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Effect of Armoring a Cohesive Nearshore with a Thin Cobble Lag, Shoreham, Michigan

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) summarizes monitoring results of the 1995 lake bed paving project conducted at Shoreham, MI, on Lake Michigan by the U.S. Army Engineer Research and Development Center (ERDC), in collaboration with The U.S. Army Engineer District, Detroit. The CHETN also discusses the effectiveness of lake bed paving in reducing cohesive lake bed downcutting and mitigation of bluff erosion. The lake bed paving concept was examined as an innovative alternative to traditional revetment construction to protect the shoreline.

BACKGROUND: The project area is located at Shoreham, MI, in Berrien County about 5 km (3.4 miles) south of St. Joseph Harbor on southeast Lake Michigan (Figure 1).

Figure 1. Project location map.

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In September–October 1995, the Detroit District placed approximately 45.7 cm (18 in.) of stone on the lake bed near Shoreham, MI (Figure 2). The purpose of this study was to demonstrate that downcutting of the lake bed could be arrested with a relatively thin layer of cobble armor. A reduction in downcutting of the nearshore should ultimately lead to a reduction in bluff recession (Parson, Morang, and Nairn 1996). The stone placement encompassed an area roughly 335 m (1,100 ft) long, commencing at the 3.7-m (12-ft) contour (IGLD 1985 datum) and extending 152 m (500 ft) lakeward. Forty-three survey lines were taken at the site following the placement of the stone in 1995. These original survey lines were reoccupied in 2005.

Figure 2. Stone placement captured in the September 1995 aerial photograph.

DATA COLLECTION

Survey Charts and Data. A number of historic maps and charts were acquired with the bathymetric and topographic conditions over time. All of the following historic maps and charts were registered using the ESRI ArcMap 9.1 Georeferencing tool. This source of data include the following:

a. General Land Office (GLO) plat maps from 1830 were downloaded from the Michigan Department of Natural Resources Web site (*http://www.michigan.gov/dnr*). These digital maps provided a top of bluff line covering the Shoreham area.

b. An 1871 digital survey map covering Shoreham, which contained bathymetric soundings and topographic contours. The map was registered to the 1938 aerial photographs. This improved the quality and accuracy of the registered product by reducing the amount of error associated with registering images over large geographic areas. The vertical datum was indicated for the soundings as referring to a water level that is 0.49 m (1.6 ft) below high water of 1838.

c. A 1945 Geophysical Data System for Hydrographic Survey Data (GEODAS) bathymetry dataset was obtained from the GEODAS DVD v4.1.18 provided by the National Ocean Service (NOS) and the National Oceanic and Atmospheric Administration (NOAA). This data set covered an area from New Buffalo Township northward to St Joseph Township.

d. A 1965 U.S. Lake Survey chart was acquired from National Archives and Records Administration (NARA). This chart contained bathymetric soundings of Shoreham area. The vertical datum for the chart was IGLD 1955.

e. Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) data collected in October 1999 was provided by the Detroit District. This data set includes bathymetry data at Shoreham. Horizontal datum was State Plane Michigan South, Zone 2113, North American Datum (NAD) 1983. The vertical datum was specified as International Great Lakes Datum (IGLD) 1985.

f. Light Detection And Ranging (LIDAR) data collected on 20 April 2001 was provided by the Detroit District as comma-delimited text files. This data set includes topographic information from the waterline to approximately 300 m (984.2 ft) inland, and covers all of the Berrien County shoreline. Horizontal datum was Universal Transverse Mercator (UTM) Zone 16 North, NAD 1983. The vertical datum was specified as North American Vertical Datum of 1988. This data set was used to determine the bluff height.

g. Post-construction USACE survey of October 1995.

h. USACE survey of 2005 reoccupying the 1995 survey.

Aerial Photographs. Historic aerial photographs from 1938, 1960, 1973, 1989, 1995, 1996, 1999 and 2002 and a satellite image from 2004 were provided by the Detroit District.

Geomorphic and Geological Conditions. Larson (2005) has produced a plan view of the surficial geology together with stratigraphic sections for the study area north and south of St. Joseph Harbor based on information collected and interpreted since more than 20 years ago. The surficial geology and stratigraphic structure along a 10-km (6.2-mile) reach south of the harbor including Shoreham has been reproduced in Figure 3. In general terms, the area immediately south of the harbor consists of three primary units: lacustrine sand sandwiched between an upper till at the surface and a lower till at and below the lake level. The bluff height is about 27.4 m (90 ft) through half of this reach and diminishes to 21.3 m (70 ft) at about 5 km (3.1 miles) south of the harbor where the upper and lower till layers no longer exist and only lenses of clay appear within a lacustrine sand body. The average bluff height is about 18.3 m (60 ft). There are lenses of clay in the lake bed just around the Shoreham area, which was exposed at the time of stone placement representing a cohesive shore.

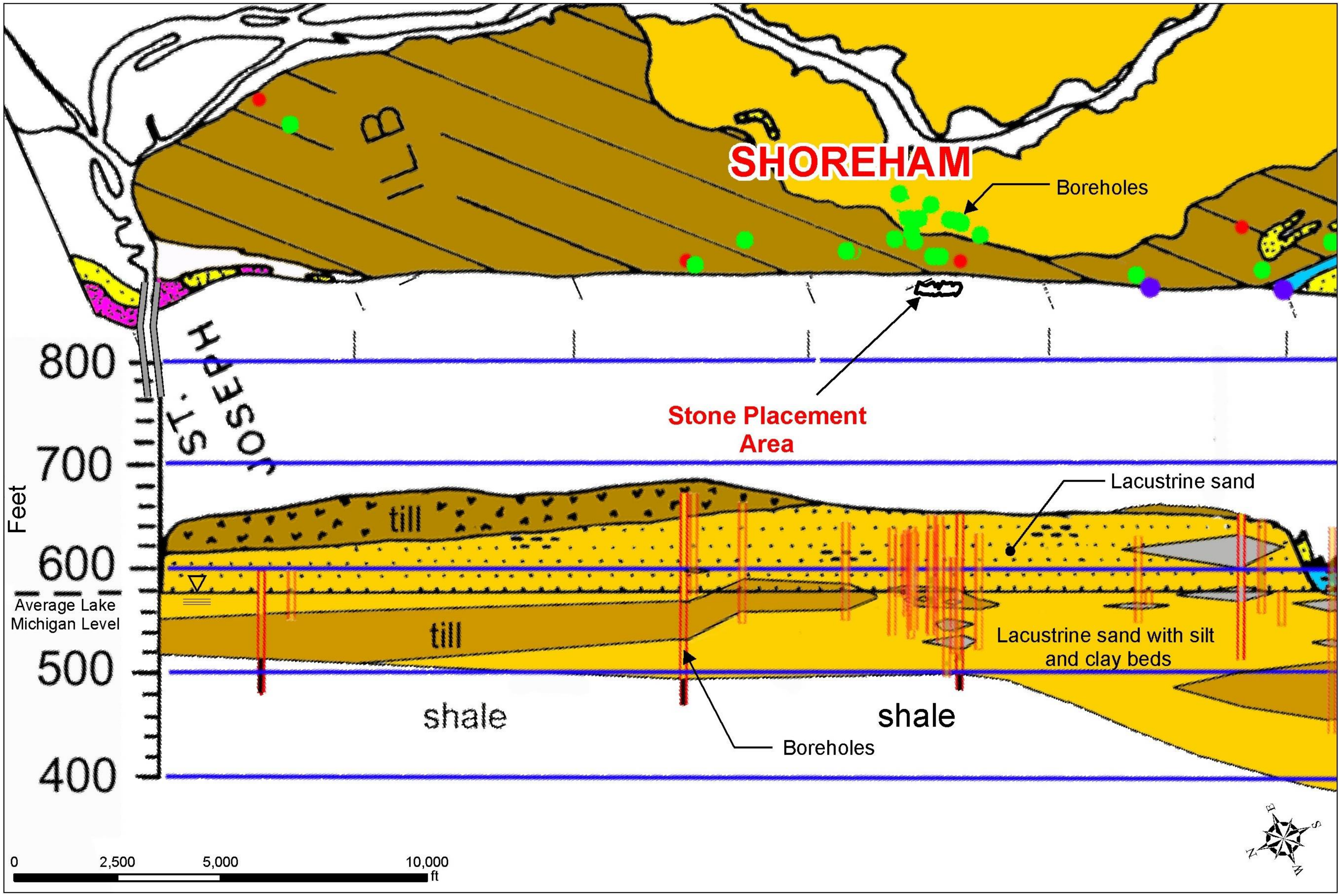

Figure 3. Surficial geology and stratigraphic structure south of St. Joseph Harbor (after Larson 2005).

Videographic Observation. Approximately 30 min of underwater videotape was collected on 21 June 2005 to document the present condition of the stone. The boat and video camera were placed upwind of the stone placement area and were allowed to drift through the study area. Several lines of videographic data were collected with this method. The stone appeared in good condition and showed evidence of little to no movement since placement. Sandy patches were observed intermittently over the rock along with small amounts of aquatic macrophytes and zebra mussels. No exposed clay was observed on the lake bed. Additional underwater videotape in or near the study area was collected in 1994, 1995, and 1996.

DATA ANALYSIS

GIS Analysis of Aerial Photographs and Survey Charts. Aerial photograph prints were available for several years between 1938 and 2004 (see "Data Collection"). These prints were scanned at high resolution to create digital versions of the prints for use with photo registration software. The digital aerial photographs were registered using PCI Geomatica 9.1 OrthoEngine extension. All of the historic maps and charts mentioned earlier in "Data Collection" were also registered using the ESRI ArcMap 9.1 Georeferencing tool.

Top of bluff lines were digitized from the registered air photographs and historical charts. Digitizing was performed by using Heads Up Digitizing (HUD) in ArcMap 9.0. For registered photographs with a scale of 1:6,000, digitizing was done at a map scale between 1:1,000 and 1:2,000. For photographs or charts with a smaller scale (e.g., 1:10,000 or higher), a smaller map scale was used (e.g., 1:2,500 – 1:5,000). Figure 4 shows the bluff line comparison results for the period between 1830 and 2004. It may be seen that the bluff has been eroding continuously at this site. The long-term average recession rate is estimated at 0.9 m/year (2.9 ft/year). Since the placement of stone layer, the bluff has continued to erode between 1995 and 1999 and between 1999 and 2002.

Figure 5 shows bluff recession details since completion of stone placement project to present. Total recession between 1995 and 2004 for every 10 m (32.8 ft) along the Shoreham bluff are also given in this figure. Average total recession is 8.4 m (27.6 ft), which translates to a recession rate of about 0.9 m/year (3 ft/year) close to its long-term average. In this figure, the 2002 and 2004 lines are identical, i.e., there was no bluff erosion between these years likely because of recent low lake levels. During low lake levels there is little or no direct wave attack on the bluff face, which explains the growth of vegetation on the bluff face. During periods of high lake levels the bluff face is much steeper with little or no vegetation.

Using this information, the historic retreat rates for periods between each available and reliable snapshot were calculated at Shoreham. Figure 6 provides: (a) time along the x-axis from 1830 to present; (b) the estimated bluff crest retreat rate (referenced to the left hand scale), which appears as a step function as it relates to the change in the bluff position between snapshots taken at the beginning and end of each segment; (c) the average bluff retreat rate for the period from 1830 to 2004; and (d) the lake level variations from 1830 to present. In general, higher retreat rates have occurred during periods of high lake levels.

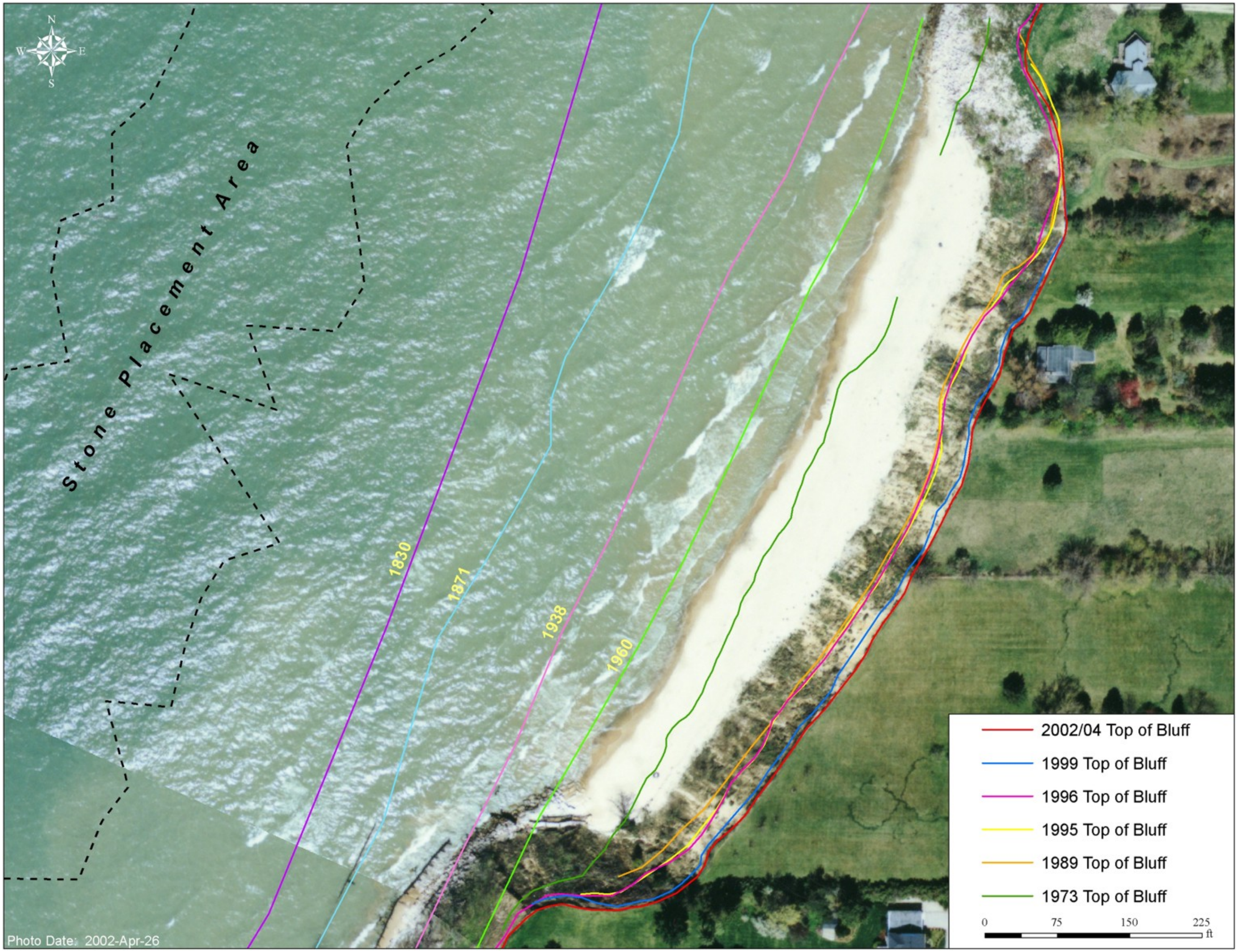

Figure 4. Historic top of bluff lines at Shoreham, MI.

Figure 5. Bluff recession at Shoreham, MI, between 1995 and 2004.

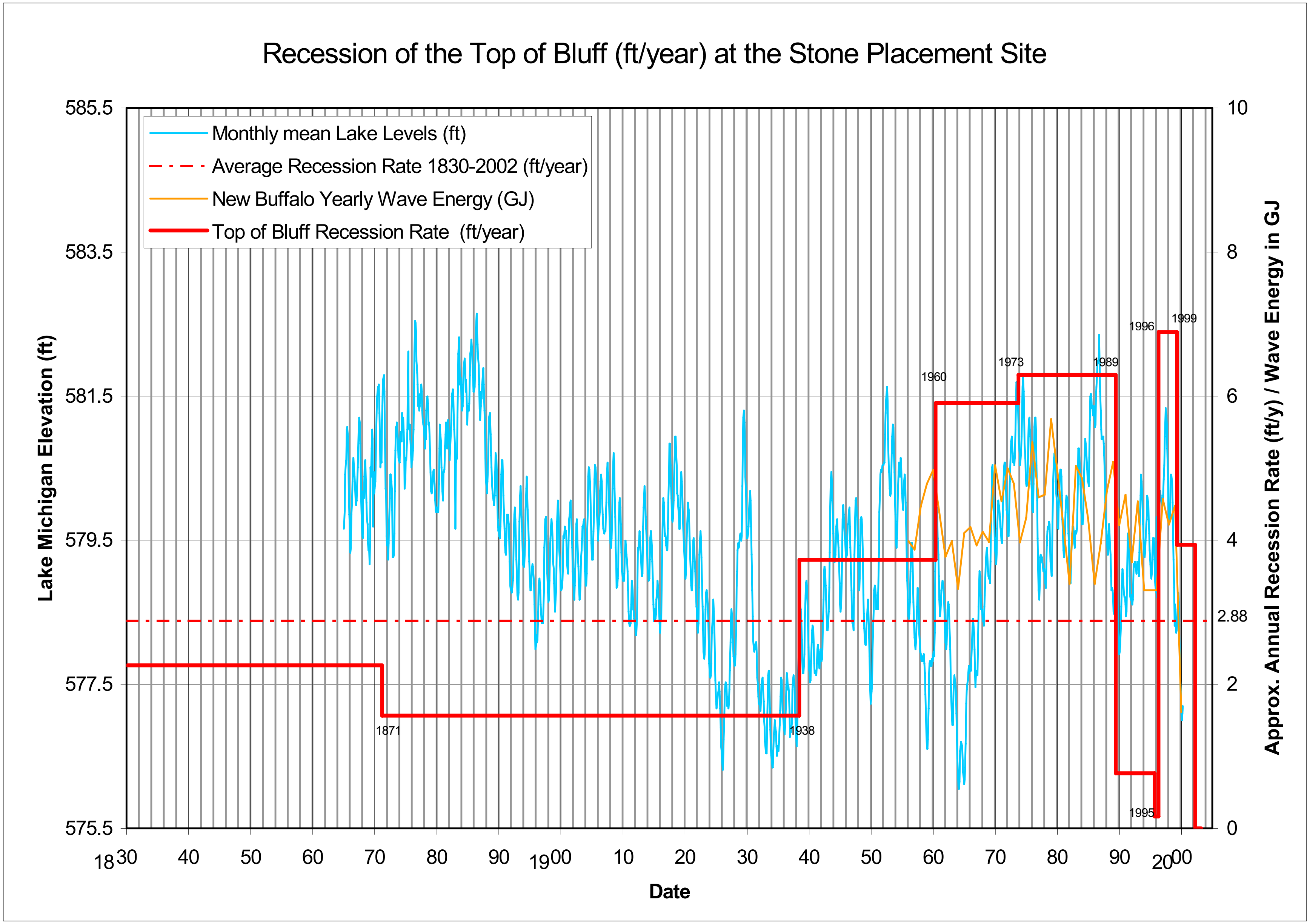

Figure 6. Bluff recession rate at Shoreham, MI, and Lake Michigan levels.

Surface Comparison. The stone placement project was completed between July and October of 1995 at Shoreham. Stone was placed on the lakebed between the 12- and 16-ft- (3.7- and 4.9-m-) depth contours below low-water datum (LWD) over an approximately 152.4-m × 335.3-m (500-ft × 1,100-ft) (cross-shore × longshore) area to create a rock apron for protecting the lake bed as well as the bluffs by reducing downcutting. A survey of the completed project was conducted in October 1995. In May 2005, a new survey of the area was conducted.

Figure 7 shows the surface comparison between the 2005 survey and the 1995 post-construction survey. The light blue and yellow area represents an area with relatively small or no change and should therefore correspond to the stone placement area. The purple box in this figure is the estimated stone placement area based on this comparison. The average elevation difference in the stone placement area (purple box) is –0.0014 m (-0.005 ft), which is within the accuracy of the surveying techniques. The stone surface has therefore been stable over the 10-year period since construction.

Figure 8 shows the data along the profile line indicated in Figure 7, together with other survey data and bluff lines. None of the data sets provide data in shallow water. Therefore, part of the nearshore bathymetry in this figure had to be estimated. It may be seen that lake bed lowering had continued between the 1871 and 1965 surveys. The lowering, however, stopped sometime after 1965, and the 2005 survey shows some sand accumulation on the lakeward side of the stone layer. This is likely because of the U.S. Army Corps of Engineers' beach nourishment activities downdrift of St. Joseph Harbor since 1970. A bar is also observed shoreward of the stone area in the 2005 survey.

EVALUATION OF PAVING EFFECTIVENESS

It was found in the previous sections that:

a. The surface of the stone layer has been stable over the 10-year period between 1995 and 2005. Therefore, the lake bed has been prevented from eroding in the area of the stone placement.

b. Sand accumulation has occurred on the lake side of the stone area in the form of a bar. A bar is also observed on the land side of the stone layer according to the 2005 survey. Sand accumulation, however, is believed to be a result of Corps beach nourishment activities downdrift of St. Joseph Harbor.

c. Subsequent to the placement of the cobble lag at Shoreham, MI, the bluff has continued to erode at a rate close to its long-term average recession rate between 1995 and 2004 (i.e., 0.9 m/year (3 ft/year); however, it is possible that some long-term benefit may be realized through the development of a shelf in the nearshore.

d. Historically, bluff erosion at Shoreham (like other parts on Lake Michigan) has been severe during high lake level periods. Recent bluff erosion after completion of the project has also occurred during high lake levels between 1996 and 1999.

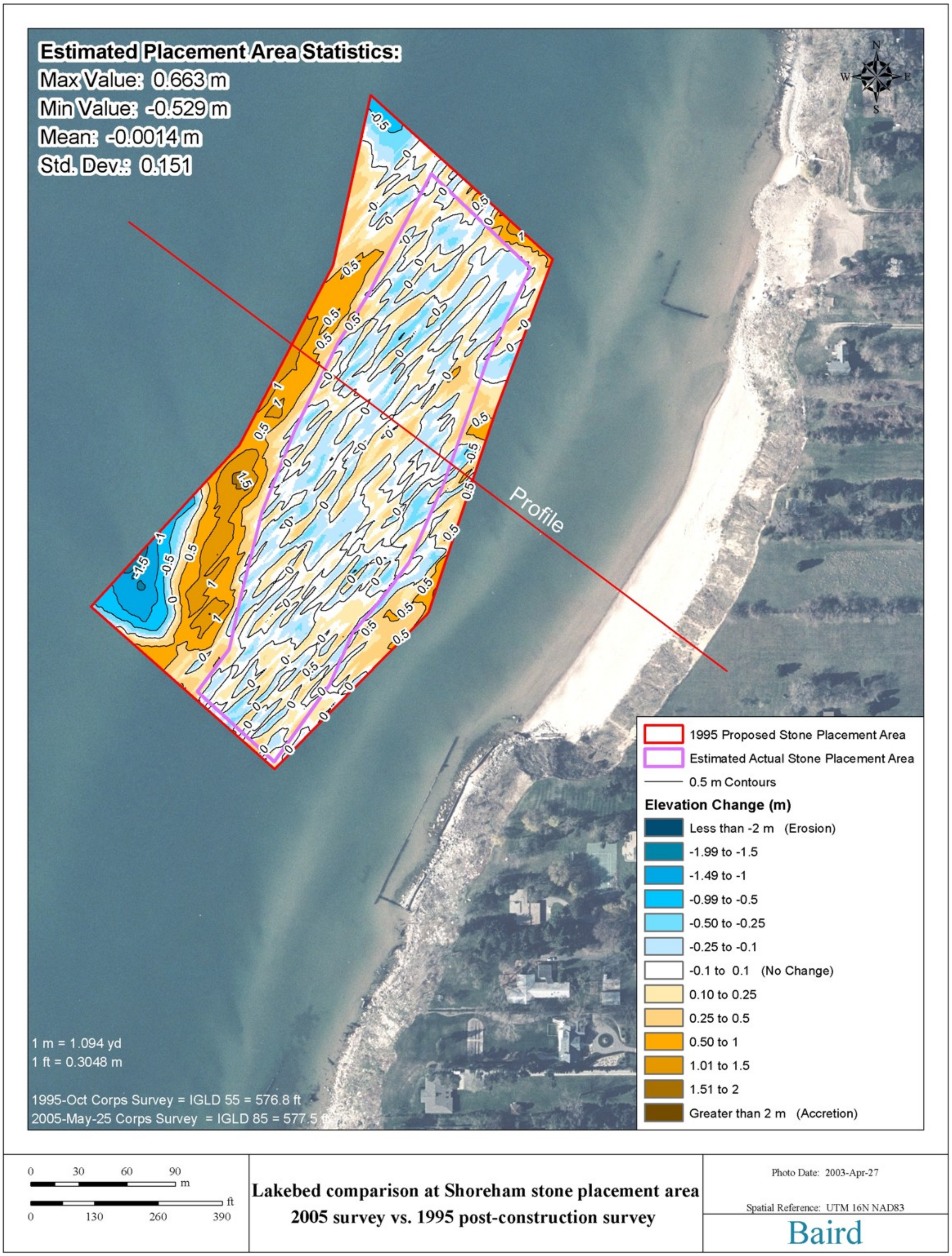

Figure 7. Surface comparison between 1995 and 2005 USACE surveys.

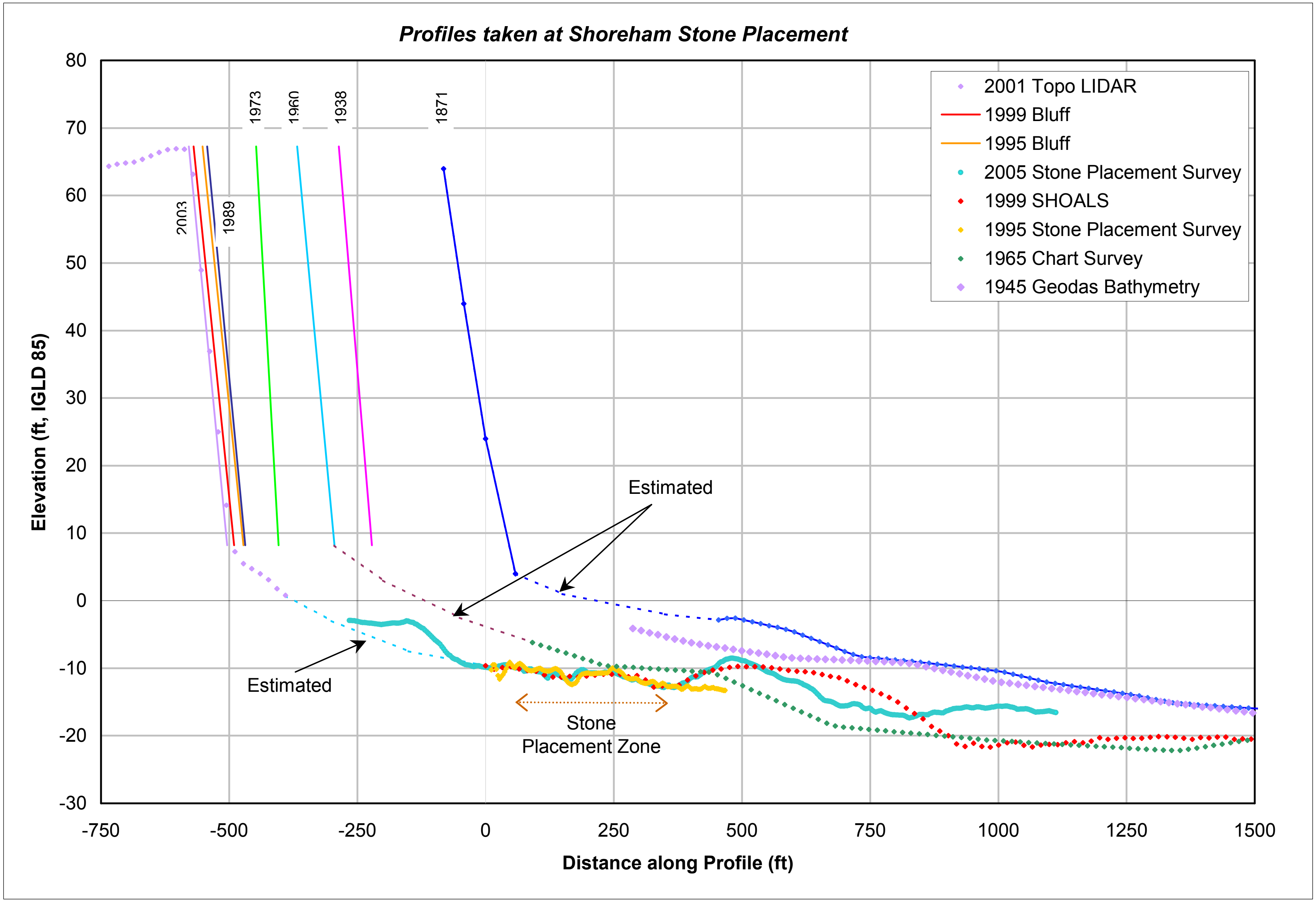

Figure 8. Historic and recent nearshore profiles at Shoreham, MI.

There is no survey data to evaluate lake bed elevation change between the stone placement area and the shoreline since the placement of the stone. It is therefore not possible to determine the nearshore downcutting rates in this zone and whether these have been influenced by the stone placement. However, even with all the required data available, it would have been difficult to isolate the effect of stone placement in reducing downcutting from the Corps' ongoing sand placement project north of the Shoreham area.

From Figure 8, it may be seen that the stone surface is at about 3 m (10 ft) below LWD. Hindcast data for other nearby projects indicates that the wave climate in the area is calm for about 30 percent of the time (40 percent when ice is included), and wave height is less than 2 m (6.6 ft) for about 55 percent of the time. Thus, for a total of 85 to 95 percent of the time the wave height is less than 2 m (6.6 ft). Consequently, most waves propagate over the placed stone surface without energy dissipation. As downcutting is believed to be proportional to the rate of wave energy dissipation, it is therefore unlikely that the stone layer has had any effect on reduction of downcutting between the stone placement area and the shore. Moreover, downcutting rate increases as the depth decreases towards the shoreline, and it is the downcutting rate in shallow water close to the bluff toe which controls the bluff erosion (Philpott 1984; Davidson-Arnott 1986; Kamphuis 1987). It is therefore concluded that the present paving was placed too far offshore. Unfortunately, the deep placement was necessary because of the barge and equipment used at the time. Lake bed paving would be more effective if placed in shallower waters close to the shoreline.

In a previous study, conducted by Baird and Associates for the U.S. Army Engineer District, Chicago, using extensive COSMOS (Nairn and Southgate 1993; Southgate and Nairn 1993) numerical modeling in addition to physical modeling, it was concluded that in order to reduce downcutting it is necessary to either cover the whole lake bed (i.e., the entire profile out to about 3.7 m (12 ft) depth) or reduce the wave energy. While the cost for complete coverage of the lake bed may not be justified, a stable berm (submerged breakwater) alternative installed in appropriate depth provided the highest degree of downcutting reduction as well as the shortest time line for some beneficial protection for existing shoreline structures as related to immediate reductions in wave energy. Even with such an alternative, a sufficient degree of reduction in downcutting, particularly in waters shallower than 1.5 m (5 ft) below LWD, was not achieved to fully justify its construction. In a subsequent study, Baird examined the combination of a stable berm (submerged breakwater) and partial lake bed paving and found that, with a proper design, a minimum reduction in downcutting of 75 percent could be expected in the nearshore area provided that the stone can be kept on the bed in the shallow waters.

POINTS OF CONTACT: This CHETN was written by Mohammad Dibajnia, W. F. Baird & Associates Coastal Engineers, 627 Lyons Lane, Suite 200, Oakville, Ontario, Canada L6J 5Z7. Andrew Benziger, U.S. Army Engineer District, Chicago, reviewed this CHETN. For additional information, contact Dr. Andrew Morang, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (Andrew.Morang@erdc.usace.army.mil) or Dr. James Selegean at U.S. Army Engineer District, Detroit (James.P.Selegean@lre02.usace.army.mil). This study is a product of the National Shoreline Erosion Control Development and Demonstration Program (Section 227 of the U.S. Water Resources and Development Act of 1996). William R. Curtis is Program Manager. For more information, visit

the program's Web site at: *http://chl.erdc.usace.army.mil/Section 227*. This technical note should be cited as:

> Dibajnia M., J. Selegean, and A. Morang. 2006. *Effect of armoring a cohesive nearshore with a thin cobble lag, Shoreham, Michigan*. Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-III-74. Vicksburg, MS: U.S. Army Engineer Research and Development Center. An electronic copy of this CHETN is available from *http://chl.erdc.usace.army.mil/chetn/*.

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