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Erie Harbor, Pennsylvania, Channel Shoaling Analysis

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Final report

Prepared for U.S. Army Engineer District, Buffalo

Abstract: Presque Isle is located on the southern shore of Lake Erie and shelters the federal harbor at Erie, Pennsylvania. The US Army Engineer District, Buffalo (LRB) requested the US Army Engineer Research and Development Center (ERDC) to quantify the amount of shoaled material from 1998 to 2009 in the federal navigation channel and to assess the suitability of the potential dredged material for beach nourishment or wetland restoration.

The project entailed review of the dredging history at Erie Harbor, including channel shoaling analysis and sediment analysis. The statistical analysis of historical data on dredged material from 1873 to 1977 indicated the loss of littoral material from Presque Isle to the Erie Harbor entrance channel.

Microstation/InRoads software was used to create digital terrain models (DTMs) of the channel soundings and to evaluate the channel sediment shoaling. Color-coded elevation change drawings were created from 1998 to 2010 and show only changes from the natural processes since no dredging occurred during that time period.

The Thiessen polygons method was used to determine 12 individual areas (zones) of influence around a set of sediment sample locations. Only four zones have measurable volume of the shoaled materials with a potential for dredging. Based upon the review of sediment size distribution, the material from these areas is primarily fine-grained and is considered suitable only for the creation or restoration of wetlands.

Contents

Figures and Tables

Figures

Tables

Preface

This report describes the evaluation of the shoaling and dredging of sediment materials from Erie Harbor as part of the Presque Isle, Pennsylvania 204 feasibility study. Dr. Mansour Zakikhani, Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Engineering Division (EPED), Environmental Laboratory (EL), and Danny W. Harrelson, Geotechnical and Structures Laboratory (GSL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, conducted the study. Michael Mohr and Shanon Chader from the US Army Engineer District, Buffalo provided all data and reports used in this study. In addition, they provided significant technical assistance and review of the project and report.

The U.S. Army Engineer District, Buffalo (LRB) funded this study. The LRB project manager was Kenneth Podsiadlo and technical manager was Michael Mohr. The LRB Coastal and Geotechnical Engineering Section Chief was Shanon Chader.

COL Kevin J. Wilson, EN, was ERDC Commander and Executive Director and Dr. Jeffery P. Holland was Director of ERDC.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
pounds (force)	4.448222	newtons
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters

1 Introduction

Problem statement

Presque Isle is located on the southern shore of Lake Erie, Pennsylvania at the city of Erie. Under Section 204 of the 1992 Water Resources Development Act, the US Army Engineer District, Buffalo (LRB) has received the authority to evaluate the use of dredged material from the existing federal harbor project to protect, restore, or create aquatic and ecologically related habitats, including wetlands; to reduce storm damage to property, or to transport and place suitable sediment. This investigation addresses the quantity and suitability of the existing dredged material in Erie Harbor to be used for these purposes. Figure 1 presents a map of the harbor.

Project tasks

The project consisted of several tasks as described below:

a. Project description:

Summarize the history of the creation of Erie Harbor, identifying significant changes in depth and extent using the following documents:

1. Chief of Engineers Annual Report for 1915, which has a description of Erie Harbor at that time.
2. Chief of Engineers Annual Report for 1938, which has a description of Erie Harbor at that time.
3. A discussion of the history of Erie Harbor up until 1941.
4. Chief of Engineers Annual Report for 1963, which has a description of Erie Harbor and is considered valid up to the present time.
5. The latest harbor map.
6. Entrance structure cross-sections map.

b. Dredging history:

Dredging quantities from 1873 to present were summarized. The analysis from the Presque Isle Phase 1 General Design Memorandum was updated. The following files were supplied by LRB to assist in this effort:

1. Erie Harbor Dredging History 1873-1930.

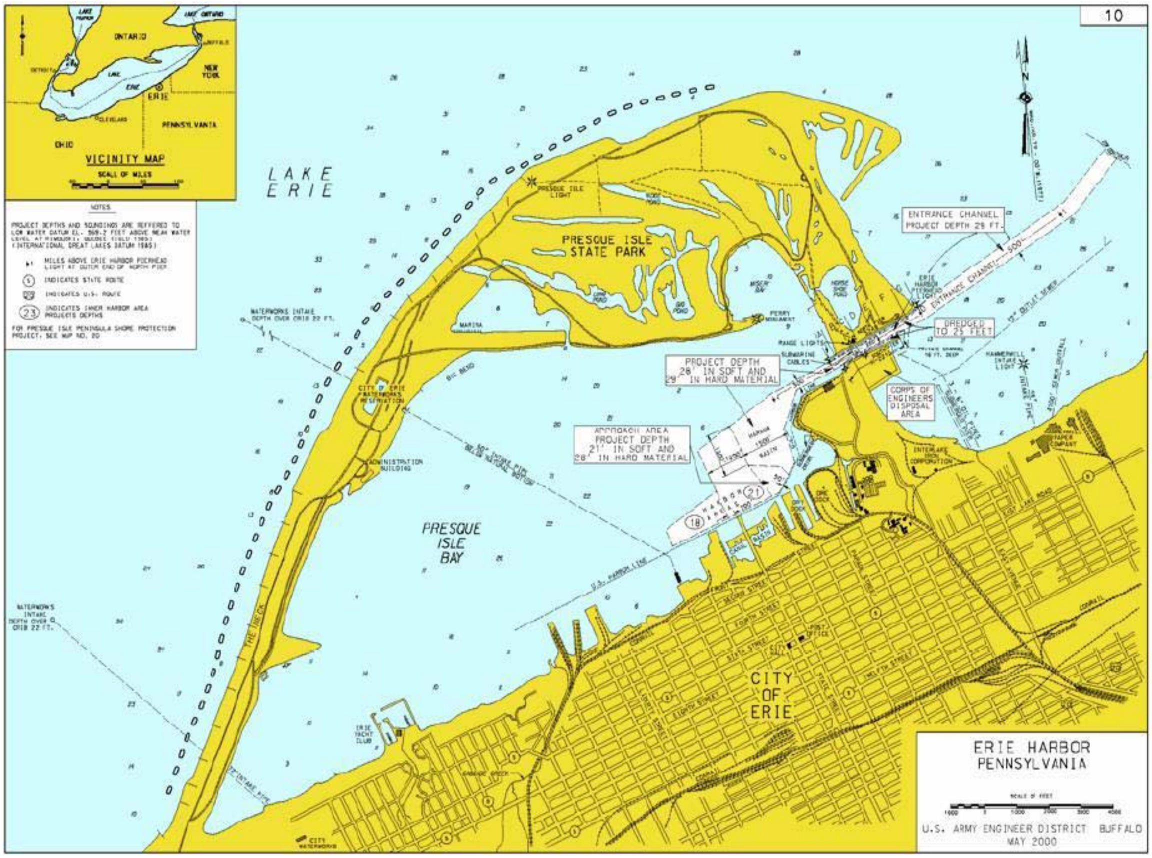

Figure 1. Map of Erie Harbor.

2. PI Phase 1.pdf – Excerpt from the Phase 1 General Design Memorandum, which lists dredging quantities from 1930 to 1977.
3. Dredging Summary 1970-2008.pdf.

c. Channel shoaling analysis:

The last time dredging occurred in the Erie Entrance Channel was 1998, and dredging is scheduled to occur in 2011. This long time span presents a perfect opportunity to observe shoaling patterns. In 1998, two surveys were done before and after dredging. Annual project condition soundings were completed from 1999 to 2009. This task includes Digital Terrain Model (DTM) development for each year given below.

LRB supplied the following files to assist in this effort. Note that there are usually several xyz files to cover the channel survey for a given year.

Table 1. Required DTM files

No	File Description	Format
1	Color-coded Elevation Change Drawing of 1998 Before and After Dredging Project.	DGN
2	Color-coded Elevation Change Drawing: After Dredging 1998 to 1999.	DGN
3	Color-coded Elevation Change Drawing: 1999 to 2000.	DGN
4	Color-coded Elevation Change Drawing: 2000 to 2001.	DGN
5	Color-coded Elevation Change Drawing: 2001 to 2002.	DGN
6	Color-coded Elevation Change Drawing: 2002 to 2003.	DGN
7	Color-coded Elevation Change Drawing: 2003 to 2004.	DGN
8	Color-coded Elevation Change Drawing: 2004 to 2005.	DGN
9	Color-coded Elevation Change Drawing: 2005 to 2006.	DGN
10	Color-coded Elevation Change Drawing: 2006 to 2007.	DGN
11	Color-coded Elevation Change Drawing: 2007 to 2008.	DGN
12	Color-coded Elevation Change Drawing: 2008 to 2009.	DGN
13	Color-coded Elevation Change Drawing: After Dredging 1998 to 2009.	DGN
14	Color-coded Elevation Change Drawing: Authorized Channel Depth to 2009 (Assume -1 ft of allowable over-depth –see typical dredging cross section in Figure 2, Erie Dredging 1998.TIF)	DGN
15	Graphical plot of potential dredging volume by channel station using information developed for the previous drawing of authorized channel depth vs. 2009 elevation change.	Excel

Table 2. Files supplied by LRB for channel shoaling analysis.

No	File Description	Format
1	Picture of dredging plan drawing from 1998.	TIF
2	File containing the xyz sounding information for the channel before dredging in 1998.	Text
3	File containing the xyz sounding information for the channel after dredging in 1998.	Text
4	File containing the xyz sounding information for the project condition soundings in 1999.	Text
5	File containing the xyz sounding information for the project condition soundings in 1999.	Text
6	File containing the xyz sounding information for the project condition soundings in 2000.	Text
7	Microstation drawing of the channel with project condition soundings plotted from 2001.	Text
8	File containing the xyz sounding information for the project condition soundings in 2001.	Text

No	File Description	Format
9	File containing the xyz sounding information for the project condition soundings in 2001.	Text
10	File containing the xyz sounding information for the project condition soundings in 2001.	Text
11	Microstation drawing of the channel with project condition soundings plotted from 2002.	Text
12	File containing the xyz sounding information for the project condition soundings in 2002.	Text
13	File containing the xyz sounding information for the project condition soundings in 2002.	Text
14	File containing the xyz sounding information for the project condition soundings in 2002.	Text
15	Microstation drawing of the channel with project condition soundings plotted from 2003.	Text
16	File containing the xyz sounding information for the project condition soundings in 2003.	Text
17	File containing the xyz sounding information for the project condition soundings in 2003.	Text
18	File containing the xyz sounding information for the project condition soundings in 2003.	Text
19	Microstation drawing of the channel with project condition soundings plotted from 2004.	Text
20	File containing the xyz sounding information for the project condition soundings in 2004.	Text
21	File containing the xyz sounding information for the project condition soundings in 2004.	Text
22	File containing the xyz sounding information for the project condition soundings in 2004.	Text
23	Microstation drawing of the channel with project condition soundings plotted from 2005.	Text
24	File containing the xyz sounding information for the project condition soundings in 2005.	Text
25	File containing the xyz sounding information for the project condition soundings in 2005.	Text
26	File containing the xyz sounding information for the project condition soundings in 2005.	Text
27	Microstation drawing of the channel with project condition soundings plotted from 2006.	Text
28	File containing the xyz sounding information for the project condition soundings in 2006.	Text
29	File containing the xyz sounding information for the project condition soundings in 2006.	Text

No	File Description	Format
30	Microstation drawing of the channel with project condition soundings plotted from 2007.	Text
31	File containing the xyz sounding information for the project condition soundings in 2007.	Text
32	File containing the xyz sounding information for the project condition soundings in 2007.	Text
33	Microstation drawing of the channel with project condition soundings plotted from 2008.	Text
34	File containing the xyz sounding information for the project condition soundings in 2008.	Text
35	File containing the xyz sounding information for the project condition soundings in 2008.	Text
36	File containing the xyz sounding information for the project condition soundings in 2009.	Text
37	File containing the xyz sounding information for the project condition soundings in 2009.	Text
38	File containing the xyz sounding information for the project condition soundings in 2009.	Text
39	File containing the xyz sounding information for the project condition soundings in 2009.	Text
40	File containing the xyz sounding information for the project condition soundings in 2009.	Text

d. Sediment analysis

The most recent sediment sample data were obtained in 2009. Physical description includes sediment type and particle distribution analysis. Chemical analysis includes bulk inorganic, metal, polycyclic aromatic hydrocarbon (PAH), polychlorinated biphenyl (PCB), and pesticide analyses along with site water and elutriate inorganics, metals, PAH, PCB and pesticide analyses, and 10-day toxicity tests (bioassay). The areal extent within the channel where each sample characteristic will be applied will be determined by the number and location of the samples. The channel shoaling quantities developed in the previous section will be combined with the sediment characteristics to assess the amounts of varying physical components of the potential shoaled material. Tasks associated with this analysis included:

1. Review the 2009 sediment data.
2. Create a Microstation drawing of the channel showing the locations of the sediment samples and assign zones of influence (areal extent) for each

sample. The latter may be established using the method of Thiessen polygons.

3. Combine the information from 2 (above) with the previous volumetric analysis (ci15). Create a table showing volumes by types of sediment (clay, silt, etc.,) and by sample zone of influence. This table should look similar to Table 3 below.

Table 3. Example of sediment volumetric analysis table.

Sediment Type	Area 1		Area 2		Etc.	
	%	Quantity Cy	%	Quantity Cy	%	Quantity CY
Fine Sediment						
Clay						
Silt						
Total						
Coarse Sediment						
Fine Sand						
Medium Sand						
Coarse Sand						
Gravel						
Total						
Total Sediment						
Total		100		100		100

4. Discuss the suitability of using sediment in each area to create wetlands or provide beach nourishment.
5. Create a Microstation drawing to summarize the findings from steps 2-4.

LRB supplied the following files to assist in this effort:

1. Entrance Channel Sample Map.pdf – Sediment sample location map within the entrance channel.
2. Inner Harbor Sample Map.pdf – Sediment sample location map within the inner harbor.
3. Erie GPS Points 09.xlsx – Latitude and longitude values for the sediment samples.

4. Erie Harbor Summary Tables 2009.xls – Excel spreadsheet of sediment sample data presented in: Particle size, Inorganics, Metal, PAHs, PAH ratios, PCBs, Pesticides, Inorganic, Metal, PCB, and Toxicity.
5. TTL_Sieve_Data.pdf – Geotechnical Laboratory testing report by TTL Associates presenting the sediment particle size analysis in tabular and graphical forms.

e. Summary report

This report summarizes the completed tasks as described above (a-d) and the data used, assumptions made, and all tables and drawings created.

f. Data DVDs

All data, drawings, and DTMs are available in a DVD. To obtain copies of the DVD, please contact:

Dr. Mansour Zakikhani (CEERD-EP-W)
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Vicksburg, MS 39180

2 History of Erie Harbor Creation

Erie Harbor is located on the south side of a bay formed by Presque Isle Peninsula on the south shore of Lake Erie approximately 78 miles west of Buffalo, New York. The primary information source of this chapter is the "History of Erie Harbor, PA, U.S Army Corps of Engineers, Buffalo, NY" (USACE 1941). Initial improvements to the harbor began after the passage of the "River and Harbor Act" of 1824, and continued in 1855, 1865, 1867, 1870, 1886, 1890, 1915, 1936 and 1963 (Table 4).

Geologically, Presque Isle was created by wave action on Lake Erie during the 10,000 years that have passed since the end of the Pleistocene ice age. The Isle was most likely located about 3 miles west of its current location when it was first formed but the constant pressure of wind, water, and longshore currents has gradually moved the peninsula to its current location where it continues to slowly migrate eastward.

In 1679, Robert de La Salle, the French explorer, built and launched the first vessel to sail on Lake Erie, at a point on the Niagara River about 6 miles above the fall. As early as 1669 the Hudson Bay Company transported its goods and pelts in bateaux on these and western waters. In the struggle with the English for possession of the Great Lakes Region, the French built a fort at Presqu'ile (meaning "nearly an island") in 1753 and garrisoned it with 100 men. Then, as now, the Bay of Presqu'ile furnished one of the best natural harbors on Lake Erie. On the east bank of Mill Creek, somewhat back from the lake, a French village was established, at one time numbering about 100 families and numerous Indians. Fields were cleared and cultivated with corn being the principal crop. A grist mill was erected, other devices of civilization were introduced, but the village was abandoned after 4 or 5 years.

After the fall of Quebec in 1759 the French lost their grip on the Great Lakes Region, and Fort Presqu'ile was abandoned in 1760. It was considered by both nations as a point of communication and defense, as well as a base for supplies between Pittsburgh, Niagara, and Detroit.

Following the War of Independence, the United States came into ownership of this portion of the country, then known as the western frontier, through treaties with the Six Nations (The Iroquois Confederacy). In 1792, Pennsylvania acquired the Erie Triangle from the United States Government by purchase and the same year the General Assembly of the State sought to stimulate settlement.

The first permanent American settlement on the site of Erie was established in 1795 by the Population Land Company, who laid out a town along the entire face of the harbor. In conformity with an act of the General Assembly providing for the survey, the name “Erie” was applied to the community. Erie early assumed commercial importance because of its excellent natural harbor, Presqu’ile Bay, about 4-1/2 miles long and 1-1/2 miles wide. Salt from Salina (Syracuse, NY) was the first article of waterborne commerce that passed through this port in steady volume. Boat building also became an industry not long after permanent settlement. It was here in 1813 that Commodore Perry took charge of the building of the U.S. Navy’s “Great Lakes” fleet. With this fleet he defeated the British in the Battle of Put-in-Bay on Lake Erie in September 1813, thus gaining control for the United States of the Great Lakes and the Northwest.

Erie Harbor was originally surveyed in 1819 by Major John Anderson of the Topographical Engineers. This survey identified a sandbar at the entrance to the harbor and a narrow and crooked channel with a depth of approximately 6 ft. Strong currents were described as flowing in or out of the bay respectively during easterly or westerly blowing winds. In March 1823 a second survey was made and was immediately followed by a harbor improvement plan, which consisted of “two parallel embankments separated by 200 feet from near Block-House point to deep water in Lake Erie.” The plan was (with the exception of the main navigation channel) to close the whole mouth of the harbor by constructing a line of contiguous piles running from Block-House point to Hospital Point, and terminating the embankments in the lake by two strong piers. Each pier would stand obliquely to the line of embankment. The logic at the time was that by constricting the width of the channel, the increase in velocity of the currents during easterly or westerly winds would scour out the sandbars and thereby keep the harbor from silting up. In 1824 construction was begun by the state of Pennsylvania, which appropriated $10,000.00 for these improvements. About two-thirds of the dike was completed when funding was exhausted and the state refused to make further appropriations. Thereafter, the harbor improvements came under the charge of the U.S. government. Tables 4 and 5 summarize the improvements to Erie Harbor for the years 1819-1962.

Table 4. Summary of authorizations and recommendations for Erie Harbor improvements (c. 1819-1962).

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
1962		340	87	2		Depth increase to 27 ft in soft material and 28 ft in hard material in approach area to Marine Terminal. Work previously authorized but uncompleted by 1935 act is combined with this act as a single improvement.
1960	House	199	86	1		Depth increase to 29 ft in entrance channel to a point opposite inner end of north pier and other general entrance channel improvements.
1954	House	345	83	2		Widen 25-ft deep approach channel to ore dock.
1945	House	735	79	2		Improvements to approach channel and turning basin and westerly docks. Add protection to peninsula south of waterworks settling basin.
1935	House	52	73	1		Deepen, widen, and straighten entrance, dredge channel at eastern end of harbor basin and deepening the harbor basin, all to current harbor dimensions. Eliminate north breakwater and limit south breakwater to a length of 1,200 ft.
1933	House	52	73	1		Deepen entrance channel to 25 ft in soft material and 26 ft in hard material, 500 ft wide lakeward of the entrance piers and 300 ft wide between the piers and into the harbor on a straight alignment; for a channel of the same depths and 600 ft wide from the entrance channel to a line 50 ft outside the pierhead line at the ore terminal, suitably widened at the junction with the entrance channel; for a harbor area 21 ft deep, and with an area of approximately 117 acres, extending to a line 50 ft outside the bulkhead line in the eastern part of the harbor; for a channel of the same depth and 300 ft wide connecting this harbor area with natural deep water in the bay; and for a channel 21 ft deep and 200 ft wide leading to a line 50 ft outside the harbor line at the westerly coal docks; estimated cost, $377,000, provided local interests give assurances that they will perform the necessary work in the approaches and alongside the iron ore and coal docks to fully utilize the increased depths, also provided that the north breakwater and the southerly 1,330 ft of the south breakwater be eliminated from the project.
1931						Construction of steel sheet pile bulkhead with stone facing completed. 614 linear ft of steel bulkhead and 3,156 ft of stone facing were completed during the year. Total lengths constructed were 5,646 linear feet of bulkhead and 5,050 linear feet of stone facing.
1923-1930						Reinforcement and extension of 1,160 ft of riprap stone wall were completed at the neck of the peninsula. Construction of about 5,200 linear feet of steel sheet pile bulkhead with stone facing at neck of peninsula was in progress, 5,032 ft of steel bulkhead and 1,894 ft of stone facing being completed in the year.

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
1922					Act of Nov. 28, 1922	Reconvened Presque Isle Peninsula to the State. Construction of sand fill protection was completed, 109,924 cu yd of sand were placed in sand fill and back fill. Riprap wall was constructed, about 1,465 ft long easterly from east end of rubble mound protection, 6,296.7 tons of stone being placed. To hold sand fill, 20,400 small poplar trees and 1,900 small willow trees were planted, and 21 bushels of rye and 6 bushels of cow peas were sown.
1921						Construction of rubble mound and sand fill protection was in progress. Rubble mound protection was completed, and backfill of trench also completed. Sand fill protection was 70% completed. Quantities were excavation of trench, 28,104 cu yd of sand, place measure; rubble stone in mound 27,136.7 short tons; sand fill and back fill, 119,857 cu yd, place measure. As prevention from another breach, a riprap wall about 310 ft long easterly from east end of rubble mound was constructed, 1,466.8 tons of riprap stone were placed. To hold filled-in area, 28 bushels of rye were sown, and 2,300 small poplar trees were planted.
1918-1920						An effort was made, unsuccessfully, to close a breach in the neck of the peninsula caused by storm and high water by means of a pile and sheet pile bulkhead. Breach in neck of Presque Isle Peninsula was closed. The breach was caused by the storm of October 12–13, 1917, and increased by the storms of December 1917, November 1918, and January 1919, being then 1,160 ft wide with water depth from 0 to 1 ft at low-water datum. In April 1920, the breach was 1,470 ft, with depth of water varying from 0.0 to 4.4 ft at low-water datum. Construction of a rubble mound protection, 1700 ft long, in trench excavated to or near bedrock and of a sand fill protection to be 5,000 ft long, as reinforcement and extension of the rubble mound, was in progress. 140,345 cu yd sand backfill in place.
1917						2,310 poplar trees and 2,280 willow cuttings were planted to replace some of the trees washed out at the neck of the peninsula.
1916						540 linear feet of the timber superstructure of the north pier was replaced with concrete. 5,000 trees and 2,275 linear feet of hedge were planted on the neck of the peninsula.
1910-1914						Harbor deepened to 20-ft areas “A,” “B,” and “D,” estimated cost, $75,625. 755 linear feet of the timber superstructure of the north pier was replaced with concrete. 290 ft of the old superstructure was removed in 1913, and the remainder of the work was finished in 1914.
1909						The 500-ft extension of the south pier lakeward was completed.

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
1908						750 linear feet of timber superstructure of the north pier was replaced with concrete. 1200 linear feet of the superstructure of the south breakwater was reconstructed with stone. South pier was extended 500 ft lakeward. The substructure cribs were laid and work on the concrete superstructure was begun.
1907						The extension of the south pier 500 ft was completed. Work continued replacing 750 linear feet of timber superstructure of the north pier with concrete. Most of the trees planted for the protection of the neck of the peninsula grew satisfactorily, but the outer ones were washed out. Jetties constructed failed to prevent wearing away of the shore.
1904-1906						Timber superstructure of the whole of the south pier was replaced by concrete, 1217 ft long. The second shore protection jetty was completed. The outer end of the north pier was rip-rapped with 272.5 cu yd of stone. Extension of the south pier 500 ft was in progress. 500 ft of the substructure was placed. The replacement of 750 linear feet of timber superstructure of the north pier with concrete was in progress.
1903						Replacing of the timber superstructure with concrete on the whole of the south pier, 1217 ft, was in progress. Work done during the fiscal year consisted of removing 421.7 ft of the wooden structure above grade and placing 31 side wall blocks. The substructure of the second shore protection jetty was completed and the superstructure was almost completed.
1902						This year the annual report made the following comment – "During 1896-1898 about 6,600 young locust and willow trees were planted on the neck of the peninsula. Most of these have grown finely, and it is believed, will furnish a permanent and living protection to this neck."
1901						The shore at the neck of the peninsula was eroded, washing out many of the locust trees that had been planted.
1898-1900						2,000 honey-locust trees and 200 willow cuttings were planted on the neck of the peninsula. 1210 linear feet of timber superstructure of the north pier was replaced with concrete. The north pier was extended 538.85 ft. This included a 60-ft crib placed crosswise at the outer end forming an L. The extension was deflected 10 deg to the north from the line of the older portion of the pier. 584 cu yd of rip-rap were placed at the outer end to prevent undermining and settling. One shore protection jetty was constructed

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
						at the neck. It was a timber crib filled with stone, 290 ft long, 12 ft wide by 11-1/2 ft deep, with a T across the outer end 10 by 11-1/2 ft deep by 32 ft long. 204 cu yd of rip-rap was placed for its protection.
1897	House	70	55	1		Repair and extend north and south piers; repair south breakwater, dredge entrance channel, width 300 ft, depth 20 ft at mean lake level; dredge area “A” in eastern end of bay to 20 ft, mean lake level; construct sand-catch and shore protection jetties; promote plant growth along neck of Presque Isle peninsula. 781 cu yd of riprap were placed along the outer 250 ft of north pier. Tree planting was continued at the neck of the peninsula. 2400 yellow locust trees were planted adding manure and leaf mold. Two bushels of seeds of native shrubs were also planted. Thus far this work was considered decidedly successful. In a report dated May 24, 1897, Major Thomas W. Symons, District Engineer proposed the following improvements: (Annual report, Chief of Engineers, 1897, p. 3236.) 1. Repairs to north pier – Replacement of timber superstructure of the western portion, 1,200 ft long with concrete. The cross section proposed was to cap the cribbing (16 ft wide) with 2 ft of concrete, and upon this to mount a concrete parapet 4 ft high, 8 ft wide at the base, and 4 ft wide at the top. Estimated cost, 1,200 ft at $21 per linear foot, $25,200. 2. Repairs to south pier – Replacement of timber superstructure, 650 linear feet to a depth of 4 ft below low water, putting in a grillage 2 ft thick, capped by concrete – An additional 150 ft was to be removed to 2 ft below mean lake level and capped by concrete. The outer 425 ft was to be cut down from a height of 6 ft to 4 ft and a new deck placed thereon. 3. Extension of north pier – 500 ft, deflected 20 deg to the north from its existing direction. Cribs were to be 30 ft wide to furnish the requisite dead weight and stability. Estimated cost, 500 ft, at $100 per foot, $50,000. 4. Extension of south pier – 1000 ft, cribs to be 20 ft wide, 16 ft high, with a superstructure 4 ft high, foundation to be a rubblestone mound extending to a depth of 22 ft to resist scour by currents and wave action. Estimated cost, 1000 ft at $64 per foot, $64,000. 5. Protection of Presque Isle. Four jetties were proposed as sand catches and erosion barriers, not more than one jetty to be built in any one year so that the effects could be studied before building another. The jetties were to be 300 ft long from the shore line, to be tight timber cribs filled with stone, decked over, to be built to fit the foreshore with dredging where necessary to obtain stable placement. The cribs were to be 12 ft wide and to extend from about 8 ft below to 5 ft above mean lake level. Estimated cost was $5,400 or $21,600 for the four. These jetties were regarded by the engineer officer as experimental, and no great conviction was held as to their necessity or as to the results they would accomplish.

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
						The promotion of plant growth was to be continued, previous efforts in this respect being considered very successful. Estimated cost, $1,500 to cover a period of five years.
1896					Act of Aug. 5, 1896	The south pier was 1,220 ft long and the north pier 2,757 ft long. At the neck of Presque Isle, 1,000 Carolina poplars, 200 Wisconsin willows, 200 yellow locusts, 200 Scotch pines, 3 bushels of blue grass, 2 bushels of orchard grass, 1 bushel of crimson clover, 600 willow cuttings, and 60 native poplars were carefully planted under the supervision of a nurseryman. The engineer officer in charge expressed his belief that the preservation, maintenance, and enlargement of the neck of the peninsula would best be attained through development and extension of plant growth.
1898						2,000 honey-locust trees and 200 willow cuttings were planted on the neck of the peninsula.
1897						781 cu yd of riprap were placed along the outer 250 ft of north pier. Tree planting was continued at the neck of the peninsula. 2400 yellow locust trees were planted adding manure and leaf mold. Two bushels of seeds of native shrubs were also planted. Thus far this work was considered decidedly successful. In a report dated May 24, 1897, Major Thomas W. Symons, District Engineer proposed the following improvements (Annual report, Chief of Engineers, 1897, p. 3236): 1. Repairs to north pier – Replacement of timber superstructure of the western portion, 1,200 ft long with concrete. The cross section proposed was to cap the cribbing (16 ft wide) with 2 ft of concrete, and upon this to mount a concrete parapet 4 ft high, 8 ft wide at the base, and 4 ft wide at the top. Estimated cost, 1,200 ft at $21 per linear foot, $25,200. 2. Repairs to south pier – Replacement of timber superstructure, 650 linear feet to a depth of 4 ft below low water, putting in a grillage 2 ft thick, capped by concrete – An additional 150 ft was to be removed to 2 ft below mean lake level and capped by concrete. The outer 425 ft was to be cut down from a height of 6 ft to 4 ft and a new deck placed thereon. 3. Extension of north pier – 500 ft, deflected 20 deg to the north from its existing direction. Cribs were to be 30 ft wide to furnish the requisite dead weight and stability. Estimated cost, 500 ft, at $100 per foot, $50,000. 4. Extension of south pier – 1000 ft, cribs to be 20 ft wide, 16 ft high, with a superstructure 4 ft high, foundation to be a rubblestone mound extending to a depth of 22 ft to resist scour by currents and wave action. Estimated cost, 1000 ft at $64 per foot, $64,000. 5. Protection of Presque Isle – Four jetties as sand catches and erosion barriers were proposed, not more than one jetty to be built in any one year so that the effects could be studied before building another. The promotion of plant growth was to be continued, previous efforts in this respect being considered

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
						very successful. Estimated cost, $1,500 to cover a period of five years.
1894-1896						The 300-ft extension of the north pier, begun in the previous year, was completed for an actual length of 301.4 ft. The south pier was 1,220 ft long and the north pier 2,757 ft long. At the neck of Presque Isle, 1,000 Carolina poplars, Wisconsin willows, 200 yellow locusts, 200 Scotch pines, 3 bushels of blue grass, 2 bushels of orchard grass, 1 bushel of crimson clover, 600 willow cuttings, and 60 native poplars were carefully planted under the supervision of a nurseryman. The engineer officer in charge expressed his belief that the preservation, maintenance, and enlargement of the neck of the peninsula would best be attained through development and extension of plant growth. Title to Presque Isle accepted by the United States.
1893						Additional extension of the north pier 300 ft was in progress. The trench for the stone foundation, and the stone foundation itself, were completed. Five of the six substructure cribs were sunk in place and construction of the superstructure was begun. At the neck of the peninsula the remaining sheet piling and waling of the shore protection were carried away. 70 small willow and cottonwood trees and cuttings were planted. At the close of the fiscal year the cuttings were dead and the small trees appeared as if they would not survive.
1892						North pier extension, length proposed 450 ft, actual, 452.15 ft, begun in previous year, completed.
1891						Extension of the north pier 450 ft eastward was in progress. During the fiscal year, the trench for the foundation was dug, 100 linear feet of foundation was completed and an additional 150 linear feet partially constructed and two cribs of the substructure were sunk.
1890						After 4500 ft of shore protection had been built, it was in large part wrecked while under construction. Upon completion of south shore arm the work was stopped. 1300 ft and the shore arms remained, the other portions having lost the sheet-piling and waling. The contract was closed with payment of all work done and the purchase of all materials on hand.
1889						The North breakwater structure ceased to exist. The drifting sands had moved to the eastward and had entirely shut it in. The project approved in 1885 provided for the construction of a protection of piles and sheet piling 6,000 ft long, parallel with and about 100 ft from the shore along the neck of the peninsula. The top of the protection was to be 3 ft above the mean level of the lake. On the shore side of the protection a brush mattress was to be laid weighted down with stones. An 805-ft section of this shore protection was constructed during the year.

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
1884-1888						521 additional feet of sand catch jetty was constructed by August 28, 1883. On the following day the outer 420 ft were entirely demolished by a storm. These 420 ft were rebuilt and then the outer 280 ft was destroyed by another storm. The engineer officer in charge reported that the protection fences and pile jetties that had been built at the neck of the peninsula for its protection were in ruins, and the effect was as if they did not exist.
1883						The engineer officer in charge reported that the protection fences and pile jetties that had been built at the neck of the peninsula for its protection were in ruins, and the effect was as if they did not exist.
1882-1883						Intermediate piles were driven in the old bulkhead fences to safeguard a breach in the neck of the peninsula. 385 linear feet of the north pier was rebuilt and 90 linear feet of superstructure was redecked.
1882						Oak piles were driven along 380 linear feet of the channel face of the north pier and tied together with waling. The north pier was extended 242 linear feet. It was rip-rapped with 1,200 tons of large stone. 2,000 linear feet of brush and stone protection at the neck of the peninsula was renewed, 200 cords of brush and 150 cords of stone being used, with 5-6 tons of the stone having been reclaimed from the lake. The south pier was extended 423 linear feet.
1881						Extension of the south pier was in progress, 150 ft of crib work being sunk to date. A 240-ft extension of the north pier was begun, 160 ft of crib work being sunk during the year. Nine pile jetties were constructed out into the lake at right angles to the peninsula to prevent shore erosion. Eight of the jetties were at the neck, 200 ft apart from each other, the ninth being at a distance of 2 miles from the neck. They consisted of lines of close piling out to a depth of 6 ft.
1880						A Board of Engineers was convened at Erie to consider the condition of the peninsula. They were of the opinion that the harbor was in no immediate danger from the action of the lake waves, but suggested as a precaution against possible damage by a succession of years of high water accompanied by severe storms that the narrower portions be reinforced. They advised the planting of silver poplar or beech where the vegetation was sparse.
1870-1880						The south breakwater was completely repaired.
1878-1879						389 linear feet of the north pier was rebuilt from the water level up.

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
1876-1877						Protection to the neck of the peninsula was in progress through the construction of a bulkhead, 4536 ft being built to date. 415 linear feet of north pier was rebuilt from the water level up.
1875						Repairs to the breach in the neck of the peninsula were in progress through the construction of a bulkhead of piles and heavy plank about 6 ft high, rip-rapped on both sides with stone, with apparently very satisfactory results, 480 ft being built. The experiment of planting young trees had failed. Nearly all of them had been destroyed. 500 ft of the old north breakwater was rebuilt in order to strengthen the bay side of the north spit.
1874						A Board of Engineers was convened to devise a means of protecting the north spit at the entrance to the harbor from being washed away. They recommended the construction of pile work and rubble stone. The recommendation was approved. 1,472 linear feet of pile work and rubble stone were constructed to protect the north spit. The north pier was extensively repaired. A heavy gale in November breached the neck of the peninsula.
1873						Fall and winter gales of 1873-1874 seriously damaged the piers.
1872						The neck of the peninsula at the west end was strengthened by anchoring and picketing brush and weighting it with stone. 350 loads of brush and 187 cords of stone were used. Over 50,000 young trees and slips were planted for the protection of the peninsula.
1871						No Data
1870						The sunken part of the north pier was removed, and the north pier was extended 120 ft. The north and south piers were thoroughly repaired. The beach in front of the light-keeper's dwelling was revetted to prevent a possible breach.
1869						70 ft of north pier and 40 ft of south pier was rebuilt.
1868						A Board of Engineers was convened at Erie to consider the cause of failure of the pier and other matters pertaining to the improvement of the harbor. The Board recommended the repair of 258 ft and the removal of 240 ft built in 1867, the prolongation of the pier to the depth of 14 ft in the lake and thorough repairs to the old piers and the south breakwater. 380 linear feet of the pier was rip-rapped, repaired, and strengthened.

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
1864-1867						A breach in the neck of the peninsula was entirely closed. Natural forces completed work that lack of funds had prevented the engineer officers from finishing. The project for a western entrance was abandoned on resumption of work in this year.
1855-1864						North pier prolonged 498 ft, giving it a total length of 1798 ft. In October a violent gale caused a settlement and a partial overturning of 300 ft of the new work.
1854						The south pier was thoroughly repaired. Revetment of shore with brush and stone at the neck of peninsula was continued.
1853						700 ft of north pier were removed and rebuilt. At the neck of the peninsula the shore was revetted to a considerable extent by brush and stone.
1847-1852						No work was done in these years. Examination by the officer in charge in 1852 showed piers and breakwaters at the east entrance in dilapidated condition. At the west end of the harbor the breach in the neck of the peninsula still existed. The crib-work that had been built had been almost destroyed.
1846						As far as funds would permit, breaches in piers and breakwaters were repaired, putting structures in comparatively good condition.
1845						The south pier was thoroughly repaired except for a length of 130 ft, and the south breakwater was entirely repaired except for one breach 280 ft long near its junction with the main shore.
1844						Condition of Harbor. 1. East end of bay. From the main shore a breakwater 2,530 ft long had been built to the south pier, the latter having been constructed for a length of 780 ft. The north pier, about parallel, and 360 ft from the south pier, was 1,240 ft long, and connected with the peninsula on the north by a breakwater 2,900 ft long. There was a depth of 18 ft between the piers, but extensive shoals were forming, both inside and outside the entrance. The piers and breakwaters were in a dilapidated condition requiring extensive repairs. 2. West end of bay. The peninsula that originally joined the main shore at its western end had become an island. To prevent the destruction of the harbor, an extensive line of crib-work had been built to close the breach with the exception of an opening to be left for a new channel at the west end. However, a portion of this crib-work left incomplete in 1839 for want of funds had been

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
						destroyed. The gap in the peninsula, which in 1835 was over a mile wide, had been reduced to a width of 3,000 ft with a depth of 5 to 6 ft. Operations – West end, construct 470 ft of crib work. East end, north breakwater was put in complete order and north pier partly repaired.
1843						Minor repairs were made to the north pier at the eastern entrance by means of a small left-over sum from the previous appropriation. The works were in a dilapidated condition.
1840-1842						No appropriations were made and no work was done, although some of the structures were deteriorating.
1839						At the neck of the peninsula, the breakwater on the south side of the proposed channel pier was extended 690 ft shoreward, and 300 ft of crib work was added at the northeast end, north of the proposed entrance.
1838						At the west end of the bay, 570 linear feet of crib work breakwater was constructed north of the proposed channel, filled with stone, and partially rip-rapped. Also 465 ft was partially completed south of the proposed entrance. At the east end of bay, the south breakwater was extended 300 ft by crib work at its inner end, where high water and heavy gales had cut a channel from 4 to 16 ft deep.
1837						An additional 1920 ft of crib work breakwater was constructed in closing the breach at the neck of the peninsula, there now being 2,340 ft built, or one-third of the whole breach. 180 linear feet of south breakwater at the east end of bay was rebuilt to repair a breach at the junction of the south breakwater with the main shore.
1836						Crib work 140 ft long was built around government buildings on the pier for their protection.
1835						The closing of the breach at the junction of the south pier and breakwater was completed. The breakwaters and channel piers were rip-rapped with stone. The piers were covered with flagging stone where the plank had decayed. The breach at the neck of the peninsula, at the west end of the harbor, had greatly widened so that where trees were thick in 1824 at the beginning of the work there was now an opening nearly a mile wide. The opening appeared to be increasing continually and to threaten the whole peninsula. A plan was submitted by Lieut. T. S. Brown, in charge of the work, to close the breach by crib work, leaving a channel 400 ft wide, with entrances at both ends of the harbor.

Year	House or Senate	Number	Congress	Session	Other Authorization	Recommendations and Improvements
1834						The closing of a breach at the junction of the south pier and breakwater by depositing 1000 cords of stone was in progress. A large amount of riprap as also placed along the piers.
1833						North dike or breakwater extended 1,234 ft, connected with the peninsula and filled with stone, closing a breach that had occurred in the previous year (1832). A breach had occurred in the neck of the peninsula at the west end of the harbor. After examination and study, Col. J. G. Totten suggested the possibility of maintaining entrances at both ends of the harbor, recommending that the effect of the breach be studied for a year or two before any plans were decided upon.
1831						Beacon light erected.
1829						Breach in peninsula closed. The initial construction phase of the harbor was now completed (1829).
1826- -1852 and 1864- -1896					Acts of 1864 to 1896 and 1826 to 1852	By inference extend and repair breakwaters and piers, increase channel dimensions, protect shore at neck of Presque Isle Peninsula. North pier prolonged 390 ft into the lake. South dike or breakwater extended 420 ft (1826). 810 ft of south pier constructed (1827). South pier completed by extending it 240 ft further and filling it with stone (1828). 600 ft of the south dike or breakwater was raised 4 ft and filled with stone and elongated an additional 390 ft (1828).
1825						North dike or breakwater and 900 ft of the north channel pier were completed.
1824	State of Pennsylvania				Act of May 26, 1824	Construct breakwaters and piers, dredge entrance channel, protect shore at neck of Presque Isle Peninsula.
1823	State of Pennsylvania					By act of March 3, 1823, another survey was made, followed by the appointment of a board of engineers, who submitted a plan of improvement. Their report proposed – "to form two parallel embankments, separated 200 ft, from near Block-House Point to deep water in the lake, and, with the exception of this passage, to close the whole of the mouth of the basin by a line of contiguous piles from Block-House Point to Hospital Point, terminating the embankments in the lake by two strong piers, each standing obliquely to the line of the embankment with which it is connected, and in the basin by placing the parts within the line of piles, also obliquely." By contracting the width of the channel, the increased velocity of the current during easterly or westerly winds would scour out the sand bars. The plan was approved.
1819		(12)				Erie Harbor was surveyed in 1819 by Major John Anderson of the Topographical Engineers, which showed a sandbar at the entrance to the harbor, a narrow and crooked channel with a depth of 6 ft, with strong currents running in or out of the bay, respectively, during easterly or westerly winds.

Table 5. The extension and lengths of breakwaters and piers improvements from 1825 to 1888.

Year	North Pier		South Pier		North Breakwater		South Breakwater	
	Extension	Total Length	Extension	Total Length	Extension	Total Length	Extension	Total Length
1825	900	900						
1826	390	1,290					420	
1827			810					
1828							390	
1833					1,234			
1844		1,240		780		2,900		2,530
1867	498	1,738						
1881	160	1,898						
1882	242	2,140	423	1,203				
1888		1,970		1,220				

3 Dredging History

The History of Presque Isle began when it was created by wave action on Lake Erie as described in Chapter 2. The peninsula was most likely located about 3 miles west of its current location when it was first formed. But the constant pressure of wind and water has gradually moved the peninsula to its current location, where it continues to slowly migrate eastward.

The data presented here are from the available government dredging records as provided in a report by the U.S. Army Engineer District, Buffalo (LRB) (LRB 1980). As described in this report, a search was conducted in 1980 to identify removal years and what quantities of material were removed from the outer entrance channel. A detailed breakdown of the historic dredging records is currently being compiled, and it is known that the outer harbor has historically dominated the dredging program at Erie Harbor. The westward littoral drift predominately travels the length of Presque Isle and eventually deposits at its east end where some sediments accumulate at Gull Point. Some sediments travel beyond Gull Point as evidenced by sandbars and shoals that have developed at the platform off of Thompson Bay. In addition, some sediments are transported to the Erie Harbor entrance channel, as the outer entrance channel has become a permanent littoral sink that is maintained through periodic dredging.

Erie Harbor channel dredging

This section of the report is based on LRB (1980). Annual quantities of material dredged from Erie Harbor during 1873-1930 are given in Table 6 and Figure 2, for 1930-1959 in Table 7 and Figure 3, and for the period of 1960-1977 in Table 8 and Figure 4. It is important to realize that the quantity dredged in a given year does not necessarily represent the need for dredging. The dredging program is strongly influenced by factors such as: the availability of floating plant, funding, scheduling problems, weather conditions, harbor demand, etc. A linear regression analysis was performed for each set of data (Tables 6, 7, and 8) to compare data trends before replenishment (1930-1959) and the data from the replenishment period (1960-1977). Fitting linear lines are superimposed on Figures 2, 3, and 4. Since replenishment, the slope of the regression line has changed from slightly negative to strongly positive (from -468 to 4,356). The

Table 6. History of Erie Harbor dredged material (1873-1930).

Data Point	Year	Quantity (yd^3)	Evaluation	
1	1873	80129	Period 1873-1930	
2	1875	8000		
3	1876	52800	Total Volume (Quantity) = 2,462,864 yd^3	
4	1877	28594	Average over 33 Years = 74,632 yd^3	
5	1878	30000		
6	1879	27237	Linear Regression (Fitting Equation)	
7	1880	102763	y = 1158.68x-2125665	
8	1882	25000		
9	1883	18000	Predicted Values	
10	1887	44000	1931	111745
11	1889	10722	1932	112904
12	1890	9764	1933	114062
13	1891	125471	1934	115221
14	1892	2800	1935	116380
15	1895	6235		
16	1897	29399		
17	1898	6535		
18	1900	203174		
19	1901	236499		
20	1903	292106		
21	1906	184445		
22	1907	197119		
23	1910	59037		
24	1911	133067		
25	1914	5110		
26	1915	40370		
27	1916	13379		
28	1918	18260		
29	1921	156509		
30	1923	94286		
31	1924	14464		
32	1925	47056		
33	1930	160534		

Table 7. History of Erie Harbor dredging records (1930-1959).

Data Point	Year	Quantity (yd³)	Evaluation	
1	1930	160534	Pre –Replenishment Period (1930-1959)	
2	1931	145338		
3	1932	147507	Total Volume (Quantity) = 3,793,177 YD^3 (YD^3)	
4	1933	196311	Average over 29 Years = 130,800 YD^3	
5	1934	150875		
6	1935	131519	Linear Regression (Fitting Equation)	
7	1936	204092	$y = -468x + 1040708$	
8	1937	110020		
9	1938	93915	Predicted Values	
10	1939	86867	1930	137432
11	1940	56974	1940	132752
12	1941	63670	1950	128072
13	1942	101166	1960	123392
14	1943	141250	1970	118711
15	1944	152023	1980	114031
16	1945	90470	1990	109351
17	1946	75479	1991	108883
18	1947	96473	1992	108415
19	1948	98720		
20	1949	228867		
21	1950	229647		
22	1951	210519		
23	1952	48756		
24	1953	163873		
25	1955	184594		
26	1956	81359		
27	1957	136377		
28	1958	88151		
29	1959	117831		

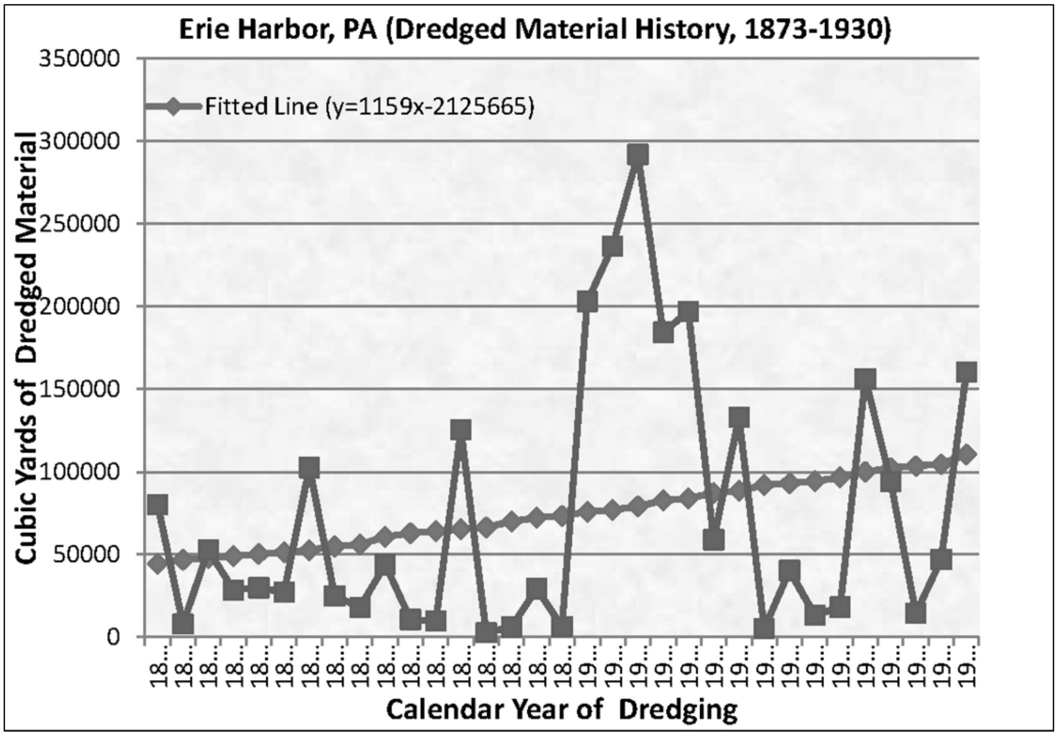

Figure 2. History of Erie Harbor dredged material (1873-1930).

Table 8. History of Erie Harbor dredging records (1960-1977).

Data Order	Year	Quantity (yd³)	Evaluation	
30	1960	126377	With –Replenishment Period (1960-1977)	
31	1961	62194		
32	1963	354526	Total Volume (Quantity) = 3,841,136 yd³	
33	1964	369726	Average over 17 Years = 225,949 yd³	
34	1965	146110		
35	1966	264685	Linear Regression (Fitting Equation)	
36	1967	295680	y = 4356x -8350423	
37	1968	151880		
38	1969	171215	Predicted Values	
39	1970	182219	Year	Dredged Materials (yd³)
40	1971	207656	1950	143698
41	1972	168660	1960	187258
42	1973	203440	1970	230818
43	1974	325464	1980	274377
44	1975	225391	1990	317937
45	1976	388076	1991	322293
46	1977	197837	1992	326649

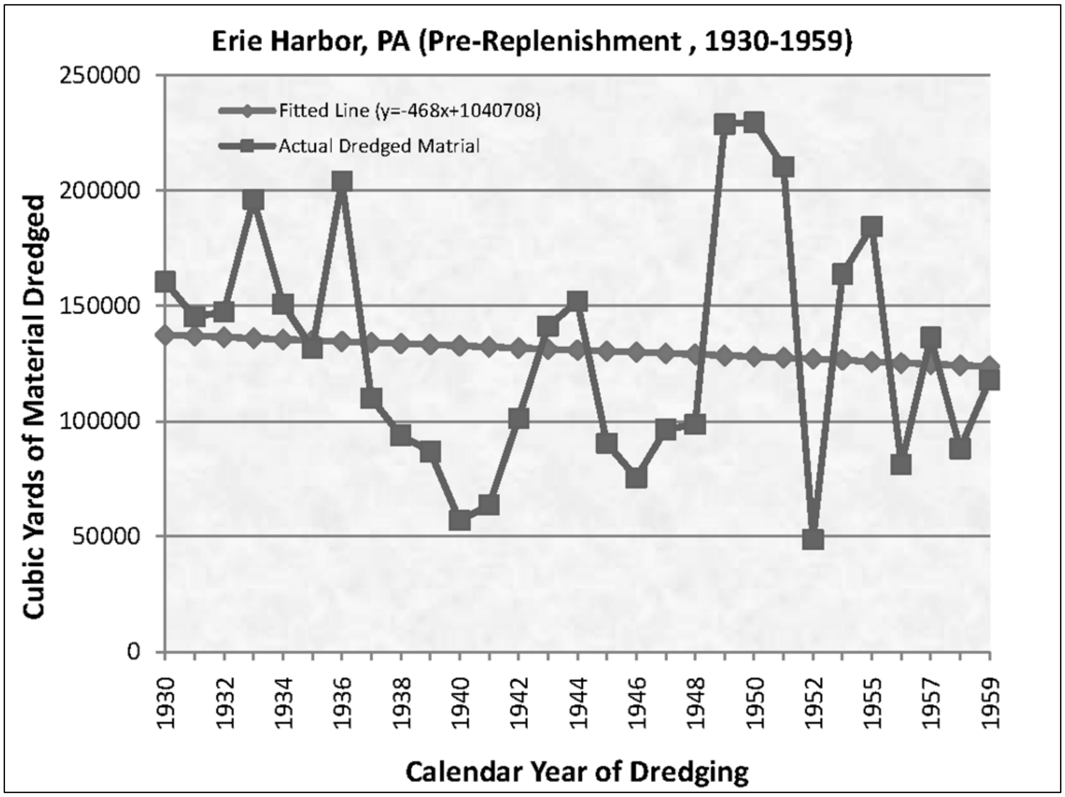

Figure 3. History of Erie Harbor dredged material (1930-1959).

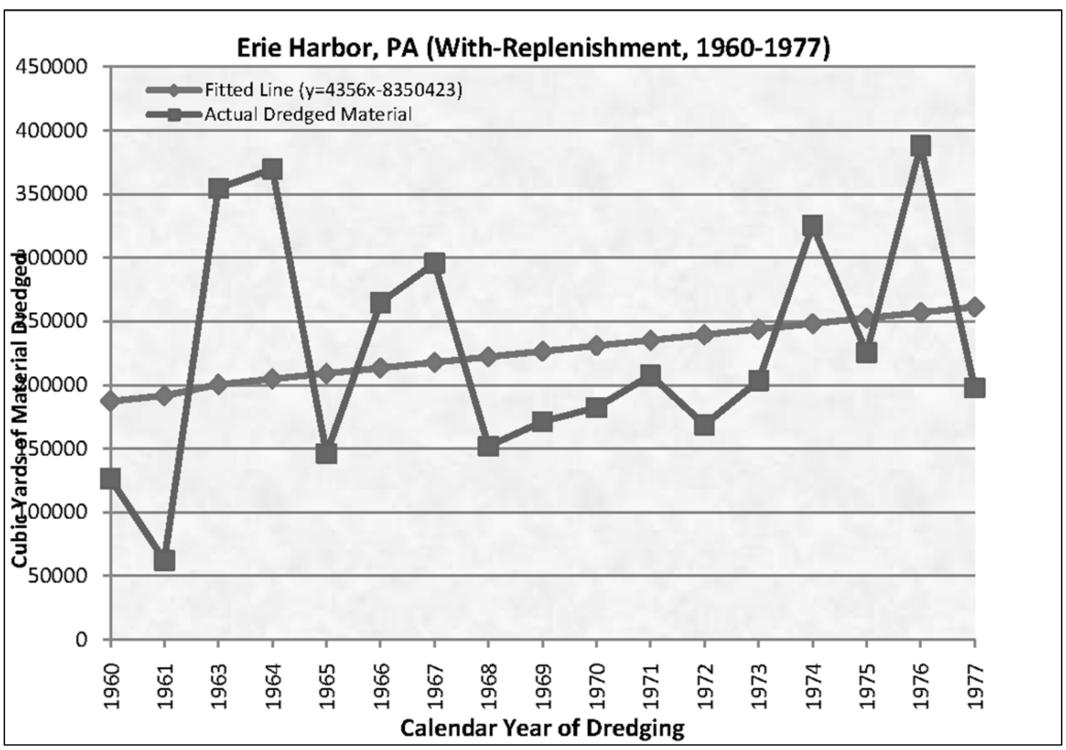

Figure 4. History of Erie Harbor dredged material (1960-1977).

pre-replenishment linear regression line suggests that less and less littoral material was actually making it around Gull Point to the entrance channel. This may reflect the extensive shore protection efforts of the early 1930's, mid-40's, and mid-50's. The linear regression fit for the data since replenishment shows a definite increasing trend as more littoral sediment is available for transport into the entrance channel. It is predicted that the replenishment period data actually follow a nonlinear relationship. Continual replenishment will reach a cumulative point where almost all the material placed on the beaches ends up in the entrance channel and the annual dredging line will flatten at some maximum value. This will occur as Gull Point continues to migrate along an axis that intersects the entrance channel. The linear fitting equations were used to predict future potential dredged material up to 1992 (Tables 7 and 8). Note that beginning in 1992, the breakwater project has been in place and nourishment is now about 19 percent of nourishment before the project.

The average annual dredging quantity before 1960 was 130,800 yd^3 and since replenishment, it has increased by 95,150 yd^3 to 225,950 yd^3. Prior to application of this data to the sediment budget, the part of the total dredging that actually represents the littoral material from Presque Isle should be determined. The logic and computations for eliminating the influence of non-littoral suspended sediment and littoral drift from the east are presented in the next section.

Transport of littoral materials to Erie Harbor

Prior to discussion of the Erie Harbor dredging record, it is necessary to determine what portion of the dredging activity represents littoral transported materials from the west (i.e., from Presque Isle). The drift rate from the east into the source (i.e., suspended sediment deposited in the inner channel) should not be affected by nourishment activities on the peninsula. The average dredging with nourishment (225950 yd^3/yr) as shown in Table 8 is the contribution from several processes such as:

$$\begin{aligned}&\text{Non}-\text{Littoral Sedimentation} + \text{Littoral Drift from East} + \text{Littoral Drift from West} = \\&\text{Dredging with Nourishment} = 225950\ yd^3 / yr\end{aligned} \tag{1}$$

Littoral transported deposition is dominated by transport from the west. BED TM 37 "wave and lake level statistics for lake Erie" was used to document the percent of the gross drift into the WSW, W, WNW, NW, and N were assumed to cause drift from the west. The statistical energy values (in ft-lb) for the western directions, as found in the General Design Memorandum for Presque Isle Peninsula (LRB 1980), were added and compared to the total.

$$\begin{aligned}
&\text{Energy from WSW} - \text{N} = 318648 \text{ ft} - \text{lbs } (81\ \%) \ (\text{from west}) \\
&\text{Energy from NNE} - \text{E} = 73094 \text{ ft} - \text{lbs } (19\ \%) \ (\text{from east}) \\
&\text{Total Energy} = 318648 + 73094 = 391742 \text{ ft} - \text{lbs } (100\ \%) \ (\text{Gross})
\end{aligned} \tag{2}$$

Although no physical data exist to determine the percent of dredging that represents non-littoral deposition, discussions produced the estimate that 20 % of present dredging is from the inner harbor. Therefore, annual average dredging of littoral transported material from the west is computed as follows:

Total dredging:

$$(0.8)\ 225950 + (0.2)\ 25950 = 2590\ yd^3 \ / \ \text{Yr} \tag{3}$$

Littoral from west:

$$(0.8) * 225950 * (0.81) = 146420\ yd^3 \ / \ \text{Yr} \tag{4}$$

With nourishment loss from Presque Isle to the Harbor, additive effect of nourishment is calculated as:

$$225950\ (\text{Table } 5) - 130800\ (\text{Table } 4) = 95150\ yd^3 \ / \ \text{Yr} \tag{5}$$

Basic littoral supply from Presque Isle (PI) to the harbor:

$$146420 - 95150 = 51270\ yd^3 \ / \ \text{Yr} \tag{6}$$

Littoral drift are materials moved by waves and current of the littoral zone to the harbor.

The loss of littoral material from Presque Isle to the Erie Harbor entrance channel with annual replenishment is 146,420 yd^3 per year. The loss of littoral material without replenishment (Do-Nothing) alternative is 51,270 yd^3 per year.

4 Channel Shoaling Analysis

Channel bottom elevation data that were provided and are listed in Chapter 1 were used to create a color-coded elevation and digital terrain model (DTM) using MicroStation/InRoads software. A DVD that includes a color-coded elevation and digital terrain model (DTM) for the items listed in Table 1 is available upon request. To obtain copies of the DVD, please contact:

Dr. Mansour Zakikhani (CEERD-EP-W)
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180

The values of depths and elevations are in feet and refer to a low water datum elevation of 569.2 ft (173.5 m) above mean water level at Rimouski, Quebec (U.S. Army Engineer District, Detroit 1985).

The data used in this analysis were collected from 1998 to 2009. However, no dredging has occurred since 1999. Therefore, all the Color-coded Elevation Change Drawings (Appendix A) after the dredging in 1998 show only changes from natural processes.

Changes of the authorized channel depth vs. 2009 elevation

The 2009 elevation survey data were subtracted from the authorized channel depth (30 ft, see Figures 5 and 6) and the changes are shown in Figure 7.

Plot of potential dredging volume by channel station

Figure 8 is a plot of potential dredging volume by channel station using information developed for changes of the authorized channel depth versus 2009 elevation (Figure 7).

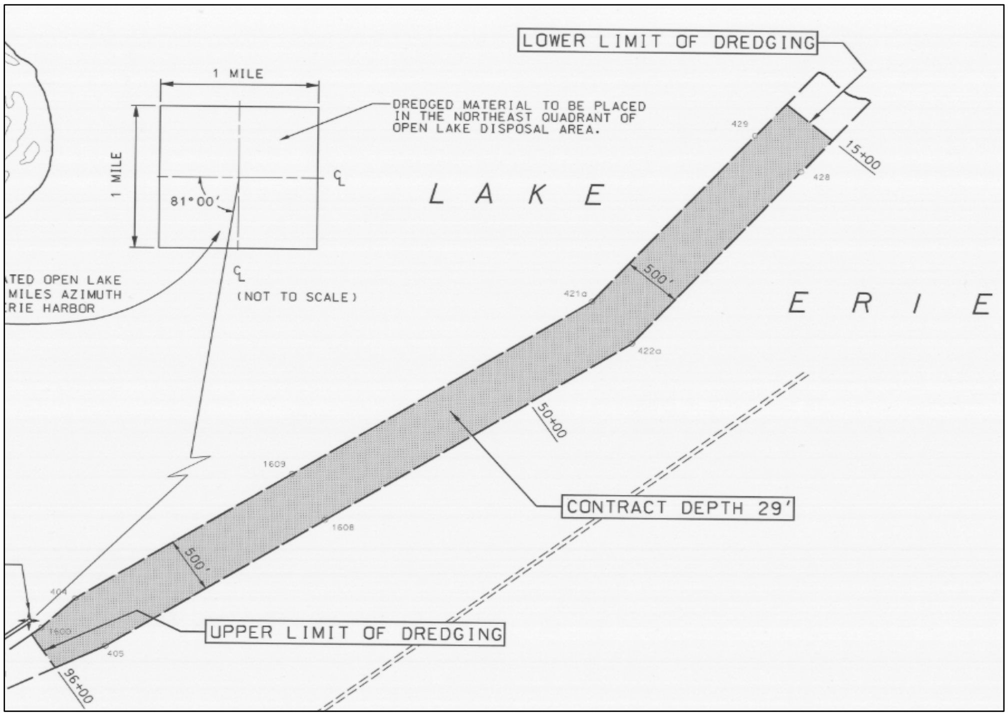

Figure 5. Contract depth of 29 ft.

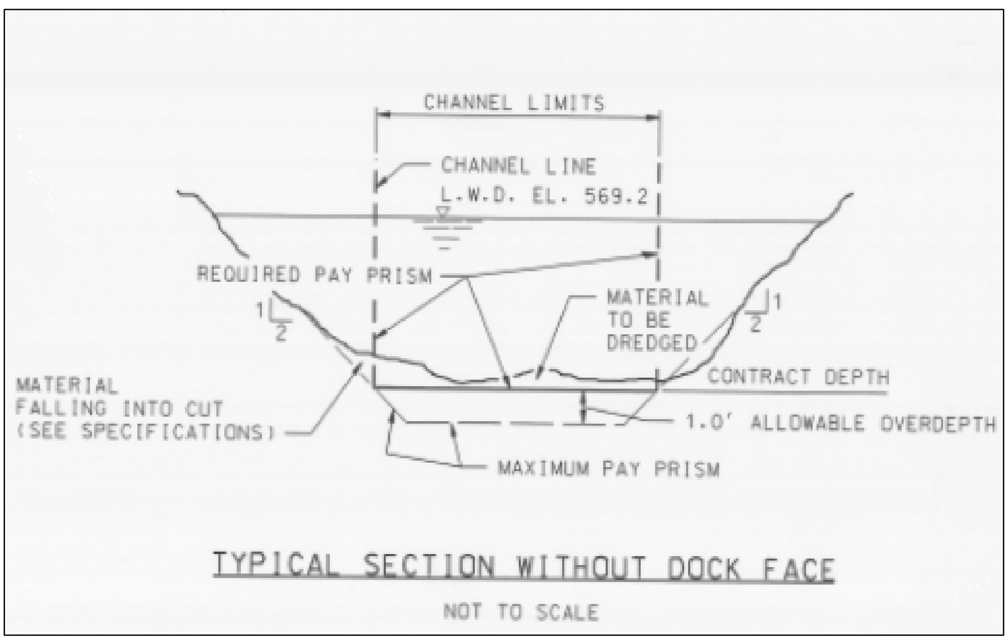

Figure 6. Typical channel cross section shows allowable overdepth of 1 ft.

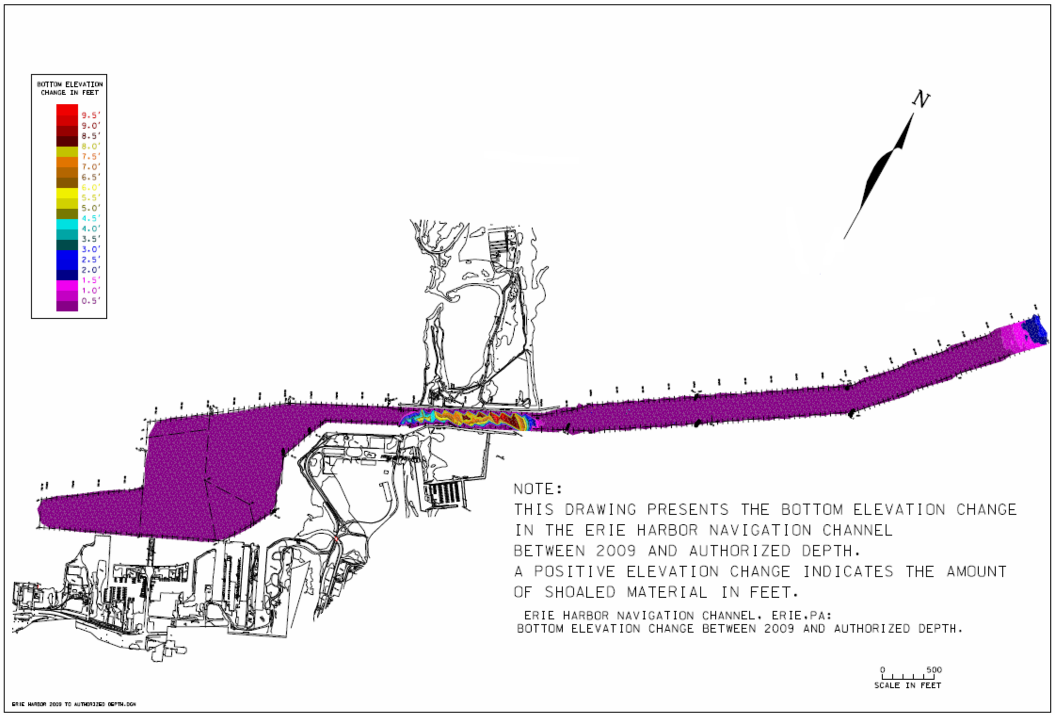

Figure 7. Changes between 2009 survey data and authorized depth of 30 ft.

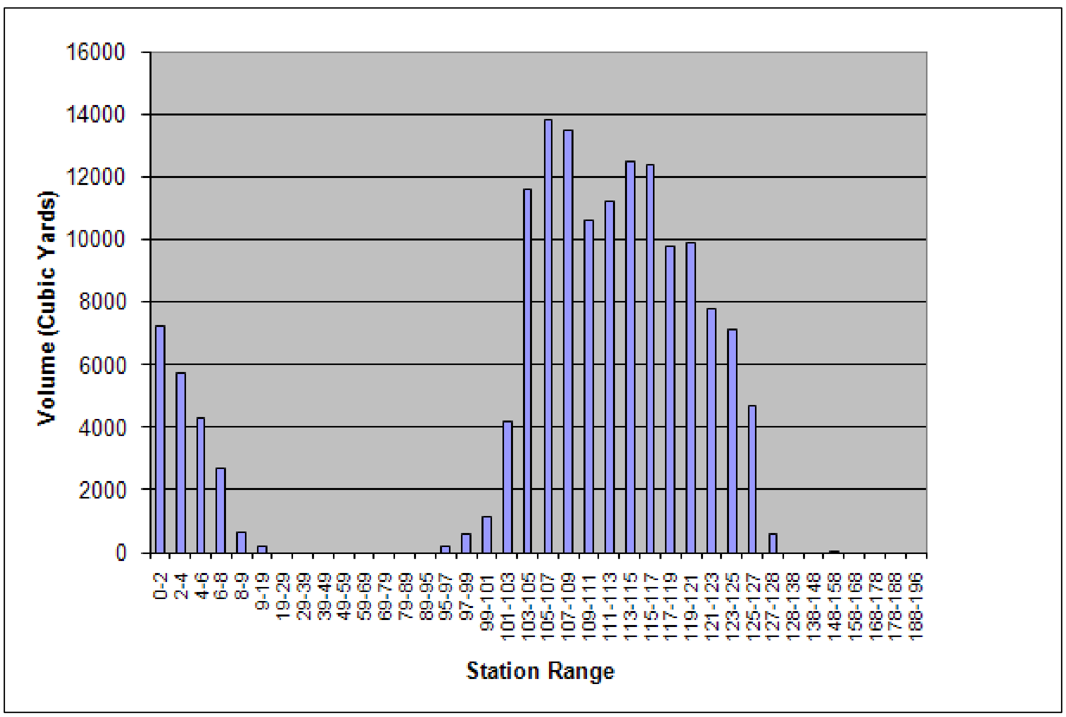

Figure 8. Plot of potential dredging volume by the channel station based upon 2009 survey.

5 Sediment Analysis

This chapter describes how the 2009 sediment sample data were used to evaluate physical distribution of shoaled material within the channel. The assigned area of influence of the sediment characteristics was determined based upon their spatial distribution. The channel shoaling quantities developed in the previous section were combined with sediment characteristics to assess the amounts of the various physical components of the potential shoaled material. DTM files created for this chapter are available in a DVD. To obtain copies of the DVD, please contact:

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Convert latitude and longitude to state plane

The latitude and longitude of sediment sample locations from 2009 survey data were converted to x and y (easting and northing) using a converting software (http://www.earthpoint.us). Table 9 shows the sediment sample locations. Figure 9 shows the sediment sample locations inside the channel.

Method of Thiessen polygons

Thiessen polygons were used to define individual areas of influence around each set of sediment sample locations. Thiessen polygons are polygons whose boundaries define the area that is closest to each point relative to all other points. They are mathematically defined by the perpendicular bisectors of the lines between all points.

Thiessen polygons can be used to describe the area of influence of a point (sediment sample location) in a set of points (all sample locations). The first step is to create a triangulated irregular network (TIN) by taking a set of points and connecting each point to its nearest neighbor. Then, each connecting line segment is bisected perpendicularly to create closed polygons with the perpendicular bisectors; the result will be a set of Thiessen polygons.

Table 9. GPS coordinates for Erie Harbor sediment sampling sites.

Management Unit	Site ID	Latitude	Longitude	Easting	Northing
Open-Lake Placement Area (ED)	ED-1	N 42° 12.233'	W80° 03.986'	1340905.74	750687.47
	ED-2	N 42° 12.236'	W80° 03.393'	1343582.39	750634.25
Open-Lake Reference Area (EL)	EL-1	N 42° 12.817'	W80° 01.868'	1350560.88	753982.10
	EL-2	N 42° 12.815'	W80° 01.124'	1353918.78	753879.29
	EL-3	N 42° 12.298'	W80° 01.893'	1350364.10	750833.73
	EL-4	N 42° 12.314'	W80° 01.079'	1354042.23	750831.90
Erie Harbor Management Unit 1 (EMU-1)	EH-1	N 42° 10.108'	W80° 02.943'	1345270.90	737661.66
	EH-2	N 42° 09.824'	W80° 03.291'	1343653.04	735976.62
	EH-3	N 42° 09.608'	W80° 03.706'	1341742.45	734715.11
Erie Harbor Management Unit 2 (EMU-2)	EH-4	N 42° 09.371'	W80° 04.163'	1339641.20	733331.26
	EH-5	N 42° 09.002'	W80° 05.117'	1335270.82	731206.63
	EH-6	N 42° 08.867'	W80° 05.174'	1334991.16	730393.89
Erie Harbor Management Unit 3 (EMU-3)	EH-7	N 42° 08.763'	W80° 05.447'	1333740.62	729796.96
	EH-8	N 42° 08.684'	W80° 05.325'	1334277.98	729301.21
	EH-9	N 42° 08.528'	W80° 05.236'	1334653.66	728343.19
Erie Harbor Management Unit 4 (EMU-4)	EH-10	N 42° 08.669'	W80° 05.677'	1332684.07	729253.18
	EH-11	N 42° 08.466'	W80° 05.445'	1333700.00	727993.45
	EH-12	N 42° 08.299'	W80° 05.806'	1332040.36	727024.87

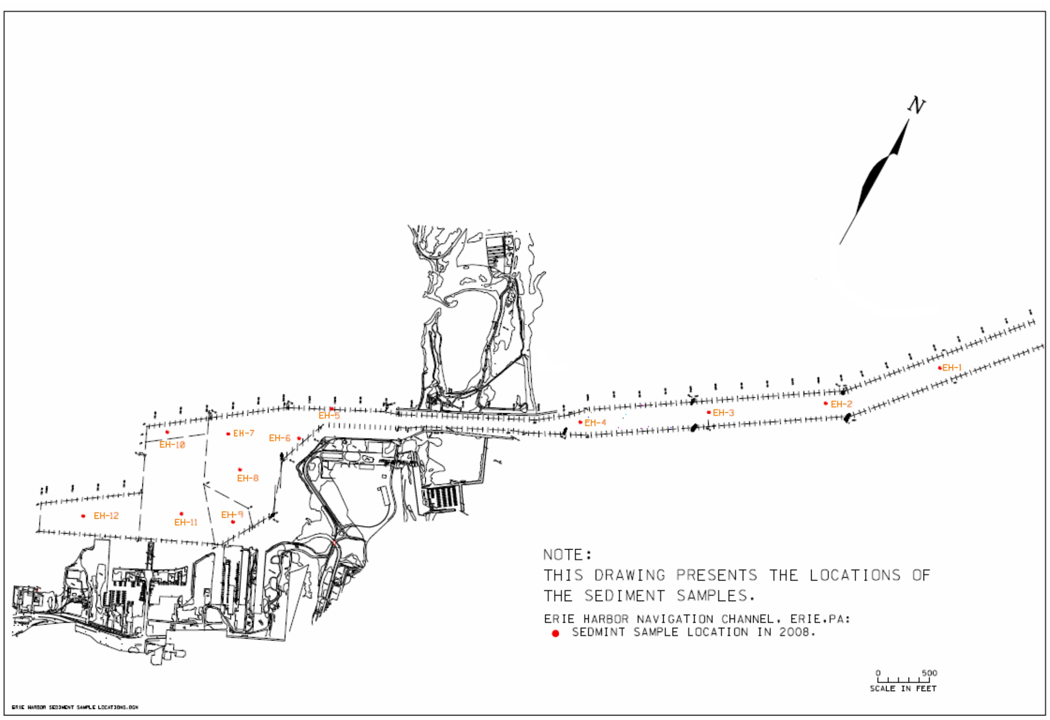

Figure 9. Location of sediment samples.

The Theissen polygon method assumes that each sediment sample location does not receive the same weight as in the arithmetic method.

Figure 10 shows four sample locations: S1, S2, S3, and S4. Using the procedure described above, the four areas of influence of A1, A2, A3, and A4 are illustrated.

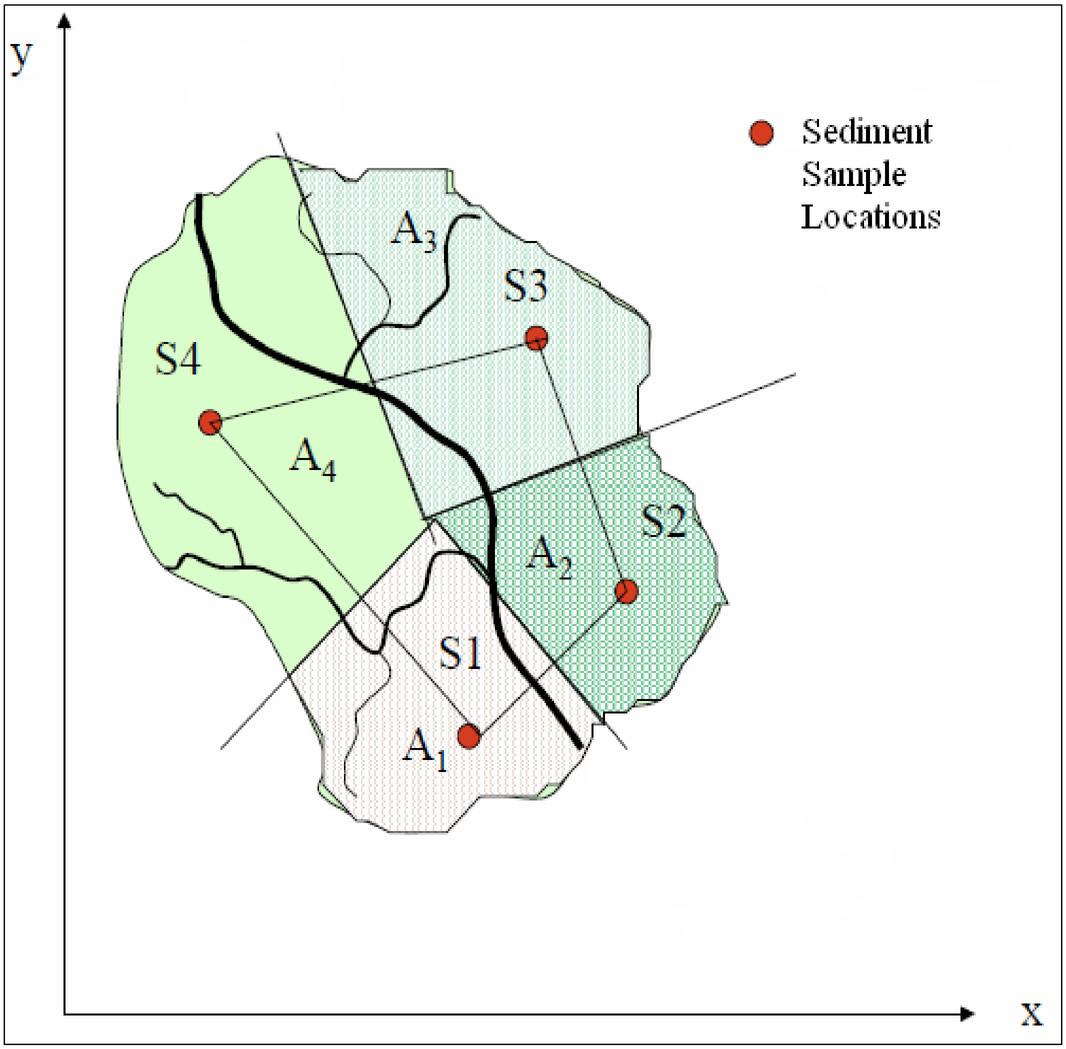

Figure 10. Use of Theissen polygon to determine area of influence.

Zones of influence (areal extent) of sediment samples

The above Theissen technique was applied to the sediment sample locations to determine each zone of influence (areal extent) as shown in Figures 11 and 12.

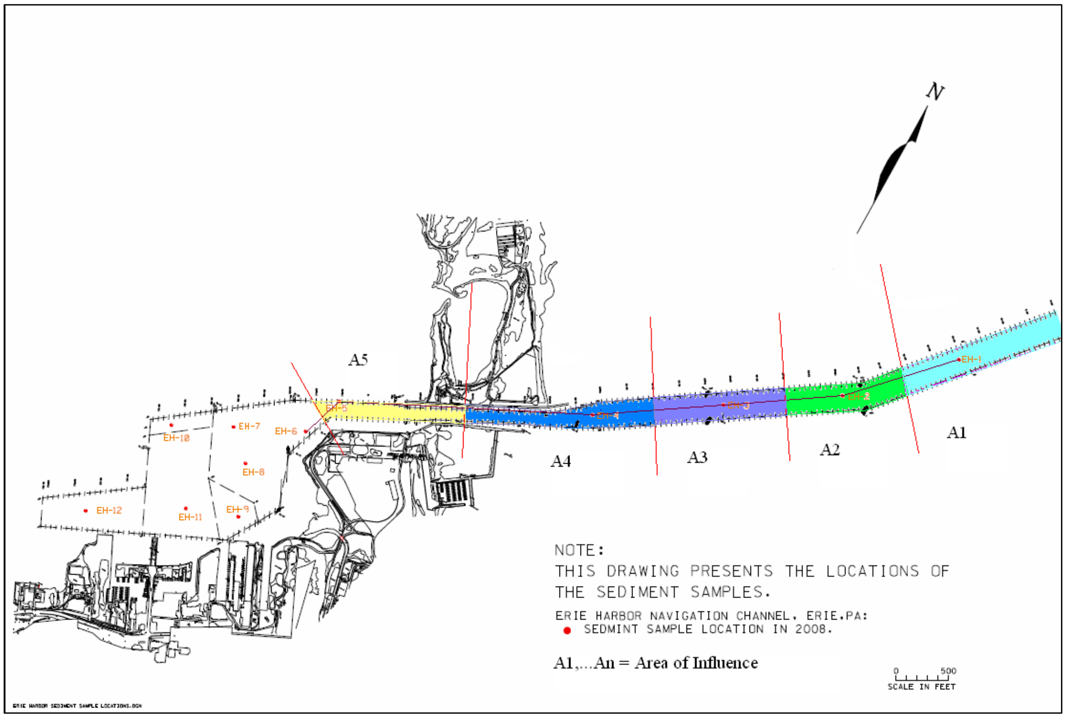

Figure 11. Zones of influence (areal extent) for samples EH-1 through EH-5.

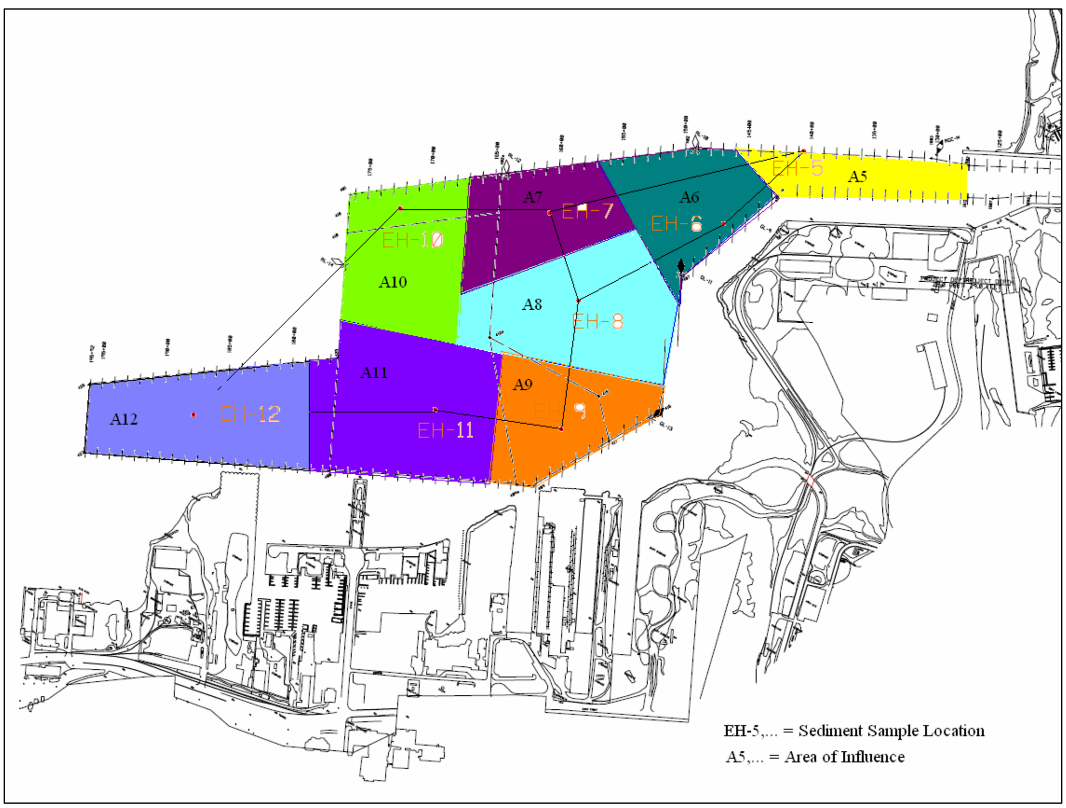

Figure 12. Zones of influence (areal extent) for samples EH-5 through EH-12.

Sediment volumetric analysis

The approximate volume of shoaled material within each zone of influence was determined using MicroStation /InRoads. The particle size distribution data given in Table 10 were used to calculate the quantity of each sediment type within each zone of influence.

Table 10. Particle size distribution of sediment samples at Harbor area.

Particle Size Distribution (%)	Harbor Area Sites											
	EH-1	EH-2	EH-3	EH-4	EH-5	EH-6	EH-7	EH-8	EH-9	EH-10	EH-11	EH-12
Clay	8	17	26	14	6	8	21	25	32	33	24	30
Silt	45	56	60	61	30	31	57	49	56	48	48	49
Fine Sand	46	24	6	21	59	59	20	18	8	13	16	11
Medium Sand	1	3	8	4	5	2	2	8	4	6	11	10
Coarse Sand	0	0	0	0	0	0	0	0	0	0	1	0
Gravel	0	0	0	0	0	0	0	0	0	0	0	0
Total Silt/Clay	53	73	86	75	36	39	78	74	88	81	72	79
Total Sand/Gravel	47	27	14	25	64	61	22	26	12	19	28	21

MicroStation/InRoads calculated the volume of shoaled material as result of changes between the original surface (2009 data) and the design surface (authorized channel depth of 30 ft). Figure 7 presents the amount of shoaled material for these changes. Table 11 provides each zone of influence volume in cubic feet and cubic yards. Table 11 provides two types of data referred to by Microstation/InRoads as "Cut and Fill." The volumes of cut materials were used for calculation of potential materials to be dredged.

As indicated by Table 11 below, only areas of A1, A4, A5, and A6 require cut of sediment (potential material to be dredged). Combined with the particle distribution, the amount of potential sediment volume by particle size was obtained and is presented in Table 12.

Suitability of sediment for creating wetlands or beach nourishment

Composition and grain size distribution are important in matching dredged material with an intended use. For simplification, the potential use here is based only on dredged material sediment type (i.e. rock; gravel and sand;

Table 11. Triangle volume report from MicroStation/InRoads.

Zone of influence	Cut Volume (ft^3)	Fill Volume (ft^3)	Cut Volume (yd^3)	Fill Volume (yd^3)
A1	657864.30	2685523.20	24365.30	99463.80
A2	0.00	5367306.90	0.00	198789.10
A3	0.00	6511183.20	0.00	241154.90
A4	2885004.30	4086262.80	106852.00	151343.10
A5	1316438.00	1645442.30	48757.00	60942.30
A6	45.60	1484926.50	1.70	54997.30
A7	0.00	3368779.60	0.00	124769.60
A8	0.00	4171102.00	0.00	154485.30
A9	0.00	2116389.90	0.00	78384.80
A10	0.00	9315191.10	0.00	345007.10
A11	0.00	8709572.20	0.00	322576.70
A12	0.00	14995083.20	0.00	555373.50

Table 12. Presque Isle sediment volumetric analysis.

	Zone of Influence							
Sediment Type	**A1**		**A4**		**A5**		**A6**	
Fine Sediment	%	CY	%	CY	%	CY	%	CY
Clay	8	1949	14	14959	6	2925	8	0
Silt	45	10964	61	65180	30	14627	31	1
Total	53	12914	75	80139	36	17553	39	1
Coarse Sediment	A1		A4		A5		A6	
Fine Sand	46	11208	21	22439	59	28767	59	1
Medium Sand	1	244	4	4274	5	2438	2	0
Coarse Sand	0	0	0	0	0	0	0	0
Gravel	0	0	0	0	0	0	0	0
Total	47	11452	25	26713	64	31204	61	1
	%	CY	%	CY	%	CY	%	CY
Total Sediment	100	24365	100	106852	100	48757	100	2

consolidated clay; silt/soft clay; and mixture of rock/sand/silt/soft clay). Other important factors such as contaminant status of materials; site selection; technical feasibility; environmental acceptability; cost/benefit; and legal constraints, which can affect the suitability of sediments for particular use or site, are not considered here.

Beach nourishment

Waves and tidal currents move beach materials continuously. If the moved material is not replaced, erosion will deteriorate the beach and eventually the shoreline. Beach nourishment may be necessary to enhance the beach profile if lost beach material is not replaced naturally. Dredging can supply the required large quantities of sand and gravel-sized material for beach nourishment.

Wetland restoration or creation

Dredged material has been used extensively to restore and establish wetlands. Wetlands restoration or rehabilitation using dredged material is usually a more acceptable alternative to the creation of a new wetland. Many of the world's natural wetlands are degraded or impacted, or have been destroyed, and the recovery of these wetlands is more important than creation of new ones. Creation of a new wetland would mean replacing one habitat type with another, which is not always desirable. Long-term planning, design, maintenance, and management are necessary to maintain a created wetland.

Wetland restoration using dredged material can be accomplished in several ways. For example, dredged material can be applied in thin layers to bring degraded wetlands up to an intertidal elevation. Dredged material sediment can be used to stabilize eroding natural wetland shorelines or to nourish subsiding wetlands. Sediment types that are suitable for restoration or creation of a new wetland are consolidated clay, silt/soft clay, or mixture of rock/sand/silt/soft clay. Table 13 summarizes the sediment type and suitability of sediment materials for each zone of influence.

Summary of sediment analysis in DTM

This chapter is summarized graphically in Figure 13 (from Microstation DTM). Figure 13 shows areas for potential dredging, sediment type and suitability (potential use) of each area, and volume of the sediment materials for each zone that has potential for dredging.

Table 13. Suitability of the sediment from each zone of influence

	Zone of Influence							
	A1		A4		A5		A6	
	Sediment Type		Sediment Type		Sediment Type		Sediment Type	
	Fine sediment and fine sand	Gravel and coarse sand	Fine sediment and fine sand	Gravel and coarse sand	Fine sediment and fine sand	Gravel and coarse sand	Fine sediment and fine sand	Gravel and coarse sand
Intended Use	Yes	NO	YES	NO	YES	NO	YES	NO
Wetland restoration or creation	yes		yes		yes		yes	
Beach nourishment	no		no		no		no	

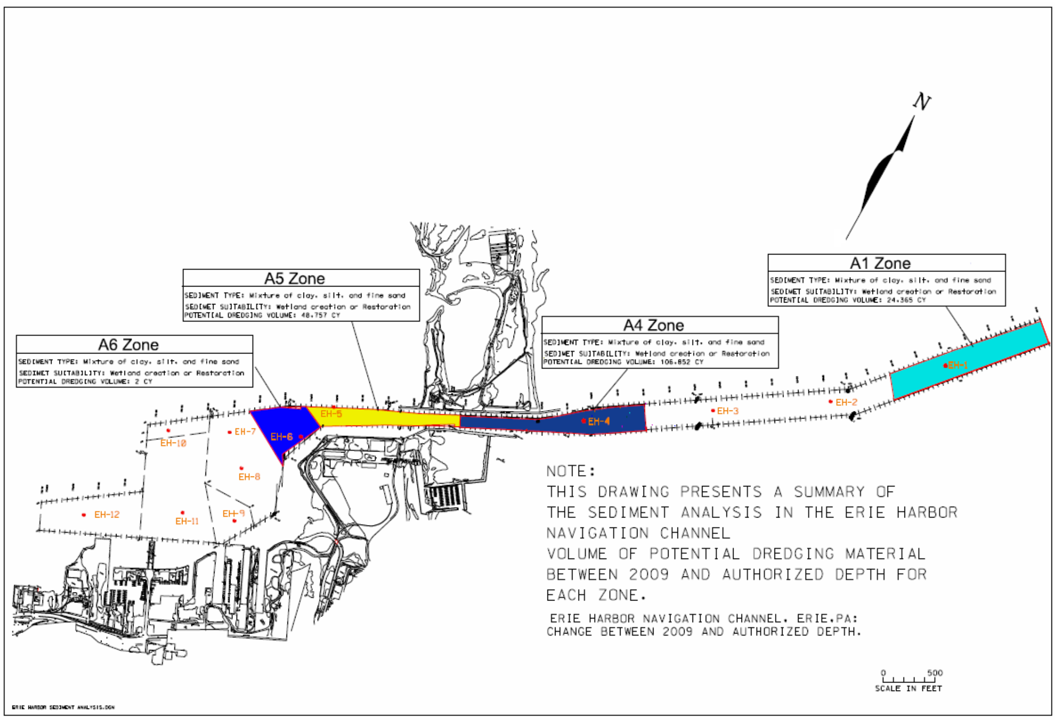

Figure 13. Summary of potential zones of dredging for changes between 2009 survey data and authorized depth.

6 Summary

Presque Isle is located on the southern shore of Lake Erie and shelters the Federal harbor at Erie, Pennsylvania. Under the Section 204 authority, the US Army Engineer District, Buffalo (LRB) is evaluating the use of dredged material from the Federal harbor project to potentially protect, restore, or create aquatic and ecologically related habitats, including wetlands; to reduce storm damage to property, and to transport and place suitable sediment. As requested by LRB, the US Army Engineer Research and Development Center (ERDC) conducted an investigation to quantify the amount of shoaled material from 1998 to 2009 in the Erie Harbor navigation channel and assess the suitability of the potential dredged material for beach nourishment or wetland restoration.

Erie Harbor is located on the south side of a bay formed by Presque Isle Peninsula on the south shore of Lake Erie approximately 78 miles west of Buffalo, New York. Geologically, Presque Isle was created by wave action on Lake Erie during the 10,000 years that have passed since the end of the Pleistocene ice age. Presque Isle was most likely located about 3 miles west of its current location when it was first formed but the constant pressure of wind, water, and longshore currents has gradually moved the peninsula to its current location where it continues to slowly migrate eastward.

This report reviews the dredging history and channel shoaling analysis at Erie Harbor. The statistical regression analysis of the available historical dredging material from 1873 to 1977 indicates that the loss of littoral material from Presque Isle to the Erie Harbor entrance channel was 130,800 yd^3 annually before 1960. With the sand replenishment program at Presque Isle up to 1992, when the breakwaters were completed and the nourishment program was reduced, the loss of littoral material substantially increased annually by 95,200 yd^3 to about 225,949 yd^3 per year.

Microstation/InRoads software version V8i was used for the channel shoaling and sediment analysis. Channel bottom elevation data were used to create digital terrain models (DTM) and color-coded elevation drawings. The depths and elevations are in feet and referred to low water datum elevation 569.2 ft (173.5 m) above mean water level. Dredging last occurred in 1998 and hence all channel bottom elevation changes are the result of natural processes.

The changes between the 2009 elevation survey data and the authorized channel depth of 30 ft (includes 1 ft overdepth) were used to calculate potential dredging volume by channel station. The majority of sediment shoaling occurred between the piers and at the lakeward end of the channel. Therefore, the volumes of potential dredging materials are high in these areas and were estimated to be 106852 and 24365 yd^3, respectively.

The 2009 sediment sample data were used to evaluate the physical characteristics of shoaled material within the channel. The channel shoaling quantities were combined with the sediment characteristics to assess the amounts of the various physical components of the potential shoaled material. The Thiessen polygons method was used to identify 12 zones of influence based on the sediment sample locations. Microstation/InRoads was used to calculate the volume of sediment material for potential dredging of each zone of interest (influence). Among these 12 zones, only four zones have potential for dredging. Based upon the review of sediment size distribution, the sediment materials from these areas are primarily fine-grained material and are considered suitable only for the creation or restoration of wetlands.

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U.S. Army Engineer District, Detroit. 1985. *International Great Lakes Datum*. Detroit, MI: Engineering and Technical Services, Great Lakes Hydraulics and Hydrology Office.

Appendix A: Color-coded Elevation and Digital Terrain Model (DTM)

This information is available on a DVD. To obtain copies of the DVD, please contact:

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Appendix B: Sediment Analysis Files

This information is available on a DVD. To obtain copies of the DVD, please contact:

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Presque Isle is located on the southern shore of Lake Erie and shelters the federal harbor at Erie, Pennsylvania. The US Army Engineer District, Buffalo (LRB) requested the US Army Engineer Research and Development Center (ERDC) to quantify the amount of shoaled material from 1998 to 2009 in the federal navigation channel and to assess the suitability of the potential dredged material for beach nourishment or wetland restoration.

The project entailed review of the dredging history at Erie Harbor, including channel shoaling analysis and sediment analysis. The statistical analysis of historical data on dredged material from 1873 to 1977 indicated the loss of littoral material from Presque Isle to the Erie Harbor entrance channel.

Microstation/InRoads software was used to create digital terrain models (DTMs) of the channel soundings and to evaluate the channel sediment shoaling. Color-coded elevation change drawings were created from 1998 to 2010 and show only changes from the natural processes since no dredging occurred during that time period.

The Thiessen polygons method was used to determine 12 individual areas (zones) of influence around a set of sediment sample locations. Only four zones have measurable volume of the shoaled materials with a potential for dredging. Based upon the review of sediment size distribution, the material from these areas is primarily fine-grained and is considered suitable only for the creation or restoration of wetlands.

15. SUBJECT TERMS

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Digital terrain models (DTMs)
Erie Harbor
Lake Erie
Presque Isle
Shoaling analysis
Thiessen polygons
Wetland restoration

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