INDEPENDENT EVALUATION OF LONGSHORE TRANSPORT OF SAND FROM THE PLANNED NOURISHMENT PROJECT DARE COUNTY, NC

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A Consulting Study

Conducted for:

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EXECUTIVE SUMMARY

The Dare County Beach Nourishment Project is planned for a 50 year life and consists of an initial nourishment of 12,200,000 cubic yards (yd^3) placed in two segments totaling 14.2 miles of shoreline and average renourishments of 3,890,000 yd^3 at three year intervals.

The effort on which this report is based was funded by the U. S. Fish and Wildlife Service with specific interest in the quality and quantity of additional sediments that will be transported to the north limits of Oregon Inlet as a result of the nourishment project. This sediment would tend to be the finer fraction and it has been found that finer sediments are detrimental to the fauna residing in the nearshore. The scope of this independent effort has included examination of the Corps design documents, comparing the native and borrow sediments and conducting numerical modeling of the performance of this beach nourishment project applying methodology that differs from that employed by the Corps. This report presents the results of the native and borrow sediment comparisons and numerical modeling of the project performance.

The performance of the beach nourishment project depends to a substantial degree on the quality of the nourishment sediments. In particular, finer sediments are transported along the shoreline more rapidly than coarser sediments and are less favorable to organisms in the nearshore zone. Therefore, special emphasis has been directed to the material to be dredged from the offshore borrow areas. Three viable offshore borrow areas were identified with the major borrow area (S1) containing approximately 14 times the volume of the other two viable borrow areas combined. The sediment characteristics of this borrow area were defined by 32 cores over a plan area of approximately 10.3 square miles. This is a relatively small number of cores for this plan area and raises questions regarding the sediment quality that may be delivered to the Dare County beaches.

The major findings of this report, considering the reported sediment characteristics to be correct, are: (1) The project appears to be overdesigned, especially with the large quantities of renourishment volumes planned at three year intervals, and (2) Our best estimate for additional sediment transported to the north limits of Oregon Inlet due to the nourishment over the 50 year project life is an average of 20,000 yd^3 per year; however, there is considerable uncertainty in this estimate due, in part, to the widely spaced cores discussed above and the associated uncertainties in sediment quality and the status of shoreline modeling. This estimate of 20,000 yd^3 per year is compared to the Corps estimate of 65,000 yd^3 per year if all material were removed from the major borrow area. Additional sediment transported to Oregon Inlet would tend to be fine and, after transport to Pea Island, would be deleterious to the fauna there. Finally, if the project were redesigned with less frequent renourishments, the potential impacts to Oregon Inlet and Pea Island would be reduced.

INDEPENDENT EVALUATION OF LONGSHORE TRANSPORT OF SAND FROM THE PLANNED NOURISHMENT PROJECT DARE COUNTY, NC

1.0 Introduction

This report presents the results of an independent evaluation of the performance of the planned Dare County beach nourishment project. The primary interest of the U. S. Fish and Wildlife Service is whether or not the project will increase the sediment transported to Oregon Inlet and thus contribute to a need for increased dredging. This evaluation was carried out with a numerical model developed to predict the performance of beach nourishment projects, and to the degree possible, this evaluation was conducted with parameters which are as realistic possible.

2.0 Project Characteristics

Two Corps of Engineers design reports are available with each report providing a different beach nourishment project design referred to as Project “A” and Project “B”, herein. Project A was presented in the U. S. Army Corps of Engineers Feasibility Report (dated September 2000) and Project B was developed in a report by Thompson and Gravens (dated August 2000); however, the version of the August 2000 report available to us was a Draft report. The overall characteristics of these two designs are presented in Table 1 and the longshore extents of the two projects are shown in Figure 1. The southern boundaries of the two projects are the same with the projects differing by displacements of the northern limits of the two project segments. Each of the designs includes a North Segment and a South segment. Because several designs were considered for Project B and some of these design characteristics differ from those in Table 1, the results to be presented later should not be considered to apply equally to all of these design variations. However, the design features of Projects A and B are sufficiently similar that the evaluations provided later will apply approximately to this range of design variations.

Table 1

Characteristics of Two Project Designs

Project	Segment	Length (Miles)	Initial Volume (yd^3)	Renourish-ment Interval (Years)	Renourishment Volume (yd^3)	Volume Density (yd^3/ft)
"A"	North	4.1	4,300,000	3	1,055,000	231
	South	10.1	8,000,000	3	2,835,000	159
"B" *	North	2.77	4,270,000	3	860,500**	367
	South	8.26	11,800,000	3	1,490,000**	291

* The variation of Project B with the 3,000 ft transitions was examined here
** These values are the averages of the first four renourishments

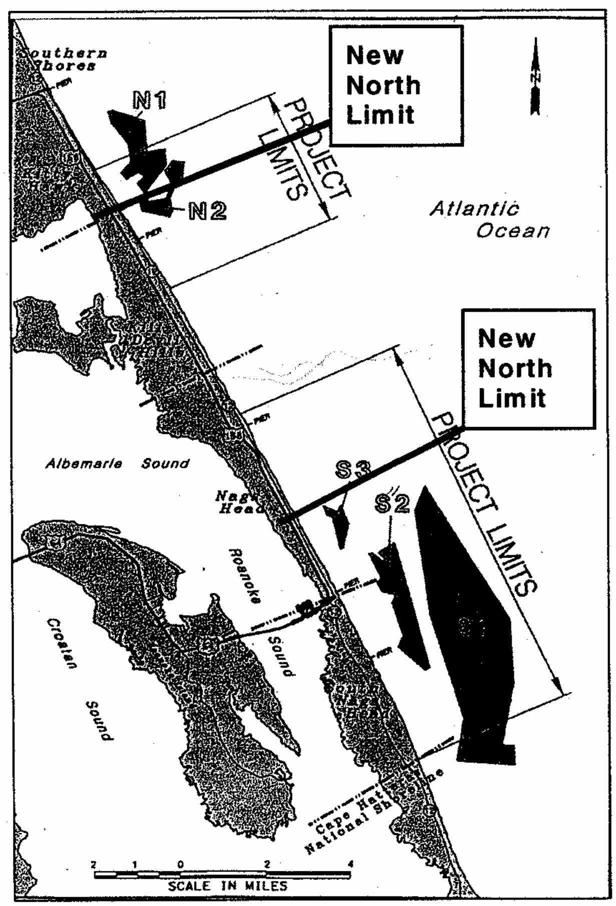

Figure 1. Showing Original (Project A) and "New North Project Limits" (Project B).

3.0 Sediments

The characteristics of the native and borrow sediments were analyzed and are discussed below.

3.1 Native Sediments

The native beach and offshore sediments were analyzed along 20 profile lines with Station 0 at approximately the Kitty Hawk Pier to the north and Station 1020 just north of the Cape Hatteras National Seashore to the south. The station numbers are expressed in hundreds of feet such that Station 1020 is 102,000 feet (19.3 miles) south of Station 0. The stations at which samples were collected were: 0, 50, 110, 160, 210, 260, 320, 370, 420, 480, 530,580, 630, 690, 740, 790, 850, 900, 950 and 1000. Samples were collected at a number of cross-shore locations (ranging from 15 to 22 samples) for each station and generally ranged from approximately 30 feet water depth to the back berm area. Each sample was analyzed and the mean diameter and standard deviation (sorting) were obtained and reported. Figure 2 presents the mean diameters (in "phi" units) for all 20 stations through which an approximate average line has been drawn. It is seen that the sediment sizes decrease (phi values increase) rapidly for depths greater than approximately 5 feet. Figure 3 presents the sorting values in the same format as for the mean sediment sizes. It is seen that the sorting values are much more uniform with depth.

Because it is of interest to evaluate the sediment characteristics in greater detail, Figures 4 and 6 present plots similar to Figure 2 for the mean sizes for the north and south projects for Design A. Although the results would vary somewhat for Design B, the results are not considered to differ sufficiently to warrant separate consideration. Figures 5 and 7 present the distributions with depth for the sorting in the north and south projects, for Design A, respectively. An approximate mean curve has been drawn through the suites of lines in each of the Figures 2 through 7.

The results in Figures 4 and 6 were analyzed to determine effective mean sizes for the two project areas. The method employed is developed in Dean (2002). These effective mean native beach sediment sizes are summarized for the two project areas in Table 2.

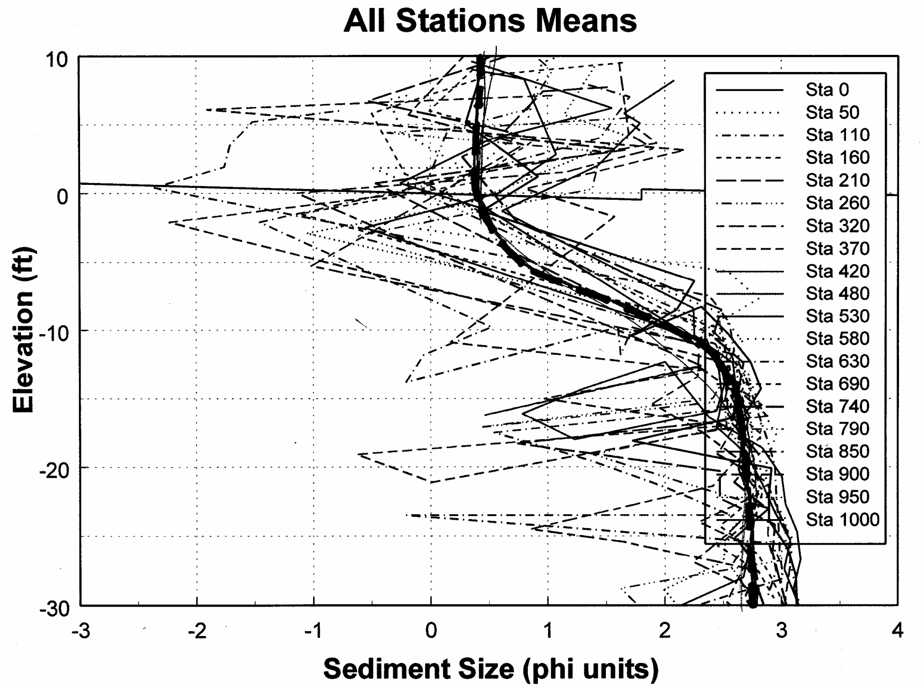

Figure 2. Distributions Over Depth of All Sample Means at All 20 Stations.

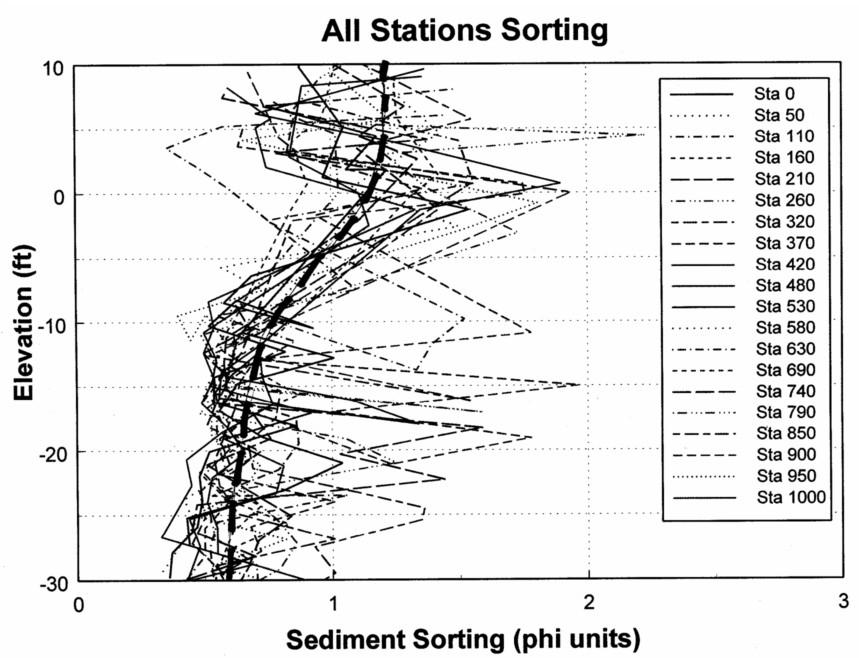

Figure 3. Distributions Over Depth of All Sample Sorting Values at All 20 Stations.

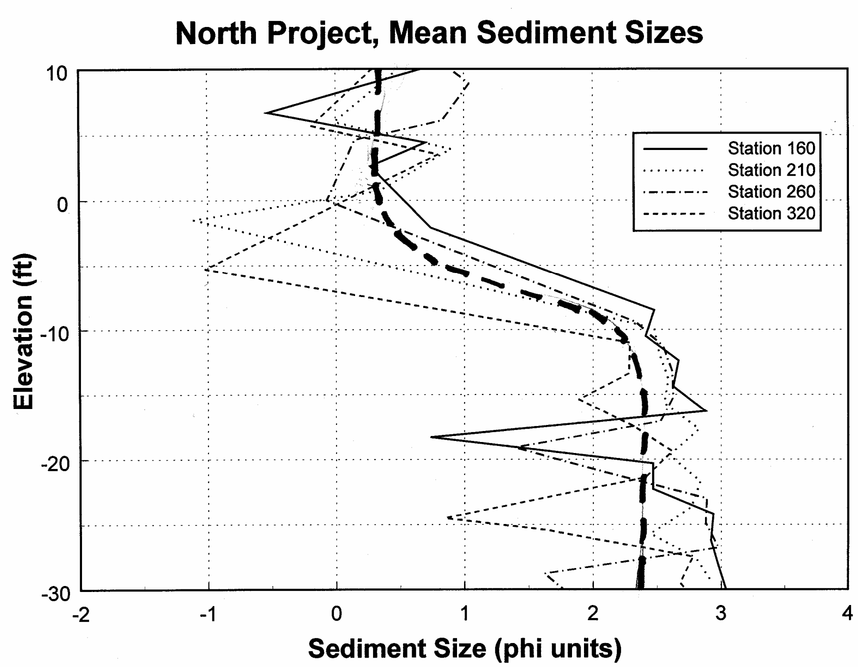

Figure 4. Distributions Over Depth of All Sample Means at Stations in North Project Area..

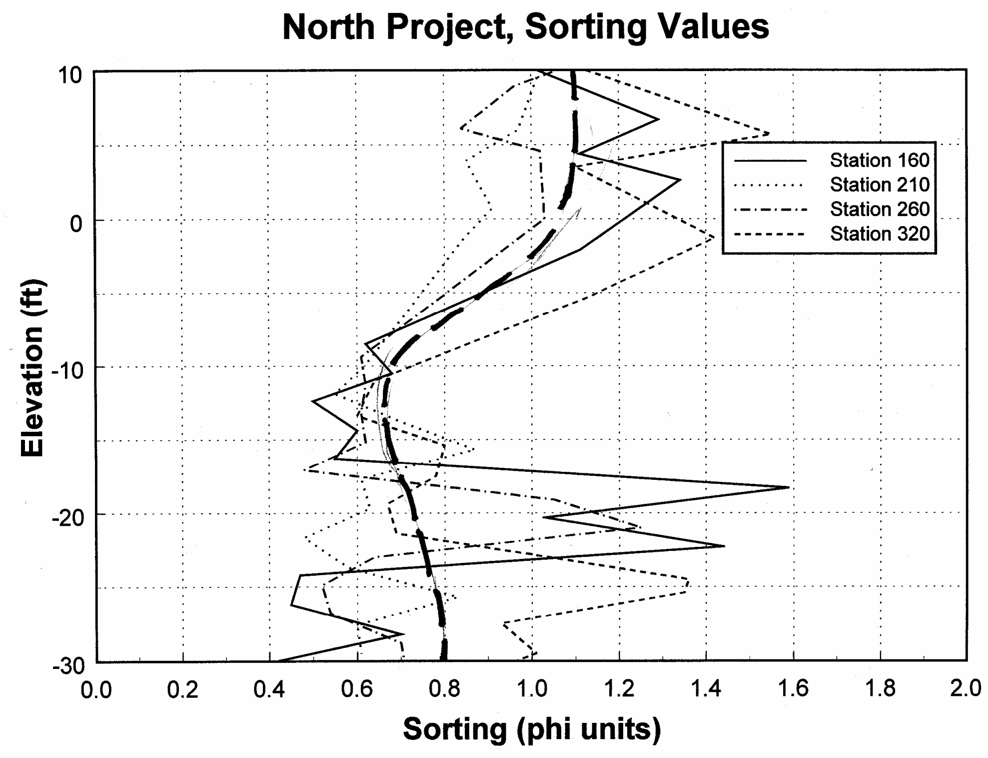

Figure 5. Distributions Over Depth of All Sample Sorting Values at Stations in North Project Area..

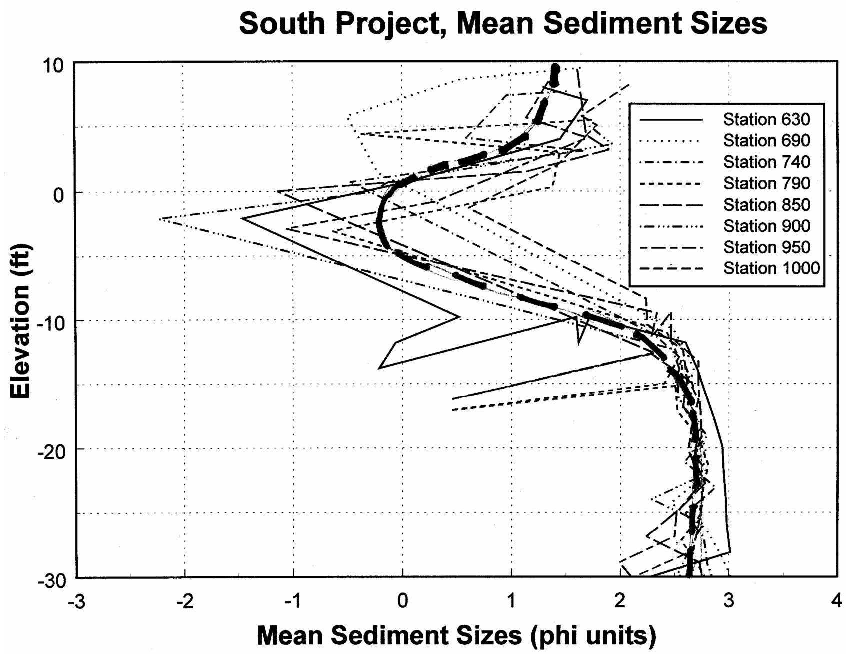

Figure 6. Distributions Over Depth of All Sample Means at Stations in South Project Area..

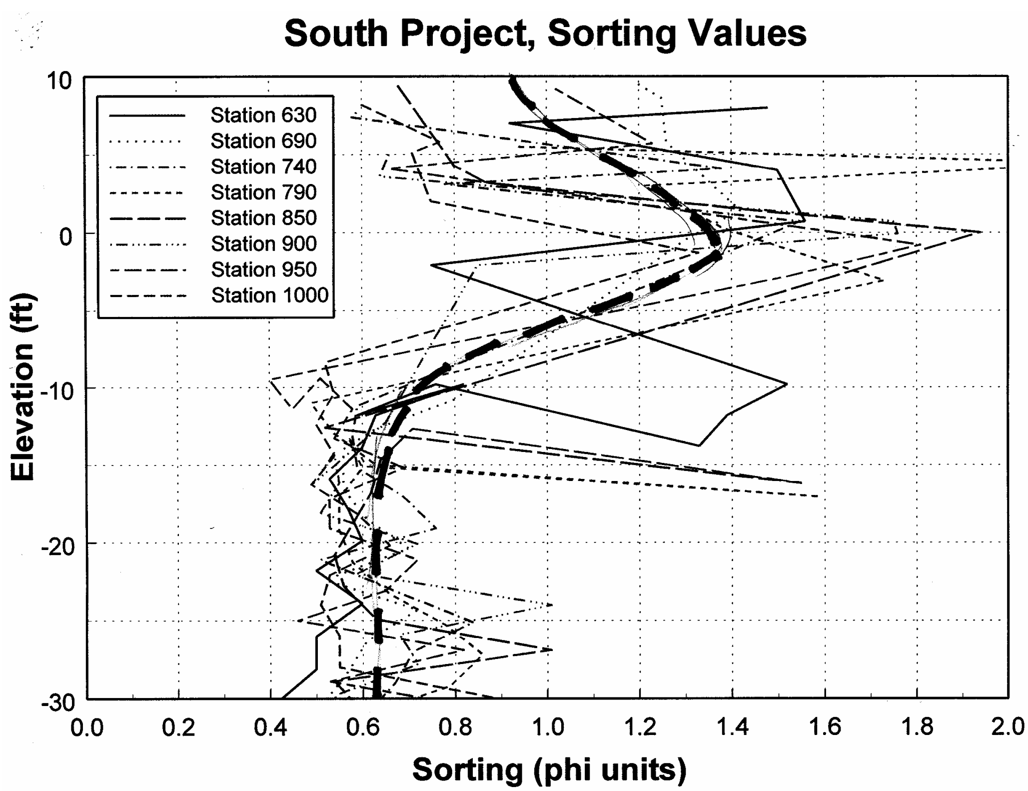

Figure 7. Distributions Over Depth of All Sample Sorting Values at Stations in South Project Area.

Table 2

Summary of Composite Mean Native Beach Sediment Sizes

Project	Composite Mean Sediment Diameter (mm)
North	0.31
South	0.26

3.2 Borrow Area Sediments

As characterizations of the borrow sediments, we have adopted the mean and sorting values provided in the Corps documents. As shown in Figure 1, the sand searches for the two project areas identified five borrow areas with two of these borrow areas located in proximity to the north project area and three borrow areas located in proximity to the south borrow area. The volumes, and composite characteristics of these five borrow areas are summarized in Table 3. Borrow Areas S2 and S3 were eliminated from nourishment consideration due to high silt content.

Table 3

Characteristics of Borrow Areas and Associated Sediments

Borrow Area	Volume Available (yd^3)	Mean Sediment Size (mm)	Sorting	Silt Content (%)	Average Depth of Cut (ft)	Number of Cores	Number of Cores per Million ft^2 of Plan Area
N1	5,192,000	0.22	1.93	9	6.6	35	0.78
N2	2,352,200	0.24	1.52	6	5.1	16	0.76
S1	104,454,000	0.34	1.43	5	9.8	32	0.12
S2	7,219,000	0.24	1.83	11	5.3	16	0.36
S3	1,388,000	0.21	1.27	13	5.5	11	0.99

Also shown in Table 3 are the numbers of cores that were taken to define the individual borrow areas. Although there are no strict coastal engineering standards specifying the spacing of cores, a reasonable spacing is at approximately 1,000 feet on centers for regularly shaped borrow areas or a core for every million square feet of borrow surface area. The last column in Table 3 presents the number of cores per million square feet of surface area for the five borrow areas. It is seen that the number of cores per million square feet is less than the approximate standard value and that for the borrow area with the greatest volume (S1), there is only an average of 0.12 core per million square feet, approximately one-eighth of the approximate standard value. This relatively small density of cores leads to greater uncertainty in the borrow material characteristics.

3.3 Evaluation of Native and Nourishment Sediment Compatibility

Comparison of the results in Tables 2 and 3 illustrates that the composite beach sands for the northern project are somewhat coarser than the composite size in the northern borrow areas. The composite sediments for the southern borrow area with the greatest volume (and the only southern borrow area to be used) are coarser than the composite native beach sand for the south project.

The Corps' document employed the so-called "overfill factor" as a measure of compatibility. The overfill factor is based solely on a measure of the similarity of the borrow and native sediment size characteristics. Here, the method of equilibrium beach profiles (EBP) is applied which we consider to be based on a more appropriate measure of the project profile response. EBP methodology for beach nourishment has been available for application to beach nourishment since 1991. The equilibrium beach widths of the nourished profiles are calculated for the cases of nourishment material compatible with the native sand and for the characteristics of the actual nourishment material. For this purpose a nominal nourishment volume density of 300 yd^3/ft is considered. The details of this approach are presented in detail in Dean (2002).

The results of applying this methodology are presented in Table 4 and Figures 8 and 9 for the north and south projects, respectively. It is seen that the equilibrium additional dry beach widths for the north project are considerably smaller than if native sand had been used and the equilibrium beach widths for the south project are considerably greater than if native sand had been used. It is noted that these results are for the case of each sediment represented by a single sized sediment. It has been shown (Dean, 2002) that the effect of sorting (a sample containing a range of sediment sizes) is to reduce the differences shown in the table and figures. Actually, the volume of sand in the two northern borrow areas is only sufficient for the initial nourishment and the following three renourishments after which the renourishments will need to use the southern borrow area. Therefore the use of the finer than native sand size discussed here is temporary.

Table 4
Characteristics of Equilibrium Beach Profiles for Borrow and Native Sands

Project	Composite Native Sand Size (mm)	Composite Borrow Sediment Size (mm)	Equilibrium Beach Width (ft)	
			Actual Borrow Sediment	Compatible Sediment
North	0.31	0.23	64	238
South	0.26	0.34	344	232

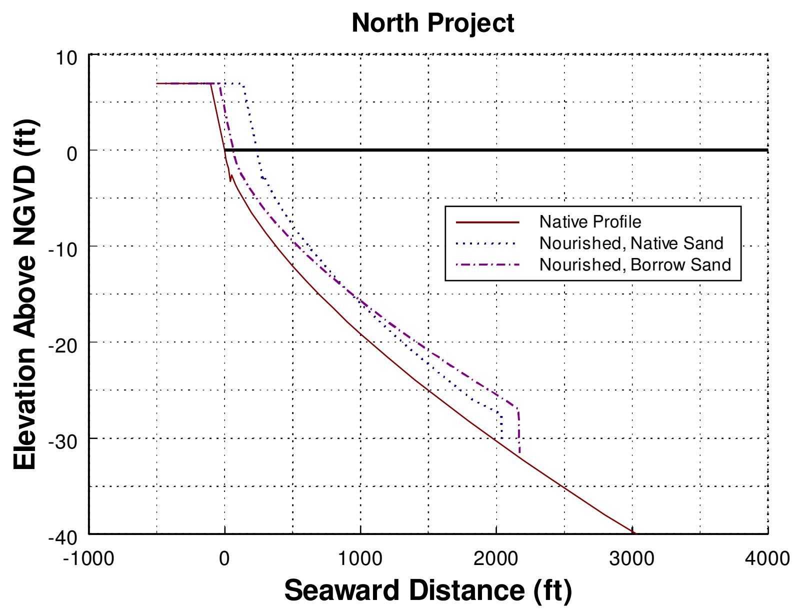

Figure 8. Predicted Characteristics of Native and Nourished Profiles, North Project.

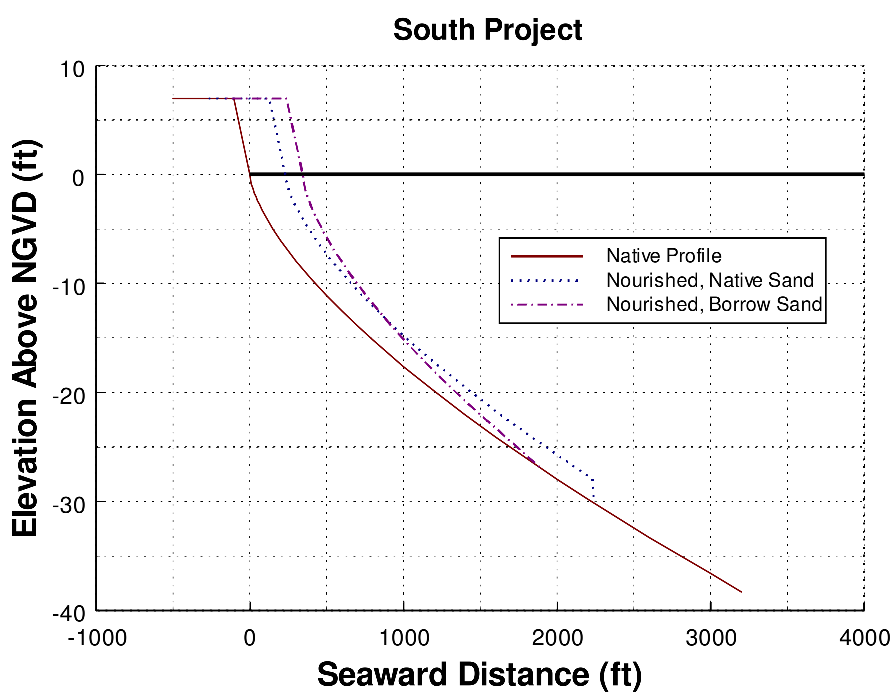

Figure 9. Predicted Characteristics of Native and Nourished Profiles, South Project.

4.0 Project Planform Modeling

Numerical modeling of the project planform is required to examine the project evolution in general and the project longevity in particular. For this purpose, we have employed a numerical model (called DNRBSM) that has been applied to the design and analysis of a number of beach nourishment projects (Dean and Grant, 1989, Dean and Yoo, 1992). The model considers nourishment with compatible sediments; however, adjustments can be made to the analysis results that account for the effects of dissimilar sediments such as those addressed in the previous section. Although the DNRBSM model employed here and the GENESIS model (Hanson and Kraus, 1989) used by the Corps are based on the same governing equations (sediment transport and conservation of sand), the source code for GENESIS is not publicly available as is the source code for DNRBSM. Thus, it is difficult to comment on any differences in results obtained by application of the two models.

The Corps design methodology is based on a "design beach width" and an "advance beach width". The design beach width is the approximate additional minimum beach width at which time the beach is to be renourished and the advance beach width is the additional beach width after nourishing considering the beach profile to have adjusted to its equilibrium profile. For purposes here, the design beach width was 150 feet and the advance beach width ranged from 195 feet to 210 feet.

4.1 Representative Wave Heights

The most significant parameter affecting the evolution of the nourishment project is the wave height. It can be shown that in the absence of structures and if the nourishment sands are compatible with the native sands that (perhaps surprisingly), to first order, the planform evolution is independent of the wave direction. This is fortunate, as generally, wave heights are much better known than wave directions, so this information allows the designer to concentrate his/her efforts on investigating the wave heights. Additionally, it can be shown that the planform evolution of a project up to a certain time depends only on the cumulative wave energy flux which has been exerted on the project up to that time. A corollary is that the evolution up to any selected time can be represented by a single representative wave height. The representative wave height is greater than the average wave height, and is closer to the root-mean square wave height. The effective wave height, H_{eff}, is defined as

$$H_{eff} = [1/N \sum_{1}^{N} H_n^{2.5}]^{0.4}$$

For calculation of evolution of the Dare County projects, we have selected two wave heights which are considered to bracket the effective wave height: 0.5 m and 1.0 m. These values are consistent with the WIS (Wave Information Studies) conducted by the Waterways Experiment Station and reported by Jensen (1983) as shown in Figure 10. Miller and Jensen (1990) compared the statistical wave height characteristics from 5 years of data from the Duck, NC Field Research Facility (FRF) wave gage in 28 feet of water depth and 20 years of WIS hindcasts. They found that the significant wave heights from the WIS data underpredicted the FRF measured wave heights for the range of heights of interest in this study. In particular, the gage average significant wave height was approximately 0.8 m. As noted above, the relevant wave height is closer to the root mean square wave height which is approximately 0.7 of the significant wave height or 0.56 m compared to the two values of 0.5 m and 1.0 m used here.

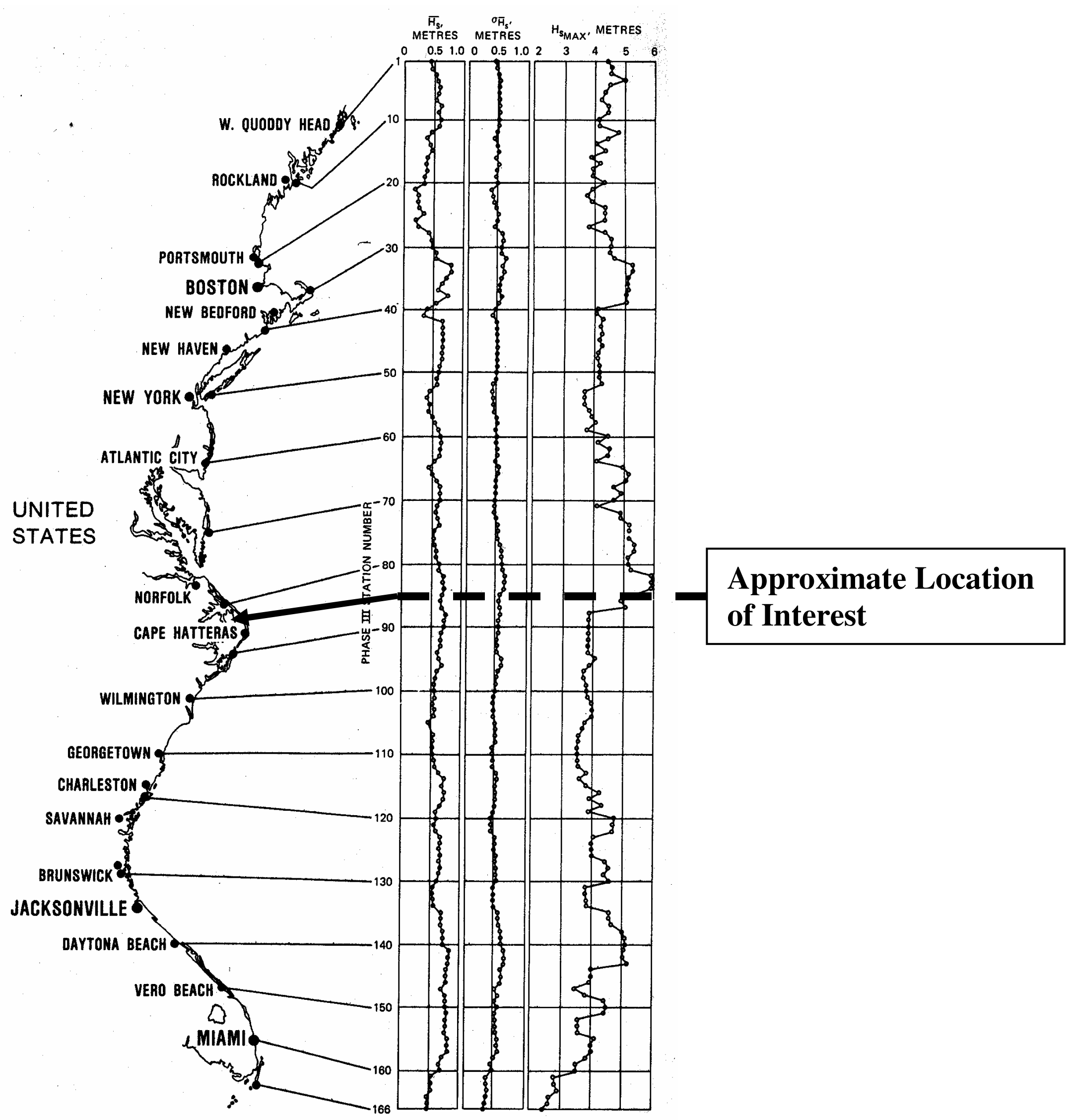

Figure 10. Wave Height Characteristics Along the U. S. East Coast (From Jensen, 1983).

4.2 Background Erosion

The background (or pre-nourishment) shoreline change characteristics contribute to the project evolution and are considered to be superimposed on the shoreline changes that occur due to the project alone. The background shoreline change rates that were adopted for this purpose were presented in both the Corps Feasibility Report and the report by Thompson and Gravens (2000) and are presented here as Figure 11 along with the approximations and extensions employed in our calculations.

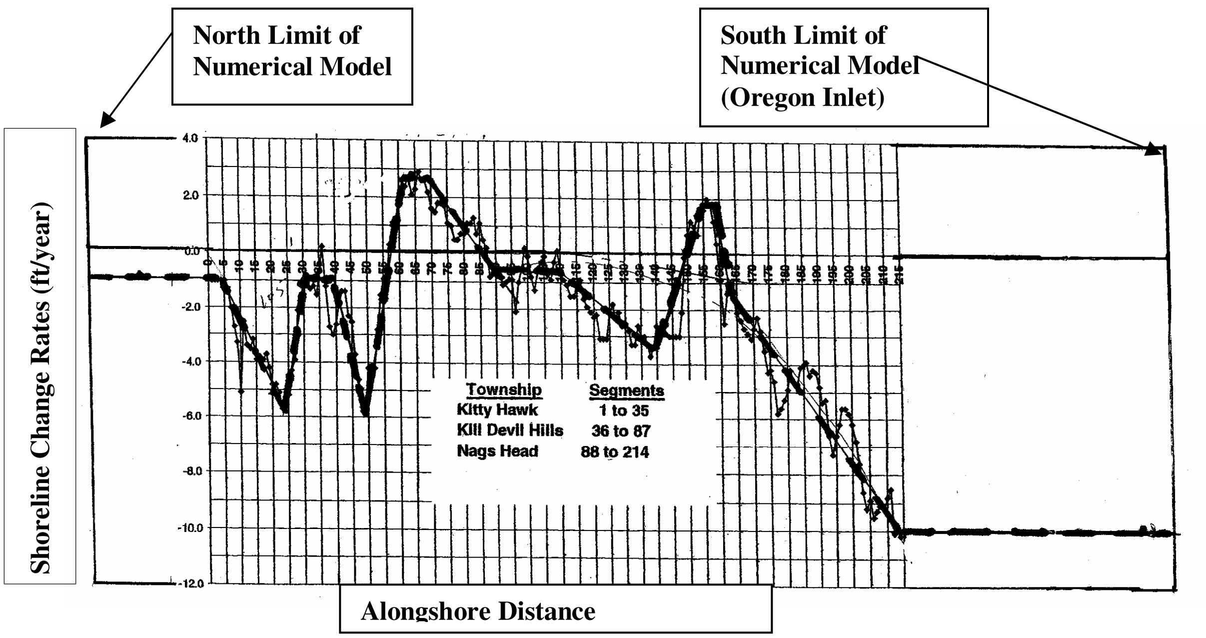

Figure 11. Shoreline Change Rates Versus Longshore Distance (Corps of Engineers, 2000)

4.3 Results of Planform and Volumetric Evolution Calculations

As discussed earlier and summarized in Table 1, two project designs have been developed. Calculations were carried out for Project B, although the evolution for Project A should be similar in many respects. The cases for which runs were conducted and the figures in which results are presented and the types of results presented are summarized in Table 5.

Table 5

Project Evolution Runs Conducted for Project B and Results Presented

Run	Results Shown	Figure Number
1	Effective Wave Height = 0.5 m. Individual Project and Total Renourishment Requirements Over 50 Year Period	12
1	Total Individual Renourishment Requirements	13
2	Same as Figure 12 for an Effective Wave Height = 1 m	14
2	Same as Figure 13 for an Effective Wave Height = 1 m	15
3	Project Planform After 9 Years But Before Scheduled 9 Year Renourishment, Effective Wave Height = 0.5 m	16
4	Same as Figure 16 for an Effective Wave Height = 1 m	17
5 - 8	Runs With and Without Nourishment to Determine Additional Transport to Northerly Limit of Oregon Inlet	18

4.3.1 Run 1. Project B. Effective Wave Height = 0.5 m.

As discussed previously, the computations were carried out for effective wave heights of 0.5 and 1.0 m. Figure 12 presents the total nourishment volume requirements over a 50 year period for Project B and an effective wave height of 0.5 m. It is seen that the total nourishment requirements over the 50 year period are approximately 10 million cubic yards for the north project and 29 million cubic yards for the south project for a total of approximately 39 million cubic yards. Figure 13 presents the three year nourishment requirements to reestablish the so-called "advance beach widths" required in the Corps' design. It is seen that the renourishment requirements decrease with renourishment number for the first 20 or so years after which the renourishment quantities are nearly constant.

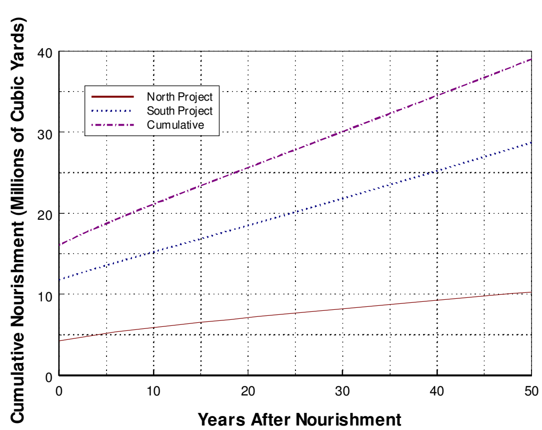

Figure 12. Total Nourishment Volumetric Requirements for Project B and an Effective Wave Height of 0.5 m.

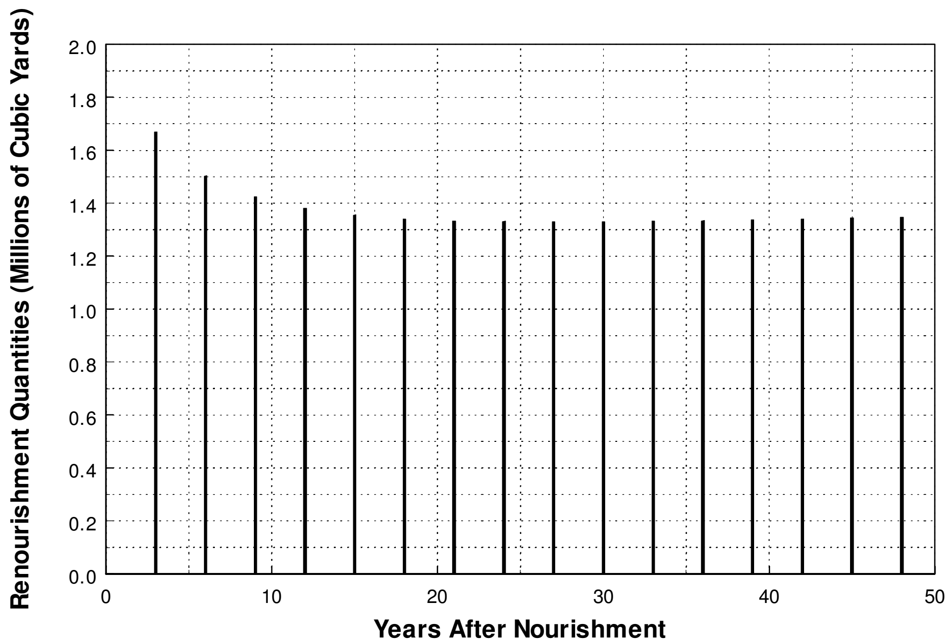

Figure 13. Total (North and South Projects) Three Year Beach Renourishment Requirements. Effective Wave Height = 0.5 m.

4.3.2 Run 2. Project B. Effective Wave Height = 1.0 m

Figure 14 presents the total nourishment volume requirements over a 50 year period for Project B and an effective wave height of 1.0 m. It is seen that the total nourishment requirements over the 50 year period are approximately 15 million cubic yards for the north project and 37 million cubic yards for the south project for a total of approximately 52 million cubic yards. It is of interest that with an effective wave height increase of a factor of two, the associated increase in renourishment requirements is only a factor of 1.3. Figure 15 presents the three year nourishment requirements to reestablish the so-called “advance beach widths” required in the Corps’ design. It is seen that the renourishment requirements decrease with renourishment number for the first 30 years of the project after which the renourishment quantities are reasonably constant.

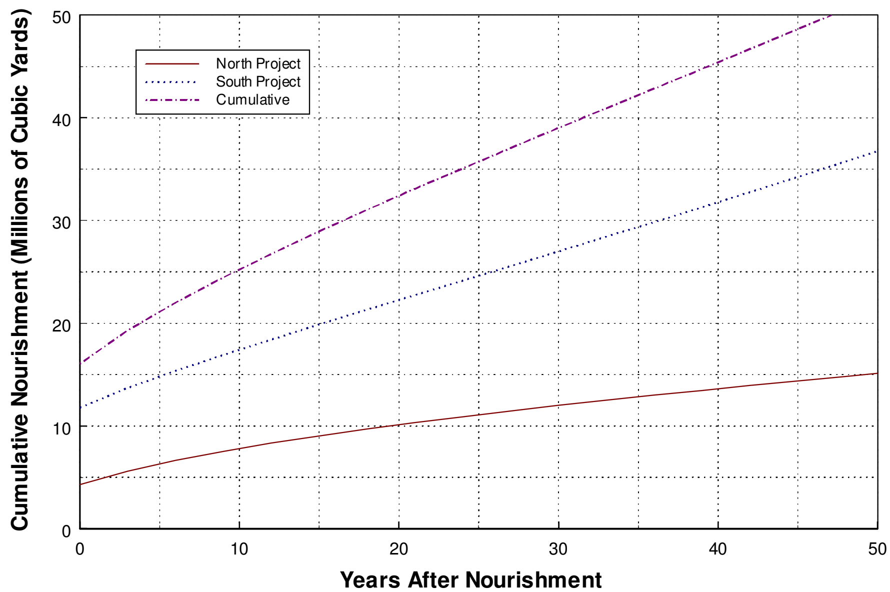

Figure 14. Total Nourishment Volumetric Requirements for Project B and an Effective Wave Height of 1.0 m.

Figure 15. Total (North and South Projects) Three Year Beach Renourishment Requirements. Effective Wave Height = 1.0 m.

4.3.3 Runs 3 and 4. Evolution With Less Renourishment. H = 0.5 and 1.0 m

The computer runs presented earlier have predicted significantly less renourishment requirements than the Corps' analyses. Table 1 indicates that the average renourishment requirement predicted by the Corps for Project B over the first four renourishment intervals is 2,350,500 cubic yards; however, the results in Figure 13 are substantially less (1,490,000 cubic yards) and the results in Figure 15 are slightly greater (2,670,000 million cubic yards). It has been noted that the two effective wave heights for which computations were conducted bracket the actual value with the most representative effective wave height being closer to 0.5 m than to 1.0 m. Thus runs were conducted to determine the planform evolution after a period of nine years, but before the scheduled 9 year renourishment was conducted. These results are presented in Figures 16 and 17, for effective wave heights of 0.5 m and 1.0 m, respectively. Inspection of these two figures indicates that although there are locations where the planform is landward of the "Design Nourishment Shoreline", these are minor and it would be possible to renourish less and still maintain good storm protection. This will be discussed in greater detail later.

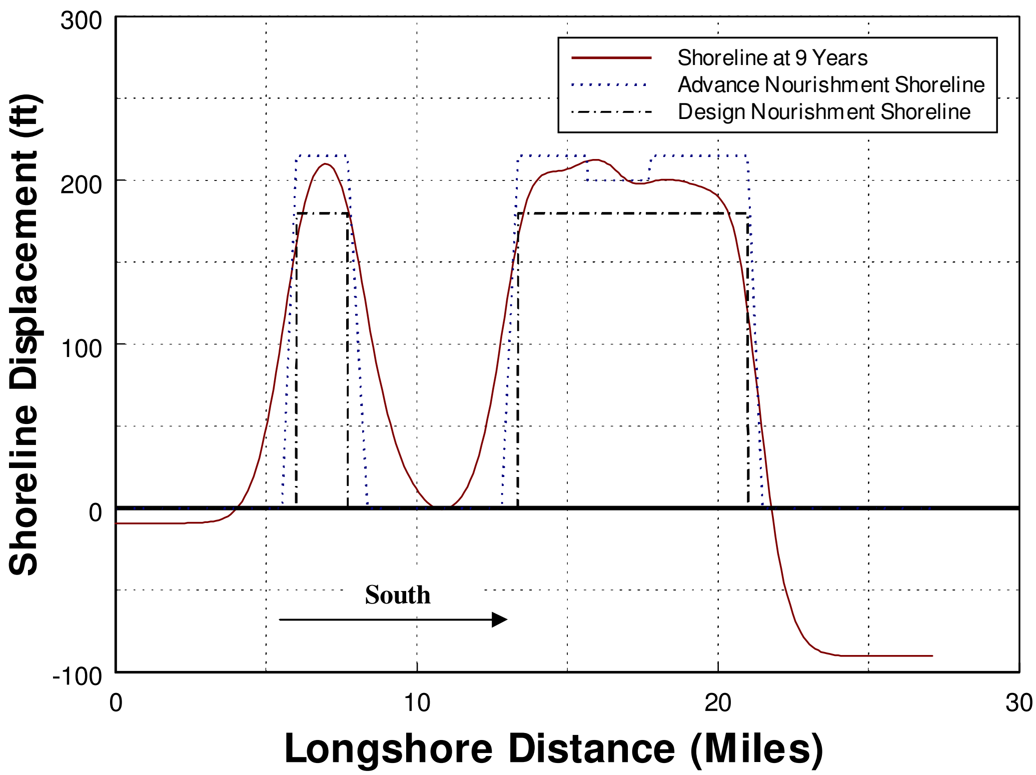

Figure 16. Project Planform After 9 Years, But Before the Scheduled 9 Year Renourishment. H_{eff} = 0.5 m.

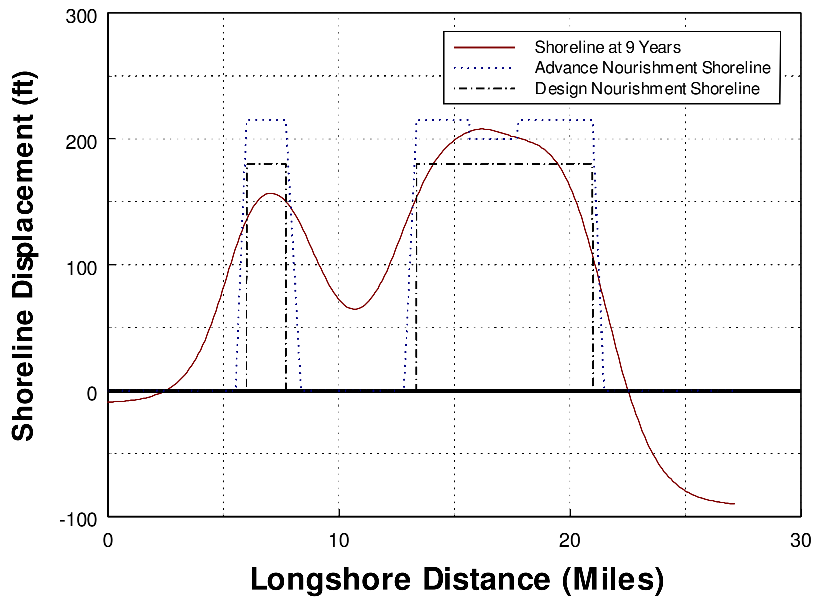

Figure 17. Project Planform After 9 Years, But Before the Scheduled 9 Year Renourishment. H_{eff} = 1.0 m.

4.4 Runs 5 – 8. Effect of Beach Nourishment on Sand Transport at Oregon Inlet

The final set of 4 runs was conducted to determine the degree to which the beach nourishment projects would influence the sand transport to Oregon Inlet and thus the required dredging. For this purpose, the sand transport at Oregon Inlet was evaluated with and without the projects and the results are presented in Table 6 and Figure 18. The numerical model requires that compatible sand be considered. It is seen that if compatible sand is used for beach nourishment, the net longshore sediment transport at Oregon Inlet is increased over the 50 year design life by approximately 70,000 cubic yards and 1,860,000 cubic yards for effective wave heights of 0.5 m and 1.0 m, respectively. These results are based on considerations of a single sand size. The actual amounts will be greater due to the range of sediment sizes in the nourishment sediments. Although it is not possible to quantify this effect precisely, our estimate is that over the 50 year life of the project, there will be an additional approximately 1,000,000 cubic yards of sediment deposited in the vicinity of Oregon Inlet as a result of the projects. This is approximately 2% to 3% of the total nourishment volume placed during this period.

The Corps of Engineers has stated that if all of the sediment were removed from Borrow Area S1, the average increase in sediment transported to Oregon Inlet would be approximately 65,000 yd^3/year and that only 67% of the total volume is to be removed from this borrow area resulting in a lesser amount of additional transport to the inlet (U. S. Army Corps of Engineers, FEIS, Pages C-54, C-55). Thus our average estimates of additional transport to Oregon Inlet over the 50 year Project life (20,000 yd^3/year) are less than those of the Corps. By comparison, the average volume dredged from Oregon Inlet is on the order of 650,000 yd^3/year.

Table 6

Volumes of Sediment Transported Into Vicinity of Oregon Inlet

Effective Wave Height (m)	Sediment Volume Transported Into Vicinity of Oregon Inlet Over 50 year Project Life (Millions of cubic yards)	
	Without Nourishment	With Nourishment
0.5	40.48	40.55
1.0	92.53	94.39

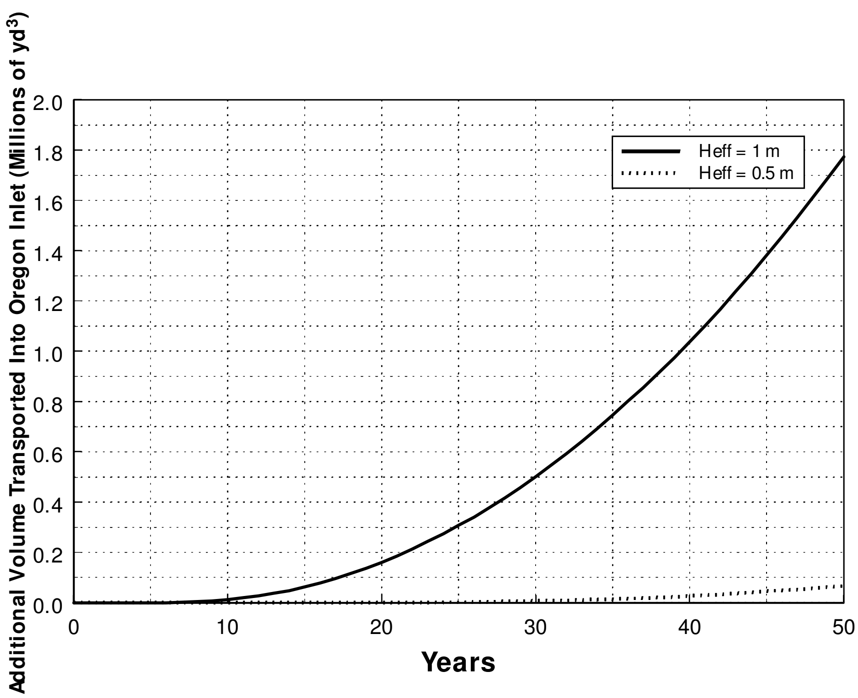

Figure 18. Additional Volume of Sand Transported Into Vicinity of Oregon Inlet as a Result of the Dare County Beach Nourishment Project.

5.0 Summary and Conclusions

5.1 Summary

This report has presented the results of an independent analysis of the performance of the Dare County Beach Nourishment Project as described in available reports (U. S. Army Corps of Engineers, 2000 and Thompson and Gravens, 2000). These reports present designs which differ in their longshore extents and in some other characteristics; however, the designs are sufficiently similar that the numerical modeling conducted herein and the associated results should be generally representative of the evolution characteristics of both designs. Both designs include a North Project in the vicinity of Kitty Hawk and a larger South Project in the vicinity of Nags Head and both designs plan renourishment on a three year cycle. Rather than conduct an exhaustive analysis of the wave characteristics, representative wave heights of 0.5 m and 1.0 m have been considered here with the actual effective wave height regarded to be nearer to 0.5 m that 1.0 m. This project is somewhat unique due to the high rates of background erosion in the South Nags Head area (approximately 10 feet per year).

The interest of the U. S. Fish and Wildlife Service for which the present study was conducted and the agency responsible for stewardship of the Cape Hatteras National Seashore is in quantifying any additional sediment transport into the vicinity of Oregon Inlet which would increase the maintenance dredging requirements to Pea Island and disruption to the adjacent shorelines. Additionally, the quality of the additional sediment transported is of concern and anticipated to be finer and thus of lesser quality than the natural sediment and of greater impact to the biota.

5.2 Conclusions

5.2.1 General Project Design

The modeling results presented here suggest that the project is overdesigned and that the broad objectives of the project could be accomplished with considerably less nourishment volumes and costs. For example, the Corps design anticipates renourishment on a three year cycle, whereas the computations show that the project planform will not retreat to the degree that storm protection to upland properties would be compromised significantly if the renourishment interval were extended since the greatest incremental nourishment benefits occur for the smaller additional beach widths. Increasing the renourishment intervals would have the dual benefits of requiring less sand and reducing the overall cost considerably with fewer mobilizations required. While the actual renourishment would probably be conducted based on monitoring and other considerations following initial construction (adaptive management), this overdesign and the associated extra costs should be recognized and planned for in the design stage.

5.2.2 Additional Sediment Transport Into Vicinity of Oregon Inlet

Calculations were carried out to estimate the volume of additional sediment reaching the vicinity of Oregon Inlet over the 50 year design life of the project. These calculations considered a single nourishment sediment grain size which would underestimate the volume. As expected, the volumes were smaller for the early years and increased with time due to the distance from the southerly limits of the South Nags Head portion of the project to Oregon Inlet. Additionally, the volumes were much greater for the 1 m wave height (1.9 million cubic yards over the 50 year design life) than for the 0.5 m effective wave height (70,000 cubic yards). Recognizing the effects of the range of sizes in the borrow sediments and the uncertainties due in part to the relatively small number of cores defining the borrow area with the greatest volume of sediment and that the finer sediments will be transported south more rapidly than the coarser sediments, a realistic estimate is that approximately 1,000,000 cubic yards of sediment will be carried into Oregon Inlet due to the nourishment project over its 50 year design life (20,000 yd^3/year). This is less than the Corps estimate of an average of 65,000 yd^3/year if all of the sediment were removed from the major south borrow area. These estimates of additional transport can be compared with the average annual amount dredged at Oregon Inlet of approximately 650,000 yd^3/year.

6.0 References

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