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1. **Plans Investigated.** Two alternative fill sections were evaluated: 1) a dune and berm and 2) a beach berm only. These beach-fill sections are described below.

   a. **Dune and Berm Plans**

      1) **Description.** Existing dunes were assumed to remain in place, with the designed dunes tying into them where appropriate. Designed dune templates were tied to a construction line, which is based on both the existing shoreline and the existing development. The landward slope of the dune template is 5 horizontal to 1 vertical, the top of the dune is 25 feet wide, and the seaward slope is 10 horizontal to 1 vertical. The berm elevation is 7 feet NGVD, with berm width measured from the toe of the constructed dune. Seaward of the designed berm width, the with-project profile parallels the existing profile out to a closure depth of –27 feet NGVD.

      2) **Dune and Berms Evaluated.** At the feasibility level, top of dune elevations of 11, 13 and 15 feet NGVD were evaluated with a 50-foot berm at elevation 7 feet NGVD. In order to envelop the NED plan, two additional plans were evaluated for a dune elevation of 13 feet NGVD, one with a 25-foot berm and one with a 100-foot berm. A typical dune and berm profile is shown on figure D-1.

   b. **Beach Berms Only**

      1) **Description.** The beach berm is a fill extending seaward from the existing profile with an elevation of 7 feet NGVD, which is approximately the elevation of the existing natural berm or normal limit of wave run-up along the Dare County Beaches. Berm width is measured seaward along the top of the berm from the point where the top of berm intersects the natural profile. Seaward of the designed berm width, the with-project profile parallels the existing profile out to the closure depth of –27 feet NGVD.

      2) **Berms Evaluated.** At the feasibility level, 50-, 100-, and 150-foot beach berm plans were evaluated. Each used a berm elevation of 7 feet NGVD and each was established from a construction line tied to both the existing shoreline and the existing development. A typical berm only profile is shown on figure D-2.

Typical Berm and Dune Profile

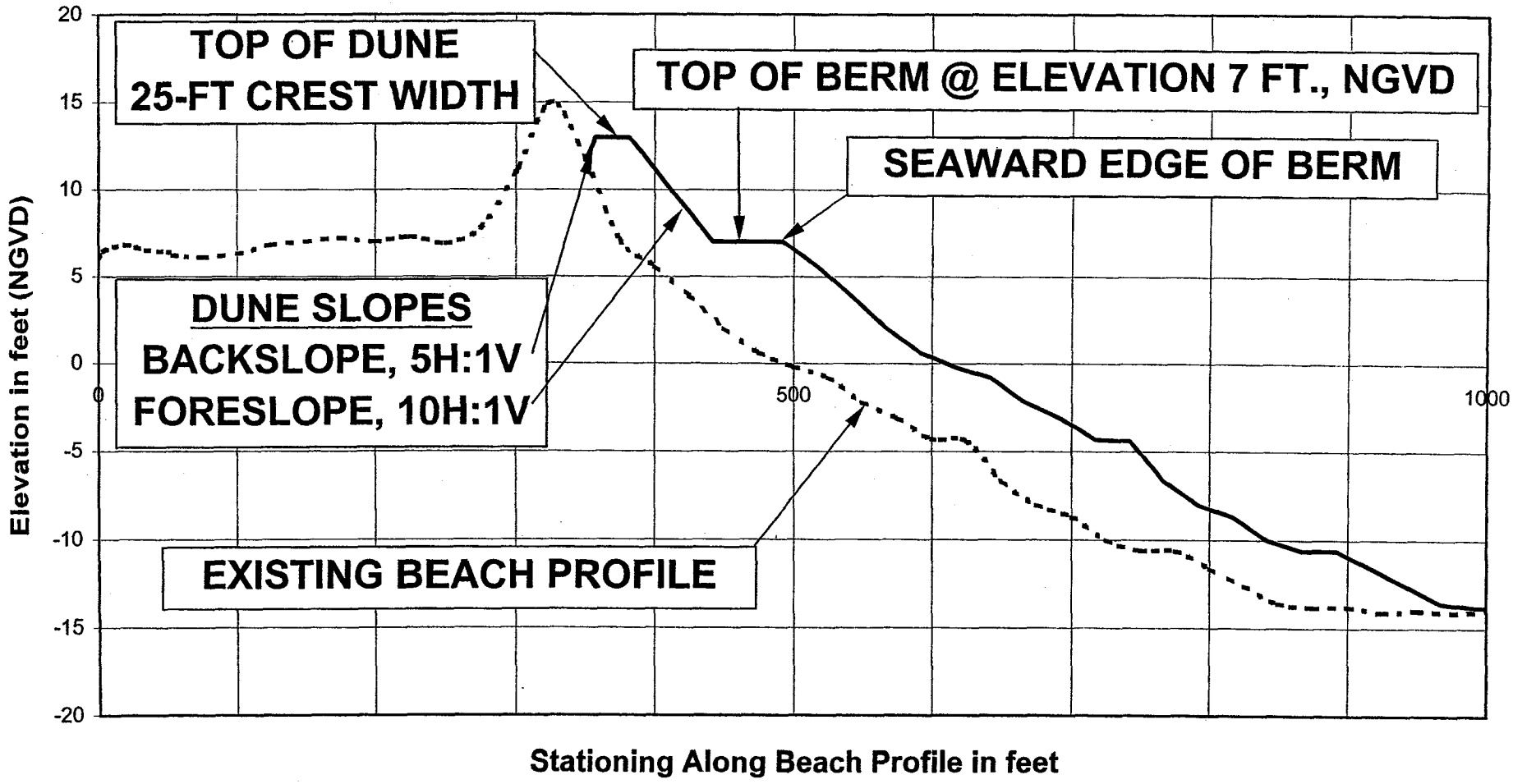


Figure D-1

Typical Berm Only Profile

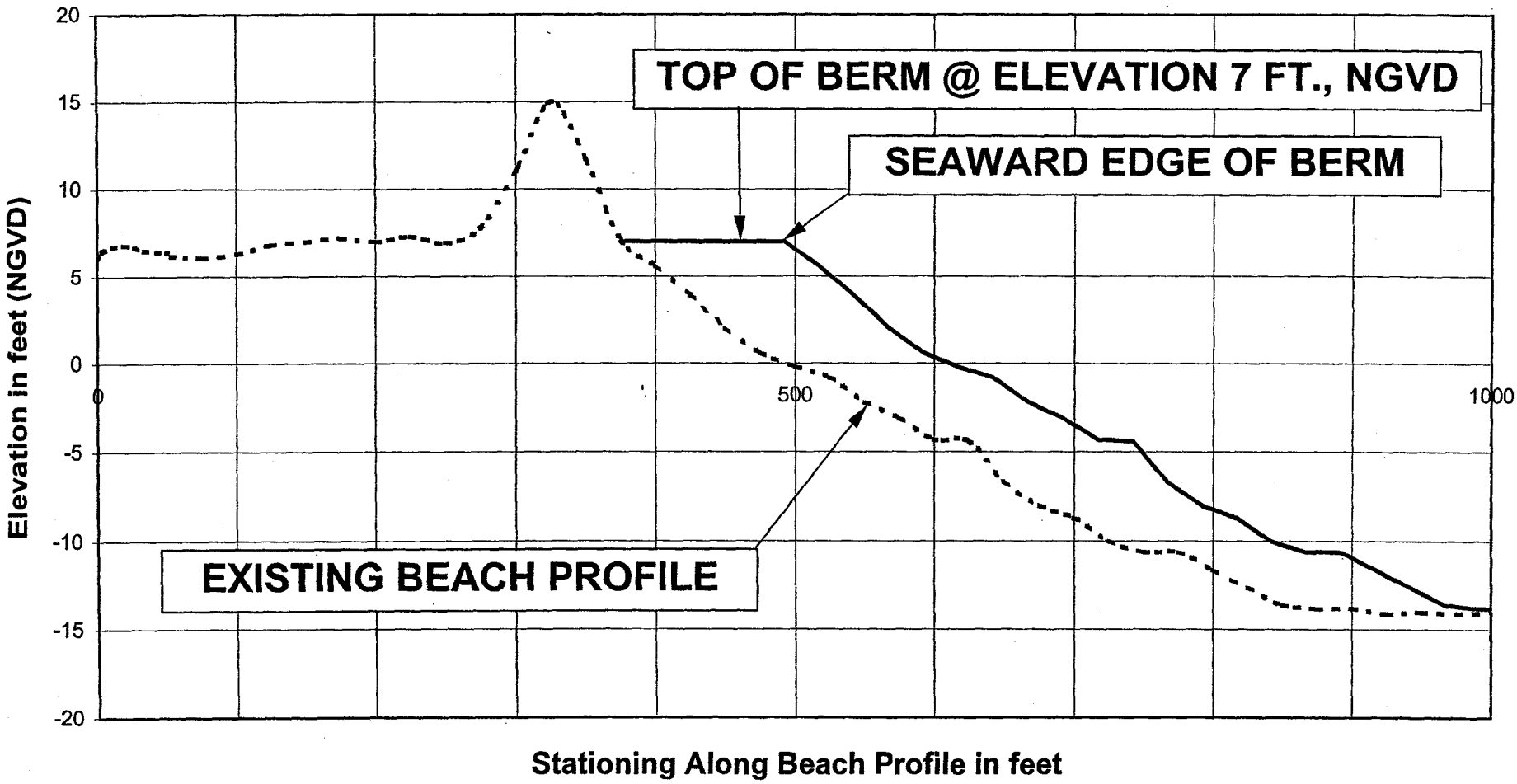


Figure D-2

c. Construction Line

The construction line for both the berm only and the berm and dune plans were established: a) to minimize impacts on existing development and b) to minimize erosion of the project by aligning the seaward edge of the berm parallel to the existing shoreline to the maximum extent practical. The construction line for the NED plan is shown on the Project Maps in Appendix C, plates C-1 through C-28.

2. Description of Recommended Plan.

a. Plan Description

The National Economic Development (NED) Plan is the recommended plan. The NED Plan consists of a 13-foot dune with a 50-foot berm that covers a 4.1-mile stretch of the Kitty Hawk/Kill Devil Hills Area (hereafter referred to as the North Project Area) and a 10.1-mile stretch of the Nags Head/South Nags Head Area (hereafter referred to as the South Project Area). The crest of the dune is 25-foot wide and the 50-foot berm is at elevation 7.0 feet, NGVD. The fore slope of the dune is 10 horizontal to 1 vertical and the back slope of the dune is 5 horizontal to 1 vertical. The back slope of the dune intersects the existing beach profile on or seaward of the construction line. The total length of the recommended plan is 14.2 miles. This includes transitions of approximately 3000-feet on the north and south ends of both the North and South Project Areas. For the NED plan, project limit stationing is shown in table D-1 and a plan view of the project study area, with project limits and borrow sites, is displayed on figure D-3. A typical berm and dune profile for the NED plan is displayed on figure D-4. Appendix C contains project maps showing the physical location of the main project and transitions on aerial photography of the study area. As shown on the profile on figure D-4, the project profile is assumed to parallel the natural contour below 0' NGVD out to a closure depth of –27 feet, NGVD. The initial construction profile will extend seaward of the final design berm profile a variable distance to cover anticipated sand movement during and immediately following construction. The variable distance will generally range from 100 to 200 feet along the project dependent upon foreshore slopes established by the fill material. Once sand redistribution along the foreshore occurs, the final design berm profile will be in place.

b. Project Data

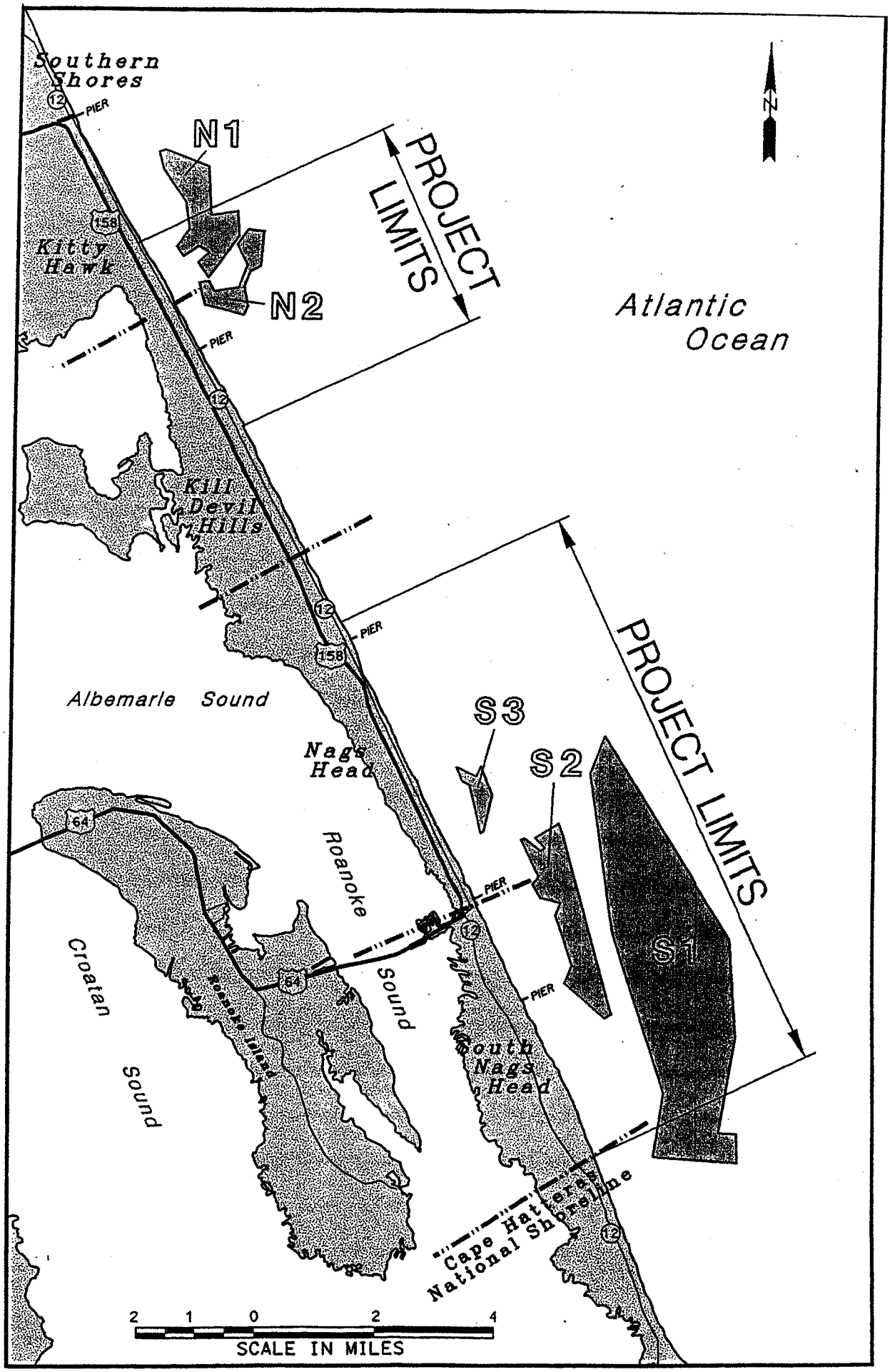
The recommended plan requires 4,300,000 cubic yards of material for the North Project Area and 8,040,000 cubic yards of material for the South Project Area during initial construction. These borrow volume quantities assume placement losses of 50 percent for the North Project Area and 10 percent for the South Project Area during initial construction. Project

Table D-1

Northern Dare County - Project Limits

Township	Main Project Begins	Main Project Ends	Main Project: Project Station	Main Project: Project Length (feet)	Main Project: Project Length (miles)	Total Project Length w/transition (miles)
North Project						
Kitty Hawk	Kitty Hawk Road (MP 4.3)		13,830	5,070	1.0	1.5
(Town Limits)			18,900			
Kill Devil Hills		500' South of 1st St. (MP 7.3)	29,730	10,830	2.0	2.6
Totals for North Project					3.0	4.1
South Project						
Nags Head	200' North of Nags Head Pier (MP 11.7)		52,160	25,940	4.9	5.5
(Town Limits)			78,100			
S. Nags Head		800' South of Altoona St. (MP 20.7)	99,650	21,550	4.1	4.6
Totals for South Project					9.0	10.1
Totals for North and South Project					12.0	14.2

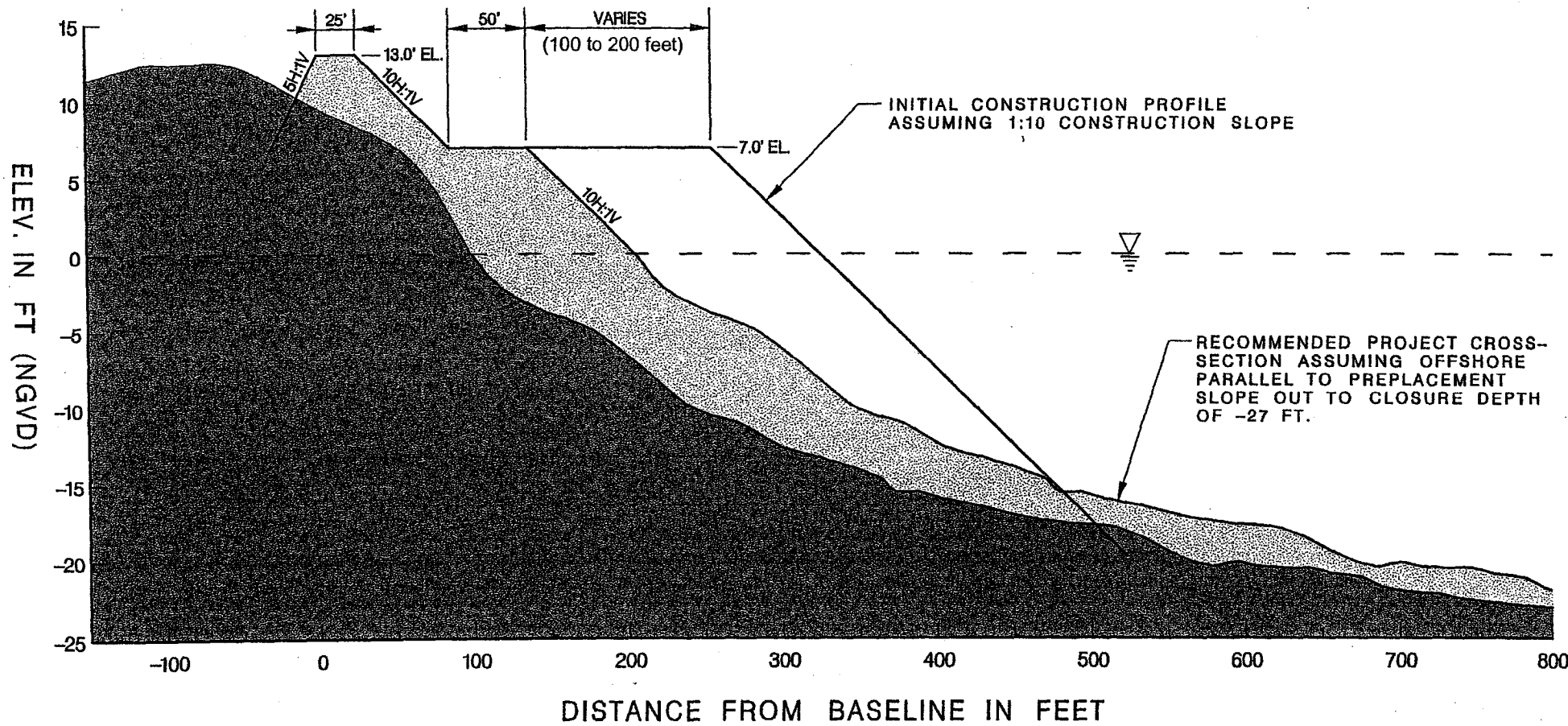
Note: The transition length at the ends of both the North and South Project is approximately 3000 feet.



PROJECT LIMITS & BORROW SITES

Appendix D-6

Figure D-3



13.0' DUNE WITH 50' BERM
TYPICAL CONSTRUCTION PROFILE

Figure D-4

nourishment requirements for a typical 3-year periodic nourishment cycle are 1,055,000 cubic yards for the North Project Area and 2,835,000 for the South Project Area. During periodic nourishment the placement losses will be approximately 10 percent for both the North and South Project Areas. Placement losses are defined as the extra volume of material that must be removed from the borrow area in order to realize the required in-place volume of material on the beach. For these projects two borrow sites will be utilized, one northern borrow site located directly offshore from the North Project Area and one southern borrow site located directly offshore of the South Project Area. The higher placement losses for the North Project Area during initial construction are due to placement of less compatible material from a northern borrow site during initial construction. Initial construction sand for the South Project Area and periodic nourishment borrow sand for both the North and South Project Areas will come from the southern borrow site which is more compatible, resulting in less placement losses.

3. Alternative Evaluation Process.

a. Study Limits

The study limits for preliminary assessment of alternatives extended from the Kitty Hawk Pier in Kitty Hawk to the Cape Hatteras National Seashore at the southern border of South Nags Head, a distance of about 20 miles. To facilitate an orderly analysis, the study area was broken into four study areas (Kitty Hawk, Kill Devil Hills, North Nags Head, South Nags Head), with Whalebone Junction being the divide between North Nags Head and South Nags Head. In reality, North Nags Head and South Nags Head form the township of Nags Head, which along with Kitty Hawk and Kill Devil Hills are the three townships covered by the 20-mile study area. Each study area was broken into segments ranging in length from 200 to 1200 feet, with an average of about 500 feet. There were a total of 214 segments for the 20-mile study area. Kitty Hawk, Kill Devil Hills, North Nags Head, and South Nags Head had 35, 52, 78, and 49 segments, respectively.

b. Alternatives Addressed

With the study limits defined, a systematic procedure for evaluating alternatives was developed. Knowing that the volume of beach-fill is a strong indicator of storm and hurricane damage protection to be expected and knowing the history of optimum protection along the North Carolina coastline, an array of four (4) berm only plans and three (3) berm and dune plans were initially addressed.

1) **Berm Only Plans.** The initial array of berm only plans addressed included the 50-, 100-, 150-, and 200-foot wide berms. Using preliminary cost information and the four study areas described earlier, preliminary

scoping evaluations were made using GRANDUC, which is the storm and hurricane damage model being used for this study. See Appendix F for a description of GRANDUC. Of the berm only plans addressed, preliminary results showed that the 100 to 150-foot wide berm only plans produced maximum net benefits in the 20-mile study area.

2) **Berm and Dune Plans.** Using the volumes associated with the 100 and 150-foot wide berm only plans, a berm and dune plan with similar volume was selected as a logical starting point. Looking between the 100 and 150-foot berm only plan, the volume for the 13-foot dune with 50-foot berm met the criteria. Historical projects in-place along the North Carolina coast having dune heights around 13-feet above NGVD with a berm width of 25 to 100 feet support this selection. In addition to the 13-foot dune with a 50-foot berm, a higher 15-foot and lower 11-foot dune, each with a 50-foot berm at 7-foot NGVD, were selected for evaluation. The initial array of berm and dune plans included an 11-, 13-, and 15-foot dune with a 50-foot berm.

3) **Refinement of Study Limits.** The project limits were defined by evaluating the economic feasibility of constructing a project in each of the 214 segments. As a result, the study area was narrowed from 20-miles down to the two areas (North Project Area and South Project Area) that have now become the recommended project limits. With the study limits redefined, the 3 berm only and 3 berm and dune plans were then rerun with better cost data and the inclusion of transitions from the main project to natural conditions. The methodology for computing cost data used as input to GRANDUC was developed to be consistent among plans and to reflect reasonable estimates that would compare favorably with final cost data developed by cost engineering.

4) **Expansion of Alternatives.** Reanalysis of the six (6) plans showed that the 13-foot dune with 50-foot berm yielded the maximum net benefits. To further refine the analysis, the 13-foot dune with a smaller (25-foot) and larger (100-foot) berm were evaluated. The results showed that the 13-foot dune with 50-foot berm still yielded the maximum net benefits and precluded the need for analysis of additional alternatives.

4. Data Collection.

a. Offshore

One of the early study activities was to identify the sources for offshore borrow material. An active program was initiated in 1994 to collect offshore sub-bottom data. The initial offshore task was to collect seismic data. A plot of the study area that was targeted for seismic data collection can be found in Appendix I, Geotechnical. The following is a brief summary of the offshore

data collection activities leading to the delineation of suitable offshore borrow sites.

1) **Seismic Surveys.** Over 535 miles of sub-bottom data was collected along 34 distinct track lines during two separate surveys in July and August of 1994. A seismic reflection system was utilized to collect 480 miles of track line data. An additional 55 miles of CHIRP-sonar data was also collected. All data was collected within North Carolina State Territorial waters (within 3 nautical miles of the coastline) between the Outer Banks Fishing Pier (South Nags Head) and the Kitty Hawk Fishing Pier (Kitty Hawk). Seismic data was used as a tool to distinguish between the various layers of sub-bottom so that the location of the most likely deposits of sand could be identified for vibracore borings.

2) **1995 Vibracore Collection.** In 1995, 197 vibracore sites were targeted in order to penetrate specific stratigraphic features identified in the sub-bottom seismic data. In August 1995, 73 vibracores were obtained aboard the Dredge Vessel (D/V) Snell. The vibracores were transported to the USGS in Raleigh, N.C. for textural analysis. The sediment characteristics of the core material were used to evaluate the suitability of the sediment as beach-fill. Only 20 of the 73 vibracores were found to contain sediment compatible for beach-fill.

3) **Preliminary Borrow Sites.** The 73 vibracores, in conjunction with the sub-bottom stratigraphic information supplied by the seismic data, were used to define the physical boundaries of 5 preliminary borrow sites within the study area. The total estimated volume of sediment contained within the 5 borrow sites exceeded 172 million cubic yards.

b. On-shore

1) **Beach Surveys.** In 1994 over 100 transects at 1000-foot intervals were sampled along the Dare County Beaches from the Kitty Hawk Pier in Kitty Hawk to the Cape Hatteras Seashore at the south end of South Nags Head. At each transect, samples were taken from the existing beach at five on-shore locations (toe of dune, center of berm, upper foreshore, mid-foreshore, lower foreshore) and at 2-foot intervals offshore down to the closure depth of –27 feet NGVD, which is the limit of the active zone for along shore transport.

2) **Analysis of Beach Sand**. Each of the beach samples was analyzed to determine the mean and standard deviation. Results for the on-shore and offshore samples were then weighted to establish a composite mean and standard deviation for each transect. The weighted transects were then grouped in accordance with selected project limits to obtain weighted project values to be used to determine compatibility with offshore borrow

areas. Appendix E, Sand Compatibility Analysis, provides details of the beach sand analysis.

5. **Final Borrow Site Selection.** Following the reconnaissance assessments of 1995, additional vibracore data was collected in 1998 to more clearly define the final borrow sources.

a. 1998 Vibracore Collection

In 1998, additional vibracore sites were identified to supplement the 1995 vibracore collection effort. In June and July of 1998, 135 vibracores were obtained aboard the D/V Snell. Contracting with Catlin Engineers and Scientists of Wilmington, North Carolina provided textural analysis for the samples. The sediment characteristics of the core material were used to evaluate the suitability of the sediment for beach-fill. Of the 135 vibracores taken 60 were found to be compatible for beach-fill.

b. Final Borrow Sites

The 60 compatible borings were grouped into five borrow areas of defined sand deposits. Refer to Appendix E for the borings within each of the five sites. These borings, in conjunction with incompatible borings around the perimeter of each of the five sites, were evaluated using inroads to determine the boundaries and quantities of sand at each borrow site using a minimum dredging depth of 3-feet to define the borrow site perimeter. Two borrow areas (defined as N1 and N2) are in the northern end of the project study area offshore of Kitty Hawk/Kill Devil Hills. Three borrow areas (defined as S1, S2, and S3) are in the southern end of the project study area offshore of Nags Head/South Nags Head. Figure D-3 shows the locations of the offshore borrow areas relative to the project areas. Table D-2 shows the volume of material available from each of the five defined borrow areas. Based on analysis of the sand compatibility of the offshore borrow material with the native beach sand in the project area, the sand in the southern borrow area is of higher quality and is much more compatible with the native beach sands. The Sand Compatibility Analysis in Appendix E fully addresses the offshore borrow areas, the quality of the material, and its compatibility with the native material found on the beach profile. Of the five defined sites only N1, N2, and S1 are compatible for beach-fill. Sites S2 and S3 in the southern area had silt contents exceeding 10% and were therefore excluded as a borrow source. N2 was also excluded as a borrow site for this study due to its irregular shape and irregular bottom depths; however, it has future potential if needed. Total potential borrow material for all five sites is 120,606, 000 cubic yards: however, the practical usable material for this study utilizing only sites N1 and S1 is 109,646,000 cubic yards. The total beach-fill material estimated for this job during the 50-year project life is 79,040,000, which is 72% of the available borrow material in sites N1 and S1. Additional vibracore holes will be

scheduled prior to preparation of the plans and specifications to more fully explore the limits of borrow material and set the final limits.

Table D-2
Offshore Borrow Site Volumes

Northern Borrow Sites	Volume (cubic yards)
N1	5,192,000
N2	2,353,000
North Total	7,545,000

Southern Borrow Sites	Volume (cubic yards)
S1	104,454,000
S2	7,219,000
S3	1,388,000
South Total	113,061,000

Total Borrow Sand (N1 + S1)>>>>>>>>>>>>>109,646,000
Total Borrow Sand (North + South)>>>>>>>120,606,000

c. Compatibility

The overfill ratio is the primary indicator of the compatibility of the borrow material to the native material, with a value of "1.00" indicating 100 percent compatibility. For the Dare County study area, the composition of native beach material varies from coarser sand in the Kitty Hawk area at the north end of the study area, becoming finer heading south, and culminating as medium sand in South Nags Head at the south end of the study area. Due to the beach variance from north to south, the native beach sand composition was grouped for the two project reaches prior to determining compatibility with offshore borrow sources. Table D-3 compares the native beach sand in the two project reaches to the borrow material found in both the northern and southern borrow areas.

Table D-3
Sand Compatibility Analysis
(Borrow Site Material placed on Native Beach Material)

Native Beach Material	Mean (mm)	Std Dev (phi)
North Project Area (NP)	0.31	1.50
South Project Area (SP)	0.26	1.52

Borrow Site	% Silt	Borrow Material Mean (mm)	Borrow Material Std Dev (phi)	Overfill Ratio Project Area North	Overfill Ratio Project Area South	Silt Factor	Final Overfill Ratio (corrected for silt content) Project Area North	Final Overfill Ratio (corrected for silt content) Project Area South
N1	9	0.22	1.93	1.3	1.2	1.10	1.5	1.3
N2	6	0.24	1.52	1.3	1.0	1.06	1.4	1.1
S1	5	0.34	1.43	1.0	1.0	1.05	1.1	1.1
S2	11	0.24	1.83	1.2	1.1	1.12	1.4	1.3
S3	13	0.21	1.27	2.0	1.5	1.15	2.3	1.7

The final overfill ratios in table D-3 show that placement of borrow sand on the native beach is not a 1 to 1 ratio, which would equate to 100 percent compatibility. The highlighted values in the table show that 1.5 cubic yards of sand would be required from borrow site "N1" to achieve 1.0 cubic yards of in-place sand for the North Project Area. Similarly, 1.1 cubic yards of sand would be required from borrow site "S1" to achieve 1.0 cubic yards of in-place sand for both the North and South Project Areas.

6. **Borrow Area Use Plan.** The economic optimization of the use of offshore borrow sites for the life of the project will be reevaluated when the final borrow area data has been collected and fully analyzed prior to plans and specifications. Additional vibracore boring data will be collected and made a part of the final borrow area use plan, but for now, the currently defined borrow sites will be utilized. In addition to borrow area parameters (material quantities and location), the dredging production rates and dredging window are critical to selection of the optimum borrow use plan.

a. Borrow Area Parameters

All of the identified borrow area sites are located within the 3-mile nautical limits and thus not subject to federal mining requirements imposed by the Minerals Management Service (MMS). Of the five (5) identified sites (N1, N2, S1, S2, and S3), sites S2 and S3 have been eliminated due to high silt content. Of the remaining three (3) sites 93% of the sand is located in site S1. Borrow sites N1 and N2 are located 1/2 to 2 miles offshore of Kitty Hawk. The material in these sites is limited and will only support a 3 to 5 mile project during initial construction. Borrow site S1 is located 1 to 3 miles offshore of the South Nags Head area and will be the major source of sand for the proposed beach-fill project. Pipeline/hopper dredging distances from site S1 are 14 to 20 miles to the northern study limit and 1 to 7 miles to the southern study limit.

b. Dredging Production

Dredging production rates were developed to reflect the expected wave environment off the Dare County coastline to assist in setting the dredging window.

1) **Production Rates.** Dredging production data for two recently completed projects by the Wilmington District (Oregon Inlet and Kure Beach) were utilized to develop relationships reflecting the expected production rates for the Dare County Beach project. Oregon Inlet is about 5 miles south of the southern end of the proposed Dare County beach-fill project. Kure Beach is located along the North Carolina coastline in the southern part of the state, well south of Dare County. Production data for the two projects

were converted to monthly production efficiency. Conversion to monthly efficiency was based on a pipeline dredging with a maximum daily production rate of 15,000 cubic yards. The result of the production analysis is shown in table D-4 and also shown graphically on figure D-5. Dredging production efficiencies for the two projects were vastly different, with the Kure Beach project showing production values 65 to 75 percent higher than the Oregon Inlet project in the months of November through March and 30 to 60 percent higher than the Oregon Inlet project during the remainder of the year. Dredging production rates for the Oregon Inlet project were hampered by the severe wave climate in the vicinity of Oregon Inlet. Due to the proximity of the Dare County project to Oregon Inlet, greater weight (2 to 1) was given to the Oregon Inlet production data. The production efficiencies for Dare County shown in table D-4 are weighted monthly efficiencies which were used as the basis for developing dredging costs for this study.

Table D-4
Pipeline Dredging Production Efficiencies

Month	Days	Oregon Inlet Project Production (cy/mo)	Oregon Inlet Project Efficiency (%)	Kure Beach Project Production (cy/mo)	Kure Beach Project Efficiency (%)	Dare Co. Efficiency (%)
January	31	181,858	39	304,473	65	48
February	28	156,181	37	273,202	65	46
March	31	176,071	38	308,765	66	48
April	30	219,033	49	347,436	77	58
May	31	257,325	55	384,648	83	65
June	30	288,315	64	407,646	91	73
July	31	341,112	73	445,656	96	81
August	31	281,623	61	402,662	87	69
September	30	207,804	46	335,147	74	56
October	31	178,092	38	304,022	65	48
November	30	187,161	42	310,019	69	51
December	31	184,605	40	306,602	66	49

Note: For each project, efficiency is based on a pipeline dredge with a maximum daily production rate of 15,000 cubic yards.

2) **Storm Reduction Adjustment.** The weighted production efficiency values from the previous table were then adjusted for occurrence of severe storms in the dredging work area. The storm reduction adjustment corrects for the time that the dredge vessel would have to relocate from the job site to a safe haven to ride out the storm. Since there is no safe haven in the immediate vicinity of the work area, any dredging plant equipment would likely relocate to either Norfolk, Virginia or Morehead City, North Carolina. The assumption is that an severe storm event would cause a loss of 7 dredging days, which includes reaction time to the incoming storm, travel to the safe haven and back, and wait time. Table D-5 displays the severe storm history in the project area over a recent

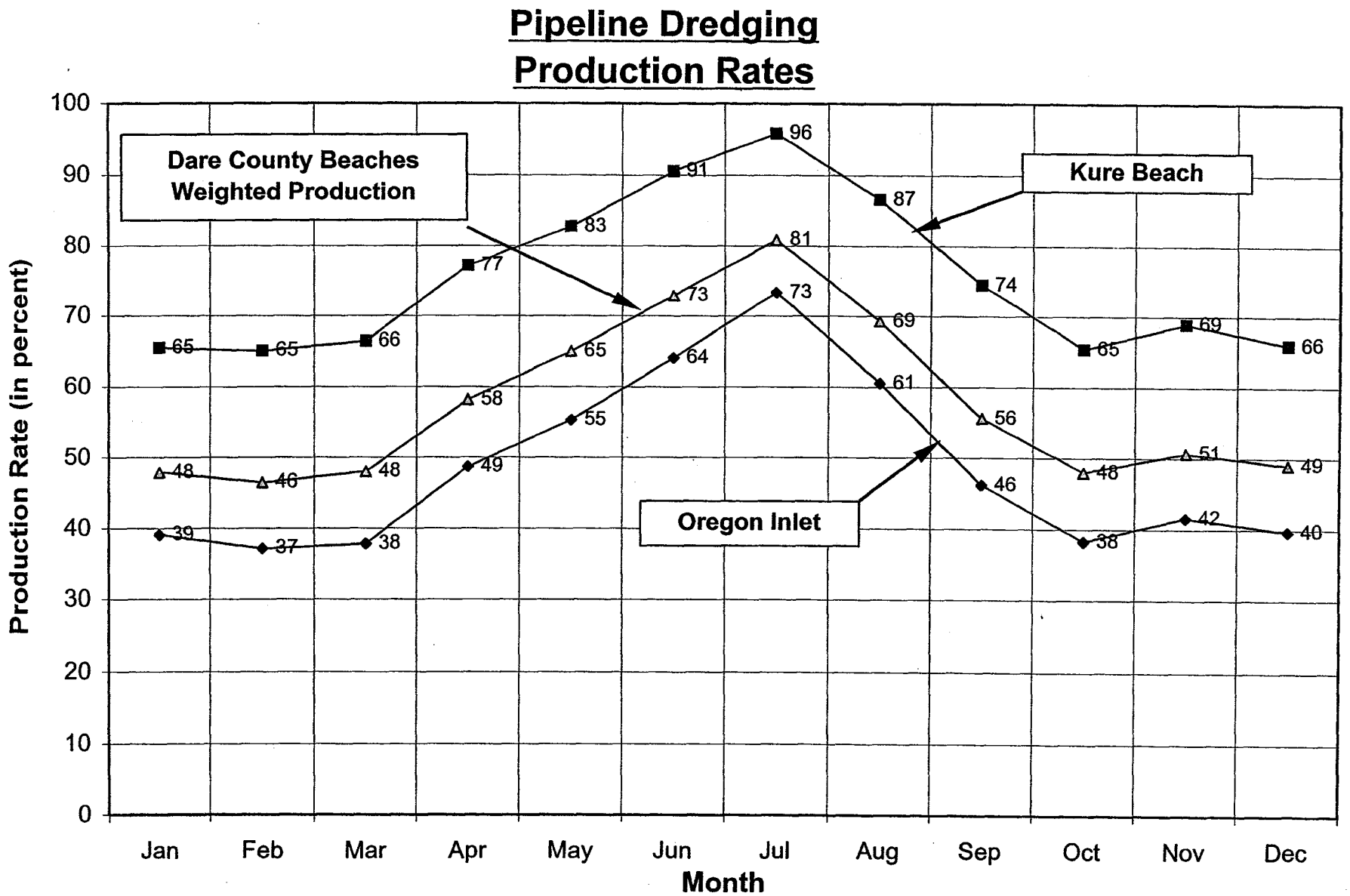

Pipeline Dredging
Production Rates
Dare County Beaches
Weighted Production
Kure Beach
Oregon Inlet
Production Rate (in percent)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
65
65
66
77
83
91
96
87
74
65
69
66
48
46
48
58
65
73
81
69
56
48
51
49
39
37
38
49
55
64
73
61
46
38
42
40

Figure D-5

seven-year period (1984-1990). The table shows that there were 16 severe storm events over the seven-year period, an average of just over 2 events per year.

Table D-5
Pipeline Dredging Down Time for Severe Storms
(Storm events that would require dredging vessel to seek safe haven)

Storm Events (1984-1990)			Storm Down Time (Events/month/year)			
Begin	End	Peak Elevation	Month	Days per Year	Total Storm Events	Events per Year
01/11/84	01/14/84	9.0	January	31	1	0.14
10/11/84	10/15/84	10.7	February	28	2	0.29
10/28/85	11/04/85	8.6	March	31	2	0.29
04/18/86	04/19/86	9.0	April	30	3	0.43
05/09/86	05/12/86	9.8	May	31	1	0.14
12/01/86	12/03/86	9.7	June	30	0	0.00
02/17/87	02/18/87	10.6	July	31	0	0.00
03/10/87	03/16/87	10.9	August	31	0	0.00
04/26/87	04/27/87	9.6	September	30	0	0.00
10/12/87	10/15/87	9.1	October	31	3	0.43
04/08/88	04/14/88	10.2	November	30	1	0.14
02/24/89	02/25/89	12.4	December	31	3	0.43
03/07/89	03/10/89	10.6				
12/09/89	12/10/89	9.7				
12/22/89	12/25/89	14.2				
10/25/90	10/28/90	10.5				

3) **Adopted Production Efficiencies.** Table D-6 shows the adopted production efficiencies for the Dare County study with adjustments for severe storms.

Table D-6
Adopted Pipeline Dredging Efficiencies

	Production Efficiency (%)		
Month	Weighted Average	Storm Reduction	Adopted Values
January	48	1	47
February	46	2	44
March	48	2	46
April	58	3	55
May	65	1	64
June	73	0	73
July	81	0	81
August	69	0	69
September	56	0	56
October	48	3	45
November	51	1	50
December	49	3	46

Figure D-6 is a plot of the adopted production efficiencies for the Dare County study. As can be seen the July peak summer production rate of 81 percent is nearly double the October through March production rates

Adopted Pipeline Dredging Production Rates
(adjusted for storm down time)

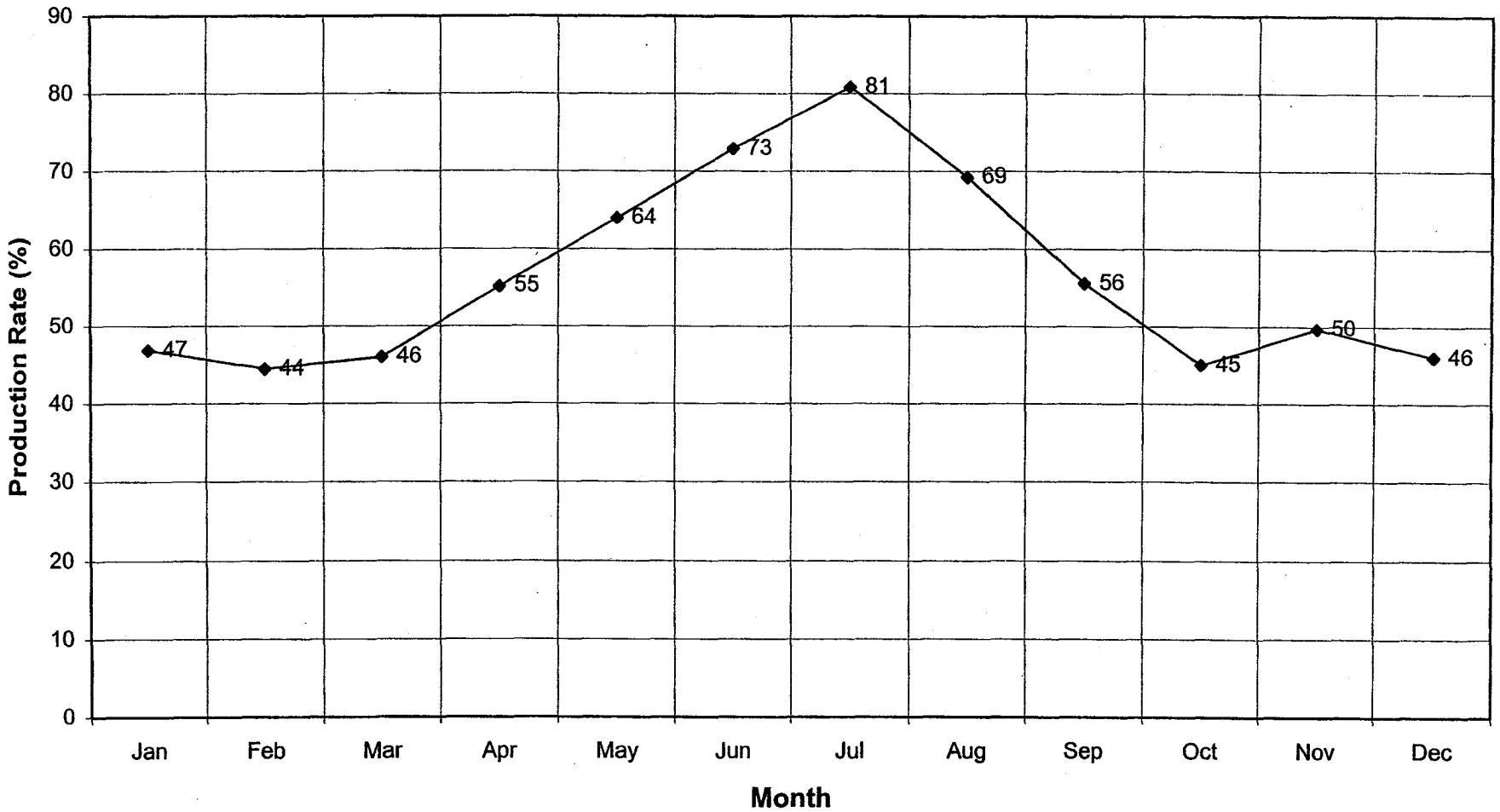


Figure D-6

that are consistently below 50 percent. A May through August time frame would be ideal for pipeline dredging efficiency, with values ranging from 64 to 81 percent; however, dredging windows will limit most operations to the winter months when less than 50 percent efficiency is the rule.

c. Dredging Window

In determining the optimum borrow use plan, dredging window restrictions were evaluated using a 3-year initial construction period plus a 3-year periodic nourishment cycle for the 50-year life of the project. This plan considers that the initial construction will be performed in one phase for the North Project Area and three phases for the South Project Area. Environmental, engineering, and cost considerations will be factored into selecting the proper dredging window. A summary for the recommended construction plan follows with a brief discussion of start-stop times, number of contracts required, type and number of dredges required, and dredging presence in the project area during the life of the project. Figure D-7 is a graphical presentation of the recommended construction plan.

d. Recommended Construction Plan

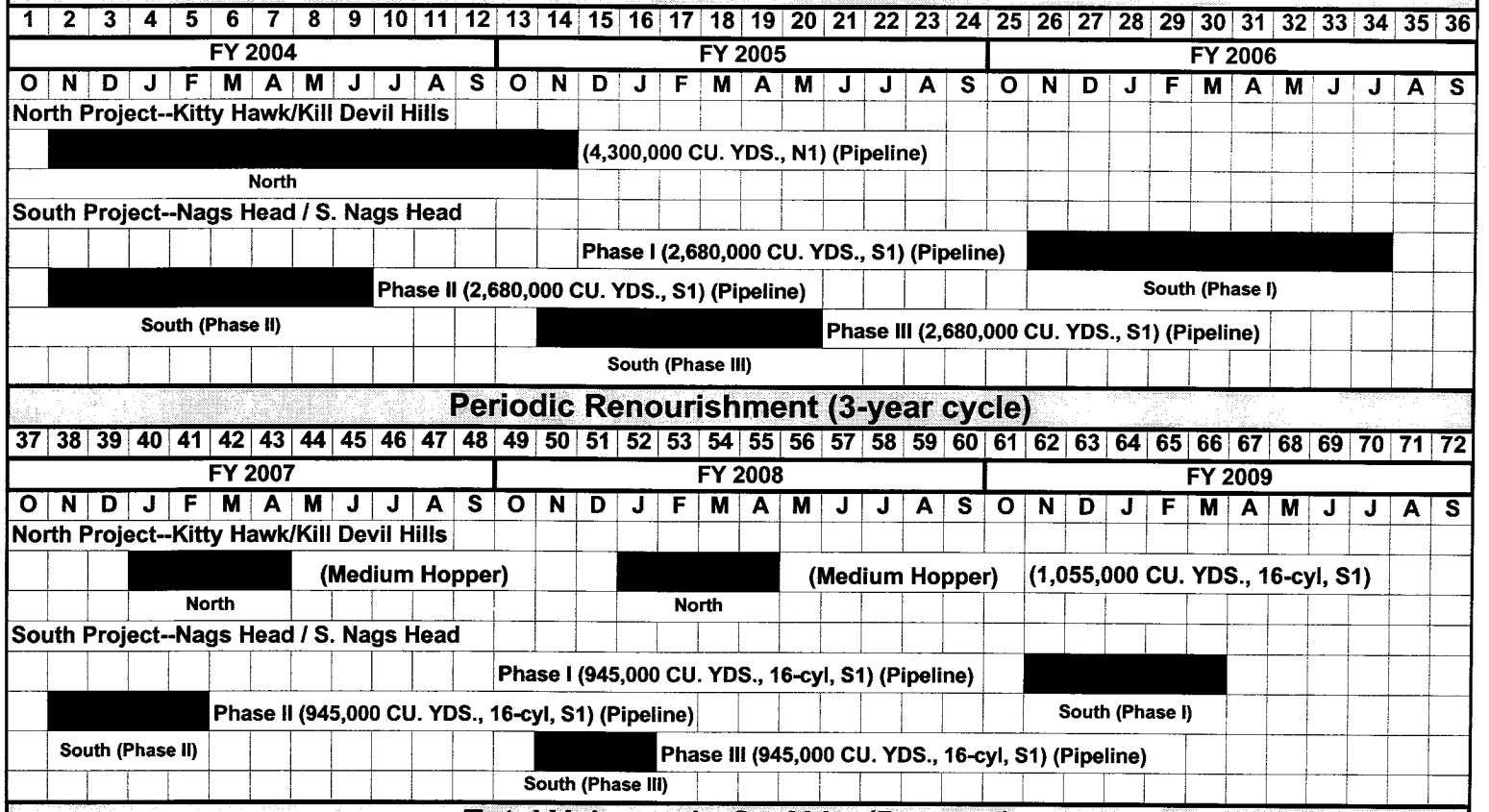
Initial construction would begin November 16 of year 1 for both the North Project Area and phase II of the South Project Area. The remaining two phases for initial construction of the South Project Area (phase III followed by phase I) would follow in subsequent years beginning on November 16. The phases are based on three equal quantities of sand being placed for each phase with phase I being the northern most portion of the South Project Area and phase III being the southern most portion of the South Project Area. Each of the 4 phases would begin November 16 using pipeline dredging and proceed until completion between May and October of the following year. For the South Project Area, the order of construction sequencing (phase II first, phase III, and phase I last) is based on minimizing both storm damages and sand quantity requirements during initial construction. Initial construction would require three years for completion. Periodic nourishment would begin in year 4 with the same sequencing of phases for the South Project Area as was used during initial construction. The major change during periodic nourishment would include the use of hopper dredging for the North Project Area due to long haul distances. Pipeline dredging would still be used for the South Project Area. Periodic nourishment of the South Project Area by pipeline dredge would begin November 16 for each phase and proceed until completion between January and February of the following year. Because of turtle nesting requirements, periodic nourishment of the North Project Area by hopper dredge would be performed in two phases over two years beginning in January and proceeding to completion in April. Three years would be required for completion of one periodic nourishment cycle. The plan would require 4 separate contracts for initial construction and 5 separate contracts

Northern Dare County - Storm Damage Reduction Project

Recommended Construction Plan

Initial Construction (4 contracts), Periodic Maintenance (5 contracts), 2 Dredges (years 1,4,5,7,8,etc), 1 Dredge (years 2,3,6,9,etc)

Note: All dredging on the chart shown as beginning in November actually begins November 16th.



Total Volumes in Cu. Yds. (Pumped)

	Initial	3-yr Maintenance	50-yr Maintenance	Total
North Project	4,300,000	1,055,000	16,880,000	21,180,000
South Project	8,040,000	2,835,000	45,360,000	53,400,000
Totals	12,340,000	3,890,000	62,240,000	74,580,000

Figure D-7

for each periodic nourishment cycle. During periodic nourishment 1 pipeline dredge would be required every year for the South Project Area and 1 hopper dredge would be required the 1st two years of the 3-year periodic nourishment cycle for the North Project Area. If a stricter hopper-dredging window (January to March) were to be imposed due to turtle nesting, a hopper dredge would be in the project area every year of the periodic nourishment cycle. The recommended plan requires the presence of 2 dredges in the project area during year 1 and 1 dredge during years 2 and 3 for initial construction. During periodic nourishment 2 dredges would be present in the project area during the 1st two years of the periodic nourishment cycle and one dredge during the 3rd year of the cycle for the entire 50-year project life.

e. Borrow Sand Requirements

Table D-7 shows the initial construction volumes and 3-year periodic nourishment volumes required for the North and South Project Areas for the NED plan (13-foot dune and a 50-foot berm). Volumes shown are borrow quantities that have been adjusted for required overfill factors.

Table D-7
Borrow Sand Requirements
(cubic yards)

Project Area	Initial Construction Volume	3-Year Periodic Nourishment Volume (average 3-year)	50-year Periodic Nourishment Volume	Total Project Volume
North Project	4,300,000	1,055,000	16,880,000	21,180,000
South Project	8,040,000	2,835,000	45,360,000	53,400,000
Totals	12,340,000	3,890,000	62,240,000	74,580,000

f. Borrow Site Utilization

The recommended borrow use plan for initial construction calls for the North Project Area to take material by pipeline dredge from borrow site N1 just offshore and the South Project Area to take material by pipeline dredge from borrow site S1 just offshore. During periodic nourishment, the plan calls for the North Project Area to take material by hopper dredge from borrow site S1 for 16 periodic nourishment cycles and for the South Project Area to take material by pipeline dredge from borrow site S1 for 16 periodic nourishment cycles. Table D-8 shows the volume that will be taken from each borrow site for the NED plan. Borrow site N1 will provide 4,300,000 cubic yards of sand and borrow site S1 will provide 70,280,000 cubic yards. These quantities result in an 83% utilization of borrow site N1 and a 67% utilization of borrow site S1. By not fully utilizing these sites, there will be more flexibility to refine the borrow use plan in future investigations to avoid any unforeseen pockets

non-compatible sand. A more detailed boring grid of the borrow sites will be developed prior to preparing the final borrow use plan.

Table D-8
Borrow Site Utilization
(cubic yards)

Borrow Site	Initial Construction (cubic yards)	50-year Periodic Nourishment (cubic yards)	Total Utilized (cubic yards)	Borrow Site Utilization (percent)
N1	(NP) 4,300,000	----------	4,300,000	83%
S1	(SP) 8,040,000	(NP & SP, 16-cycles) 62,240,000	70,280,000	67%
Totals	12,340,000	62,240,000	74,580,000	

Note: "NP" denotes North Project Area and "SP" denotes South Project Area.

7. Shoreline Analysis

a. Background Information

The project shoreline is composed of two reaches, one to the north that is 4.1 miles long and one to the south that is 10.1 miles long. The two project areas are separated by 3.1 miles of undisturbed natural beach. The south end of the South Project Area is located 5.4 miles north of Oregon Inlet. The southern transition of the South Project Area ends at the Cape Hatteras National Seashore. Located within the project areas are four piers, one (Avalon Pier) in the North Project Area and three (Nags Head Pier, Jennette's Pier, and Outer Banks Pier) in the South Project Area. The seaward edge of the project berm elevation 7 foot NGVD will extend about 145, 115, 135, and 130 feet beyond the construction line at Avalon Pier, Nags Head Pier, Jennette's Pier, and Outer Banks Pier, respectively. See Project Maps of Appendix C to determine encroachment on the piers.

b. Shoreline Adjustments

Immediately after the project is constructed there will be major adjustments to the beach-fill profile that will occur naturally in response to the existing wave environment and may take several months or longer to finally stabilize. As explained earlier in the report, the initial berm width will extend 100 to 200 feet beyond the final design width. When stable, the final profile should approximate and parallel the pre-fill profile. Simultaneously, there will be erosion to the profile caused by longshore transport and offshore migration of the sand placed on the beach. See figures D-8 to D-10 for initial construction profiles at three typical project sections.

Beach Profile @ Station 199+93.01

(Kill Devil Hills, Near Helga Street)
(Between Mile Posts 5 and 6)

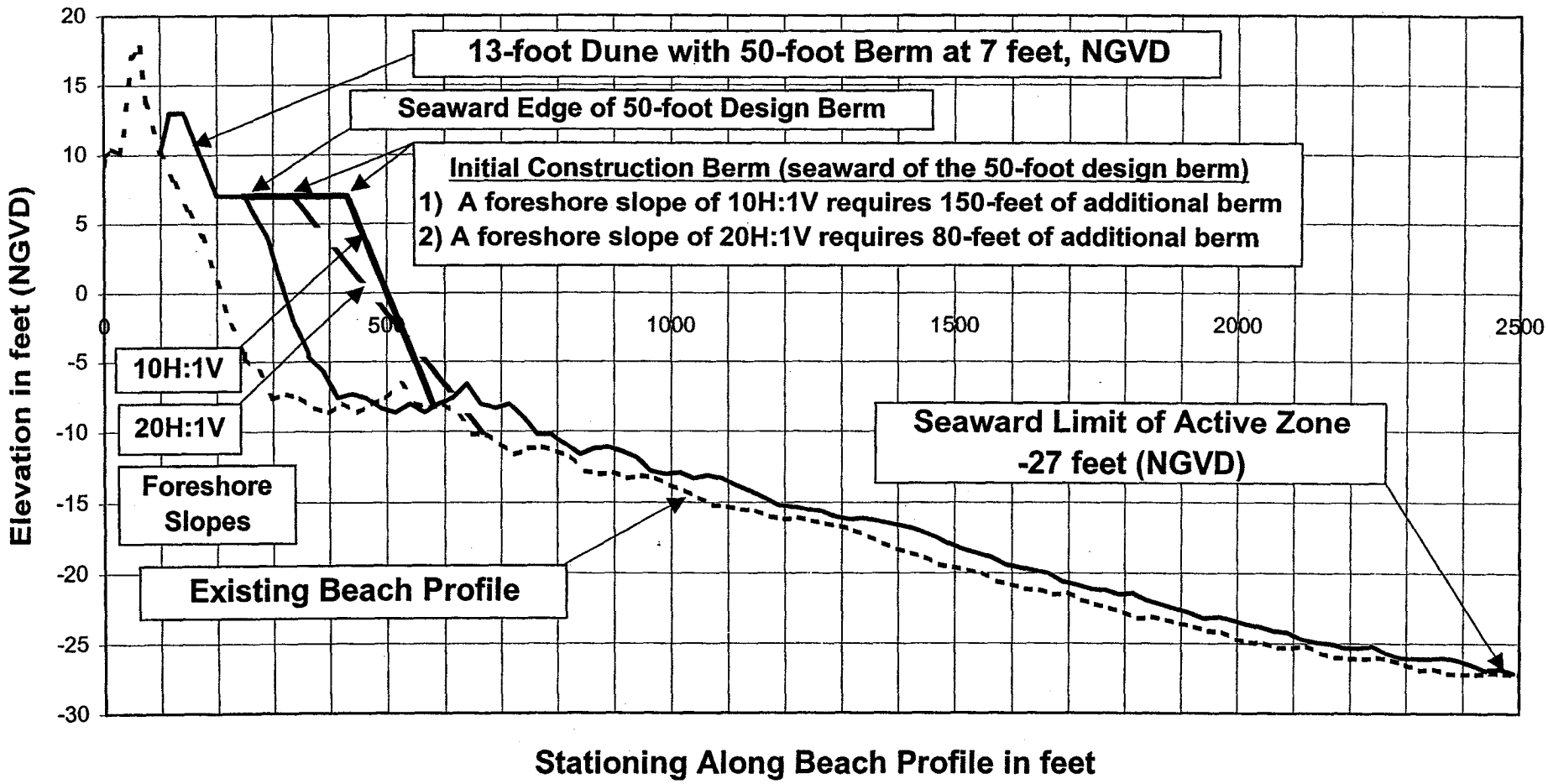


Figure D-8

Beach Profile @ Station 679+70.59

(Nags Head, North of Whalebone Jct, Near Hawks Nest Court)
(Between Mile Posts 14 and 15)

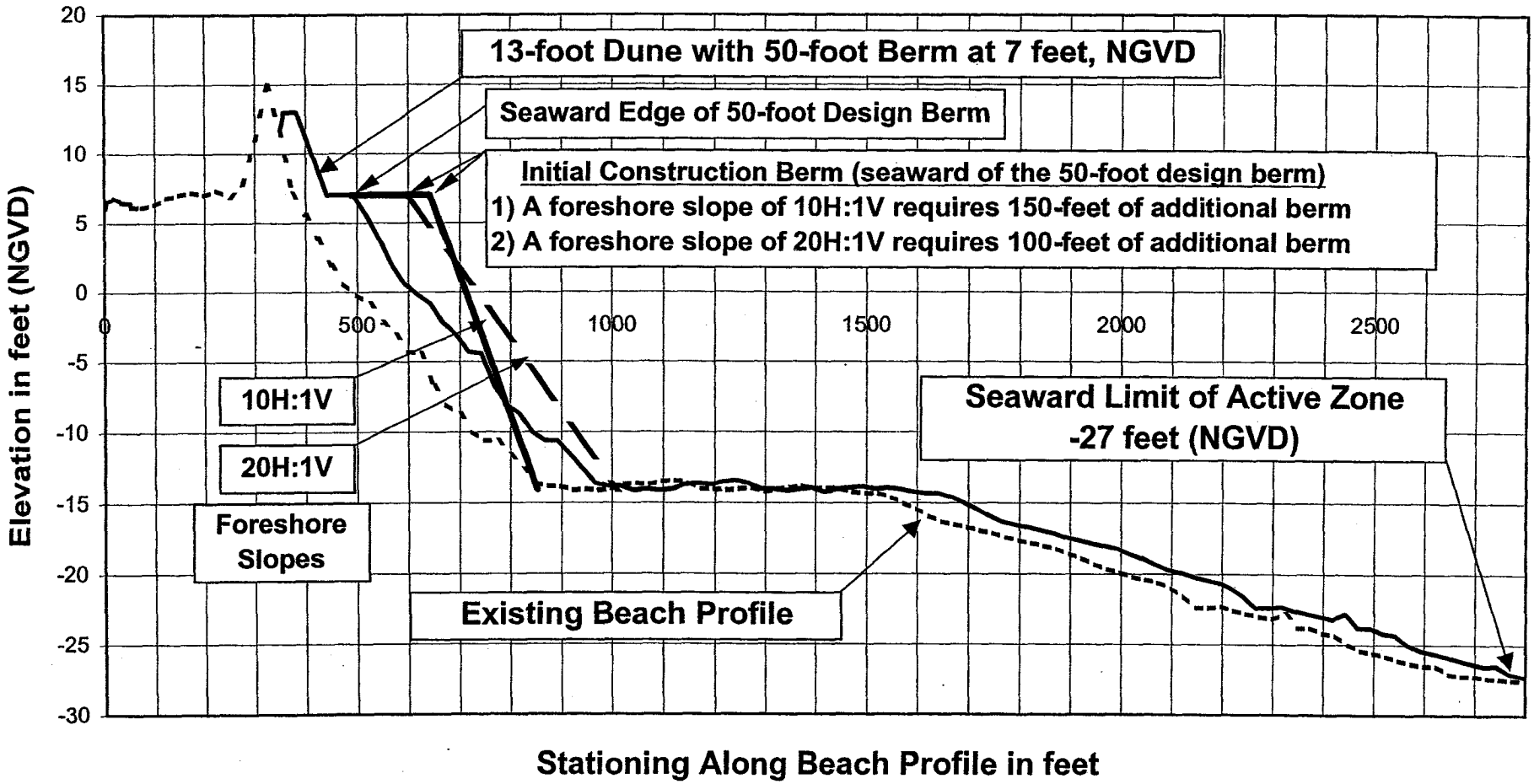


Figure D-9

Beach Profile @ Station 951+00.34

(Nags Head, South of Whalebone Jct, Near Camelot Street)
(Between Mile Posts 19 and 20)

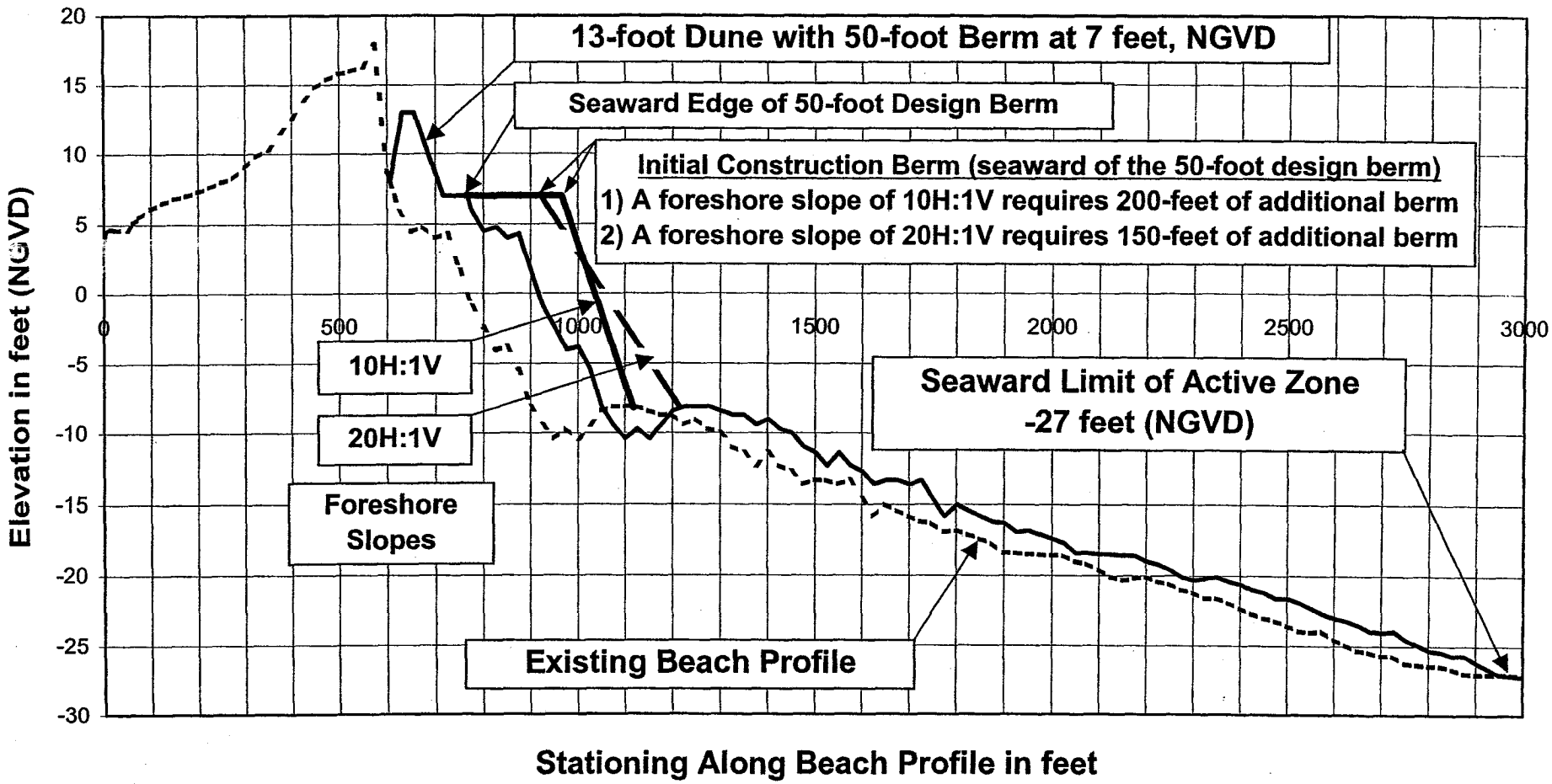


Figure D-10

c. Long-Term Erosion Rates

1) **Adopted Long-Term Erosion Rates.** The long-term erosion rates developed by the North Carolina Division of Coastal Management (NCDCM) were adopted as input to the project analysis tool (GRANDUC) for without project conditions. NCDCM values were verified using comparisons of long-term shoreline movement (1985 to 1997) taken from aerial photography. Inherent in the long-term erosion rates is 0.65 feet per year of shoreline retreat due to sea level rise. Figure D-11 is a plot of the NCDCM rates that were used in this study. It should be noted on the plot that the annual long-term annual erosion rate varies considerably, with rates ranging from 0 to 6 feet of annual erosion in Kitty Hawk, from 6 feet of annual erosion to 3 feet of annual accretion in Kill Devil Hills, from 4 feet of annual erosion to 2 feet of annual accretion in North Nags Head, and from 0 to 10 feet of annual erosion in South Nags Head. The high accretion area in the southern part of Kill Devil Hills corresponds closely with the non-project area that separates the North and South Project Areas.

2) **Other Sources of Long-Term Erosion.** Prior to the adoption of the NCDCM rates for use in this study, several other sources of long-term erosion were evaluated. These sources included: (a) Technical Report TR-CERC-83-1, entitled "Shoreline Movements" by Everts, Battley, and Gibson, (b) shoreline changes determined by Dr. Robert Dolan of the University of Virginia, (c) comparisons of historic profile surveys made by the U.S. Army Coastal Engineering Research Center (CERC) Field Research Facility (FRF) located at Duck, North Carolina, and (d) alternative analysis of the shoreline change database developed by Dolan.

3) **TR-CERC-83-1.** CERC and NOAA (National Ocean Service/National Oceanic and Atmospheric Administration) used historical surveys and maps of the Outer Banks between the N.C./Va. State Line to Cape Hatteras dated between 1915 and 1980 to determine long-term shoreline changes on both the ocean and sound sides of the Outer Banks. The resulting long-term shoreline change rates for the ocean shoreline are shown on figures D-12 through D-20 designated as CERC 1915-1980. The shoreline change rates determined from this study were reported as average rates over each one-mile shoreline segment. The shoreline lengths represented on figures D-12 through D-20 are based on base maps used by Dr. Dolan of the University of Virginia. An explanation of the data on these figures follows.

NCDCM Long Term Erosion Rates

(verification using 1985 & 1997 aerial photography)

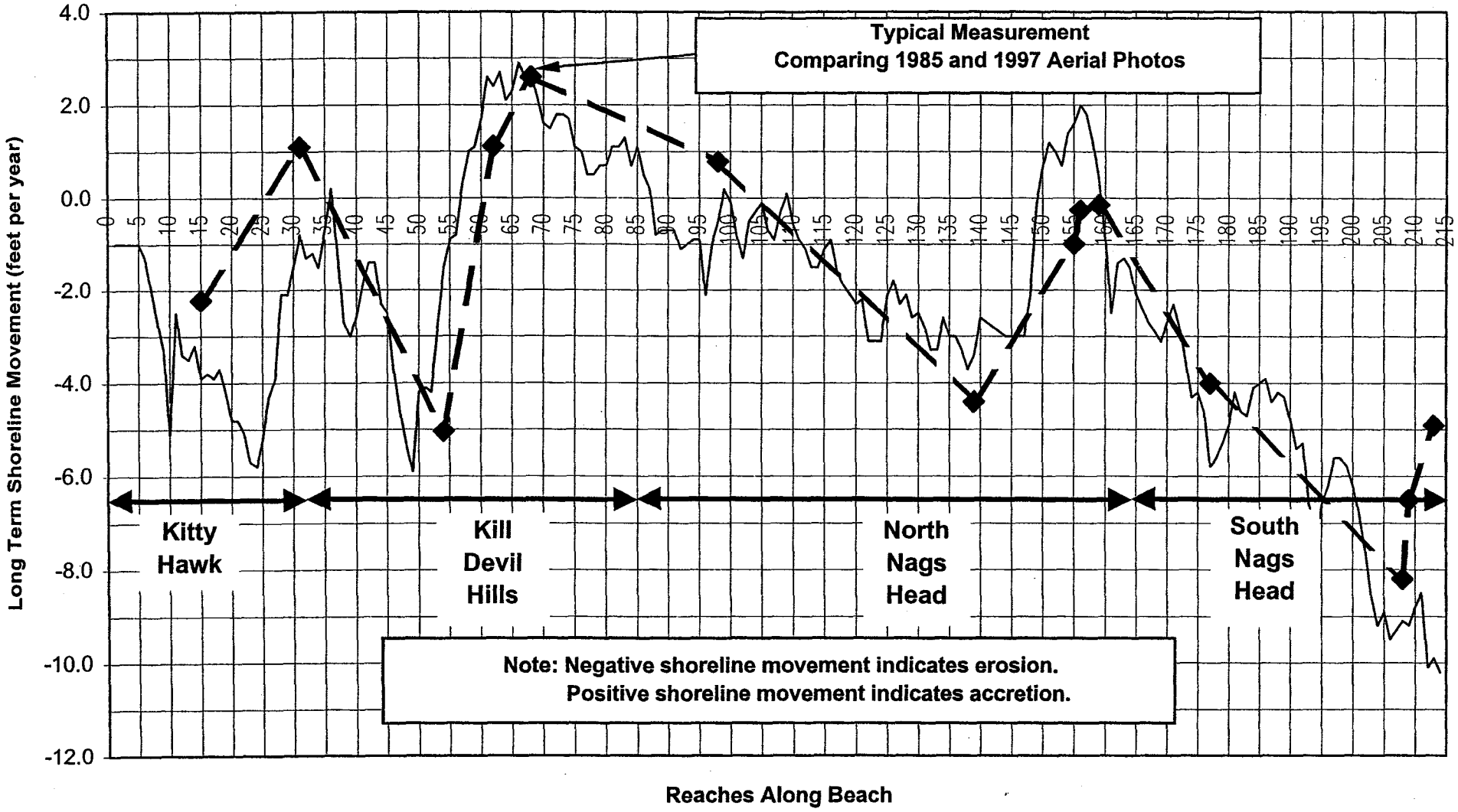


Figure D-11

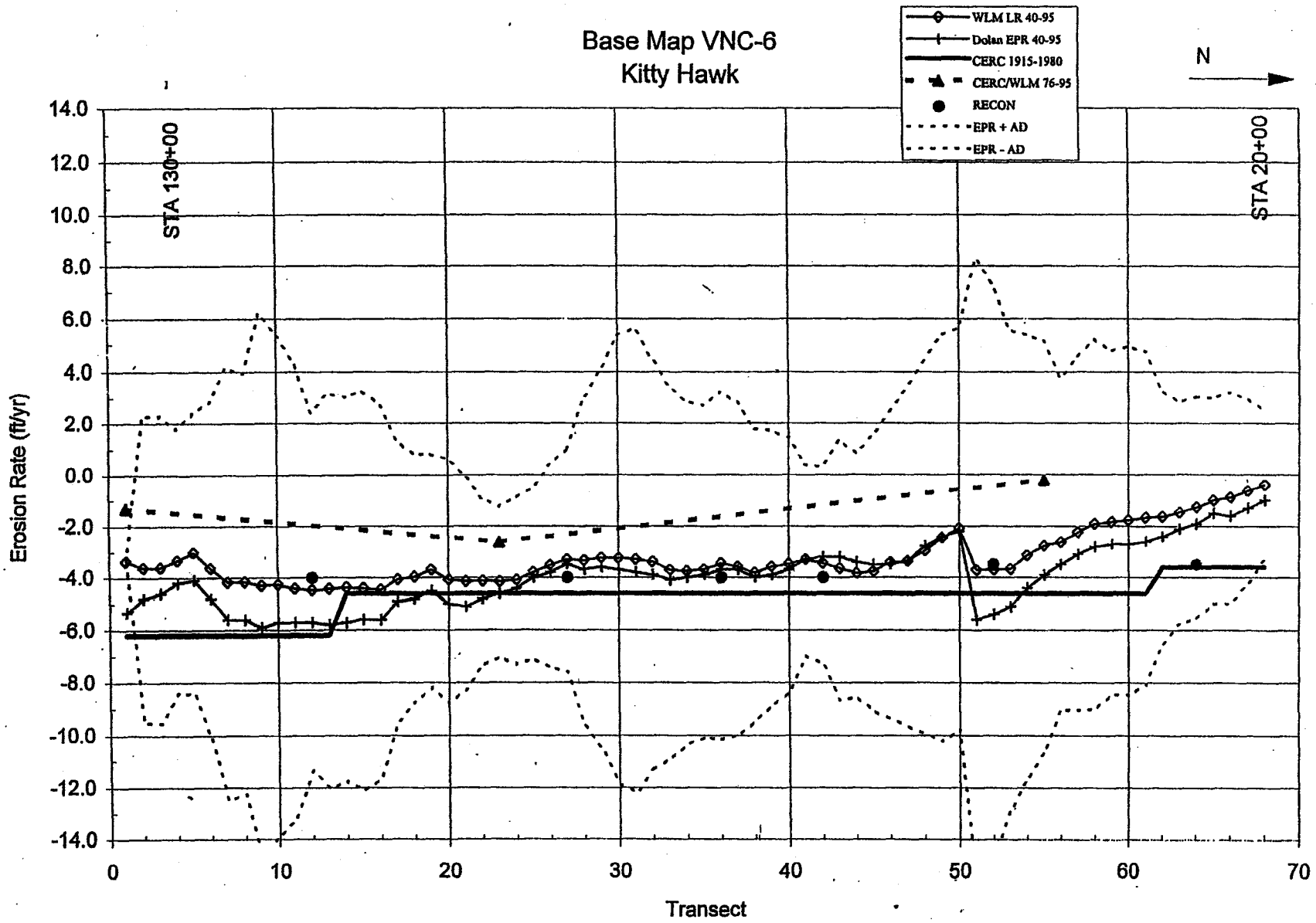

Base Map VNC-6
Kitty Hawk
WLM LR 40-95
Dolan EPR 40-95
CERC 1915-1980
CERC/WLM 76-95
RECON
EPR + AD
EPR - AD
N
STA 130+00
STA 20+00
Erosion Rate (ft/yr)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
0
10
20
30
40
50
60
70
Transect

Figure D-12

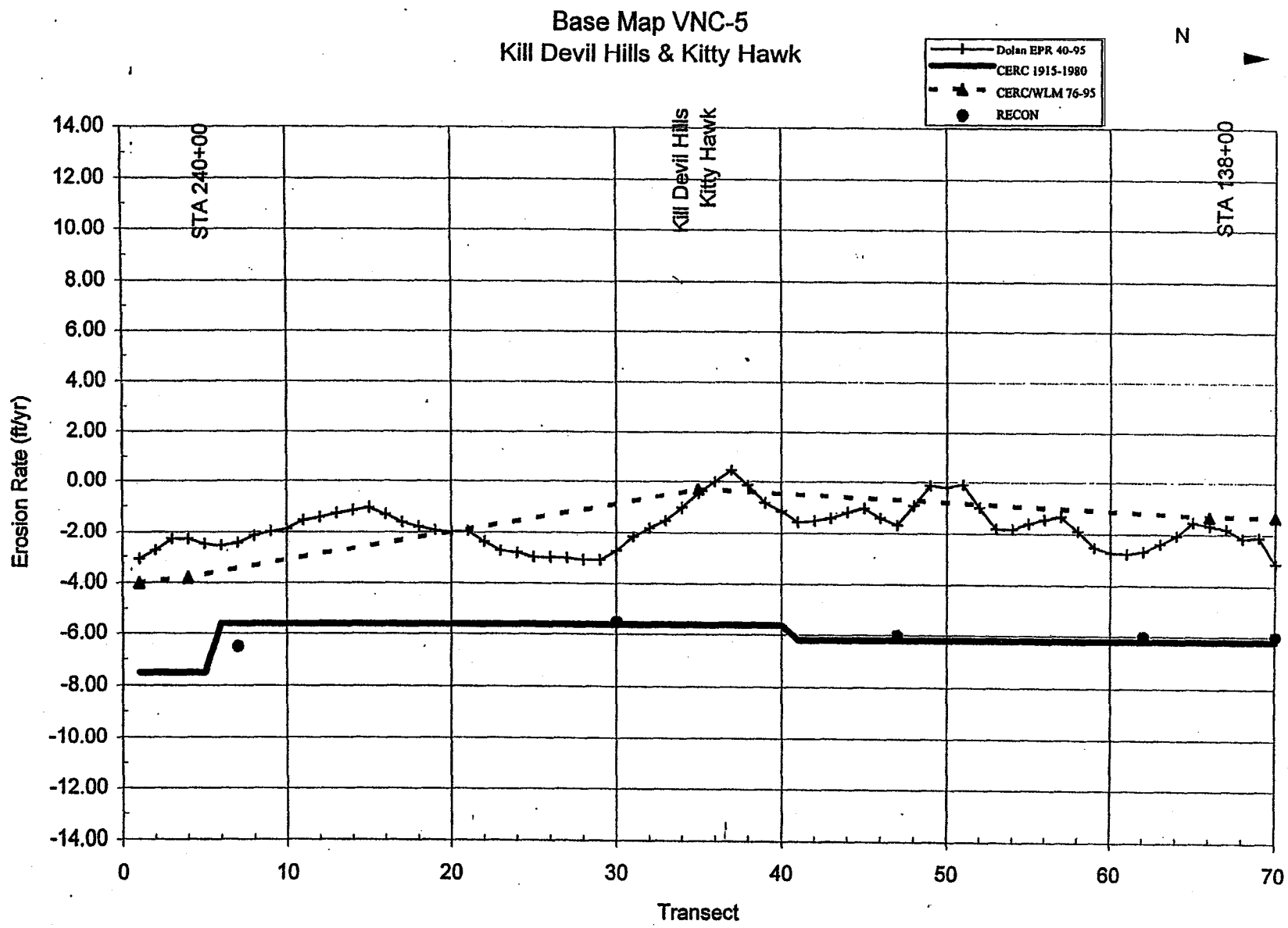

Base Map VNC-5
Kill Devil Hills & Kitty Hawk
Dolan EPR 40-95
CERC 1915-1980
CERC/WLM 76-95
RECON
N
STA 240+00
Kill Devil Hills
Kitty Hawk
STA 138+00
Erosion Rate (ft/yr)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
0
10
20
30
40
50
60
70
Transect

Figure D-13

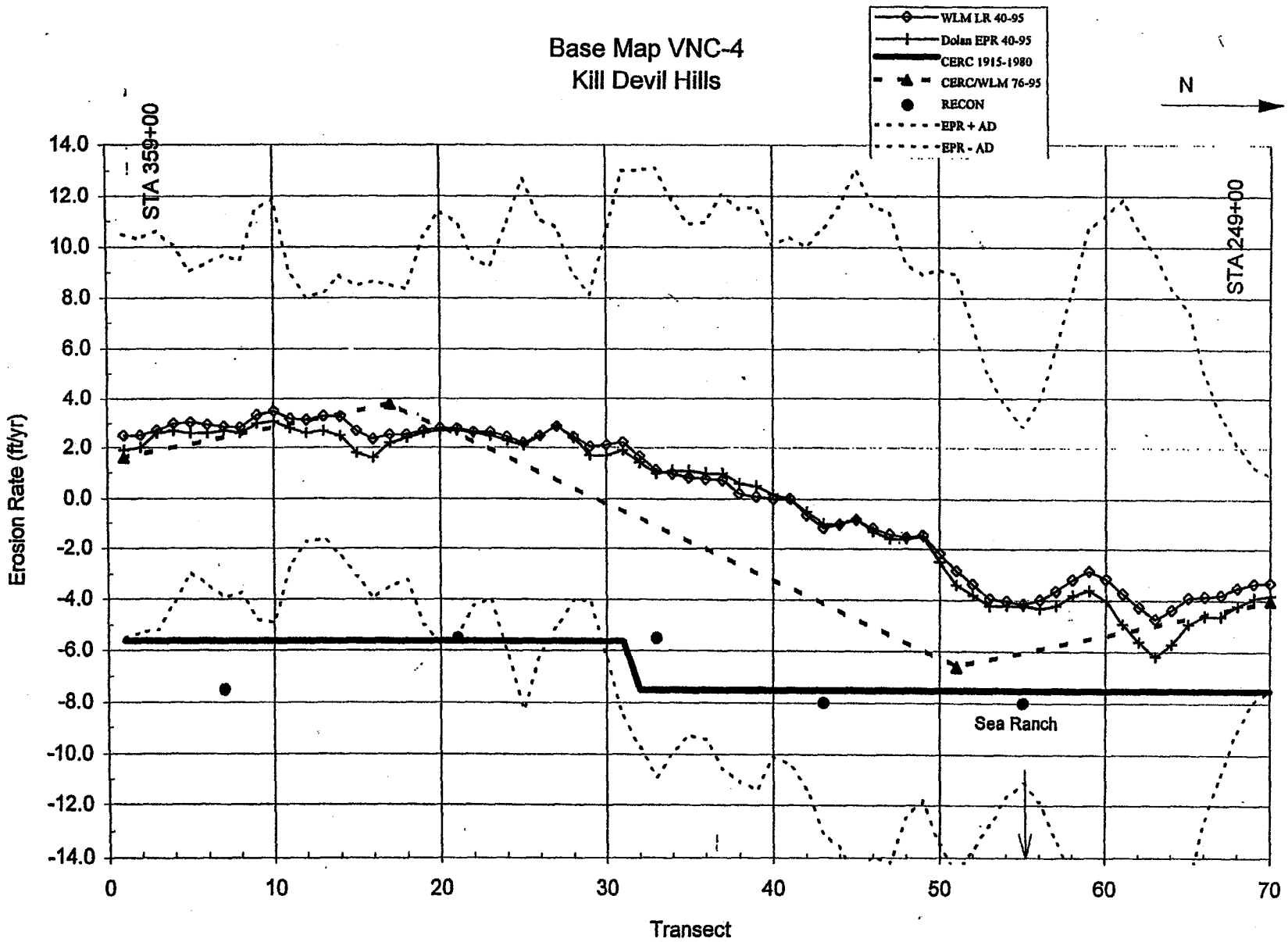

Base Map VNC-4
Kill Devil Hills
WLM LR 40-95
Dolan EPR 40-95
CERC 1915-1980
CERC/WLM 76-95
RECON
EPR + AD
EPR - AD
N
STA 359+00
STA 249+00
Sea Ranch
Erosion Rate (ft/yr)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
0
10
20
30
40
50
60
70
Transect

Figure D-14

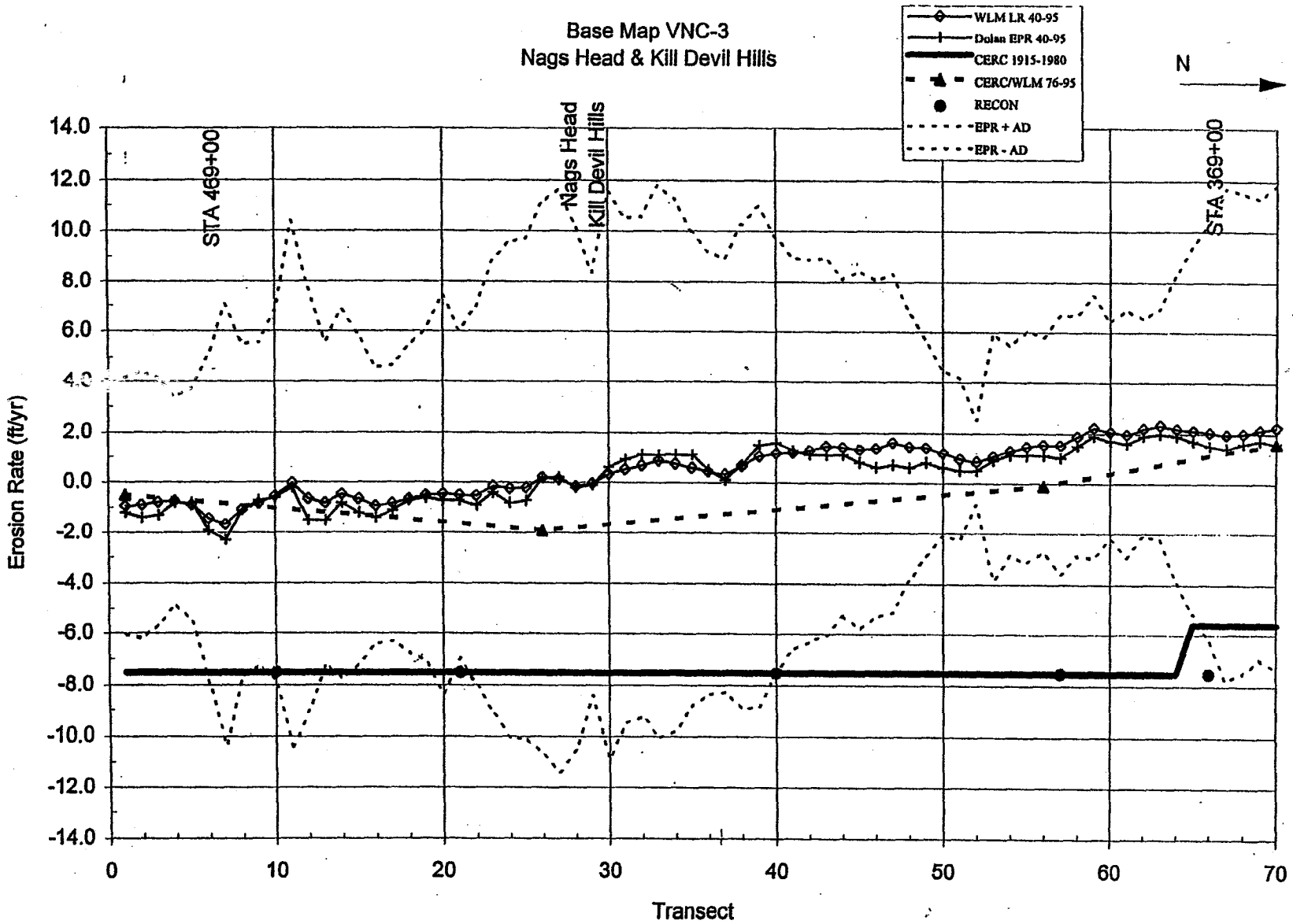

Base Map VNC-3
Nags Head & Kill Devil Hills
WLM LR 40-95
Dolan EPR 40-95
CERC 1915-1980
CERC/WLM 76-95
RECON
EPR + AD
EPR - AD
N
STA 469+00
Nags Head
Kill Devil Hills
STA 369+00
Erosion Rate (ft/yr)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
0
10
20
30
40
50
60
70
Transect

Figure D-15

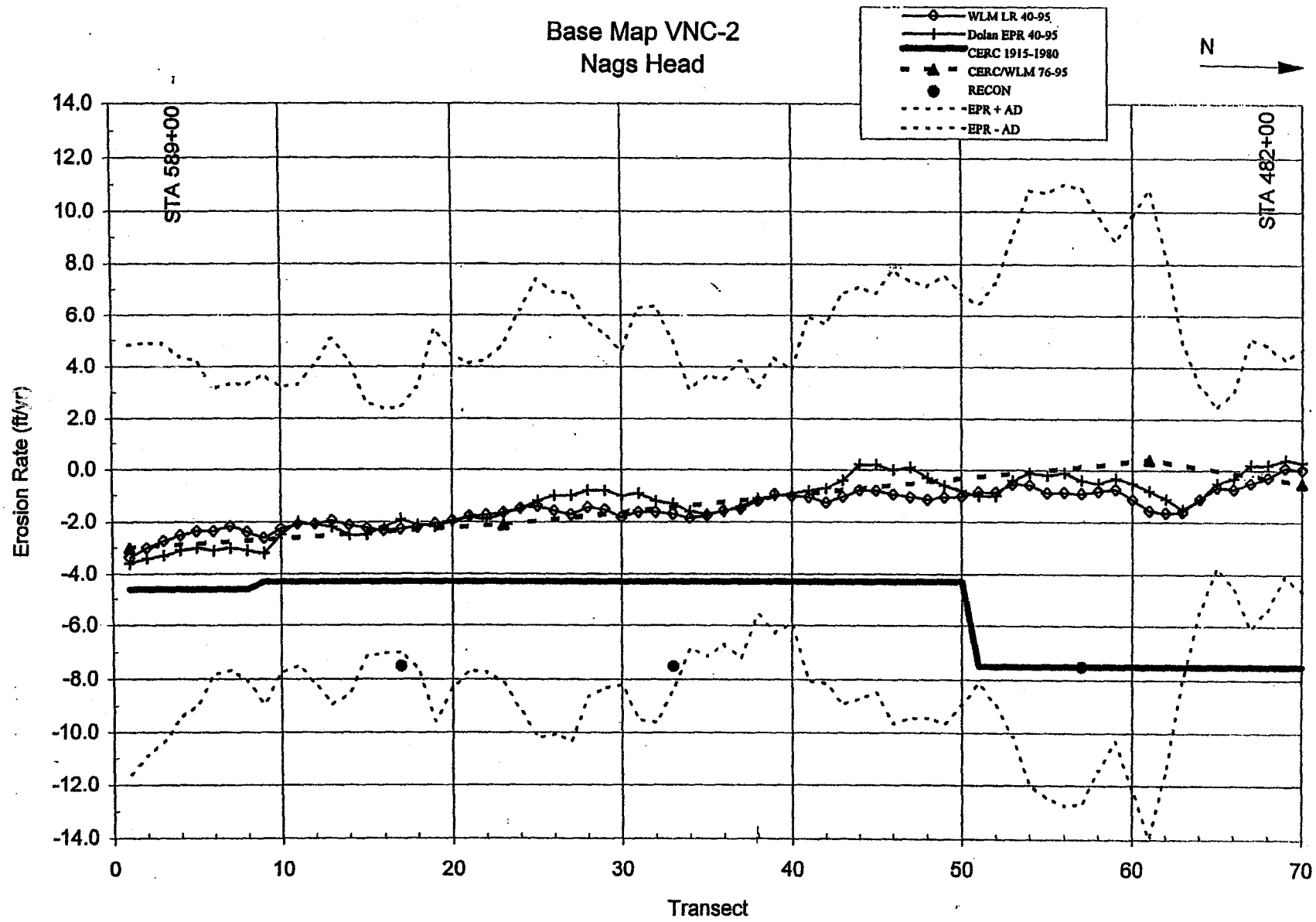

Base Map VNC-2
Nags Head
WLM LR 40-95
Dolan EPR 40-95
CERC 1915-1980
CERC/WLM 76-95
RECON
EPR + AD
EPR - AD
N
STA 589+00
STA 482+00
Erosion Rate (ft/yr)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
0
10
20
30
40
50
60
70
Transect

Figure D-16

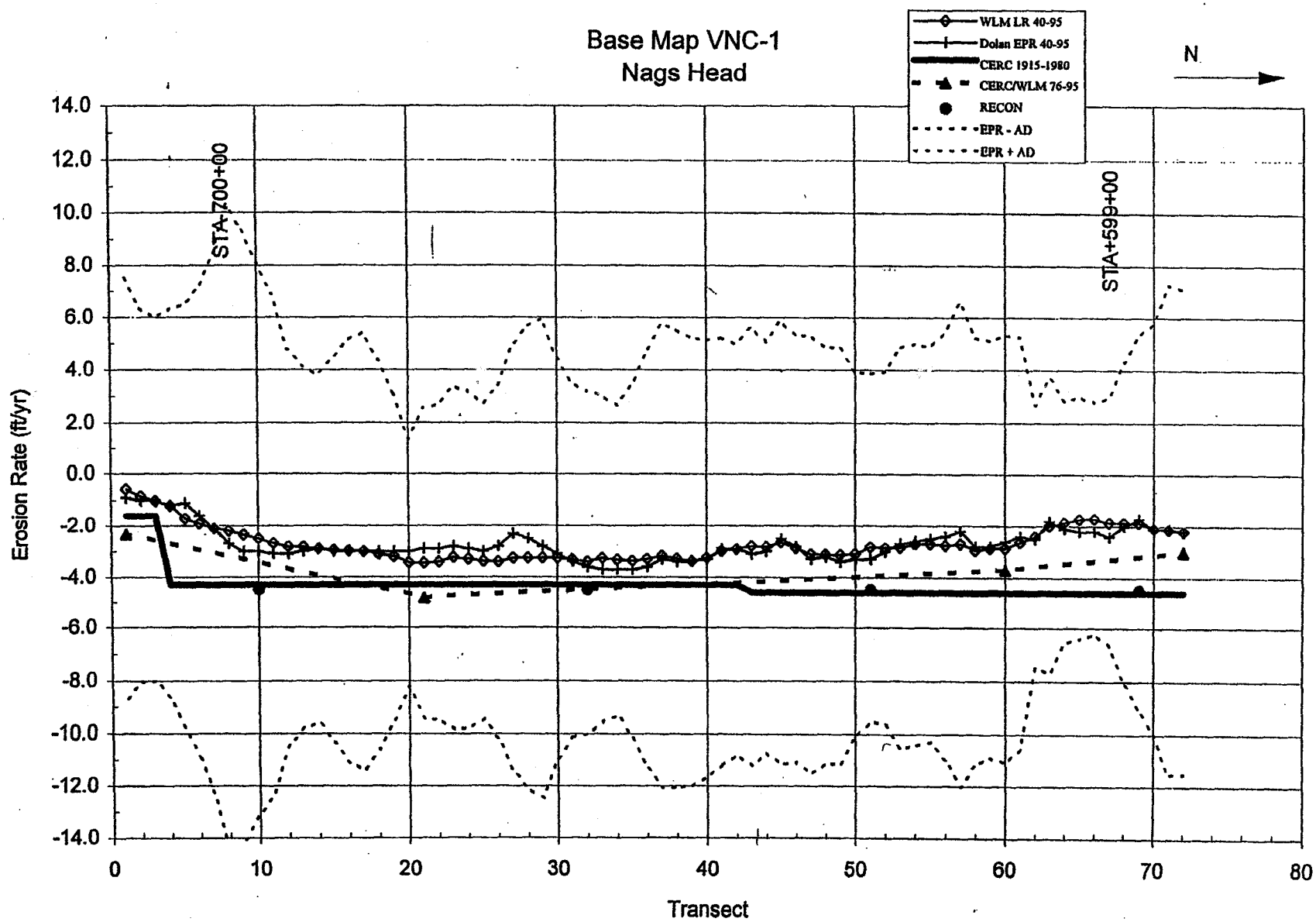

Base Map VNC-1
Nags Head
WLM LR 40-95
Dolan EPR 40-95
CERC 1915-1980
CERC/WLM 76-95
RECON
EPR - AD
EPR + AD
N
STA+700+00
STA+599+00
Erosion Rate (ft/yr)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
0
10
20
30
40
50
60
70
80
Transect

Figure D-17

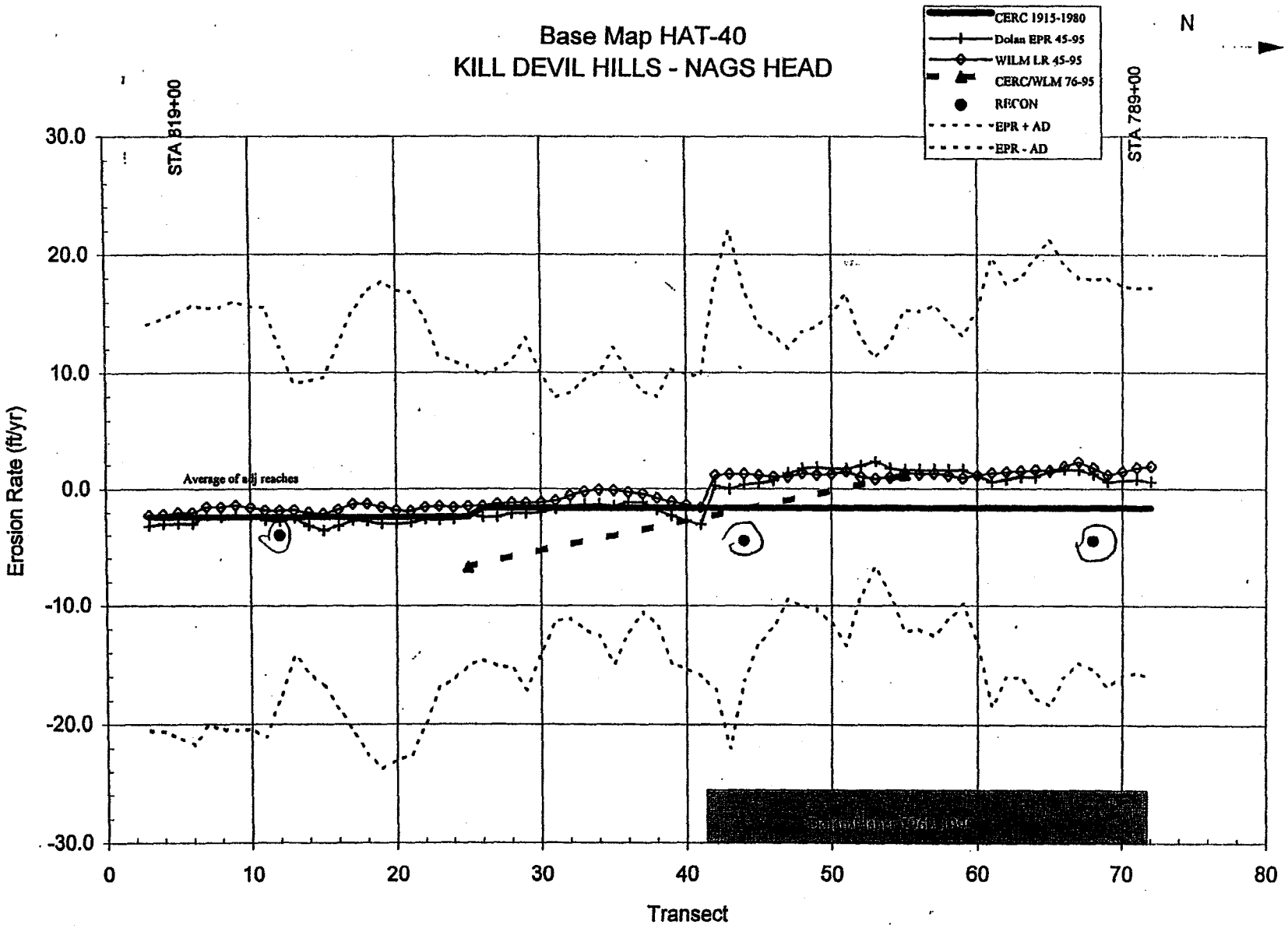

Base Map HAT-40
KILL DEVIL HILLS - NAGS HEAD
CERC 1915-1980
Dolan EPR 45-95
WILM LR 45-95
CERC/WLM 76-95
RECON
EPR + AD
EPR - AD
N
STA 819+00
STA 789+00
Average of adj reaches
Erosion Rate (ft/yr)
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
0
10
20
30
40
50
60
70
80
Transect

Figure D-18

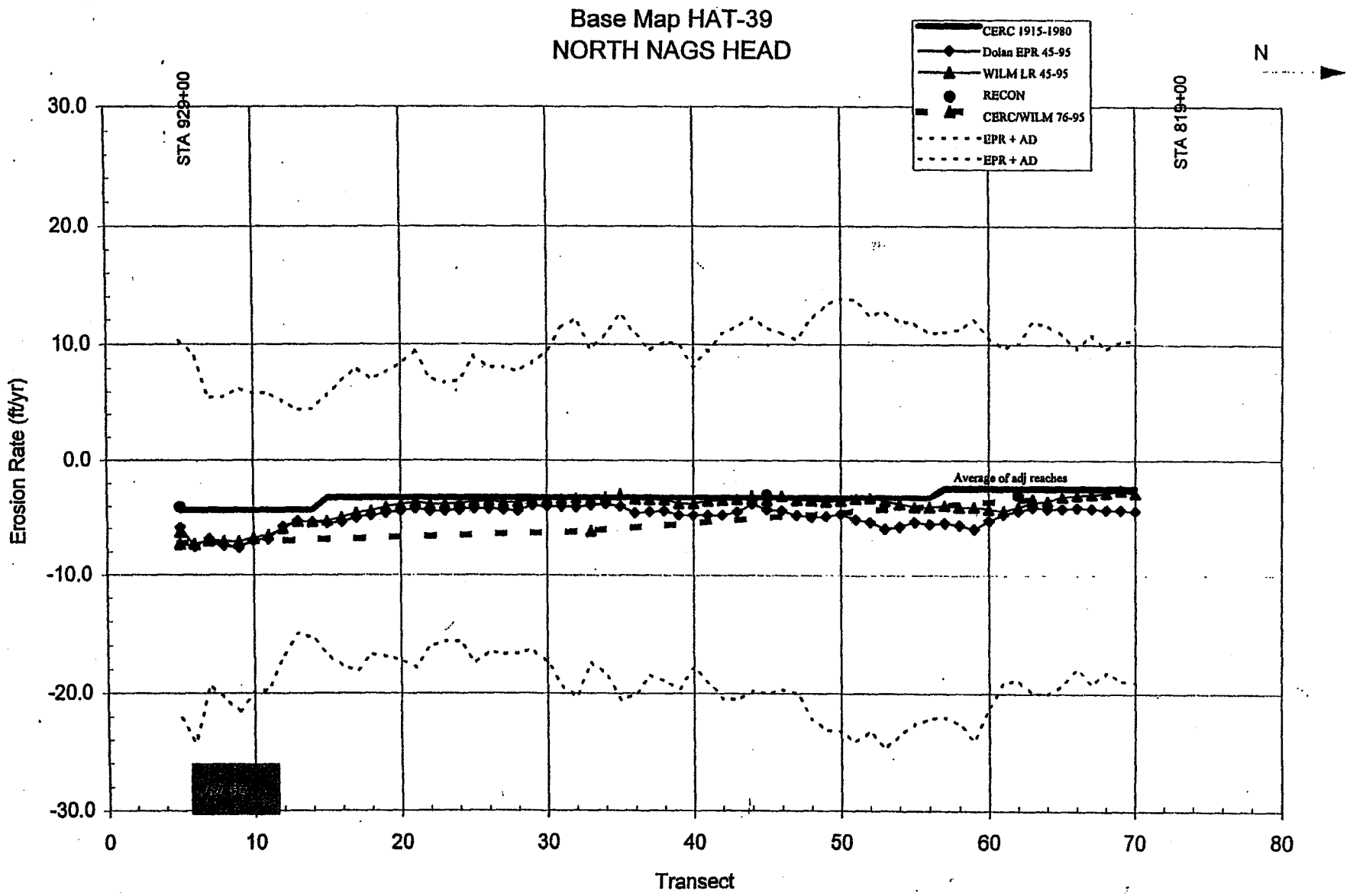

Base Map HAT-39
NORTH NAGS HEAD
CERC 1915-1980
Dolan EPR 45-95
WILM LR 45-95
RECON
CERC/WILM 76-95
EPR + AD
EPR + AD
N
STA 929+00
STA 819+00
Average of adj reaches
Erosion Rate (ft/yr)
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
0
10
20
30
40
50
60
70
80
Transect

Figure D-19

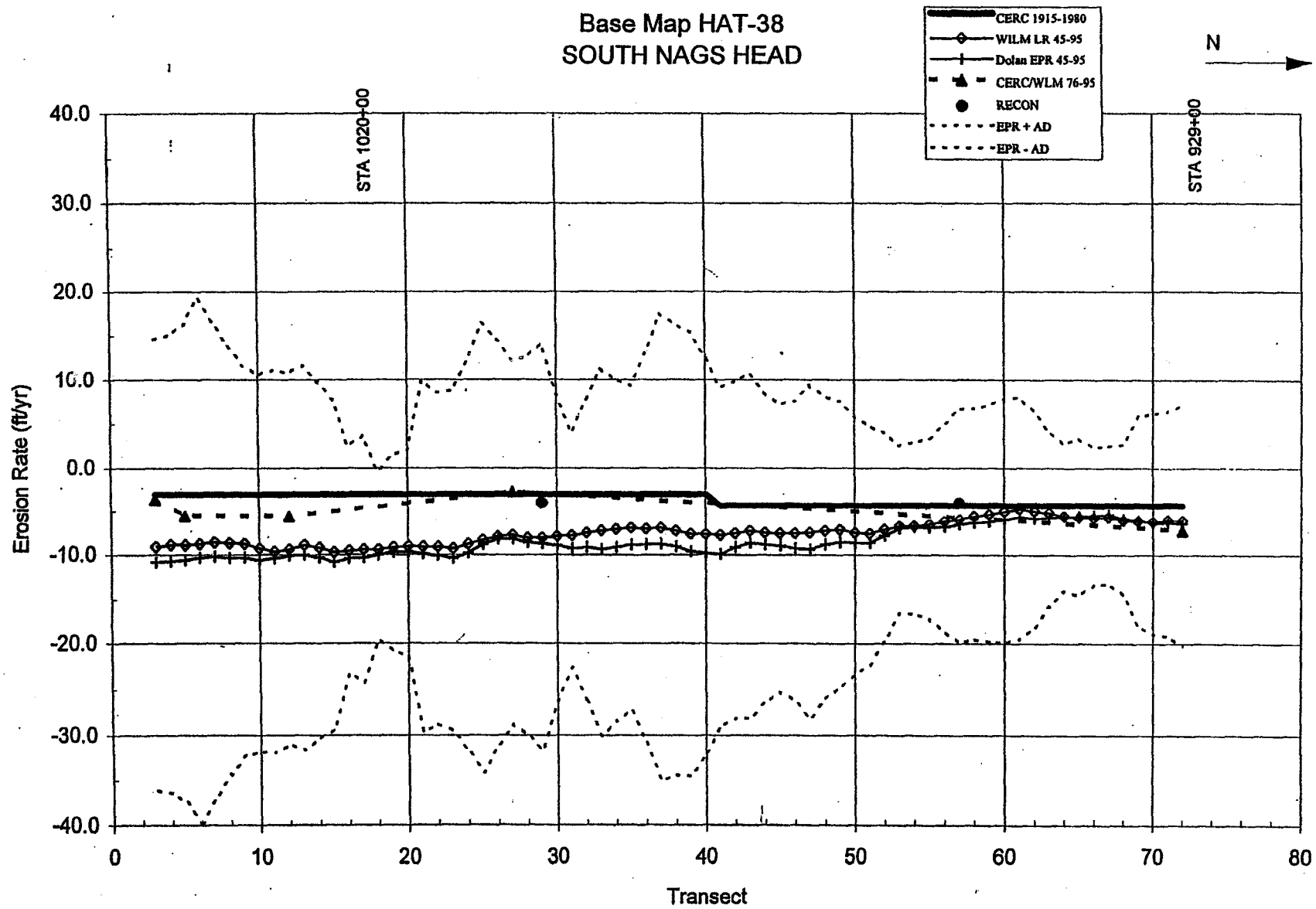

Base Map HAT-38
SOUTH NAGS HEAD
CERC 1915-1980
WILM LR 45-95
Dolan EPR 45-95
CERC/WLM 76-95
RECON
EPR + AD
EPR - AD
N
STA 1020+00
STA 929+00
Erosion Rate (ft/yr)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
0
10
20
30
40
50
60
70
80
Transect

Figure D-20

4) **Dolan Data.** The shoreline change data by Dr. Dolan, known as the COAST database, was developed from a comparison of aerial photos dated from the late 1930's and early 1940's to 1995. This shoreline change database is also the basis of the long-term shoreline changes used by NCDCM. Dolan divided the shoreline into a series of base maps with each base map covering slightly more than 2 miles. Shoreline positions on each set of aerial photographs were measured at transects spaced at 50 meters (164 feet). Measurements were made to both the seaward vegetation line and the water line. The seaward vegetation line represents the landward limit of the dry beach area and generally indicates the cumulative effects of long-term changes. However, the shoreline change information obtained from the vegetation line can be greatly distorted if a storm event predated the photography. If the storm caused significant retreat of the vegetation line, post-storm recovery will not be captured due to the time required for the vegetation to reestablish. The water line, which is usually discernible on the photos as a line separating the dry beach (light color) and the wet beach (dark color), is more sensitive to short term fluctuations in the shoreline position and will generally capture post-storm recovery of the beach. Accordingly, the shoreline change rates developed from the high water mark data in the Dolan shoreline change data base is the basis of the shoreline change rates used by NCDCM in establishing the building setback requirements. The NCDCM long-term shoreline changes are based on the end point method in which the earliest shoreline position for a particular transect is compared to the shoreline position of the latest photograph. The shoreline change rates developed by Dolan for each transect are also plotted on figures D-12 to D-20 and are designated as Dolan EPR 40-95 (note, EPR stands for end point rate). Also shown on these figures are the end point rates plus and minus one standard deviation. These lines are designated as "EPR + AD" and "EPR – AD", respectively. As a matter of note, NCDCM does not directly apply the shoreline change rates for each transect in the administration of its coastal structures setback. Given the variability of the shoreline change rates, NCDCM uses a running average of 17 transects (850 meters or 2,788 feet) to determine shoreline change rates. Accordingly, the Dolan shoreline change rates shown on figures D-12 to D-20 differ slightly from the NCDCM rates shown on figure D-11.

5) **FRF Profile Survey Data.** The CERC Field Research Facility conducted a series of beach profile surveys in the mid-1970's throughout the entire study area. In 1995, the Wilmington District resurveyed the same profile lines and developed shoreline change data from a comparison of these profile survey data sets. The resulting shoreline change rates from this data source are also plotted on figures D-12 to D-20 and are designated as CERC/WLM 76-95.

6) **Alternative Analysis of the COAST Database.** As mentioned above, the NCDCM uses the end point method to determine long-term shoreline changes. In essence, this method ignores the shoreline position data obtained form photographs taken between these dates. The risk associated with the end point method is that either the first point or the last point could be an anomalous shoreline position that could have been affected by a storm or even large measurement errors. In general, each transect within the COAST database has 8 to 12 shoreline position measurements. These measurements were subjected to a linear regression analysis for each transect and the resulting shoreline change rates determined. These linear regression rates are also shown on figures D-12 to D-20 with the designation WLM LR 40-95.

7) **Summary of Various Shoreline Change Rates.** Comparisons of shoreline change rates determined from the various data sources and shoreline change rates from various analyses of the COAST data base show basically the same general trends along the entire study area. While some differences do occur, particularly between the relatively short-term data represented by the profile survey data set and the longer term photo data sets, the comparative analysis of all of the various sources confirmed that the DCM shoreline change rates accurately portray the long-term behavior of the shoreline throughout the entire study area. Accordingly, in the interest of maintaining consistency between the plan formulation process for the current study and the construction set back requirements as dictated by the DCM, the DCM long-term shoreline change rates through 1995 were adopted for this study.

8. Wave Transformation and Shoreline Modeling.

a. General

A numerical modeling effort was undertaken to investigate the performance of the proposed beach project. All of the analysis included the simulation of wave transformation over the 5 identified offshore borrow areas for both the existing and future dredged conditions (assuming a worse case where all 5 sites are fully utilized). In the recommended borrow use plan, only two borrow sites (N1 in the north and S1 in the south) will provide beach sand, each utilizing about 70 percent of maximum capacity over the 50-year project life. The modeling was accomplished by the Corps of Engineers' Waterways Experiment Station (WES), Coastal and Hydraulics Laboratory (CHL) over the period of August 1999 through January 2000. This effort utilized two models, namely a wave model and a shoreline simulation model. The CHL spectral wind-wave growth and propagation model STWAVE (STeady-state spectral WAVE) was chosen for wave transformation modeling. GENESIS (GENEralized model for SImulating Shoreline change) was used to predict changes in the project shoreline in the project study area. Following is a

summary of modeling results. Complete details of the modeling efforts by WES can be found in Draft Technical Report CHL-99-xx, dated 6 December 1999, entitled "Analysis of Wave Transformation, Littoral Sediment Transport and Beach Fill Performance: Dare County Beaches, North Carolina."

b. Wave Transformation Model

The CHL spectral wind-wave growth and propogation model STWAVE was chosen for wave transformation modeling given its ability to transform waves over complex bathymetry existing offshore of Dare County. Waves selected as input to the STWAVE model were taken from the Wave Information Study (WIS) 20-year hindcast for years 1976 to 1995. WIS data includes three parameters, significant wave height, H_s, peak spectral period, T_p, and peak direction, θ_p, which are available at 3-hour intervals over the 20-year period. An STWAVE grid was developed to include coastal bathymetry extending from the shoreline seaward to a distance of about 5 miles. Average water depth along the seaward boundary is 68 feet. The grid encompasses both the North and South Project Areas and all five identified borrow areas. It extends about 6 miles beyond the north boundary of the North Project Area and 4 miles beyond the south boundary of the South Project Area. The south grid falls just north of shoal features associated with Oregon Inlet. The STWAVE grid has a spatial resolution of approximately 200-feet. Removal of sediment from the various borrow areas will result in depressions offshore of the project sites with the depressions being possibly 8 to 10 feet below the present bottom. In order to determine if total removal of the sediment from all of the borrow sites would have any impact on the concentration of longshore wave energy and thus littoral sand transport potential, wave transformation over the borrow sites was analyzed for both existing and future (end of 50-year project life) conditions. Project conditions at the end of the 50-year project life were integrated into the existing depth grid representing the future with project wave transformation analysis.

c. Shoreline Change Model

Results from the two wave transformation analyses (with and without dredged bathymetry) provided input to the second model, GENESIS (GENEralized model for Simulating Shoreline change). GENESIS was then used to predict changes in the project shoreline, as well as, the corresponding southward, northward, net and gross littoral transport potentials along the study area. The GENESIS baseline parallels the STWAVE grid and follows the general trend of the existing coastline covering 131,400 feet with a grid cell spacing of 200 feet. The GENESIS model was calibrated to match long-term shoreline change rates, as well as, established sediment transport rates for the study area. The shoreline change rates selected for calibration were those developed by the North Carolina Division of Coastal Management, computed over the period 1940 to 1995. These rates ranged from approximately 3 feet

of accretion to 10 feet of erosion per year over the project domain. Longshore sand transport rates computed with the model under average wave conditions resulted in net and gross longshore sand transport rates of 762,000 and 2,184,000 cubic yards per year, respectively, averaged over the whole model domain. The modeled longshore transport rates are reasonably consistent with the net and gross rates documented by previous studies of the area. Figure D-21 displays the net longshore transport that could be expected in the North and South Project Areas for no project conditions with the existing bathymetry (no borrow material removed) and with the borrow areas fully utilized.

d. Project Modeling Simulations

Once the model was calibrated, the recommended NED plan was incorporated into the model, effectively moving the existing beach profile an average of 150 feet seaward of its present location. The proposed project will create seaward protuberances in the shoreline that will increase rates of longshore transport, particularly at the ends of the fills. Accordingly, GENESIS simulations were used to evaluate transition lengths at the ends of the projects and the overall project performance at the end of the 3-year periodic nourishment cycle. Simulations were run over a 3-year cycle for both the North and South Project Areas. These initial runs indicated that the project design berm width of 150 feet would not be maintained in the North Project Area or at the ends of the South Project Area regardless of the transition length. Accordingly, a second set of model simulations were made to quantify the volume of sand required to maintain the 150-foot minimum design berm width and also to quantify the berm width that would be provided by the original periodic nourishment plan using a sequence of multiple periodic nourishment cycles. Economic evaluations show that maintaining the 150-foot minimum design berm does not maximize net benefits. Therefore, advanced nourishment was eliminated from further consideration. Two other cases evolved where periodic nourishment material was added non-uniformly along the project reach based upon the shoreline response at the end of the prior cycle. This type of simulation mimics how the project would operate under prototype conditions. Additional model simulations were performed to examine sensitivity of the project evolution under very high transport conditions and drift reversals.

e. Wave Transformation Results

Modeling results indicate that dredging will have minor impact on nearshore waves shoreward of borrow areas when the borrow areas are fully depleted at the end of the 50-year project life. These impacts are quite variable spatially, increasing wave height in some areas and decreasing it in other areas. The magnitude of the wave height change is generally small, ranging from plus 3 to minus 5 percent. Changes in wave angle are generally limited to plus 3 to

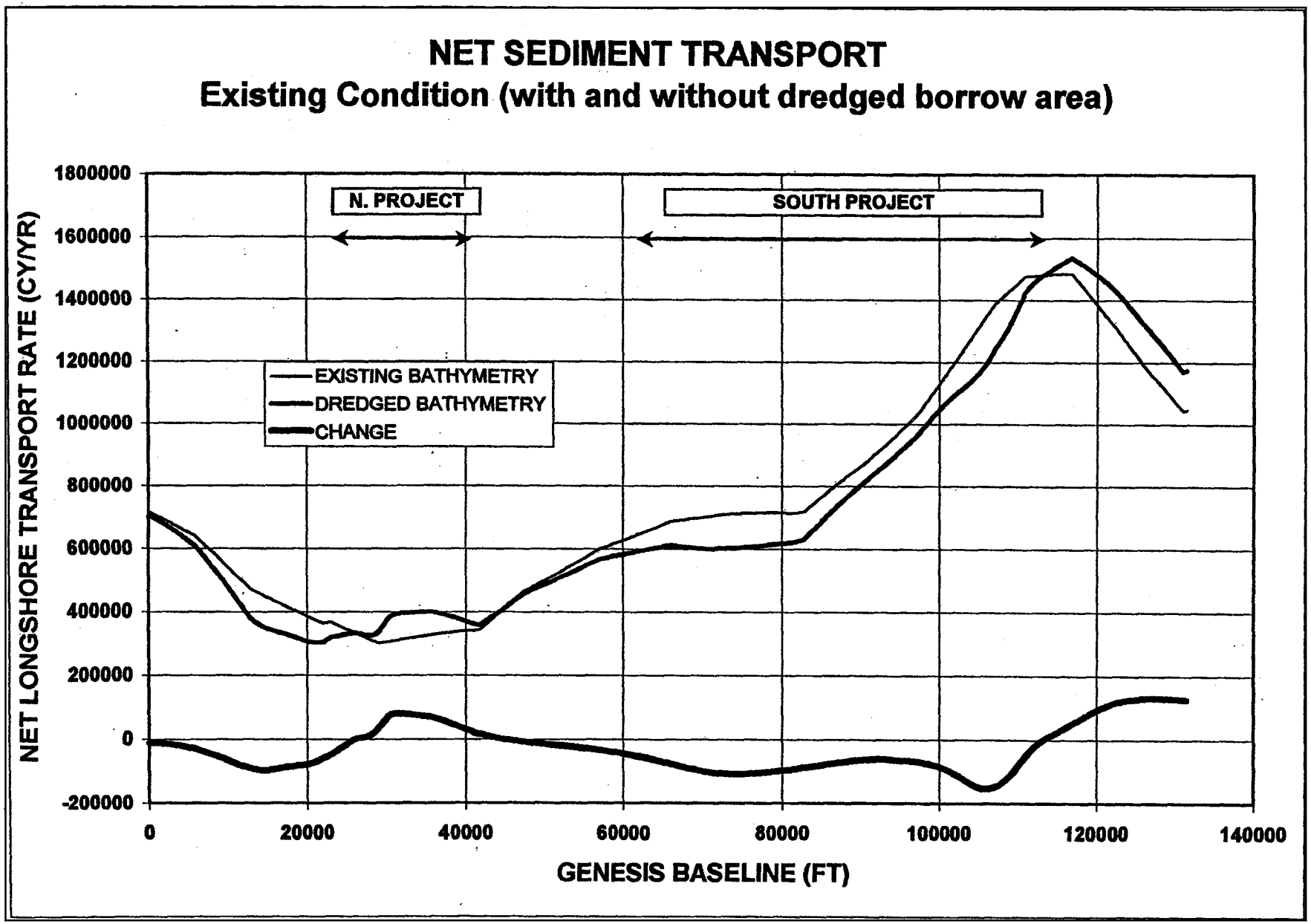

NET SEDIMENT TRANSPORT
Existing Condition (with and without dredged borrow area)
N. PROJECT
SOUTH PROJECT
EXISTING BATHYMETRY
DREDGED BATHYMETRY
CHANGE
NET LONGSHORE TRANSPORT RATE (CY/YR)
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
-200000
0
20000
40000
60000
80000
100000
120000
140000
GENESIS BASELINE (FT)

Figure D-21

minus 3 degrees. General trends for the North Project Area show that wave heights, although variable, are expected to be lower over the northern most 1000 feet of the project and then larger over the next 1000 feet. Elsewhere in the North Project Area the incident wave conditions are expected to be relatively unchanged. Expected changes in wave conditions for the South Project Area for the fully dredged condition are that wave heights are expected to be larger over the northern most 5,000 to 10,000 feet, followed by generally lower wave heights over the remainder of the South Project Area.

f. Project Performance

Under dredged conditions, the northern half of the North Project Area is seen to perform more poorly, whereas the southern half is seen to have an enhanced project performance. However, over the entire North Project Area, the performance is seen to improve under fully dredged conditions. For the South Project Area the response is more complex. Over the northern half of the South Project Area wave transformation over the dredged bathymetry has a generally negative but minor effect on the project performance. However, in the southern half of the South Project Area wave transformation over the dredged bathymetry is predicted to induce a shoreline advancement over the middle segments bordered by an area of shoreline retreat over the southernmost 8,000 feet.

g. Issues Addressed by Modeling

1) **Periodic Nourishment Requirements.** The results of the simulations run over multiple periodic nourishment cycles provided the information necessary to estimate the periodic nourishment volumes. The model produced results showing the expected volume losses with the recommended project during a 3-year periodic nourishment cycle. These volumes were served as input to the GRANDUC model as target annual erosion volumes over the project life. Model results support an average 3-year periodic nourishment volume of 1,055,000 cubic yards for the North Project Area and 2,835,000 cubic yards for the South Project Area. Actual 3-year periodic nourishment volumes will vary from cycle to cycle and periodic field surveys will determine actual periodic nourishment needs.

2) **Transitions.** The GENESIS model simulations were used to investigate a range of transition lengths at the project boundaries. Transitions are used to minimize project "end losses" resulting from increased sediment transport off of the beach-fill due to the offset in the shoreline between the natural and man-made beach.

   a) **Initial Transition Modeling.** The initial series of model runs included transition lengths of 0, 1000, 1600 (South Project Area only), 2000, 3000, and 6000 feet with each simulation covering a single 3-year

periodic nourishment cycle. The results indicated that the overall project performance increased with increasing transition length, as the longer transition zones served to "pre-fill" the adjacent beach areas. In practice the transition length is limited by the cost of placing the additional volume of sediment in the transition areas and/or by the practical construction limitation of placing a very long thin tapering fill along the beach. A further consideration is that as the project undergoes additional periodic nourishment cycles, less expensive transitions are typically required as more sediment is dispersed from the main fill to the adjacent areas.

b) **Final Transition Modeling.** Given the above considerations, additional model runs were accomplished covering four periodic nourishment cycles using transition lengths of 1,000 and 3,000 feet. At the end of each cycle, the performance of the beach-fill was assessed and periodic nourishment material was added non-uniformly along the project reach in anticipation of the beach response over the next three years. In each case no additional material was placed beyond the 1,000 or 3,000 foot transition limits. Overall, the beach-fill response was similar for each case, however the 3000 foot transition length resulted in less total fill volume over the four periodic nourishment cycles for both the North and South Project Areas. This being the case, the recommended transition length for all project transitions is 3,000 feet.

3) **Sand Placement on Cape Hatteras National Seashore.** As discussed above, a 3000-foot transition is included as part of the project design. The transition will end at the National Seashore boundary along the southern segments of the South Project Area. The shoreline modeling shows that the beach-fill sand can be expected to spread into the National Seashore for about 9,000 feet south of the National Seashore boundary under average wave conditions.

4) **Maintenance at Oregon Inlet.** Another issue addressed is whether the project will increase potential sediment transport out of the southern limits of the study area toward Oregon Inlet, thereby increasing maintenance dredging of the channel. Model investigations reveal that a minor increase in net southerly transport would result from fully excavating all offshore borrow areas during the 50-year project life. The project as presently formulated is expected to remove about 70% of the available borrow volume by the end of the 50-year project life, therefore model results using 100% removal of borrow material represent a worst case. Under this condition, an approximate 13% increase in maintenance dredging could result at Oregon Inlet or about 65,000 cubic yards per year. Since 1983, when intensive hopper/pipeline dredging of the inlet was resumed, an average of 490,000 cubic yards has been dredged annually but the yearly

dredged quantity has varied greatly from zero to more than 1,100,000 cubic yards with a standard deviation of 320,000 cubic yards per year. Given this wide range in dredging, the possible increase in maintenance dredging is well within the historical variation under the worse case condition. Annual increases in dredging costs at Oregon Inlet would only be about $3,000 per year based on the 65,000 cubic yards that has been projected for project year 50. This cost would not change the overall project b/c ratio. Since this cost has no impact on project selection and is minor in magnitude compared to historical dredging variations, inclusion of this cost as a project cost does not appear to be warranted since it falls well within normal cost contingencies for the project.

9. Storm Data.

a. Storm Data Input Files

Storm files contain the independent variables from which the economic model (GRANDUC) calculates damages. Storms files are described by a combination of the hydrodynamic parameters:

Surge elevation – derived from FEMA flood insurance data
Wave setup – calculated from WIS data and beach profiles

and the following shoreline responses to the hydrodynamic parameters:

Net volume lost – calculated from empirical method developed by CESAW
Erosion distance – calculated from empirical method developed by CESAW
Maximum elevation of the shoreline profile – taken from beach profile data

b. Storm Frequency Curves

For each of the five independent variables just described, a frequency curve was developed. Frequency curves for net volume lost and erosion distance were calculated from an empirically based method developed in the Wilmington District. The method is based on taking storm erosion volume losses reported in the literature, along with calculated average dune height, and predicting reasonable erosion distances for both high frequency and rare storms. A program (STORM9) was then written to use the independent variable frequency curves, a Poisson distribution with an average number of storms per year of one, and a random number generator to create storm histories for a large number of simulations. For each year of a simulation, the program generates a random number and uses it with the Poisson distribution to determine the number of storms for that year. Then, for each storm, another random number is generated that is used with each of the five independent variable frequency curves to determine the parameters for that storm. Storm conditions for each of the 9 plans investigated were developed

as input to the GRANDUC model for the 21 typical beach profiles that were chosen to represent the 214 study segments used in the study area from Kitty Hawk to the Cape Hatteras National Seashore.

1) **Existing Conditions.** Figure D-22 is a plot of erosion distance versus frequency for existing conditions showing maximum and minimum boundaries for the 21 typical profiles and other selected typical profiles. The 500-year storm erosion distance for all beach profiles is 260 feet. Erosion distance for existing conditions is measured from the existing natural berm at elevation 7 feet NGVD.

2) **Plan Conditions.** One representative typical profile was chosen to display erosion distance comparisons between the various plans investigated. Figure D-23 is a plot of erosion distance versus frequency for the berm only plans at the representative typical profile. Figure D-24 is a similar plot for varying dune heights with a 50-foot berm at the representative typical profile. Figure D-25 is a plot of 13-foot dune heights with varying berm widths at the representative typical profile. The 500-year event was not plotted on figures D-22 through D-25 to allow clearer plotting of the storm events less than the 100-year frequency. For figure D-23, the erosion distance for the 500-year event is 310, 360, 410, and 460 feet for the 50-foot, 100-foot, 150-foot, and 200-foot berms, respectively. For figure D-24, the erosion distance is 310 feet for all the dune plans with a 50-foot berm. For figure D-25, the erosion distance for the 500-year event is 285, 310, and 360 feet for the 13-foot dune with 25-foot, 50-foot, and 100-foot berms, respectively. Erosion distance for plan conditions is measured from the seaward edge of the berm at elevation 7 feet NGVD.

3) **NED Plan Conditions.** Figure D-26 is a plot of erosion distance versus frequency for the NED plan (13-foot dune with 50-foot berm) showing the maximum and minimum boundaries for the 21 typical beach profiles and selected typical profiles between these boundaries. It can be seen from figure D-26 that the 5-year event for all beach profiles is about 20 feet. For larger events, such as the 50-year storm event, the range of storm erosion is from a minimum of 125 feet to a maximum of about 190 feet. The 100-year and 500-year storm erosion for all beach profiles is 240 feet and 310 feet, respectively.

c. **Post-Storm Beach Recovery**

1) **Base Condition.** For base conditions, the net storm erosion after post-storm recovery is calculated by GRANDUC to be consistent with long term erosion for the area. For each 50-year life cycle, the recovery from individual storm events during the life cycle would be adjusted to match the total long term erosion for the life cycle.

Storm Erosion Distance for No Project Conditions

(for a range of typical beach profiles)

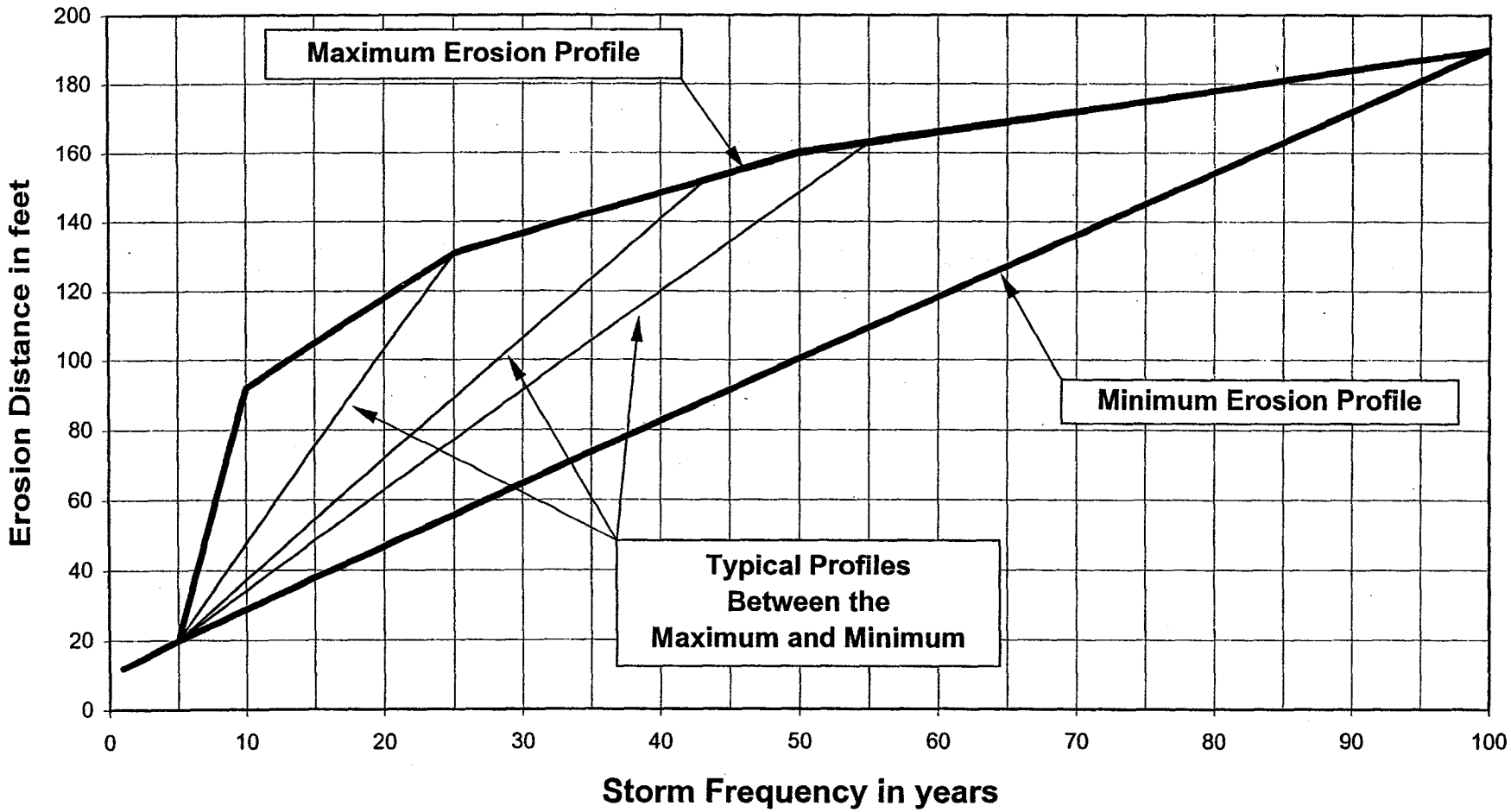


Figure D-22

Storm Erosion Distance for Berm Only Plans

(for a representative typical section)

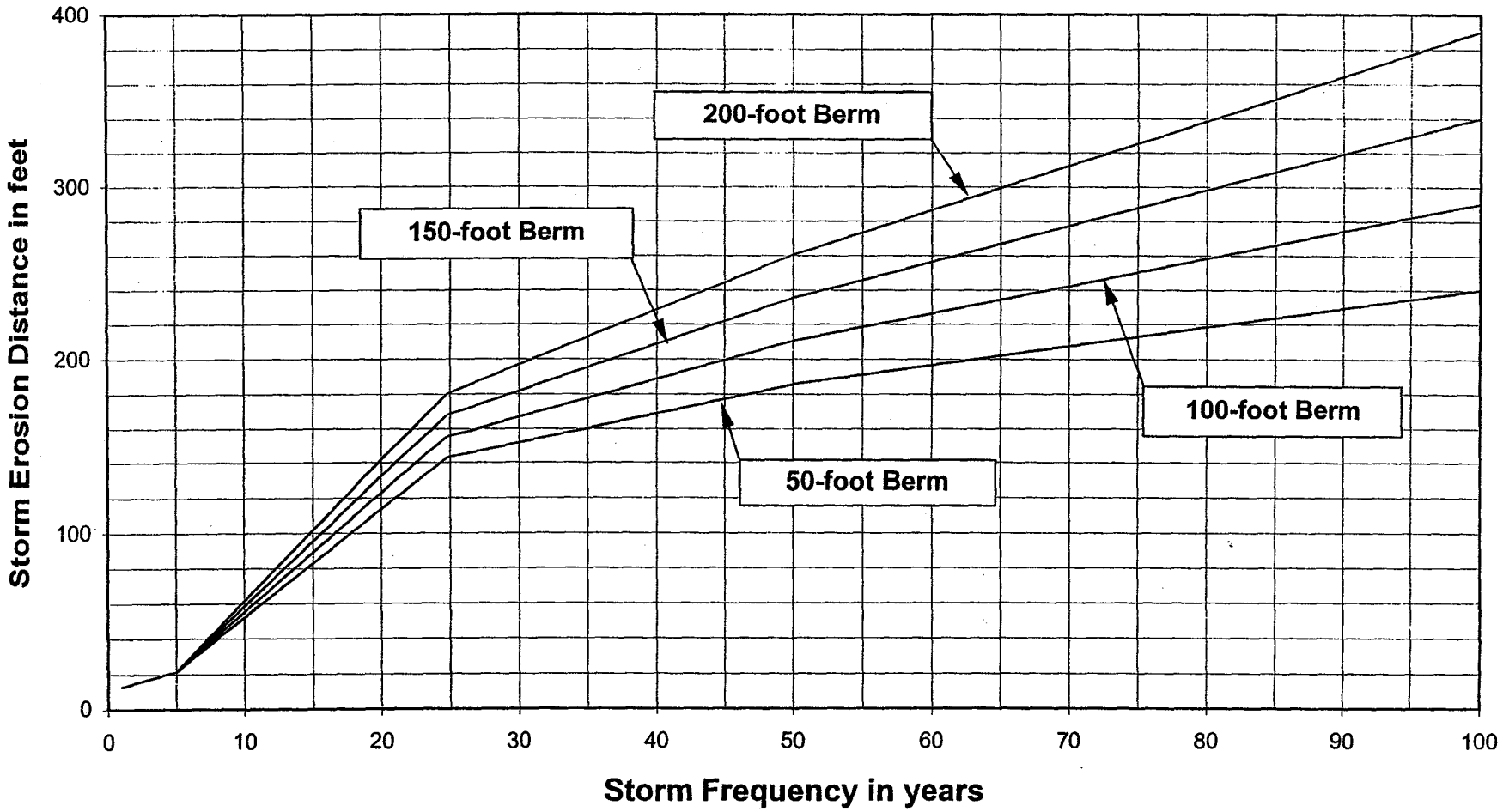


Figure D-23

Storm Erosion Distance for Dune Plans with 50-ft Berms

(for a representative typical section)

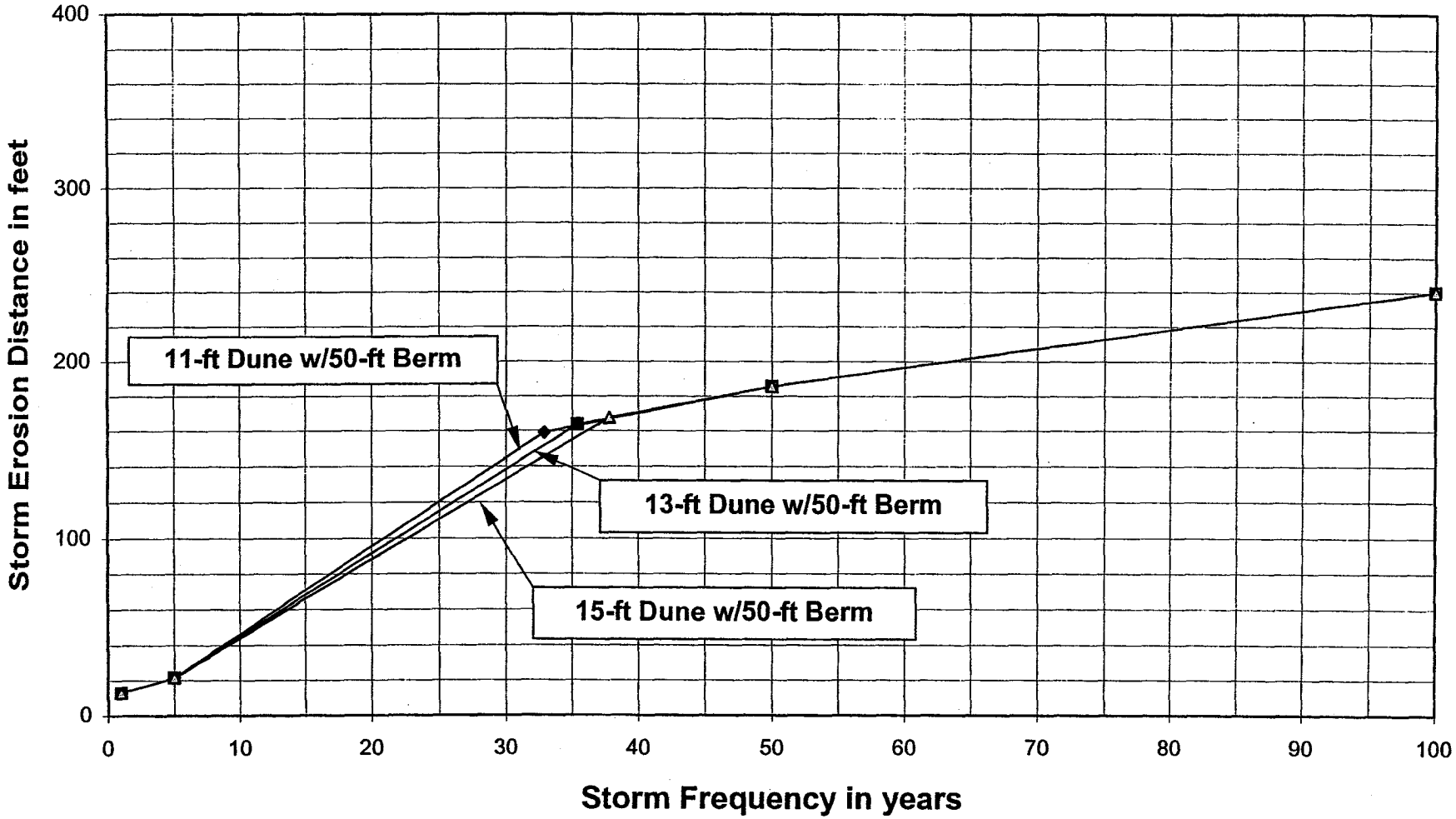


Figure D-24

Storm Erosion Distance for 13-ft Dune with Various Berm Widths

(for a representative typical section)

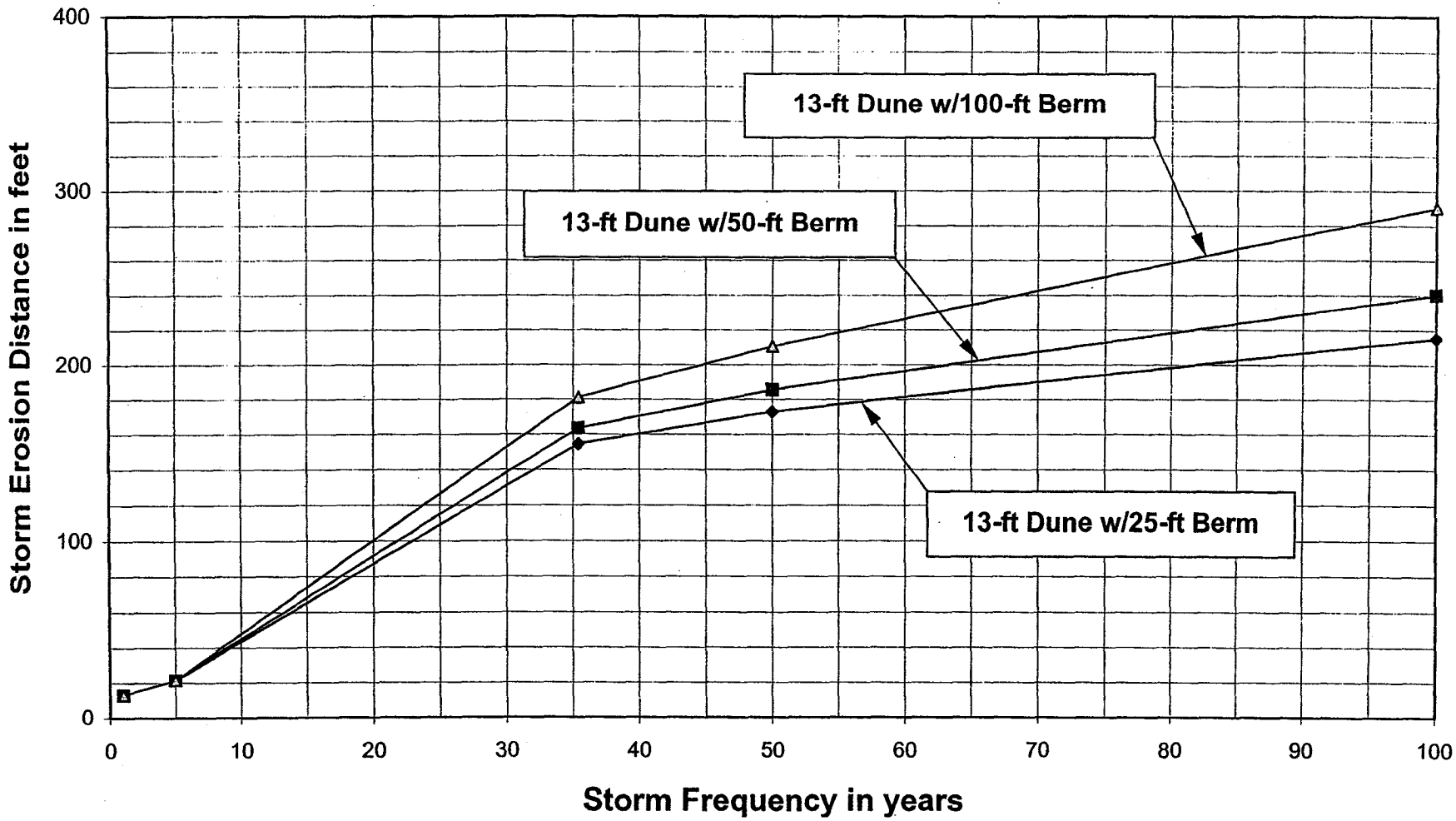


Figure D-25

Storm Erosion Distance for a 13-ft Dune with 50-ft Berm

(for a range of typical beach profiles)

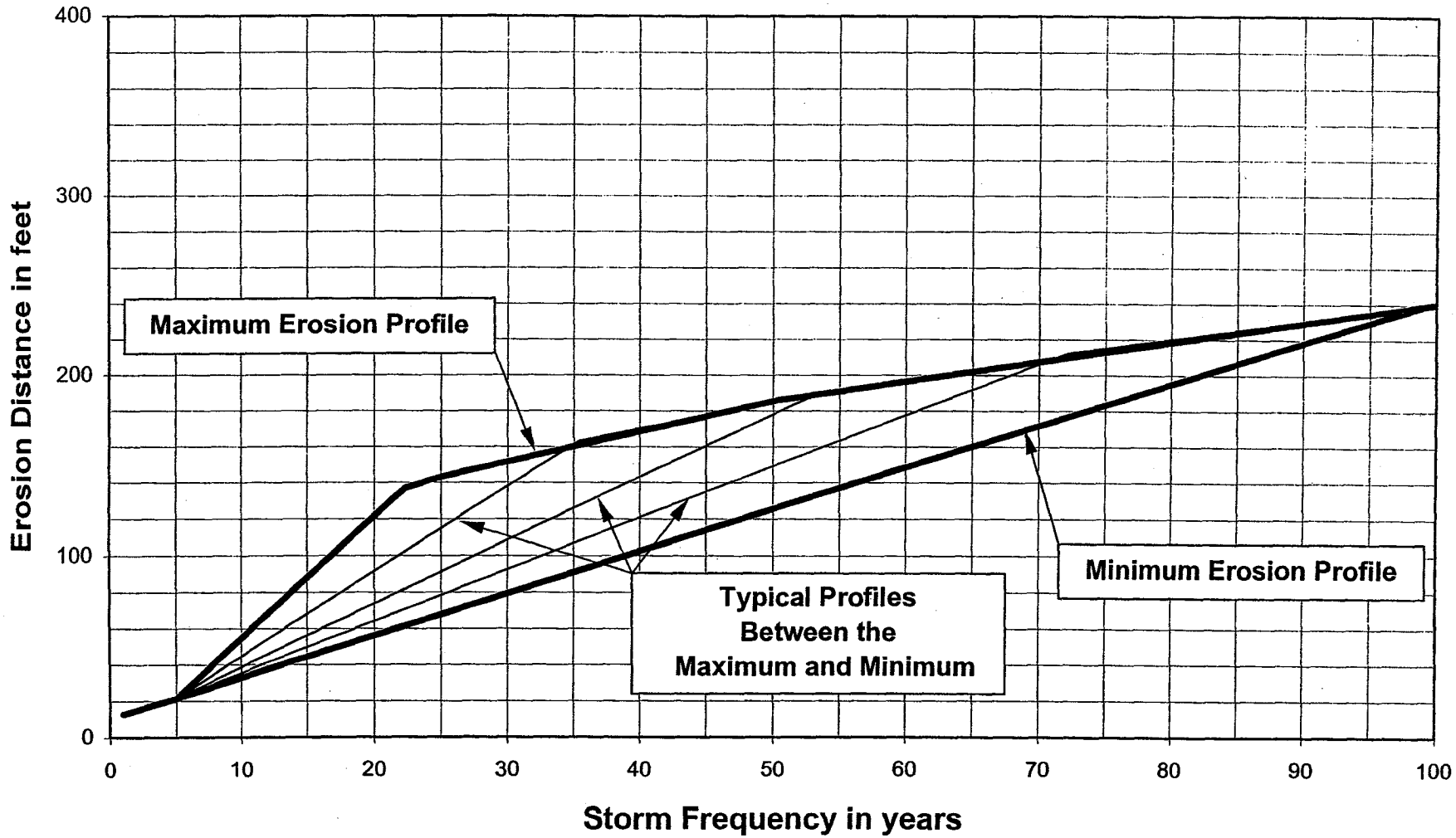


Figure D-26

2) **With Project Conditions.** For with project conditions, the net (shoreline) recovery factor is entered externally to GRANDUC. The recovery factors were computed to simulate both expected project conditions and long term erosion for the study area.

d. Storm Impacts

In assessing the storm damages for a given structure, the GRANDUC model independently computes the damages due to erosion, flooding/inundation, and waves. Only the maximum of the three damages is used to tabulate total storm damages. A brief description of each of the three damage categories follows.

1) **Erosion Damage.** Erosion damage is based on a relationship between the storm erosion distance for a given storm and the amount of undermining at a given structure. An erosion damage curve is developed for each structure type to represent percent damage versus percent undermining of the structure.

2) **Flooding/Inundation Damage.** Flooding damage is based on a relationship between the storm water elevation for a given storm and the first floor elevation of a given structure. A flood damage curve is developed for each type structure to represent percent damage to the structure versus depth storm water elevation above the first floor elevation.

2) **Wave Damage.** Wave damage is computed for areas where the wave height exceeds 3 feet and the area impacted is at least 2 feet below the wave crest.

10. Selection of the Periodic Nourishment Interval.

a. Adopted Periodic Nourishment Interval

A 3-year periodic nourishment interval has been adopted for the Dare County Beach Project. Other periodic nourishment intervals were considered but eliminated due to limited plant availability, operation window constraints, and cost considerations.

b. Periodic Nourishment Requirements

For the 3-year periodic nourishment interval, the North Project Area will need 1,055,000 cubic yards of material and the South Project Area will need 2,835,000 cubic yards of material. Beach nourishment volumes were obtained from shoreline modeling efforts performed by WES.

c. Periodic Nourishment Interval Considerations

Several considerations impacted the selection of the periodic nourishment interval. These considerations include the method of placing beach material, environmental time windows for placing beach material, the use (or non-use) of advanced nourishment, and the maximum allowable interval that would maintain the project design fill without allowing project design failures.

1) Method of Placement.

a) **Borrow Source Distance.** Periodic nourishment for both the North and South Project Areas will come from borrow site S1. Transport distances from S1 to the North Project Area would range from 10 to 15 miles. Transport distances from S1 to the South Project Area would range from 3 to 6 miles.

b) **Required Plant Equipment.** Transport distances dictate the use of a hopper dredge for the North Project Area and a pipeline dredge for the South Project Area. A medium hopper would likely be needed to satisfy dredging window requirements.

c) **Plant Equipment Availability.** Plant availability is likely to be limited, thereby, restricting the number of viable dredging options.

Hopper Dredges. The current Corps/Industry Dredge Fleet status shows a total of 6 medium sized hoppers with direct pumpout capability, each scheduled for operation at some time during the projected dredging window of January through March. On addition, two large hopper dredges would be capable of performing this work. Industry data shows that there will always be a high demand for hopper dredges from January to March because of the turtle take issue.

Pipeline Dredges. Data shows that the availability of ocean certified pipeline dredges is limited to around 9. Because of the ever increasing magnitude of projects that are ongoing there will always be a high demand for these pieces of plant equipment.

d) **Practical Limitations**. Due to limited plant availability, only one hopper and one pipeline dredge is considered practical in a given year.

2) **Environmental Windows.** Hopper dredging for the North Project Area will be limited to January though March, possibly extending into April, due to the likely presence of sea turtles in the borrow area. Pipeline dredging will be limited to mid-November through early summer due to fish & wildlife issues.

3) **Advanced Nourishment.** After establishing the 13-foot dune with a 50-foot berm as the plan with the maximum net benefits (the NED plan), the issue of advanced nourishment was addressed. In order to maintain the beach fill as designed, an additional 50-foot of berm would be required for a 3-year periodic nourishment interval. The advanced nourishment plan was evaluated as the 13-foot dune with a 100-foot berm plan. The net benefits computed by GRANDUC for this plan accounted for the reduction in berm profile (100-foot to 50-foot) over a 3-year periodic nourishment interval. The project net benefits for the 13-foot dune with 100-foot berm plan decreased; therefore, the use of advanced nourishment is not recommended.

3) **Timely Restoration of Project Design Fill.** Since the project is being constructed without advanced nourishment, the timely restoration of the project design fill becomes critical. Shoreline modeling efforts show that the adopted 3 year periodic nourishment interval would not compromise the design integrity of the currently proposed beach fill project. A longer periodic nourishment interval would, however, increase the amount of shoreline retreat between periodic nourishment intervals and, thus; increase the chance of project beach design failure.

d. Plan of Periodic Nourishment for the 3-year cycle

Plant availability will most likely limit the plan to one hopper dredge for the North Project Area and one pipeline dredge for the South Project Area for any given year. With both environmental window restrictions and plant availability limitations imposed, the North and South Project Areas can be restored during a 3-year cycle without compromising design integrity. Referring to the recommended construction plan shown on figure 5, it can be seen that the environmental windows are nearly fully utilized for the total 3-year periodic nourishment period. A cycle less than 3 years would require multiple dredges and was therefore not considered as practical. A greater cycle would decrease project design protection and jeopardize project design integrity; therefore, a cycle greater than 3 years was considered unacceptable. Figure D-27 illustrates the process for selecting the periodic nourishment interval.

11. Risk and Uncertainty.

a. Background

Analysis of shore protection projects has moved from the traditional deterministic approach to a more comprehensive probabilistic, risk-based methodology. Shore protection projects are now formulated to provide economical protection for storm and erosion prone areas, selecting the plan that maximizes net economic benefits consistent with acceptable risk

Periodic Nourishment Interval

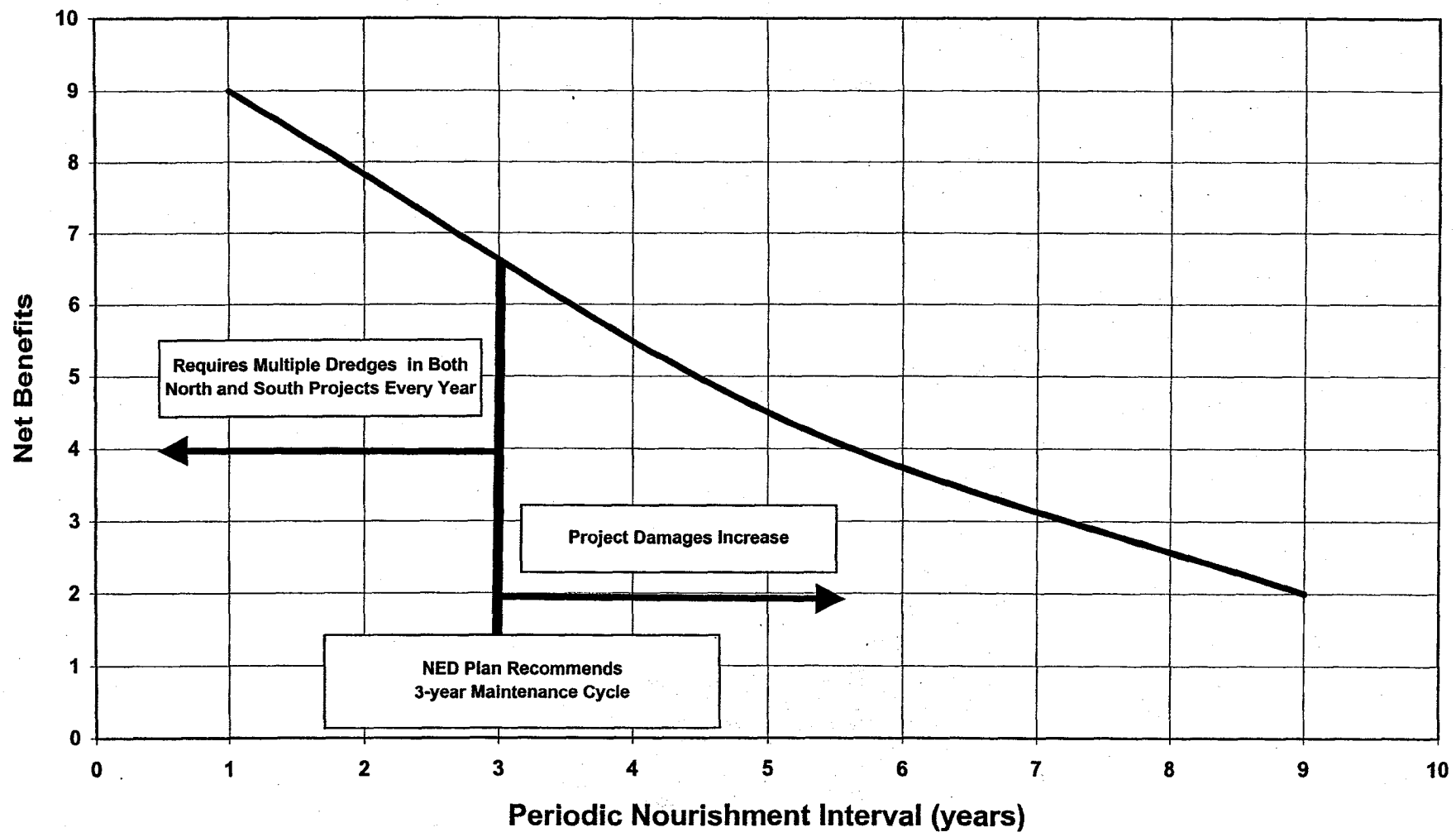


Figure D-27

and functional performance. The technical task of any risk-based analysis is to balance the risk of design exceedance with damages prevented, uncertainty of storm characteristics with design accommodations, and to provide for safe, predictable performance. Risk-based analysis enables risk issues and uncertainty in critical data to be explicitly included in project formulation and evaluation. The uncertainties associated with the sequencing of storms and natural recovery and those associated with storm damages and erosion losses can now take on a very large number of values. Evaluating the effects of each sequence of storms becomes a life cycle analysis problem and many lifecycles must be evaluated in order to quantify the distribution of economic losses both without a shore protection project and with each alternative formulated. The use of the lifecycle approach helps explain the evaluation process for erosion and nourishment much more easily since the lifecycle approach is more realistic and more closely mimics the dynamic coastal conditions.

b. Guidance

A major design consideration for this project was to incorporate risk and uncertainty as an integral part of the formulation process. Chapter 6 of ER 1105-2-100, entitled "Risk-Based Analysis for Evaluation of Hydrology/Hydraulics and Economics in Shore Protection Studies" specifies the analysis requirements for shore protection projects, the fundamental requirement being that all shore protection analysis adopt a life cycle approach. The Wilmington District model, GRANDUC, which was used for this study incorporates the life cycle approach into the formulation process.

c. Analysis Requirements

ER 1105-2-100 also specifies that the analysis be risk-based and that the following variables be explicit in the analysis and some, by implication, be considered as uncertain:

1) the erosion damage function
2) the stage damage function
3) the wave damage function
4) storm-related parameters
5) wave height above the dune
6) wave penetration
7) shoreline retreat or eroded volume
8) natural post-storm recovery

All of these variables are explicitly covered in the GRANDUC model.

d. Uncertainty

The GRANDUC model is currently programmed to measure uncertainty using the following three variables:

1) erosion distance – plus or minus 2.0 feet
2) structure distance – plus or minus 5.0 feet
3) structure elevation – plus or minus 0.1 feet

More variables can and will be added to GRANDUC as the model becomes more fully developed. These three variables utilized, however, are considered a reasonable measure of uncertainty for this study. A triangular distribution has been chosen to represent the variance for each variable.

e. Risk Results for Alternatives Evaluated

Given the probabilistic nature of the analysis, each alternative was evaluated to determine the percent chance that the given alternative would have a favorable benefit to cost (B/C) ratio of at least 1.0. These evaluations are summarized in tables D-9 and D-10 for the North Project Area and South Project Area, respectively.

Table D-9
North Project Area – Percent Chance of Having a Favorable B/C Ratio

Berm Only Plans	Percent Chance	Berm and Dune Plans	Percent Chance
50-ft Berm	63.6	11-ft Dune w/50-ft Berm	77.3
100-ft Berm	70.7	13-ft Dune w/50-ft Berm	76.7
150-ft Berm	63.6	15-ft Dune w/50-ft Berm	67.9
		13-ft Dune w/25-ft Berm	76.9
		13-ft Dune w/100-ft Berm	62.5

Table D-10
South Project Area – Percent Chance of Having a Favorable B/C Ratio

Berm Only Plans	Percent Chance	Berm and Dune Plans	Percent Chance
50-ft Berm	99.8	11-ft Dune w/50-ft Berm	99.9
100-ft Berm	99.6	13-ft Dune w/50-ft Berm	99.9
150-ft Berm	99.3	15-ft Dune w/50-ft Berm	99.8
		13-ft Dune w/25-ft Berm	99.9
		13-ft Dune w/100-ft Berm	99.5

The tables show that the risk associated with North Project Area is much greater than the risk associated with the South Project Area. Risk-based analysis using GRANDUC shows that a feasible project (B/C ratio of 1.0 or greater) could be justified for the North Project Area in roughly 7 out of every 10 lifecycles performed. For the South Project Area a feasible

project could be justified for almost 10 out of every 10 lifecycles performed. A total of 500 lifecycles were evaluated with each lifecycle being 50-years, the economic life of the project. Plots of the GRANDUC uncertainty results for the NED plan (1350BD) are displayed on figures D-28 and D-29 for the North and South Project Areas, respectively, with pertinent statistics for each included. For the NED plan, the North and South Project Areas have a 76.7 and 99.9 percent chance, respectively, of having a favorable benefit-cost ratio.

North Project - Risk Analysis for 1350BD

(Total Net Benefits vs Cumulative Probability Distribution)

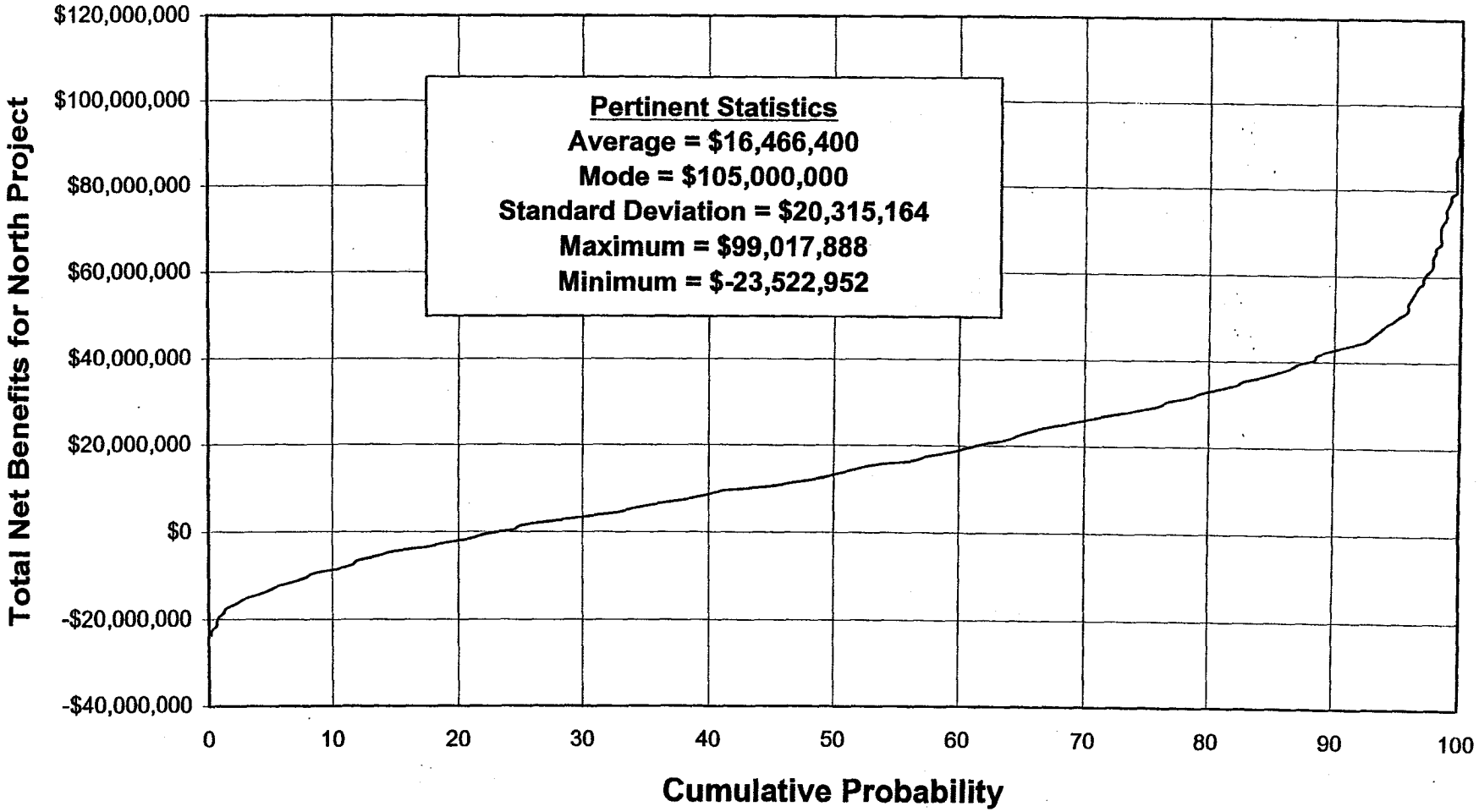


Figure D-28

South Project - Risk Analysis for 1350BD

(Total Net Benefits vs Cumulative Probability Distribution)

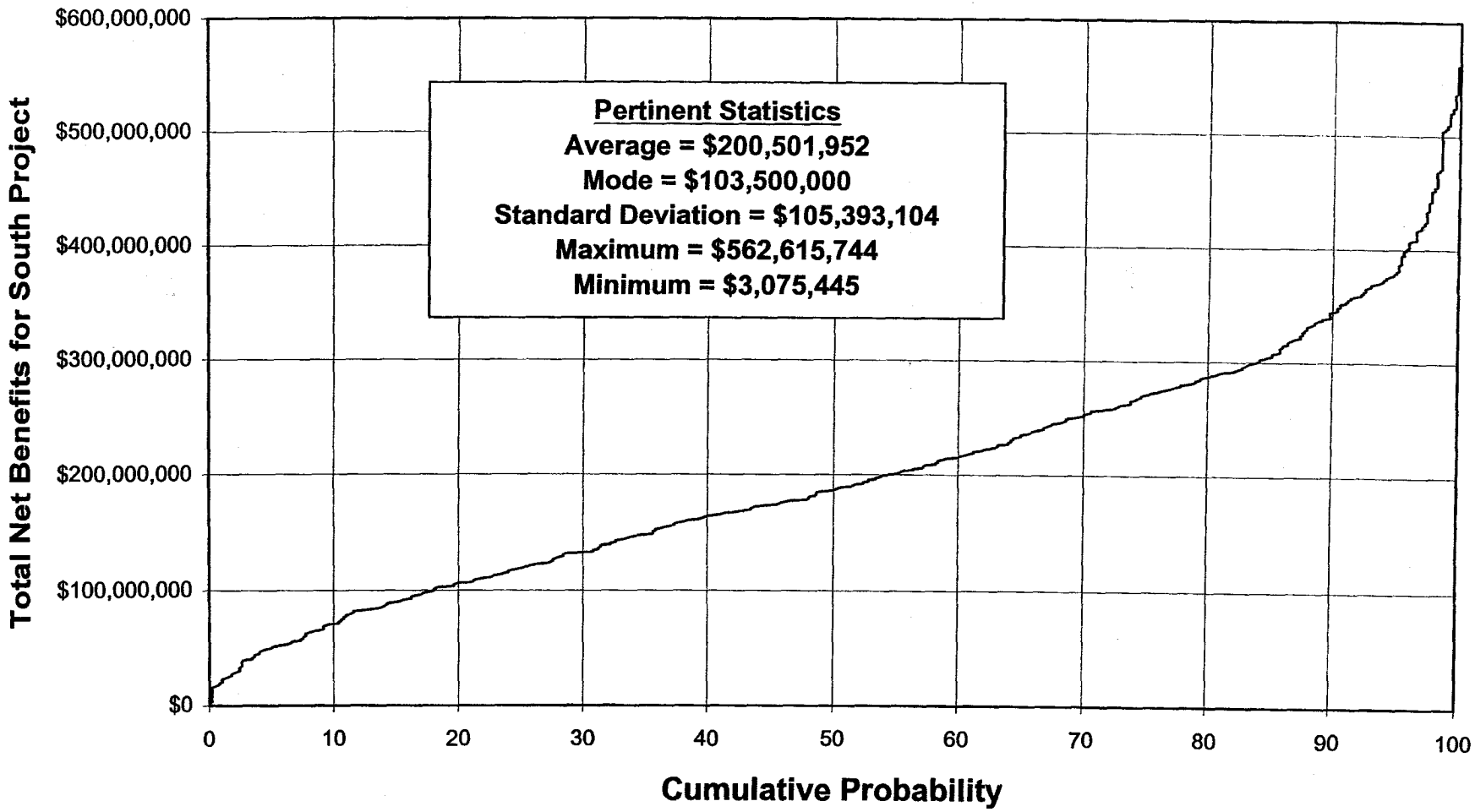


Figure D-29