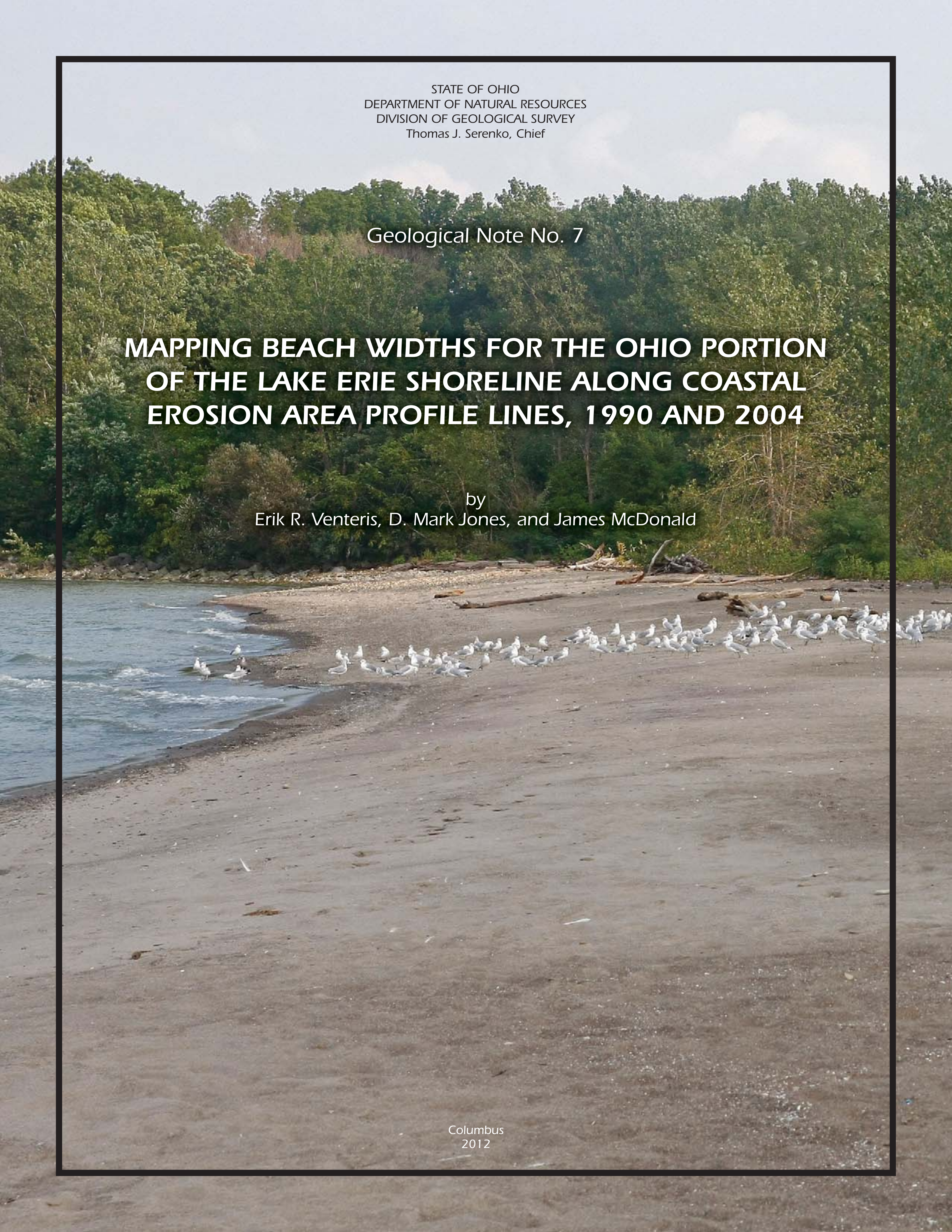

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
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Thomas J. Serenko, Chief

Geological Note No. 7

MAPPING BEACH WIDTHS FOR THE OHIO PORTION OF THE LAKE ERIE SHORELINE ALONG COASTAL EROSION AREA PROFILE LINES, 1990 AND 2004

by
Erik R. Venteris, D. Mark Jones, and James McDonald

Columbus
2012

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Editing: Charles R. Salmons
Graphic design and layout: Lisa Van Doren

Front cover: View looking southeast along the barrier beach at the mouth of Old Woman Creek, Erie County, Ohio.

Back cover: Two aerial views of the mouth of Old Woman Creek showing the variability of beach width over time. In 1990 (top image), the beach was narrower, particularly towards its northwest end (upper left), than in 2004 (bottom image). Southeast of the creek's mouth, a barrier beach extends beyond the photograph to a total length of about 800 feet (244 meters; see front cover image).

CONTENTS

FIGURES

TABLE

ABBREVIATIONS USED IN THIS REPORT

cosine	cos
foot (feet)	ft
meter (s)	m
mile (s)	mi
square meter (s)	m^2
tangent	tan

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MAPPING BEACH WIDTHS FOR THE OHIO PORTION OF THE LAKE ERIE SHORELINE ALONG COASTAL EROSION AREA PROFILE LINES, 1990 AND 2004

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ABSTRACT

The beaches of the Lake Erie coast provide critical protection against shore erosion, in addition to providing wildlife habitat and recreational opportunities. Accordingly, our study inventories the changes in beach widths along the Ohio portion of the Lake Erie shoreline. Beach boundaries were digitized from 1990 and 2004 aerial photography into a geographic information system (GIS). Beach widths were measured along previously defined transects, which were originally drawn to monitor shore erosion (bluff retreat). There are 13,875 transects covering the mainland shoreline and the islands. Our study was initiated as part of a broader work to better understand changes to the shoreline over time and to assess the relative impacts of natural and human processes. The work adds two additional time periods to shoreline monitoring that has been conducted periodically by various government agencies since 1876. In addition to providing a valuable inventory of the beach resource, this data can be used to better understand lake processes, including sedimentary mass balance; the interaction between bluff retreat and beach geometry; and the long-term impact of engineering projects, such as the construction of structures (e.g., groins, jetties, dams on tributaries) and beach nourishment. Analysis of previous studies and new data shows a steady decrease in the length of the shoreline containing beaches from 1937 to 1990. Much of this loss is due to an increase in the amount of armored shoreline (e.g., riprap, break walls) from 30 percent to 54 percent. The latest measurements show a reversal in this beach-loss trend from 1990 to 2004, due to a combination of beach engineering projects and a drop in lake level.

INTRODUCTION

Beaches are an integral part of the Lake Erie shoreline, providing both essential protection against shoreline erosion and necessary habitat for wildlife, as well as recreational opportunities and aesthetic qualities. However, beaches are subject to areal and volumetric changes brought on by storms, climatic trends, urbanization and development, dredging, beach nourishment, sand mining, nearshore downcutting, and changes in lake level. Such processes may result in a beach becoming substantially larger or disappearing altogether, either for a few weeks, seasonally, or permanently.

Because beaches are critical to coastal settings, many parties share an interest in understanding the changes in beaches and in whether some changes can be predicted, prevented, or reversed. While the prevailing wisdom holds that Ohio's beaches are diminished in width from pre-settlement or preindustrial times, any effort to assess the changes and causes is complicated by the short-term and long-term factors previously described, as well as natural temporal and spatial variability. For example, is a change in beach width at a given locale due to changes in local conditions (shore armoring, groin installation), or is it related to a system-wide change in lake level or the sediment budget?

Our study was designed to quantify the changes in the widths of Ohio's Lake Erie beaches. Beach width is a convenient metric because aerial photography and survey data from which to measure beach widths are readily available for most of Ohio's coast and islands (fig. 1) for a number of dates.

METHODOLOGY

Measuring beach widths

The base aerial imagery for this study was originally collected for the legislatively mandated Coastal Erosion Area mapping program[1]. Panchromatic imagery (film-based) at a nominal scale of 1:1,000 was collected April 18–19, 1990, and converted to a digital format through scanning and was georeferenced using ArcMap (ESRI, 2009). Digital, color orthoimagery was collected on April 9, 10, and 14 in 2004 by Kucera, Inc. The imagery was flown at a nominal scale of 1:1,200 and has a spatial resolution of 0.5 feet (ft; 0.2 meters [m]). Orthorectification was based on a digital elevation model (DEM) derived from LiDAR data collected concurrently with the imagery.

There is no unique way to define what material represents a beach. For this project, near-shore sediment that can be mobilized by wave or wind action was considered a beach. Generally, beaches are composed mainly of sand and gravel but can range from silt to cobble-sized grains. The lithologic composition (quartz sand vs. shale fragments) is not a part of the definition for this project. Sedimentary texture was identified using aerial photography. Sediment lakeward of the active wave wash zone was considered beach for the purposes of this study. Any areas covered by dense vegetation, even those that were clearly sand (for example, spits), were considered stabilized and therefore not beach.

Beach widths were digitized in ESRI ArcGIS along Coastal Erosion Area transect lines. Widths in this data set are horizontal or map distances. Transects were originally drawn to be perpendicular to the bluff crest. An alternate orientation for the measurement of beaches would be a line

[1]See Ohio Revised Code 1506.06, available online at <http://codes.ohio.gov/orc/1506.06>, last accessed July 23, 2010.

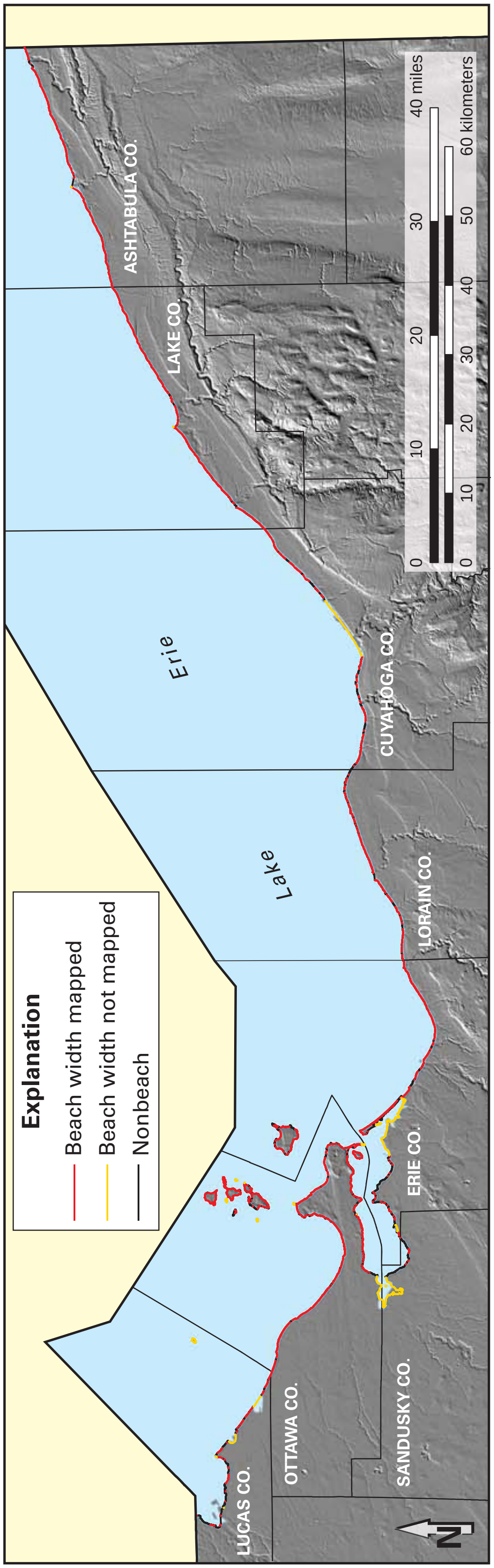

FIGURE 1.—Map of Ohio's Lake Erie shoreline showing where beach widths have been mapped, where beach does not exist, and areas where measurements have not been collected.

perpendicular to the water interface. For the majority of beaches, the bluff crest and lakeward beach boundaries are parallel, so there is no geometric difference between the definitions. Where transects were not perpendicular to the shore (usually isolated situations where erosion had altered the shoreline orientation), transects were corrected. The width of a beach was defined as the distance between the lakeward and landward boundaries along the transect line. The lakeward points were digitized to approximate the midpoint of the wave wash zone. The landward boundary was defined as the furthest landward extent of wave- and wind-transportable sediment. For the Ohio Lake Erie shoreline, this is typically the base of the till or bedrock bluff. Additional common boundaries include structures, such as retaining walls, and the beginning of vegetation.

Geometric correction of Coastal Erosion Area transect orientations

One potential correctable error arises when the Coastal Erosion Area transects do not cross the water-shore interface at a perpendicular angle (fig. 2). Such errors are systematic and always result in an overestimation of the width of a beach. The error caused by the departure angle from 90 degrees was assessed using the transect lines and the 1990 shoreline. The correction is

$$A_c = \cos\theta \cdot A \qquad (1)$$

where θ is the angle of difference between the transect line and a line perpendicular to shore, A is the measured distance, and A_c is the corrected distance. The correction was estimated from a low-resolution digitization of the 1990 shoreline. Correction statistics were calculated for the transects that contained beaches. Ninety percent of the corrections were less than 1.4 ft (0.43 m), which is much less than the estimated error from digitization. Occasional large corrections were required for combinations of wide beaches and large departure angles. Beach widths for such areas typically are invalid because they cut across intervening features or have other problems that render the width measurement meaningless (fig. 3). Overall, most transects are perpendicular to the shore, and the correction was not applied to individual transects when performing the final calculations presented herein.

Geometric correction of beach widths due to lake level changes

The digitized beach boundaries provide information on the changes in beach width between 1990 and 2004 but do not separate potential causes. The width of a beach can change because of lake level fluctuations or changes in amount of sediment (mass balance) or both. To detect changes in the configuration of sediment (true mass balance cannot be calculated from this data), beach widths must be corrected for differences in lake level between the 1990 and 2004 photo dates. The correction to remove the effect of lake level changes from the width comparison was calculated by the equation

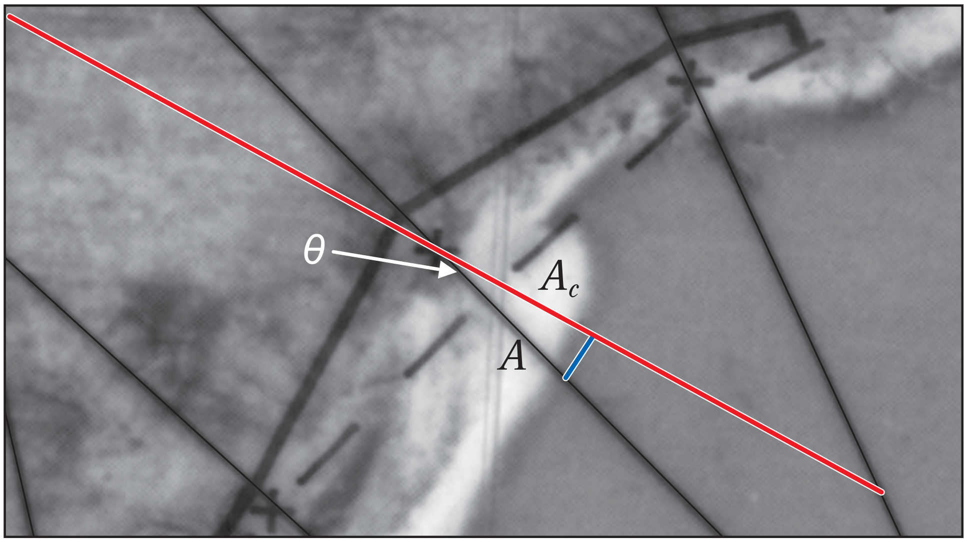

FIGURE 2.—Illustration showing a Lake Erie Coastal Erosion Area transect that does not intersect the shoreline at a right angle and the correction variables from equation 1. The black line is the original transect, and the red line shows the corrected orientation. The blue line is added to complete the right triangle to aid visualization of the geometry.

FIGURE 3.—Photo showing a Lake Erie Coastal Erosion Area transect that does not cross the beach in a meaningful way. Most such lines were established with a proper shoreline orientation, but later construction projects (in this case a jetty for a harbor) can render individual transects meaningless.

$$A' = A - a \qquad (2)$$

where A' is the corrected distance, A is the original digitized distance, and a is the correction. The correction term is calculated

$$a = \frac{b}{\tan \alpha} \qquad (3)$$

where b is the lake level change and $\tan \alpha$ is the slope of the beach.

Changes in lake levels were determined using data from lake level gauges operated by the National Oceanic and Atmospheric Administration (NOAA, 2006), National Ocean Service and located at Toledo, Marblehead, Cleveland, and Fairport, Ohio. The Erie, Pennsylvania, station also was used because it is the closest station for a portion of the eastern Ohio shore. An average lake level was calculated for each station over the range of collection days for each year. (It is possible to correct only for differences in mean lake level and lake-wide, wind-driven events, not local wave conditions.) Lake levels were nearly constant from east to west for the 1990 data, but there was a wind-driven seiche event for 2004, with levels decreasing from west to east. The difference in lake levels between the dates—the lake level in 2004 ranged from 0.4 to 1.0 ft (0.1 to 0.3 m) less than in 1990—followed a very predictable west-to-east trend, allowing the lake level correction to be applied for each location using a linear regression based on the *X* geographic coordinate (fig. 4).

The beach slope for the lake level correction was calculated for the Ohio portion of the Lake Erie shoreline from the 2004 LiDAR data by utilizing a 10-ft- (3.0-m)-resolution DEM, created using QT Modeler software (Applied Imagery, 2009). The data likely support a higher-resolution DEM; the 10-ft resolution was chosen strictly for processing efficiency over the large study area. Slope was calculated using three methods:

1. Using adjacent cells (10-ft [3.0-m] span) at the shoreward point.
2. Spanning four cells (40-ft [12-m] span) at the shoreward point.
3. Using the elevation of shoreward elevation minus lakeward elevation over the beach width.

Each of the methods for calculating the slope and beach width correction were utilized for each transect.

Statistics on the lake level correction a—only for points with beaches—were compared between the slope calculation approaches. The median correction for method 1 was 5.7 ft (1.7 m), with 90 percent of the corrections being less than 12.7 ft (3.87 m); method 2 was 6.2 ft (1.89 m); and method 3 was 4.4 ft (1.34 m). Method 1 was the preferred correction, as it was the best approximation of the slope conditions near the waterline. The slope used for the final correction was prioritized by the order presented above. If method 1 produced a slope of zero, then method 2 was used. If both method 1 and method 2 slopes were zero, then method 3 was used (this was necessary in only three cases). A few (n<10) very small slopes remained in the data set, which produced unrealistically large correction factors. These may be addressed in future refinements of this study.

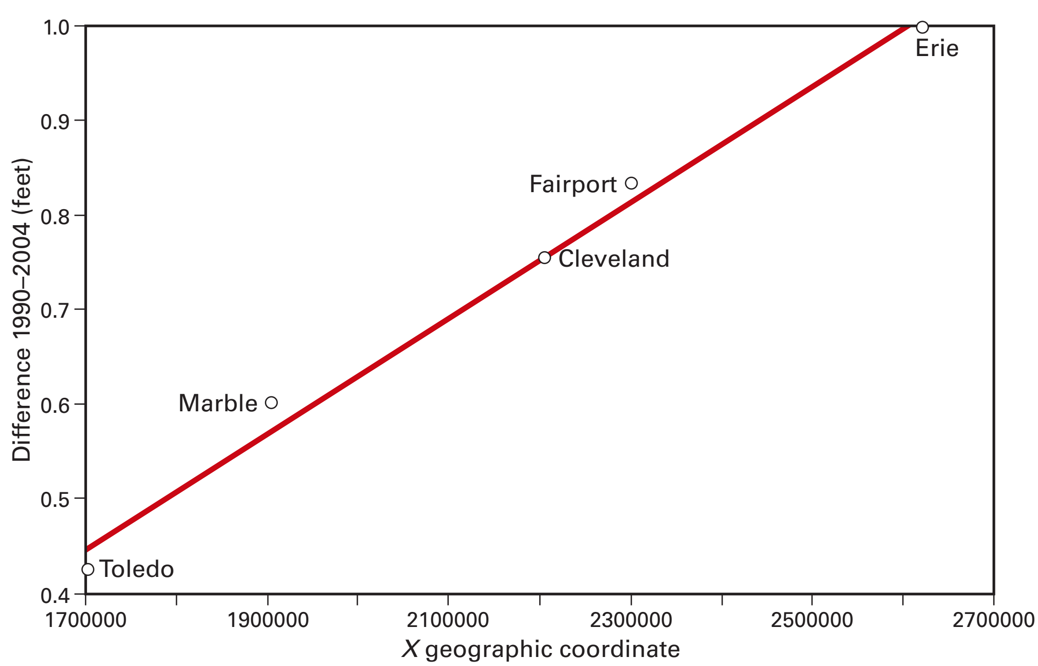

FIGURE 4.—Calibration curve predicting the difference in Lake Erie lake levels between 1990 and 2004, from the *X* geographic coordinate (Ohio State Plane North, feet). The lake did not undergo large changes in level from east to west during 1990. However, lake level increased towards the west during the 2004 photo dates, producing a clear trend in lake level change from east to west.

In general, the corrections because of lake level are small compared to typical local changes in beach width and have little impact on process interpretations (see "Sources of uncertainty " below). However, lake level correction is critical when interpreting net changes in the entire Ohio portion of the Lake Erie shoreline (table 1).

Sources of uncertainty

Informed use of any data set requires knowledge of the associated uncertainty, thus we identified and quantified sources of such uncertainty. Many of the figures presented in this preliminary report are estimates. Further studies are needed to fully quantify the errors, including the potential for covariance between error sources. However, the mathematical framework will facilitate future work and provides an estimate of what beach width changes can be detected for an individual transect.

For this data set, most uncertainty was produced from the digitization of boundary points. Errors in the georectification of the photos were considered minor (less than 2 ft [0.6 m]). For the lakeward point, ambiguity arose because of the variation of the position of waves on the shoreline. For the landward point, uncertainty occurred due to transitional boundaries caused by bluff erosion deposits or vegetation, as well as visual blocking of the boundary by tree canopy. Defining boundaries in areas where sand was blown into residential or sparsely vegetated areas was particularly challenging. Occasional interpretation issues arose when determining whether a particular portion of the shoreline fit our definition of *beach* (see "Measuring beach widths" on p. 1). This was particularly an issue for the 1990 panchromatic imagery, where spatial resolution of the images limited reliable identification of sedimentary textures smaller than large riprap. For the older photos, most beaches were identified based on the large albedo (reflectivity) of typical beach materials. A particular risk was declaring a beach or no beach for 2004 and misidentifying it in the 1990 photo. Such cases were given special scrutiny during quality checks.

The error in digitization is estimated to be 5 ft (1.5 m) for both lakeward and landward points (the one sigma or 68 percent confidence level) and is mainly due to ambiguity in choosing digitization points; but it also incorporates photogrammetric distortions. Assuming the errors are uncorrelated (no covariance), the error in the digitized length (*A*) is

$$\sigma_A = \sqrt{\sigma_{dk}^{\;2} + \sigma_{dd}^{\;2}} \qquad (4)$$

where σ_{dk} is the error in the digitized lakeward point and σ_{dd} is the error in the landward point. The total digitization error is 7.1 ft (2.2 m). The nominal error is likely less for the 2004 photography because of the lower quality of the 1990 images (panchromatic, scanned photographs). In addition, the error is more applicable to the wave wash zone. In general, the error for the landward point is probably less but may be significantly more when interpretation issues arise as previously mentioned. Interpretation errors are not quantified for the current

TABLE 1.—*Beach width and shoreline summary statistics for the Ohio portion of the Lake Erie shoreline*

Corrected for Lake Level	Number of transects	Mean Width, ft (m)	Median Width, ft (m)	Quartiles Width, ft (m)	Length, ft (m)	Length, mi (km)	Proportion by length	Area Balance, acres (m²)
Beach	5,414	−0.20 (−0.06)	−2.9 (−0.88)	−15.1/12.6 (−4.60/3.84)	571,856 (174,302)	108 (174)	0.39	−2.6 (−11,000)
Beach Gained	1,550	23.5 (7.16)	15.0 (4.57)	8.5/25.3 (2.6/7.71)	169,548 (51,678)	32.1 (51.7)	0.12	91.5 (370,000)
Beach Lost	860	−36.2 (−11.0)	−28.8 (−8.78)	−42.7/−19.7 (−13.0/−6.00)	89,230 (27,197)	16.9 (27.2)	0.06	−74.2 (−300,000)
Nonbeach	6,051				624,383 (190,312)	118 (190)	0.43	
Net	13,875	−12.9 (−3.93)	−16.8 (−5.12)		1,455,017 (443,489)	276 (443.5)	1.00	14.7 (59,500)
Uncorrected								
Beach	5,576	6.9 (2.09)	3.7 (1.12)	−8.6/19.6 (−2.62/5.97)	589,117 (179,562)	112 (180)	0.40	92.6 (375,000)
Beach Gained	1,670	27.4 (8.35)	18.8 (5.73)	11.4/30.5 (3.47/9.30)	181,415 (55,295)	34.4 (55.4)	0.12	114 (461,300)
Beach Lost	698	−32.5 (−9.91)	−25.3 (−7.71)	−38.9/−16.1 (−11.9/−4.91)	71,969 (21,936)	13.6 (21.9)	0.05	−53.7 (−217,000)
Nonbeach	5,931				612,517 (186,695)	116 (187)	0.42	
Net	13,875	1.75 (0.53)	−2.8 (−0.85)		1,455,018 (443,489)	276 (444)	1.00	153 (619,200)

analysis. For the differences in lake level between dates, the digitization introduces an error of approximately 10 ft (3.0 m) for any individual line.

There is additional potential error from correcting the 2004 data for lake level changes. The beach slope, *tan* α, is calculated from

$$\tan\alpha = \frac{d-k}{l} \qquad (5)$$

where d is the elevation landward, k is the elevation lakeward, and l is the horizontal distance between d and k. Errors in equation 5 propagate according to

$$\sigma_{\tan} = \sqrt{\frac{1}{l^2}\left(\sigma_d^{\,2} + \sigma_k^{\,2}\right)} \qquad (6)$$

where σ_d and σ_k are the errors in the elevations from the LiDAR DEM (l is a constant). We estimated the vertical error in the LiDAR and interpolated DEM to be 0.5 ft (0.2 m). For slopes calculated by finite difference on the 10-ft- (3.0-m)-resolution DEM, the typical error in *ttan* α is 0.07. The error in equation 3 is

$$\sigma_a = \sqrt{\frac{\sigma_b^{\,2}}{b^2} + \frac{\sigma_{\tan}^{\,2}}{(\tan\alpha)^2}} \qquad (7)$$

where σ_b is the uncertainty (standard deviation) in the mean lake level. The mean lake level change is 0.7 ft (0.2 m), the standard deviation of the mean in 2004 lake levels is approximately 0.2 ft, and the mean *tan* α for locations with beaches is 0.16. By equation 7, the typical error in the correction term a is approximately 0.5 ft (0.2 m). The correction of beach width for lake level does not introduce significant additional uncertainty for typical values, but this error (as with all aforementioned estimates) can be larger for specific locations.

RESULTS

Results are presented for two beach areas as illustrative examples, which present some potential methods of mapping the data. The maps (figs. 5–10) were created in ESRI's ArcGIS by converting the study results to feature classes. We applied color ramps to the data to represent the magnitude of beach retreat. Colored dots at the 2004 lakeward extent of the beach indicate the changes, by transect, in width (in feet). Four potential categories describe the general changes in shoreline between 1990 and 2004:

1. Beach for both times.
2. Beach gained (where no beach existed in 1990).
3. Beach lost.
4. Nonbeach (e.g., rock cliffs, armored shorelines).

A digitized shoreline, provided by the Ohio Department of Natural Resources (ODNR), Office of Coastal Management (based on 2006 Ohio Statewide Imagery Program[2] high-resolution, color orthoimagery), was attributed with these categories based on that of the closest point. We created points and line GIS data for both corrected and uncorrected data to allow comparison, thus each type and magnitude of beach change can be displayed concurrently.

Example local investigations

The first example site is in Ashtabula County (figs. 5–7; in each figure the top frame is immediately to the west of the bottom frame, and the panels should be read from left to right beginning with the top panel.). This site is a headland upon which a private residence sits. This setting is typical for the northeastern Ohio shore, consisting of a high-relief, steep, retreating till bluff fronted by a narrow beach. The prevailing longshore current is from west to east. The beach and headland are protected or augmented by a variety of structures, in particular a groin, seawalls, and retaining walls constructed at multiple levels and apparently made of concrete modules and cast-in-place concrete. Tires have also been emplaced as an ineffective protective measure.

This stretch of shore contains examples of all four change categories listed above. The beach width changes appear to be influenced by and largely consistent with the presence of the shore structures and overall shore geometry and longshore current direction. The four transects directly west of the headland and groin (fig. 7) lie on a site of beach width shrinkage, despite the fact that groins usually trap sand on their updrift sides. Conversely, the headland and groin caused sand deposition over the two transects directly to their east, likely due to an eddy or low wave energy zone that allows the deposition of sediment on the immediate downdrift side. Moving farther east, the roughly three-transect-wide area of tires exhibits beach loss, likely due to sediment starvation induced by the groin's tendency to direct longshore current towards deeper water. Slump scarps at the top of the bluff testify that erosion over this three-transect area is an ongoing occurrence. For the rest of the upper frame, width changes alternate between growth and shrinkage. In the lower frame (farther east), the shore geometry is straighter and the patterns of change are less variable.

The second site is Locust Point in western Ottawa County (figs. 8–10). This location was chosen as a contrast to the Ashtabula County site, as it consists of a relatively wide, sandy beach and lacks a retreating bluff. Locust Point sits immediately west of a large and abrupt curvature in the shoreline (a surface expression of a bedrock high associated with the Findlay Arch). This curvature causes the longshore drift in the vicinity of Locust Point to diverge to both east and west, as suggested by published maps (Herdendorf, 1973; Mackey, 1996) as well as unpublished data on file with the Division of Geological Survey (Guy, 1994)[3]. Therefore, sediment transport is variable and may

[2]More information is available at the Ohio Geographically Referenced Information Program Web site at <http://ogrip.oit.ohio.gov/ProjectsInitiatives/StatewideImagery.aspx>, last accessed July 23, 2010.

[3]Guy, D.E., Jr., 1994, Estimated rates of sand transport for the Ohio shore of Lake Erie, 2 sheets, on file at the ODNR Division of Geological Survey.

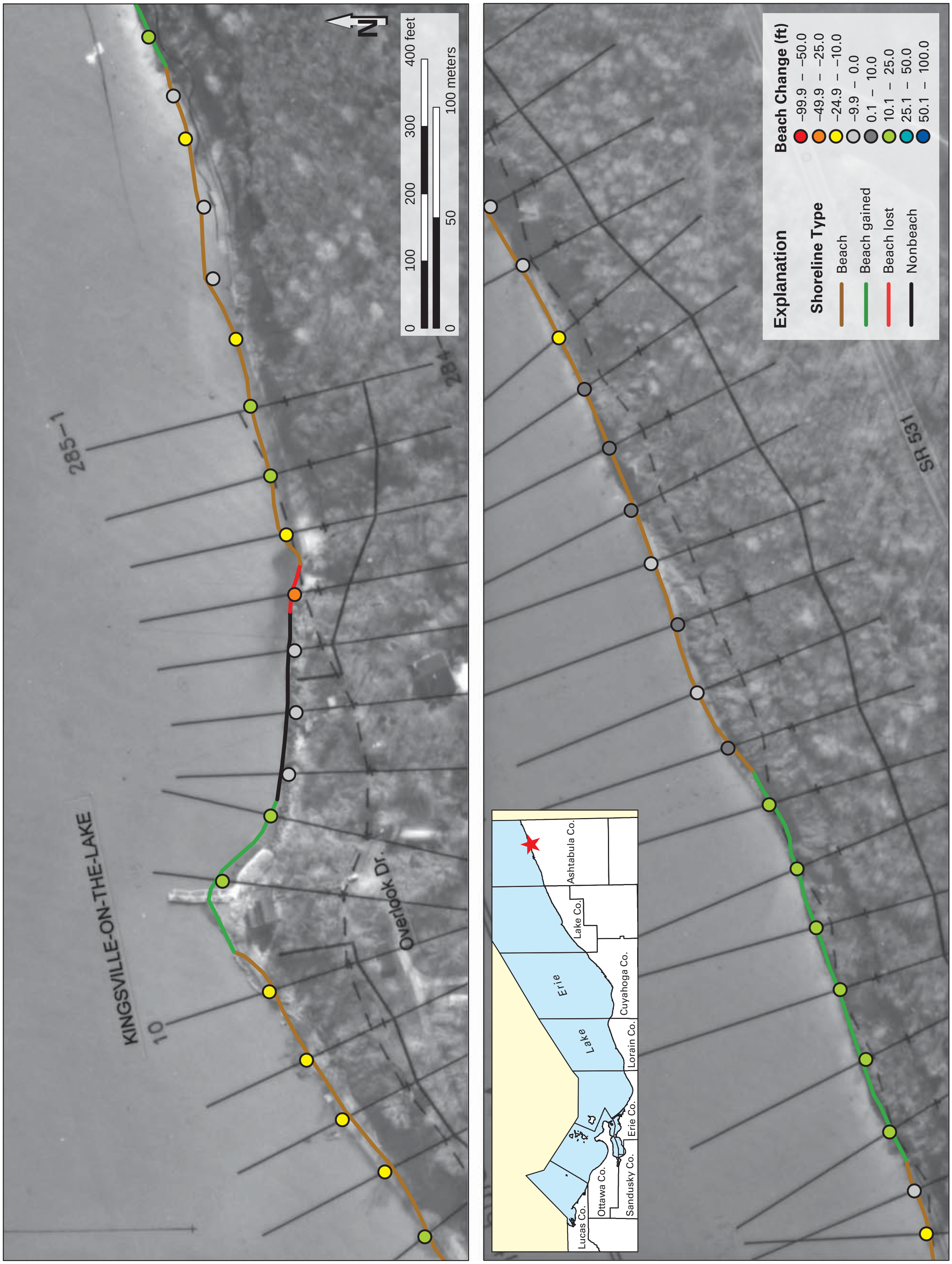

FIGURE 5.—Uncorrected Lake Erie beach width changes (in feet) and shoreline types superimposed on the 1990 panchromatic photo, Ashtabula County, Ohio. The panels should be read from left to right beginning with the top panel.

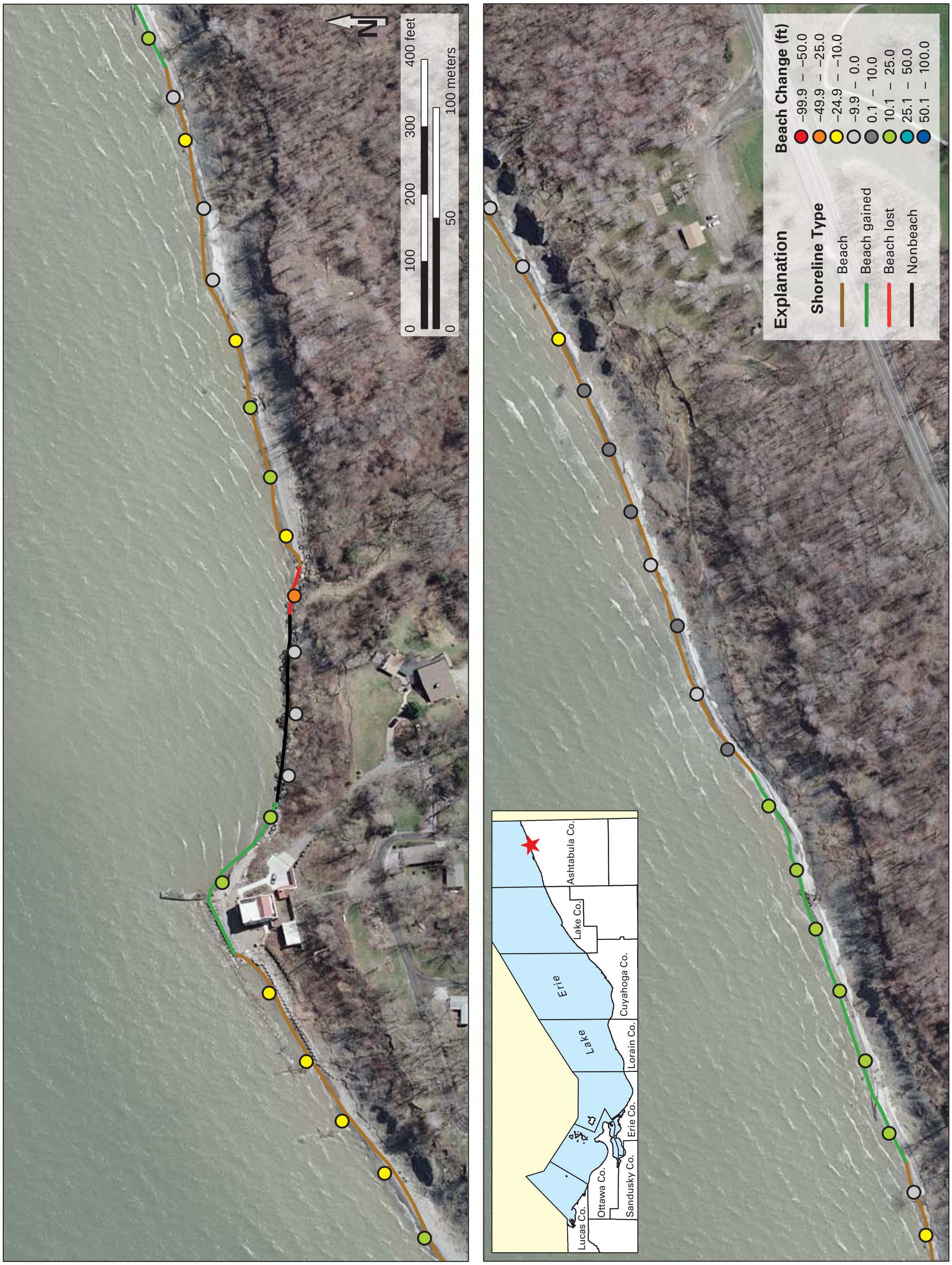

FIGURE 6.—Uncorrected Lake Erie beach width changes (in feet) and shoreline types superimposed on the 2004 color orthophoto, Ashtabula County, Ohio. The panels should be read from left to right beginning with the top panel.

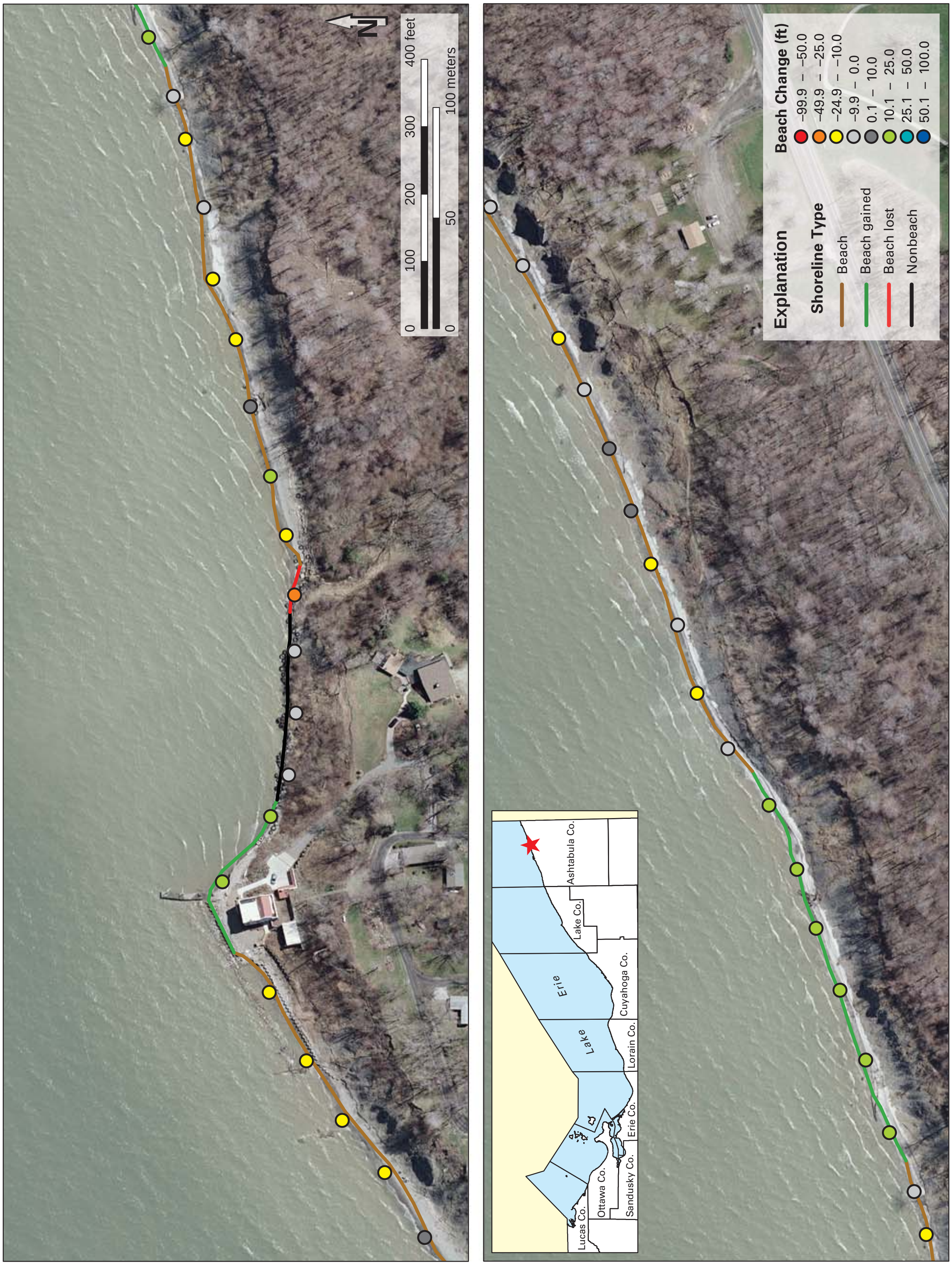

FIGURE 7.—Corrected (for lake level) Lake Erie beach width changes (in feet) and shoreline types superimposed on the 2004 color orthophoto, Ashtabula County, Ohio. The panels should be read from left to right beginning with the top panel.

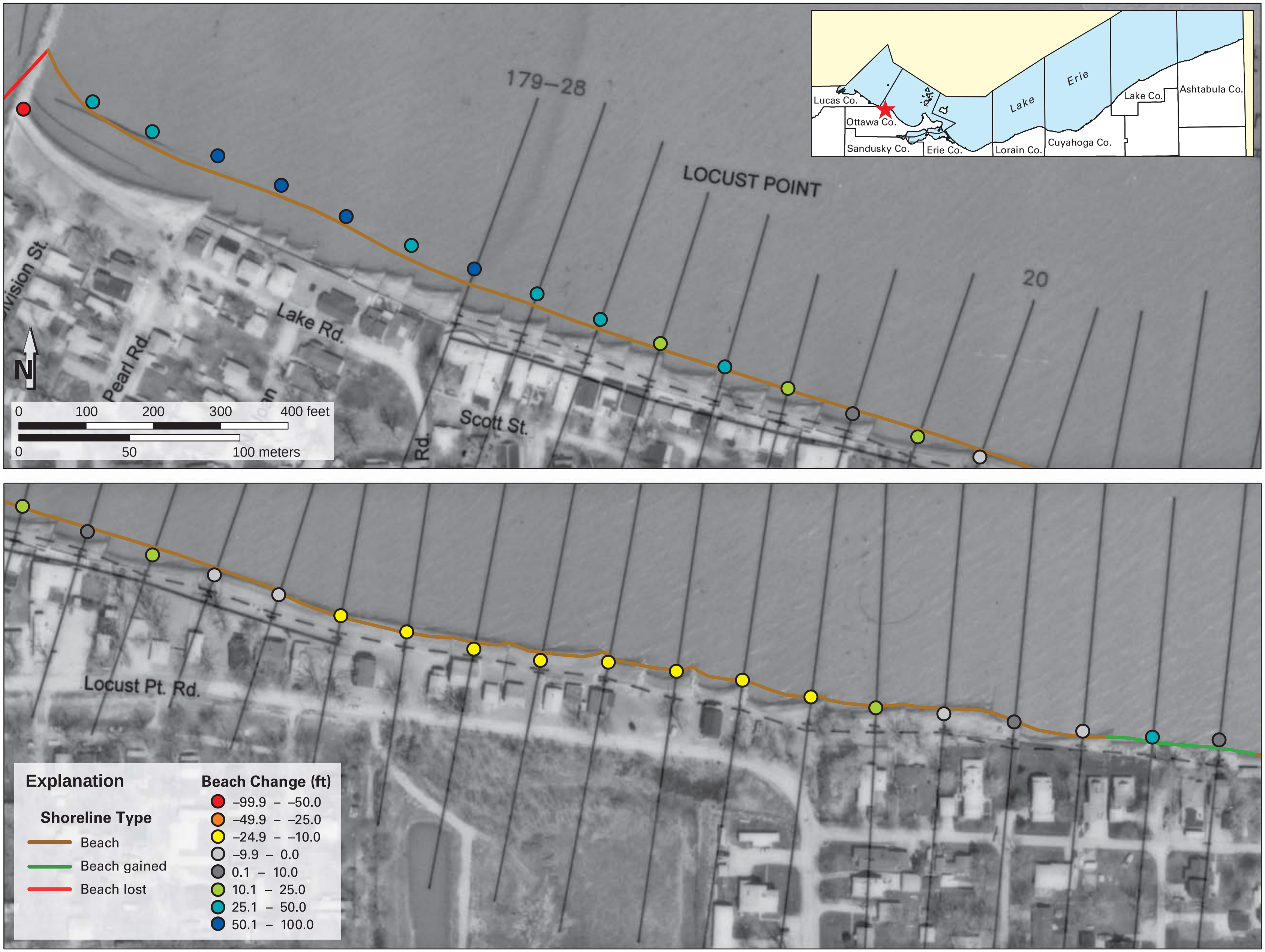

FIGURE 8.—Uncorrected Lake Erie beach width changes (in feet) and shoreline types superimposed on the 1990 panchromatic photo, Ottawa County, Ohio. The panels should be read from left to right beginning with the top panel.

FIGURE 9.—Uncorrected Lake Erie beach width changes (in feet) and shoreline types superimposed on the 2004 color orthophoto, Ottawa County, Ohio. The panels should be read from left to right beginning with the top panel.

FIGURE 10.—Corrected (for lake level) Lake Erie beach width changes (in feet) and shoreline types superimposed on the 2004 color orthophoto, Ottawa County, Ohio. The panels should be read from left to right beginning with the top panel.

occur to either the west or the east, most likely dependent on prevailing winds. Sedimentation patterns in the 1990 photo (fig. 8) suggest transport to the east. The area from 0 to 1,000 ft (0 to 300 m) east of the jetty (top frame, figs. 8 and 9) is generally one of beach growth and cannot be explained simply from lake level changes (fig. 10). The gains in beach width (fig. 10) are most likely the result of a reversal in longshore drift subsequent to the 1990 photo, augmented by the jetty at the west end of the upper frame. The groin system to the east shows a decrease in beach width (lower frame, figs. 8 and 9); the gains that occurred to the immediate west appear to have happened at the expense of the beach to the east. (In fact, between photo dates, complex changes in sediment deposition between the groins can be seen, especially in accumulation on the down-current side of the groins).

Together, these example sites serve as reminders that this project documents changes in beach widths resulting both from natural processes (e.g., longshore current) and human activities (e.g., groin construction). At any given site, it is necessary to consider the geomorphic framework when evaluating the likely reasons for beach width change.

Statewide inventory of beach width changes, 1990–2004

We calculated statistics describing the net changes in the beaches on the Lake Erie shoreline of Ohio (table 1). The uncorrected data provides information on the changes to beach widths regardless of the cause, whereas the data corrected for lake level changes serves as proxy for changes in sediment balance. The results show overall gains in beach width over the time period. Widths for beaches existing in both photos increased an average of nearly seven feet. Accounting for lost and gained beaches over the time period, there was an increase in beach area of 153 acres (619,000 square meters [m^2]). However, comparison of corrected and uncorrected beach widths shows that most of these gains can be attributed to the lower lake level of 2004. The average beach width change when corrected for lake level is nearly zero, and accounting for lost and gained beaches gives a net increase of only 14.7 acres (59,500 m^2) or only 10 percent of the total gain in area from the raw measurement.

In addition, the data can be compared with past studies to document the changes to Ohio's Lake Erie beaches since 1876. Carter and others (1982) compiled beach data from mapping studies conducted in 1876, 1937, and 1968. The proportion of shoreline with wide beach (arbitrarily set at >49 ft [15 m]), narrow beach (<49 ft [15 m]), and nonbeach was tracked over time[4]. Our uncorrected data for 1990 and 2004 were added to this data to document changes from 1876 to 2004 (fig. 11). The plot shows that wide beaches

[4]We assumed this data was not corrected for changes in lake level; however, this is not specified in the paper by Carter and others (1982).

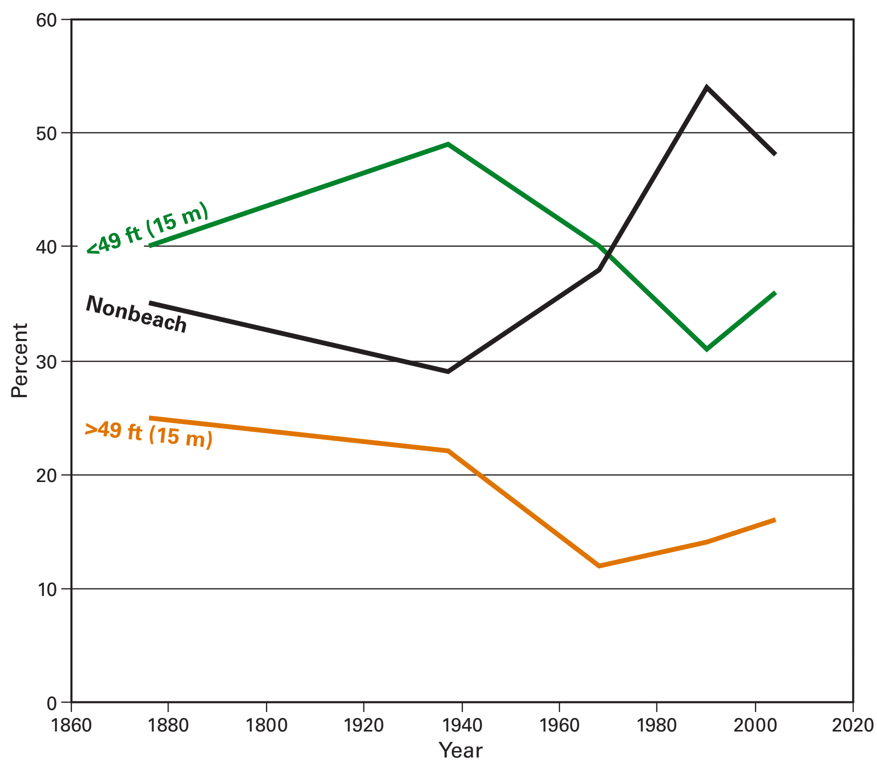

FIGURE 11.—Plot showing the percent for each Lake Erie shoreline category—wide beach (>49 ft [15 m]), narrow beach (<49 ft [15 m]), and nonbeach—with time. Data points from 1876, 1937, and 1968 are taken from Carter and others (1982).

decreased from 1876 to 1968. This initially resulted in an increase in narrow beaches, as the amount of nonbeach shoreline also decreased. However, after 1937 beach was lost to nonbeach shoreline, as both narrow and wide beaches decreased in proportion. Beach loss and loss of narrow beaches continued up to 1990. In contrast, wide beaches have increased since 1968. Overall, the changes between 1990 and 2004 are small and show modest beach gains, in general agreement with the results shown in table 1.

CONCLUSIONS

Results of this project illustrate the dynamic nature of Ohio's Lake Erie beaches. Changes in width of ±20 ft (6 m) are common and can be attributed to the interaction of longshore sediment transport with shoreline structures and geometry. In addition, there can be occasional large changes in beach width in excess of 100 ft (30 m). While our one example of large change is attributable to variable longshore transport, other possible causes exist, such as sand nourishment projects and harbor construction projects. Local changes notwithstanding, the portion of shoreline containing beaches was stable over the time period, with most of the increase caused by a drop in lake level. The overall degradation in the amount of beaches apparent from 1876 to the 1960s (fig. 11) appears to have stabilized over the time period of our new study.

REFERENCES CITED

Applied Imagery, 2009, Quick Terrain Modeler software version 6.1.2: Silver Spring, Md., Applied Imagery, last accessed October 14, 2011, at <http://www.appliedimagery.com/>.

Carter, C.H., Benson, D.J., and Guy, D.E., 1982, Man-made structures and geomorphic changes since 1876 along the Ohio shore of Lake Erie, *in* Craig, R.G., and Craft, D.E., eds., Applied geomorphology: Boston, Allen and Unwin, p. 148–164.

ESRI, 2009, ArcGIS software version 9.3: Redlands, Calif., Environmental Systems Research Institute, Inc., last accessed October 14, 2011, at <http://www.esri.com/software/arcgis/index.html>.

Herdendorf, C.E., 1973, Shoreline changes of Lakes Erie and Ontario: The Ohio State University, Center for Lake Erie Area Research, Technical Report 11, p. 13.

Mackey, S.D., 1996, Relationship between sediment supply, barrier systems, and wetland loss in the western basin of Lake Erie—A conceptual model, *in* Folger, D.W. ed., Lake Erie Coastal Erosion Study Workshop—August 1996: U.S. Geological Survey Open-File Report 96-507, p. 28–30.

National Oceanic and Atmospheric Administration (NOAA), 2006, Historic Great Lakes water level data: National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services, last accessed February 9, 2012, at <http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic+Great+Lakes+Water+Level+Data>.

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