REGIONAL SAND TRANSPORT STUDY:
MOREHEAD CITY HARBOR FEDERAL NAVIGATION PROJECT

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Abstract

Since principal improvements commenced in 1936, construction and maintenance through 2004 of the Morehead City Harbor Federal Navigation Project, at Beaufort Inlet, North Carolina, is estimated to have removed 48.7 million cubic yards (Mcy) of material from the littoral system. About 48% and 8% of this impact is manifest as depletion of the inlet's ebb and flood tidal shoals, respectively. The remaining 21.1 Mcy of impact represents an unmitigated net loss to the adjacent beaches beyond the inlet's shoal complex; equating to 300,000 cy/yr on long-term historical average. About 79% of this impact is attributed to Bogue Banks, amounting to 16.7 Mcy – in addition to the depletion of sand within the immediate vicinity of the inlet. These values include the effects of prior beach disposal totaling 10.8 Mcy of beach-compatible dredged material from the navigation project.

Existing dredge disposal practices do *not* offset either the historical *or current* littoral impact of the inlet. The effective rate of beach disposal equates to about 372,000 cy/yr, or about *one-third* the rate of current maintenance dredging of littoral material from the navigation project (1,120,300 cy/yr). The result is a net shortfall of at least 748,300 cy/yr between the rates of beach disposal and maintenance dredging of littoral material. The current practice of nearshore disposal of dredged material provides no net benefit to the littoral system. At its historic rate of erosion, the inlet's existing ebb tidal shoal will be depleted of sand within the next 35 to 110 years. The chronic deflation of the inlet's shoal complex – which controls the littoral balance of sand movement along the adjacent beaches – coupled with the direct loss of littoral material from the adjacent beaches, has resulted in historic and ongoing damage to the adjacent shores that will continue (or accelerate) in the future unless corrective actions are taken.

To mitigate both the historic and future littoral impacts of the navigation project upon the inlet and beach system, modifications to dredging and disposal practices are required. These modifications should be implemented by a Sand Management Plan and may be best accomplished through (1) a Memorandum of Agreement among the project's affected parties, and (2) enhanced statutory legislation to foster resource recovery and protection through prudent and enforced dredged material management practices.

An Executive Summary of the findings is presented in the following seven pages, with an expanded summary in the remainder of this report (108 pp). Supporting documentation of the study's findings is presented in Technical Appendices, under separate cover.

Executive Summary

Dredging and Disposal Practices. The Morehead City Harbor Federal Navigation Project includes construction and maintenance of a channel and basins for navigation through Beaufort Inlet, North Carolina. Project improvements began in 1911-1935 with periodic dredging of an outer bar channel to -20 ft depth at a non-fixed alignment. Improvements during this period likely resulted in little net, long-term impact to the inlet's littoral system or adjacent beaches. Significant project improvements began in 1936 when the channel was increased to -30 ft depth and fixed in location. The current authorized dimensions, since 1994, are -47 ft depth and 450-ft width along the outer channel, with interior channels and harbor maintained to -45 ft depth.

Since 1936 through 2004, the project dredged a total of 69.6 million cubic yards (Mcy) of sediment from Beaufort Inlet. Of this, 50.4 Mcy was maintenance dredging estimated to be of littoral material (sand of beach quality or origin), equating to about 740,600 cubic yards per year, on average, from 1936-2004.

The present rate of maintenance dredging is about 1,170,000 cy/yr, of which about 1,120,300 cy/yr is estimated to be of littoral origin. This is comprised of 956,100 cy/yr from the outer channel and 164,200 cy/yr from the inner channel. It appears that all of the dredged maintenance material from the outer channel and the seaward end of the inner channel is of littoral origin and beach quality. The quality of dredged material along the interior channels varies. The pattern of shoaling along the navigation channel, compared to the inlet's bathymetry, demonstrates the probable sediment transport paths as sand moves from the beaches into the channel -- along the shoreline and the relic bar of the ebb tidal shoal.

Existing dredge disposal practices do not offset the historical *or current* littoral impact of the inlet. From 1978 to 2004, 13.8 Mcy of dredged material from the navigation project has been placed onto the beaches of Bogue Banks. Of this amount, 10.8 Mcy is estimated to have been beach-compatible material. This equates to a current rate of about 372,000 cy/yr, or about 33.2% of the rate of maintenance dredging of littoral material from the inlet (1,120,300 cy/yr) – resulting in a net shortfall of at least 748,300 cy/yr between the rates of effective beach disposal and littoral maintenance dredging.

Of the effective beach disposal volume, about 142,000 cy/yr has been placed within 2.4 miles west of the inlet, where most of the material is transported directly back to the inlet. The remaining 205,200 cy/yr of beach-compatible disposal has been placed between about 2.4 and 5.5 miles west of inlet, in addition to about 0.7 Mcy placed to central Bogue Banks by Section 933 beach disposal from the outer channel in 2004. Excepting the latter, all of the beach disposal material was dredged from the inner channel/harbor, and placed to the beach directly or through the upland disposal area of Brandt Island.

The non-compatible fraction of dredged material placed to the beach consists of clayballs, large shell, fine sands and silt – much of which remained along the beach at least 8 months after placement. From 1984 to 2003, an additional 4.1 Mcy of dredged material has been placed to central Bogue Banks, separate from the federal navigation project.

Since the practice of nearshore disposal began in 1997, slightly less than half of the eligible dredged material from the outer channel (~47%) has been placed to the nearshore disposal area. The remainder was placed in the offshore disposal area (excepting 0.7 Mcy placed to Bogue Banks by Section 933 disposal in 2004). The current practice of nearshore disposal, in ambient seabed depths of -26 to -40 feet within 9,500 ft west of the inlet, provides *no littoral benefit* to the beaches because the material is placed in water depths that are too deep and too near the inlet. Dredged material placed to both the nearshore and offshore disposal areas is removed from the littoral system and does *not* mitigate the effects of dredging at the navigation project.

Morphologic Changes. The natural, *pre-project* inlet was characterized by a generally symmetric, broad, ebb tidal shoal with an ocean bar of about -10 to -15 ft depth. Sand was exchanged between the beaches and the inlet and was bypassed across the bar. From 1900-1933, the net rate of natural sand bypassing was about 94,000 cy/yr from east to west. During this period, the inlet's ebb shoal volume increased by about 208,000 cy/yr.

In contrast, the existing, *post-project* inlet condition is characterized by a non-symmetrical ebb tidal shoal that has simultaneously deepened, decreased in volume, elongated, and been displaced toward the sea. The shoal and ocean bar are wholly severed by the fixed navigation channel, maintained at about -45 ft controlling depth. The channel precludes natural sand bypassing across the inlet and intercepts the sand that would otherwise be exchanged between the beaches and the inlet shoals.

Since 1952, about 16 years after major project improvements began, the inlet's submerged ebb shoal volume has eroded by about 680,500 cy/yr. Losses have been 3.6 to 8.2 times greater on the west (Bogue Banks) side of the bar channel than on the east (Shackleford Banks) side, excluding and including changes above the waterline, respectively.

During the overall post-project period, from 1936 through 2004, net volume losses to the submerged ebb shoal total about 26.6 Mcy; or 375,000 cy/yr on annual average. During this period, 81% of the total losses below the waterline have been on the west side of the bar channel. The average rate of ebb shoal deflation over the last fifty years – compared to the existing shoal volume -- suggests that the active ebb shoal platform will be depleted of sand within the next 35 to 110 years.

Prior to the principal navigation improvements, from 1876-1933, Bogue Banks was advancing eastward *toward* the inlet, and Shackleford Banks was retreating eastward *away* from the inlet. After 1936, the shoreline processes reversed. Bogue Banks retreated rapidly back toward its 1876 location, and efforts were made to stabilize its eastern shoreline by small groins and structures built to protect Fort Macon (c. 1950's). Shackleford Banks advanced westward, approaching its current location by 1974. Over the next 30 years, from 1974 to 2004, the Bogue Banks shoreline recovered slightly as a result of beach fill placement from inner-harbor dredging, and the sand spit at Fort Macon advanced along and into the western bank of the navigation channel inside the inlet throat. Shackleford Banks consolidated its westerly growth and advanced into the eastern bank of the channel at the inlet throat.

Wave Refraction and Littoral Drift. For both pre-project and existing conditions, wave refraction analysis indicates an overall net *westerly-directed* littoral drift (east to west transport potential) along both Shackleford Banks and Bogue Banks. There is a localized *reversal* in net transport along the eastern 2.4 miles of Bogue Banks (east of the Triple S / Oceanana Piers in eastern Atlantic Beach), where the net transport potential is directed *toward* the inlet (west to east) in the lee of the inlet's ebb shoal.

Along most of Bogue Banks, the potential volumes of sand moving both east and west are much greater than the *net* amount of sand moving *toward the west*. In an equilibrium condition, this would result in only minor net transport and shoreline changes. However, in a perturbed condition – where there is a sediment sink at one end of the system (such as caused by dredging at Beaufort Inlet) -- the system can become unbalanced. Easterly-transported sand that is "trapped" by the inlet's dredging and eroding shoals is no longer available for westerly-transport. The result is net erosion to the beach system.

The system is analogous to marbles rolling back and forth in a pan. In a balanced system (with no holes), the marbles move back and forth with no net change. In an unbalanced system (with a hole, or "sink", at one end), marbles can fall out of the pan at one end and are no longer available to roll back to the other end. The impact of the pan's hole is upon the *total* ("gross") amount of marbles moving in the system; it is not limited to the *net* movement of the marbles. In this way, an improved inlet can act as a "sink" to the *gross* transport rate directed toward the inlet – *not* just the *net* transport rate. In existing conditions, the total gross transport potential directed toward Beaufort Inlet is on the order of 600,000 cy/yr from the west (Bogue Banks) and 500,000 cy/yr from the east (Shackleford Banks).

The effects of the navigation project upon the waves and sediment transport patterns, from pre-project (*c.*1900) to existing (*c.*2004) conditions, were mostly limited to within about 4 miles west of the inlet (to central Atlantic Beach), and to within about 3 miles east of the inlet. Pre- to post-project differences included a minor eastward shift of the

transport "reversal" zone along eastern Atlantic Beach. Notably, the transport potential directed from Bogue Banks into the inlet significantly *increased* (on the order of +300,000 cy/yr), while the transport potential from Shackleford Banks into the inlet *decreased* (on the order of -200,000 cy/yr). The breaking wave energy increased along both sides of the inlet, but the increases along Bogue Banks were about 3.2 times greater than along Shackleford Banks.

The deepening of the ebb tidal shoal increased the wave energy along the west bank of the channel (at Ft. Macon), along the navigation channel, and at the inlet throat and entrance to the interior sound. Further additional wave height increases of 10% and 20% are predicted for 15- and 30-year future projections of ebb shoal deflation, respectively. Increasing wave height at the channel and inlet is adverse to navigation, and potentially increases wave energy within the interior waters, including portions of the Rachel Carson National Estuarine Research Reserve.

Shoreline and Beach Profile Changes. Comprehensive shoreline and beach survey data – from which one might deduce accurate, large-scale, quantitative conclusions of shoreline and beach volume change – do not exist at this location. Early data (c. 1850's – 1950's) are limited to nautical charts and shoreline tracings of aerial photographs, both of limited comparative accuracy. Recent survey data are limited in alongshore resolution and length of shoreline coverage, and include anomalous effects of beach fill. The paucity of data, inherent error, and atypical influence of beach fill changes, do not allow discrimination of meaningful trends from the available shoreline or dune-line location data.

Long-term beach profile data on Bogue Banks are limited to Corps surveys from 1958 to 2000 along the eastern 5 to 6 miles of the island (central Atlantic Beach to Fort Macon). Comparative surveys that span *all* of Bogue Banks are limited to 1999 through 2004, of which only the last two years include profiles that extend sufficiently far offshore to determine total volume change and offshore seabed change. (Survey data from 2005 are not included in this study.) Beach profile survey data on Shackleford Banks are limited to two, island-wide Corps surveys in 1991 and 2000.

Where available, measured shoreline changes are a poor indicator of volume changes (and vice-versa). This precludes use of standard coastal engineering tools that relate the two changes. Losses in beach profile volume measured above the -30 ft depth contour were typically between 2.5 and 4 times greater than changes measured above the -15 ft depth contour. Gains in beach profile volume associated with beach fill appear mostly above -15 ft, with some equilibration extending beyond -20 ft depth. Future beach profile surveys and analysis should extend to at least the -25 or -30 ft NGVD contours.

After removing (subtracting) the volume of beach fill placement, the available survey data suggest beach volume losses above -20 to -30 ft depth on the order of

- -520,000 cy/yr erosion along the entire zone of easterly-transport reversal comprising eastern Atlantic Beach and Fort Macon State Park (within 2.4 miles west of the inlet), of which -360,000 cy is along Fort Macon State Park;
- -670,000 cy/yr erosion along the western and central remainder of Atlantic Beach (2.4 to 6.4 miles west of the inlet)
- -200,000 to -400,000 cy/yr erosion along Pine Knoll Shores (6.4 to 11 miles west of the inlet)
- Variable erosion, stability, and/or modest gains along Salter Path/Indian Beach and Emerald Isle (11 to 24 miles west of the inlet).

These values, particularly along and west of Pine Knoll Shores, are based upon *limited* data. Estimated volume loss along Shackleford Banks is on the order of 900,000 cy/yr, based upon only the single available set of Corps surveys.

Deepening ("deflation") of the offshore profile is evident in all of the survey data, and is not limited to the shore along the ebb tidal shoal complex. As far as 5+ miles west of the inlet, along the -20 to -30 ft depth contours, the seabed elevation decreased by about 3 ft between 1958 and 2000. The decreases were greater nearer the inlet. Surveys from 2002-04 imply island-wide profile deepening, but are not conclusive. By theory, a 3-ft deepening of the offshore profile will ultimately translate to a 305-ft horizontal recession of the mean high water shoreline. Analogous cases of large scale, chronic shoreline recession – subsequent to offshore profile deflation – are documented in North Carolina. A well known case is that of Bald Head Island, where a period of shoreline growth and stability was followed by pervasive erosion after the adjacent inlet's ebb tidal shoal was severed by the navigation entrance of Wilmington Harbor.

Historic Littoral Impacts. Since major improvements commenced, and after accounting for beach disposal, the net littoral volume removed from the inlet system by the Morehead City Harbor federal navigation project, computed over 1933-2004, is 48.7 Mcy, or, about 685,800 cy/yr on annual average. Of this total impact, about 23.6 Mcy (48%) and 3.8 Mcy (8%) has occurred as measured volume losses ("deflation") of the ebb and flood tidal shoals, respectively. Of these two values, losses to the flood shoal are less certain. The remaining 21.2 Mcy (44%) of the historical impact represents a net loss to the littoral system beyond the limits of the inlet ebb shoal complex. On annual historic average, this equates to 300,000 cy/yr of outstanding impact to the inlet-adjacent barrier islands beyond the inlet complex, i.e., beyond 2.4 miles west and 2.1 miles east of the inlet channel.

Based upon the post-project changes in wave energy, littoral transport potential, and ebb shoal losses on the west side versus east side of the channel, it is concluded that between

76% and 81% of the outstanding 300,000 cy/yr littoral impact is associated with the west shoreline of the inlet (Bogue Banks). This equates to between 228,000 cy/yr and 243,000 cy/yr – and totals to between 16.2 and 17.3 Mcy of historic littoral impact -- *beyond* the losses that occurred within the inlet complex, 2.4 miles west of the inlet. These volumes account for the placement of beach disposal. The remainder of the outstanding littoral impact is attributed to Shackleford Banks, beyond 2.1 miles east of the inlet, amounting to between 4.1 and 5.1 Mcy; or, 57,000 and 72,000 cy/yr on annual average.

Existing Littoral Impacts. In *existing* conditions (c. 1994-2004), the approximate net impact of the navigation project – for prevailing dredge practices, and after accounting for the current effective rate of beach disposal from the project -- is comprised of :

- 426,700 cy/yr of depletion of the inlet's existing volumetric reserves, plus
- 327,100 cy/yr of littoral influx from the adjacent beaches that would otherwise have accrued to the inlet/beach shoal system and/or have been bypassed or backpassed across the inlet.

The second of these values is computed beyond the limits of the inlet complex; i.e., outside of 2.4 miles west and 2.1 miles east of the inlet. Beyond these limits, the alongshore length of influence of the littoral impacts, for either historic or existing conditions, cannot be determined from available data.

Corps' Section 111 Study. The technical findings of the Corps' Section 111 Study of the effects of the Morehead City Harbor federal navigation project upon the adjacent shores (USACE, 2001) are in fundamental agreement with this study's findings. The Corps' estimates of historic volumetric impact to the littoral system are actually about 35% *greater* than those computed in the present study. The Corps' study likewise finds significant nearshore profile deepening along both inlet-adjacent shores that is related to the deflation of the ebb tidal shoal. Nonetheless, the Corps' study *dismisses* the bulk of its technical findings and ultimately concludes – based *singularly* upon its estimates of pre-project versus post-project *shoreline change* rates -- that there is no evidence that the harbor project has had an impact on any of shorelines in the vicinity of the harbor project. This finding is not supported by the bulk of the Corps' technical analysis.

Recommended Actions. This study concludes that there is both an historic and ongoing adverse littoral impact of the Morehead City Harbor federal navigation project upon the shores adjacent to the project. To mitigate both historic and future anticipated impacts, modifications to dredging and disposal practices of the navigation project are warranted and recommended. These modifications may be implemented by a Sand Management Plan (a/k/a Dredged Material Management Plan), and might be best accomplished through a Memorandum of Agreement (MOA) between the navigation project's affected parties. The objectives of the Plan are to stipulate practices for resource recovery and protection: viz., (1) all beach-quality dredged material is restored to the active littoral

system, (2) the net equivalent of the natural, pre-project sand bypassing rate across the inlet is restored, (3) the quality of dredged material placed to the beaches is ensured, (4) existing sand resources/disposal areas are protected from contamination by disposal of unsuitable material, and (5) the influx of littoral material to the navigation project, requiring dredging, is reduced. Enhanced statutory legislation for the State of North Carolina is required to foster dedicated implementation of proper sand management at Morehead City Harbor and at other coastal inlets in the state.

Priority importance should be given to resource recovery of future, annually dredged material and for protection of existing sand resources – relative to mitigation of historical project impacts to the adjacent shores or inlet shoals. Nonetheless, implementation of a federal shore protection project for Bogue Banks is warranted and recommended, and would mutually benefit beach disposal of dredged material from the navigation project. Future beach restoration of Bogue Banks should derive from material dredged from the navigation project – either annually in the future or from historic disposal areas.

Requisite near-term engineering work to foster sand management at this inlet includes (1) development, permitting, and protection of existing sand resource (disposal) areas for use as future beach-fill borrow sources; (2) identification of means to segregate beach-quality material from incompatible material dredged from the Inner Harbor, and (3) preliminary engineering study of modifications to the groin field at Fort Macon State Park for the purposes of decreasing sand transport into the inlet and improving beach stability. The first of these tasks would facilitate rapid response to emergency post-storm beach renourishment requirements. A detailed description of recommendations regarding the Sand Management Plan, shore protection project, State legislative initiatives, and requisite near-term engineering studies is included as Chapter 11 of the following Summary Report.