative consists of the construction of a "Galveston type" seawall with a top elevation of +20 feet NGVD placed along the entire 15,200 foot length of the study area, replacing all of the existing dunes. The structure includes fronting toe scour stone protection, pile supports, and underlying sheeting to reduce underseepage. This alternative would provide storm damage protection consistent with other structural alternatives. However, the relative cost would be prohibitively high. This alternative was not considered further.

3.3.7. Seawall with Berm Restoration

This alternative consists of the berm restoration plan with the addition of the "Galveston type" seawall, both described above. This alternative is also prohibitively high in cost.

3.4. Alternatives Evaluation

In the second evaluation of alternatives 1) berm restoration, 2) berm restoration with dune, 3) groin field with berm restoration and dune, and 4) offshore detached breakwater with berm restoration and dune were analyzed for environmental, socio-economic, and institutional factors, as well as preliminary cost comparisons. In each case, moderate scale plans were evaluated using typical cross-sections as a basis for assessing preliminary costs per linear foot of shoreline, and were generalized as follows:

a. Low Cost - less than $100/lf
b. Moderate Cost - $100 to $200/lf
c. High Cost - greater than $200/lf

Berm restoration and berm restoration with dune would entail placement of sand along a 15,000 foot stretch of beach using the borrow source areas illustrated in Figure 4. Groin field with berm restoration and dune would entail construction of a timber bulkhead at the landward end and quarry stone at the seaward end. Beachfill and dune were also included in this alternative. An offshore detached breakwater with berm restoration and dune would entail the construction of rubble mound breakwater segments along the study area with a top elevation coinciding with the high tide level. Beachfill and dune was also included in this alternative. This last alternative (offshore detached breakwater with berm restoration and dune) was eliminated due to concerns raised by the study sponsor that the breakwater would be a navigation hazard. Table 3 details this evaluation. A more detailed discussion of the Cycle 2 evaluation can be found in the Plan Formulation section of the Main Report.

3.4.1. Screening of Beach Restoration Alternatives

The initial alternative evaluation of berm restoration and berm restoration with dune plans assumes a nourishment cycle of 3 years. Upon selection of the National Economic Development (NED) plan, consideration is given to the placement of groins and optimization of periodic nourishment requirements.

The alternative of beach nourishment requires optimization of the berm widths and the dune height. The methodology followed to optimize these features is accomplished by varying parameters between a set of boundary conditions established at the beginning of the analysis. Design of the beach restoration alternatives was done in accordance with CETN-II-5, the Shore Protection Manual, and accepted engineering practices.

Design Baseline. A design baseline was established along the length of the study area in order to determine the alignment of the proposed beach restoration alternatives. In Broadkill Beach, the design baseline was initially located to follow as close as possible to the landward edge of the existing dune line or private property line (see Figure 15 in the Main Report). However, two structures near Polk Avenue lie further bayward in relation to the other bayfront structures in the community. The design baseline was therefore relocated bayward of these two structures in order to avoid potentially higher real estate costs due to propterty acquisition. An analysis was performed to ensure that the cost associated with the relocation (such as potentially higher beachfill quantities) offset the cost to acquire the two properties (see Main Report for further details). For each option analyzed, the seaward edge of the proposed berm was located by offsetting the beach width from the design line. For those options that included a dune, the design baseline was used to locate the toe of the dune.

Berm Elevation. Design berm heights for each alternative have an elevation set at the natural berm elevation as determined by historical profiles. The average berm elevation for Broadkill Beach is +7 to +8 ft. NGVD. Therefore, a berm elevation of +8 ft. NGVD was used to analyze all alternatives.

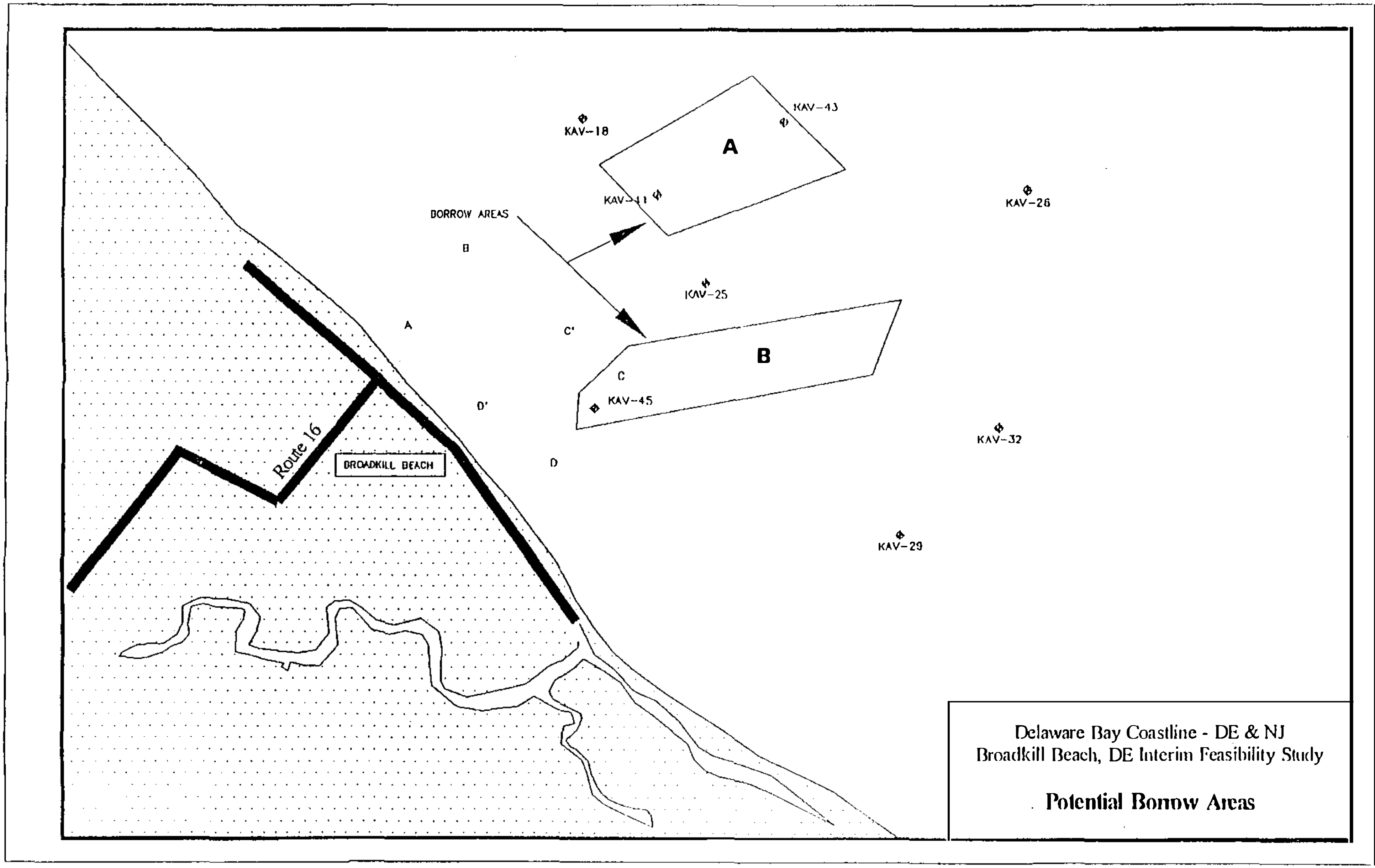

KAV-43
KAV-18
A
KAV-41
KAV-26
BORROW AREAS
B
KAV-25
A
C'
B
C
KAV-45
D'
KAV-32
Route 16
BROADKILL BEACH
D
KAV-29
Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study
Potential Borrow Areas

FIGURE 4

TABLE 3
BROADKILL BEACH
EVALUATION OF ALTERNATIVES

Description	Environmental Considerations	Socio-Economic Considerations	Institutional Considerations	Relative Cost	Further Consideration In Cycle 3?	Remarks
Berm Restoration	Temporary destruction of benthic habitat in borrow area. A minor increase in turbidity in construction area.	Provides useable beach area and reduces erosion damages.	State preferred plan.	Low	Y	Adverse environmental impacts may be minimized through coordination with environmental agencies.
Berm Restoration with Dune	Same as above with the addition of dune habitat.	Same as above but dune may obstruct some bayfront view of the Delaware Bay. Provides storm protection in addition to erosion protection.	State supports further study.	Low	Y	Can provide aesthetic value by planting of dune grass.
Groin Field with Berm Restoration and Dune	In addition to above, groins may disrupt benthic environment. However they may provide habitat for sessile organisms.	In addition to above, aesthetics would be reduced.	Same as above.	Low to Medium	Y	Costs of groins may be offset by reduction in periodic nourishment requirements.
Offshore Detached Breakwater with Berm Restoration and Dune	Same as berm restoration and dune.	Same as berm restoration and dune with the addition of possible navigation hazard.	Navigation hazard is a concern of the State.	High	N	Warning buoys may be placed at segment locations.

Berm Width. The minimum design berm width considered is approximately the average width of the without project condition along the length of the study area. This design alternative requires beachfill for some locations to establish a consistent berm height, and includes advanced nourishment along the entire area to ensure a constant design template between nourishment cycles. The minimum berm width is 50 feet.

An interval between berm widths is chosen so that the optimum berm width can more easily be identified. This interval is set wide enough to discern significant differences in costs and benefits between alternatives, but not so great that the NED plan cannot be accurately determined. In order to satisfy these criteria, a 50 foot interval is used.

Beachfill Slope. The slope of the proposed beachfill was determined to be 15H:1V down to the Mean Low Water elevation. This slope matches closely with the existing beaches in the study area. Below Mean Low Water, the slope follows that of the existing profile down to the elevation of closure.

Beachfill Taper. All beachfill alternatives include a taper at each project terminus to transition the constructed project into the existing beaches outside the project area. For the optimization analysis, a 1000 foot taper was used at the northern and, at the request of the study Sponsor, a 500 foot taper was set for the southern limit of the project area to terminate at the boundary between Broadkill Beach and Beach Plum Island State Park.

Dune Height and Width. Dune elevations in the vicinity of Broadkill Beach vary from +12 ft to +15 ft NGVD. For the optimization analysis, dunes with top elevations of +14 ft, +16 ft, and +18 ft NGVD were used. Dune top width was 25 ft for all alternatives. The side slopes chosen for the dune were 5H:1V, which is the average for naturally occurring dunes in the area.

Dune Alignment. The landward toe of the dune was located as close as possible to the design baseline, at the landward edge of the berm. Where feasible, the proposed dunes tie into existing dunes to take advantage of conditions that reduce required quantities.

Beachfill Quantities. To determine quantities for each alternative, the proposed design templates were drawn on the existing beach survey cross sections. Average end area methods were used to compute volumes. Initial construction volumes presented in this report include quantities required to attain the design profile and advanced periodic nourishment.

Periodic Nourishment. In order to maintain the design profile, an advanced nourishment fill is placed in addition to the initial design beachfill. The nourishment volume is sacrificial and protects the design beachfill. Nourishment quantities include an overfill factor of 1.4 (refer to Borrow Area Investigation in Main Report).

Based on the boundary condition assumptions discussed above, 12 combinations of berm widths and dune heights was generated. A preliminary evaluation was performed to reduce the total number of hydraulic (SBEACH) and economic model runs utilized during the optimization to identify the NED plan.

Some berm and dune alternatives were quickly identified as virtually non-constructable considering the footprint requirements of the various dune options and toe protection required for dune stability. For example, the smallest dune (at +14 NGVD top elevation) requires a base width of 85 feet which would significantly exceed the 50 foot berm (at +8 NGVD). This eliminated all dune options on the 50 foot berm. In addition, placing a dune with a +18 NGVD top elevation on the 100 foot berm is not feasible because the dune base requires 125 feet. As a result, a total of 4 combinations were eliminated from the matrix. The remaining alternatives were then subjected to a screening consisting of limited model runs and quantity calculations. This initial screening was used to assess the performance of the alternatives in the study area, and provide a basis for progression to the full analysis of benefits and costs.

The results of the initial screening eliminated the berm-only alternatives from the matrix. The majority of the Broadkill Beach study area contains dunes which have an average top elevation of +12 ft NGVD (Table 14 of the Main Report). The without project analysis shows that, even with an average elevation of +12 NGVD, significant damages occur due to erosion and inundation. Alternatives which include a dune with a higher top elevation prevented considerably more damages than berm-only alternatives. This finding would point to the conclusion that a much larger amount of fill is required for a berm-only alternative to achieve the same level of damage reduction provided by a higher dune. As a result, three alternatives were eliminated from further consideration. Table 4 summarizes the full matrix of alternatives and the recommendations of the preliminary screening.

Table 4
Matrix of Berm Restoration Alternatives

Dune Elevation (Feet NGVD)	Berm Width (Feet)		
	50	100	150
0	E	E	E
+14	X	R	R
+16	X	R	R
+18	X	X	R

E = Eliminated in the preliminary screening analysis
R = Recommended for further analysis
X = Inappropriate design template

Based on this initial screening, 5 alternatives remained in the matrix and were recommended for further analysis. These alternatives are listed in Table 5.

Table 5
Alternatives Recommended for Optimization

Alternative	Dune Elevation (Feet NGVD)	Berm Width (Feet)
Plan 1	+ 14	100
Plan 2	+ 16	100
Plan 3	+ 14	150
Plan 4	+ 16	150
Plan 5	+ 18	150

3.4.2. Optimization of Alternative Plans

Benefits and costs for Broadkill Beach were developed for the alternative plans discussed above to optimize the NED plan in the study area. This was accomplished using the same numerical modeling techniques utilized in the without-project analysis (see Main Report), coupled with engineering and technical assessments to interpret model results as applied to the various alternatives. Reduced damages, based on the predicted reduction in storm impacts due to the with-project alternatives, were compared to the without-project results to generate project benefits. Costs for each alternative were estimated based on standard construction practices and District experience in the construction of beach nourishment projects.

The with-project conditions are the conditions that are expected based on the predicted impacts of storm events on the various project alternatives. The periodic nourishment associated with the project is designed to ensure the integrity of the project design. In the case of beachfill, this ensures the project design cross-section will be maintained and the elimination of shoreline recession due to long-term erosion. However, coastal processes will continue to impact the shoreline along the project area. Storm-induced erosion, wave attack, and inundation were evaluated for the with-project conditions using the same methodologies utilized in the without-project analyses (refer to Appendix A, Section 2 for more information on storm impact optimization).

In order to maintain the integrity of the design beachfill alternatives, beach nourishment must be included in the project design. If periodic nourishment is not performed throughout the life of the project, longshore and cross-shore sediment transport mechanisms will act to erode the design beach. This erosion will reduce protection from storm damage afforded by the project design. The nourishment quantities are considered sacrificial material which act to protect the design fill volume. Refer to Appendix A, Section 2 for information on estimated required nourishment volumes.

In addition to storm damage reduction benefits, reduced maintenance benefits accrue under the with-project scenario. The State of Delaware has provided beachfill material to Broadkill Beach on an as-needed basis. This expenditure will not accrue under the with-project condition. Optimization of the alternatives is based on the priority benefit category of storm damage reduction (including reduced maintenance) indexed to an October 1995 price level. A periodic nourishment cycle of 3 years was chosen to screen the alternatives. The initial construction and periodic nourishment costs for the with-project alternatives are presented in Table 40 of the Main Report. The average annual costs are subtracted from average annual benefits to calculate net benefits. The NED plan is the plan which maximizes net benefits. A summary of the reduction in with-project storm damages for each project alternative is listed in Table 41 of the Main Report. Table 43 of the Main

Report identifies the optimized plan for Broadkill Beach including average annual benefits and costs, net benefits, and the benefit-cost ratio. Plan 2 which provides a 100 foot berm with a top elevation of +16 feet NGVD is the optimal plan.

3.4.3. Periodic Nourishment Cycle

Upon selection of the preferred alternative design, an attempt was made to economically optimize the periodic nourishment cycle. Required quantities were obtained for 3 to 7 year nourishment cycles and are shown in Table 6 below. Initial construction and periodic nourishment costs were computed for the cycles. Table 7 shows the economic comparison of the nourishment cycles including average annual costs, average annual benefits, net benefits, and the benefit-cost ratio. Similar to the alternative optimization, the optimal nourishment cycle would provide the highest net benefits. The highest benefit-to-cost ratio occurred for the 5 year renourishment cycle. This interval for renourishment is in accordance with currently operating District storm protection projects and the historic frequency with which Broadkill has required fill in the past.

Table 6
Periodic Nourishment Quantities - 3 Through 7 Year Cycles
(Cubic Yards)

Nourishment Cycle (Years)	Initial Construction	Periodic Nourishment
3	898,000	190,400
4	947,000	239,400
5	1,066,000	358,400
6	1,255,000	547,400
7	1,514,000	806,400

Table 7
Benefit-Cost Comparison - 2 Through 7 Year Cycles
(Oct 1995 Price Level, 7.75% Discount Rate)

Cycle (Years)	Avg. Annual Benefits	Avg. Annual Costs	Net Benefits	BCR
3	$1,589,000	$1,099,00	$642,000	1.58
4	$1,589,000	$1,053,000	$688,000	1.65
5	$1,589,000	$1,046,000	$695,000	1.66
6	$1,589,000	$1,174,000	$567,000	1.48
7	$1,589,000	$1,320,000	$421,00	1.32

3.4.4. Groin Analysis

Following the selection of the optimized beachfill alternative and appropriate nourishment cycle, groins were analyzed to determine whether the cost to construct them is offset by the savings in periodic nourishment reduction. Reduced nourishment rates were estimated for a groin field consisting of 16 timber groins spaced 720 feet apart (Appendix A, Section 2).

The annualized cost of the proposed groin field is $372,000. The annualized savings (benefits) from reduced periodic nourishment associated with construction of the groin field is $159,000. Therefore, the placement of a groin field in combination with Plan 2 is not justified and not considered further.

3.4.5. Project Length

The focus area for the optimization analysis was conservatively defined by the community's beachfill history. During the optimization analysis, the Sponsor requested that the District examine extending the project southward of DNREC station S76+00. The area south of station S76+00 has not received beachfill material in the past and was much less developed than the northern and central areas of Broadkill Beach. However, substantial development has occurred in recent years. In order to provide protection to as much of the community as possible, the project length was extended approximately 1500 feet. This included, at the Sponsor's request, minimizing the length of the southern taper to 500 feet so as not to pass the boundary of Beach Plum Island State Park. An analysis was performed on the optimized plan and nourishment cycle for a total project length of approximately 13,100 feet (excluding tapers). Table 46 of the Main Report compares the average annual benefits, average annual costs, and net benefits of both plans at the updated discount rate of 7.625%. The plan suggested by the State has higher total net benefits, and is therefore the NED plan.

3.5. Selected Plan

The selected plan for storm damage protection and erosion control along the community of Broadkill Beach is shown in Figures 5, 6, and 7. The NED plan is defined as that plan which maximizes beneficial contributions to the Nation while meeting planning objectives (refer to the Plan Formulation Section of the Main Report for more detailed information). The plan consists of a 100 foot wide berm at an elevation of +8 feet NGVD. Total quantities for the selected plan are presented in Table 8 below. Figures 5 and 6 show the limits of the selected plan including taper areas; and a typical cross-section is presented in Figure 7.

* A berm extending seaward 100 feet from the design line. The beachfill extends from Alaska Avenue southward for 13,100 linear feet. Tapers of 1,000 feet extending from the northern end and 500 feet extending from the southern limit of the main project, brings the total project length to 14,600 linear feet.

* On top of the berm lies a dune with a top elevation of +16 ft NGVD and a top width of 25 feet.

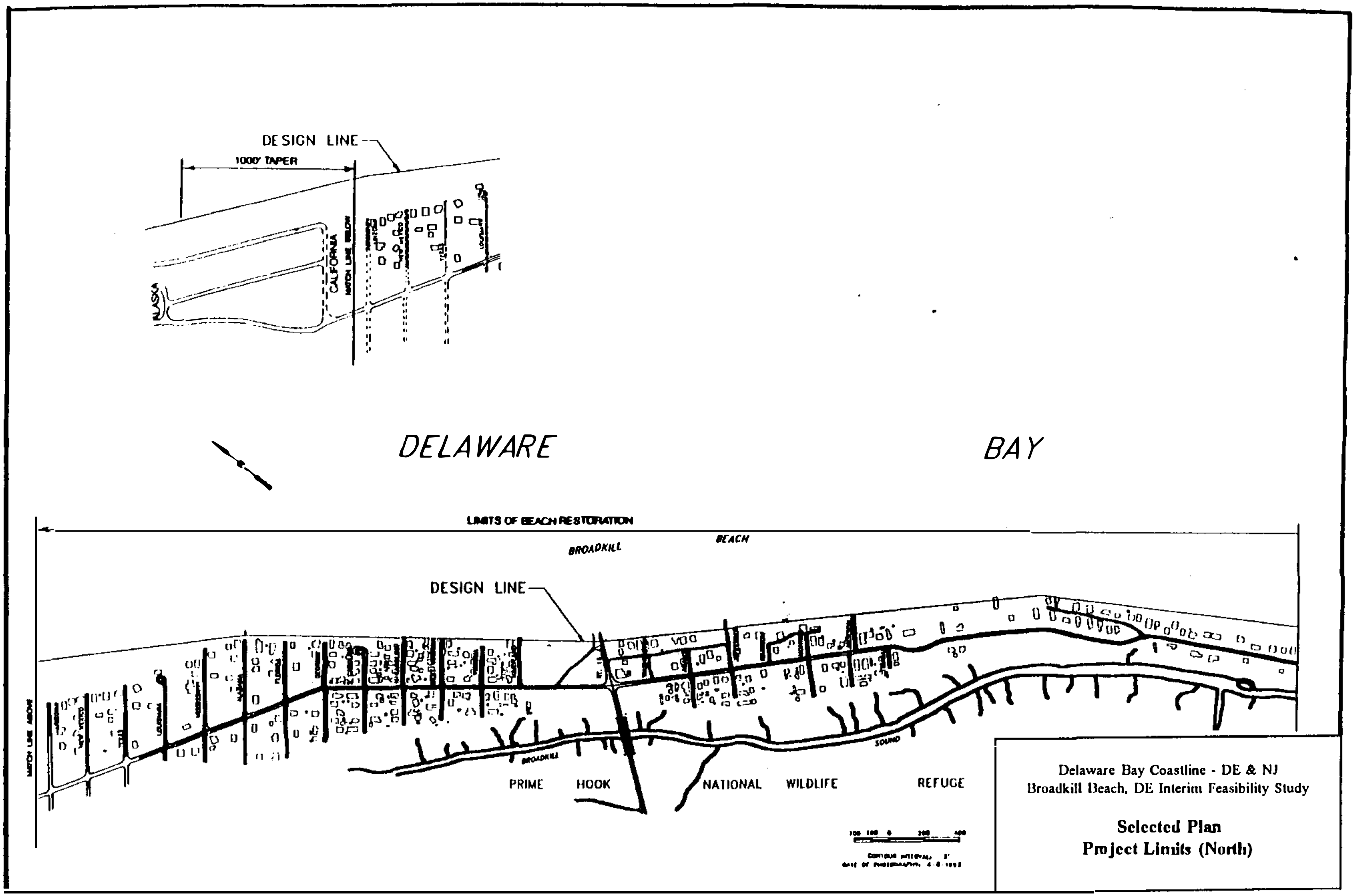
* A total initial volume of 1,305,000 cubic yards of sand fill will be placed along the area. This fill volume includes initial design fill requirements and advanced nourishment.

* Periodic nourishment of 358,400 cubic yards of sand fill will be placed every 5 years.

* Planting of 174,800 square yards of dune grass and 21,800 linear feet of sand fence are included for dune stability.

* Vehicular access to the beach will be provided at Route 16 in the center of Broadkill Beach. Sand fence will be used to create a path 12 feet wide along both sides of the dune at a skewed angle to the dune alignment. This would allow vehicles to climb along the side of the dune at a flatter slope than 5H:1V.

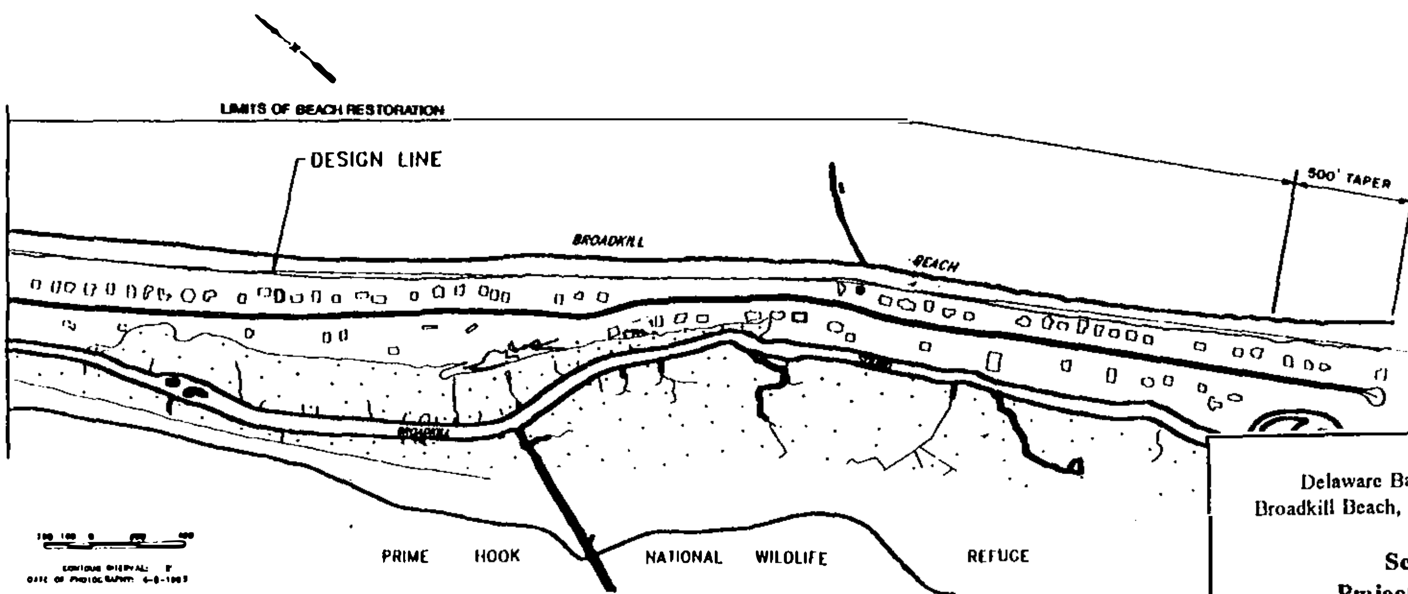
* Pedestrian access paths will be located at each street end in a similar fashion as the vehicular access. However, the access path will be smaller in width and at a somewhat steeper slope.



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Selected Plan
Project Limits (North)

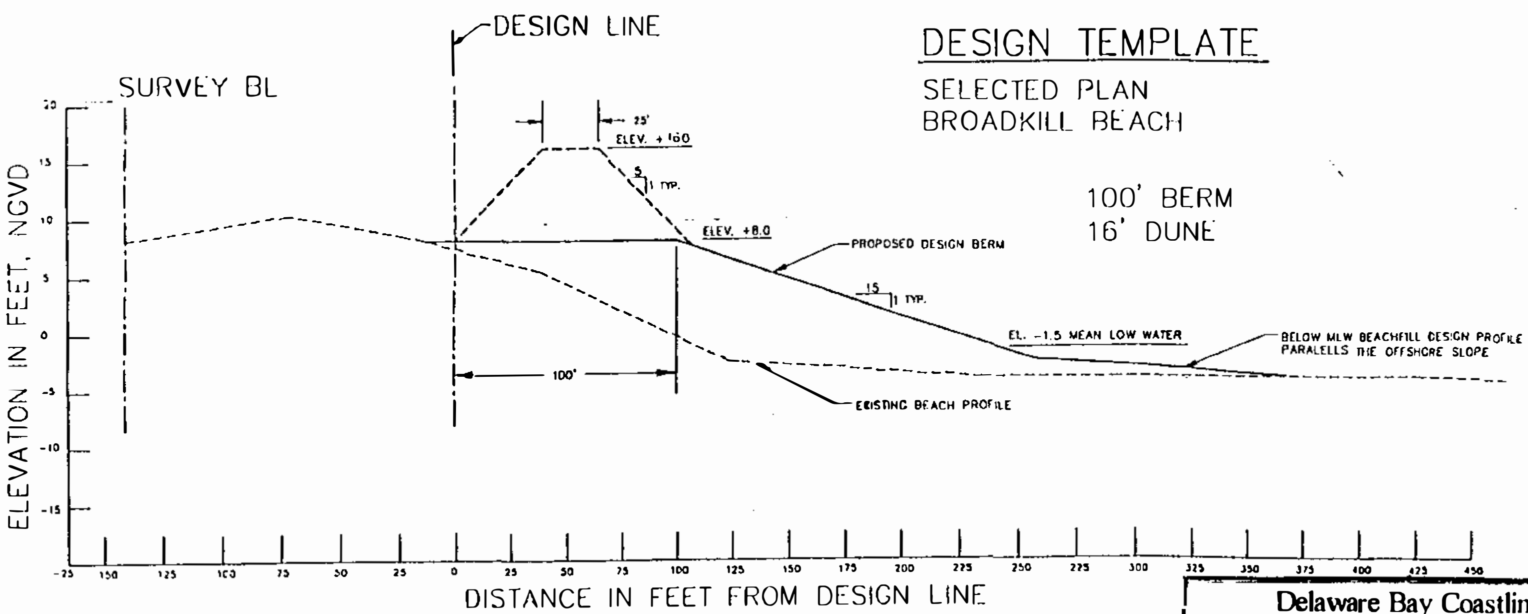
FIGURE 5



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Selected Plan
Project Limits (South)

FIGURE 6



Delaware Bay Coastline - DE & NJ
Broadkill Beach, DE Interim Feasibility Study

Typical Section of Selected Plan

FIGURE 7

Table 8
Total Quantities for the Selected Plan

Feature	Quantity
Beachfill (c.y.)	
Berm	685,600
Dune	261,000
Advanced Nourishment	358,400
Total Initial Quantity	1,305,000
Periodic Nourishment (c.y.) 5-Year Cycle	358,400
Sand Fence (l.f.)	21,800
Dune Grass (s.y.)	174,800

Two offshore borrow source areas have been proposed (see Figure 4). Area A is 312 acres and is defined by the following coordinates:

Delaware State Plane Coordinates	Longitude/Latitude
722395, 305225	75° 11' 03.0"W, 38° 50' 16.3"N
727078, 306921	75° 10' 03.8"W, 38° 50' 33.0"N
724619, 309377	75° 10' 34.8"W, 38° 50' 57.3"N
720580, 307037	75° 11' 25.9"W, 38° 50' 34.3"N

Area B is 349 acres and is defined by the following coordinates:

Delaware State Plane Coordinates	Longitude/Latitude
720000, 300000	75° 11' 33.4"W, 38° 49' 24.8"N
727780, 301481	75° 09' 55.1"W, 38° 49' 39.2"N
728541, 303528	75° 09' 45.4"W, 38° 49' 59.4"N
721336, 302245	75° 11' 16.5"W, 38° 49' 47.0"N
720072, 300982	75° 11' 32.5"W, 38° 49' 34.5"N

Acoustic subbottom profiling and vibracores indicate that these areas contain large quantities of coarse to fine-grained sand (see Appendix to the Main Report). Periodic renourishment on a 5 year cycle for a 50-year project life is included in the preferred plan of action. Approximately 1,305,000 cubic yards of sand will be needed for initial placement, with approximately 358,400 cubic yards needed for periodic renourishment.

4.0. AFFECTED ENVIRONMENT

4.1. Socioeconomics

4.1.1. Demographics

The community of Broadkill Beach is mainly a summer home town with a permanent population of less than 500. Being of relatively small size, Broadkill Beach is unincorporated and is under the jurisdiction of Sussex County. The study area is predominately residential with approximately 430 single family homes, mostly cottages, and only 1 commercial structure, the Broadkill Store.

The population is concentrated on the eastern, bay side of the town. A single main road, Bayshore Drive runs parallel to the bay, and about 3/4 of the residents have homes along the bayside of this road. The remaining 1/4 live on small side streets, often just limited access dirt roads on the western side of Bayshore Drive.

There is a recent population growth in the area, though it is mainly confined to the southern end of Bayshore Drive. Newer, more expensive homes are being built, and existing vacant lots predict continued development. The overall population of the county is expected to continue to increase over the next twenty years, however, the rate of growth should decrease.

4.1.2. Employment

The community of Broadkill Beach is not dependent on and does not generate tourism unlike many of the other shoreline communities. However, this town is fairly representative of the overall economy of Sussex County. In 1990 the unemployment rate for the County was projected to be 4.2%, which is just over the state's unemployment rate of 4.0%. The study area mainly depends on the manufacturing/processing industry as well as on agriculture. Broadkill's labor force is similar to Sussex County, where approximately 1/3 of the workforce is employed in retail or services, while another 1/3 is in manufacturing.

4.1.3. Income

The per capita income of Sussex County in 1990 was an estimated $12,723, which is slightly lower than the per capita income for Delaware which was $15,584. The study area has similar income estimates, but as a result of the strict reliance on agriculture and industry, Broadkill Beach's economy fluctuates greatly from year to year. Other coastal areas differ from Broadkill because their dependence on tourism which provides a much more constant economy during times of poor agriculture or recession.

4.1.4. Land Use

Broadkill Beach, being primarily residential, is developed extensively along the beach with single family homes and cottages. Most homes are situated at the southern end of the town due to the nature of the land. The Primehook National Wildlife Refuge lies to the west of Broadkill Beach, and Beach Plum Island, owned by the state, lies to the south.

Route 16 intersects Bayshore Drive and is the only access road leading into the study area. The road, because of its importance as the sole evacuation route, was raised slightly twenty years ago to prevent flooding. However, the road still floods during major storms and access to the Broadkill area becomes impossible.

Portions of the beach are very narrow at high tide, so over the years several structures have been constructed to help reduce shoreline erosion. Between 1950 and 1954, five timber groins were constructed by the state, and in 1964, two rubble mound groins were added.

4.2. Physical Resources

4.2.1. Climate

The entire area of Sussex County lies in one climatic zone. The climate is considered subtropical which generally produces mild summer and winter seasons with only a few short hot, humid periods in summer, and cold, windy periods in winter. The summer weather is dominated by maritime tropical air masses which remain stable for several days at a time, creating high pressure systems. Continental, polar air masses in the winter produce rapidly moving fronts and intense weather patterns. The area is susceptible to strong beach eroding storms as a result of these weather patterns. Northeasters have a frequency of once every 2.5 years, and hurricanes occur about once every 5.5 years, producing an average of one storm every two years. Spring and fall are milder and are dominated by quickly changing air masses. The mean annual temperature in the area is a range of 55 to 57 degrees F. The annual precipitation for the area is about 45 inches, with the average monthly rainfall amounting to three or more inches. Temporary droughts, however, are not uncommon.

4.2.2. Geology

The Broadkill Beach study area lies entirely within the Atlantic Coastal Plain Physiographic Province. This province can be divided into two segments: a submerged section known as the continental shelf, and an emerged or subaerial section. The Atlantic Coast shoreline divides these two segments, and forms a boundary between them. This province is a primarily flat plain, with elevations rarely exceeding 100 feet above mean sea level.

The beaches that lie nearly continuous along the lower Delaware Bay are fairly narrow, with an average width of 10 to 50 feet during high water. The water often reaches the foot of the low dunes behind the beach during storm waves or unusually high tides. A belt of grass-covered dunes, averaging fifty to several hundred feet in width and 8 to 12 feet in height, separates the beach from extensive salt marshes. In many locations, however, the dune crest is only 3 to 4 feet above the high water line.

There are several rivers and streams which drain the Delaware Bay Shore area. The St. Jones, Murderkill, and Mispillion Rivers, and Cedar, Primehook, and Broadkill Creeks are the principal streams on the Delaware side. The Salem, Cohansey, and Maurice Rivers are the principal streams on the New Jersey side. The streams flow through a region of sand and silt, yet they input very little sand-sized sediment onto the Delaware Bay shoreline. Small dams at the head of the tidal reaches and small stream gradients hinder sediment input.

4.2.3. Surface and Groundwater

Delaware is very similar to New Jersey in its geologic setting, therefore like New Jersey, Delaware has abundant groundwater resources. Of Delaware's total available water supply, 58 percent comes from groundwater. Presently however, only 43 percent of the water used by the state comes from groundwater. The surface water withdrawals are negligible in Sussex County in comparison to the groundwater use. The Coastal Plain sediments found along the coast of Delaware such as in Broadkill Beach, are much more abundant in groundwater than the inland cities of Newark and Wilmington, which lie on crystalline rock of the Piedmont Province. These cities depend much more heavily on surface water.

The Pleistocene deposits are the most important aquifer in the State of Delaware, and are the most valuable water resource for Sussex and southern Kent counties. Several other aquifers such as the Manokin, Potomac, Piney Point, Cheswold, and Frederica Formations also have extensive water supplies, and are presently untapped.

With the exception of the following local problems, Delaware's groundwater quality is generally good. The Potomac, Magothy, and Rancocas formations are high in iron, and the St. Georges area is contaminated with nitrate. However, the largest problem is saline encroachment. There is a natural high chloride content within two miles of the Delaware Bay and within one mile of tidal streams. The New Castle area especially shows evidence of increased saline intrusion due to overpumping.

4.2.4. Hydrology and Tidal Hydraulics

Broadkill Beach has mixed, semi-diurnal tides that have a mean tide range of 4.1 feet. The maximum flood and ebb tidal currents are about 0.6 ft/sec, and normal flood and ebb tides have velocities of 0.3 ft/sec. Broadkill Beach is affected by both hurricanes and northeasters. Both cause severe beach erosion and damage to structures along the coast. Extreme low pressure systems are associated with hurricanes and often result in large increases in water level. When coupled with high tide conditions and waves superimposed on the flood profile, hurricanes can cause significant flooding. Northeasters, however, cause damage through wave attack on the beach and coastal structures. These storms may be as damaging if not more damaging than hurricanes depending on their duration, which may last as long as several tide cycles. Extensive beach erosion is caused by successive high tides and steeper waves caused by wind. Thirty significant storms have occurred near the Broadkill Beach area since 1933.

4.2.5. Sediment Quality

The mouth of Delaware Bay consists mainly of medium-to-coarse sands. This sand extends upbay in linear bands, which coincide with the axes of the major tidal channels. The median grain diameter increases in the upbay direction and away from the channel center. The linear sand shoals, the channel margins, most of the Lower Jersey Platform, and the area between Mispillion River and Lewes Harbor are characterized by very fine sands. The Upper Jersey Platform and the Cape May Shoal Complex do not follow the upbay and shoreward fining pattern. Sediments here become coarser in the shoreward direction. Poorly sorted medium-to-coarse sands with a low mud content dominate the mouth of the bay and the lower bay channels. These sediments also occur near the shore along the Lower Jersey Platform. The upper and middle bay and the margins of the lower bay tend to be characterized by finer sands and a highly variable mud content. Poorly sorted sands with a very high mud content can be found in patches throughout the bay, but occur most commonly along the Delaware shoreline of the middle and upper bay.

Recent sediment quality data is not available for the Broadkill area, however sediment samples collected offshore in the Big Stone Beach Anchorage have been analyzed. Chemical testing consisted of bulk and elutriate procedures (Greeley Polhemus Group, 1993). Detections of pesticides, PCBs, volatiles, and semivolatiles are extememly rare. Some metals were detected in the bulk sediment samples but none of the levels exceeded EPA standards for non-residential surface soil.

4.2.6. Salinity and Water Quality

Salinity levels in the vicinity of Broadkill Beach range from 25-30 parts per thousand (ppt). The Bay is classified into three salinity zones, and with this salinity range Broadkill falls within the upper polyhaline zone.

Other than input from the ocean, the Delaware Bay receives water from indirect runoff such as rivers of the drainage system, and direct runoff from the land or marshes. The water column is generally well mixed throughout the year, and as a result of high concentrations of suspended sediments and strong wind and tidal currents, turbidity is fairly high. This large mixing of the water column also produces a high dissolved oxygen content. Large amounts of nutrients also enter the bay as a result of runoff from the land. The Delaware Bay owes its productivity to these nutrients and to the extensive recycling that occurs between the overlying water and the biologically active bottom sediments. Phytoplankton utilize this nutrient source as a result of the vertical mixing that occurs with surface water.

The Delaware River Basin Commission (DRBC), a four-state Federal Agency, is responsible for managing the water resources within the entire Delaware River Basin. Pursuant to Section 305(b) of the Clean Water Act (33 U.S.C. 1251 et seq.), the DRBC prepares biennial assessments of water quality for the 339 mile long Delaware River and Bay. Water quality in zone six includes the 782 square miles of the bay below Liston Point. The DRBC characterizes the water quality of zone 6 as good. Average DO concentrations are consistently above 6.0 mg per liter. pH values are generally within the limits of DRBC standards. The geometric mean of fecal coliform readings were less than 15 colonies per 100 ml, which indicates that the bay has an excellent sanitary quality.

4.3. Biological Resources

4.3.1. Habitats

General Setting. The community of Broadkill Beach is located on land that was formed from sand carried northwestward along the bay shore by the littoral transport system. Sand was carried along the shore from Breakwater Harbor by flood tide currents, and wave refraction around the tip of Cape Henlopen (Kraft and Caulk, 1972). Accretion continued around the Lewes Beach area and a sand spit began to grow northwestward. By 1882 it had advanced to the Broadkill Beach area, deflecting the mouth of the Broadkill River to the northwest. As the Cape Henolopen spit grew more northward toward the inner breakwater, flood tidal currents were deflected northward into the deeper water of the Delaware Bay, and the sediment supply that once flowed onto Lewes Beach was cut off. The result was a net littoral drift at Broadkill Beach that shifted to the southeast, beginning an erosional period. Over time, a new inlet broke through the barrier beach to the southeast, and Broadkill Beach was cut off from its former sand source (Kraft, *et al.*, 1975).

Beaches. The narrow sandy beach at Broadkill is flanked by a continuous dune system, resulting from development and erosion. The predominant plant species on the dunes is American beach grass (Ammophila breviligulata). This species can survive harsh conditions such as low fertility, temperature extremes, and high energy from the bay and wind. These conditions are typical of sand dunes. Beach grass is valuable as a beach binder since the plant spreads by long rhizomes and stolens, which form a fibrous network to keep sand from blowing away. The plants also grow when partly buried in the sand. The upper portions of the dune system are colonized by seaside goldenrod (Solidago sempervirens) and cocklebur (Xanthium echinatum).

To a limited extent, the dune system grades into a zone of shrubby vegetation where development has not occurred. This is observed for the most part, directly south and north of the community. The shrub-thicket zone is typically populated by dwarf trees and shrubs such as wax-myrtle (Myrica cerifera), bayberry (Myrica pensylvanica), dwarf sumac (Rhus copallina), poison ivy (Toxicodendron radicans), groundsel bush (Baccharis halifolia), loblolly pine (Pinus taeda), pitch pine (Pinus rigida), and Virginia creeper (Parthenocissus quinquefolia).

Wetlands. Wetlands have long been recognized for providing an essential habitat for wildlife, and they are now being recognized for their economical and environmental values as well. Fish and wildlife utilize this habitat in many ways. While some organisms spend their entire lifetime within a wetland, others use it for certain life stages such as nursery or feeding areas. Wetlands are also essential for the majority of endangered plants and animals. Coastal and inland wetlands are critical for fish and shellfish habitats. Approximately two-thirds of the major U.S. commercial fishes depend on estuarine saltmarshes for nursery and spawning grounds. Broadkill Beach is surrounded by 8,818 acres of wetlands and forested uplands which make up the Prime Hook Wildlife Refuge. This refuge lies directly west and north of the beach community. The saltmarshes around Broadkill Beach have a salinity range of 20 to 30 parts per thousand, and the area is generally flooded twice each day by the tides. The dominant plant species in these productive areas is smooth cordgrass (Spartina alterniflora). The high marsh, which is flooded less often, is located above the tall cordgrass zone and is predominately inhabited by salt hay grass (Spartina patens), spike grass (Distichlis spicata), and common reed (Phragmites australis). Other floral species commonly found in a cordgrass marsh are big cordgrass (S. cynosuroides), black grass (Juncus gerardii), and switch grass (Panicum virgatum).

Wetlands in the Broadkill area are home to many organisms. Such species include snails (Melampus bidentatus), fiddler crab (Uca sp.), ribbed mussel (Modiolus demissus), blue mussel (Mytilus edulis), marsh crab (Sesarma sp.), snapping turtle (Chelydra serpentina), and the diamond back terrapin (Malaclemys terrapin). When the saltmarshes are flooded, several species of fish also inhabit the area. These species are mullet (Mugil cephalus), mummichog (Fundulus heteroclitus), red drum (Scianops occelatus), sheepshead minnow (Cyprinodon variegatus), and striped killifish (Fundulus majalis). The wildlife habitat in the Broadkill Beach area is excellent, and waterbird management is especially emphasized. Hunting, trapping, boating, fishing, and wildlife observation are all important recreational activities.

Intertidal Zone. The upper marine intertidal zone is primarily barren. Organic inputs are derived from the bay through beach wrack, made up of drying seaweed, tidal marsh plant debris, decaying marine animals, and miscellaneous debris that is washed up and deposited on the beach. The beach wrack provides a cool and moist microhabitat suitable for crustaceans such as the amphipods: Orchestia spp. and Talorchestia spp., which are commonly referred to as beach fleas. Beach fleas are important prey to ghost crabs (Ocypode quadrata). Various foraging birds and some mammals are attracted to the beach fleas, ghost crabs, carrion, and plant debris found in this zone.

The intertidal zone is much more biologically active than the upper intertidal zone. Frequent inundation of water provides a suitable habitat for benthic infauna. The horseshoe crab (Limulus polyphemus) is a very notable inhabitant of the intertidal zone along the sandy beaches of Delaware Bay. The crabs migrate into shallow water in late spring to spawn in the upper tidal zone. Spawning activity peaks in May and June. Because of the large seasonal abundance of horseshoe crab eggs, the lower bay region ranks as one of the largest migratory shorebird staging areas. Adult horseshoe crabs play a minor role in commercial fisheries and are harvested for medical use, fertilizer, and animal feed.

Broadkill Beach is a productive benthic habitat according to results from a benthic habitat assessment study. Invertebrate phyla inhabiting the coastline are represented by Cnidaria (jellyfish), Platyhelminthes (flatworms), Nemertinea (ribbon worms), Nemathelminthes (Nematoda), Bryozoa, Mollusca (chitons, clams, mussels), Echinodermata (sea urchins, sea cucumbers, sand dollars, sea stars), and the Urochordata (tunicates).

4.3.2. Aquatic Species

Phytoplankton. The growth of phytoplankton depends on temperature, light, nutrients, and trace elements such as metals and vitamins. These factors are crucial to the health of the bay and its food web. Several hundred species of phytoplankton have been observed in the Delaware Bay, and perhaps the most predominant are the diatoms. These organisms are well suited for growth in the spring when nutrient levels are high and temperatures are low. The spring diatom bloom supports the growth of larval and juvenile shellfish and fish species. Summer phytoplankton is mostly made up of small green and brown algae, occurring for the most part in the lower Bay.

Zooplankton. Zooplankton graze on phytoplankton during productive periods. These zooplankton range in size from microscopic single celled organisms to larger jellyfish. Populations of zooplankton reach a peak in the lower Bay during April, and another lower peak building from June through August. These organisms provide an essential trophic link between primary producers such as phytoplankton, and higher organisms such as larger invertebrates and fish. Sampling in the lower Bay by Watling and Maurer (1976) resulted in the observation of 60 species of zooplankton representing the following Phyla: Protozoa, Cnidaria, Ctenophora, Ectoprocta, Annelida, Mollusca, Arthropoda, Chaetognatha, and Chordata. Three copepod species, Acatria tonsa, Eurytemora hirundoides, and Eurytemora affinis, dominate the lower Bay, and constitute about 84% of all zooplankton (Pennock and Herman, 1988).

Benthic Organisms. Benthic macroinvertebrates are organisms that dwell in the substrate (infauna) or on the substrate (epifauna). They provide an important food source for both fish and humans, and were found to be abundant in the study area. A benthic assessment conducted in July 1994 by Battelle revealed the following abundant species: 3 bivalves Gemma gemma, Nucula annulataq, and Tellina agilis; 5 crustaceans Protohaustorius wigleyi, Tanaissus psammophilus, Corophium tuberculatum, Ampelisca verrilli, and Neomysis americana; 8 annelids Oligochaeta spp., Parapionosyllis longicirrata, Sabellaria vulgaris, Spiophanes bombyx, Brania wellfleetensis, Polydora cornuta, Spio setosa, and Mediomastus ambiseta; and 1 urochordate Ascidiacea spp. A Greeley Polhemus study (1994) assessed the benthic habitat of a 500 acre site 1,000 yards offshore of Broadkill Beach. Fifty-one species of benthic organisms, mostly crustaceans and polychaete worms, were collected in 40 samples. The crustacean Ampelisca sp., the bivalve mollusk Mulinia lateralis, the crustacean Cerapus tubularis, and the bivalve mollusk Nucula proxima were most abundant in descending order. The benthic macrofauna at the two offshore borrow sites represents a typical community. No exploitable populations of commercially important species are believed to occur here.ltiyconsist of species typical icb

Finfish. Over 100 species of finfish occupy the Delaware Bay, and many of these species are recreationally important. This great diversity results from the overlap between the northern and southern species in the mid-Atlantic coastal region. The bay is used by many species as a breeding ground and nursery area for their young. Maurer and Tinsman (1980) conducted surveys of the finfish in Delaware's coastal waters, and annual surveys have also been conducted for several years by the National Marine Fisheries Service. Included in the abundant finfish species are the red hake (Urophycis chuss), northern sea robin (Prionotus carolinus), spot (Leiostomus xanthurus), windowpane flounder (Scopthalmus aquosus), silver hake (Merluccuns bilinearis), bluefish (Pomatomis saltatrix), summer flounder (Paralichthys dentatus), clearnose skate (Raja eglanteria), hogchoker (Trinectes maculatus), and weakfish (Cynocion regalus).

The weakfish is one of the most abundant and valuable species, in terms of commercial and recreational importance, within the Delaware Bay. It lives in the area between April and October, and normally spawns between Mispillion River and Lewes. Spawning primarily occurs during June and July. The larvae develop into juveniles once they are transported to the middle and upper estuary. By the fall, they have reached a length of 4 to 6 inches, and they then migrate to spend the winter in the warmer waters off Virginia and North Carolina.

Shellfish. The surf clam (Spisula solidissima) was once an important commercial species harvested from Delaware's coastal waters. Commercial harvesting ceased in 1975, and subsequent surveys conducted by the State in 1982, 1986, and 1992 confirmed that no significant populations of surf clams exist within Delaware's territorial zone. Although commercially harvestable clams are lacking, the number of juveniles in the area has increased in recent years. Results from the benthic assessment conducted for the candidate borrow sites indicate that one to seven individuals were collected from each sample grab.

The blue crab (Callinectes sapidus) is an important commercial species within the Delaware Bay. Blue crabs seasonally migrate into the area. In early spring and summer, the crabs are caught nearshore in the lower bay. As temperatures increase, the crabs are caught further upbay. When temperatures drop again in the fall, the crabs travel back down to the lower bay and burrow under the sediment to overwinter (Shuster 1959). Despite the annual fluctuation in catch, the blue crab population is considered healthy and sustainable. Over two million pounds are harvested each year by a dredge in the fall (Price *et al.*, 1983). The yearly recreational catch approximates 10% of the yearly commercial catch.

4.3.3. Terrestrial Species

There are a number of non-marine mammals, reptiles, amphibians, and birds that inhabit or are associated with the Broadkill area. Most noticeable are the many species of birds that inhabit the beach. Gulls typically forage on beach wrack such as carrion and plant parts. Such species of gulls include the laughing gull (Larus atricilla), herring gull (L. argentatus), and ring-billed gull (L. delawarensis). Other beach dwelling birds are the savannah sparrow (Passerculus sandwichensis), song sparrow (Melospiza melodia), mourning dove (Zenaida macroura), gray catbird (Dumetella carolinensis), northern mockingbird (Mimus polyglottos), and brown thrasher (Toxostoma rufum). The Delaware Bay ranks as the largest spring staging site for shorebirds in eastern North America, therefore shorebird numbers are especially noticeable during spring and fall migrations. These staging sites are critical to the survival of hundreds of thousands of migrating shorebirds, as they provide a link between wintering areas and breeding sites.

Burger (1983) documented over 400,000 shorebirds, representing 21 different species between May and October of 1982. The birds arrive in early May from Brazil, Patagonia, Tierra del Feugo, Chile, Peru, Suriname, Venezuela, and the Guyanas. After a nonstop flight of up to 5,000 miles, lasting several days, the birds have depleted their energy reserves and need to stop to refuel. The Delaware Bay provides an ideal resting site, and the birds feast on horseshoe crab eggs before continuing their northward migration to Arctic nesting grounds. Common species include sanderling (Calidris alba), dunlin (C. alpina), semipalmated sandpiper (C. pusilla), red knot (C. canutus), western sandpiper (C. mauri), willet (Catoptrophorus semipalmatus), ruddy turnstone (Arenaria interpres), and short-billed dowitcher (Limnodromus griseus). In 1985, Delaware Bay became a charter member of the Western Hemisphere Shorebird Reserve Network, an organization that encourages protection for internationally significant staging areas.

Avian use of wetlands is also extensive. The laughing gull (L. atricilla), sharp-tailed sparrow (Ammospiza caudacuta), seaside sparrow (Ammospiza maritima), clapper rail (Rallus longirostris), black duck (Anas rubripes), blue-winged teal (Querquedula discors), willet (Catoptrophorus semipalmatus), and marsh hawk (Circus hudsonius) all nest in the saltmarsh areas. Wading birds such as the great blue heron (Ardea herodias), little blue heron (Florida caerulea), black-crowned night heron (Nycticorax nycticorax hoactli), glossy ibis (Plegadis falcinellus), common egret (Casmerodius albus), and snowy egret (Egretta thula) feed in the salt marshes and nest in the adjacent woody vegetation. The bay's coastal marshes are also important feeding and stopover areas for migrating birds such as greater snow geese (Chen caerulescens), black duck (Anas rubripes), Canada geese (Branta canadensis), and mallard (Anas platyrhynchos).

Over a dozen raptor and many owl species migrate through the area on an annual basis. These species include the sharp-shinned hawk (Accipiter striatus), Cooper's hawk (Accipiter cooperii), red-tailed hawk (Buteo jamaicensis), common barn owl (Tyto alba), northern saw-whet owl (Aegolius acadicus), and long-eared owl (Asio otus). The owls generally use the forested areas of the Refuge during their migration.

In addition, there are several reptiles, mammals, and amphibians that are associated with the beach habitat. These include the Fowler's toad (Bufo woodhousei fowleri), eastern hognose snake (Heterodon platyrhinos), box turtle (Terrapene carolina), raccoon (Procyon lotor), eastern cottontail (Sylvilagus floridanus), red fox (Vulpes fulva), white-footed mouse (Peromyscus leucopus), meadow vole (Microtus pensylvanicus),and white-tailed deer (Odocoileus virginianus).

4.3.4. Threatened and Endangered Species

Several threatened and endangered species are known to inhabit or migrate through the project area. The American peregrine falcon (Falco peregrinus anatum) and the Arctic peregrine falcon (Falco peregrinus tundrius) migrate through the Broadkill area, but are not known to nest there. Bald eagles (Haliaetus leucocephalus) have been observed nesting in the Prime Hook National Wildlife refuge. Eagles in the Delaware Bay area do not migrate out of the area, and remain loosely associated with their nests year round (pers. comm. Lisa Gelvin -Invaer, Delaware Fish & Wildlife). Eagle pairs bond around December or January, and egg incubation begins as early as February.

Piping plovers (Charadrius melodus) have previously nested south of Broadkill

Beach on Beach Plum Island, but they have not been observed there in recent years. Piping plovers normally begin nesting in March or April. The Prime Hook National Wildlife Refuge has forested areas which are home to the Delmarva fox squirrel (Sciurus niger), but the squirrels do not approach the project area. Sea turtles, including the Federally-listed threatened loggerhead (Caretta caretta) and green (Chelonia mydas), as well as the Federally-listed endangered Kemp's Ridley (Lepidochelys kempii), leatherback (Dermochelys coriacea), and hawksbill (Eretmochelys imbricata imbricata) have been observed offshore Broadkill Beach.

The northern diamondback terrapin (Malaclemys terrapin) is a Federal candidate species found in Delaware Bay within the tidal flats and marshes. The terrapin breeds in vegetated dunes above the high tide line. The harbor porpoise (Phocoena phocoena) normally feeds at the river mouths and occasionally becomes entangled within the gillnets in the project area. Dead porpoises have been found washed up on Broadkill Beach, and the harbor porpoise is currently a candidate for threatened status.

Six species of endangered whales have also been observed migrating along the Atlantic Coast, and are occasionally seen in the lower bay. These whales include the sperm whale (Physeter catodon), fin whale (Balaenoptera physalus), humpback whale (Megaptera novaeangliae), blue whale (Balaenoptera musculus), sei whale (Balaenoptera borealis), and black right whale (Balaena glacialis). All marine mammals are protected by Federal laws.

In addition, the shortnose sturgeon (Acipenser brevirostrum), an endangered species within the purview of the National Marine Fisheries Service, migrates through the project area in the spring from the sea to spawn in the upper estuary. Most of these fish have been observed in the upper tidal freshwater area of the Delaware River, but they also utilize the Delaware Bay, especially during the winter months.

Only one plant species, the sea beach pigweed (Amaranthus pumilus) is a concern within the project area. This species is Federally-listed and does not normally occur north of the Indian River. However, propagation on Beach Plum Island could result from a major storm event, when propagules are carried north or existing dormant seeds are exposed as a result of erosion.

4.4. Cultural Resources

In preparing the DEIS, the Corps has consulted with the Delaware State Historic Preservation Office (DESHPO) and other interested parties to identify and evaluate historic properties in order to fulfill its cultural resources responsibilities under the National Historic Preservation Act of 1966, as amended, and its implementing regulations, 36 CFR Part 800. As part of this work, a cultural resources investigation was conducted in the project area. The study findings are presented in a draft report entitled "A Phase 1

Submerged and Shoreline Cultural Resources Investigation, Broadkill Beach, Broadkill Hundred, Sussex County, Delaware" (Cox and Hunter, 1994) (see Appendix in main report). The following discussion is taken largely from the above referenced report.

4.4.1. Prehistoric Resources

The prehistoric occupation of Delaware and the Delmarva Peninsula has been categorized by archaeologists into three general periods of cultural development: Paleo-Indian (15,000 years before present (B.P.) - 8,500 B.P.), Archaic (8,500 B.P. - 5,000 B.P.), and Woodland (5,000 B.P. - 400 B.P.). Few Paleo-Indian sites have been located in the Delaware region of the Delmarva Peninsula. This is partly due to the low population density and nomadic lifestyle of the people from the period, as well as from the inundation of sites by sea level rise. During this time, the present site of Broadkill Beach was not coastal, but was covered by an inland forest possibly located near a tributary of the ancestral Delaware River. Evidence of Paleo-Indian occupation across the northern half of the Delmarva Peninsula is generally seen as isolated fluted point sites. No Paleo-Indian period sites have been recorded in the project vicinity.

Archaic sites in Delaware are attributed to macro-band and micro-band base camps located adjacent to freshwater swamps and bay/basin areas. Sites tend to be relatively small, suggesting short-term and intermittent occupations. The period is also marked by the appearance of ground stone tools in addition to flaked stone artifacts. Three prehistoric sites have been recorded in the project vicinity. One of these sites, Site 7S-d-42, has yielded a jasper Poplar Island projectile point attributed to the Archaic. The site is located adjacent to and slightly west of a modern salt marsh.

The emergence of the Woodland period roughly corresponds to warmer and dryer climatic conditions starting around 4,600 years ago. Early Woodland sites exhibit new diagnostic stone tools, an increase in base camps, and the appearance of storage pits and ceramic vessels. Evidence of trade is seen in Adena artifacts from the Ohio River Valley found at habitation and mortuary sites. Late Woodland occupation exhibits more permanent settlements, an increased reliance on shellfish, harvesting of plants, and the emergence of agriculture. In addition, distinctive ceramic forms and small triangular projectile points mark the Late Woodland. Two prehistoric sites in the Broadkill Beach vicinity have yielded both Early and Late Woodland period assemblages.

4.4.2. Historic Resources

The first documented exploration of the Delaware Coast was accomplished by Giovanni de Verranzo (1524) and Estevan Gomez (1525). The first Dutch explorers came to the Delaware Bay from New Amsterdam (New York City) in 1614, and soon set up trading stations and settlements at various locations along the banks of the bay and river. In 1631, the Dutch established a small whaling community near Cape Henlopen named "Zwaanendael." The Swedes and Dutch co-existed in the Delaware Valley until 1664 when the British, under the command of Sir Robert Carr, assumed command of the region. King Charles II deeded a substantial portion of the territory to William Penn in 1682, and subsequently established an English colony on the Delaware with Philadelphia as its capital. In the project vicinity, Wilmington, New Castle and Lewes began to emerge as viable port communities and regional trade centers in the second quarter of the 18th century. Other nucleated settlements developed locally at Newport, Newark and Christiana Bridge. Delaware remained predominantly agricultural throughout the colonial period, with dispersed farmsteads and a loosely defined road network.

Delaware exhibited rapid population growth, a relative decline in agricultural productivity and an increase in water-powered milling during the early Federal Period (1780-1810). Road improvements and the construction of the Chesapeake and Delaware Canal increased economic activity. The Broadkill area remained largely agricultural, with the lumber and fishing industries continuing to be important. By the mid-19th century, a relatively well-developed secondary road network was in place and was replacing coastal shipping as the chief means of marketing agricultural produce in Sussex County. The lumber and charcoal industries in Sussex County persisted well into the 20th century.

Both Broadkill Beach and Broadkill Hundred derive their names from the Broadkill River, which flows from the historic port of Milton through the center of the hundred towards the Delaware Bay. Within Broadkill Hundred, most 18th and 19th century activity centered around three landings located along the Broadkill River: Milton, Drawbridge and Oyster Rocks. Scattered farmsteads were mostly located within one mile of the bay shoreline. The D.G. Beers Atlas of 1868 shows the study area within a lightly settled, poorly drained area known as Broadkiln Neck. Broadkiln Neck Road, likely in existence by the first quarter of the 19th century, terminated at the Delaware Bay near present day Wall Island. The study area was still undeveloped in the first quarter of the 20th century. By 1914, the current Route 16 had been constructed from Petersfield Island to the tip of Cape Lewes. A road also roughly paralleled the coast, connecting the former Broadkiln Neck Road with Route 16. Early 20th century maps show no buildings at Broadkill Beach. With the exception of one building noted as a possible late 19th century remodeled farmhouse, a recent architectural survey identified 19 buildings, constructed in the second quarter of the 20th century, that represent the original settlement on Broadkill Beach. The size of Broadkill Beach has increased dramatically, and today, Broadkill contains over 300 buildings, most of them frame residences.

4.4.3. Maritime History

The first comprehensive navigation chart of the Delaware Coast vicinity was not completed until 1756, when Joshua Fisher charted the Delaware Bay and provided the first bottom contours based on soundings. Standardized charting of the coast was not initiated until the first United States Coast Survey was completed in the middle of the nineteenth century. The earliest known aid to navigation in Delaware was the 1767 Cape Henlopen Light. A second lighthouse was constructed on Fenwick Island in 1858 to further aid mariners traversing the Delaware coastal waters. Two breakwaters, creating a Harbor of Refuge, were constructed inside Cape Henlopen between 1869 and 1901 to provide vessels protection from storms and ice at the mouth of the bay. By the middle of the nineteenth century the U.S. Coast Guard had established a series of lifesaving stations at Lewes, Cape Henlopen, Rehoboth Beach, Indian River Inlet, Bethany Beach and Fenwick Island. Historic maritime activity within the project area was almost exclusively transient, with vessels crossing the area on coastal networks linking the Delaware River Ports and New York with other ports from Maine to Texas and the Caribbean to Central and South America.

Over the years, many types of ships and vessels have wrecked while enroute up and down the coast. Many vessels were lost along the coast in an attempt to reach the Harbor of Refuge. Coastal storms, treacherous northeast winds and swift tidal currents coupled with historically heavy coastal traffic has caused the loss of dozens of documented sailing vessels, steamships, barges, tugs and large modern ships off the Delaware Coast. A variety of potential submerged cultural resource types in the project vicinity could date from the first half of the seventeenth century through the Second World War.

Broadkill River, known until 1889 as Broadkiln River and then Broadkill Creek, rises in the neighborhood of Georgetown. Milton, the historic head of navigation on the waterway lies approximately 12.5 miles above the mouth. Milton had three shipyards producing sailing vessels. Larger vessels were often towed to Philadelphia to complete their masting, rigging and outfitting. Vessels registered from Broadkill include the 10-ton shallop "Broad Kill", built in 1737. Between 1815 and 1915, local shipyards produced 271 vessels. A regular steamboat service was established between Milton and Philadelphia during the second half of the nineteenth century. The steamer "Mary M. Vineyard" carried a wide variety of general merchandise and passengers on a regular schedule. In addition to steamers, freight boats, steam barges, and two- and three-masted schooners were actively engaged in transporting farm produce, piling and brick, fertilizer and coal from Broadkill River to Philadelphia. Lack of water depth and the winding course of the river adversely effected Broadkill navigation. By the twentieth century, commercial maritime activity on the river declined, and ceased to operate by the 1930's.

In 1872, the U.S. Government inaugurated an improvement project on the Broadkill. By 1907, a curved jetty was constructed to create a new river mouth to the south. A five-foot deep channel was cleared and maintained to Milton. In 1909, the jetty was repaired and reinforced with additional stone filling. However, a major storm breached a new opening from Delaware Bay through to the Broadkill River. The new opening, which was south of the jetty, diverted water flow, and the former river mouth at the jetty eventually closed when additional improvements did not occur. By 1953, the Federal project which provided for an entrance channel from the bay to the river was abandoned. In addition, the Federal Government constructed a series of groins at Broadkill Beach in 1950.

4.4.4. National Register Properties

There are no properties in the Broadkill Beach project area listed on the National Register of Historic Places. However, numerous listed properties are located in the vicinity and are located generally in the Lewes area. These include three districts - the Cape Henlopen Archaeological District, the Lewes Historic District, and the National Harbor of Refuge and Delaware Breakwater Harbor Historic District. National Register listed residences include the Coleman House, Fisher Homestead, Maull House, and Norwood House. Significant religious buildings include the Cool Spring Presbyterian Church, Lewes Presbyterian Church and St. George's Chapel. One significant vessel, Lightship WLV 539, is also designated. No National Register listed properties will be impacted by the proposed construction described in the Feasibility Report.

4.4.5. Cultural Resources Investigations

Two remote sensing surveys of potential sand borrow areas have been completed in the Broadkill Beach area. The Delaware Division of Soil and Water Conservation conducted a Phase 1 survey of a potential offshore borrow area located adjacent to Broadkill Beach in 1985. The study results, presented in a report entitled "Offshore Cultural Resources Survey Between Pickering Beach and Broadkill Beach, Delaware" (Tidewater Atlantic Research, 1985), identified three magnetic targets exhibiting shipwreck signature characteristics in a location lying outside of, but adjacent to, the present study area. The Philadelphia District completed a remote sensing investigation of the present project borrow areas in 1994. The survey results, discussed in a draft report entitled "A Phase 1 Submerged and Shoreline Cultural Resources Investigation, Broadkill Beach, Broadkill Hundred, Sussex County, Delaware" (Cox and Hunter 1994), identified one remote sensing target displaying shipwreck characteristics. No significant cultural resources were identified along the project area shoreline. No prehistoric sites have been documented in the project vicinity.

4.5. Hazardous, Toxic, and Radioactive Wastes

In accordance with ER 1165-2-132 entitled Hazardous, Toxic, and Radioactive Wastes(HTRW) Guidance for Civil Works Projects, dated 26 June 1992, the Corps of Engineers is required to conduct investigations to determine the existence, nature and extent of hazardous, toxic, and radioactive wastes within a project impact area. Hazardous, toxic, and radioactive wastes are defined as any "hazardous substance" regulated under the Comprehenisve Environmental Response, Compensation and Liability Act (CERCLA), 42

U.S.C. 9601 et seq. as amended. Hazardous substances regulated under CERCLA include "hazardous wastes" under Section 3001 of the Resource Conservation and Recovery Act (RCRA), 42 U.S.C. 6921 et seq; "hazardous substances" identified under Section 311 of the Clean Water Act, 33 U.S.C. 1321; "toxic pollutants" designated under Section 307 of the Clean Water Act, 33 U.S.C. 1317; "hazardous air pollutants" designated under Section 112 of the Clean Air Act, 42 U.S.C. 7412, and "imminently hazardous chemical substances or mixtures" that EPA has taken action on under Section 7 of the Toxic Substance Control Act, 15 U.S.C. 2606.

An HTRW literature search was conducted for this study area by Environmental Risk Information and Imaging Services (ERIIS). The literature search identified no documented or potential HTRW sites in the project area. An additional search by the Philadelphia District Army Corps of Engineers of the DERP-FUDS database identified the Broadkill Beach Fire Control Station as a site of potential concern.

The Broadkill Beach Fire Control Station inventory project report was completed in 1991. Although the potential for ordnance, unexploded waste and chemical surety materials is unknown, the possibility for a project at Broadkill Beach to encounter HTRW or to degrade the existing environmental conditions is low.

The two identified borrow areas lie approximately 0.5 to 2.5 miles offshore of Broadkill Beach. The Broadkill Beach Fire Control Station has the potential to impact the borrow areas, in that ordnance may have been directed into the borrow areas by this station. A freedom of information record search was requested from the U.S. Coast Guard, but as of this time, no response has been received. However, consultation with knowledgeable officials and NOAA charts indicate that there is little potential for contamination of the borrow areas.

5.0. ENVIRONMENTAL IMPACTS

5.1. Comparative Effects of Alternatives

Unlike beach nourishment, structural alternatives, such as the construction of an offshore submerged sill and perched beach, groins, or breakwaters, result in a permanent displacement of habitat in the area of the footprint, and recolonization and recruitment of benthic organisms cannot take place. The no action alternative will allow the continuation of existing conditions as well as the existing processes which currently modify those conditions. Consequently, the following discussion will focus on the impacts of the beach nourishment alternative.

5.2. Physical Resources

5.2.1. Topography, Soils, and Groundwater

Under the no action alternative, erosion would continue and more beach would be lost. Without further engineering efforts, the existing groins and erosion control measures would continue to be ineffective.

The beach nourishment alternatives would result in topography changes in the borrow source locations offshore. Dredging would increase the depth in the borrow source areas by approximately 5-8 feet. This would result in a decrease in the average depth from 12 feet in 20 feet. The resulting cross-sectional configuration would be designed to approximate natural ridge slopes and therefore promote free exchange of water with the overlying and adjacent waters. The excavation would also be designed to ensure that all of the bottom substrate would not be removed, and therefore the bottom would retain its existing substrate character. The intent of excavating a broad basin with depth, contours, and substrate consistent with the adjacent areas was to simulate the character of the nearby environment. It is not anticipated that the proposed excavation of material would adversely affect sand and gravel production within the region.

Beach nourishment would result in the creation of a beach berm 100 feet wide at an elevation of +8 NGVD, with a dune at an elevation of +16 feet NGVD. The grade of the foreshore and underwater slopes would essentially parallel the existing profile. The increase in beach elevation would effectively widen the beach between the intersection of Beach Plum Drive and California Avenue to the north, and the intersection of S. Bayshore Drive and Truman Avenue to the south, with 1,000 foot tapers at both ends. The total project length would be approximately 13,100 feet. The net result would be a larger buffer against the erosion from storm events, and also an increase in usable beach in the project area.

The two potential borrow areas in the vicinity of the study area were identified from a coastwide acoustic subbottom profile and vibracore study. Borrow Area A contains large quantities of coarse to medium grained sand and Borrow Area B contains coarse to fined grained sand. This material was determined to be compatible beachfill based on the utilization of the U.S. Army Corps of Engineers Automated Coastal Engineering System. Consequently the substrate of the proposed beach should be similar in nature to the existing beach. Periodic renourishment is not expected to be required more often than if native beach materials were used.

Due to the relatively large distances between the borrow areas and the shore, the effects of using an offshore borrow source on groundwater should be negligible.

5.2.2. Hydrodynamics

The borrow areas lie approximately 2500 to 13,000 feet offshore of Broadkill Beach. Based on the distance of the borrow area from the shoreline, quantities of material in the borrow areas, and the rate of sedimentation in this zone, it is concluded that initial beachfill and planned periodic nourishment will have a negligible adverse effect on the physical or hydraulic characteristics of the adjacent shoreline.

5.2.3. Noise and Air Quality

Minor short-term impacts to air quality and noise levels would result from the construction phases of the beach nourishment alternative. Dredging activities and grading equipment use would produce noise levels in the 70 to 90 dBA (50 feet from the source) range but these would be restricted to the beach area. These noises would dissipate with distance. Ambient air quality would also be temporarily degraded, but emission controls and limited duration aid in minimizing the effects. In the case of equipment use associated with the periodic nourishment efforts, conducting the work in the off-season would further minimize the impact.

Noise and air quality impacts would be restricted to site construction preparation (generally beginning two weeks prior to dredging) and the actual dredging and placement operation. Noise is limited to the utilization of heavy equipment such as bulldozers to manipulate the material during placement. Additional noise may be caused by a pumpout station, if necessary. Depending on future circumstances, the construction may be conducted overnight to meet construction schedules. Air quality impacts would similarly be limited to emissions from the heavy equipment and pumpout station (if used). No long-term significant impacts to the local air quality are anticipated. Based on informal consultation with the U.S. EPA, Region III the construction activities described herein will comply with the State Implementation Plan for Delaware. EPA, Region III has reviewed the DEIS pursuant to Section 309 of the Clean Air Act.

5.2.4. Water Quality

Short-term adverse impacts to water quality in the immediate vicinity of the dredge will occur. Aquatic ecosystems concentrate biological and chemical substances such as organic matter, nutrients, heavy metals, and toxic chemical compounds in bottom sediments. When introduced to the water column, these substances tend to bind with suspended particulate matter and eventually settle to the bottom. Dredging operations typically elevate levels of suspended particulates in the water column through excessive agitation of the sediment. Suspension of sediments exposes associated biological and chemical constituents to dissolved oxygen, which can result in a variety of chemical reactions. Adverse impacts to water quality may include oxygen depletion and the release of chemical substances, making them biologically available to aquatic organisms through ingestion or respiration. The impacts of the potential for oxygen reduction or increased bioavailability of organic material due to dredging will be minimized by conducting dredging operations during the cooler months of the year when oxygen levels are higher and productivity is lower.

The dredging associated with the beach nourishment alternative would result in short-term adverse impacts to water quality. Dredging in the proposed borrow area will generate turbidity resulting in sedimentation impacts within the immediate vicinity of the operation. Short-term increased turbidity can effect organisms in several ways. Primary production in phytoplankton and/or benthic algae may become inhibited from turbidity. Suspended particulate matter can inhibit filter-feeding species. Reilly *et al.*, 1983 determined that high turbidity could inhibit recruitment by pelagic larval stocks. In addition, midwater nekton like finfish and mobile benthic invertebrates may migrate out of the area where turbidity and deposition occur.

The amount of turbidity and its associated plume is mainly dependent on the grain size of the material. Generally, the period of turbidity is less with larger grained materials. The proposed borrow locations contain primarily medium grained sands, coarser than silts and clays. Turbidity resulting from the resuspension of these sediments is expected to be localized and temporary in nature. Utilization of a hydraulic dredge with a pipeline delivery system will help to minimize the impact, however, some disturbance will occur.

Similar water quality effects on aquatic organisms could likely be incurred from the deposition of borrow material on the beach. Increased turbidity resulting from the deposition of a slurry of sand will be temporary in nature and localized. This effect should not be significant as turbidity levels are naturally high in the bay environment.

The borrow material is not expected to be chemically contaminated. The use of beach nourishment quality sand coupled with the absence of nearby dumping activities, industrial outfalls, or contaminated water infers the low probability that the borrow material is contaminated by pollutants.

5.3. Biological Resources

5.3.1. Aquatic Ecology

The majority of the impacts of beachfill placement will be felt on organisms in the intertidal zone and nearshore zones. The nearshore and intertidal zones are more dynamic, and are characterized by great variations in various abiotic factors. Approximately 69 acres of aquatic habitat (below mean high water) will be impacted by beachfill placement. Fauna of the intertidal zone are highly mobile and respond to stress by displaying large diurnal, tidal, and seasonal fluctuations in population density (Reilly *et al.* 1983). Despite the resiliency of intertidal benthic fauna, the initial effect of beachfill deposition will be the smothering and mortality of existing benthic organisms within the shallow nearshore (littoral) zone. This will initially reduce species diversity and density. Burial of less mobile species such as amphipods and polychaetes would result in losses, however, densities and biomass of these organisms are relatively low on beaches. Beach nourishment may also temporarily inhibit the return of adult intertidal organisms from their nearshore-offshore overwintering refuges, cause reductions in organism densities on adjacent unnourished beaches, and inhibit pelagic larval recruitment. Parr *et al.*, 1978 notes that the nearshore community is highly resilient to this type of disturbance, however, the offshore community is more susceptible to damage by receiving high sediment loads from fines sorting out from a beachfill.

The ability of a nourished area to recover depends heavily on the grain size compatibilities of material pumped on the beach (Parr *et al.*, 1978). Reiley *et al.* (1983) conclude that nourishment initially destroys existing macrofauna, however, recovery is usually rapid after pumping operations cease. Recovery of the macrofaunal component may occur within one or two seasons if grain sizes are compatible with the natural beach sediments. However, the benthic community may be somewhat different from the original community. Hurme *et al.* (1988) caution, "macrofauna recover quickly because of short life cycles, high reproductive potential, and planktonic recruitment from unaffected areas. However, the recolonized community may differ considerably from the original community. Recolonization depends on the availability of larvae, suitable conditions for settlement, and mortality. Once established, it may be difficult for the original community species to displace the new colonizers." Benthic recovery on the beach/intertidal zone may become hampered by periodic nourishments. Based on the above-mentioned studies, the benthic community may take 1-2 years to recover. With a five year renourishment cycle, the benthic community may be in a higher than normal state of flux as a result of the periodic disturbances of renourishment. It is conceivable that the benthic community may attain a recovered state for a period of 3-4 years before being disturbed again by a renourishment cycle.

The primary ecological impact of dredging the sand borrow areas will be the complete removal of the existing benthic community through entrainment into the dredge. Mortality of benthic and epibenthic organisms will occur as they pass through the dredge and/or as a result of being transplanted into an unsuitable habitat. This impact will be minimized by scheduling dredging during the least productive months of the year (fall and winter). A secondary disturbance results from the generation of turbidity and deposition of sediments on the benthic community adjacent to the dredging. Despite the initial effects of dredging on the benthic community, recolonization is anticipated to occur within one year. Saloman *et al.* (1982) determined that short-term effects of dredging lasted about one year resulting in minor sedimentological changes, and a small decline in diversity and abundance within the benthic community.

The recovery of a borrow area is dependent upon abiotic factors such as depth of the borrow site and the rate of sedimentation in the borrow site following the dredging. Dredging a borrow site can result in changes that affect circulation patterns, resulting in pits where fine sediments can accumulate, which may lead to hypoxia or anoxia in the depression. Accumulations of fine sediment may also shift a benthic community from predominantly a filter-feeding community to a deposit-feeding community. It is important that for recovery, the bottom sediments are composed of the same grain sizes as the pre-dredge bottom. Cutler *et al.* (1982) investigated long-term effects of dredging on the benthic community and noted that faunal composition was different than the pre-dredge community, however, the difference was attributed more to normal seasonal and spatial variations. In this study, it was determined that neither borrow area is faunistically unusual. The faunas of the two areas differ slightly, but these differences appear explainable in terms of the sedimentological differences in the two areas (see Appendix for results of the subbottom acoustical analysis). Considering faunal and sediment data, Borrow Area A is similar to the control site just to its north, and Borrow Area B is similar to the control site just to its south. Neither site appears to contain any commercially important species, nor any rare species (Kropp, 1994).

Periodic disturbances from maintenance of the project may favor the development of benthic communities composed primarily of colonizers. Assuming that the same location is dredged every five years, the secondary benthic community may be in a higher state of flux than the original community. This may, in effect, favor more r-selected (rapid reproduction, short life span) benthic species in the sand borrow impact area over the 50-year project life. In addition, benthic organism abundances may be lower than normal. However, this may not be the case if subsequent dredging cycles are conducted at different locations within the borrow areas. This would allow disturbed areas from previous dredging disturbances to become reestablished.

Benthic investigations in and around the two proposed borrow areas indicate the presence of a benthic community that is higher in mean total abundance in area A (2126 (=1114 indivs./0.1 m^2) than in area B (374 (= 68 indiv./0.1 m^2). Mean total abundance in the two control sites was 1085 (=754 indivs./0.1 m^2). The relative contribution of the major taxonomic groups varied considerable within these areas. The total number of species per sample was higher in Area A (21-41) than in Area B (15-29). However, species diversity at stations in Area A was found to be relatively low, ranging from 0.33 at Station A-10 to 3.04 at Station A-4). Species diversity at stations in Area B was higher than at stations in Area A (1.72 at Station B-7 to 3.30 at Station B-15). Refer to the benthic assessment report in the appendix. The most striking feature of borrow area A was the very high abundance of the small venerid clam Gemma gemma, which averaged about 1362 (= 1164) indivs./0.1m^2. Haustoriid amphipods, oligochaete worms, and the capitellid polychaete Amastigos caperatus were also relatively more abundant in Area A than elsewhere. Borrow Area B was characterized by relatively high abundances of the gastropod Acteocina canaliculata, the clam Tellina agilis and ampeliscid amphipods.

The existing benthic community is adapted to dynamic conditions and is capable of rapidly recovering from such a disturbance (USFWS, 1994). Recolonization of the benthic community may occur within 1-2 years following dredging, however, the effects of the three year periodic project maintenance over a 50 year project life may have more profound adverse effects if conducted in the same locations. Hurme *et al.* (1988) recommended that borrow materials be obtained from broad, shallow pits in nearshore waters with actively shifting bottoms, which would allow for sufficient surficial layer of similar sediments for recolonization. Measures that would minimize the effects of dredging in the borrow areas include dredging in a manner as to avoid the creation of deep pits, alternating locations of periodic dredging, dredging during periods of lowest biological activity, and the utilization of a hydraulic dredge with a pipeline delivery system.

Impacts to horseshoe crabs are not anticipated to occur as a result of the beach nourishment project. No construction activities will take place during the spring when horseshoe crabs congregate on Delaware Bay beaches to spawn.

Shellfish. Since the 1970s, there have been no commercially harvestable stocks of surf clams within the study area. For this reason, it can be expected that there will be no significant adverse impacts to this fishery from initial project construction. However, the potential conflicts with periodic operation and maintenance of the project and the surf clam fishery may arise during the 50 year life of the project. Despite the current conditions of the fishery, the potential for the surf clam fishery to recover and reach commercially harvestable sizes and densities does exist. Adverse impacts to a recovering surf clam population may be avoided by implementing a monitoring program for the subsequent periodic dredging in the borrow areas. Future monitoring may be necessary to determine if a commercially viable population of surf clams has become established, and to locate areas within the proposed borrow site where densities are low enough to avoid the destruction of any significant stocks. Coordination with the appropriate resource agencies prior to periodic dredging for beach maintenance will be conducted to determine if and/or where surf clam monitoring is necessary.

Finfish. With the exception of some small finfish, most bottom and pelagic fishes are highly mobile and should be capable of avoiding entrainment into the dredging intake stream. It is anticipated that some finfish would avoid the turbidity plume while others may become attracted to the suspension of food particles in the water column. Little impacts to fish eggs and larvae are expected because these life stages are widespread throughout the bay, and not particularly concentrated in the study area. The primary impact to fisheries will be felt from the disturbance of benthic and epibenthic communities. The loss of benthos and epibenthos entrained or smothered during dredging and beachfill placement will temporarily disrupt the food chain in the impact area. This effect is expected to be temporary as these areas become rapidly recolonized by pioneering benthic and epibenthic species.

5.3.2. Terrestrial Ecology

Construction of the beach nourishment alternative would result in the initial placement of approximately 1,066,000 cubic yards of sand on the beach, with subsequent periodic nourishments of approximately 358,400 cubic yards every 5 years for a project life of 50 years. This construction will disturb the impacted beach area, however, impacts to terrestrial species are expected to be minor and temporary. The present species inhabiting the beach are capable of surviving under adverse conditions, and most are capable of migrating out of the impacted area. Therefore, impacts are not expected to be significant. It would be reasonable to expect reinvasion from adjacent areas shortly after the end of construction, and a rapid return to pre-construction conditions.

5.3.3. Threatened and Endangered Species

The piping plover, which is state- and Federally-listed as a threatened species, is an inhabitant of Delaware sandy beaches. Although nesting sites have not been observed within the study area in recent years, the lack of human disturbance on Beach Plum Island makes the study area suitable habitat for the plover. If a piping plover or nest is discovered within the project area prior to initial project construction or the maintenance activities, the Corps will contact the Delaware Department of Natural Resources and Environmental Control, Division of Fish & Wildlife and the U.S. Fish & Wildlife Service to determine appropriate measures to protect the piping plovers from disturbance. Measures may include establishing a buffer zone around any nest sites, and limiting construction to be conducted outside of the nesting period (1 April - 1 September).

From June through November, Delaware's coastal waters may be inhabited by transient sea turtles, especially the loggerhead (Federally-listed threatened) or the Kemp's ridley (Federally-listed endangered). Sea turtles have been known to be adversely impacted by dredging operations that utilize a hopper dredge. Shallow water in the Broadkill Beach project area preclude the use of a hopper dredge.

Dredging encounters with sea turtles have been more prevalent along waters of the southern Atlantic and Gulf coasts, however, incidences of "taking" sea turtles have been increasing in waters of the middle Atlantic coast. Coordination with the National Marine Fisheries Service (NMFS) in accordance with Section 7 of the Endangered Species Act has been undertaken on all Philadelphia District Corps of Engineers dredging projects that may pose an impact to Federally threatened or endangered species. A Biological Assessment that discusses potential effects of dredging on Federally threatened or endangered species has been provided to NMFS. Projects which utilize a hopper dredge between June and November currently require a NMFS approved sea turtle observer on the dredge to monitor for sea turtles during dredging. Shallow water depths in the Broadkill Beach project are preclude the use of a hopper dredge and therefore, turtle monitoring will not be necessary. The Philadelphia District has entered into a formal consultation with NMFS on all District dredging activities that may impact threatened and endangered species under NMFS jurisdiction. A Biological Opinion by NMFS will be issued to the District to complete the formal consultation process. The District will adhere to the findings and requirements in the Biological Opinion in compliance with Section 7 of the Endangered Species Act, as amended.

5.4. Impacts on Cultural Resources

5.4.1. Project Impact Areas for Cultural Resource Review

Proposed project construction has the potential to impact cultural resources in three areas. These are the existing beach, near-shore sand placement area and offshore borrow areas. In the beach and near-shore sand placement areas, potential impacts to cultural resources could be associated with the placement and compaction of sand during berm and dune construction. Dredging activities in offshore borrow areas could impact submerged historic properties.

5.4.2. Shoreline and Near-shore Sand Placement Areas

On the basis of the current project plan, the Corps is of the opinion that sand placement within shoreline and near-shore project areas will have no effect on significant cultural resources. These areas are located in a highly unstable and shifting coastal environment, where the likelihood for intact and undisturbed cultural resources is considered extremely minimal. No archaeological sites or historic structures were identified within the project area during documentary and pedestrian shoreline surveys (Cox and Hunter

1994). A remote sensing survey was not conducted in the near-shore project area due to unsafe conditions in a very high energy, tidal surf zone. No properties listed on the National Register of Historic Places are within project boundaries, and none will be impacted by proposed construction.

5.4.3. Offshore Borrow Areas

Remote sensing investigations were conducted in project borrow areas (Cox and Hunter 1994). One remote sensing target exhibiting strong shipwreck characteristics was identified in Borrow Area B. Proposed sand borrowing activities will adversely impact this target location, which may represent a significant submerged cultural resource. Therefore, in order to eliminate construction impacts at this location, the Philadelphia District proposes to completely avoid this target during sand borrowing operations by delineating at least a 200 foot buffer around this target.

5.4.4. Section 106 Coordination

Based on our review of the draft report entitled "A Phase 1 Submerged and Shoreline Cultural Resources Investigation, Broadkill Beach, Broadkill Hundred, Sussex County, Delaware" (Cox and Hunter, 1994) and consultation with the DESHPO, the District has found that proposed dredging activities in Borrow Area B could potentially cause physical destruction or damage to one potentially significant submerged cultural resource. However, it is our position that impacts can be avoided and that measures can be taken to ensure that the project will have no adverse effect on this site. The Delaware SHPO concurred with the District's finding in a letter dated September 10, 1996 (see Pertinent Correspondence, Appendix D).

5.5. Socioeconomic Resources

The no action alternative would allow the beach to continue to erode, and this would increase the risk of damage to private property from flooding or direct wave action. Property values would also fall as the risk became more and more perceived by the market. Recreational opportunities would also decrease with the size of the beach. Although Broadkill Beach is utilized primarily by its inhabitants, a loss of recreational value can be translated into lost tourism revenue, which has a secondary effect on employment in the surrounding areas. The proposed project will pose a temporary impact on recreational use of the beach during actual construction.

Beach nourishment is a more natural and nonstructural solution to reducing storm damages in the project area. With the exception of short-term impacts during construction, overall aesthetics of the beach would be improved as a result. A natural-looking beach and dune would be more aesthetically pleasing and attractive to residents and tourists.

5.6. Unavoidable Adverse Environmental Impacts

The long-term adverse impact of the no action alternative would not be to the natural environment but to the regional economic environment. Increased flooding and decreased recreational use would occur as beach loss continues. As the risk of storm damage increases, property values would decrease. The long-term adverse impact of the beach nourishment alternative would be the decreased benthic community standing stocks, which would be affected during each dredging and placement operation.

5.7. Short-term Uses of the Environment and Long-term Productivity

The no action alternative does not involve short-term uses but would affect the long-term economy of the project area. The beach nourishment alternative would enhance the economy by storm damage reduction as well as provide additional recreational area.

5.8. Irreversible and Irretrievable Commitments of Resources

The no action alternative does not involve a commitment of resources. The beach nourishment alternative would involve the utilization of time and fossil fuels which are irreversible and irretrievable. Impacts to the benthic community would not be irreversible as benthic communities would reestablish with cessation of dredging activities.

5.9. Cumulative Effects

Cumulative Impact as defined by CEQ regulations is the "impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time".

Projects of this nature using beach nourishment from an offshore borrow area are becoming increasingly common in coastal areas of high development as they become susceptible to the erosive forces present. Numerous beach nourishment projects have been conducted along the Atlantic Coast since the 1960's by local, state, and Federal agencies, as well as private interests. Depending on circumstances such as the methods utilized to alleviate the coastal erosion and ensuing storm damages and the existing ecological and socio-economic conditions, it is difficult to gauge the net cumulative effects of these actions. The scientific literature generally supports beach nourishment projects over structural alternatives. If properly planned, impacts of beach nourishment projects are short-term, and have minor ecological effects.

Since the project was designed to minimize adverse environmental effects of all types, the project should not culminate in adverse cumulative impacts on ecological and socio-economic resources.

5.10. Mitigation

Mitigation measures are utilized to minimize or mitigate for project impacts to environmental resources within the project area. The appropriate application of mitigation is to formulate a project that first avoids and then minimizes adverse impacts and last, compensates for unavoidable impacts. Several measures can be adopted to avoid or minimize project impacts on effected resources such as benthic organisms, fisheries, endangered species, cultural resources, recreation, and noise.

Mitigation measures are either institutional in that environmental mitigation is inherent in project alternative selection, or as measures incorporated into the construction and operation and maintenance of the project. Several institutional measures have already been adopted to minimize the impacts on these resources. These measures include the selection of the beach nourishment alternative. This alternative offers a more natural and nonstructural approach for storm damage reduction. Selection of this alternative is based on its relatively low ecological impact and its cost effectiveness. Another measure is the selected use of suitable sand grain sizes for beach nourishment. The selection of the borrow area is based on compatibility studies for sand grain sizes. The selection of coarser beach nourishment material will minimize impacts on water quality at the dredging site and discharge site.

One of the most important ecological aspects of the Broadkill Beach study area occurs during the spring when tremendous numbers of migrating shorebirds arrive to feed on recently deposited horseshoe crab eggs. The eggs are a major source of food for the shorebirds and enable them to continue their northern migrations. Delaware Bay beaches provide a critical stop-over area for shorebirds. In recognition of its international significance as a shorebird staging area, the lower 25 miles of the Delaware Bay shoreline in Delaware and New Jersey has been included in the Western Hemisphere Shorebird Reserve Network. For this reason, dredging activities will not take place during the spring migration.

One potentially significant underwater cultural resource (a magnetic-acoustic anomaly) identified within Borrow Area B will be avoided during dredging operations. This will be accomplished by delineating at least a 200 foot buffer around the target.

In summary, the beach nourishment alternative does possess unavoidable impacts to several environmental resources of concern. These impacts can be minimized by implementing several measures during construction and operation and maintenance of the project. Mitigation measures recommended for construction, and operation and maintenance of the project involve minimizing impacts to benthic organism, fisheries, endangered species, recreation, and noise. The following measures are recommended.

Benthic Resources. The majority of the unavoidable impacts are likely to be incurred by the benthic organisms within the project area. Measures to minimize the effects of dredging in the borrow areas will include dredging in a manner as to avoid the creation of deep pits, alternating locations of periodic dredging, conducting dredging during months of lowest biological activity, and the utilization of a pipeline delivery system to help minimize turbidity. Implementation of a benthic monitoring program prior to periodic maintenance activities would document project impacts and aid in avoiding impacts to sensitive areas during periodic maintenance activities.

Fisheries. Adverse impacts to a potentially recovering surf clam population may be avoided by implementation of a monitoring program for subsequent periodic dredging and selection of borrow sites. This monitoring program would serve to avoid areas where surf clam densities may be increasing and avoid destruction of any significant stocks. Coordination with the appropriate resource agencies prior to periodic dredging for beach maintenance will be conducted to determine if and/or where surf clam monitoring is necessary.

Threatened and Endangered Species. The piping plover does not nest within the limits of the study area. This is probably due to the existing level of development. However, if piping plovers were to nest in the study area, such as to the south on Beach Plum Island, the Corps will contact the Delaware Department of Natural Resources and Environmental Control Division of Fish & Wildlife and the U.S. Fish & Wildlife Service to determine appropriate measures to protect the piping plovers from disturbance. These measures may include establishing a buffer zone around nesting birds and limiting construction in these areas to periods outside of the nesting season.

Sea turtles, especially the loggerhead (Caretta caretta), the Kemp's ridley (Lepidochelys kempii), green (Chelonia mydes), and leatherback (Dermochelys coriacea) may occur in the lower Delaware Bay from June to November. Sea turtles have been adversely impacted by dredging operations which utilize a hopper dredge. Shallow water depths at Broadkill Beach preclude the use of a hopper dredge and therefore, turtle monitoring will not be necessary during hydraulic dredging operations. Sea turtles and the endangered shortnose sturgeon (Acipenser brevirostrum) are under the purvue of the National Marine Fiseries Service (NMFS), which will issue a Biological Opinion that will specify any measures required, if any, to avoid impacts to these species.

The piping plover (Charadrius melodus) is protected under the State of Delaware's active endangered species program. The piping plover has not been observed in the study area. The FWS provided a Planning Aid Report in

January 1991 which states that with the exception of occasional transient individuals, no other federal or state listed endangered or threatened species occur in the study area.

Finally, beachfill operations typically occur in segments, subsequently moving as the work progresses. As each work segment is completed, it can be opened for recreational use. This would allow access to the beach in all areas outside of the segment under construction. Air quality and noise impacts can be reduced by utilizing heavy machinery fitted with approved muffling apparatus that reduces noise, vibration, and emissions.

6.0. LIST OF PREPARERS

The following individuals were primarily responsible for the preparation of this Environmental Impact Statement.

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7.0. PUBLIC INVOLVEMENT

Agencies notified of this study included the U.S. Fish & Wildlife Service (USFWS), the U.S. Environmental Protection Agency (USEPA), National Marine Fisheries Service (NMFS), Delaware Department of Natural Resources and Environmental Control (DNREC), and Delaware's State Historic Preservation Office.

A Planning Aid Report and Section 2(b) Fish & Wildlife Coordination Act Report prepared by the USFWS are provided in the appendix and correspondance section, respectively. The Section 2(b) Report provides official USFWS comments on the project pursuant to the Fish and Wildlife Coordination Act. A Benthic Animal Assessment Report and a Phase 1 Submerged and Shoreline Cultural Resources Investigation Report for Broadkill Beach are also provided in the appendix.

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8.0. EVALUATION OF 404(b) (1) GUIDELINES

I. Project Description

A. Location

The proposed project site is located at Broadkill Beach, a small coastal community located 5 miles from the mouth of the Delaware Bay in Sussex County, Delaware.

B. General Description

The proposed project involves reducing erosion and potential storm damages at Broadkill Beach by placement of dredged material (sand) from two offshore borrow source areas to the beachfront in the form of a berm 100 feet wide at an elevation of +8 feet NGVD with 15H:1V sideslope and a dune at an elevation of +16 feet NGVD with a 25 foot topwidth and 5H:1V sideslope. The total length of the project (including northern and southern tapers) is 13,100 feet. Dune grass will be planted on 27.5 acres with 18,800 linear feet of dune fencing.

C. Authority and Purpose

The authority for the proposed project is the resolution of the Committee on Public Works and Transportation, United States House of Representatives on 1 October 1986. The resolution reads as follows:

> "RESOLVED BY THE COMMITTEE ON PUBLIC WORKS AND TRANSPORTATION OF THE UNITED STATES HOUSE OF REPRESENTATIVE, that the Board of Engineers for Rivers and Harbors is hereby requested to make a compreehsive review of the existing reports on communities within the tidal portion of the Delaware Bay and its tributaries with a view to developing and updating a physical and engineering data base as the basis for actions and programs to privide shoreline protection or to provide up-to-date information for state and local management of this coastal area and to determine whether any modifications of the conclusions and recommendations contained in the previous reports of the Chief of Engineers that pertain to the Delaware Bay Coasts of Delaware and New Jersey are advisable at the present time. Such modifications to previous conclusions and recommendations shall be cognizant of, and incorporate where feasible, the findings of the final report of the Chief of Engineers on the Shoreline Erosion Control Demonstration Program, Section 54, of Public Law 93-251."

The purpose of the project is to reduce erosion and storm damages to the beaches and oceanfront structures of Broadkill Beach, Sussex County, Delaware.

D. General Description of Dredged or Fill Material

1. The proposed dredged material is fine to coarse grained sand with little or no gravel present. This material has been trapped by a combination of tidal and littoral forces and has been exposed to a high energy circulation regime.

2. The quantity required is estimated to be approximately 1,066,000 cubic yard initially with approximately 358,400 cubic yards every 5 years comprising periodic nourishment over a 50 year project life.

3. The two proposed sources of borrow material are located immediately offshore. Refer to Section 3.4 for borrow area coordinates. Borrow area A is 312 acres and Borrow Area B is 349 acres. The average depth in the borrow areas is 12 feet.

E. Description of the Proposed Discharge Site

1. The proposed location is depicted in Figure 3.

2. The proposed discharge is site is comprised of an eroding beach berm approximately 13,500 feet long with a minimum design width of 100 feet. The total area impacted below mean high water is approximately 69 acres.

3. The proposed discharge site is unconfined with placement to occur on a shoreline area.

4. The type of habitat present at the proposed location is a coastal intertidal and nearshore habitat.

5. Berm and dune restoration will be accomplished by beach nourishment. This plan will require approximately 1,066,000 cubic yards of sand for initial beachfill placement with approximately 358,400 cubic yards for periodic re-nourishment every 5 years over a 50 year project life. The proposed plan includes approximately 13,500 linear feet of beachfill extending from the southern end of Broadkill Beach at the intersection of Beach Plum Drive and California Avenue and extend north to the intersection of S. Bayshore Drive and Truman Avenue with 1,000 foot tapers at both ends. The net result will be a larger buffer against erosion from storm events and also an increase in usable beach. A dune is proposed along 11,500 feet of the berm with a top elevation of +16 feet NGVD and a top width of 25 feet. Dune grass will be planted on 27.5 acres with 18,800 linear feet of dune fencing.

F. Description of Disposal Method

A hydraulic dredge would be used to excavate the borrow material from the borrow sites. The material would be transported using a pipeline delivery system to the beachfill placement site. Subsequently, final grading would be accomplished using standard construction equipment.

II. Factual Determination

A. Physical Substrate Determinations

1. The final proposed elevation of the beach substrate after fill placement would be +8 feet NGVD at the top of the berm. The proposed profile would have a foreshore slope of 15H:1V and an underwater slope that parallels the existing bottom to the depth of closure. The dune will have a top elevation of +16 feet NGVD and a top width of 25 feet and a foreshore slope of 5H:1V.

2. The sediment type involved would be sand.

3. The planned construction would establish a construction template whichis higher than the final intended design template or profile. It is expected that compaction and erosion would be the primary processes resulting in the change to the design template. Also, the loss of fine grain material into the water column would occur during the initial settlement.

4. The proposed construction would result in removal of the benthic community from the borrow areas, and burial of the existing beach and nearshore benthic communities when the material is placed during berm construction.

5. Other effects would include a temporary increase in suspended sediment load and a change in the beach profile, particularly in reference to elevation.

6. Actions taken to minimize impacts include selection of fill material that is similar in nature to the preexisting substrate. Also, standard construction practices to minimize turbidity and erosion would be employed.

B. Water Circulation, Fluctuation, and Salinity Determinations

1. Water.
   - a. Salinity - no effect
   - b. Water chemistry - no significant effect
   - c. Clarity - minor short-term increase in turbidity
   - d. Color - no effect
   - e. Odor - no effect
   - f. Taste - no effect
   - g. Dissolved gas levels - no significant effect
   - h. Nutrients - minor effect
   - i. Eutrophication - no effect
   - j. Others as appropriate - none

2. Current patterns and circulation

a. Current patterns and flow - circulation would only be impacted by the proposed work in the immediate vicinity of the borrow area, and in the beach zone where the existing circulation pattern would be offset seaward the width of the beach.

b. Velocity - no effects on tidal velocity and longshore current velocity regimes.

c. Stratification - thermal stratification occurs beyond the mixing region created by the surf zone. There is a potential for both winter and summer stratification. The normal pattern should continue post construction of the proposed project.

d. Hydrologic regime - the regime is marine. This will remain the case following construction of the proposed project.

3. Normal water level fluctuations - the tides are semidiurnal with a mean tide range of 4.1 feet in the Delaware Bay. Construction of the proposed project work would not affect the tidal regime.

4. Salinity gradients - there should be no significant effect on the existing salinity gradients.

5. Actions that will be taken to minimize impacts - the borrow areas would be excavated in a manner to approximate natural ridge slopes to ensure normal water exchange and circulation. Utilization of sand from a clean, high energy environment and its excavation with a hydraulic drege would also minimize water chemistry impacts.

C. Suspended Particulate/Turbidity Determinations

1. Expected Changes in Suspended Particulates and Turbidity Levels in the Vicinity of the Disposal Site and Borrow Site - there would be short-term elevation of suspended particulate concentrations during construction phases in the immediate vicinity of the dredging and the discharge. Elevated levels of particulate concentrations at the discharge locations may also result from "washout" after beachfill is placed.

2. Effects (dredge and duration) on Chemical and Physical Properties of the Water Column -

a. Light Penetration - short-term, limited reductions would be expected at the borrow and disposal sites from dredge activity and berm washout, respectively.

b. Dissolved Oxygen - there is a potential for a decrease in dissolved oxygen levels but the anticipated low levels of organics in the borrow material should not generate a high, if any oxygen demand.

c. Toxic materials and organics - because the borrow material originates from a clean, high energy environment, and because it is essentially all coarse to fine grained sand, no toxic metals or organics are anticipated.

d. Pathogens - pathogenic organisms are not known or expected to be a problem in the borrow or disposal areas.

e. Aesthetics - construction activities and the initial construction template associated with the fill site would result in a minor, short-term degradation of aesthetics.

3. Effects on Biota

a. Primary production, photosynthesis - minor, short-term effects related to turbidity.

b. Suspension/filter feeders - minor, short-term effects related to suspended particulates outside the immediate deposition zone. Sessile organisms would be subject to burial if within the deposition area.

c. Sight-feeders - minor, short-term effects related to turbidity.

4. Actions taken to minimize impacts include the selection of clean sand with a small fine grain component and a low organic content. Standard construction practices would also be employed to minimize turbidity and erosion.

D. Contaminant Determinations

The discharge material is not expected to introduce, relocate, or increase contaminant levels at either the borrow or placement sites. This is assumed based on the characteristics of the material, the proximity of the borrow sites to sources of contamination, the area's hydrodynamic regime, and existing water quality.

E. Aquatic Ecosystem and Organism Determinations

1. Effects on Plankton - the effects on plankton should be minor and mostly related to light level reduction due to turbidity. Significant dissolved oxygen level reductions are not anticipated.

2. Effects on Benthos - although the project will result in a major disruption to the benthic community in the borrow areas when the fill material is excavated, the 404(b)(1) analysis focuses on the disposal area effects. Here the disruption is as significant as the entire community is subject to burial or displacement; however, the actual biomass of organisms impacted is far less

due to the harsher environmental conditions present on the beach and surf zone. The loss is somewhat offset by the expected rapid opportunistic recolonization from adjacent areas that would occur following cessation of construction activities. Recolonization is expected to occur in the disposal (beachfill placement) area through horizontal and in some cases, vertical migrations of benthic organisms.

3. Effects of Nekton - only a temporary displacement is expected as the nekton would probably avoid the active work area.

4. Effects on Aquatic Food Web - only a minor, short-term impact on the food web is anticipated. This impact would extend beyond the construction period until recolonization of the buried areas takes place.

5. Effect on Special Aquatic Sites - no special aquatic sites are to be significantly impacted.

6. Threatened and Endangered Species - the piping plover (Charadrius melodus), a Federal and state threatened species, could potentially be impacted by the proposed project. This birds nests on sandy beaches, however, no nesting sites have been observed within the project area. Several species of threatened and endangered sea turtles may be migrating through the sand borrow areas depending on the time of year. Sea turtles have been known to become entrained and subsequently destroyed by suction hopper dredges. A hopper dredge will not be utilized for this project and hydraulic dredging will not occur during the active periods of the year (summer months) when turtles are most likely to be present in the study area.

7. Other Wildlife - the proposed plan would not affect other wildlife.

8. Actions to Minimize Impacts - impacts to benthic resources can be minimized at the borrow areas by dredging in a manner as to avoid the creation of deep pits and alternating locations of periodic dredging. Impacts to Federal and state threatened piping plover can be avoided or minimized by establishing a buffer zone around any piping plover nests and limiting construction outside of the nesting season.

F. Proposed Disposal Site Determinations

1. Mixing Zone Determination

a. Depth of water - 0 to 20 feet mean low water
b. Current velocity - generally under 3 feet per second
c. Degree of turbulence - moderate
d. Stratification - none
e. Discharge vessel speed and direction - not applicable.
f. Rate of discharge - typically this is estimated to be 780 cubic yards per hour.

g. Dredged material characteristics - fine to coarse grained sand.
h. Number of discharge actions per unit time - continuous over the construction period.

2. Determination of consistency concurrence with the state's Coastal Zone Management Program has been obtained from the state of Delaware. Water Quality Certification will be issued upon favorable review of plans and specifications and subaqueous lands permit in the next phase of study.

3. Potential Effects on Human Use Characteristics -

a. Municipal and private water supply - no effect
b. Recreational and commercial fisheries - short-term effect during construction; there would be a minor loss of surf clam stocks within the borrow area from dredging.
c. Water related recreation - short-term effect during construction
d. Aesthetics - short-term effect during construction
e. Parks, national and historic monuments, national seashores, wilderness areas, etc. - no effect.

G. Determination of Cumulative Effects on the Aquatic Ecosystem - none anticipated.

H. Determination of Secondary Effects on the Aquatic Ecosystem - any secondary effects would be minor and of short duration.

III. Findings of Compliance or Non-Compliance with the Ecosystem

A. No significant adaptation of the Section 404(b)(1). Guidelines were made relative to this evaluation.

B. The alternative measures considered for accomplishing the project objectives are detailed in Section 3 of the document of which this 404(b)(1) analysis is a part.

C. A water quality certificate will be obtained from the Delaware Department of Natural Resources and Environmental Control in the next phase of study pending receipt of plans and specifications and favorable review of a subaqueous lands permit application.

D. The proposed beach nourishment will not violate the Toxic Effluent Standards of Section 307 of the Clean Water Act.

E. The proposed beach nourishment will comply with the Endangered Species Act of 1973. Informal coordination procedures have been completed.

F. The proposed beach nourishment will not violate the protective measures for any Marine Sanctuaries designated by the Marine Protection, Research, and Sanctuaries Act of 1972.

G. The proposed beach nourishment will not result in significant adverse effects on human health and welfare, including municipal and private water supplies, recreational or commercial fishing, plankton, fish, shellfish, wildlife, and special aquatic sites. Significant adverse effects on lifestages of aquatic life and other wildlife dependent on aquatic ecosystems; aquatic ecosystem diversity, productivity, and stability; and recreational, aesthetic, and economic values will not occur.

H. Appropriate steps to minimize potential adverse impacts of the discharge on aquatic systems include selection of borrow material that is low in silt content, has little organic material, is uncontaminated, and compatible with existing material.

I. On the basis of the guidelines, the proposed disposal site for the dredged material is specified as complying with the requirements of these guidelines, with the inclusion of appropriate and practical conditions to minimize pollution or adverse effects on the aquatic ecosystem.

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10.0. INDEX

RECOMMENDATIONS

284. In making the following recommendations, the Philadelphia District has given consideration to all significant aspects in the overall public interest, including environmental, social and economic effects, as well as the engineering feasibility and compatibility of the project with the policies, desires, and capabilities of the State of Delaware and other non-Federal interests.

285. As a requirement in completing the feasibility study, a public notice shall be issued to inform all interested parties of the plan selected herein. Because the design of the recommended plan is not technically complex and is essentially complete, a typical Design Memorandum would not be required before the initiation of construction. The only technical work remaining consists of borrow area sampling and final environmental coordination and documentation, which can be accomplished concurrent with preparation of plans and specifications for construction. In the event that this study leads to construction, the costs for these activities shall be reimbursed by the non-Federal sponsor as a cost-shared item.

286. The recommended storm damage reduction plan generally extends 14,600 feet along the community of Broadkill Beach and consists of :

* A berm extending bayward 100 ft. from the design line at an elevation of +8 ft NGVD, with a foreshore slope of 1V:15H to mean low water (MLW). From MLW bayward, the slope parallels the bottom out to the depth of closure. The beachfill extends from just north of Arizona Avenue southward along Broadkill Beach for approximately 13,100 feet. Tapers of 1000 feet and 500 feet, will extend from the northern and southern beachfill limits, respectively, for a total project length of 14,600 l.f.

* A dune with a top elevation of +16 ft NGVD and a top width of 25 ft. The landward and bayward slope of the dune face is 1V:5H.

* From the offshore borrow area, a total sand fill quantity of 1,305,000 cubic yards for the initial beachfill placement.

* 174,800 s.y. of planted dune grass for sand entrapment.

* 21,800 lf of sand fence to maintain dune stability and to delineate 20 walkovers and 1 vehicle access ramp.

* Renourishment of approximately 358,400 cubic yards of sand fill from the offshore borrow area every 5 years for the 50 year project life.

* Beachfill for the proposed project is available from an offshore borrow area located approximately 0.5 to 2.5 miles offshore of Broadkill Beach.

* To properly assess the functioning of the proposed plan, monitoring of the placed beachfill, borrow area, shoreline, wave and littoral environment is included with the plan. Environmental monitoring is being addressed through coordination with other interested agencies, and will be finalized in the Final Environmental Impact Statement.

287. If this project were to go to construction, the Federal Government shall contribute 65% of the first cost of the NED plan for developed land, which is currently estimated to be $5,258,000. Periodic nourishment of the selected plan shall be similarly cost shared when authorized by Congress. The plan described above is subject to modification at the discretion of the Commander, HQUSACE.

288. The plan which has been identified is technically sound, economically justified, and socially and environmentally acceptible. However, the current Administration's budgetary policy precludes further Federal participation in the design and construction of hurricane and storm damage reduction projects. The feasibility phase of study will be completed, but Federal funds will not be budgeted for future construction of this project.

289. The recommendations contained herein reflect the information available at the time and current Departmental policies governing formulation of individual projects. These recommendations may be modified before they are transmitted to the Congress as proposals for authorization and implementation funding. However, prior to transmittal to Congress, the Sponsor, the States, interested Federal agencies, and other parties will be advised of any modifications and will be afforded an opportunity to comment further.

For Robert B. Keyser
Lieutenant Colonel, Corps of Engineers
District Engineer