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New GIS Tools for Mapping Ohio’s Lake Erie Coastal Erosion Areas

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Abstract

Every 10 years, the Ohio Department of Natural Resources (ODNR), Division of Geological Survey identifies and maps coastal erosion areas along Ohio’s 262-mile Lake Erie shore. Coastal erosion areas are those likely to erode over the next 30 years if no additional shore protection is emplaced. Historically, eroding bluffs and shores have caused considerable economic damage to property, buildings, and public infrastructure. The objective of the Coastal Erosion Area (CEA) Program is to minimize economic losses by ensuring that new development along the Ohio shore is adequately protected from coastal erosion.

To perform mandated remapping of coastal erosion areas, the ODNR Division of Geological Survey developed three new GIS applications. The first application assigned identification numbers to shoreline intersections and shore-normal transects, which ensured a unique, contiguous series of identification numbers that have a spatially sequential orientation. The second application allowed staff members to digitally map the 2004 shoreline intersections on high-resolution, orthorectified digital imagery that improved the overall quality and precision of the 2004 shoreline recession dataset. Finally, staff members translated the original FORTRAN 77 code into VBA and ArcObjects for ArcGIS® to create the third application, which automatically calculates the amount and rate of recession and the 30-year average recession distances for each shore-normal

transect. These applications facilitated the coastal erosion areas mapping effort and significantly reduced the time needed to complete the project. Moreover, the new coastal erosion area maps can now be distributed electronically to the public via Web site or a Web map service, and geospatially integrated with other coastal datasets such as property parcel ownership and shore-structure inventory datasets.

Shore Erosion along the Ohio Coast of Lake Erie

Erosion along the Ohio Lake Erie shore is a major geologic hazard that has significantly affected coastal residents. Erosion occurs as a result of the removal of material at the base of a bluff by wave action and the combined effects of gravity and groundwater, which erode the bluff face by slumping or debris flows or both. In areas of exposed bedrock, undercutting at the base of the bluff causes catastrophic failure and collapse of the bluff face into the lake. The rate at which the shore erodes is a function of the geologic composition of the shore, lake levels, prevailing winds, and the presence or absence of shore protection.

Shore erosion along Lake Erie can be either dramatic or relatively steady in nature. Between 1973 and 1990, the average shore recession rate was 1.41 feet per year, or approximately 24 feet over the 17-year period. Recession rates along the coast range from 0 feet per year to up to 56 feet per year along certain reaches of the coast. Large-scale changes can also occur. Near Painesville, Ohio, the coast has undergone between 34 and 207 feet of recession from 1973 and 1990 (fig. 1). The Sheldon Marsh barrier beach, which was overwashed and eroded during the great November 1972 storm (Carter, 1973), has undergone between 268 and 953 feet of recession over the 17-year time period (fig. 2). While these large-scale changes are very dramatic, relatively steady erosion rates along the coast are also a hazard, eroding bluffs and damaging properties. As a bluff recedes, buildings are lost by either falling into the lake, or being torn down before they are destroyed, or moved back from the bluff (figs. 3A and 3B).

Historically, shore erosion has caused a large amount of damage along the coast. Studies performed by the U.S. Army Corps of Engineers (1971) between the spring of 1951 and the spring of 1952 computed erosion-related damages along Ohio's Lake Erie shore to be $11.3 million. The most significant storm of the 20th century was the storm of November 14, 1972 (Carter, 1973), which caused approximately $22 million in damages (Environmental Data Service, 1972). An economic study of damages caused by coastal erosion shows that even if buildings are not damaged, property values decline rapidly when the home or building is within 25 feet of the bluff or shore edge (Kriesel and Lichtkoppler, 1989; Kriesel and others, 1993). A study performed by the ODNR Division of Geological Survey found that 25 percent of lakefront homes were within 25 feet of the bluff or shoreline, and another 22 percent were between 25 and 50 feet of the bluff or shoreline (Guy, 1999).

Given the proximity of homes to the shore, the State of Ohio developed the CEA Program to identify areas at risk to erosion along the Ohio shore. The objective of the CEA Program is to minimize economic losses by ensuring that new development along the Ohio shore is adequately protected from coastal erosion. The Ohio Revised Code (ORC 1506.06) states that the ODNR Director shall review and may revise the identification of the Lake Erie coastal erosion areas at least once every 10 years. Coastal erosion area maps identify areas at risk of being lost to coastal erosion over a 30-year period. Once coastal erosion areas are designated, the CEA Program requires a permit to construct or modify a habitable structure within a coastal erosion area. To receive a permit, a property owner must demonstrate that adequate shore protection is in place to protect the new structure from erosion.

The first designation of coastal erosion areas was finalized in 1998. The 1998 coastal erosion area mapping used uncontrolled aerial photography from 1973 and 1990 as the basis for measuring coastal erosion. The 1990 aerial photographs were enlarged to approximately 1:2,000 scale and printed onto a Mylar base. Shore-normal transects were drawn on the 1990 imagery, approximately 100 feet apart. These shore-normal transects serve as reference lines from which recession distances and rates are measured. The 1973 aerial photos were enlarged to the same scale as the 1990 images and the 1973 shoreline was then transferred to the 1990 imagery. Where the 1973 shoreline, the 1990 shoreline, and the 1990 toe of the bluff intersected the shore-normal transects, the intersections were mapped on the 1990 imagery.

The transects, the 1973 and 1990 shoreline intersections, and the 1990 toe of the bluff were digitized using SigmaScan® software, with each 1990 aerial-photo image having its own relative coordinate system. Once digitized, the vector data were then used as input into a FORTRAN 77 program that calculated (1) the recession distance and recession rate between 1973 and 1990 and (2) a smoothed 30-year average recession distance, that is, where the shoreline is projected to be in 2020. The 30-year recession (or coastal erosion area) distance was then plotted back onto the 1990 imagery (Mackey and others, 1996; Guy, 1999). The preliminary coastal erosion area maps were released to the public in 1996. After an extensive public notification and review process, the final coastal erosion area maps were approved by the ODNR Director in 1998 (fig. 4).

Gis Applications for the Updated Coastal Erosion Area Designation

The latest remapping of coastal erosion area designations involved three steps: (1) converting the 1998 coastal erosion area maps to a GIS (McDonald, 2009); (2) mapping of the 2004 toe of the bluff and the shoreline intersections at each shore-normal transect; and (3) calculating the new coastal

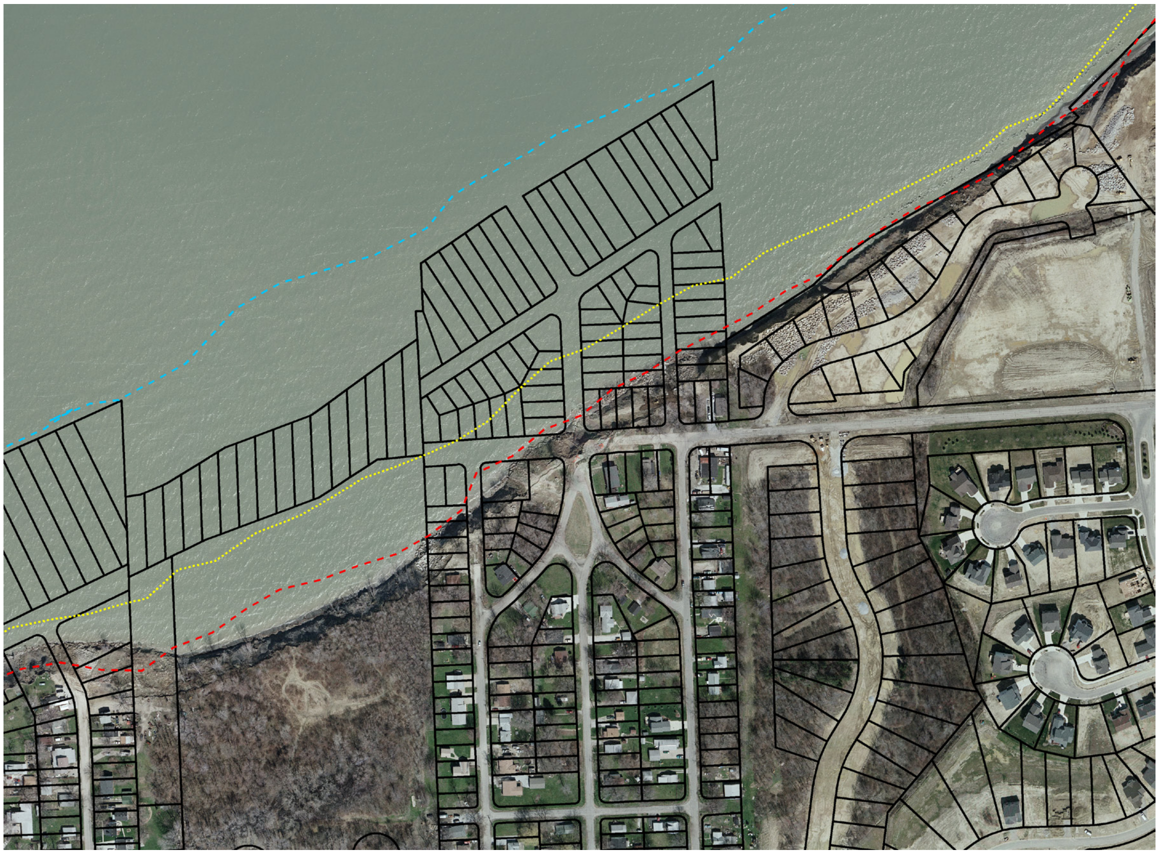

Figure 1. An area of the Lake Erie coast near Painesville, Ohio, that has undergone up to 207 feet of recession during the 17-year period. The blue dashed line indicates the 1876 shoreline; the yellow identifies the 1973 shoreline; and the dashed red line represents the 1990 shoreline. Aerial photo was taken in 2004. The black outlines are parcel boundaries. As can be seen, parcels have been lost due to coastal erosion.

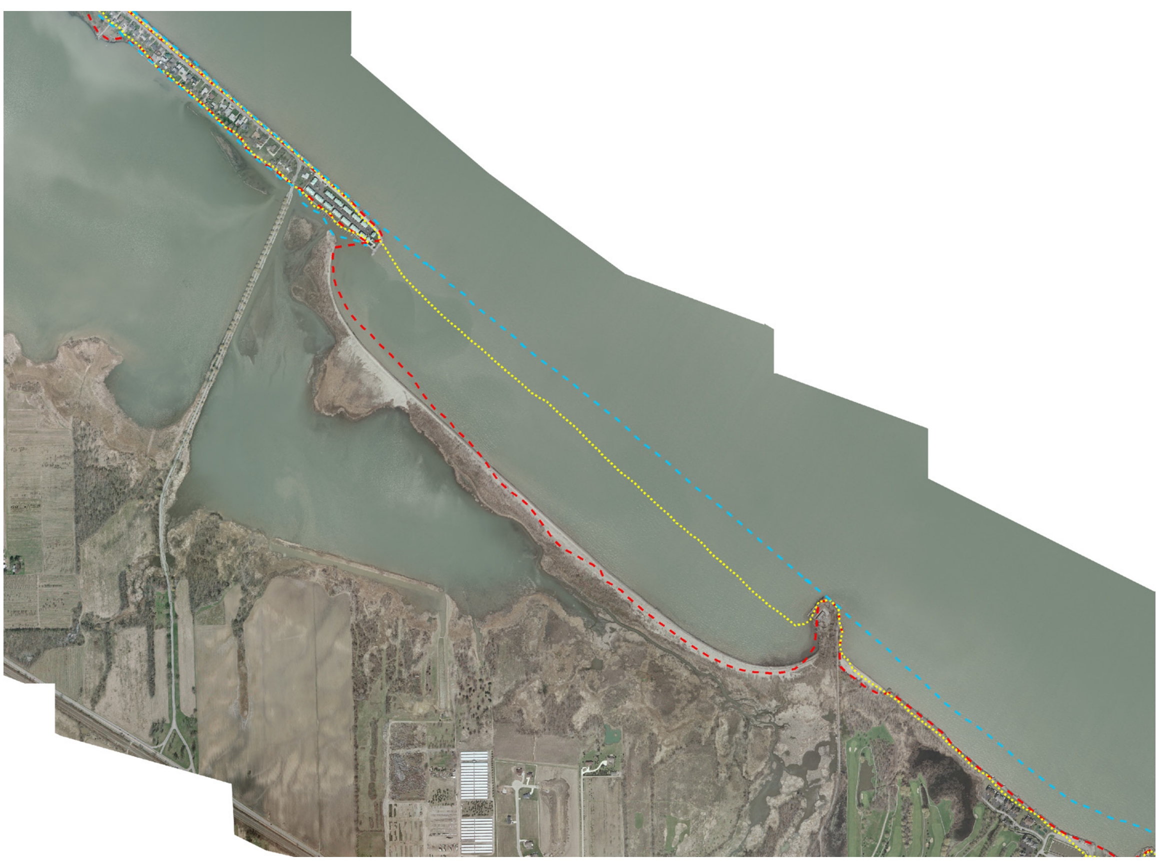

Figure 2. The Sheldon Marsh barrier island, which was eroded and moved landward during the great November 1972 storm, has been retreating at a rate between 15 and 56 feet per year.

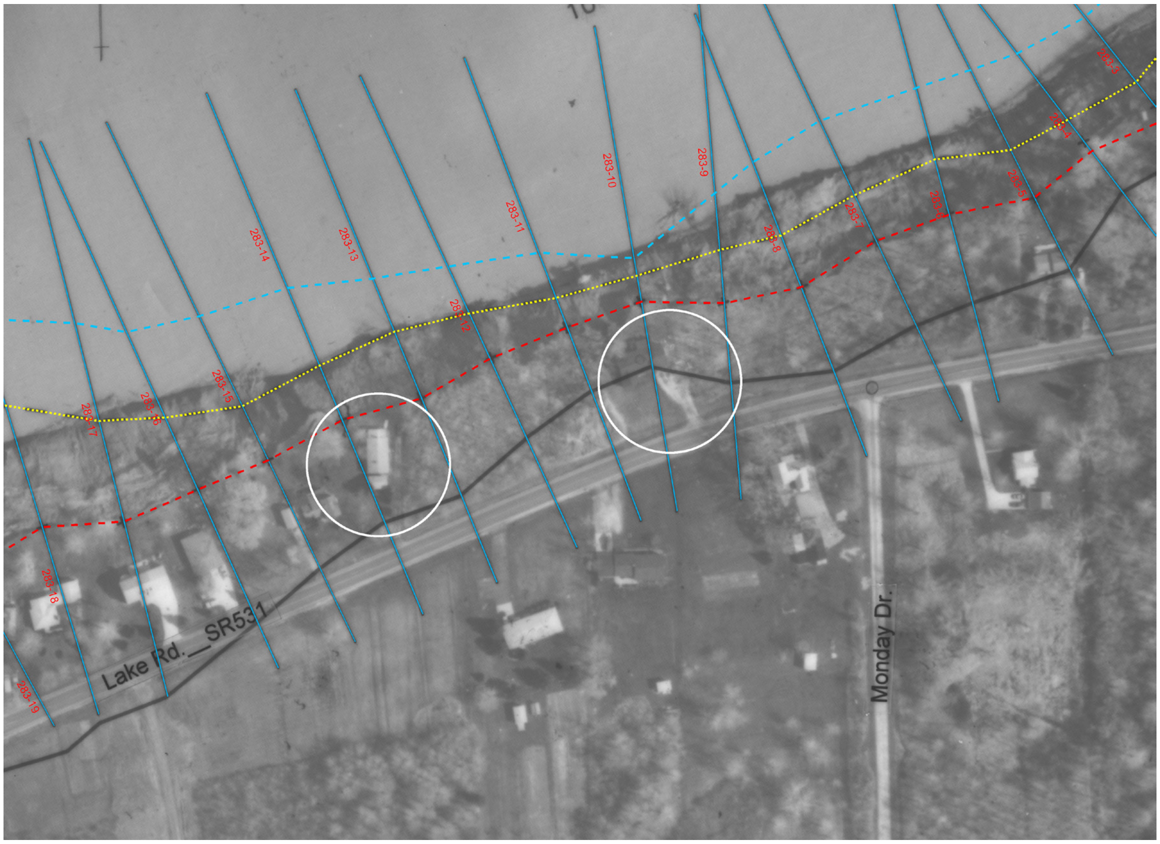

Figure 3A. Properties can be lost to coastal erosion. This 1990 aerial image shows two houses that will be lost to coastal erosion. The blue dashed line indicates the 1876 shoreline; the yellow identifies the 1973 shoreline; and the dashed red line represents the 1990 shoreline. The black line represents the coastal erosion area designation line. The houses are circled in WHITE.

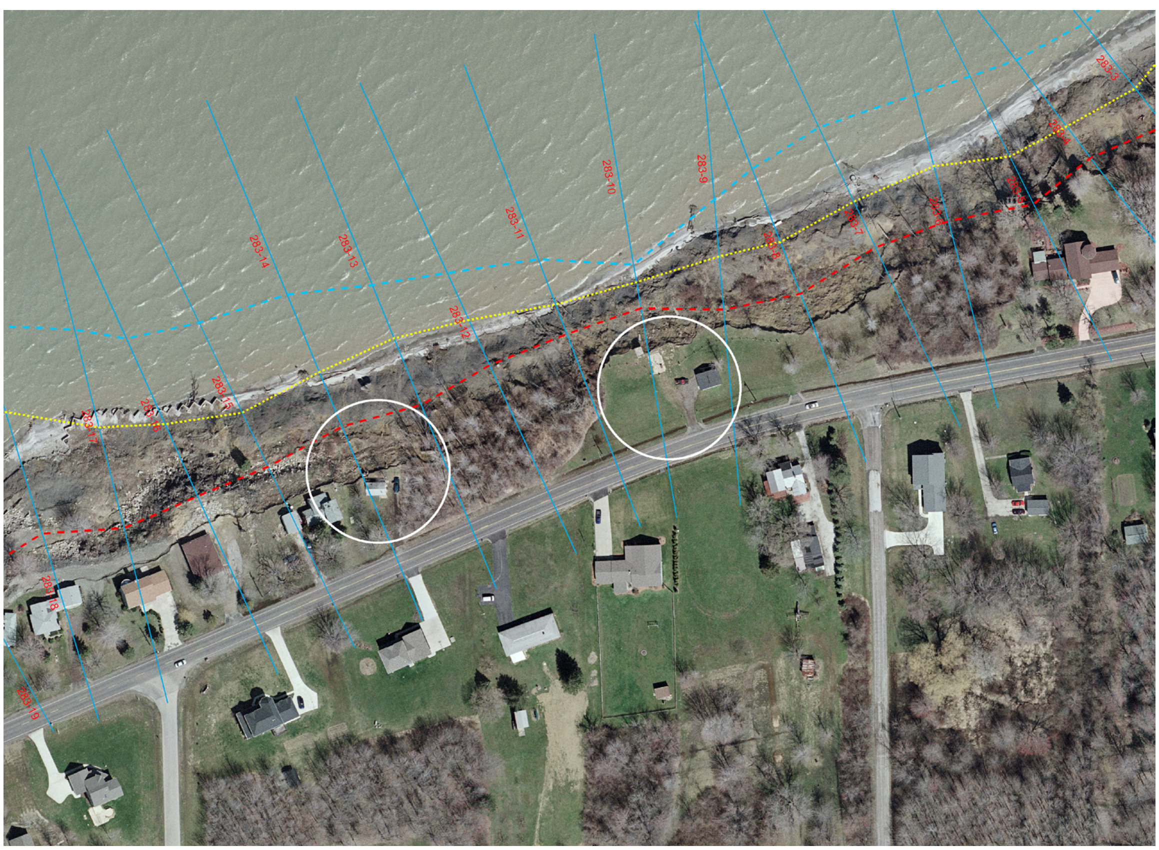

Figure 3B. By 2004, the two houses have been lost to coastal erosion. The location of the former houses are circled in WHITE.

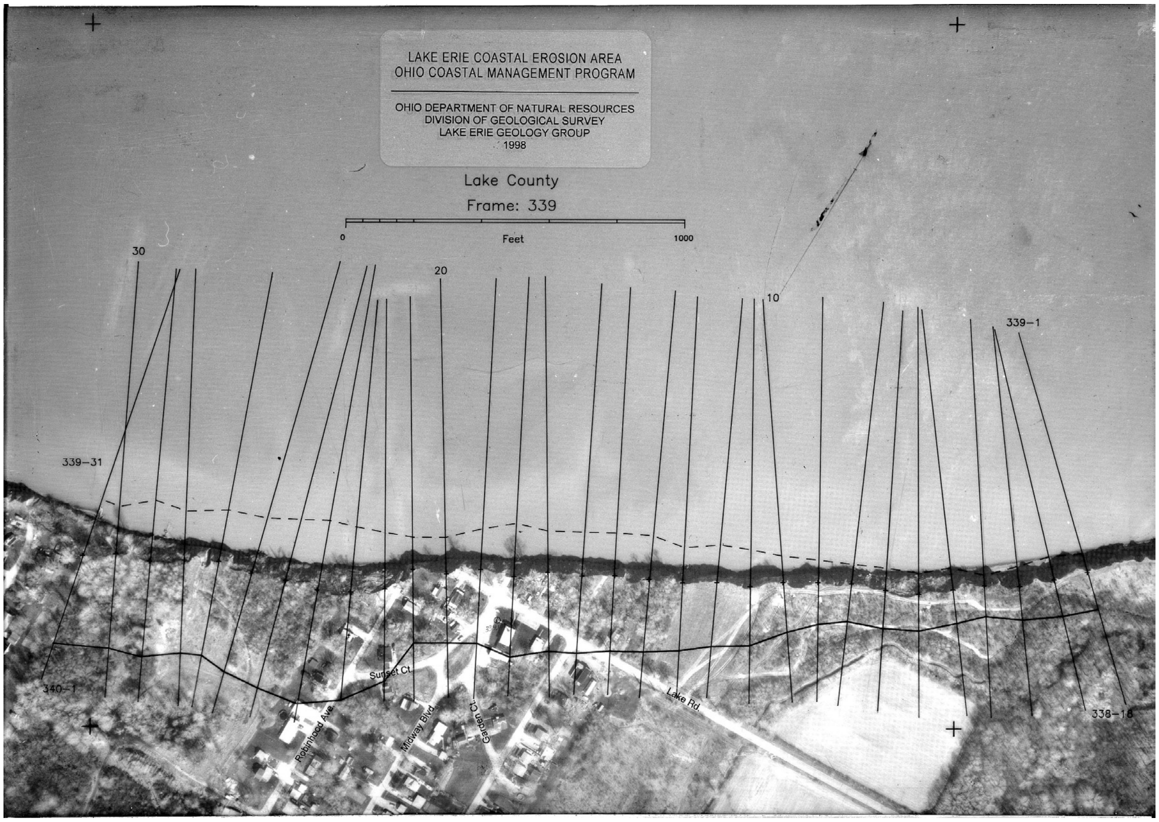

Figure 4. Example of a 1998 coastal erosion area mapbook page for section of Lake Erie coast in Painesville, Ohio.

erosion area delineation using the 1990 and 2004 shorelines. To perform the mandated remapping of coastal erosion areas, the ODNR Division of Geological Survey developed three new GIS applications. First, a GIS application was written that assigns identification numbers to the shore intercepts and shore-normal transects located every 100 feet (or 30 meters) along the Ohio Lake Erie shore. This first GIS application ensures that the identification numbers are unique, contiguous, and have a spatially sequential orientation. Second, a GIS application was written to assist staff members with mapping the 2004 shoreline. This application provided a digitization workflow that significantly reduced the attribute errors associated with digitizing the 2004 shoreline and improved overall quality and precision of the 2004 recession dataset. Third, staff members translated the original FORTRAN 77 code into VBA and ArcObjects for ArcGIS to create an application that automatically calculated the amount and rate of recession and the 30-year average recession distance for each shore-normal transect. These three GIS applications facilitated the task of remapping coastal erosion areas and reduced the time to complete the mapping of the 2004 shoreline from more than 1 year to less than 3 months.

Transect Identification Number Application

Before any work could be performed for the new coastal erosion area delineation, identification numbers had to be assigned to all the shore-normal transects. These Transect Identification numbers (TIDs) are unique, contiguous, and spatially sequenced. The TIDs must be spatially sequenced in order to apply a five-point moving average algorithm used to smooth coastal erosion area lines.

To assign the TIDs, we took advantage of the fact that the 1990 aerial photography was flown in an east-to-west sequence along the coast. Therefore, a sequence number was assigned to each air photo frame. During the 1998 coastal erosion area mapping, shore-normal transects were drawn on each 1990 aerial photo. These transects were uniquely numbered for each aerial photo; the numbers range from 1 to 72, depending in the width of the aerial photo. Using the aerial-photo sequence number and the sequential-transect numbers on each aerial photo, the application iteratively assigns the unique TIDs for the entire coastal dataset (fig. 5). The TIDs range from 1 at the Ohio-Pennsylvania border to 12,157 at the Ohio-Michigan border. The Lake Erie islands TIDs range from 12,158 to 14,164.

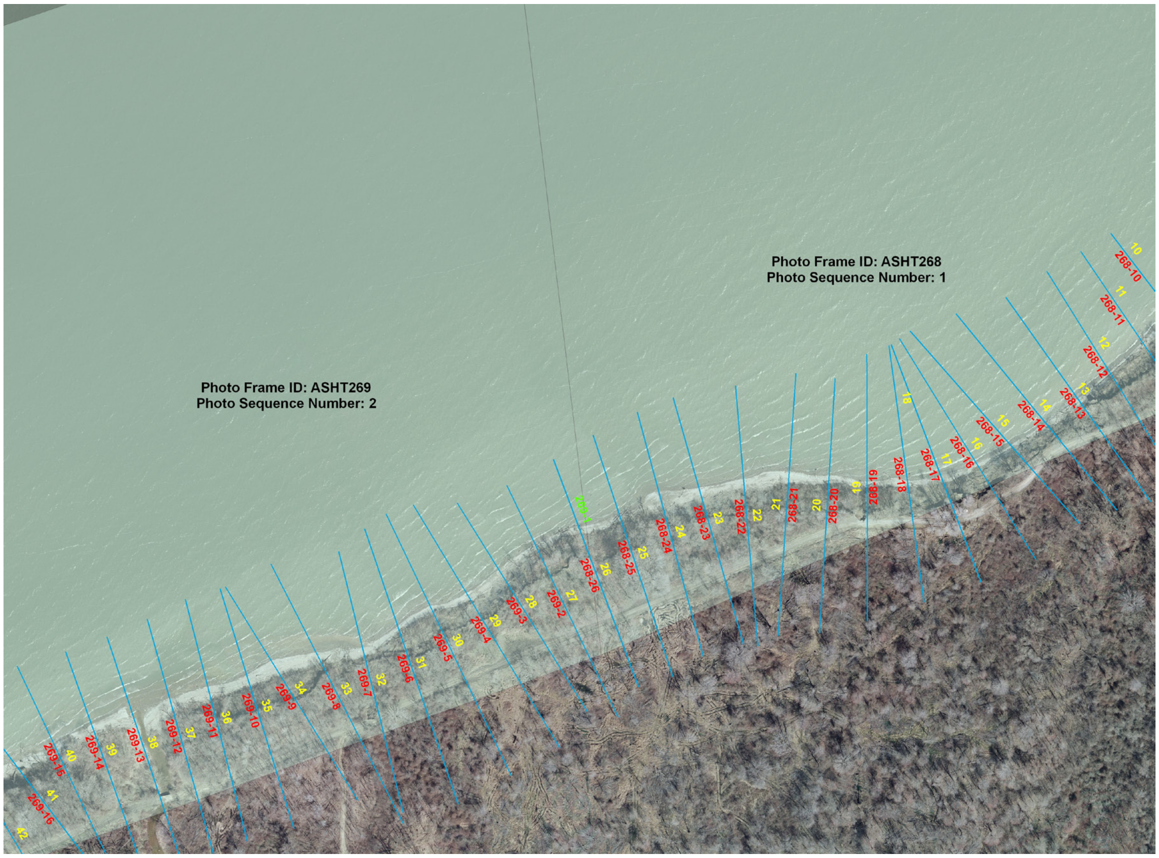

Figure 5. A portion of the Lake Erie coast near the Ohio-Pennsylvania border. The outlines of two 1990 aerial photo frames—frame 268 and frame 269—are shown. Also shown are the aerial-photo sequence numbers. The shore-normal transects (blue lines) are labeled with the original frame and transect identification (TID) numbers (in red). A tie transect (in green, along the boundary between photo frames) is the last transect in a 1990 aerial photo frame and also the first transect in the next frame. The new TIDs are in yellow. The new TID numbers are assigned to the 1870's, 1973, 1990, and 2004 datasets. Aerial photo was taken in 2004.

CEA 2004 Digitizing Application

The CEA 2004 Digitizing Application is a simple, user-friendly application that allows for digitizing the toe of the bluff and the shoreline intersections (fig. 6). Once activated by the user, the application turns on the ArcMap Editor toolbar and sets the snapping tolerance (2 feet) for snapping to the shore-normal transect. The user is then prompted to first digitize the bluff toe (base of the bluff) and then the bluff crest (2004 shore) for each shore-normal transect. The application automatically switches between digitizing the bluff toe and the bluff crest (or other appropriate shore erosion reference feature) for each shore-normal transect. Attributes, such as the TID, the 1990 aerial photo frame number, and the original transect identification number, are automatically copied from the shore-normal transect and written to the newly digitized features in the geodatabase, thereby removing all keyboard entry errors. The application also identifies the user who digitized the feature, along with the date and time the feature was digitized. A user can also assign attributes to the shore-normal transect, including presence or absence of shore protection and an offset to account for anthropogenic erosion (that is, slope grading). By automating the process and significantly reducing keyboard entry errors, the Digitizing Tool application reduced the amount of time for GIS quality-control editing from approximately 160 hours to 8 hours.

CEA Calculator Application

Coastal erosion area calculations are a multistep process (Ohio Department of Natural Resources, 1996). The first step is to calculate the recession distance, which is the distance along the shore-normal transects between the reference shoreline intersection and the older shoreline intersection. Next, the recession rate is calculated by dividing the recession distance by the time interval between the reference shoreline and the most recent shoreline (for example, the 14 years between 1990 and 2004 [fig. 7]). The 30-year recession distance is calculated by multiplying the recession rate by 30 years (see figure 6). The 30-year recession distance is then smoothed using a five-point, center-weighted, moving-average filter (fig. 8). The

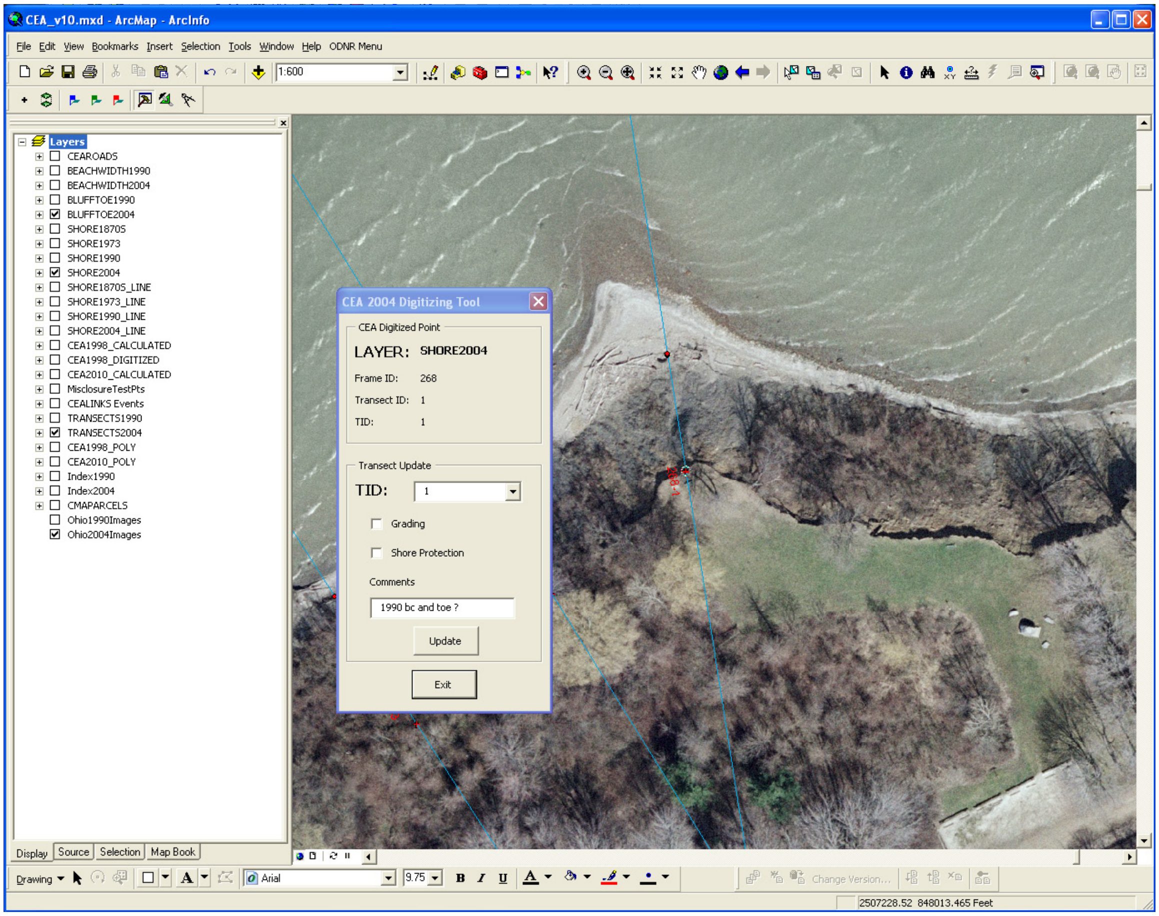

Figure 6. The CEA 2004 Digitizing Application. The VBA form displays the attributes being transferred from transects to the new points. The user has the ability to add attributes as to whether manmade grading has occurred to the bluff slope, whether shore protection has been installed, and other comments about the points which can be included in the dataset.

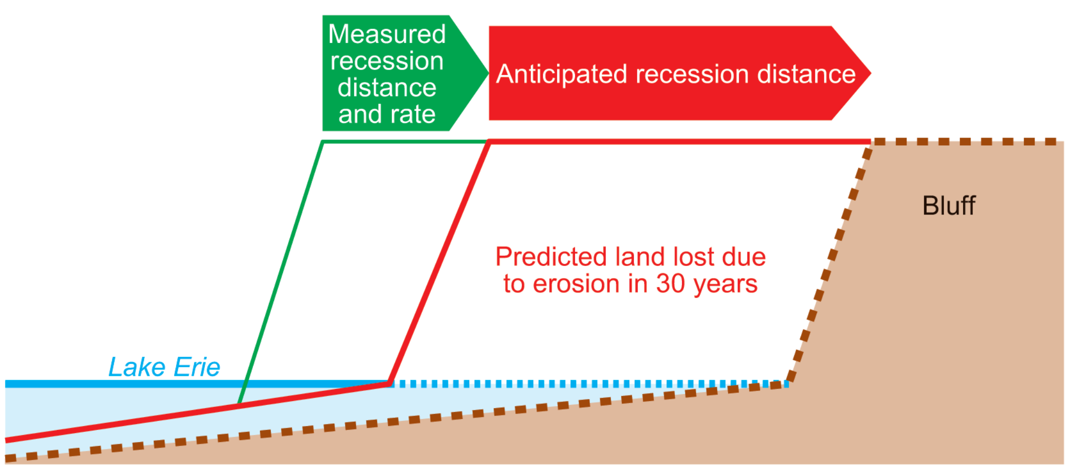

Figure 7. Sample cross section of the Lake Erie bluff showing the measured recession distance (that is, between 1990 and 2004) and the projected 30-year recession distance.

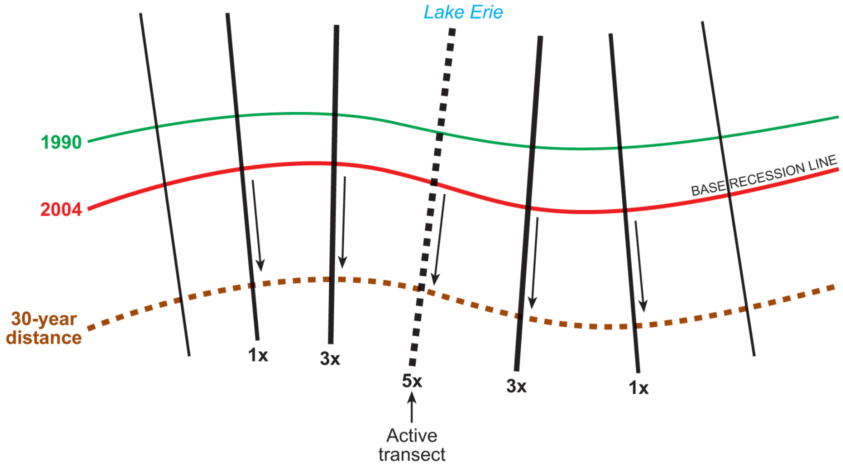

Figure 8. A five-point moving average is used to smooth the projected (30-year) shoreline.

five-point, center-weighted, moving-average filter is required because any small changes in the recession rate are magnified by a factor of 30 and the coastal erosion area designation would be a jagged line. The five-point, center-weighted, moving-average filter is calculated using the 30-year recession distance at a central transect and two transects on either side of the central transect. Weights of 5, 3, and 1 are applied to the five transects. The weighted values are summed and divided by 13 to produce the 30-year average recession (or coastal erosion area) distance at the central transect. The filter then shifts to the next adjacent transect and the process is repeated.

The final step is to plot the coastal erosion area (CEA) designation line (fig. 9). The CEA designation is plotted when the 30-year average recession distance is greater than the Calculated Accuracy Limit (CAL). The CAL value provides a way to incorporate mapping uncertainty into coastal erosion areas. The administrative code (Ohio Department of Natural Resources, 1996) specifies the mapping uncertainty be set at 5 feet total error between the two different mapping epochs. The 5-foot mapping error is divided by the interval in years and then multiplied by 30 to propagate 30 years into the future, creating the CAL. For the first coastal erosion area mapping in 1998, the CAL was computed to be 9 feet. For the upcoming remapping of coastal erosion areas, the CAL is computed to be 11 feet. The CAL acts as a minimum coastal erosion area distance. If the 30-year average recession distance is less than the CAL value, then a coastal erosion area is not designated. If the 30-year average recession distance is greater than the CAL value, then a coastal erosion area is designated.

The CEA Calculator incorporates all of the calculations described above into an easy-to-use application (fig. 10). The application requires four different GIS layers: the reference shoreline and the older shoreline, the toe of the bluff for the most recent year mapped, and the shore-normal transects. For the special case of coastal erosion areas being calculated for a Lake Erie island, a simple checkbox is provided to designate an island calculation.

Coastal erosion area calculations are a three-step process. After selecting all the layers, the operator first creates the CAL line. Then, the operator calculates the recession distance, recession rate, and the 30-year average recession distance. These values are written into the attribute table of the shore-normal transects feature class. Finally, the coastal erosion area designation lines are plotted using the application. These three operations are performed using a simple selection of the three command buttons.

The CEA Calculator application was originally written in FORTRAN 77 for the 1998 coastal erosion area mapping project. For the latest remapping, the application was converted to VBA using ArcObjects. Since coastal erosion area designation is a regulatory program, the ODNR Division of

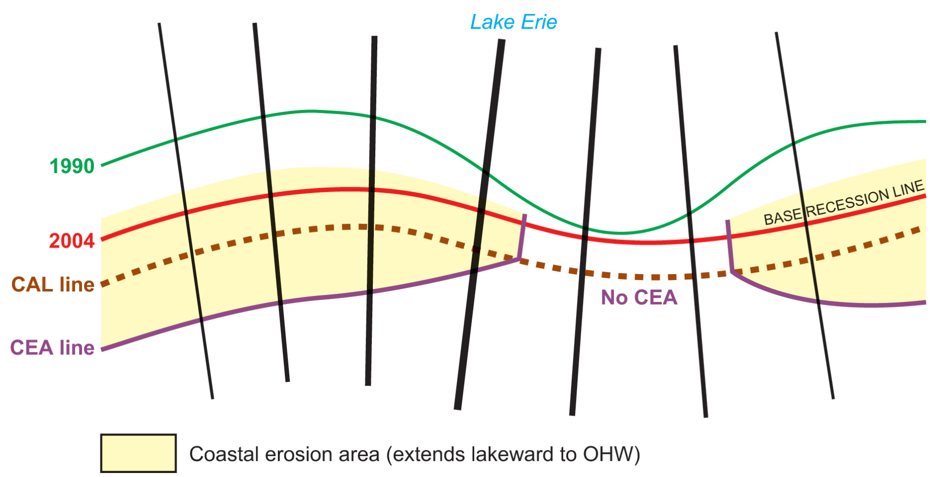

Figure 9. All the components either used or calculated during the Lake Erie coastal erosion area designation are shown here. The 1990 shoreline/bluff crest (green line) and 2004 shoreline (red line) are mapped using aerial photography. The black lines perpendicular to the shore are the shore-normal transects, which are used as reference lines for measuring shore recession. The Calculated Accuracy Limit (CAL; dashed, brown line) is created using the 2004 shoreline/bluff crest as the base recession line. Finally, coastal erosion area (CEA) lines (purple line) are calculated and plotted back into the GIS database using the CAL line and annual-recession distance projected 30 years into the future. The coastal erosion area (yellow shaded area) extends lakeward from the CEA line to the ordinary high-water (OHW) mark on the lake.

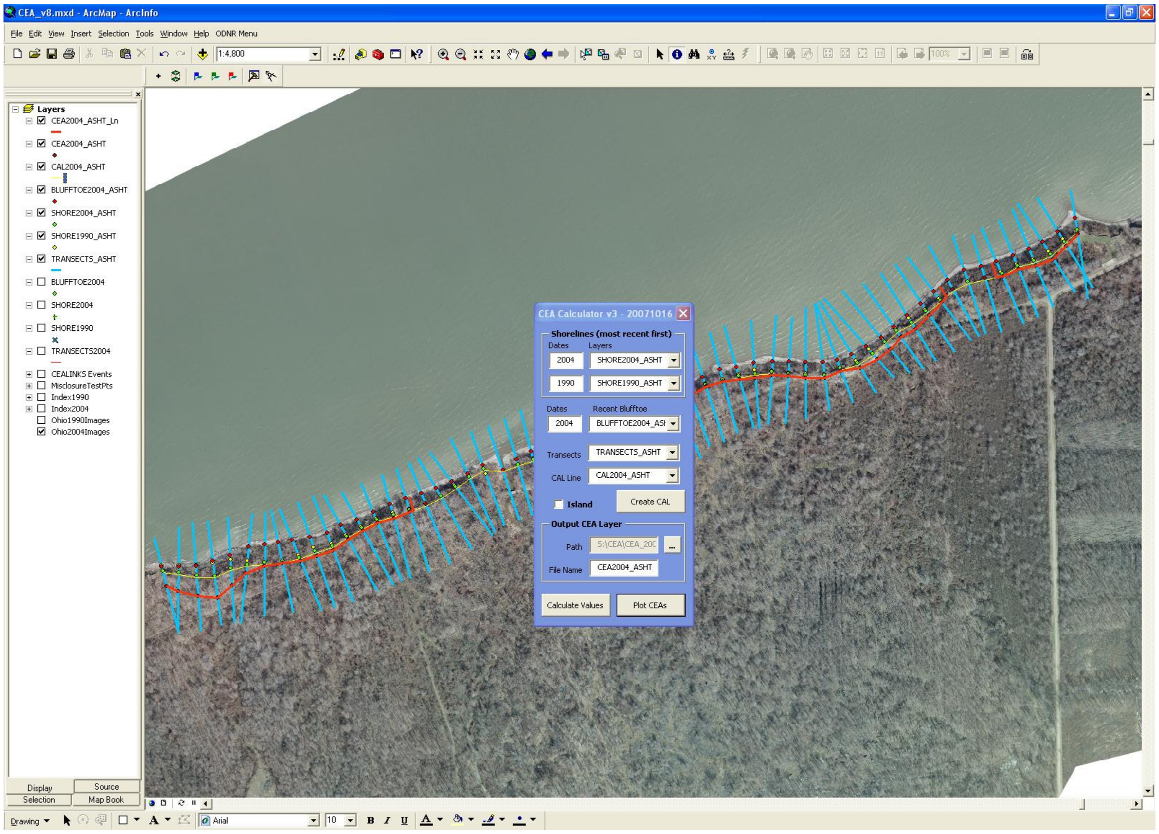

Figure 10. The CEA Calculator application.

Geological Survey had to ensure that the output from the VBA using ArcObjects code exactly reproduced the output from the FORTRAN 77 code by comparing the output from the two applications (fig. 11). The 30-year average recession distances compare to within 0.01 feet. These results assure us that we correctly translated the application code from FORTRAN 77 to VBA using ArcObjects.

Conclusions

Three GIS applications were developed to assist the ODNR Division of Geological Survey to map coastal erosion areas along the Ohio Lake Erie Shore, which resulted in significant time and cost savings to the coastal erosion area mapping project. The TID application assigned unique identification numbers to all the features in the coastal erosion area GIS. Over 166,000 features have TIDs assigned. We used the 2004 Digitizing Application to map shore features that were used to calculate recession distances, which significantly reduced keyboard entry errors. Digitizing the 2004 shoreline took approximately 3 months to complete using this application, while the previous coastal erosion area mapping took approximately 1 year to complete. The CEA Calculator tool was successfully converted from FORTRAN 77 to VBA using ArcObjects and then applied to the 2004 dataset to calculate new coastal erosion areas and to identify coastal properties at risk to Lake Erie-related coastal erosion.

Now that the preliminary mapping is complete, additional products can be developed with the new GIS data. Traditional products created for the 1998 coastal erosion area mapping project included map books (fig. 12) and data table books. Similar products can be easily produced using the 2004 GIS dataset. The public is already familiar with these products, and these products can be rapidly generated and updated with ease. The maps will be made public via a Web map application on the ODNR Web site, and hard copies will be made available at select repositories and public buildings along the coast.

The new coastal erosion area GIS data can be combined with other geospatial datasets. For example, the coastal erosion area GIS dataset can be overlaid with county auditors' parcel owner data, and those parcels affected by coastal erosion area designations can be easily identified. In addition, those parcel owners that are dropped from the 1998 coastal erosion area designation can be easily identified. By performing these overlay operations in the GIS environment, we can rapidly identify the property owners who are affected by the new coastal erosion area designation, along with those property owners who were originally in the 1998 coastal erosion areas and are being dropped from the new designation. Affected property owners can then be notified.

Microsoft Excel - CEA Software Comparison.xls

A2 | TID

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1				2008 ARCGIS PROGRAM					1998 FORTRAN PROGRAM						DIFFERENCE COMPARISON			
2	TID	TRANS	YRS	M_DIST	RATE	A_DIST	OFFSETS	STATUS	M_DIST	RATE	A_DIST	OFFSETS	STATUS		M_DIST	RATE	A_DIST	STATUS
1480	1478	315-22	17	0.22	0.01	0.58	0.00	NO CEA	0.22	0.01	0.58	0.0	NO CEA		0.00	0.00	0.00	
1481	1479	315-23	17	0.39	0.02	0.64	0.00	NO CEA	0.39	0.02	0.63	0.0	NO CEA		0.00	0.00	-0.01	
1482	1480	315-24	17	0.53	0.03	0.66	0.00	NO CEA	0.53	0.03	0.66	0.0	NO CEA		0.00	0.00	0.00	
1483	1481	315-25	17	0.00	0.00	0.61	0.00	NO CEA	0	0	0.60	0.0	NO CEA		0.00	0.00	-0.01	
1484	1482	315-26	17	0.83	0.05	0.77	0.00	NO CEA	0.83	0.05	0.77	0.0	NO CEA		0.00	0.00	0.00	
1485	1483	315-27	17	0.00	0.00	0.82	0.00	NO CEA	0	0	0.82	0.0	NO CEA		0.00	0.00	0.00	
1486	1484	315-28	17	1.02	0.06	1.00	0.00	NO CEA	1.02	0.06	1.01	0.0	NO CEA		0.00	0.00	0.01	
1487	1485	315-29	17	0.49	0.03	0.75	0.00	NO CEA	0.49	0.03	0.75	0.0	NO CEA		0.00	0.00	0.00	
1488	1486	315-30	17	0.00	0.00	0.34	0.00	NO CEA	0	0	0.34	0.0	NO CEA		0.00	0.00	0.00	
1489	1487	316- 1	17	0.00	0.00	0.07	0.00	NO CEA	0	0	0.07	0.0	NO CEA		0.00	0.00	0.00	
1490	1488	316- 2	17	0.00	0.00	0.00	0.00	NO CEA	0	0	0.00	0.0	NO CEA		0.00	0.00	0.00	
1491	1489	316- 3	17	0.00	0.00	0.00	0.00	NO CEA	0	0	0.00	0.0	NO CEA		0.00	0.00	0.00	
1492	1490	316- 4	17	0.00	0.00	0.04	0.00	NO CEA	0	0	0.04	0.0	NO CEA		0.00	0.00	0.00	
1493	1491	316- 5	17	0.00	0.00	0.15	0.00	NO CEA	0	0	0.15	0.0	NO CEA		0.00	0.00	0.00	
1494	1492	316- 6	17	0.27	0.02	0.33	0.00	NO CEA	0.27	0.02	0.33	0.0	NO CEA		0.00	0.00	0.00	
1495	1493	316- 7	17	0.28	0.02	0.41	0.00	NO CEA	0.28	0.02	0.41	0.0	NO CEA		0.00	0.00	0.00	
1496	1494	316- 8	17	0.23	0.01	0.36	0.00	NO CEA	0.23	0.01	0.36	0.0	NO CEA		0.00	0.00	0.00	
1497	1495	316- 9	17	0.12	0.01	0.26	0.00	NO CEA	0.12	0.01	0.26	0.0	NO CEA		0.00	0.00	0.00	
1498	1496	316-10	17	0.00	0.00	0.24	0.00	NO CEA	0	0	0.24	0.0	NO CEA		0.00	0.00	0.00	
1499	1497	316-11	17	0.33	0.02	0.37	0.00	NO CEA	0.33	0.02	0.36	0.0	NO CEA		0.00	0.00	-0.01	
1500	1498	316-12	17	0.16	0.01	0.42	0.00	NO CEA	0.16	0.01	0.42	0.0	NO CEA		0.00	0.00	0.00	
1501	1499	316-13	17	0.44	0.03	0.41	0.00	NO CEA	0.44	0.03	0.40	0.0	NO CEA		0.00	0.00	-0.01	
1502	1500	316-14	17	0.00	0.00	0.20	0.00	NO CEA	0	0	0.20	0.0	NO CEA		0.00	0.00	0.00	
1503	1501	316-15	17	0.00	0.00	0.10	0.00	NO CEA	0	0	0.10	0.0	NO CEA		0.00	0.00	0.00	
1504	1502	316-16	17	0.00	0.00	0.13	0.00	NO CEA	0	0	0.13	0.0	NO CEA		0.00	0.00	0.00	
1505	1503	316-17	17	0.32	0.02	0.22	0.00	NO CEA	0.32	0.02	0.22	0.0	NO CEA		0.00	0.00	0.00	
1506	1504	316-18	17	0.00	0.00	0.18	0.00	NO CEA	0	0	0.18	0.0	NO CEA		0.00	0.00	0.00	
1507	1505	316-19	17	0.00	0.00	0.96	0.00	NO CEA	0	0	0.96	0.0	NO CEA		0.00	0.00	0.00	
1508	1506	316-20	17	0.36	0.02	2.55	0.00	NO CEA	0.36	0.02	2.55	0.0	NO CEA		0.00	0.00	0.00	
1509																		
1510																		
1511														Mean:	0	-2.77322E-05	6.83931E-05	
1512														Min:	0.00	0.00	-0.01	
1513														Max:	0.00	0.00	0.01	
1514														Sigma	0	0.002542205	0.003608402	
1515														2 Sigma	0	0.00508441	0.007216805	
1516																		

CEA Software Comparison

Ready NUM

Figure 11. Portion of a table showing the comparison of the recession distance, recession rate, and 30-year average recession distance generated by both the original FORTRAN 77 coastal erosion area code and the new VBA and ArcObjects coastal erosion area code.

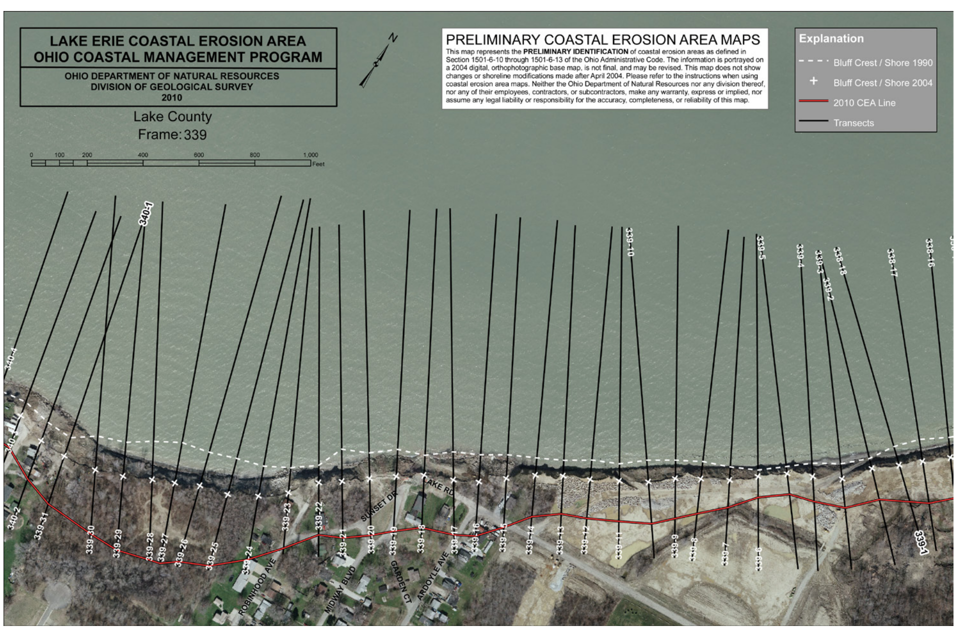

Figure 12. Example map book page (for a section of Lake Erie coast in Painesville, Ohio) from the coastal erosion area GIS dataset.

The coastal erosion area GIS dataset also can be combined with other datasets to perform scientific investigations. The ODNR Division of Geological Survey has created a shore structure inventory along the Lake Erie coast of Ohio (Fuller and Gerke, 2005). The combination of the shore structure inventory, the 1998 coastal erosion area results, and the newly available coastal erosion area designation can be used to evaluate the relative effectiveness of shore structures in reducing coastal erosion rates.

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References

Carter, C.H., 1973, The November 1972 storm on Lake Erie: Ohio Department of Natural Resources, Division of Geological Survey Information Circular 39, 12 p.

Environmental Data Service, 1972, Storm data: U.S. Department of Commerce, NOAA, v. 14, no. 11, p. 178–185.

Fuller, J.A., and Gerke, B.E., 2005, Distribution of shore protection structures and their erosion effectiveness and biological compatibility: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2005-02, 32 p.

Guy, D.E., Jr., 1999, Erosion hazard area mapping, Lake County, Ohio: Journal of Coastal Research, Special Issue 28, p. 185–196.

Kreisel, Warren, and Lichtkoppler, Frank, 1989, Coastal erosion and the residential property market: Columbus, Ohio, Ohio Sea Grant Fact Sheet 044 and appendix, 6 p.

Kreisel, Warren, Randall, Alan, and Lichtkoppler, Frank, 1993, Estimating the benefits of shore erosion protection in Ohio’s Lake Erie housing market: Water Resources Research, v. 29, p. 795–801.

Mackey, S.D., Foye, D.A., and Guy, D.E., 1996, Lake Erie recession-line mapping—An update, in Folger, D.W., ed., Proceedings 4th annual Lake Erie coastal erosion study workshop, U.S. Geological Survey Center for Coastal Geology, St. Petersburg, FL, April 16–18, 1996: U.S. Geological Survey Open-File Report 96-507, p. 37–39.

McDonald, James, 2009, Project-management GIS applications for coastal-erosion mapping in Ohio, in Soller, D.R., ed., Digital Mapping Techniques ’08—Workshop Proceedings: U.S. Geological Survey Open-File Report 2009-1298, p. 177–184, accessed June 16, 2010, at *http://pubs.usgs.gov/of/2009/1298/pdf/usgs_of2009-1298_mcdonald.pdf*.

Ohio Department of Natural Resources, 1996, Rules for designating Lake Erie coastal erosion areas: Columbus, Ohio, State of Ohio, Ohio Administrative Rules 1501-6-10 through 1501-6-13, 16 p., accessed June 16, 2010, at *http://codes.ohio.gov/oac/1501-6*.

U.S. Army Corp of Engineers, 1971, National shoreline study—Great Lakes inventory report: Chicago, Illinois, Department of the Army, 221 p.