Final General Reevaluation Report
and
Final Environmental Impact Statement

on

Hurricane Protection and Beach Erosion Control

WEST ONSLOW BEACH AND NEW RIVER INLET (TOPSAIL BEACH), NORTH CAROLINA

Appendix D

Coastal Engineering

Appendix D: Coastal Engineering

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Appendix D: Coastal Engineering

1. Plans Investigated

Two general alternative beachfill plans were evaluated for this study: 1) a dune-and-berm plan and 2) a berm-only plan. Numerous templates for each of these plans were evaluated and are described below.

a. Dune-and-Berm Plans

1) **Description.** Existing dunes were assumed to remain in place, with the design dunes tying into them where appropriate. The design 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. The seaward slope of the berm is 15 horizontal to 1 vertical extending down to MLW elevation (-1.9 feet-NGVD), below which the with-project profile parallels the existing profile out to a closure depth of -23 feet-NGVD.

2) **Dune-and-Berms Evaluated.** Initially dune-and-berm templates with dune elevations of 11, 13, and 15 feet-NGVD were evaluated, each with 25-, 50-, and 75-foot berm widths at elevation 7 feet-NGVD. In order to envelop the NED plan, additional plans with dune elevations up to 17 feet-NGVD were evaluated. A typical dune-and-berm profile is shown in Figure D-1. Specific plans are referred to by their combination of dune height and berm width (e.g., the 1350 Plan refers to a 13-foot dune elevation and 50-foot berm width).

b. Berm-Only Plans

1) **Description.** The berm-only template is fill extending seaward from the existing profile with an elevation of 7 feet-NGVD, which is approximately the elevation of the existing natural berm. Berm width is measured seaward along the top of the berm from the point where it intersects the natural profile. The seaward slope of the design berm is 15 horizontal to 1 vertical extending down to MLW elevation (-1.9 feet-NGVD), below which the with-project profile parallels the existing profile out to a closure depth of -23 feet-NGVD.

2) **Berms Evaluated.** At the feasibility level, 50-, 100-, and 150-foot berm-only plans were evaluated. Each used a berm elevation of 7 feet-NGVD. A typical berm-only profile is shown in Figure D-2.

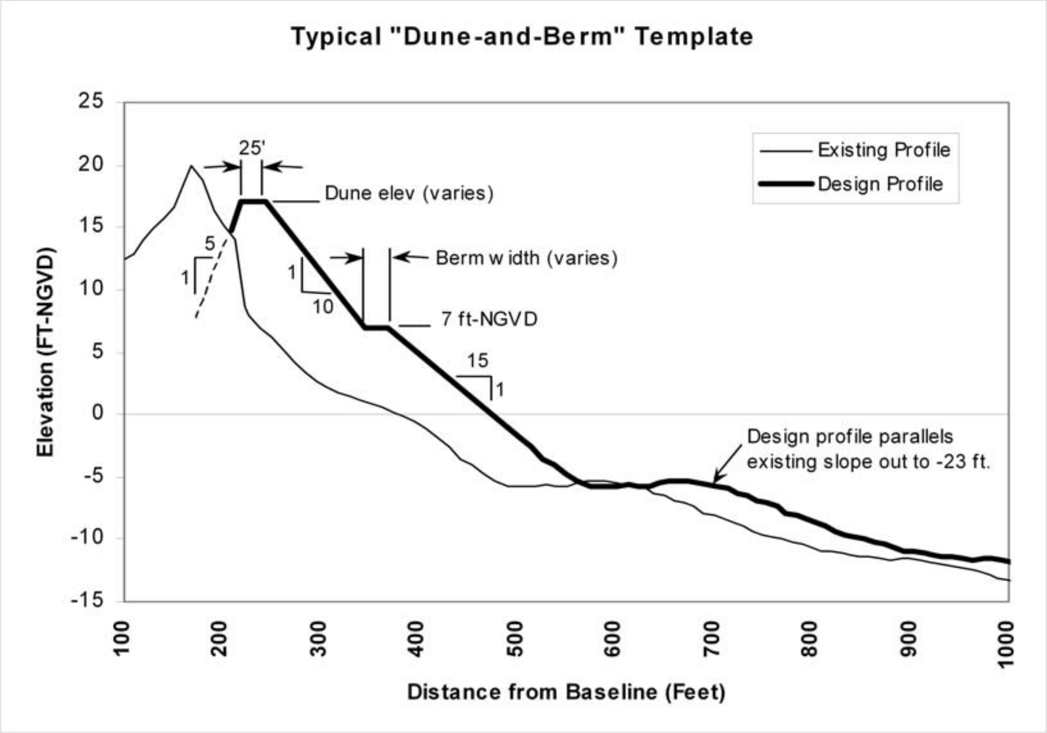


Figure D-1. Typical “Dune-and-Berm” Template

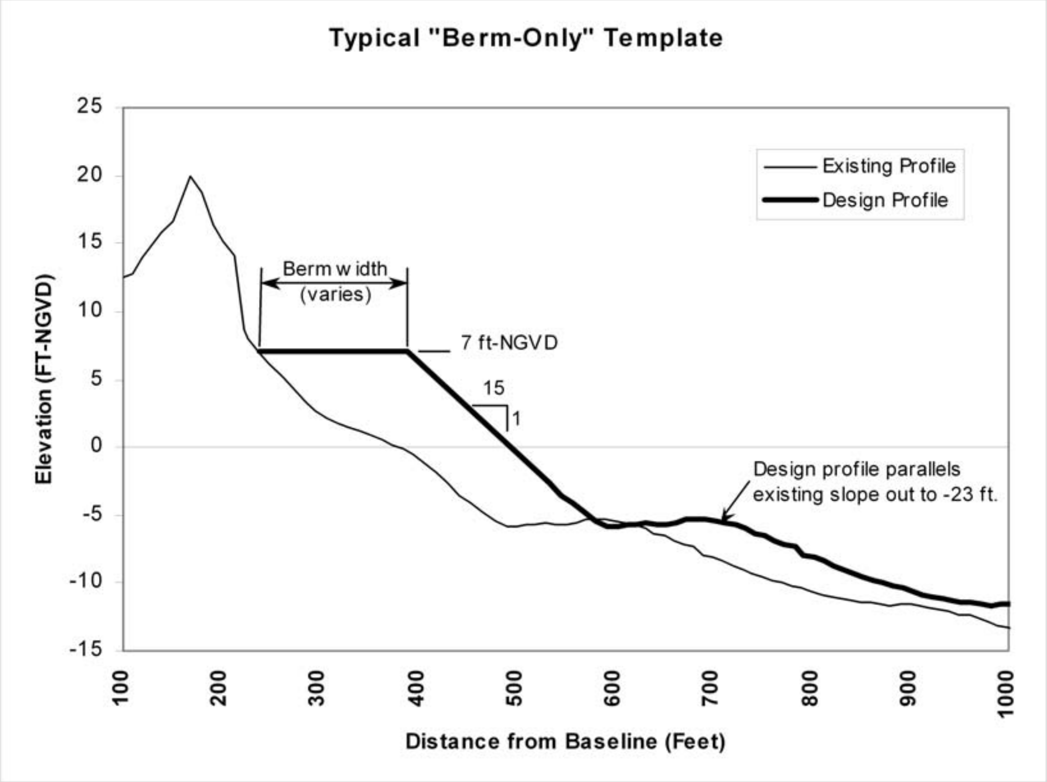


Figure D-2. Typical “Berm-Only” Template

c. Construction Line

The construction line was established to: a) minimize impacts on existing development and b) minimize erosion of the project by aligning the seaward edge of the berm parallel to the existing shoreline to the maximum extent practical. Additionally, the construction line needed to account for the easement line that is located an additional 20 feet landward of the construction tie-in line to ensure adequate room for initial project construction and re-construction in the event of severe storm damage. Another constraint was that the landward toe of the beachfill needed to tie into the existing profile at a minimum elevation of 7 feet-NGVD along the construction line. The resulting construction tie-in line is shown on the Beachfill Plan Layout plates (Appendix A, Figure 4) as the landward edge of the hachured beachfill area.

2. Alternative Evaluation Process

a. Study Limits

The Topsail Beach study limits for preliminary assessment of alternatives included the entire developed shoreline of Topsail Beach, a distance of about 4.5 miles from its northern town limit south to New Topsail Inlet. The study area was divided into 26 reaches approximately 1000 feet wide. Reaches 1 and 2 are undeveloped reaches immediately adjacent to New Topsail Inlet, while Reaches 3 through 26 encompass the developed shoreline area.

b. Alternatives Addressed

With the study limits defined, a systematic procedure for evaluating alternatives was developed. Knowing that the volume of beachfill 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 three berm-only plans and nine dune-and-berm plans were initially addressed.

1) **Berm-Only Plans.** The berm-only plans evaluated included the 50-, 100-, and 150-foot wide berms that tied directly into the existing dune face and relied solely on the existing dune protection. Evaluations were made using GRANDUC, which is the storm and hurricane damage model being used for this study. (See Addendum at end of Coastal Engineering Appendix for a description of GRANDUC.) In spite of a fairly substantial existing dune, these berm-only plans did not provide the level of storm damage protection as did the dune-and-berm plans, resulting in significantly lower total net benefits and did not warrant further consideration.

2) **Dune-and-Berm Plans.** Historical projects in place along the North Carolina coast have dune heights of about 13-feet above NGVD with a berm width of about 50 feet. Therefore, in addition to the 13-foot dune with a 50-foot berm, a higher 15-foot and lower 11-foot dune, each with a 25-, 50-, and 75-foot berm at 7 feet-NGVD, were selected for initial evaluation. A fixed dune width of 25 feet was used for all plans.

3) **Refinement of Study Limits.** The project limits were refined by evaluating the economic feasibility of constructing a project in each of the 24 developed reaches. As a result, the study area was slightly reduced from 24 to 23 reaches after eliminating Reach 3 because of consistently negative net benefits due mainly to the relatively large structure setback distances in this reach.

4) **Refinement of Alternatives.** Reanalysis of the initial array of dune-and-berm plans using the reduced project limits showed that the 50-ft berm widths consistently generated higher net benefits than the 25-foot and 75-foot berm widths. Therefore, for final optimization, only 50-foot berm heights were evaluated further. In addition, 12-,14-, 16-, and 17-foot dune height plans were incorporated into the final plan formulation to fully envelop the NED plan. Final plan formulation also accounted for expected end losses associated with the transitions from the main project to the without-project adjacent shoreline. Of this final array of 11 to 17-foot dune heights, the 15-foot dune elevation with a 50-foot berm (i.e., the 1550 Plan) yielded the greatest net benefit and is therefore the NED plan.

5) **Modifications.** Originally, a 2000-foot transition was planned for both the north and south transitions. However, because of the bulbous shoreline configuration south of reach 3 and the existing alignment of the 7-foot contour in the transition area, it was feasible to transition from the southern terminus of the main fill into the adjacent shoreline over a shorter distance. By shortening the south transition to 1400 feet, it also meant that the transition could avoid direct impact of the piping plover critical habitat area. An additional modification investigated was extension of the main fill through the northern half of reach 3, since the damages are more concentrated in that half because its structures are not set back as far from the shoreline. While benefits of extending the plan were significant, they were not adequate to justify inclusion of a portion of reach 3 as part of the NED plan formulation. However, extension of the main fill section into the northern half of reach 3 was desirable to the local sponsor and was incorporated into the locally preferred plan as described later in Section 3. Those “extended” plans are designated by the suffix “X“ (e.g., the 1550X Plan).

6) **Re-evaluation of Terminal Groin Alternative.** Placement of a terminal groin at the southern terminus of the beachfill near New Topsail Inlet was evaluated as an alternative to a tapered fill transition for the selected template. Because the net longshore transport is to the north (as discussed in more detail later in Section 5, Shoreline Modeling), the efficacy of a southern terminal groin is greatly diminished and was not shown to be justified. Therefore, the tapered berm-only fill transition is the preferred southern project terminus.

7) **Nonstructural Alternative.** An alternative to beachfill that was evaluated is the nonstructural plan, which includes a combination of retreat, relocation, and demolition to avoid or delay damage to structures by removing them from the hazard area. For this GRANDUC analysis all of the oceanfront structures were eliminated from the structure database. The without project damages were then recomputed using this revised structure database to estimate residual damages for the nonstructural plan. Benefits were determined as the difference in residual damages between the without project GRANDUC runs for the original and modified structure database. However, the nonstructural plan yielded negative net benefits overall and was eliminated from continued consideration. For additional details of the nonstructural plan, including associated costs, refer to Section 5.05.2 and Appendix P.

3. Description of Selected Plan

a. Plan Description

The NED plan was determined to be the 1550 Plan (15-foot dune elevation and 50-foot-wide berm) with a main fill length of 22,800 feet (Reaches 4-26) and northern and southern transition lengths of 2000 and 1400 feet, respectively. However, the selected plan recommended for federal action is the Locally Preferred Plan, 1250X (12-foot dune elevation and 50-foot-wide berm that extends into part of reach 3). A typical 1250X dune-and-berm profile for the selected plan is shown in Figure D-3.

The selected plan has a total project length of 26,200 feet (5.0 miles). As shown on Figure A-3 (Selected Beachfill Plan - Plan View) in Appendix A, the selected plan consists of three distinct segments: (1) the 23,200-foot main beachfill section in reaches 4 through 26 and the northern 400 feet of reach 3 with the full 1250 design template; (2) a 1,000-foot southern transition comprising the southern 600 feet of reach 3 and about 400 feet of reach 2; and (3) a 2,000-foot northern transition comprising all of reach 27 and about 700 feet of reach 28. The transitions are tapered berm-only sections that taper uniformly from the seaward edge of main fill's berm down to a zero-width berm at the northern and southern terminuses of the project.

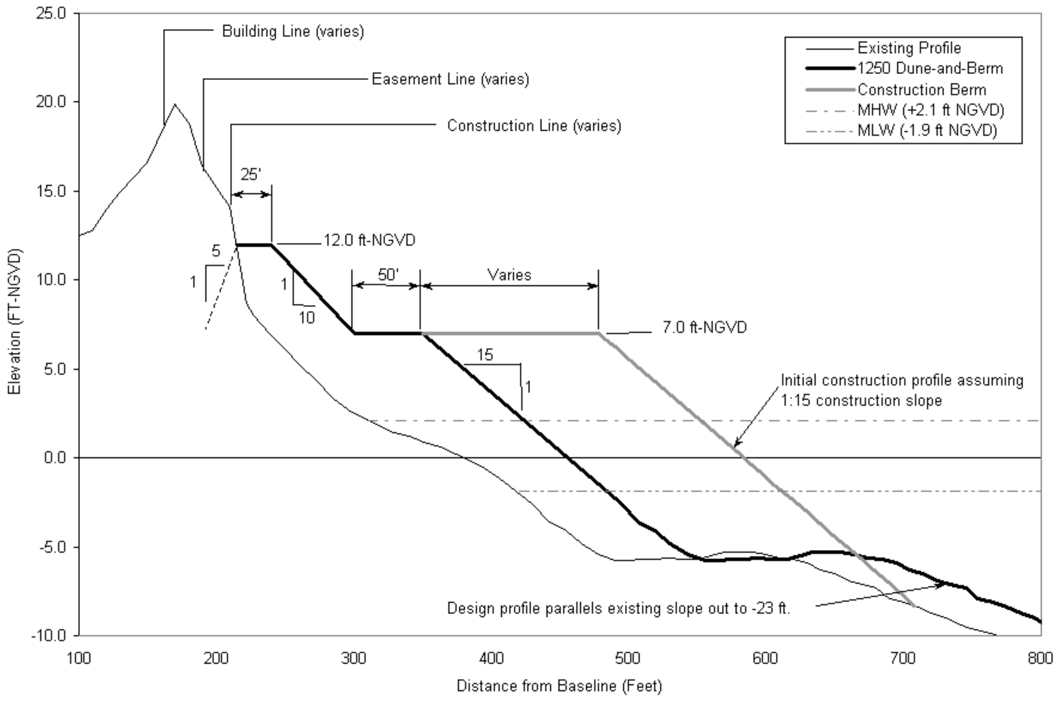


Figure D-3. Typical 1250X Beachfill Profile - Selected Plan

Appendix A also contains the more detailed Beachfill Plan Layout plates showing the physical location of the main project and transitions on aerial photography of the study area. As shown on the typical beachfill profile in Figure D-3, the design profile is assumed to parallel the natural contour below MLW (-1.9 feet-NGVD) out to a closure depth of -23 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. This variable distance will generally range from 100 to 200 feet along the project depending upon foreshore slopes established by the fill material. Once sand redistribution along the foreshore occurs, the adjusted profile should resemble the design berm profile.

b. Project Data

The selected 1250X plan requires about 3.2 million cubic yards of borrow material during initial construction. This borrow volume quantity is actually 35 percent greater than the desired in-place template volume to account for placement losses during initial construction, which equates to an overfill factor of 1.35. 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. Project maintenance requirements for the 4-year renourishment cycle is 866,000 cubic yards of borrow material. During periodic renourishment only about 25 percent additional material is needed to offset the placement losses. The higher placement losses during initial construction are due to placement of less compatible material from an offshore borrow site with thicker sand deposits that will allow for more economical hydraulic pipeline dredging. Renourishment operations will utilize thinner sand deposits in other offshore borrow areas that are more suited for hopper dredging. In total, about 13.6 million cubic yards of borrow material will be required for the 50-year selected 1250X project. For comparison, the NED 1550 plan would have required about 4.6 million cubic yards for initial construction and 866,000 cubic yards per renourishment cycle, for a total 50-yr volume of about 15 million cubic yards.

4. Shoreline Analysis

a. Shoreline Adjustments

Immediately after the project is constructed there will be major adjustments to the beachfill 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 construction 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 Figure D-3 for a depiction of the initial construction profile relative to the design template profile.

b. Long-Term Shoreline Change Rates

1) **Computed Shoreline Change Rates.** Long-term erosion rates were determined by comparing the 2002 MHW (+2.1 feet-NGVD) shoreline position for each reach to a historical 1963 Corps of Engineers shoreline survey of Topsail Island, a period of 40 years. The 1963 MHW shoreline (approximated using the +2 feet-NGVD contour) was digitized using MicroStation to readily allow comparison of shoreline position for each reach. The 2002 MHW shoreline was available from photogrammetric digital mapping of Topsail Island conducted for this study at a scale of 1”=200’ with 1.0’ contour intervals, along with validation using 26 beach profile surveys taken every 1000 feet. Shoreline positions within each reach were determined every 250 feet and then averaged with shoreline positions in the two adjacent reaches to determine the average long-term shoreline change rate for each reach. Figure D-4 is a plot of the long-term shoreline change rates that

were computed. Shoreline change rates are relatively low in the northern half of the study area (less than one foot per year), with some slight accretion occurring along the interior reaches 13 through 22 (about 10,000 feet). In the southern portion of the study area, erosion rates gradually increase to over 3 feet of erosion per year (Reaches 5 to 7). In the immediate vicinity of the inlet (Reaches 1 to 4), inlet migration has resulted in accretion. Rates could not be determined for reaches 1 and 2, since no shoreline existed in 1963 for comparison.

2) **Comparison with Other Data.** Shoreline change rates computed for this study were compared to the North Carolina Division of Coastal Management's (NCDCM) long-term shoreline change rates, as shown in Figure D-5. NCDCM rates were only available through 1989 at that time, which is why updated shoreline changes rates as described above were deemed necessary. The NCDCM rates show accretion in all reaches except Reaches 8, 9, 25, and 26, which show slight erosion (0.5 feet/year or less). Except for the southernmost reaches near New Topsail Inlet, most of the accretion is slight also (less than 1.0 feet/year). Since the NCDCM data only extended through 1989 and do not reflect the severe storm activity the region experienced during the 1990s, it is not unreasonable for the NCDCM rates to be more accretionary than the 1963-2002 shoreline change rates computed for the study.

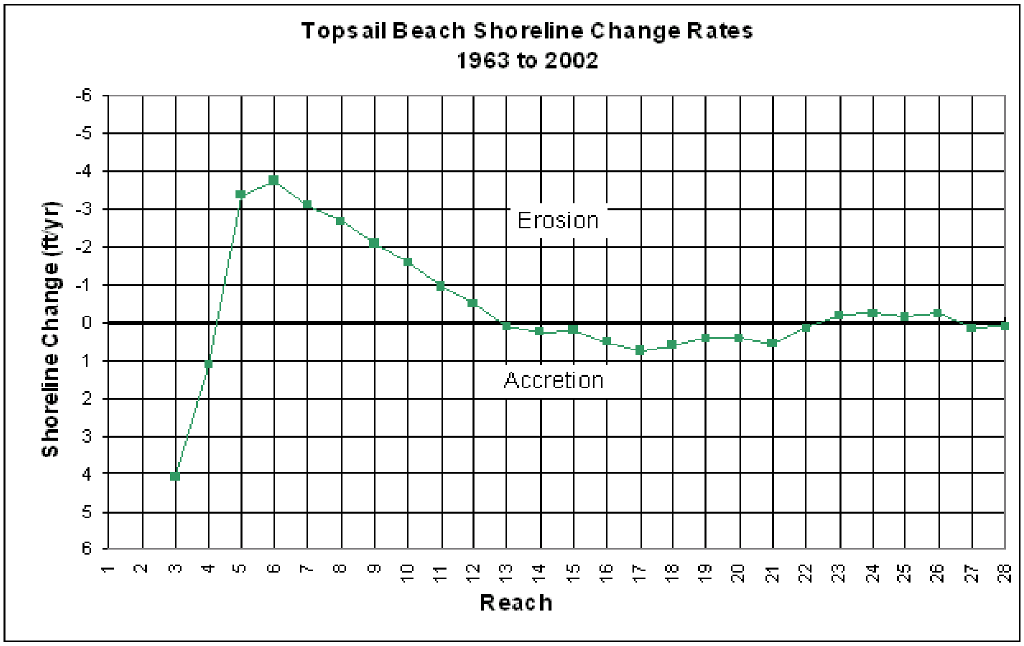


Figure D-4. 1963-2002 Shoreline Change Rates

3) **Sea Level Rise Impacts.** Inherent in these historic shoreline change rates is about 0.2 feet per year of shoreline erosion due to sea level rise. This is based on NOS historical sea level rise for the Wilmington,

NC station (No. 865810) which indicates sea level rise of about 0.008 feet per year from 1953 to 1993.

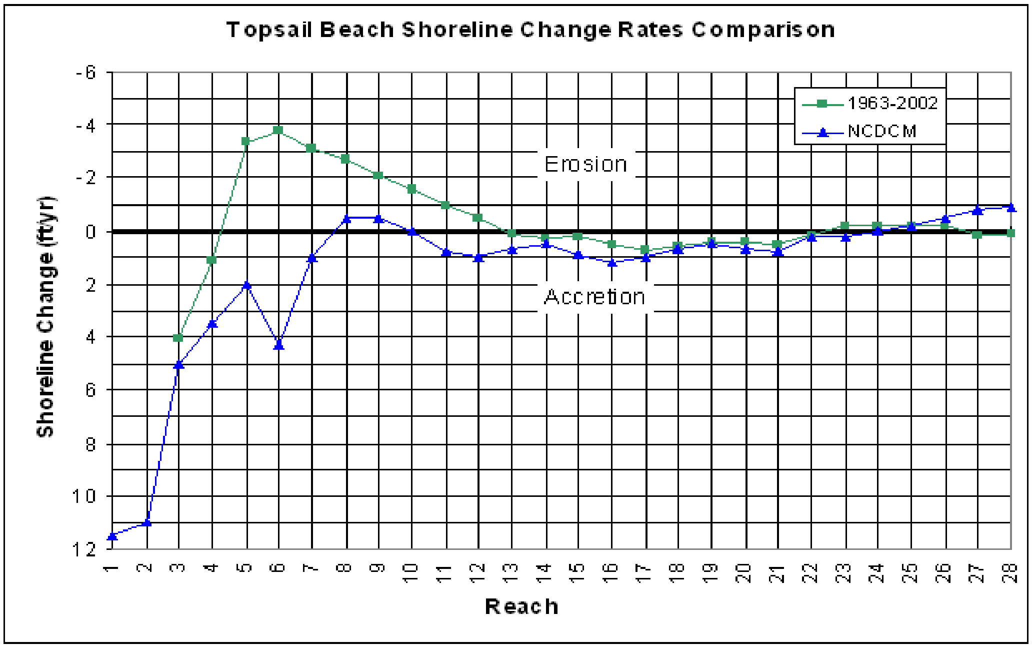


Figure D-5. Shoreline Change Rate Comparison to NCDCM Rates

5. Shoreline Modeling

a. General

A numerical modeling effort was undertaken to investigate the performance of the proposed beach project (with and without the terminal groin) using the shoreline simulation model GENESIS (GENEralized model for SImulating Shoreline change). This model was also used to determine sediment transport potentials in the project area. In addition, a second model (the Planform Evolution Model), was used to evaluate the beachfill evolution, including transition lengths and associated end losses.

b. Longshore Sediment Transport

Shoreline response and sediment transport modeling are driven by wave data. Wave data used for this effort were updated hindcast data for the period 1990-1999 for the WIS Level 3 Station 292, located about 10 miles offshore of Topsail Island. Waves hindcast for this location were transformed using the WIS Phase III transformation program from this station's 60-foot water depth landward to a water depth of 30 feet offshore of the project area for input into GENESIS. GENESIS was then used to predict the littoral transport potential for all of Topsail Island, along with the local project responses. Model results (shown below in Table D-1) indicated an average gross longshore transport rate of 567,000 cubic yards per year (cy/yr) for all of Topsail Island, with a northerly average net longshore transport rate of about 2,000 cy/yr for Topsail Island.

Table D-1
Annual Longshore Sediment Transport Rates for Topsail Island
(Based on Updated 1990-1999 WIS Data for Station 292)

Year	Northward Transport CY/YR	Southward Transport CY/YR	Gross Transport CY/YR	Net* Transport CY/YR
1990	-212,000	212,000	425,000	0
1991	-200,000	191,000	391,000	-9,000
1992	-242,000	337,000	579,000	95,000
1993	-287,000	354,000	641,000	67,000
1994	-368,000	382,000	750,000	14,000
1995	-330,000	319,000	649,000	-11,000
1996	-475,000	274,000	749,000	-201,000
1997	-160,000	149,000	309,000	-11,000
1998	-282,000	226,000	508,000	-56,000
1999	-285,000	381,000	666,000	97,000
Average	-284,000	283,000	567,000	-2,000

* NOTE: Negative net transport is to the north; positive net transport is to the south.

Figure D-6 depicts how the average annual net longshore transport potential varied along Topsail Island for the 1990-1999 period. As shown, the net average longshore transport rate along the Topsail Beach project area is estimated to be about 200,000 cy/yr to the north, based on northward transport of 380 cy/yr and southward transport of 180 cy/yr. This net northerly transport in the study area is corroborated by the sediment transport rates previously reported in the original August 1992 Design Memorandum for the project (page B-4, Appendix B, Beach Fill Design). According to the 1992 report, average net longshore sediment transport for Topsail Beach for the 20 year period from 1956 to 1975 was 325,000 cy/yr to the north, which is comparable to the updated 200,000 cy/yr northerly transport estimate.

c. Terminal Groin Evaluation

GENESIS runs were made to evaluate the necessity of the southern terminal groin. After incorporating the beachfill into the GENESIS setup, runs were made using 1990 wave conditions to simulate average sediment transport conditions for a 10 year period both with and without the terminal groin. The groin was initially modeled as a non-diffracting, low-permeability groin, meaning that sand passage across the groin was quite restricted, which would have exaggerated the impact that the actual more-permeable groin would be expected to have. However, if initial modeling did not show a project enhancement with the low-permeable groin, then additional modeling to better match the actual permeability would not be warranted. Comparisons of GENESIS shoreline change results over the 10-year modeling period (shown in Figure D-7) did not show improved project performance with the terminal groin in place. In fact, because of the net northerly average sediment transport documented by current and previous work, modeling results show the groin tending to trap sediment on the south side of the groin, instead of the north side as would be intended. Therefore, a gradually tapered berm is a more appropriate transition for this project.

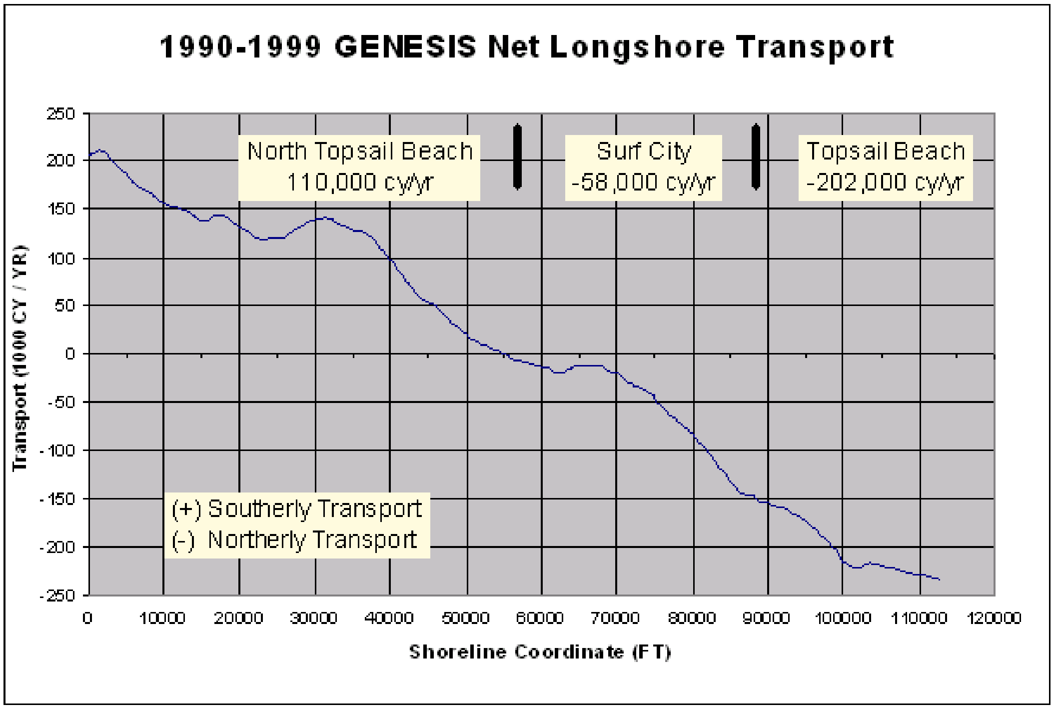


Figure D-6. Net Average Longshore Transport along Topsail Island

An additional consideration is the proximity of New Topsail Inlet to the southern terminus of the project. Proximity to the inlet was a contributing factor to selection of a terminal groin for the 1992 NED plan, since distance was inadequate to construct a tapered beachfill transition. However, due to southward migration of New Topsail Inlet over the last decade (as shown in Figure D-8), the current location of the inlet is now sufficient to allow construction of a tapered transition. Further, because of the modification to the southern transition which incorporates the taper into the reaches 4 and 5 instead of allowing it to extend into reaches 2 and 3, proximity to the inlet is no longer a concern.

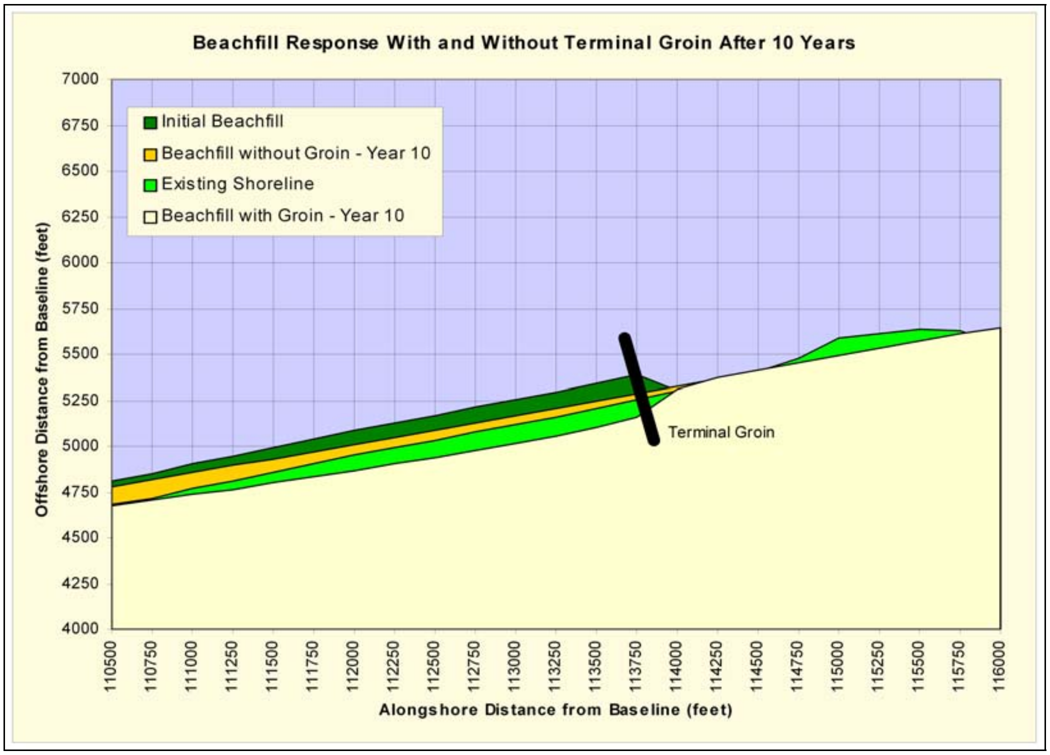


Figure D-7. With and Without Groin 10-Year Shoreline Analysis

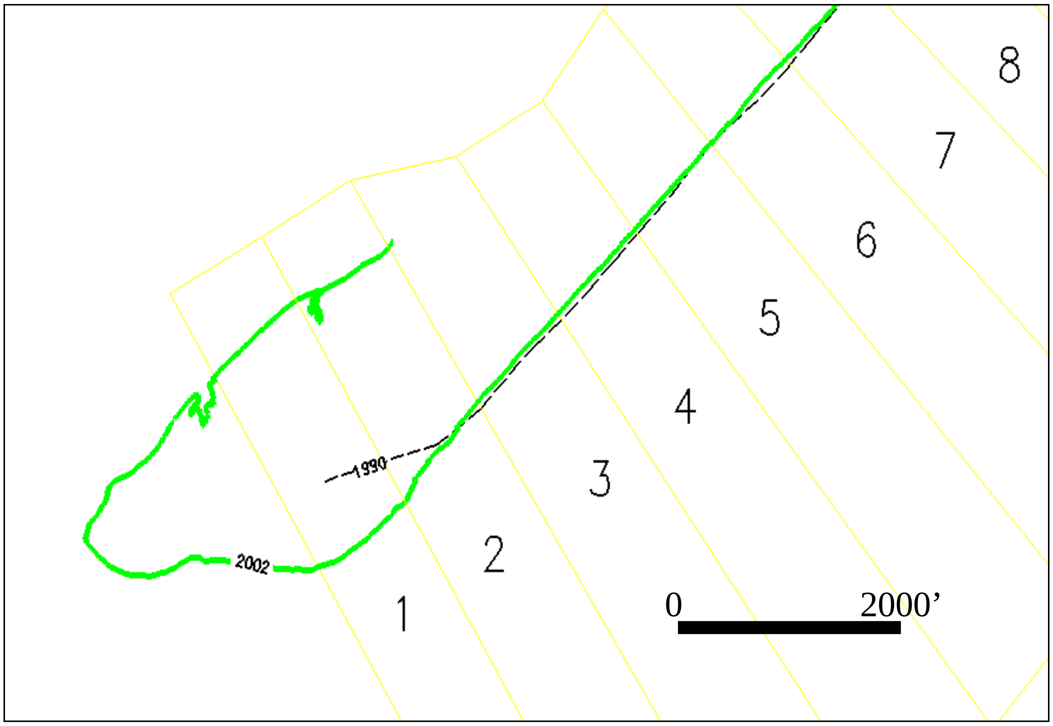


Figure D-8. Shoreline Change near New Topsail Inlet (1990 to 2002)

Even though present analysis of the 1990-1999 wave data and the earlier analysis of the 1956-1975 wave data have indicated a predominantly northern drift along the project area, New Topsail Inlet has been experiencing a southerly migration. While it is more common for inlets to migrate downdrift (i.e., in the direction of the predominant drift), updrift migration does occur. One mechanism that may account for this is the attachment of swash bars to the inlet's downdrift shoreline. Historically, episodic deflections of the ebb channel away from the southern end of Topsail Island to a more shore-normal position have resulted in the bypassing of sediment to the Topsail Beach shoulder of the inlet.

d. Beachfill Evolution and Transition Modeling

In general, when sand is placed in conjunction with a beach nourishment project, this project represents an "anomaly" to the shoreline planform, and the natural processes will tend to smooth out this anomaly. The Planform Evolution Model (within the Beach Fill Module developed by the Engineering Research and Development Center's Coastal and Hydraulics Laboratory) was used to simulate beachfill planform evolution. The model is a rapidly applied model that considers both background erosion rate, which is the normal rate in areas that have not been nourished, and shoreline retreat due to "spreading out" losses from the beach nourishment project. The model also requires input of sediment characteristics and effective wave conditions for longshore transport. The effective wave conditions consist of a single set of wave parameters that result in the same net longshore transport as determined in the GENESIS analysis. Model output consists of shoreline positions at user-specified time intervals along with sediment transport rates. Post-processing of the output was performed to compute shoreline change rates associated with the project. Based on typical transition lengths of 2000 feet, shoreline change rates and associated volumetric losses were determined over a 10 year period. These end losses were then input to GRANDUC to determine the NED plan and optimum renourishment cycle.

6. Storm Damage Analysis

a. General

The economic analysis of storm damages for the range of beach conditions throughout the study area requires development of frequency-of-occurrence relationships for water levels, wave conditions, and erosion distances. In order to account for risks and uncertainties inherent to the analysis procedure, methods were selected to express storm damages in a probabilistic manner. In other words, the results were required in the form of erosion distance or water levels versus frequency-of-occurrence relationships. A suite of storm events was used to assess the performance of alternatives in reducing potential damages due to erosion, wave attack, and inundation. Profiles were developed to characterize the alternatives dimensions and serve as input to the storm damage calculations. The numerical model SBEACH (Storm Induced BEAch CHange) was used to further transform the waves into the nearshore across proposed alternatives and simulate beach profile change, including the formation and movement of major morphological features such as longshore bars, troughs, and berms, under varying storm waves and water levels. In addition to computing beach profile response, the wave transformation algorithms within SBEACH were utilized to characterize incident wave conditions and total water levels (including wave setup) for each storm. Key response parameters from the SBEACH output were extracted for each storm and used to generate frequency of occurrence relationships using the Empirical Simulation Technique (EST) model. The frequency of occurrence relationships for erosion distances and other parameters serve as input to the GRANDUC model for computation of storm damages.

b. SBEACH Analysis

The computer model SBEACH was used to estimate erosion expected to occur during various storm events for the without-project condition and the with-project templates considered. Additionally, the wave transformation routines in SBEACH provide transformed wave conditions and wave-induced setup values for each simulation. SBEACH simulations were performed for the suite of storm events against the range of beach profile conditions. Input data for the SBEACH model included onshore and offshore survey data, storm water elevations, and storm wave heights and periods as discussed previously. The results from SBEACH modeling (i.e., “response parameters”) that are used in storm damage calculations include: erosion distances (landwardmost occurrence of 0.5-, 2.0-, and 4.0-ft vertical erosion), the ground elevations at these erosion points, erosion volumes, maximum dune elevation, maximum wave height at dune crest, and maximum total water level (including wave setup).

1) **Beach Profiles.** During the spring of 2002, beach profile data were collected along 26 transects at approximately 1000-foot spacing throughout Topsail Beach. These surveys extended offshore to a depth of 30 feet, or a minimum of one mile. Photogrammetric one-foot contour maps and digital orthophotos of Topsail Beach were also generated to complement the beach profile surveys. Seven of the 26 beach profiles were selected as representative reaches, based on important features such as dune height, berm, and nearshore profile, to be used as input into SBEACH as existing conditions.

2) **Storm Surge.** Storm surges are storm-induced rises above normal water levels due to the action of wind stress on the water surface and also atmospheric pressure reduction during hurricanes. Storm surge time-series were developed for all significant hurricanes in the Atlantic Ocean from 1890 to 1990 as part of the Dredging Research Program (DRP-1-17, Scheffner, 1994). The ADCIRC model was used to update the hindcast to include recent hurricanes through from 1999, including named hurricanes Bertha, Fran, Dennis, Floyd, Bonnie, and Irene. Time-series of storms surge were coupled with astronomical tide data to serve as input to SBEACH for the storm damage assessment. For the 100-plus years of coverage, 37 events were identified using a minimum storm surge threshold of one foot. In addition to the tropical storm surge database, extratropical storm surge values for 23 events were calculated for the dates from 1976 to 1993.

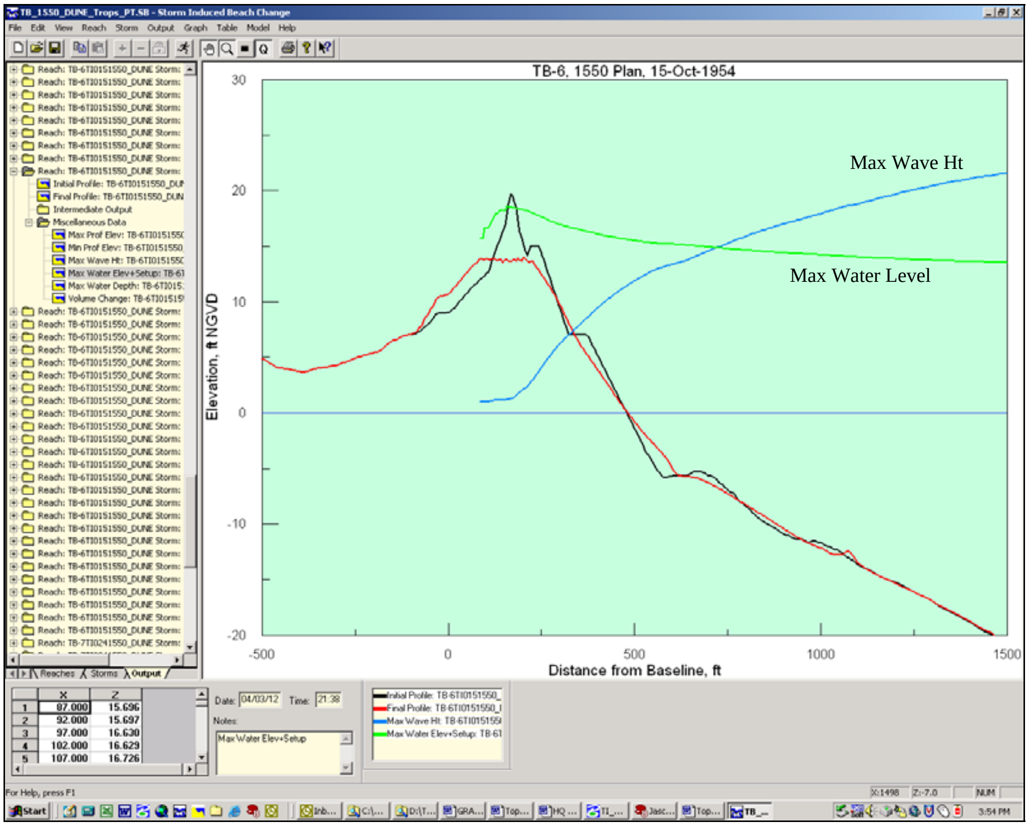
3) **Storm Waves.** Wave heights and periods corresponding to the storm surge events discussed above were determined from a combination of WIS hindcast data and empirical numerical modeling by the Wilmington District. Combined with the water level time-series, these wave height and period time-series will serve as the storm input to SBEACH for the damage analysis.

c. Storm Response Parameters

Simulation of storm events yields various responses. The parameters that directly impact storm damage include nearshore wave height, total water level, storm surge, wave setup, runup, erosion distances, dune lowering, dune recession, and volumetric changes above MHW. Select parameters were extracted from the SBEACH analysis and used to characterize the performance of the alternatives against each storm event. Figure D-9 displays SBEACH output for an extreme event for existing conditions at Topsail Beach. The plots display initial and final profile conditions, along with maximum water elevations (includes storm surge and wave setup) and maximum wave height observed throughout the simulation. The profile response over the simulation, as indicated by the difference between initial and final profiles, provides an indicator of the severity of the storm on potential offshore losses.

d. EST Analysis

1) **Frequency Curves.** The EST (Empirical Simulation Technique, Scheffner and Borgman, 1992) utilizes observed and computed parameters associated with site-specific historical events as a basis for developing multiple life-cycle simulations of storm activity and the effects associated with each simulated event. The first step in EST is an analysis of historical events that have impacted a specific locale.



	X	Z
1	87.000	15.696
2	92.000	15.697
3	97.000	16.630
4	102.000	16.629
5	107.000	16.726

Date: 04/03/12 Time: 21:38

Notes: Max Water Elev+Setup

Figure D-9. Typical SBEACH Output Parameter Plot

The storm events simulated (as described previously) were parameterized to define the characteristics of each event and the impacts of that event. Parameters that define the event are referred to as input vectors. Response vectors define storm-related impacts such as total water level and shoreline/dune erosion. These input and response vectors were then used as a basis for generating life-cycle simulations of storm-event activity with corresponding impacts. Results of the multiple repetitions were post-processed to generate frequency-of-occurrence relationships. These relationships were developed for all profile conditions (existing and alternatives) and all response parameters. Select return periods were extracted from each frequency-of-occurrence relationship and provided as input to the GRANDUC model used to calculate storm-induced damages.

2) **Modifications to EST Frequency Curves.** Water level frequency curves generated by EST for low frequency events (50-, 100-, and 500-year events) tended to exceed FEMA surge level estimates for Topsail Beach by 10 to 20 percent. Adjustments were made to these response curves so that they better reflected the FEMA surge elevations. Also, the EST erosion distance frequency curves were "smoothed" in some cases to result in more uniform and expected erosion responses.

e. Storm History Simulations

From the response frequency curves, one-thousand different equally-likely storm series were generated as actual input to GRANDUC. A program was written to use the response parameter frequency curves, a Poisson distribution with an average number of storms per year of one, and a random number generator to create the storm histories for the multitude of GRANDUC simulations to be run. 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 variable frequency curves to determine the parameters for that storm.

7. Selection of the Periodic Renourishment Interval

a. Optimum Periodic Renourishment Interval

A series of GRANDUC runs were made varying the renourishment interval from 2 to 8 years to determine the optimum interval that provides the maximum net benefits. Based on these results (shown in Figure D-10), it appears that a 7-year periodic nourishment cycle results in slightly higher net benefits. However, for cycle lengths of 4 years or more, the net benefits are not extremely sensitive to the cycle length, so adjustment of the cycle length would not have a significant impact on net benefits or plan selection.

b. Periodic Renourishment Interval Considerations

1) **Dredging Window.** Because of the limited sand thicknesses of the offshore borrow sites available for renourishment, it is likely that a hopper dredge will be used. The environmental dredging window for hopper dredging to avoid the possible presence of sea turtles in the borrow area is Dec 1 to March 31. It is estimated that a single hopper dredge would only just be able to accommodate the renourishment volumes required for the 7-year cycle volume. Therefore, renourishment intervals longer than 7 years would require a second dredge to ensure that the renourishment volume could be placed during the 4-month window. These additional costs were factored into the optimum analysis results shown in Figure D-10.

2) **Scarping.** For such long renourishment intervals, impacts are likely on turtle nesting, recreation, and storm protection due to loss of the berm and scarping of the dune. This is particularly true for the outer reaches of the project (reaches 4-8 and 24-26), who's estimated with-project erosion rates are 10 to 15 feet per year based on planform evolution

analysis. Based on a 7-yr renourishment cycle, this could translate into erosion distances of more than 100 feet. Interior reaches could experience erosion distances upwards of 50 feet for a 7 year cycle, which would also result in major berm loss and probable scarping.

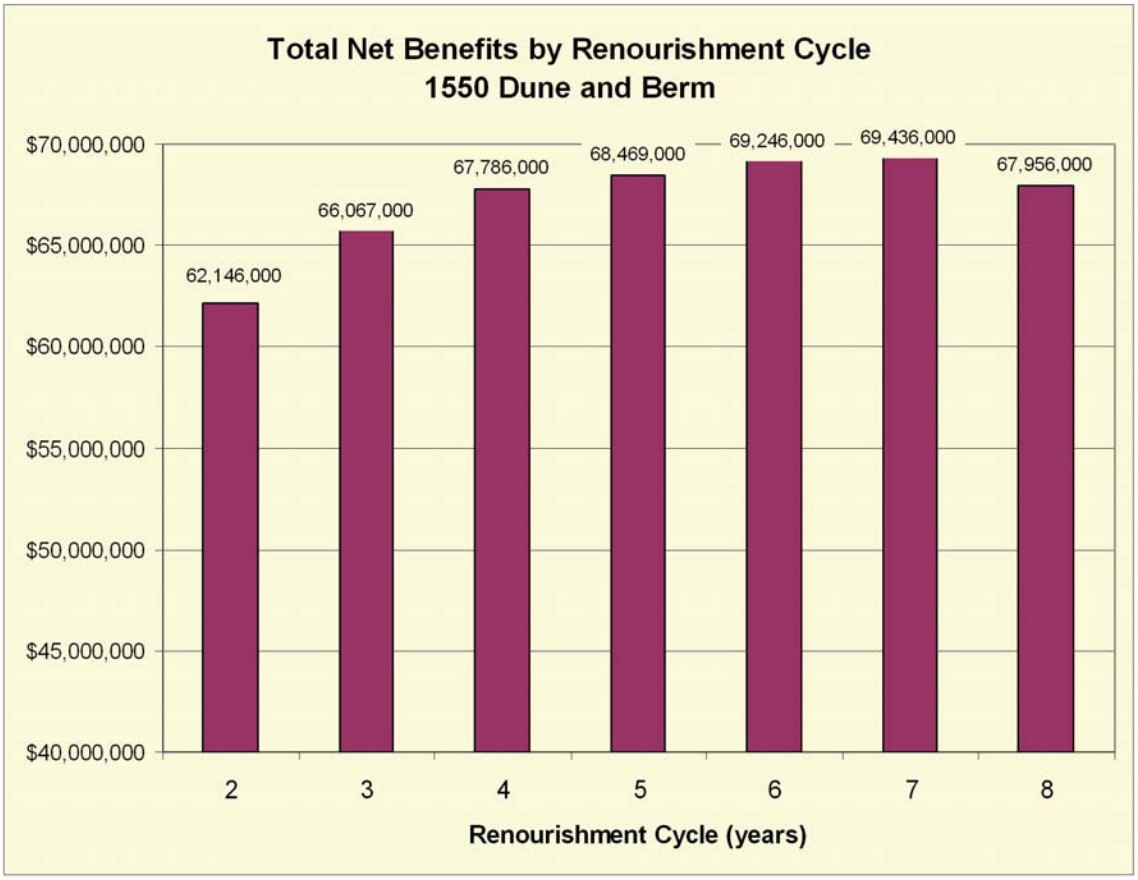


Figure D-10. Total Net Benefits by Renourishment Cycle

c. **Recommended Renourishment Interval.** Because of concerns over dredging window constraints and impacts on turtle nesting, recreation, and storm protection due to loss of the berm and scarping of the dune with a 7-year renourishment interval, the District and the local sponsor agree that it would be prudent to recommend a shorter renourishment interval. Since Figure D-10 shows a more pronounced reduction in net benefits for intervals less than 4 years, it is recommended that the renourishment interval be reduced from 7 years to 4 years. Annual surveys will also be used to monitor the project performance. Should monitoring indicate that renourishment is not needed after 4 years (perhaps due to less severe storm activity or sporadic placement of sand from nearby channel maintenance dredging), renourishment can be delayed beyond 4 years as appropriate.

8. Borrow Sand Requirements

Table D-2 shows the borrow sand requirements for the initial construction volume and 4-year periodic nourishment volumes for the Topsail Beach selected 1250X Plan (12 feet-NGVD dune elevation and 50-foot berm). Volumes shown are borrow quantities that have been adjusted for the required overfill factors. The recommended borrow plan for initial construction calls for 3,223,000 cubic yards of material to be pumped by pipeline dredge from offshore borrow site A. During periodic renourishment, the plan calls for the 866,000 cubic yards of material to be taken by hopper dredge from borrow sites A through F over the course of the 12 periodic renourishments (based on a 4-year cycle).

Table D-2
Borrow Sand Requirements
(cubic yards)

Initial Construction Volume	4-Year Periodic Renourishment Volume	50-year Periodic Renourishment Volume	Total Project Volume
3,223,000	866,000	10,392,000	13,615,000

9. 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 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 5.0 feet
2) structure distance – plus or minus 2.0 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, dune-and-berm alternatives were evaluated to determine the percent chance that the given alternative would have positive net benefits. These evaluations are summarized below in Table D-3.

Table D-3
Percent Chance of Having Positive Net Benefits

Dune-and-Berm Plans	Percent Chance
11-ft Dune Elev / 50-ft Berm (1150 Plan)	99.1
12-ft Dune Elev / 50-ft Berm (1250 Plan)	99.3
12-ft Dune Elev / 50-ft Berm / Extended LPP (1250X Plan)	99.6
13-ft Dune Elev / 50-ft Berm (1350 Plan)	99.4
14-ft Dune Elev / 50-ft Berm (1450 Plan)	99.3
15-ft Dune Elev / 50-ft Berm (1550 Plan)	99.1
16-ft Dune Elev / 50-ft Berm (1650 Plan)	98.5
17-ft Dune Elev / 50-ft Berm (1750 Plan)	98.1

For the above-listed alternatives, risk-based analysis using GRANDUC shows that a feasible project (i.e., net benefits greater than 0) was indicated in over 98 percent of all lifecycle analyses performed. (GRANDUC performs a total of 1000 lifecycles for each run, with a lifecycle being the 50-year economic life of the project.) Specifically, the selected Locally Preferred Plan 1250X had a slightly higher percentage of generating positive net benefits compared to the other plans (99.6 percent).

Addendum: GRANDUC Documentation

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Addendum GRANDUC Documentation

GRANDUC

Generalized Risk AND Uncertainty - Coastal

1. Introduction

GRANDUC is a group of numerical programs that estimates the benefits and costs associated with shore protection projects and provide a measure of the risk and uncertainty associated with them. The programs are driven by storm water elevation, the associated erosion distances, erosion volumes, and ground elevations. They calculate damages due to storm erosion, annual erosion (sea level rise, littoral sand deficits, etc.), inundation, and wave attack. Structure, contents, and land loss damages are determined along with nourishment costs. Present worth values for benefits and costs are calculated for each simulated life cycle. The life cycle storm data is generated by the Empirical Simulation Technique (EST). Armoring is modeled (if applicable) and an option to track all of the damages associated with one structure for one life cycle is available.

2. Data Requirements

The following is general information on data requirements for the programs. The specific information on running the programs is contained in the program documentation.

a. Project Reaches

The criteria for selecting reaches are as follows:

1) Straight Shoreline: The shoreline in each reach must be straight enough to satisfy the model assumption that the shoreline retreats uniformly.
2) Similar Beach Profile: The beach profile along the reach should not have large variations. This allows one set of storm response predictions to be applied to the reach.
3) Resolution: Long reaches make it difficult to determine the length of the project or how a limited quantity of sand should be distributed. Reach lengths of 500 to 1000 feet have been used satisfactorily.

Figure 1 is a sample reach that is 1000 feet long and contains 40 structures. A reference line and a shoreline are shown in the Figure 1. The reference line is the location from which the structure distances are measured, and the shoreline is the location from which the erosion is measured.

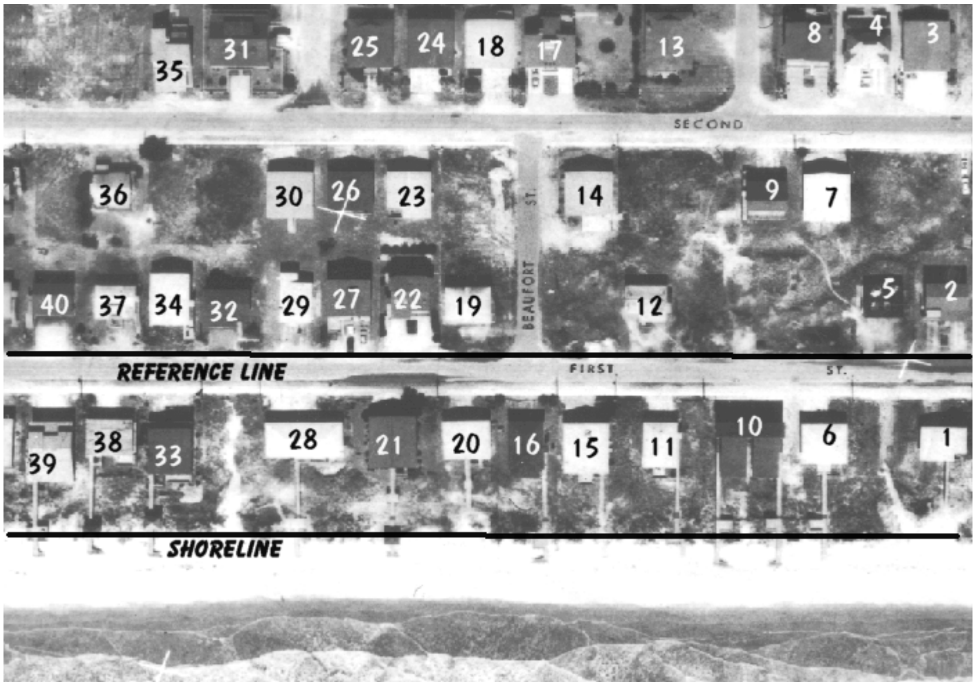

Figure 1. Sample Reach

b. Structure Database

The structure database contains the following information:

1) Reach Number
2) Structure ID
3) Distance from the Reference Line to the Front of the Lot
4) Lot Length
5) Lot Width
6) Distance from the Reference Line to the Front of the Structure
7) Structure Length
8) Attack Angle Ratio - this is the cosine of the angle between the lot orientation and the direction of erosion
9) Structure Type - determines which flood damage curve to use
10) Structure Value
11) Contents Value
12) Ground Elevation - at the structure
13) First Floor Elevation
14) Active Flag: +1 the structure is used in the damage calculations
    -1 the structure is not used in the damage calculations
15) Erosion Type - determines which erosion damage curve to use
16) Armor Flag: +1 the structure is armored
    -1 the structure is not armored
17) Erosion Indicator - indicates whether to use the 0.5-, 2.0-, or 4.0-foot erosion distances.

c. Life Cycle Storm Histories

Each of the 1000 life cycle simulations needs a sequence of storms and storm responses to be generated for it. These sequences are generated by the Empirical Simulation Technique (EST) which uses a historic storm data base, a storm response model such as SBEACH, and a multi-dimensional interpolation procedure to generate a multitude of new storm histories. The data generated for each storm is:

1) Simulation Number - the number of the life cycle to which the storm belongs (ranging from 0 to 999)
2) Life Cycle Year - the year in the life cycle in which the storm occurred
3) Erosion Distances – calculated using SBEACH; the landward most occurrence of 0.5-, 2.0-, and 4.0-foot vertical profile erosion measured from the specified shoreline reference.
4) Erosion Volume - the volume of sand eroded by the storm
5) Surge Elevation - the peak storm water elevation
6) Wave Setup - the nearshore setup as calculated in the Coastal Engineering Manual (formerly Shore Protection Manual)
7) Ground Elevation - the ground elevation at the erosion point

Table 1 contains a sample 50-year life cycle storm history.

Table 1. Sample Life Cycle Storm Histories

Simulation Number	Life Cycle Year	Erosion Distance	Erosion Volume	Surge Elevation	Wave Setup	Ground Elevation
1	2	78	10.2	6.7	2.3	9.6
1	4	29	4.3	6.2	1.4	13.7
1	7	87	11.1	7.2	2.4	9.3
1	11	14	2.5	6.0	1.1	15.0
1	11	60	8.1	6.5	1.9	11.0
1	14	70	9.3	6.6	2.1	10.3
1	16	33	4.8	6.2	1.4	13.3
1	21	35	5.0	6.2	1.5	13.2
1	25	14	2.5	6.0	1.1	14.9
1	29	20	3.2	6.1	1.2	14.5
1	33	21	3.3	6.1	1.2	14.4
1	35	57	7.7	6.5	1.9	11.3
1	37	61	8.2	6.5	1.9	11.0
1	40	69	9.2	6.6	2.1	10.3
1	41	50	6.9	6.4	1.7	11.9
1	50	30	4.5	6.2	1.4	13.6
1	53	70	9.3	6.6	2.1	10.2

d. Global Data

The following data apply to all the reaches:

1) Run Title
2) The Number of Life Cycles to be Simulated
3) Interest Rate - the annual interest rate
4) Economic Period - the length of the life cycle
5) Base Year - the year to start the analysis. Storms that occur before the base year cause damage and can remove structures but the damages are not added to the output totals.
6) Total Initial Volume
7) Switches to Vary Erosion Distance, Structure Distance, and Structure Elevation - if a switch is on, the program will introduce some uncertainty into the calculations using a number selected from a distribution around the inputted number.
8) Nourishment Cycle in Years
9) Initial Benefits - such as benefits during construction
10) Annual Benefits - such as recreation
11) Initial Costs - construction, real estate, studies, etc.
12) Annual Costs - surveys, aerial photographs, and reports
13) Dredge Mobilization and Demobilization Costs - separate cost allowed for nourishment and renourishment, if different.
14) Costs Other than Dredging - separate cost allowed for nourishment and renourishment, if different.
15) ID of Structure to be traced - all of the damages incurred by this structure during the first life cycle will be stored in a file.
16) The Number of Reaches

e. Reach Data

The following data are repeated for each reach:

1) Reach Distribution - the portion of the initial volume applied to each reach; used to determine the fraction of the mobilization and other nourishment costs that should be applied to this reach.
2) Distance from the Shoreline to the Reference Line – erosion is measured from the shoreline and structures are measured from the reference line. This is a useful parameter when the project width shifts the shoreline seaward.
3) Long Term Erosion Rate for the Reach - this would be the rate calculated from historic data and is the result of all the different causes of erosion.
4) Annual Erosion Rate for the Reach - the erosion rate from non-storm related causes such as sea level rise.
5) Annual Volume Loss for the Reach - volume lost to non-storm related causes.

6) Storm Erosion Volume that Initiates Dune Repair - erosion volume associated with a storm that removes the dune. It is assumed that after a large storm some repairs to the dune, such as scraping or truck hauling, will take place.
7) Repair Volume - the volume needed to repair the dune.
8) Unit Repair Cost - the cost per cubic yard to repair the dune.
9) Unit Dredging Cost - dollars/cubic yard and does not include mobilization; separate cost allowed for nourishment and renourishment, if different.
10) Total Fill Placement Adjustment Ratio - overfill requirement and transport losses.
11) Land Value - dollars per square foot.
12) Reach Length
13) Parameters for Wave Attenuation - parameters relating drag losses and obstructions.
14) Wave Zone - this is a 200 to 300 foot zone from the erosion line in which a wave reduction is applied for an effective row of structures. The wave reduction is calculated using all the structures located within this zone as a row of structures.

f. Flood Damage Curves

Two curves are given for each type of structure. One curve is for the structure damage and the second curve is for the content damage. The curves are the distance that the water is above or below the first floor elevation versus the percent damage. Figure 2 displays a sample curve.

g. Erosion Damage Curves

Two curves are given for each type of structure. One curve is for the structure damage and the second curve is for the content damage. The curves are a representation of the percent undermining of the structure (the ratio of the erosion distance under the structure over the structure length) versus the percent damage.

3. Program Operation

The program starts by reading the global data and damage curves. Next a reach loop is begun in which reach data is read and all of the simulations are performed on the structures in the reach before proceeding to the next reach. Then the data for the next reach is read and all of the simulations are repeated on this reach. The loop proceeds until all of the reaches are analyzed. See Figure 3.

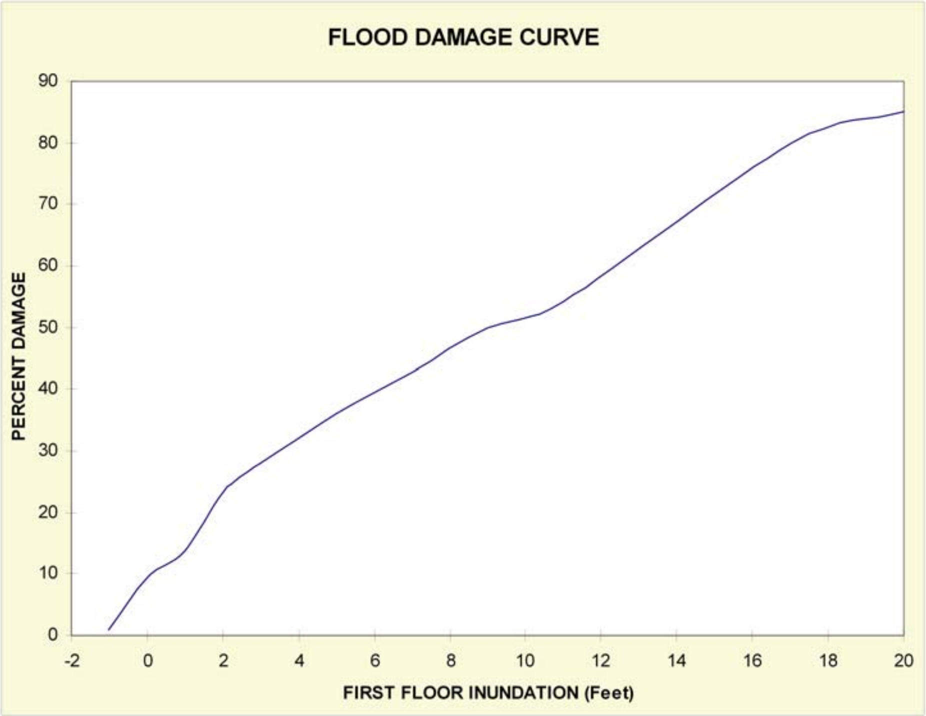

Figure2. Sample Flood Damage Curve

At the beginning of the reach loop, the program reads in the long-term erosion data and the parameters used in calculating the flood profile. The structure is read in and the random number generators are reset.

The program then begins the life cycle simulation loop. Damage values are set to zero and all parameters are set to their initial value. All storms associated with this life cycle are then read in and for the without project runs the net erosion after recovery is calculated as follows:

$$NetStormErosion = \frac{(LongTermErosion - AnnualErosion)\ x\ LifeCycleDuration}{CumulativeStormErosion}$$

This equation forces the net storm erosion to be consistent with the observed long-term erosion rate. Project runs require this parameter to be entered as input data. Project profiles may have a different recovery factor, however, the average of the calculated net storm erosion values is printed out and can be used if other information is unavailable.

The program then enters a year loop. At the beginning of the loop all structures that can be repaired are restored to their original value. The program checks if there has been storm. If there has been a storm, the erosion value is varied if this option was chosen. The flood profile is calculated by going to the point of erosion and using the storm surge,

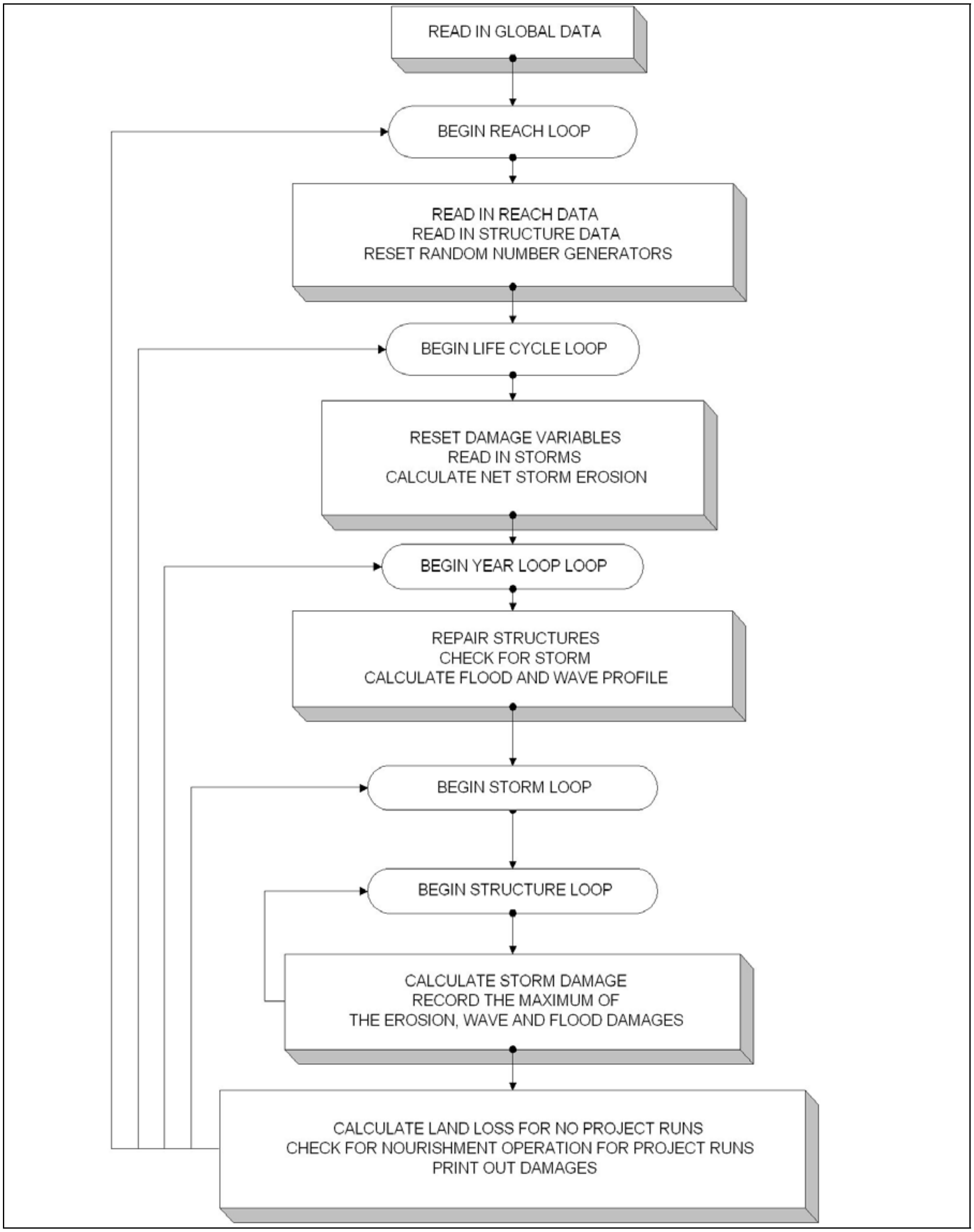

Figure 3. Program Operation Flow Chart

wave setup, and ground elevation to calculate the water depth and largest wave that can exist at that point. The wave height and wave setups are then reduced at landward points on the profile using the drag coefficient and obstruction parameters read in for the reach. In order to calculate the wave reduction due to a row of structures, the structures are sorted according to distance from the reference line. The structure distances are then summed until the distance between two structures is greater than the row distance parameter. If a distance is greater than the row distance parameter, then the distances of the previously summed structures are averaged and a wave reduction factor is applied. This procedure continues until all structures are checked. Since most of the wave activity can happen in the first couple of hundred feet of the erosion point and structures can be staggered which could prevent the row distance from being exceeded, a wave reduction is calculated using the structures located in the wave zone as defined by the input parameter wave zone. The wave crest is used to define the flood profile. A wave impact profile is defined for areas where the wave height exceeds 3 feet and is two feet below the wave crest.

Having calculated the storm characteristics, a structure loop is begun. Erosion, flood, and wave damages are calculated for each structure. The maximum of these damages is multiplied by a present worth factor and is added to a cumulative variable. However, if the life cycle year is earlier than the base year, no damages are recorded. If the structure is armored, erosion is stopped at the armor line until the armor is outflanked. The value of the structure and its contents is reduced by the maximum storm damage amount. This is done to prevent double counting in case there are multiple storms in one year or if at the end of the year the structure is lost to long term erosion. Structures totally destroyed are assumed to be replaced only once during a life cycle. Future damages to these replacement structures for the remainder of the life cycle are based on updated erosion and flood damage curves appropriate for the replacement structure.

At the end of the year loop, the shoreline is adjusted for net storm erosion and annual erosion. Land losses are calculated and undermined structures are made inactive. At the end of each life cycle, the total damage is printed out.

Runs with projects differ from base condition runs in that there is no land loss and there is a periodic nourishment cycle. At the end of each periodic nourishment cycle, annual and storm erosion damage is repaired. During the periodic nourishment cycle, only minor repairs are made to the project after major storms that reduce project protection by causing the shoreline to retreat. The output for project runs includes project costs, partial benefits, and damages.

A separate program compares the damages from a project run and the base run to calculate benefits and outputs a probability versus net benefits table.

Figure 4 contains a sample project profile, which was applied to the reach shown in Figure 1. Runs with and without the project are made and compared. Sample results for the first 15 life cycles are shown in Table 2.

Table 2. Partial Results for the Sample Project

Benefits	Costs	BCR	Net Benefits
1,758,779	723,043	2.43	1,035,736
1,922,766	710,440	2.71	1,212,326
1,758,698	714,167	2.46	1,044,531
2,699,991	783,825	3.44	1,916,166
1,662,882	714,438	2.33	948,444
1,859,573	710,070	2.62	1,149,503
2,672,781	724,054	3.69	1,948,727
1,942,507	70,8590	2.74	1,233,917
1,091,978	696,686	1.57	395,292
1,942,585	716,308	2.71	1,226,277
761,246	675,450	1.13	85,796
971,021	666,249	1.46	304,772
790,800	685,589	1.15	105,211
1,450,528	715,683	2.03	73,4845
1,041,401	683,001	1.52	358,400
1,880,998	710,466	2.65	1,170,532

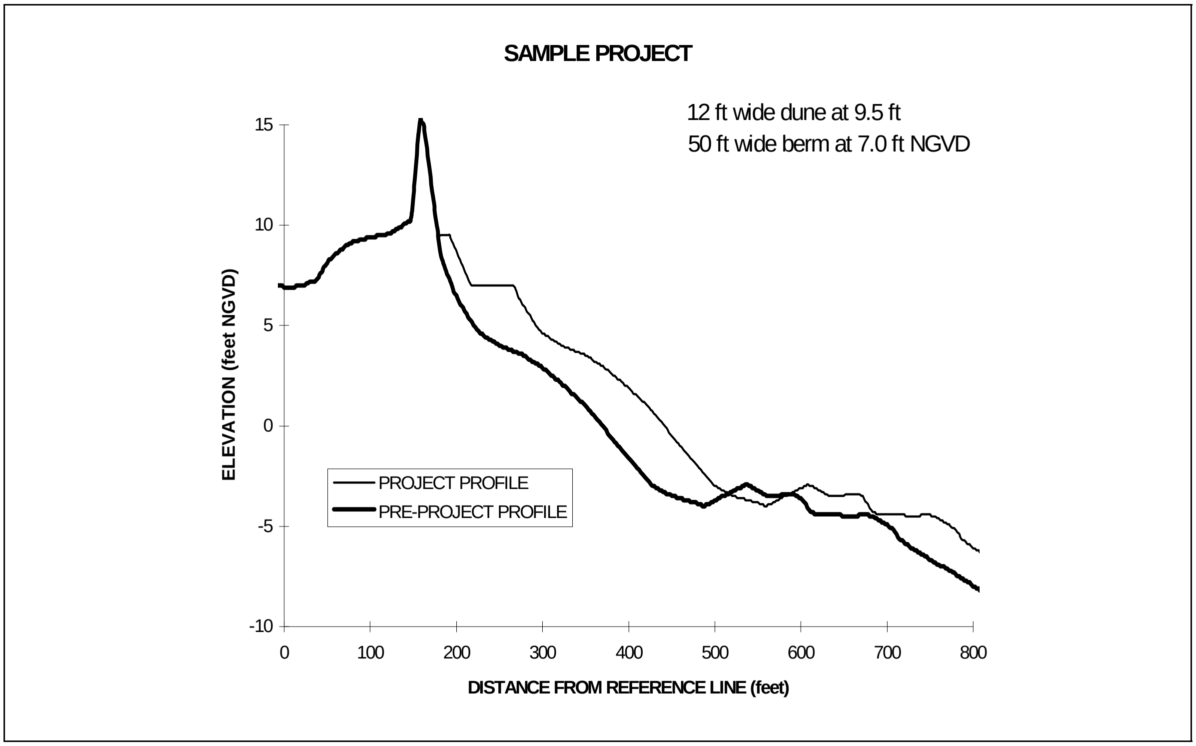

Figure 4. Sample Project Profile

Figure 5 is a sample frequency plot of the net benefits output for 7,000 life cycles. The range of the net benefit outputs was divided into $50,000 intervals. The number of times a net benefit result occurred within an interval was tallied to produce the frequency plot. The frequencies in Figure 5 can be converted into probabilities by dividing them by the total number of life cycles. The probabilities can then be totaled to produce a cumulative probability distribution as shown in Figure 6. There are some negative net benefits results in this sample. These negative net benefits result from life cycle simulations in which there are few storms and no years in which there are more than one storm. It is difficult to read the probability from the graph but the data for this sample shows that there is less than a 3% chance that the net benefits will be negative.

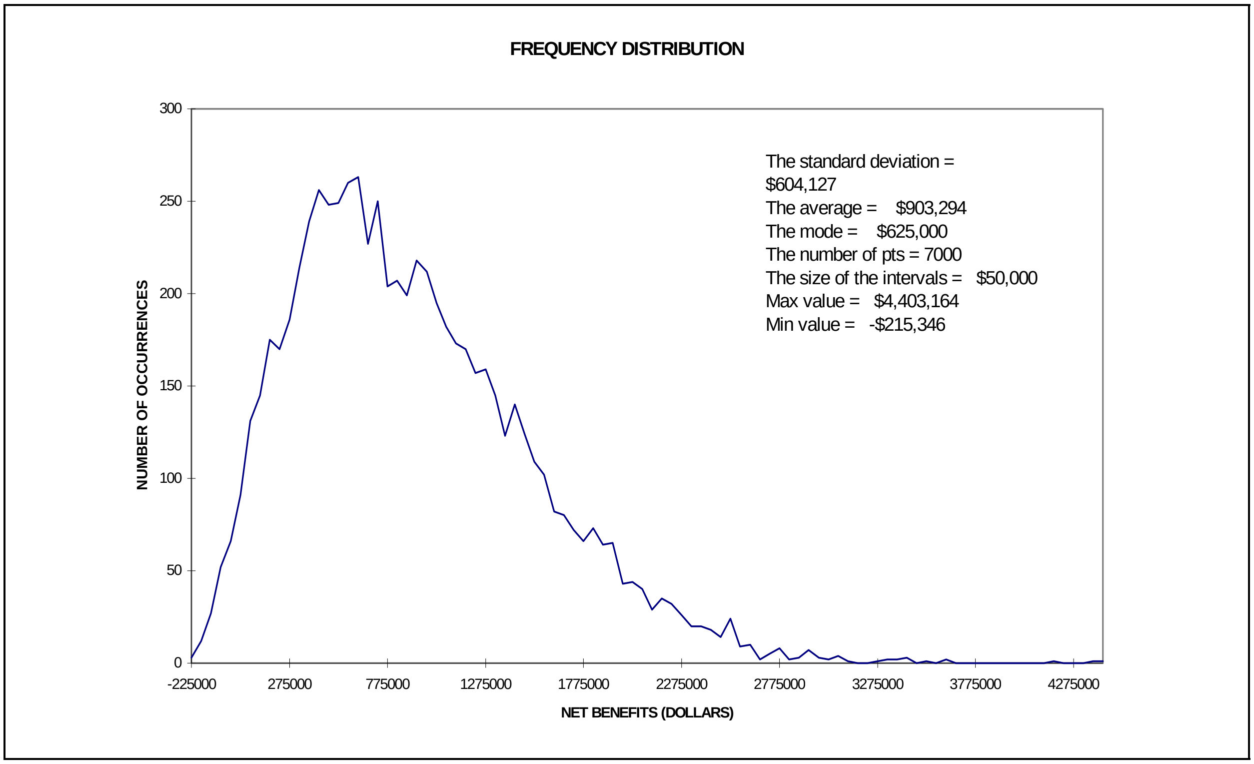

Figure 5. Sample Frequency Plot

4. Recent Model Enhancements

Significant enhancements made to the model since the Alternative Formulation Briefing have had a significant impact on plan formulation. These changes are summarized below.

a. Storm Responses

GRANDUC has been revised to allow for a secondary set of storm responses to be triggered for the remainder of a renourishment cycle, at

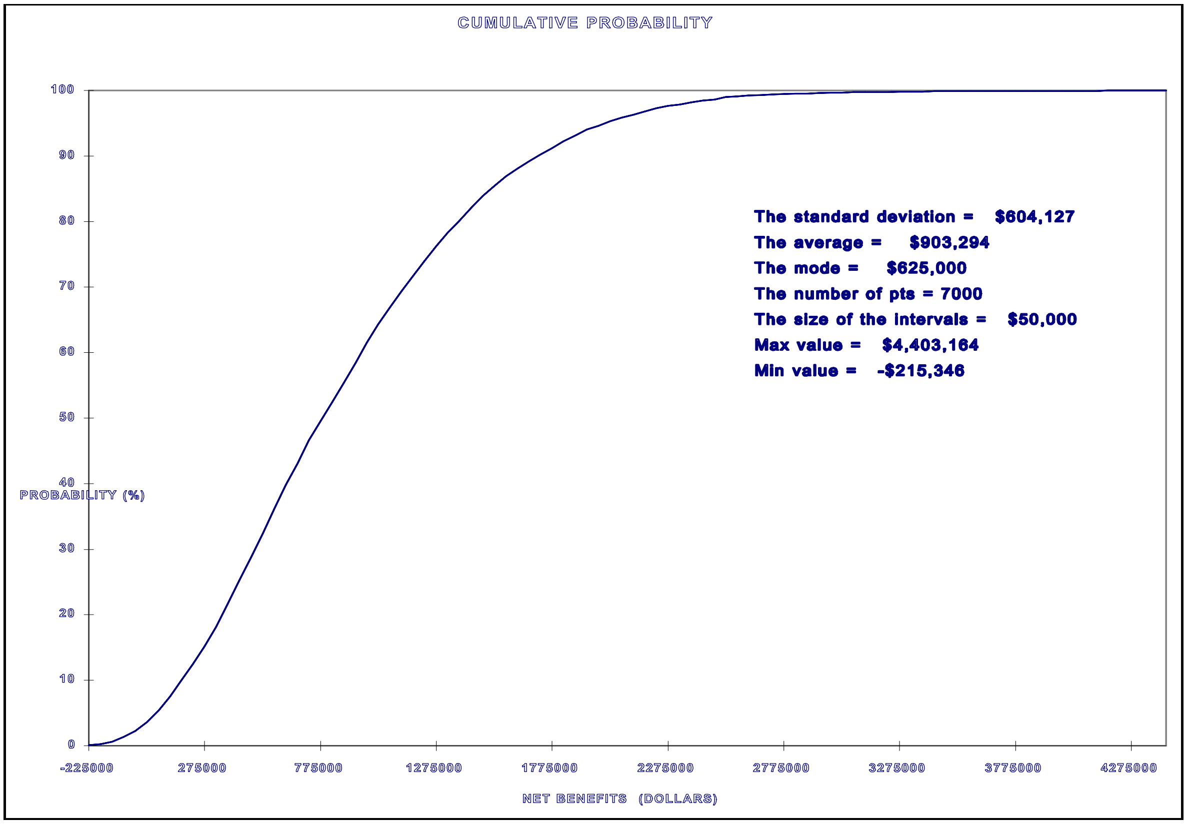

Figure 6. Sample Cumulative Probability Distribution

which time GRANDUC would revert then back to the primary set of storm responses. This allows for a switch-over from the primary “beachfill” responses to the secondary “existing condition” responses, triggered by either an erosion distance or a storm erosion volume. First, this allows for GRANDUC to more realistically model the diminished shore protection following major storm damage until the project template can be re-established during the subsequent renourishment. Second, since the “existing condition” at Topsail Beach is basically that of a reconstructed dune (following the extensive damage of hurricanes in the late 90s), switching over to these secondary responses allows GRANDUC to simulate this interim dune rebuilding as part of its operating scheme.

b. Structure Replacement

Previous versions of GRANDUC allowed for structures that were taken out by storm damage to be replaced multiple times with an identical structure, as long as the structure was not taken out by long-term erosion. GRANDUC has been revised to incorporate the following more realistic criteria:

- Structures are replaced only if adequate buildable lot depth remains (100-foot minimum distance from back of lot).

- Only one structure replacement per lot is allowed.
- Residential structures taken out by storm damage are replaced with new residential structures that conform to the latest building codes. While the replacement structures have a higher value, they are also more resistant to storm damage, which will be reflected in their revised erosion damage curve.
- Non-residential structures are replaced with structures of the same type and value, however, the first-floor elevation will be set at "ground" plus 10 feet. This assumption will exceed the 100-yr storm surge elevation and it is predicated on actual current building practices. Revised erosion damage curves will limit total structure damages to 20 percent maximum and only when the erosion indicator is 100 percent through the structure footprint.

5. Topsail Beach GRANDUC Input

a. Global Data

1) **Number of Life Cycles**: To achieve model stability, 1000 life cycles were simulated.

2) **Interest Rate:** An interest rate of 5.375% is used for this analysis.

3) **Economic Period:** A 50-year length of life cycle is used.

4) **Base Year:** The base year for GRANDUC analysis is the first year the project is in place. Adjustments were made to the shoreline and structure database to reflect project in-place conditions.

5) **Uncertainty**: Uncertainty was introduced into the model via three variables: erosion distance, structure distance, and first floor structure elevation. A variance of ± 5 feet is used for erosion distance, ± 2 feet for structure distance, and ± 0.1 feet for first-floor structure elevation.

6) **Nourishment Cycle:** A 4-year periodic nourishment cycle is used.

7) **Initial Benefits:** No initial benefits were included in the GRANDUC analyses.

8) **Initial Costs, Annual Costs, Dredging Mobilization and Demobilization Cost during Nourishment:** Study team members provided cost input data.

b. Reach Data

1) **Reaches:** The Topsail Beach study area was broken into a total of 26 reaches. Each of the reaches were approximately 1000 feet in length, except the northernmost reach at the Topsail Beach/Surf City town limits, which was only about 700 feet in length.

2) **Shoreline and Reference Line:** The existing mean high water line (+2.1 feet-NGVD) was used as both the shoreline and the reference line. Erosion is measured from the shoreline and structure setbacks are measured from the reference line.

3) **Long Term Erosion Rates:** For pre-project (base) conditions, long-term erosion rates were computed using historic surveys. For project conditions, long-term erosion losses were calibrated using the Planform Evolution Model.

4) **Annual Erosion:** An annual erosion rate of 0.2 feet per year was used to represent losses due to sea level rise.

5) **Dune Damage and Repair:** Scraping costs of $2.00 per cubic yard were input to the model to account for emergency repairs that may occur following severe storms.

6) **Unit Dredging Cost:** Initial construction dredging costs (for pipeline dredging) varied by reach from $3.72 to $6.09 per cubic yard, with unit prices increasing from south to north. During periodic renourishment, a uniform dredging cost of $5.44 per cubic yard (for hopper dredging) was used.

7) **Total Fill Placement Adjustment Ratio:** An overfill ratio of 1.35 was used for initial construction. During periodic renourishment, an overfill ratio of 1.25 is expected.

8) **Land Value:** An updated land value of $25 per square foot was used throughout the study area.

c. Life Cycle Storm Histories

1) **Erosion Distance:** Erosion distances for 0.5-, 2.0-, and 4.0-foot vertical erosion were determined using the SBEACH model.

2) **Surge Elevation and Wave Setup:** Surge elevation is the peak storm water elevation, and wave setup is the increase in nearshore water surface elevation due to wave action alone. Surge elevation and wave setup for each typical profile for 1-year to 500-year recurrence intervals were determined using EST analysis of SBEACH output.

d. Structure Database

The Economics Section of the Wilmington District developed all input data to the structure database. Most of the information in the database was determined by measuring distances from available project area GIS mapping. These measurements included distance from the reference line to the front of the lot and structure, lot width and length, and structure length. Values also had to be assigned to each structure for the following:

1) **Structure Type** selection determines which flood damage curve (piling, slab, etc.) is assigned to a given structure.
2) **Structure Value** is based on replacement value less depreciation.
3) **Content Value** is normally computed as a percentage of the structure value.
4) **Ground Elevation** (at the structure) was taken from field surveys and March 2002 contour mapping of the study area.
5) **First Floor Elevation** for each structure was taken from surveys.

The actual structure file is included in *Appendix B: Economic Analysis*, along with a detailed discussion of all structure-related inputs.

e. Flood Damage Curves

For each type of structure in the study area, flood damage curves were developed for both the structure and contents. Damages for each structure are tied to the first-floor elevation. A total of 65 flood/inundation type curves were selected by the Economics Section of the Wilmington District to present all the structures in the study area.

f. Erosion Damage Curves

For each type of structure in the study area, erosion damage curves were developed for both the structure and contents. A total of 34 erosion damage curves were selected by the Economics Section of the Wilmington District to represent all the structures in the study area. A more detailed description of the erosion damage curves is provided in *Appendix B: Economic Analysis*, along with the actual erosion damage curves.