8.0 INLET SEDIMENT BUDGET & LITTORAL IMPACTS

Appendix F presents a detailed formulation of the Beaufort Inlet sediment budget for pre- and post-project conditions, and it also evaluates the probable littoral impacts of the Morehead City Federal Navigation Project upon the inlet and adjacent shorelines. The principal findings are summarized below.

Pre-Project Conditions (1900-1933). It is reasonably concluded that there was a net, average-annual sand bypassing of about 94,000 cy/yr from east to west across Beaufort Inlet in the 1900-1933 pre-project conditions. During this period, the interior flood shoal system was mostly stable to slightly accretional, the ebb shoal accumulated sand at a net rate of about +208,000 cy/yr, and the *overall* inlet complex exhibited a net average annual gain of about +206,000 cy/yr. The sediment budget concludes a minor net residual gain of +24,000 cy/yr along central/west Atlantic Beach, between 14,000 ft and 24,000 ft west of the inlet. This volume resulted in modest accretion along this area and/or ultimately supplemented accelerating westerly drift rates further to the west, or the easterly growth of Bogue Banks into the inlet.

Post-Project Conditions (1933-2004). In post-project (1933-2004) conditions, the overall inlet complex was erosional at an average-annual rate of -303,000 cy/yr, there was no bypassing, and the rate of littoral supply from the shoals to the shorelines did not meet (balance) the potential littoral requirement.

Inlet Impacts (1933-2004). Following the approach outlined in the Corps' Section 111 study[24], the net loss of sediment from the littoral system attributed to the Morehead City Federal Navigation Project was computed as follows, and as summarized in ***Table 2***. Corresponding values from the Corps' study are included in the table.

The net littoral volume removed from the inlet system, after beach disposal, is computed by the present study as -48.7 Mcy; or, about -685,800 cy/yr on annual average over 1933-2004. Of this total impact, it appears that about 23.6 Mcy (48%) has been manifest as volume losses ("deflation") of the ebb tidal shoal, and 3.9 Mcy (8%) has been manifest as volume losses of the flood tidal shoal. This leaves another 21.2 Mcy (44%) of inlet impact that is unaccounted for at the inlet, and which has been manifest as a net loss to the littoral system *outside* of the inlet ebb shoal complex. Over 71 years, this equates to -300,000 cy/yr of outstanding impact to the inlet-adjacent barrier islands beyond the inlet complex, where the latter is between 2.4 miles west and 2.1 miles east of the inlet channel.

[24] USACE, 2001; Table 5.1, page 18.

Table 2				
Estimate of the Net Loss of Littoral Sediment from the Littoral System due to the Morehead City Harbor Project				
	OLSEN (present study) **1933-2004**		USACE (2001) **1936-2000**	
	Cu. Yds.	Equiv cy/yr	Cu. Yds.	Equiv cy/yr
Total Maintenance Dredging	51,596,400	726,700	39,302,400	614,100
Accumulation to Shackleford Banks	5,910,000	83,200	6,500,000	101,500
Littoral Vol. Removed by Maint. Dredging & Shackleford Banks	57,507,000	809,900	45,802,500	715,600
Less Beach Disposal	-8,818,600	-124,300	-6,908,700	-108,000
Net Littoral Volume Removed from System ("Impact")	48,688,400	685,700	38,893,800	607,700
Total meas'd change in Ebb Tide Delta Volume	-33,982,000	-478,700	-19,652,000	-307,100
Less New Work in Bar Channel	10,414,000	146,600	6,954,000	108,600
Net Change in Ebb Tide Delta	-23,568,000	-332,000	-12,698,000	-198,500
Net Loss Littoral Volume from System	**25,120,400**	353,800	**26,195,800**	409,300
	71 years		64 years	
Equiv. Annual Rate of Littoral Volume Removal	**-353,800 cy/yr**		**-409,300 cy/yr**	

Post-project changes in wave energy, volumetric losses of the ebb tidal shoal, and increases in inlet-directed littoral transport potential were all significantly greater on the west side of the inlet than the east side. Specifically, from pre- to post-project conditions,

- increases in breaking wave energy density were 3.2 times greater along the Bogue Banks (west) shoreline than along the Shackleford Banks (east) shoreline;
- volume losses to the submerged ebb shoal platform were 4.3 times greater west of the bar channel than east of the bar channel (and over 8 times greater by other measures);
- near the inlet mouth, net longshore transport potential directed toward the inlet *increased* by about 300,000 cy/yr along the Bogue Banks (west) shoreline and *decreased* by about -200,000 cy/yr along the Shackleford Banks (east) shoreline.

From these measures, it is reasonable to conclude that the outstanding littoral impact, beyond the immediate inlet complex, is at least 3.2 to 4.3 times greater on the west (historically downdrift) side of the inlet than the east side of the inlet. From these values, it is thus reasonably concluded that between 76% and 81% of the 300,000 cy/yr littoral impact outside of the inlet complex is associated with the Bogue Banks side of the inlet. This equates to between 228,000 cy/yr and 243,000 cy/yr. Over 71 years (1933-2004), this totals between 16.2 Mcy and 17.3 Mcy of littoral impact to Bogue Banks beyond that associated with shoreline losses and ebb tidal shoal deflation within 2.4 miles west of the inlet. These volumes account for the placement of beach disposal from Inner Harbor / Brandt Island. The remainder of the net littoral impact beyond the inlet complex is attributed to Shackleford Banks, beyond 2.1 miles east of the inlet, amounting to between 57,000 and 72,000 cy/yr. From 1933 to 2004, this equates to between 4.1 and 5.1 Mcy impact along Shackleford Banks.

From a different approach – but one which results in similar values -- the project's net, *historic* littoral impact over **1933-2004** is comprised of

- 386,500 cy/yr (27.4 Mcy) of direct impact to the inlet complex by measured volumetric depletion of the inlet sand reservoir, plus
- 206,000 cy/yr (14.6 Mcy) of impact to the inlet complex and the littoral system by 'forgone accretion' of littoral influx that previously accrued to the inlet shoals but is now intercepted by the channel and dredging, plus
- 94,000 + 65,400 = 159,400 cy/yr (11.3 Mcy) of direct impact to the adjacent beaches (beyond the inlet complex) from interception of littoral drift that would have otherwise bypassed or backpassed through the inlet system, respectively.

The project's cumulative effects are thus 27.4 Mcy of direct impact to the inlet (by depletion of the shoals), plus another 14.6 +11.3 = 25.9 Mcy of impact to the beaches (by diversion of the littoral exchange between the inlet and the beaches). The latter value does not account for beach-disposal of suitable material from the navigation project *beyond* the inlet complex (beyond 2.4 miles west of the inlet), which amounts to 4.7 Mcy. Thus the net direct, historical littoral impact to the beach beyond the inlet complex is 25.9 - 4.7 = 21.2 Mcy. Additional to this is the effect of the 27.4 Mcy of sand depleted from the inlet shoal complex.

Computed for *current* conditions (generally averaged over the **1994-2004** timeframe), the approximate net impact of the navigation project is comprised of

- 426,700 cy/yr of depletion of the inlet's existing volumetric reserves, and
- 206,000 cy/yr of littoral influx from the adjacent beaches that would otherwise have accrued to the inlet/beach shoal system ("foregone accretion"), and
- 94,000 + 255,900 = 349,900 cy/yr of littoral influx from the adjacent beaches that would otherwise have been bypassed or backpassed, respectively, across the inlet.

The second and third elements represent a 555,900 cy/yr littoral impact to the beaches beyond the boundaries of the inlet shoal complex [2.4 miles west and 2.1 miles east of the inlet channel]. About 228,800 cy/yr of this impact is mitigated by beach disposal of suitable material from the navigation project beyond these boundaries (additional to beach disposal already included above). Thus, in current dredging practices, there is a net outstanding, impact of (555,900-228,800=) *327,100 cy/yr* to the littoral system beyond the limits of the inlet shoal complex, *plus* additional indirect littoral impact of *426,700 cy/yr* of sand depleted from the inlet shoal complex itself.

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9.0 COMPARISON OF FINDINGS WITH CORPS' SECTION 111 STUDY

The Corps' Section 111 Feasibility Study of Morehead City Harbor (USACE, 2001) examines the impact of the federal navigation project upon the littoral system and the inlet-adjacent shorelines. The technical findings are generally similar to those of the present study except that (1) the Corps' study ultimately relies upon comparison of historical shoreline changes, and (2) the Corps' study *dismisses* all of its technical findings *except* for shoreline changes and ultimately concludes that there is no net outstanding littoral impact of the navigation project upon the adjacent beaches.

Both the Corps' and present studies examine similar technical topics. The present study carries the analysis further or in greater detail for many of these topics; and, it updates the analysis from 2000 to 2004 using new dredging and survey data. Nonetheless, as noted above, the subject findings of the two studies are mostly similar. It is principally the final *conclusion* of the studies that differ.

Both the Corps' and present studies utilize basically the same dredging data. The present study considers the outer channel dredging to be of 100% littoral quality versus the Corps' presumption of 86%. The present study considers 77% of the inner harbor dredging to be of littoral origin, versus the Corps' presumption of 69% [p. 8].[25] This likewise means that the present study gives about 8% greater volume credit for beach disposal from the federal navigation project than does the Corps.[26]

The Corps' report describes net beach-disposal placement of 6.9 Mcy from the navigation project since 1978 to the time of the report (2001)[27]. This equates to about 300,400 cy/yr. The Corps describes maintenance dredging during this period, however, amounted to 970,700 cy/yr [pp. 6-8]; or about 3.2 times more than the beach disposal volume. Both values reflect only the beach-compatible fraction of material, as estimated by the Corps.

Both studies conclude that less than half of the outer-channel dredging has been placed as nearshore disposal since the activity began in 1997 [p. 32]. Both studies conclude that material placed as nearshore disposal – like offshore disposal -- has been taken out of the active littoral transport zone [p. 48]. The Corps' original

[25] [Page and paragraph numbers refer to the Corps' Section 111 Final Report, USACE (2001)]

[26] In formulation of the sediment budget, the present study actually considers 82% of the beach disposal from the Inner Harbor/Brandt Island as effective volume, because of the manner in which it is assumed to return to the navigation channel for subsequent maintenance dredging. See Appendix F, pp. F13-F14.

[27] [Executive Summary, page 4].

recommendations of location and depth for nearshore disposal (USACE 1990, 1992, respectively) agree with the present study's findings; viz., that disposal must be shallower than the 18 to 20 ft contour and 3 to 5 miles west of the inlet for the material to move shoreward and away from the inlet.

Both studies conclude that essentially all of the material placed on the Fort Macon shoreline appears to be rapidly transported back to the inlet [pars. 5.6; 7.45; 9.2] but likewise recognize the need for some level of placement of dredged material along eastern Bogue Banks [Par. 9.3, pp. 53-54]. The Corps' Section 111 study states that "performance of future disposal operations could be greatly improved by modifying the manner in which material is distributed along the shoreline. Recommendations for the disposal of the dredged material removed from the Morehead City harbor project are provided later in this report." [p. 45, par. 7.46]. However, no such recommendations are ultimately included in the Corps' Section 111 final report [pg. 54, par. 9.3, last sentence].

Both studies conclude that the predominant direction of net littoral transport potential at the inlet is from *east to west*, excepting the easterly reversal node within about 2.4 miles west of the inlet [pp 29-30, par. 7.14, Fig. 7.11, 7.13]. The Corps report also notes that "The greater amount of [profile] deepening on the Bogue Banks side versus the Shackleford Banks side appears to be consistent with a predominant sediment transport direction from east to west along the study area." [p. 41, par. 7.38].

Both studies conclude that changes in wave and transport patterns from pre-project to post-project conditions are mostly limited to the immediate inlet complex: within 2.8 miles west and 2 miles east of the inlet [p. 31, par. 7.18]. The present study finds changes in transport potential extending slightly further alongshore, up to 4.5 miles west and 3.8 miles east, but these changes are less significant.

From pre-project to existing conditions, both studies compute that the location of the easterly-transport reversal 'node' shifted eastward toward the inlet by about 2000-feet. Both studies compute a significant *increase* in transport potential directed *toward* the inlet along eastern Bogue Banks, and a significant *decrease* in transport potential directed toward the inlet along western Shackleford Banks [pp. 29-30, par. 7.15-7.16]. Both studies' examination of wave and transport patterns include consideration of the effects of nearshore disposal, offshore disposal, and ebb shoal changes relative to pre-project conditions.

The Corps' study reports that the inlet cross-sectional flow area has remained fairly stable from 1862 to 1974, and thus the inlet's implied tidal prism has not been significantly altered by the navigation project [p. 15, par. 4.16]. In contrast, the present

study found that the existing cross-sectional flow area is 1.3 to 1.7 times larger than in pre-project conditions, implying a 30% to 67% increase in inlet tidal prism.

The Corps study includes, and ultimately relies upon, comparison of apparent pre-project versus post-project shoreline change rates. Pre-project and early post-project data derived from nautical charts and aerial photographs (1854 through 1946), supplemented by post-project data from beach surveys of 1978-2001. The sources of these data vary and the Corps describes probable errors in shoreline mapping accuracy of each, including requisite interpolation between measured data points along the shoreline for beach profile survey data. Error estimates range from +/-10 feet for survey data to +/- 55 feet for historic maps [pp. 33-34]. Reasoning that the error may be random, the Corps' study presumes that the potential error in comparing two maps is not additive and may cancel. The Corps' analysis decreases the potential error in half (from $\pm$50 ft to $\pm$25 ft) for comparison of map data at long shoreline stretches. In this way, for comparison of maps spanning 56 to 92 years, "the average annual shoreline change rate determined over relatively long shoreline segments should be accurate to within $\pm$0.5 ft/yr" [p. 33, par. 7.22]. This would appear to be a suspect presumption given the error associated with historical nautical charts and associated with interpretation of shoreline locations from the "wet/dry" line of aerial photographs [p. 36, par. 7.30]. Shoreline locations developed from recent beach profile survey data (1978-2001) should exhibit less error; however, most of these surveys covered only the eastern portion of Bogue Banks and included effects of beach disposal to varying degrees. Meaningful interpretation of shoreline changes and littoral processes is inherently and significantly confounded by survey data that include placement of beach fill.

In contrast, the present study concluded that the available historical shoreline data adjacent to Beaufort Inlet are useful in qualitatively describing morphologic trends in shoreline behavior but are not sufficient to develop meaningful, quantitative conclusions of shoreline change rates – at least for the purposes of unilaterally determining inlet impacts to adjacent shorelines. Because the Corps' Section 111 findings ultimately rely *only* upon comparative shoreline-change analysis, the Corps' assumptions regarding the accuracy of the shoreline data are of central importance to their study.

The Corps' Section 111 study computed beach volume changes for the limited profile data available along eastern Bogue Banks from 1958 to 2001, and along Shackleford Banks from 1991 to 2000. Along Bogue Banks, the Corps computed smaller volume losses than the present study within 26,000 feet west of the inlet: about -191,000 cy/yr versus -310,000 cy/yr. Subtracting beach fill placement during this period, the adjusted losses equate to -406,000 cy/yr and -525,000 cy/yr, respectively. Along Shackleford Banks, both studies computed average annual losses of over -900,000 cy/yr [pp. 39-40]. Both studies concluded that measured shoreline changes are poorly

correlated with beach volume changes, and that this obviates use of standard engineering tools which typically seek to relate the two measurements [p. 41, par. 7.39].

Both the Corps' study and the present study found significant deepening of the offshore beach profiles, with the effect being greatest near the inlet. The Corps' study states [p. 40, par. 7.37]:

> 7.37. Changes in the offshore bottom on the east end of Bogue Banks demonstrate that the Beaufort Inlet ebb tide delta acts as a control over the offshore deptsh west of the inlet. As the ebb tide delta of Beaufort Inlet has deflated or increased in depth, the offshore depths west of the inlet have also increased. The influence of the ebb tide delta deflation extends at least to station 290+00 [approximately 5 miles west of the inlet] and perhaps beyond. While the 1958 profile survey did not extend beyond station 290+00, the July 1991, November 2000, and April 2001 surveys did. Comparison of the profile changes at these three station since 1991 showed that the profiles deepen by an average of from 1.0 to 1.6 feet.

The Corps found that offshore profile deepening on the Bogue Banks side of the inlet was greater than on the Shackleford Banks side: about 2.8 ft vs. 1.5 feet on average, from 1991 to 2001 [p. 40-41, par. 7.38]. The Corps' study concluded that sea level rise is not a dominant factor controlling shoreline changes in the area [p. 45, par. 7.47].

Both the Corps' Section 111 study and the present study concur that between the commencement of the navigation project's principal improvements in 1936 and the present, the ebb tidal delta volume has decreased in volume, deepened, increased in area, and elongated seaward [p. 10, par. 4.4-4.6]. The Corps describes the seaward movement of the ebb shoal as a result of the channel deepening and "yearly repetition of maintenance dredging along a fixed alignment." The Corps describes the latter as having "greatly reduced the ability of Beaufort Inlet to naturally bypass littoral sediment from Bogue Banks to Shackleford Banks and vise versa" and to likewise allow Shackleford Point to "store a large volume of littoral sediment that would have otherwise remained in the active littoral zone." [p. 11, par. 4.7]. The present study concurs with these findings.

The Corps' study notes that unlike other inlets in North Carolina, the ebb tide delta volume at Beaufort Inlet has not exhibited recovery after periods of intense storm activity, but instead, has continued to decrease even during periods of relatively low storm activity [p. 14, par 4.13].

From 1936 to present, the Corps computes the net average-annual rate of ebb shoal volume loss as about -198,400 cy/yr [Table 4.1, p. 10] versus the present study's estimate of about -332,000 cy/yr. The difference is attributed to the present study's computation across a larger grid and at much higher spatial resolution than the Corps' study. Unlike the present study, the Corps does not quantify the rate of ebb shoal volume

losses on the west side versus the east side of the inlet, but notes that deepening on the west side is greater than on the east side [p. 41, par. 7.38].

Both the Corps' Section 111 and present study describe the effective physical behavior of the inlet's navigation improvements as a trap to littoral sediment. From the Corps' report [p. 14, Par. 4.14]:

> The deep ocean entrance channel through the Beaufort Inlet ebb tide delta collects any ebb tide shoal material set in motion by wave and tide action under normal and storm conditions. The channel also intercepts littoral materials transported to the inlet from the adjacent beaches. Once the material deposits in the entrance channel, it cannot escape the channel by natural processes. Rather, it is removed and deposited offshore during each maintenance operation. The volume of littoral material removed annually from the Beaufort Inlet entrance channel and inner portion of the Morehead City Harbor exceeds the annual rate of longshore transport moving into the inlet. With the amount of material being removed from the inlet system by dredging exceeding the rate of supply, the expected result would be the deflation or erosion of the ebb tide delta.

The Corps' generalized sediment budget assessment concludes that "the net loss of sediment from the littoral systems of Bogue Banks and Shackleford Banks has been 26,195,200 cubic yards during the 64-year period from 1936 to 2000. This is equivalent to an annual rate of littoral sediment removal from the system of 409,300 cubic yards/year [beyond the inlet ebb shoal complex]." [p. 17, par. 5.7]. Using the same approach, this study computes a similar, though slightly smaller value of 25,120,400 cubic yards, equating to 353,800 cubic yards per year. (See Table 2, page 66 of this study.) The difference in values is mainly due to the present study's estimate of larger ebb shoal volume losses than the Corps' study.

The Summary of Findings of the Corps' Section 111 report [page 49, par. 8.2] states that

> Over the 64-year period from 1936 to 2000, during which time the channels and basins associated with the Morehead City Harbor project were incrementally deepened and widened, the operation and maintenance of the project resulted in the net removal of an average of 409,300 cubic yards/year of littoral material from the littoral system adjacent to Beaufort Inlet. This rate of littoral sediment removal is 216,100 cubyic yards/year greater than the pre-project rate of littoral sediment removal attributable to the inlet…. Recently, the annual net rate of sediment removal has been ameliorated to some extent by the disposal of dredged material from the Morehead City Harbor project on the shorelines of Atlantic Beach and Fort Macon. The present net rate of littoral sediment removal attributable to Beaufort Inlet and the Morehead City Harbor project is 350,700 cubic yards/year or 157,500 cubic yards/year greater than the pre-project rate.

Subsequently, the Conclusions of the Corps' Section 111 report [page 53, par. 9.1, 9.3] state that

> 9.1 The construction, operation, and maintenance of the Morehead City Harbor project has caused significant physical changes in the configuration of the Beaufort Inlet ebb tide delta and has altered the ability of the inlet to naturally bypass sediment from one side of the inlet to the other. The harbor project is also responsible for the net removal of large quantities of littoral sediment from the area. However, the removal of this sediment has not negatively impacted the shorelines on either side of Beaufort Inlet…. The major impacts determined from this study have been the gradual deepening or deflation of the Beaufort Inlet ebb tide delta and the accompanying deepening of the near shore beach profiles 6 to 7 miles west of the inlet and at least 5 to 6 miles east of the inlet. Without any change in the dredged material disposal practices for the harbor project, these impacts will likely continue….
>
> 9.3 While the Morehead City Harbor project has significantly altered normal inlet and shore processes of the area, there is no direct evidence that the harbor project has had a negative impact on the Pine Knoll Shores shoreline or any of the shorelines in the vicinity of the harbor project. Therefore, mitigation for shoreline damages under the authority provided by Section 111 of Public Law 90-483, as amended, is not warranted. Apart from any mitigative element, the sand management practices for the harbor project could be improved to lessen the possible future impacts on the shorelines that could result from the continued deepening of the near shore ocean bottom, which is associated with the deflation of Beaufort Inlet ebb tide delta.

Notwithstanding the intent of brevity, the Executive Summary of the Corps' Section 111 report does not mention the study's findings of inlet impacts to the littoral system nor improved sand management practices to prevent future impacts. Instead, it states [pp. 2-3, Executive Summary]:

> The Section 111 authority is limited to mitigating damages to shorelines that can be directly attributed to Federal navigation projects. Accordingly, the focus of this study was on the evaluation of changes in shoreline behavior on both Bogue Banks and Shackleford Banks that occurred following the implementation of major harbor improvements at Morehead City Harbor….
>
> The study found that the shoreline change rates for the Town of Pine Knoll Shores were basically the same for the period with the navigation project as for the period prior to the navigation project…. Not only is there no direct evidence that the harbor project has had a negative impact on the Pine Knoll Shores shoreline, there is no evidence that the harbor project has had an impact on any of the other shorelines in the vicinity of the harbor project. Therefore, mitigation for shoreline damages under the continuing authority provided by Section 111 of Public Law 90-483, as amended, is not warranted.

The Corps' report thus implies that Section 111 applies (1) only to the identification of *shoreline* changes, and (2) historic damages. In contrast, the Section 111 legislation says nothing of limiting analysis to *shoreline changes*; and, the legislation

clearly states that it addresses *prevention* or mitigation of damages. Thus, to the extent that accepted coastal engineering principles demonstrate that the practices of the navigation project are damaging -- or will damage -- the adjacent shores, then the principles of Section 111 apply.[28] Specifically, the actual language of Section 111 of P.L. 90-483, states:

> The Secretary of the Army, acting through the Chief of Engineers, is authorized to investigate, study, and construct projects for the prevention or mitigation of shore damages attributable to navigational works. The cost of installing, operating, and maintaining such projects shall be borne entirely by the United States. No such project shall be constructed without specific authorization by Congress if the estimated first cost exceeds $1,000,000 [$2,000,000 per amendment of P.L. 90-662, Paragraph f]….

The position concluded by the Corps' Section 111 study is based upon a limited (or possibly incorrect) interpretation of both the pertinent legislation and technical data. The Corps' Section 111 study ultimately relies upon shoreline-change data which are of limited accuracy and arbitrarily biased by artificial, temporal fluctuations associated with beach fill. It concurrently dismisses the remainder of its own study's comprehensive findings of significant (volumetric) littoral impacts from the navigation project and associated nearshore beach profile losses. Principal use of shoreline change data would comprise an acceptable analysis if accurate data were available from which meaningful interpretations could be made. But such shoreline data are not available along the shores adjacent to Beaufort Inlet. Accordingly, the conclusions of the Corps' Section 111 study do not conform to prevailing, accepted standards of coastal engineering analysis and practice. As such, the Corps' ultimate conclusion that there is no outstanding littoral impact of the Morehead City Harbor federal navigation project upon the adjacent shores is incorrect and is *not* supported by the bulk of its own technical analyses.

[28] Dean, 2001

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