CEERD-HV-B 8 June 2008

Memorandum for Record

Subject: Beach Erosion along Plum Island, MA, and Recommended Newburyport Harbor Navigation Project Actions, DOTS Study

1. This Memorandum for Record documents a short-term study of possible factors contributing to beach erosion on Plum Island by the Newburyport Harbor Federal Navigation Project. The study was requested by Mr. Edward G. O'Donnell, U.S. Army Engineer District, New England, and was performed as an activity of the Dredging Operations Technical Support (DOTS) Program administered at the U.S. Army Engineer Research and Development Center. The DOTS Program facilitates access to environmental and engineering technical expertise in support of U.S. Army Corps of Engineers operations and maintenance dredging mission and navigation mission, and it is intended to assist in solving immediate problems.

2. Conclusions of this study are that beach erosion along the northern and central ends of Plum Island can be reduced by:

(a) Sand-tightening and raising the landward end of the south jetty at Newburyport Harbor, and

(b) Distributing material dredged as part of navigation channel maintenance in a more linear manner alongshore in the Plum Island Nearshore Disposal Site to avoid wave focusing that can lead to local shoreline recession.

3. It is anticipated that a regional sediment management study will be conducted for the Plum Island area in the near future, and this report was written with selected background information included to facilitate such a study. As part of a study for a long-term solution for erosion along Plum Island, it is recommended that mining of beach-quality sand from the sub-tidal flood shoal at the mouth of the Merrimack River be investigated.

4. This study was performed by Dr. Nicholas C. Kraus, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Mr. O'Donnell led a site visit on 30 April 2008 and provided much information. Dr. Duncan M. FitzGerald, Professor in the Department of Earth Sciences, Boston University, participated in the site visit and contributed his considerable knowledge of the study area.

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Beach Erosion along Plum Island, MA, and Recommended Newburyport Harbor Navigation Project Actions, DOTS Study

1. Introduction

This study was performed at the request of the U.S. Army Engineer District, New England (NAE), under the Dredging Operations Technical Support (DOTS) Program administered by the U.S. Army Engineer Research and Development Center. DOTS Program responses are intended to provide information and identify solutions in a short time frame, typically representing a week or less of effort. The DOTS request concerns examination of a possible connection between the Federal Navigation Project at Newburyport Harbor, MA, and erosion of the adjacent beach to the south, Plum Island, with the objective of improving project performance. Literature consulted is listed at the end of this document.

Newburyport Harbor is a small coastal city in Essex County, MA, and is located on the Merrimack River about 38 miles northeast of Boston. Salisbury Beach lies to the north, and Plum Island lies to the south with sections both in Newburyport and the Town of Newbury. Both beaches have experienced erosion, and the nearshore areas of both have received sand dredged during entrance channel maintenance. The Merrimack River is the major source of sediment for the surrounding beaches. Plum Island is separated from the mainland by an estuarine channel of the Merrimack River and by Plum Island Sound. Plum Island is part of the Merrimack River barrier island chain north of Cape Ann, MA. Predominant beach sediment is coarse to very coarse (approximately 0.5 – 1 mm), lightly tan-colored sand, and the beach slopes steeply from the backshore bluffs to the ocean. Coarse-grained beaches are steeper than their finer grained counterparts. The mean range of tide in the area is about 8 ft, so this beach responds significantly to changes in daily water level and waves, probably contributing to its steepness.

Improvements to the Atlantic Ocean entrance of Newburyport Harbor were first authorized by Congress in 1828 with a channel dredged through the bar that year. Shortly afterward, two timber and stone dikes were built across the flats and back channels south of the river to further constrain flow to the main channel and inlet. The first stonework constructed in the inlet was a training dike built out from the Salisbury shore in 1835 to further constrict the river mouth. Construction of the two stone jetties at the river mouth was accomplished in 1881 to 1914 (north jetty) and 1883 to 1906 (south jetty). These jetties were intended to scour a channel to -17 ft Mean Low Water (MLW). The south jetty included a core of wood sheet piling in its shoreward 500 ft to arrest sand migration. Additional timber sand-catch measures were constructed landward of the south jetty in the 1880s. In 1883, a third timber and stone dike was constructed across the mouth of Plum Island Basin in response to concerns that the river was seeking another outlet to the sea. Both jetties were reconstructed in 1968-1970, with additional armor stone added. At that time, the south jetty was extended landward and a stone revetment constructed along the south shore of the inlet from the jetty back to the U.S. Coast Guard Station.

The original rubble stone jetty sections were of converging type, and subsequent modification added two parallel seaward segments (1887 to 1914). The present Federal Navigation Project consists of a 12-ft deep entrance channel at the Merrimack River mouth (with advance maintenance to 15 ft MLW) connecting to a 9-ft deep inner channel that extends up the river (Figure 1). Authorized jetty crest elevation is +12 ft MLW. Since 1987, sand dredged from the navigation channel has been placed by hopper dredge in the nearshore disposal areas off Salisbury Beach and Plum Island, as opposed to disposal further offshore. In the past, dredging was performed every 3-5 years. Last dredging of the entrance channel was in July-August 1999, when about 125,000 cubic yards (cy) was placed in the Nearshore Disposal Site off Plum Island Beach. Depths at the placement site are in the approximate range of 20-30 ft.

The National Oceanic and Atmospheric Administration long-term tide gauge in Boston (No. 8443970) documents sea level rise of 0.87 ft/century for the period 1921-1989. Therefore, the jetties at Newburyport Harbor are about 1 ft lower than mean sea level now than when originally constructed. The trend of decrease in crest elevation of the jetties relative to mean sea level is expected to continue.

A well-defined concentric ebb-tidal shoal rings the inlet entrance, and the flood shoal is large and complex, including Plum Island Point and the Joppa Flats. The ebb shoal is oriented to the south, indicating the dominant transport is to the south, which occurs during winter storms. The entrance navigation channel approaches and runs parallel to the western end of the north jetty, in part pressed there by the encroaching flood shoal and in part in conformance with the finding that inlet entrance channels tend to migrate toward the longer of two jetties.

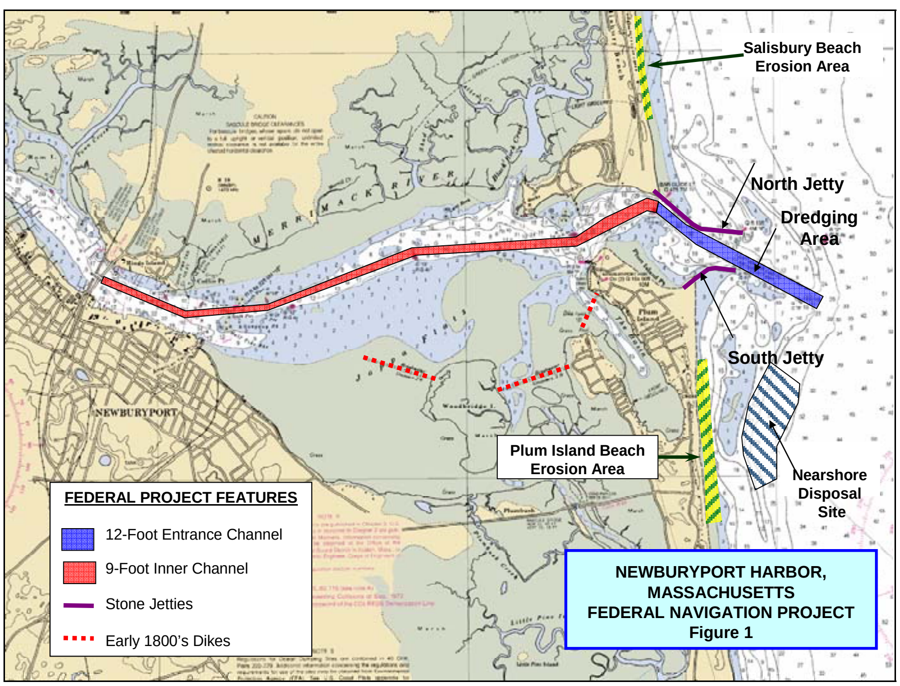

Fig. 1. Newburyport Harbor Federal Navigation Project entrance (NAE Fact Sheet).

Fig. 2. (Left) Landward base of south jetty; (Right) and view of beach and jetties from Plum Island bluff (photographs taken April 2008, courtesy Edward O'Donnell, NAE).

Figure 2 contains recent ground photographs of the base of the south jetty and the beach adjacent to it. The photograph on the left indicates that sand is being transported off the northern end of Plum Island and onto the flood shoal. Northward-directed longshore sand transport can occur during times of wave incidence from the south and also waves from the north because of diffraction at the jetties and refraction over the concentric ebb-tidal shoal. Sand penetration over and through the landward end of the south jetty is promoted by increased water elevation around high tide.

2. Analysis

This study mainly relied on LIDAR (Light Detection and Ranging) data available from the U.S. Army Corps of Engineers' Joint Airborne Lidar Bathymetry Technical Center of Expertise (see http://shoals.sam.usace.army.mil/). This system includes the capability for LIDAR laser beam penetration of shallow water, if the water is not too turbid, to obtain a synoptic survey of the underwater and land portions of a beach. Two surveys were examined, those of June 1998 and of April-August 2007, Figures 3 and 4, respectively.

The 1998 survey (Figure 3) delineates the ebb-tidal shoal, which consists of an inner shoal and outer shoal circling the entrance, both skewed to the south. Such multiple shoals are associated with different incident wave heights, larger waves responsible for outer shoal development, and smaller waves for the inner shoal. A submerged sand deposit is impounded on Salisbury Beach along the north (up-drift) jetty, and this nearby material may contribute to formation of a jetty tip shoal that is commonly observed at the seaward ends of up-drift jetties at inlets with a dominant direction of sand transport. Jetty tip shoals encroach on navigation channels after large storms that cause rapid collective movement of bed material, requiring dredging. Plum Island Point flood shoal contains a submerged ridge that is oriented toward the navigation channel and likely also promotes sediment transport into the navigation channel.

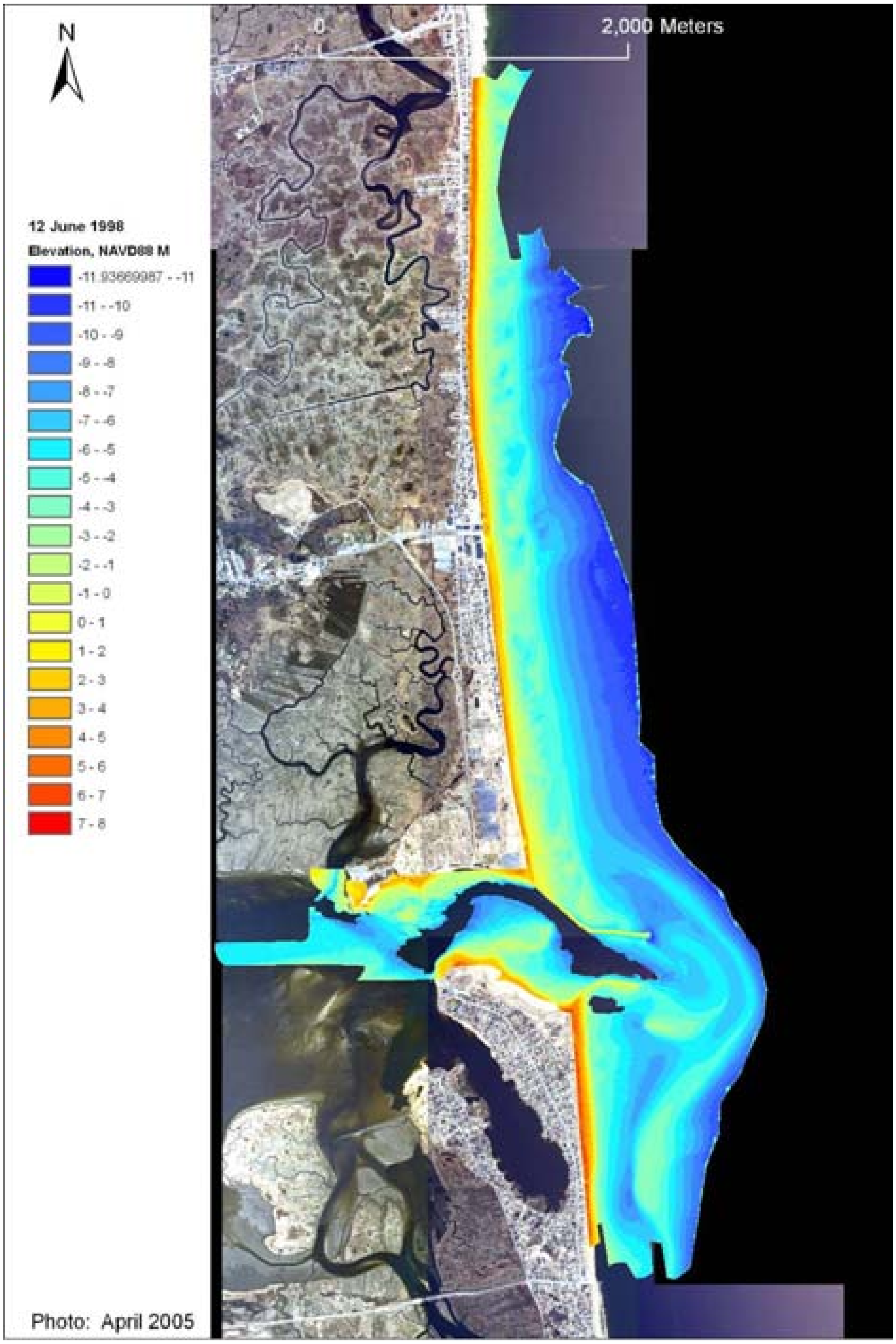

Figure 3. LIDAR survey, 1998.

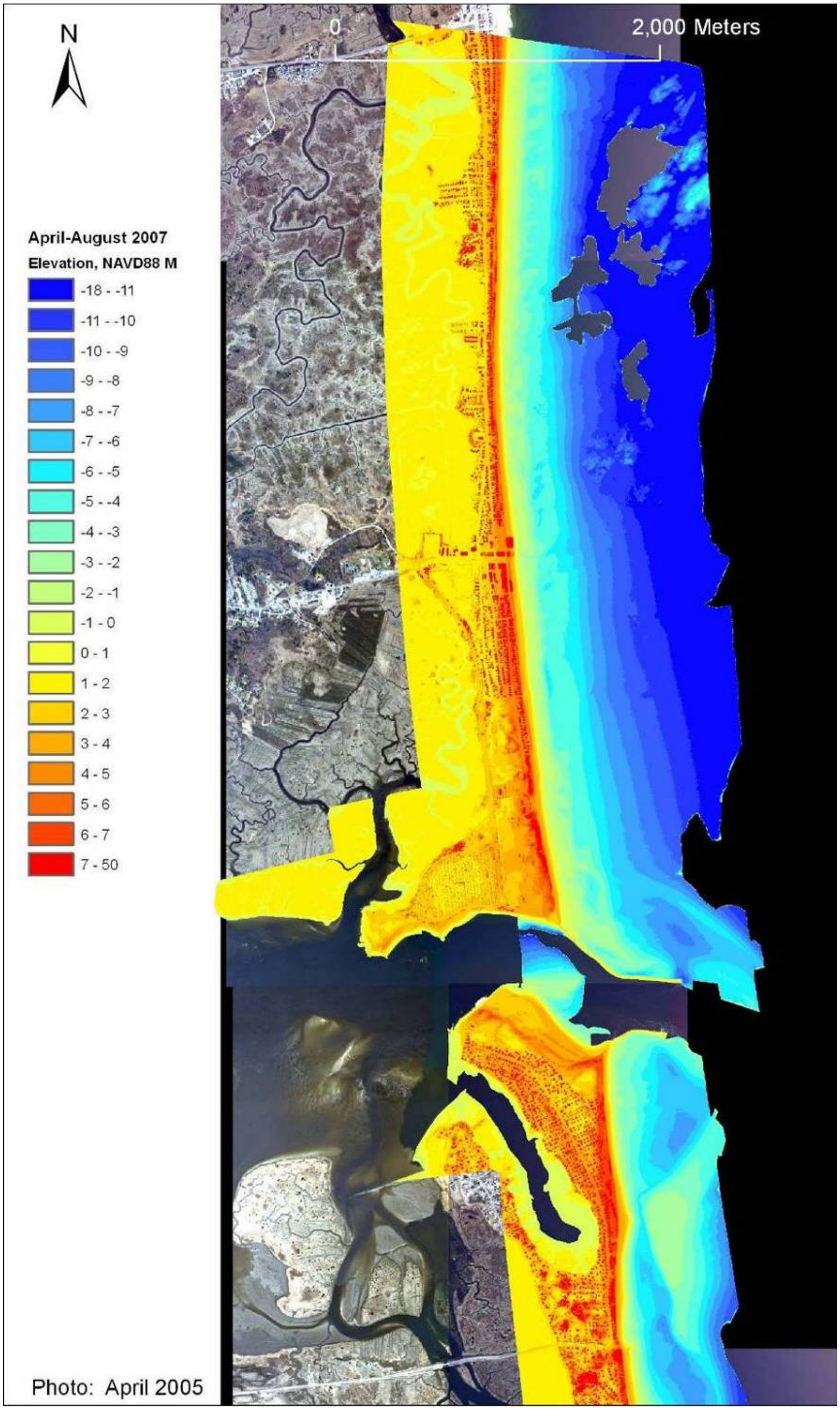

Figure 4. LIDAR survey, 2007.

Comparing Figures 1 and 3, most entrance channel dredging occurs at and around the inner ebb shoal and, possibly, at the jetty tip shoal. Placement of dredged sand in the Plum Island Nearshore Disposal Site is also evident in the 1998 survey. From 1987 to 1998, NAE placed dredged material in this site three times – in 1987 (156,365 cy), in 1991 (135,290 cy), and in 1993 (125,040 cy).

The 2007 survey (Figure 4) evidently encountered turbid water and could not reveal as much nearshore bathymetry as in 1998. The Plum Island Nearshore Disposal Site increased in apparent volume compared to the 1998 survey because of dredged-material placement in 1999 (145,017 cy). Placement of sand in a localized shallow area causes wave to focus on the beach behind it. Sheltering and wave bending is evidenced by seaward growth of the beach directly behind the Nearshore Disposal Site and perhaps erosion to either side, in particular, erosion north of the groin near the Newbury Turnpike entrance to Plum Island. However, it is possible that the 2007 survey was done after typical longshore transport to the north during the summer, causing a shoreline offset at the groin.

It is inferred from Figure 4 that most material placement in the Plum Island Nearshore Disposal site in 1999 occurred at its northern end, closest to the navigation channel. Minimum haul distance reduces fuel cost and allows more disposal actions per day. However, mounding of material must be avoided.

3. Discussion and Recommendations

Plum Island is located on the down-drift side of the Merrimack River inlet, and the river is a major source of beach sediment. The inlet was stabilized beginning in the 1880s by converging dual jetties. The entrance navigation channel and the navigation channel through the Merrimack River estuary are located on the north side of the inlet. Large flood shoals constrict the channel at a few locations and force it to the north side, although jetty configuration and dimensions may promote a northward channel location as well.

A relatively narrow concentric ebb-tidal shoal formed in response to jetty construction. This more compact shoal replaced a broader ebb shoal (as shown on 19th century NAE surveys) that provided more efficient, shallower pathways for river sand to be transported to the adjacent beaches and for sand to naturally bypass the inlet from north to south.

Based on observations and analysis as described above, the following recommendations are made as potential actions related to the Newburyport Harbor Federal Navigation Project to reduce beach erosion along Plum Island.

a. Sand-tighten and raise the landward end of the south jetty along the beach.

   During times of higher water elevation and larger waves, sand on Plum Island can be transported over and through the present jetty by a north-directed longshore current. Sand-tightening can be accomplished by raising jetty elevation and by grouting or driving of a sheet pile through the center of the landward end of the structure. It is recommended that the landward end of the jetty to the MLW shoreline be tightened and raised, perhaps by as much as 3 ft, transitioning into the existing grade. Reduction of sand infiltration from the south will increase beach width on Plum Island and reduce flood shoal growth. Such measures were taken in the past at this location with apparent success to arrest sand movement off the beach.

b. Distribute dredged material in the Plum Island Nearshore Disposal Site in a uniform fashion alongshore.

Placement of dredged material along the full longshore extent of the disposal site will avoid mounding of material and sheltering of waves on the beach, which can result in a local redistribution of the sand to form a bulge in the sheltered region with possibly two eroded sections of beach next to it. Uniform placement of the dredged material will also more closely follow the contour of the ebb-tidal shoal and promote sand bypassing.

In a possible future study for a long-term solution for beach erosion along Plum Island, it is recommended to consider portions of the sub-tidal flood shoal as a sand source for beach nourishment. Such material could be pumped to the beach without necessity and expense of an ocean-going dredge. Sand mining of portions of the sub-tidal shoal would reduce encroachment of the shoal on the navigation channel and in part replicate the natural sand bypassing process in which sand from the Merrimack River is transported by waves and currents to the adjacent beaches via the ebb-tidal shoal. The study should include investigation of alterations of the current, tidal circulation, and waves in the estuary, especially on the inter-tidal flood shoal, estuarine beaches, and harbor.

4. Literature Consulted

Abele, R.W., Jr. 1977. Analysis of short-term variations in beach morphology (and concurrent dynamic processes) for summer and winter periods, 1971-72, Plum Island, Massachusetts. Miscellaneous Report 77-5, U.S. Army Corps of Engineers, Coastal Engineering Research Center, 101 pp.

Brogden, N.J., and White, D.M. 1979. Newburyport Harbor, Massachusetts, Report 2: Hydrodynamics, salinity, and sedimentation; hydraulic model investigation. Technical Report HL-79-1, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, 534 pp.

Curren, C.R., and Chatham, C.E., Jr. 1979. Newburyport Harbor, Massachusetts, Report 1: Design for wave protection and erosion control. Technical Report HL-79-1, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, 119 pp.

FitzGerald, D.M., Buynevich, I.V., Davis, R.A., Jr., and Fenster, M.S. 2002. New England tidal inlets with special reference to riverine-associated inlet systems. *Geomorphology* 48: 179–208.

McIntire, W.G., and Morgan, J.P. 1969. Recent geomorphic history of Plum Island, Massachusetts and adjacent coasts. Technical Report No. 19, Part A, Coastal Studies Institute, Louisana State University, Baton Rouge, LA, 44 pp.

U.S. Army Corps of Engineers, Reports of the Chief of Engineers, U.S. Army. Various reports dated from 1880 to 1918 provided by Mr. Edward G. O’Donnell, U.S. Army Engineer District, New England.