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# Geomorphic Feature Extraction to Support the Great Lakes Restoration Initiative's Sediment Budget and Geomorphic Vulnerability Index for Lake Michigan

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**PURPOSE:** This Coastal and Hydraulics Engineering technical note (CHETN) details a Geographic Information Systems (GIS) methodology to produce advanced lidar-derived datasets for use in a coastal erosion vulnerability analysis conducted by the US Army Corps of Engineers (USACE) and other federal partners for the Great Lakes Restoration Initiative (GLRI).

**INTRODUCTION:** The GLRI is a multiyear collaborative effort among federal agencies to accelerate efforts that protect and restore the largest freshwater system in the world—the Great Lakes. High water levels in the Great Lakes accelerate rates of shoreline erosion, threaten critical infrastructure and industry, and degrade important ecosystem services (i.e., fish and wildlife habitat) (GLCR 2021). The US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), is collaborating with multiple districts within the Great Lakes Division (LRD), as well as partners in the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS) in a GLRI-funded initiative to focus efforts on protection and restoration. Rates of shoreline erosion vary within each lake. Sediment availability in the nearshore, as well as nearshore geomorphology influences on local wave climate, contribute to spatial variations in shoreline erosion that need to be understood to design targeted, sustainable, and cost-effective mitigation efforts.

ERDC's contribution to this GLRI initiative includes the development of nearshore geomorphology features (i.e., coastal bluffs and sand bars) and metrics (i.e., beach slope, beach width, and nearshore concavity) shown in Figure 1 to support the development of sediment budgets and a Geomorphic Vulnerability Index (GVI) for each lake. ERDC tasks detailed in this technical note include (1) the integration of high-resolution, high-accuracy topobathy lidar data products provided by the USACE National Coastal Mapping Program (NCMP) and other available bathymetry into lake-wide, near-seamless Digital Elevation Models (DEMs), (2) the application of a novel geomorphic feature extraction workflow implemented in a GIS environment to produce a suite of nearshore geomorphology features and metrics, and (3) the incorporation of extracted features into a web-based feature service for visualization in a web browser or for local download and further analysis in GIS software.

ERDC's initial work for the GLRI initiative focused on Lake Michigan, where outputs from the geomorphic feature extraction workflows are being used by LRD in the development of sediment budgets through the USACE Sediment Budget Analysis System tool (Rosati and Kraus 1999; McGill et al. 2022). LRD is also collaborating with USGS and ERDC to use these outputs in support of developing a GVI. This index work employs a Bayesian statistical approach to determine the contribution of these extracted features to coastal vulnerability. Together, the sediment budgets and vulnerability index can be used to identify and understand key influences on the varying rates and impacts of shoreline erosion for each lake. This knowledge, informed by the characterization of nearshore geomorphology, is key to identifying appropriate mitigation and restoration efforts for shoreline erosion and ecosystem degradation in the Great Lakes.

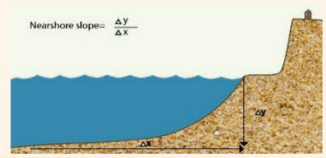
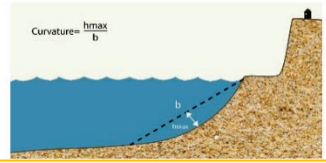
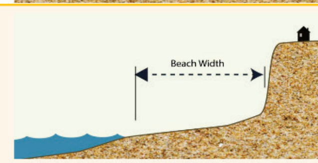
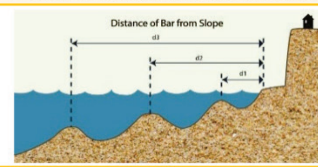
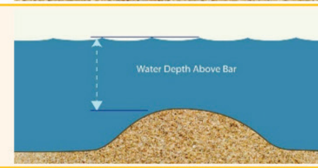
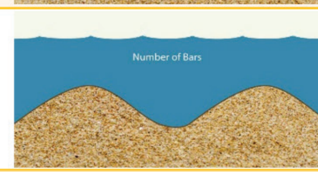
| Measurement | Explanation/Definition | Figure |
|---|---|---|
| **Nearshore Slope** | Average slope from shoreline to 30 feet of water depth or depth of closure. |   |
| **Nearshore Curvature** | Shape of the nearshore slope. Concavity given as up/down, and values calculated as shown. |   |
| **Beach Width** | Width of active beach between the bluff or dune toe and the shoreline. |   |
| **Bar distance from shoreline** | Distance from the shoreline to the crest of the bar. |   |
| **Bar water depth** | Water depth above bar crest |   |
| **Number of bars** | Number of bars in the cross shore |   |

Figure 1. Summary of sand bar geomorphology metrics extracted from topobathy lidar.

**SOURCE DATASETS:** The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) is a partnership among the federal government, industry, and academia to perform operations, research, and development in airborne lidar bathymetry and complementary technologies. Under a collaborative agreement signed in 1998, the USACE, the US Naval Meteorology and Oceanography Command, and NOAA formed the JALBTCX to address coastal mapping and charting requirements within their organizations. Over the last 23 yr[1] , the JALBTCX partnership pioneered the development of three generations of technology for the acquisition of

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[1] For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–7, respectively. https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

airborne lidar bathymetry, deployed this technology operationally in over 20 countries, expanded the federal partnership to include USGS, and collaborated with industry to expand the utility of the data to address emerging environmental concerns such as coastal storm risk and habitat degradation.

The USACE operations are executed by JALBTCX under the USACE NCMP. USACE Headquarters funds the NCMP to acquire high-resolution, high-accuracy topographic and bathymetric lidar and imagery data along sandy shorelines of the United States on a recurring basis. The NCMP operates counterclockwise around the United States and maps coastlines in the Gulf of Mexico, Southeast, Northeast, Great Lakes, and West Coast approximately every 5 yr. Mapping in Hawaii and Alaska is performed as funding permits. In Lake Michigan, the NCMP completed regional mapping from 2006 to 2008, 2012 to 2013, and most recently from 2018 to 2020 (Figure 2). Data coverage typically includes an approximately 1,500 m wide swath of data that extends from 500 m inland of the shoreline to 1 km offshore. Lidar elevation point clouds, DEMs, shoreline vectors, true-color image mosaics, and hyperspectral image mosaics comprise the basic tier of NCMP data products that were available for use by ERDC-CHL to develop geomorphic features in support of the GLRI sediment budget and GVI initiatives.

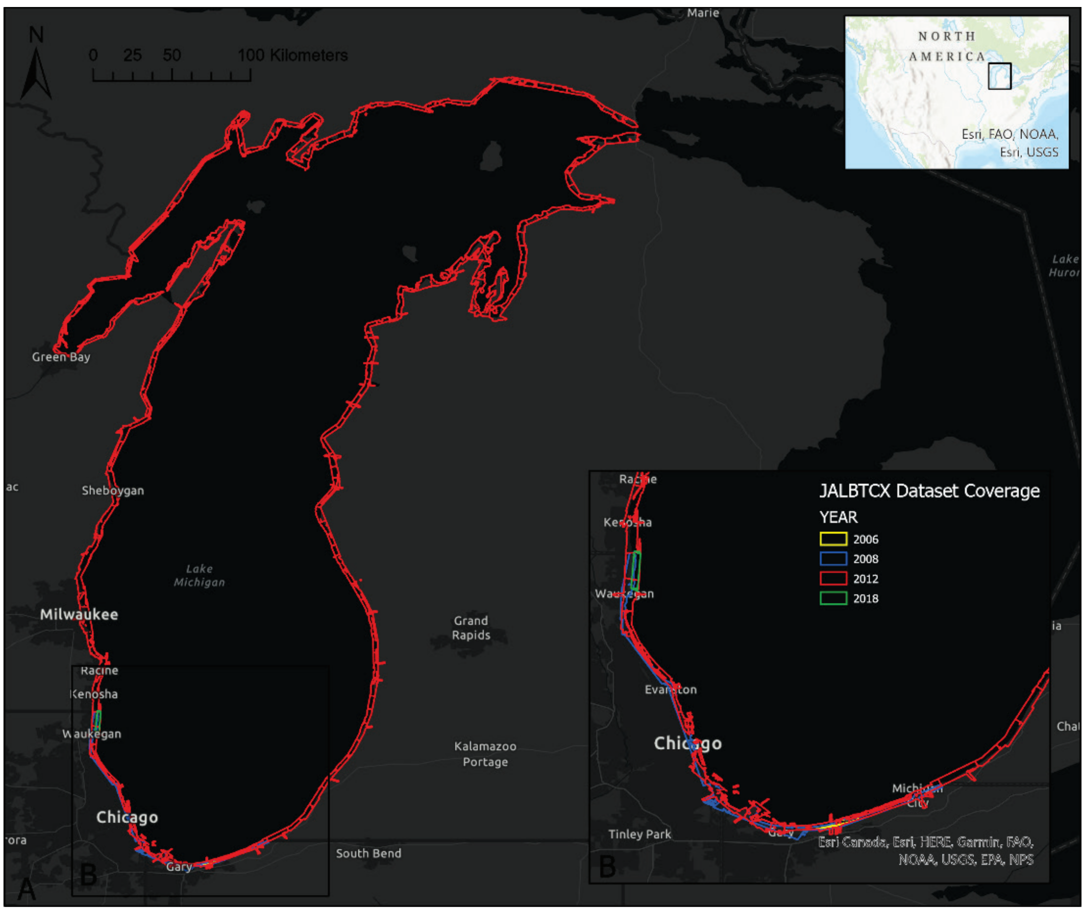



Figure 2. Study area includes (*A*) the shoreline of Lake Michigan; (*B*) NCMP data coverage extent polygons are symbolized in colors by acquisition year.

**SEAMLESS DEMs FOR FEATURE EXTRACTION:** Chief limitations of bathymetric lidar include water clarity, breaking waves, water-surface roughness, and the reflectivity of the seabed. Turbidity in the water column, for example, scatters the lidar signal and obscures the lidar return from the seabed. Turbid areas result in data gaps in the final lidar data coverage. While attempts are made to accomplish complete lidar coverage of the nearshore, data gaps in bathymetry may unfortunately exist in nearshore areas coincident with geomorphology features that are critical to understanding geomorphic vulnerability.

JALBTCX recently pioneered a workflow to address nearshore data gaps and produce near-seamless regional DEMs that support nearshore geomorphology feature extraction. The mosaic dataset architecture in Esri ArcGIS Pro provides a means for integrating available, multisource, multitemporal, and multiresolution datasets for Lake Michigan that are inventoried in Table 1. Note that for the purposes of this DEM workflow, all DEM products available for these datasets are referenced to the International Great Lakes Datum of 1985 (IGLD85) vertical datum.

**Table 1. Inventory of data sources for integration into near-seamless DEMs. Data access is provided through NOAA's Digital Coast. The dataset URL is *https://coast.noaa.gov/dataviewer/#/lidar/search/where:ID=*, where # is the numeric digits in the Data Access column.**

| Dataset Name | Mosaic Z-order | Collection Year | Start Date | End Date | Data Access |
|---|---|---|---|---|---|
| NOAA National Centers for Environmental Information Lake Level Viewer 3 m DEM | 9 | 2006–2016 | 1/1/2006 | 12/30/2016 | *https://coast.noaa.gov/digitalcoast/tools/llv* |
| 2006 USACE NCMP Topobathy Lidar: Lake Erie (OH, PA), Lake Huron (MI) and Lake Michigan (Porter County, IN) | 8 | 2006 | 6/1/2006 | 9/1/2006 | ID = 40 |
| 2007 USACE NCMP Topobathy Lidar: Lake Erie (Erie County, PA) and Lake Michigan (Manitou Islands) (MI, PA) | 7 | 2007 | 8/1/2007 | 9/1/2007 | ID = 115 |
| 2008 USACE NCMP Topobathy Lidar: Lake Michigan (Michigan Coastline) | 6 | 2008 | 7/1/2008 | 9/1/2008 | ID = 518 |
| 2008 USACE NCMP Topobathy Lidar: Lake Michigan (Illinois Coastline) | 6 | 2008 | 9/1/2008 | 9/1/2008 | ID = 563 |
| 2008 USACE NCMP Topobathy Lidar: Lake Michigan (Wisconsin Coastline) | 6 | 2008 | 9/1/2008 | 10/1/2008 | ID = 564 |
| 2008 USACE NCMP Topobathy Lidar: Lake Michigan (Indiana Coastline) | 6 | 2008 | 9/1/2008 | 9/1/2008 | ID = 588 |
| 2012 USACE NCMP Topobathy Lidar: Lake Michigan (MI, WI) | 5 | 2012 | 6/1/2012 | 8/1/2012 | ID = 3663 |
| 2012 USACE NCMP Topobathy Lidar: Lake Michigan (IL, IN, MI, WI) | 5 | 2013 | 9/2/2012 | 11/26/2013 | ID = 2644 |
| 2013 USACE NCMP Topobathy Lidar: Lake Michigan South (MI) | 4 | 2013 | 7/1/2013 | 7/1/2013 | ID = 4845 |
| 2018 USACE Ecosystem Management and Restoration Research Program Lake Michigan Topobathy Lidar: Lake Michigan (Illinois Beach State Park) | 3 | 2018 | 7/13/2018 | 7/17/2018 | Data delivered to Digital Coast |
| 2019 USACE NCMP Topobathy Lidar: Lake Michigan (MI, WI) | 2 | 2019 | 4/25/2019 | 7/31/2019 | Data in final QC |
| 2020 USACE NCMP Topobathy Lidar: Lake Michigan (MI, IN, IL, WI) | 1 | 2020 | 6/3/2020 | 6/30/2020 | Data in final QC |

Dataset DEMs are loaded into individual source mosaic datasets and attributed with metadata related to their collection. Attribution includes the source's collection date(s), access URL and *Z*-order, or dataset ranking. The *Z*-order is manually assigned such that the most-recent, highest-resolution dataset is assigned the highest priority for mosaicking while the lowest-resolution dataset, often older, is assigned a low priority. A derived mosaic dataset is then constructed with the source mosaic datasets. The derived mosaic dataset can be thought of as "mosaic dataset of mosaic datasets." Mosaicking on the derived mosaic dataset is accomplished by setting the display options to utilize a mosaic operator of "By Attribute" using the attribute "Z-Order." In effect, much like a Swiss cheese sandwich, any holes in the highest-priority (newest) dataset are successively filled by lower-priority (older) datasets farther down in the layer stack. Figure 3 presents a conceptual diagram of the mosaic data set architecture using the Swiss cheese analogy.

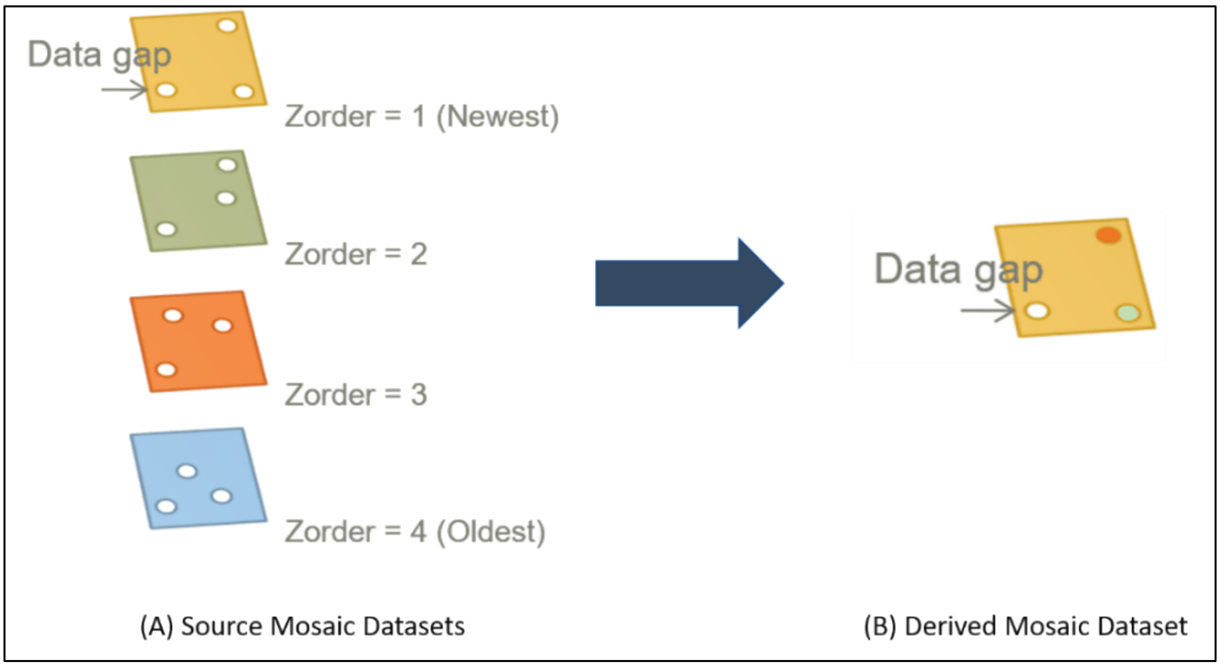



Figure 3. Conceptual diagram of a mosaic dataset architecture that includes (*A*) source mosaic datasets and (*B*) a final derived mosaic dataset.

Once the datasets are integrated into this mosaic dataset architecture, a series of clip extent rectangles are used to develop DEM tiles from the derived mosaic dataset for post processing into near-seamless DEMs for the nearshore feature extraction workflow. For Lake Michigan, this process produced 20 DEMs that covered approximately 2,000 km of shoreline. The following steps executed in Esri ArcGIS Pro summarize the postprocessing workflow used to produce near-seamless DEMs:

1. Convert the DEM clip to UTM.
2. Extract pixel values between 166 m and 178 m IGLD85, which is approximately the 10 m depth contour and the Ordinary High-Water Line, respectively for Lake Michigan, and defines the area where nearshore geomorphology features will be extracted.

3. Manually edit pixels using the Esri ArcGIS Pro Pixel Editor to remove pixels representing low elevation located well inland of the nearshore area of interest.
4. Convert the DEM clip from raster to point.
5. Perform Empirical Bayesian Kriging (EBK) using the DEM-derived points as input, and leveraging parameters developed by USGS for the Coastal National Elevation Database model development (Danielson 2016).
6. Trim the EBK raster to remove bands of interpolated data around the edges of the DEM.
7. Apply an average filter using a 5 × 5 neighborhood to smooth flightline-related artifacts.
8. Manually quality control or edit the DEM to address remaining interpolation artifacts.

The near-seamless DEM workflow developed by JALBTCX leverages the expertise of technicians responsible for generating source DEMs from point clouds using best practices and standards implemented across the lidar mapping community. The workflow produces near-seamless DEMs from multiple disparate data sources in an efficient manner compared to methods that require combining, and manually interpreting or editing, lidar point cloud data to ameliorate temporal artifacts. This workflow, based on existing DEM data products, has built-in flexibilities to readily assimilate new data products once they become available. Challenges with this workflow, namely artifacts in the final output DEMs that are related to either temporal changes along data seamlines or to an absence of sufficient data points to perform interpolation, still exist. Users of these near-seamless DEMS should also have awareness of areas in the DEMs that were filled by interpolation. To that aim, an interpolation mask raster is an ancillary workflow product provided to users. The interpolation mask raster provides a means to inform the quality control (QC) of geomorphology features extracted from these DEMs and assist in determining whether the feature is valid as represented in the DEM or is an artifact of interpolation and should be discarded.

**JALBTCX TOOLBOX:** The set of geomorphology features and associated metrics developed in support of the GLRI sediment budget and GVI initiatives include bluff and dune crest and toe locations, beach slope, sand bar locations and their associated metrics (i.e., distance offshore and depth), beach width, beach slope, and nearshore concavity. The framework for feature extraction is based in GIS using a set of transects that circumnavigate Lake Michigan (Figure 4). The framework is implemented with the JALBTCX Toolbox (Figure 5), which is a toolbox available for Esri ArcGIS Pro that provides a standard workflow for the development of shoreline baselines and transects, and the extraction of coastal engineering metrics including nearshore geomorphology features, shoreline change, beach volume quantities and engineering resilience metrics (Robertson et al. 2017).

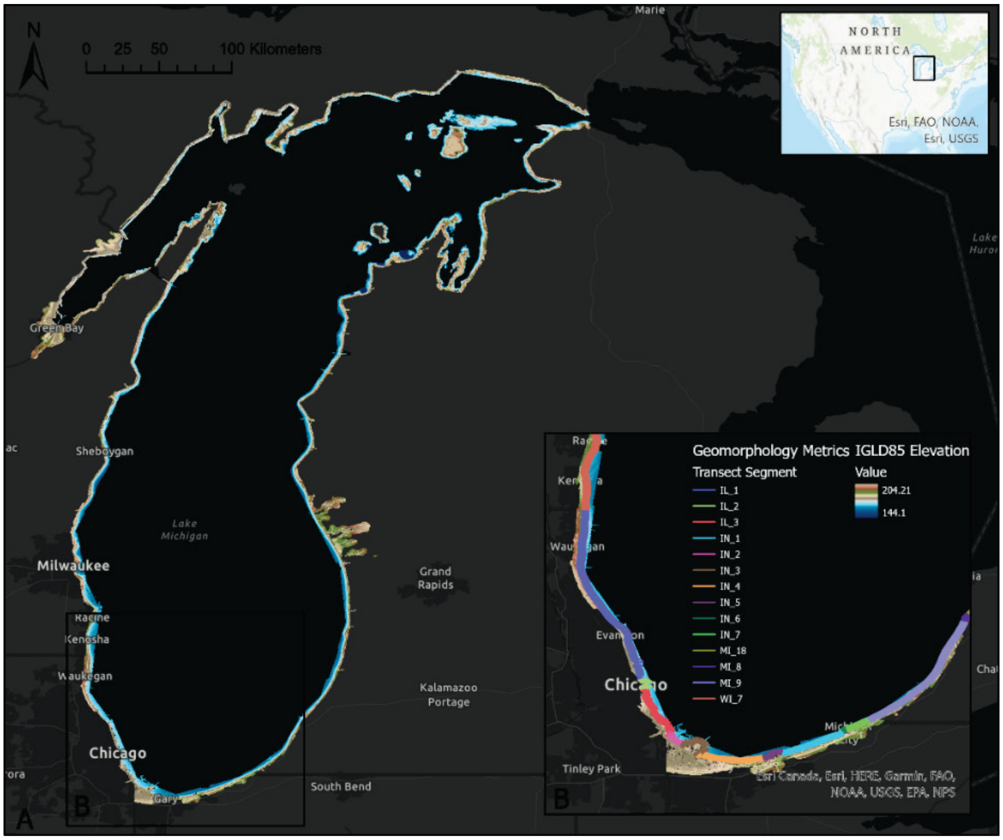



Figure 4. (*A*) Lake Michigan DEM colorized by IGLD85 elevation in meters. (*B*) Transects developed to support geomorphology feature extraction circumnavigate Lake Michigan and are colored by the shoreline segment.

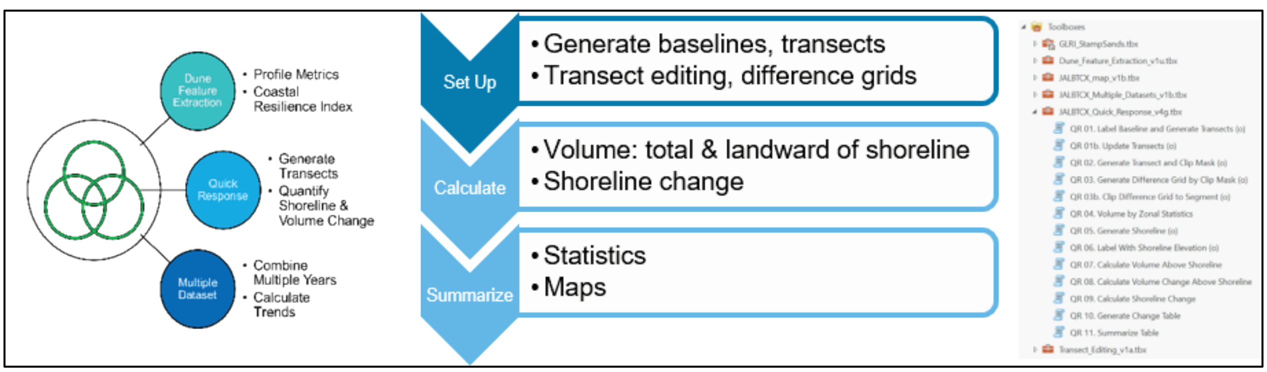



Figure 5. Overview of the JALBTCX Toolbox.

**BLUFF AND DUNE CREST AND TOE:** Dunkin et al. (2019) provides a detailed summary of the automated bluff extraction workflow. Inputs to the bluff extraction module include the original source DEMs from 2012 and a set of shoreline transects that were developed at 10 m spacing. Additional inputs for bluff extraction include a smoothing parameter, a cross-shore limit, a bluff percent slope minimum, and a minimum bluff elevation. Table 2 provides the values used for Lake Michigan. While not part of the user inputs, note that the slope drop-off value reported in the table may be adjusted as needed, but the default value was used for Lake Michigan. Also, bluff extraction was performed by separating the lake into western and eastern portions to account for varying bluff geomorphology around the lake.

**Table 2. Bluff extraction parameters.**

| Input Parameter | Input Value | Parameter Unit |
|---|---|---|
| Smoothing Parameter | 1 | meters |
| Cross-Shore Limit | 150, 600 (W. Lake Michigan, E. Lake Michigan) | meters |
| Bluff Percent Slope Minimum | 35 (.35) | % |
| Minimum Bluff Height | 190, 180 (W. Lake Michigan, E. Lake Michigan) | meters |
| Lake Level | 183.5 | meters |
| Slope Drop off | .05 (5%) | N/A |

In general, the automated bluff extraction module derives both elevation and slope profiles along each transect. Figure 6 depicts an idealized elevation and slope profile in blue and red, respectively. Along the profiles, it is expected that the bluff is located where elevations exceed the lake level and minimum bluff height parameters and are within the distance specified by the cross-shore limit parameter. Profile points at which the bluff percent slope minimum and slope drop-off criteria are found defines the location of the bluff crest and toe. These points are generated via algorithm through a Matlab script and exported to a shapefile format to be used in Esri ArcGIS Pro.

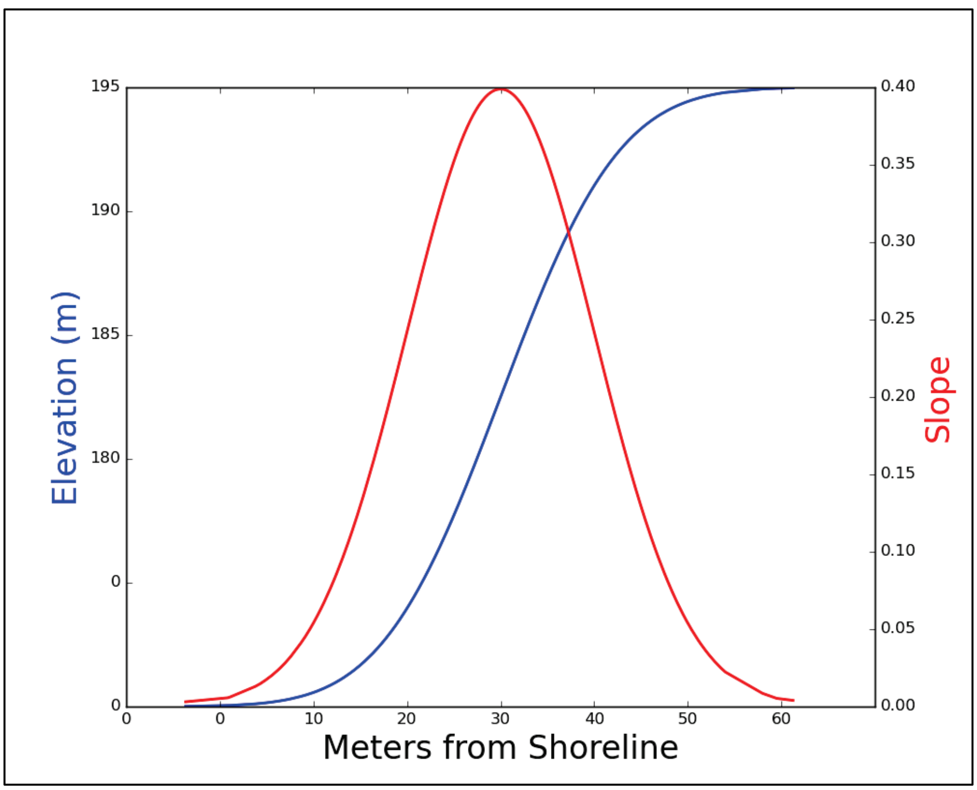



Figure 6. Idealized elevation and slope profiles for bluff extraction.

The bluff crest and toe locations undergo QC in Esri ArcGIS Pro. The manual QC process entails visual inspection of the features against a hillshade DEM and recent imagery to identify, and remove, features extracted on coastal infrastructure such as roads and jetties, features located too far inland for use in coastal studies, and features that are not considered representative of the first line of defense against waves and water levels. Data points are not manually digitized unless necessary to fulfill large gaps in the bluff dataset. Figure 7 shows examples of features that were manually removed as they had been extracted on coastal structures and not on actual coastal bluffs.

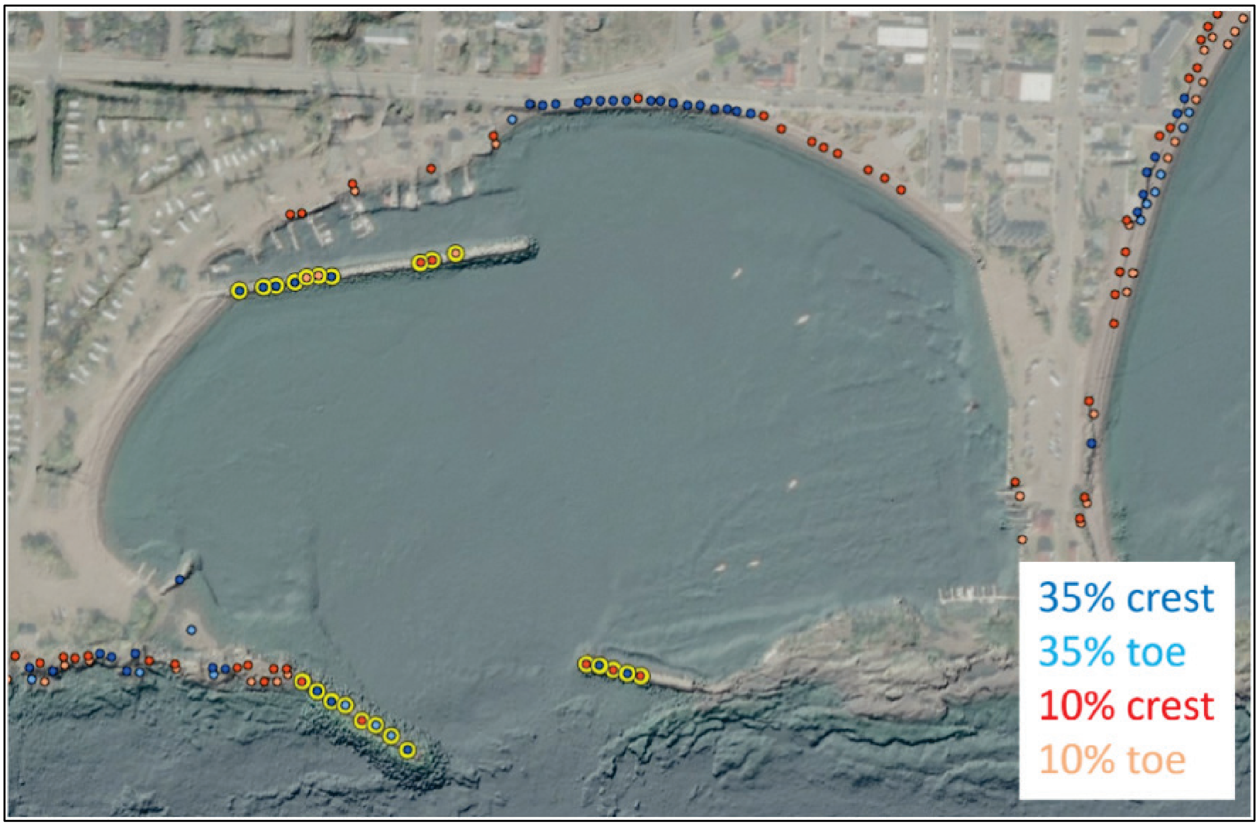



Figure 7. Bluff extraction results shown as *blue* and *red* points for two slope threshold parameters of 35% and 10%, respectively. *Yellow* highlighted features were manually removed during QC as these points were located along coastal structures.

Upon completion of the QC process, the bluff crest and toe features are packaged into a geodatabase for integration into web-based feature services and for use in other GIS applications. Figure 8 shows an example of a well-defined bluff line with bluff crest points (*blue* stars) found consistently. Bluff toe points (*red* points) were detected as well; however, the bluff toe points are not detected as consistently as the bluff crests in this area. A modification of the bluff parameters in the automated extraction module may produce bluff toes more consistently.

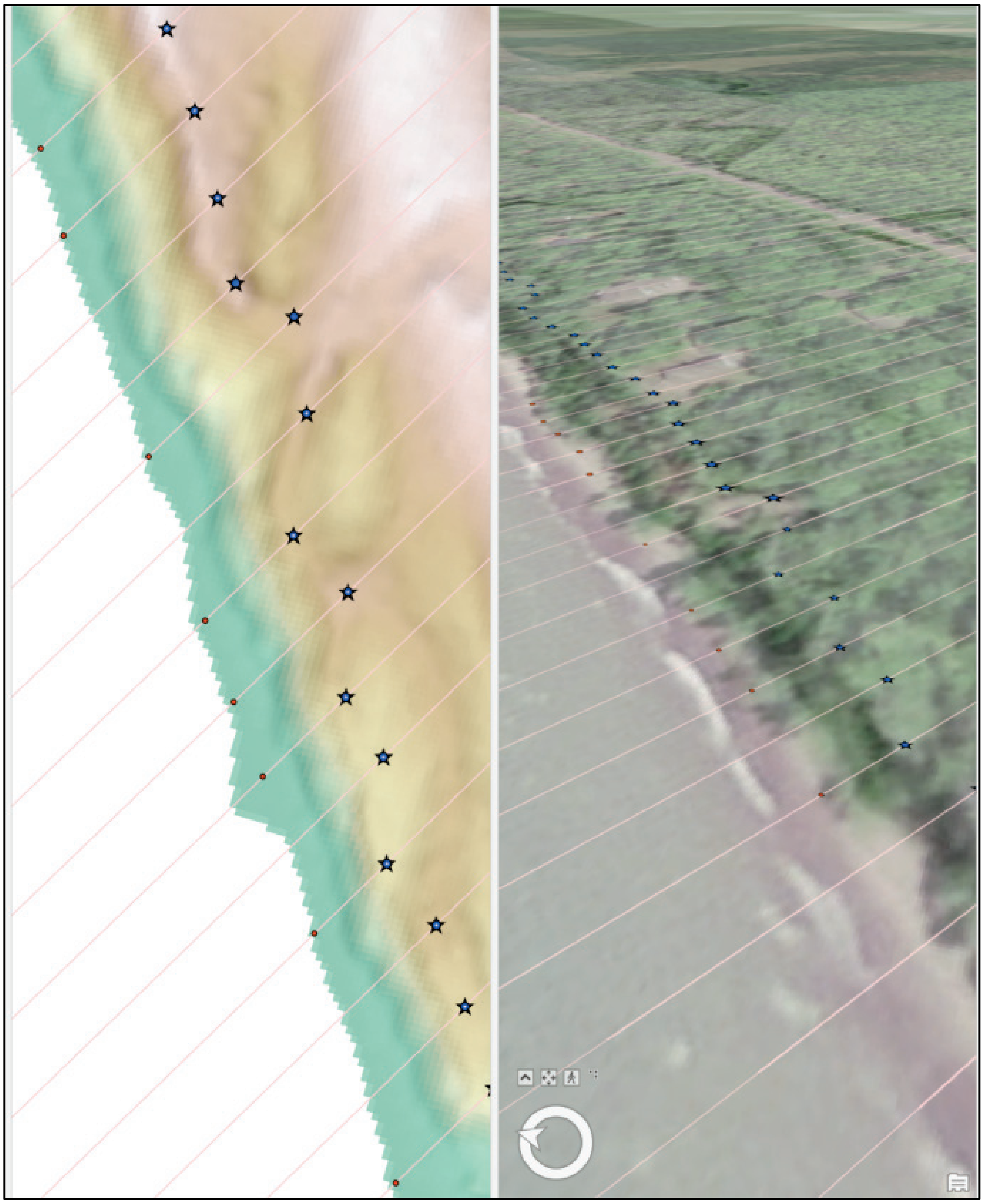


Figure 8. Consistent bluff crest locations (*blue stars*) extracted via automated means along a series of transects (*pink lines*) shown overlaid on a hillshade DEM (*left panel*) and 3D imagery (*right panel*).

**NEARSHORE SANDBARS:** Nearshore depth profiles along each transect were extracted from the DEM at a 1 m along-transect spacing and exported as a point shapefile to be post processed with a custom Matlab script. Within the Matlab script, the elevation along the depth profile is smoothed using a 5 m moving average. Then, a 3 m moving window is used to locate local maximums, or potential crests, along the profile. Potential crests are filtered again to remove potential crests that were detected due to proximity to data gaps or do not have any nearby crests. The remaining potential crests undergo QC, where they are also grouped by sand bar.

**TRANSECT TOOLBOX:** The **T**ransect-based **R**esearch **A**nalyzing **N**earshore and **S**ubaerial **E**xtracted **C**haracteristics **T**oolbox (TRANSECT) is a custom Esri ArcGIS Pro toolbox developed to support the derivation of sand bar features and associated metrics. Scripts from TRANSECT were recently incorporated in the JALBTCX Toolbox to streamline feature extraction workflows for the GLRI sediment budget and geomorphic vulnerability index initiatives. Written in Python, the toolbox performs analysis on the extracted nearshore geomorphology features in combination with the DEM to calculate beach width, sand bar metrics, and nearshore curvature for each transect. All metrics are saved as attributes within the transect shapefile.

**BEACH WIDTH:** Beach width is calculated at each transect based on the distance between the shoreline and a landward reference line (dune toe, bluff toe, hard engineered shoreline). For each transect, the beach width is computed via the horizontal distance formula using the transect coordinates of the shoreline and the reference line. The user of the beach width tool has the option of using multiple reference lines to calculate the beach width. When using multiple reference lines, all beach widths relative to the reference line can be returned, or the user can rank the priority of the lines. The ranking returns only the beach width relative to the highest priority reference line, which is annotated in the results (Table 3).

**Table 3. Beach width tool output. *Table A* shows the nonprioritized output, with columns named for the beach width in relation to the reference lines "bw_BluffToe" (bluff toe), "bw_Contour" (elevation contour), "bw_Hardened_Shoreline" (hardened shoreline), "bw_Dune_Toe" (dune toe), and "bw_Interp_Bluff_Toe" (interpolated bluff toe). *Table B* shows the prioritized results.**

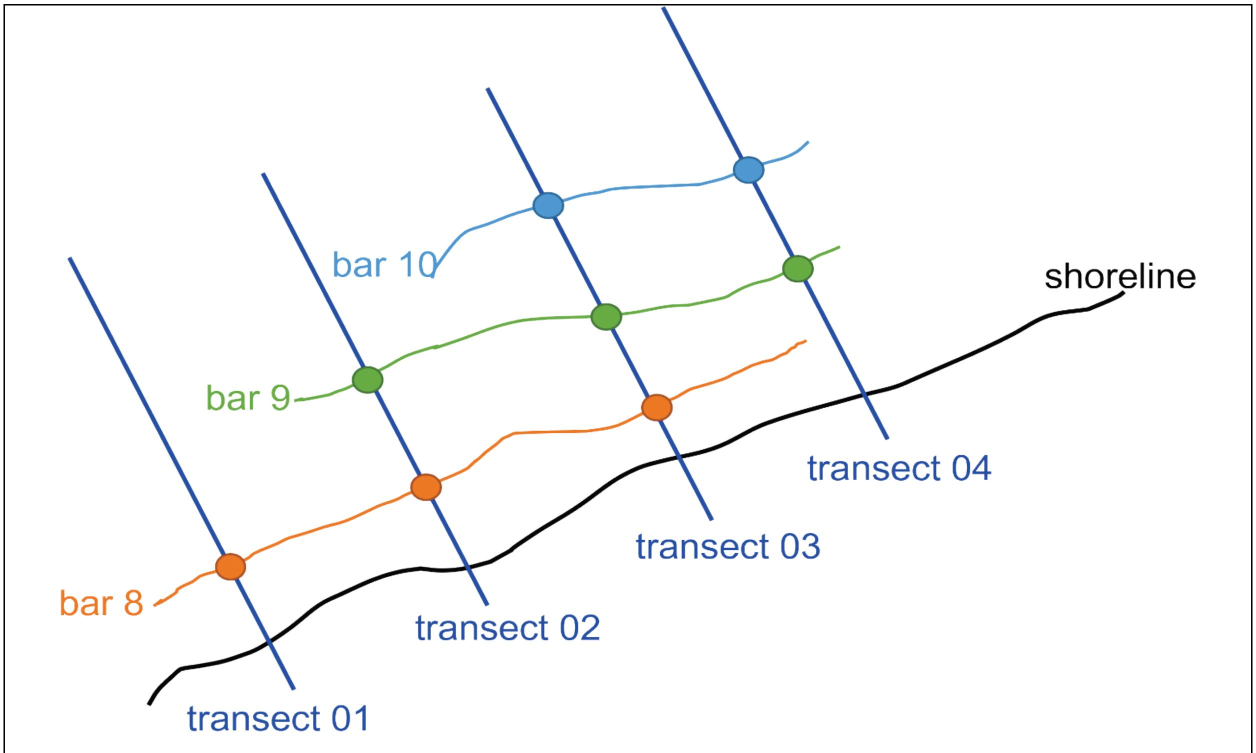
**A**

| State | Segment | Line ID | bw_Bluff Toe | bw_Hardened_ Shoreline | bw_Dune_ Toe | bw_Interp_Bluff_ Toe | bw_ Contour |
|---|---|---|---|---|---|---|---|
| MI | 18 | 322 | Null | 10.94 | Null | 1.55 | 620.03 |
| MI | 18 | 323 | Null | 4.78 | Null | 5.52 | 534.22 |
| MI | 18 | 324 | Null | 3.76 | Null | 1.10 | 3.83 |
| MI | 18 | 325 | Null | 3.22 | Null | 1.65 | 3.57 |
| MI | 18 | 326 | Null | 6.07 | Null | 8.55 | 6.11 |
| MI | 18 | 327 | 0.48 | 4.96 | Null | 0.48 | 5.00 |
| MI | 18 | 328 | Null | 0.50 | Null | 5.57 | 3.33 |
| MI | 18 | 329 | Null | 5.72 | Null | 8.75 | 3.84 |
| MI | 18 | 330 | 16.96 | 5.48 | Null | 16.96 | 3.96 |
| MI | 18 | 331 | Null | Null | Null | 3.01 | 2.14 |
| MI | 18 | 332 | Null | Null | Null | 4.48 | 3.02 |
| MI | 18 | 333 | Null | Null | Null | 15.73 | 11.75 |

**B**

| State | Segment | LineID | Beach_Width | Ref_Line |
|---|---|---|---|---|
| MI | 18 | 322 | 10.94 | Hardened_Shoreline |
| MI | 18 | 323 | 4.78 | Hardened_Shoreline |
| MI | 18 | 324 | 3.76 | Hardened_Shoreline |
| MI | 18 | 325 | 3.22 | Hardened_Shoreline |
| MI | 18 | 326 | 6.07 | Hardened_Shoreline |
| MI | 18 | 327 | 4.96 | Hardened_Shoreline |
| MI | 18 | 328 | 0.50 | Hardened_Shoreline |
| MI | 18 | 329 | 5.72 | Hardened_Shoreline |
| MI | 18 | 330 | 16.96 | BluffToe |
| MI | 18 | 331 | 3.01 | Interp_Bluff_Toe |
| MI | 18 | 332 | 4.48 | Interp_Bluff_Toe |
| MI | 18 | 333 | 15.73 | Interp_Bluff_Toe |

**SAND-BAR COUNT:** The sand-bar count tool provides the sand-bar metrics for each transect. Tool inputs include transects, a DEM, the sand-bar points file, and the shoreline vector. The tool first converts the sand-bar points into a polyline feature based on the grouping done by the user during QC. The tool then iterates through each transect to create points at intersections between the transect, the shoreline and each sand bar group. The distance from shoreline and the depth of the sand bar at each sand bar point is extracted from the DEM. These metrics are provided in the attribute table associated with the transect file. The total number of intersecting sand bars and the average distance between sand bars on each transect are also provided (Figure 9).




| TransID | BarCount | BarID1 | BarDist1 | BarDepth1 | BarID2 | BarDist2 | BarDepth2 | BarID3 | BarDist3 | BarDepth3 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 8 | 5.2 | # | Null | Null | Null | Null | Null | Null |
| 2 | 2 | 8 | 4.5 | # | 9 | 11.2 | # | Null | Null | Null |
| 3 | 3 | 8 | 4.2 | # | 9 | 10.5 | # | 10 | 12.1 | # |
| 4 | 2 | 9 | 10.2 | # | 10 | 16.3 | # | Null | Null | Null |

Figure 9. Hypothetical markup of the results of sand-bar counting.

**NEARSHORE CURVATURE:** The nearshore curvature tool calculates the concavity, height of the curve, and length of the curve base at each transect. Points spaced at 1 m intervals along each transect are created between the shoreline and depth of closure. Depth is extracted to each of these points, and a second-degree polynomial of best fit is created. A line is created between the most seaward and most landward point of the interpolated curve, and the distance is recorded as *b*. The largest tangent distance between this line and the curve is calculated and recorded as *h*. The derivative of the polynomial is used to calculate the concavity of the interpolated curve (Figure 10).

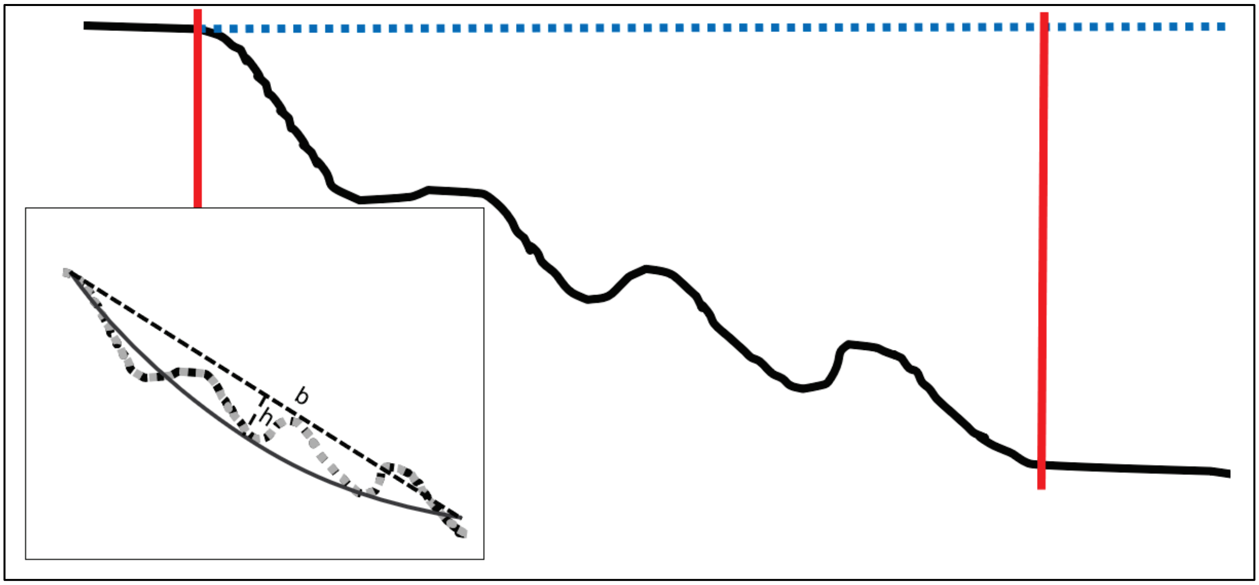



Figure 10. Hypothetical markup of the nearshore curvature calculation. *Red* lines indicated the extent of the curvature calculation, the *blue* dotted line represents the water line, and the *black* solid line is the lidar elevation profile. In the inset window, the interpolated curve is shown.

**SUMMARY AND DATA ACCESS:** Nearshore geomorphology features for Lake Michigan's 2,633 km of shoreline were extracted along 21,379 individual transects from 20 near-seamless DEM products (EPA 2023). The features include 75,683 bluff features and 19,432 sand bar features. Transect spacing distances of 10 m and 100 m for bluff and sand bar extraction, respectively, account for the nearly three times reduction in the number of extracted sand bar features compared to the bluff features. Metrics associated with the sand bar features include the depth of the sand bar and its distance from the shoreline. Derived metrics associated with the sand bars, including beach width, bar count and nearshore curvature, were provided for each transect such that geospatial visualization and interrogation of the transect metrics would facilitate an understanding of spatially varying contributions of nearshore geomorphology to erosion rates. Figure 11 depicts the sand-bar line features overlain on the near-seamless DEM used for feature extraction. Derived metrics including the nearshore curvature and beach width are symbolized using a bivariate color map that highlights section of shoreline with high (and low) values for these metrics.

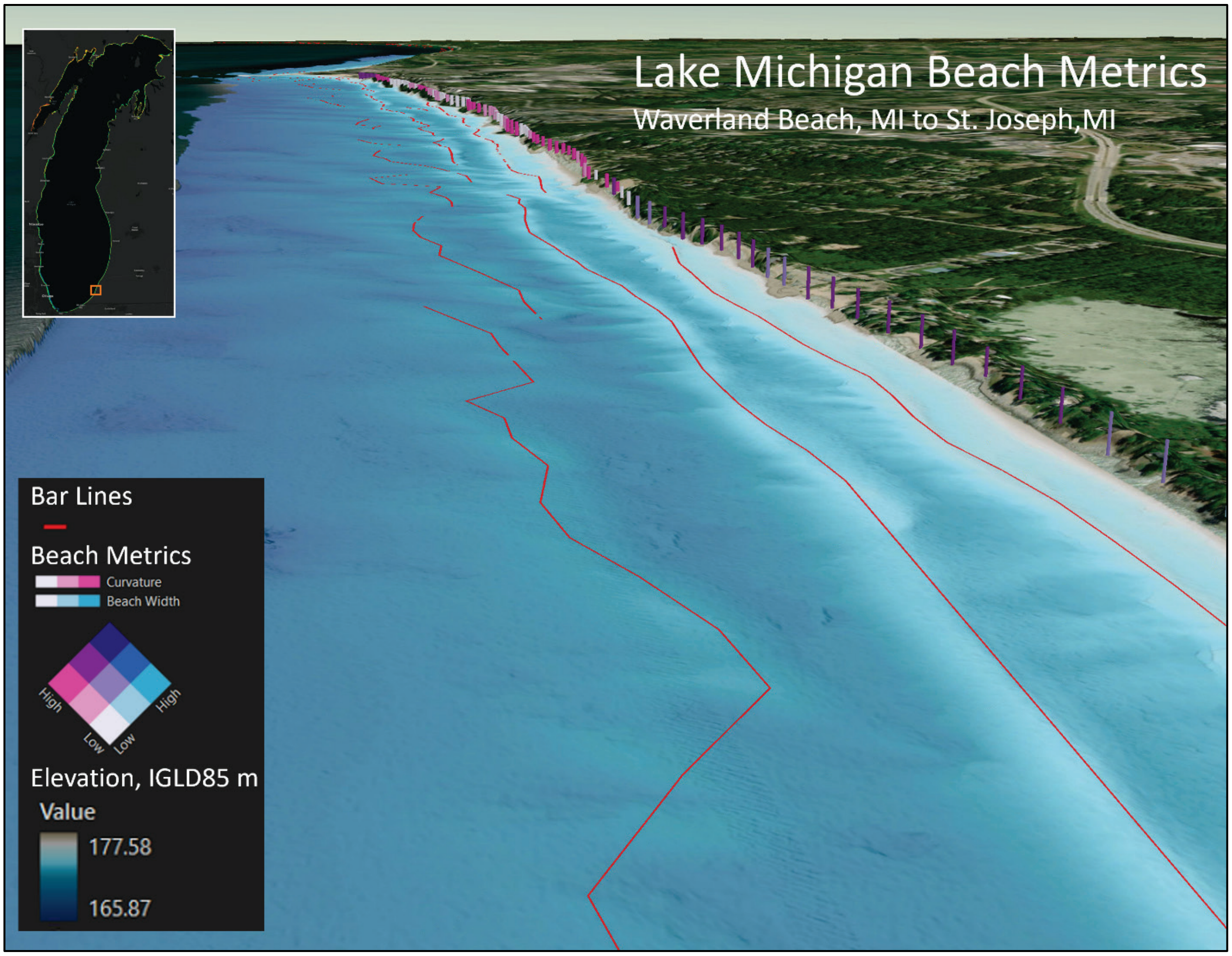



Figure 11. Results from nearshore geomorphology extraction of the sand bars and derived metrics including nearshore curvature and beach width for a 13 km section of the Lake Michigan shoreline just south of St. Joseph, Michigan.

Access to these nearshore geomorphology datasets is accomplished through web-based feature services provided in Table 4. The services are intended for consumption in web-mapping applications and standard GIS software applications.

**Table 4. Data access URLs.**

| Feature Service | Feature Service URL |
|---|---|
| JALBTCX Bare Earth DEMs | *http://arcgis.usacegis.com/arcgis/rest/services/JALBTCX/JALBTCX_Products_BareEarth_1mGrid/ImageServer* |
| Bluff Features | *http://arcgis.usacegis.com/arcgis/rest/services/JALBTCX/JALBTCX_Geomorphic_Features/FeatureServer* |
| Sand Bar Features | *http://arcgis.usacegis.com/arcgis/rest/services/JALBTCX/GLRI_GVI_Sandbar_Parameters/FeatureServer* |

Figure 12 shows a screenshot of a web-based dashboard application for visualizing and interrogating the bluff features. This dashboard is one of many dashboard components being developed for integration into a website for discovery, visualization, and sharing of data products developed underneath the GLRI.

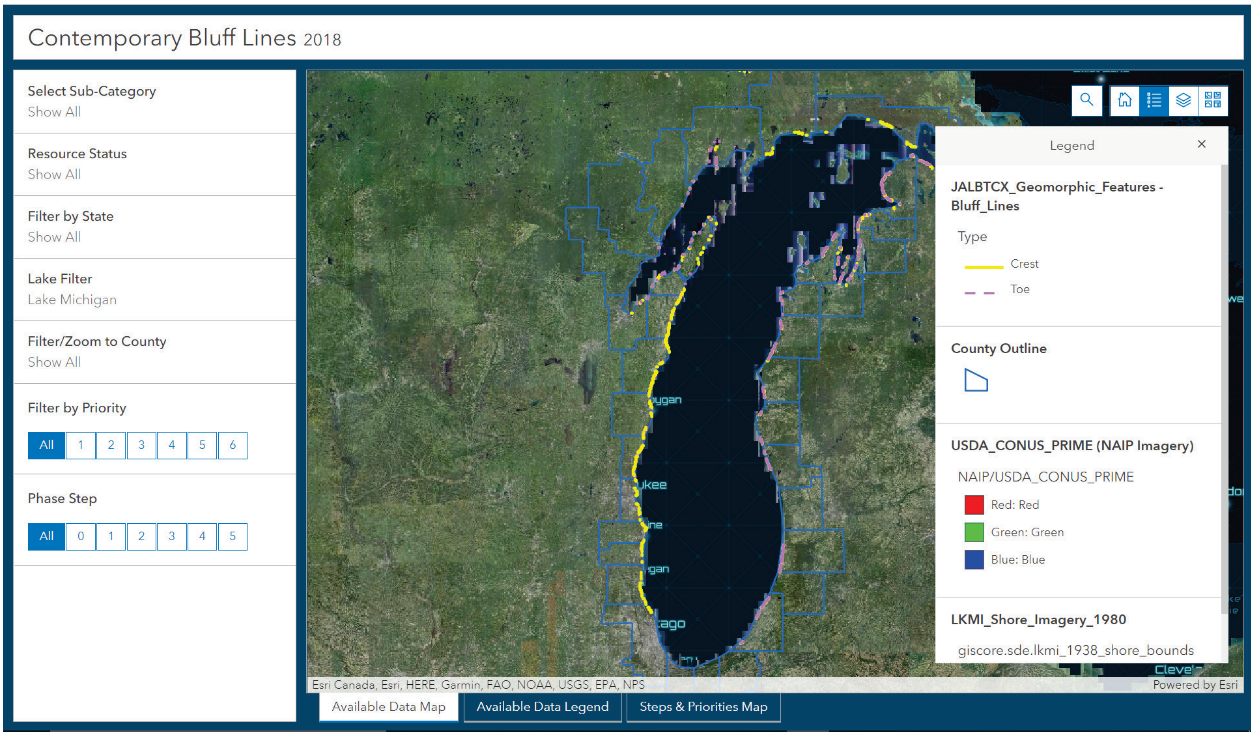



Figure 12. A screenshot of a web-based dashboard application that provides a means to visualize and interrogate the bluff features.

**ADDITIONAL INFORMATION:** This CHETN was prepared as part of the USACE NCMP by Charlene Sylvester, Scott Spurgeon, Sean McGill, and Lauren Dunkin, ERDC-CHL, Coastal Engineering Branch, Vicksburg, Mississippi. Questions pertaining to this CHETN may be directed to Charlene Sylvester (*charlene.s.sylvester@usace.army.mil*) or to the USACE NCMP program manager, Jennifer Wozencraft (*jennifer.m.wozencraft@usace.army.mil*).

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