Lake Erie Bluff Crest Mapping
Project Report

July 2016

Task Description

Woolpert delineated bluff lines along the Lake Erie shoreline (Figure 1). Woolpert conducted an inventory of relevant mapping data and assessed the relative quality, consistency and adequacy of the data for inclusion on the bluff line delineation. Such data included any existing GIS data, geological maps and aerial imagery. Woolpert also gathered imagery and lidar acquired by Woolpert on behalf of the client in 2012 and utilized the latest feature extraction techniques to delineate bluff crest lines. Woolpert attributed each bluff line along the shorelines with elevation information and other slope characteristics.

Figure 1. Lake Erie Shoreline

Definitions

Pennsylvania has 77 miles of Lake Erie shoreline contained entirely within Erie County. Most of the shoreline consists of bluff geomorphologies (Figure 2) ranging in height from 5 to 180 feet above the lake level. Notable exceptions include the mouths of major tributaries and Presque Isle, adjacent to the City of Erie. Nearly all of the shoreline is designated as Bluff Recession Hazard Areas (BRHA) under the framework established in the Bluff Recession and Setback Act (the Act) and companion regulations in Pa. Code Title 25, Chapter 85. Municipalities having BRHAs designated within their jurisdictions are required to enact specific setback ordinances relating to construction and development activities occurring within the BRHAs. This guidance is intended to aid municipalities in promulgating and implementing local zoning ordinances that satisfy Chapter 85 requirements.

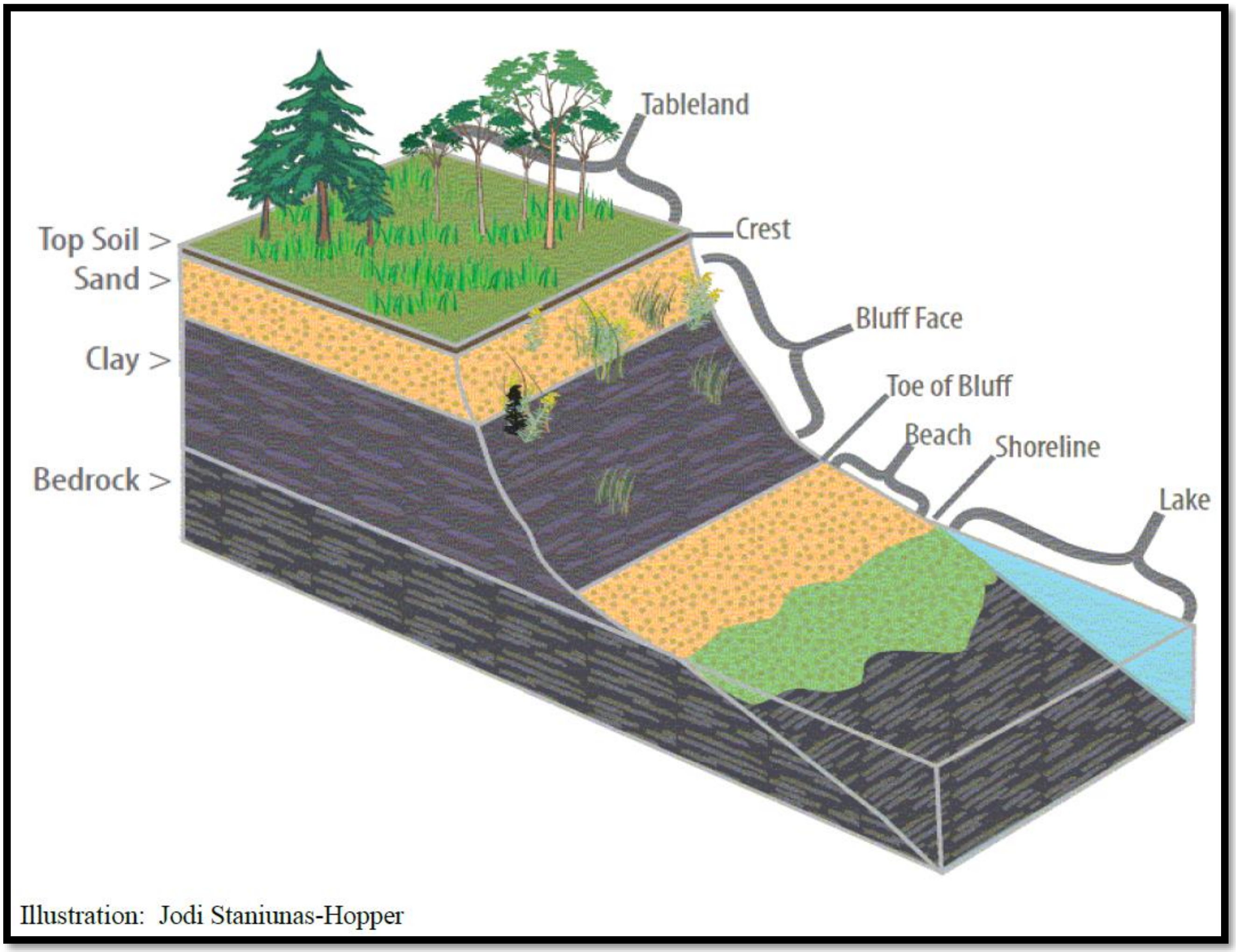

Figure 2 Bluff terminology and typical geologic layers along Pennsylvania Lake Erie Coast

Source Data

1. Existing HUC drainage boundaries.
2. Existing bluff line
3. Any existing planimetric data.

From Woolpert

4. 2012 6 inch 4-band imagery
5. 2012 0.7m NPS lidar.
6. 2015 6 inch 4-band imagery
7. 2015 1.4m NPS lidar.

Analysis Procedure

Ground Filtering

Airborne lidar system collects information not only from land surface but also from every object between the sensor and the terrain that can reflect the laser beam. The bluff crest is a geomorphological feature of the terrain. Lake Erie shoreline is mostly covered by vegetation. It was therefore necessary to remove from the point cloud these vegetation points. This is accomplished through filtering. Filtering out non ground points from raw point clouds was the first and most important step in bluff crest line delineation. Without these non-ground points, the ground can be modelled more accurately. The objective of this task phase was to remove the non-ground point and preserve terrain features. This was accomplished through the following steps:

1. Created a 1ft by 1ft grid.
2. Filter out the lowest points in each grid square.
3. Successively increase the size of the grid by 25%.
4. Compare the elevation difference in the larger grid with the previous smaller grid.
5. If the elevation difference between each point and the lowest point was smaller than a set threshold, the point was classified as a terrain point. The threshold was determined by the slope of the terrain. The slope was calculated iteratively by comparing the filtered and non-filtered points.

This process increased the accuracy of ground filtering and resulted in a more densified point cloud representation of the ground as shown in Figures 3 and 4 below.

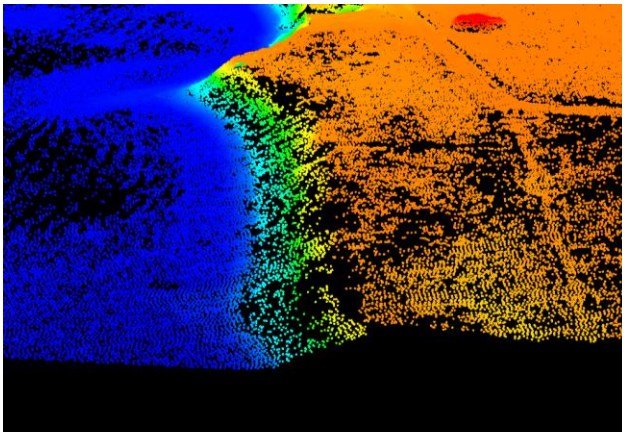

Figure 3 An image of the pre-filtered ground points

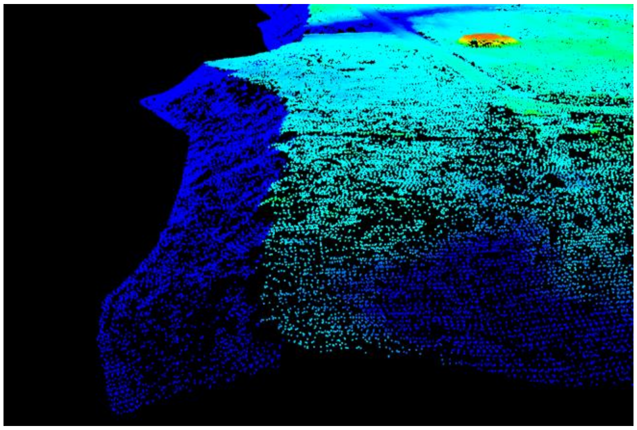

Figure 4 An image of the post-filtered ground points

<u>DTM Preparation</u>

DTM creation was the next step in bluff crest delineation. In order to identify the location of the crest line, we needed to model the terrain using an interpolation technique that will smooth out insignificant breaklines and exaggerate the bluff crest. We utilized a mathematical function that minimized the overall surface curvature, resulting in a smooth surface that passed exactly through all the input ground points.

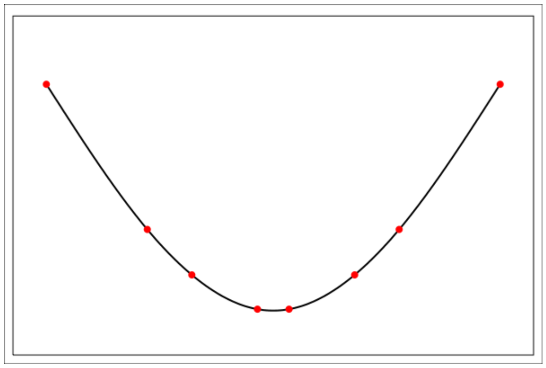

Figure 5 Interpolates the DTM from points using a two-dimensional minimum curvature spline technique.

The sampling distance used for the two terrains created were as follows:

- 2012
  - 2.5 feet
- 2015
  - 1.0 feet

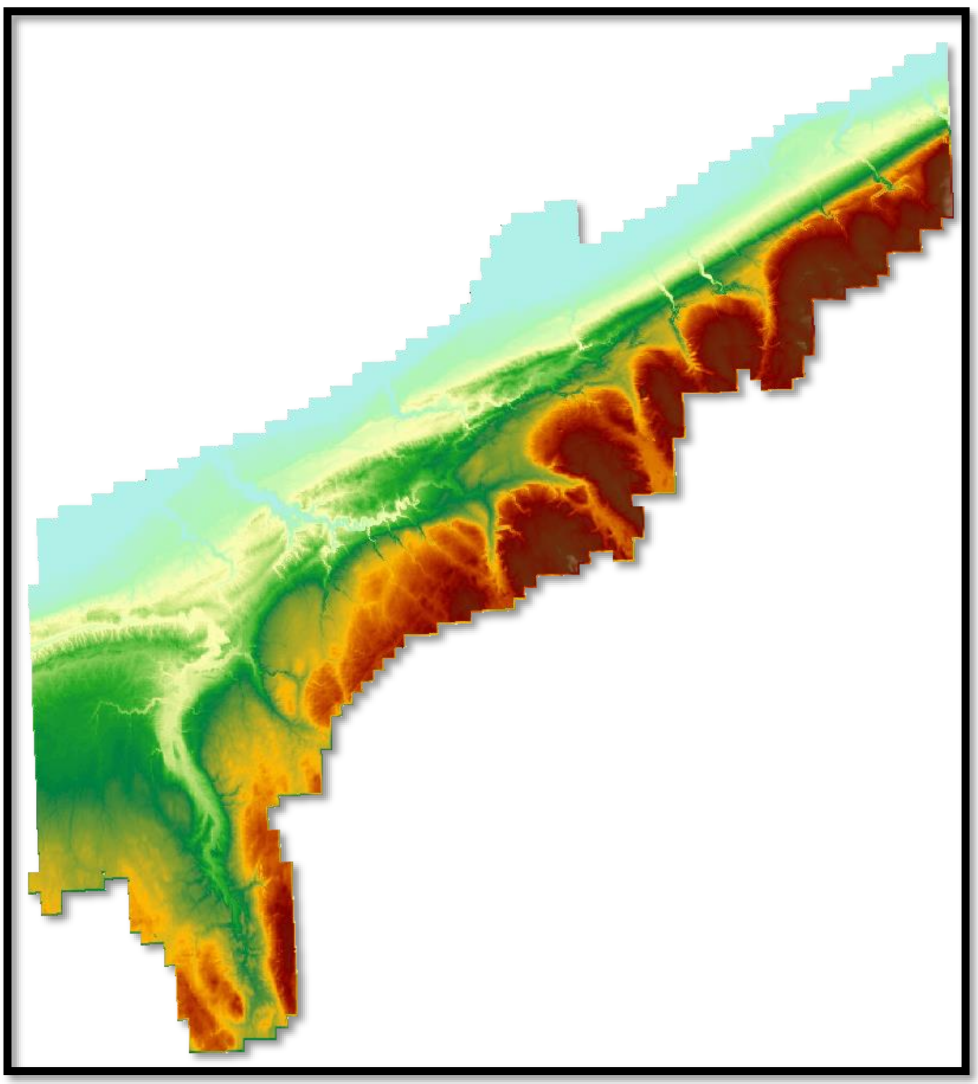

Figure 6 The resulting DTM of entire Lake Erie shoreline.

Hillshading

The next step in crest line delineation is terrain enhancement. In this phase task, the goal was to capture local variations to show areas of rapid change in slope and/or aspect i.e. bluff face. Hillshading is the hypothetical illuminating a surface. It is accomplished by calculating the illumination values of each cell in relation to neighboring cells. By default, shadow and light are shades of gray associated with integers from 0 to 255 (increasing from black to white).

The primary factor when creating a hillshade map for any particular location is the location of the sun in the sky. The azimuth is the angular direction of the sun, measured from north in clockwise degrees from 0 to 360. An azimuth of 90 degrees is east. The azimuth value used in this project was 315 degrees (NW).

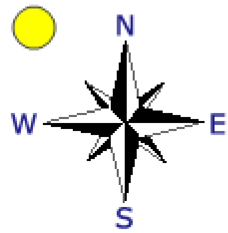

Figure 7 The sun azimuth (direction) for hillshade at 315º

The altitude is the slope or angle of the illumination source above the horizon. The units are in degrees, from 0 (on the horizon) to 90 (overhead). The altitude value used in this project was 45 degrees.

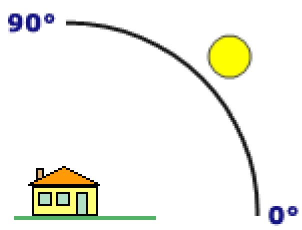

Figure 8 The sun altitude for hillshade it 45º

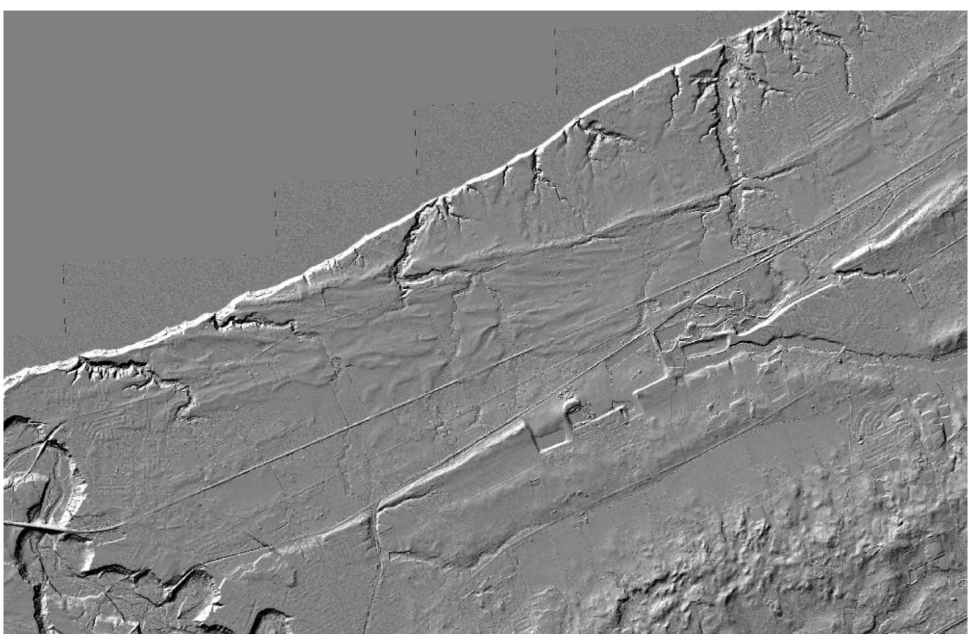

Figure 9 The hillshade image

Slope Calculation

The maximum rate of change in value from every cell to their neighbors was calculated. Basically, the maximum change in elevation over the distance between the cell and it's eight neighbors identifies the steepest downhill descent from the cell i.e. slope.

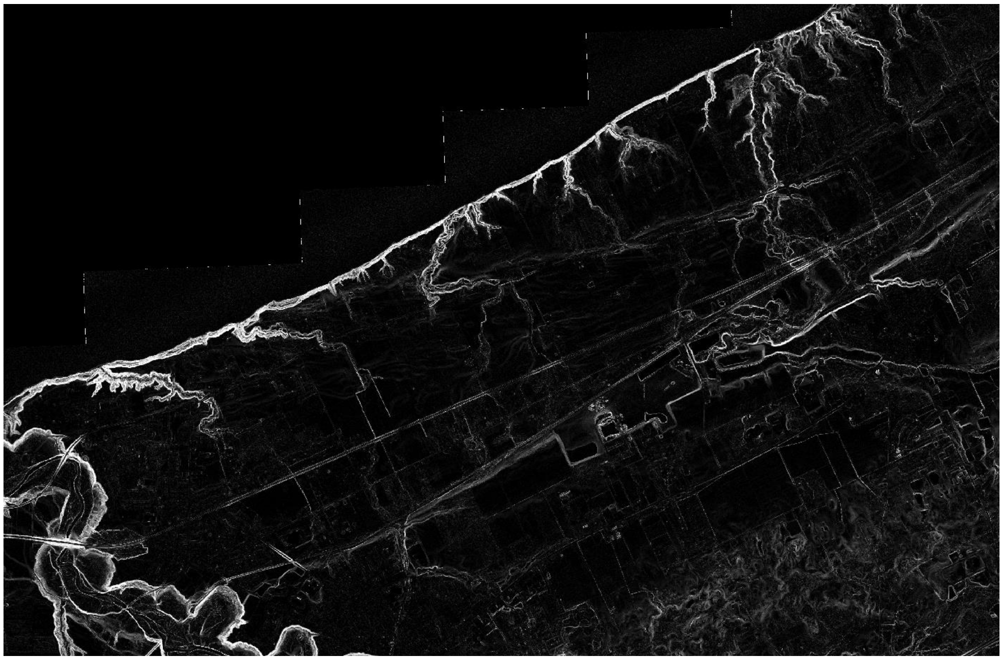

Figure 10 The slope image

Curvature Calculation

The Curvature function displays the shape or curvature of the slope. A part of a surface can be concave or convex; you can tell that by looking at the curvature value. The curvature is calculated by computing the second derivative of the surface, the first is represented by slope.
Three curvatures were calculated:

1. Profile
2. Planform
3. Standard

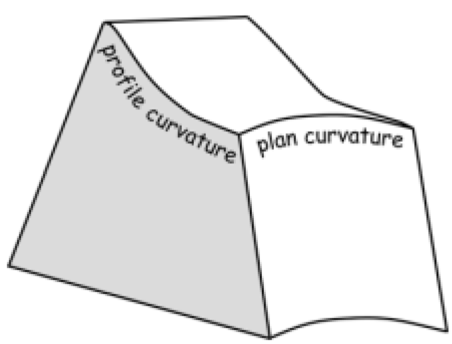

Figure 11 Terrain shape

Profile
The Profile curvature is parallel to the slope and indicates the direction of maximum slope. It affects the acceleration and deceleration of flow across the surface. A negative value (A) indicates that the surface is upwardly convex at that cell, and flow will be decelerated. A positive profile (B) indicates that the surface is upwardly concave at that cell, and the flow will be accelerated. A value of zero indicates that the surface is linear (C).

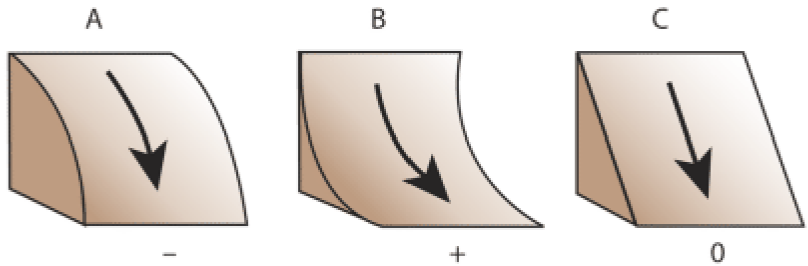

Figure 12 Profile curvature

Planform
The Planform curvature (commonly called plan curvature) is perpendicular to the direction of the maximum slope. Planform curvature relates to the convergence and divergence of flow across a surface. A positive value (A) indicates the surface is laterally convex at that cell. A negative plan (B) indicates the surface is laterally concave at that cell. A value of zero indicates the surface is linear (C).

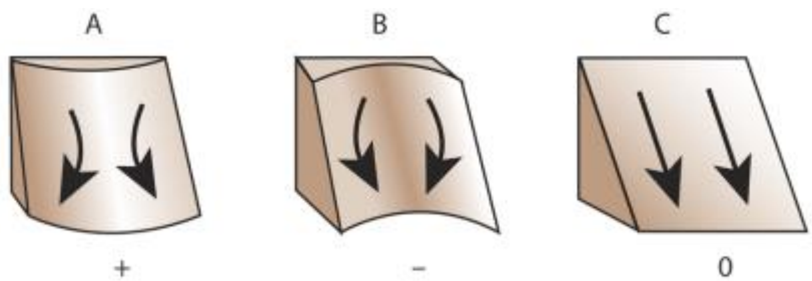

Figure 13 Planform curvature

Standard
The Standard curvature combines both the profile and planform curvatures. The profile curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition. The plan curvature influences convergence and divergence of flow. Considering both plan and profile curvature together allows you to understand more accurately the flow across a surface.
In the following diagram, the columns show the planform curves and the rows show the profile curve. The planform columns are positive, negative, and 0—going from left to right. The profiles curves are negative, positive, and 0—going from top to bottom.

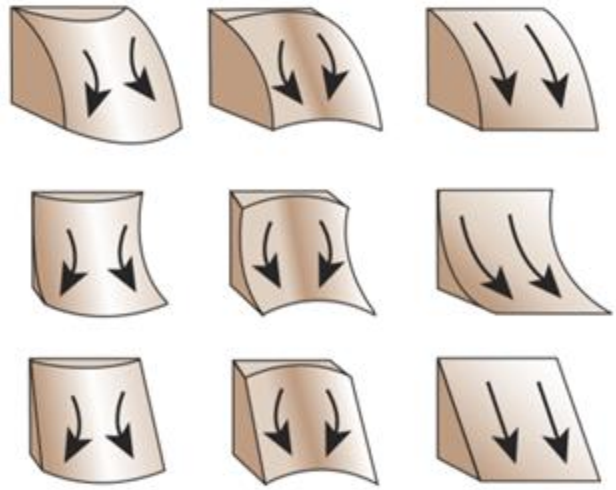

Figure 14 Standard curvature generated both profile and planform curvature

Feature Extraction

The next step in the crest line delineation process was to carry out feature extraction through pattern matching and object recognition. This was performed using a OBIA platform called eCognition. eCognition is a ruleset creation software sold by Trimble.

Data Stack

The first step was to create a layer stack. A layer stack is achieved when all the input data sources (DTM, hillshad, slope and curvature are layered together and co-registered.

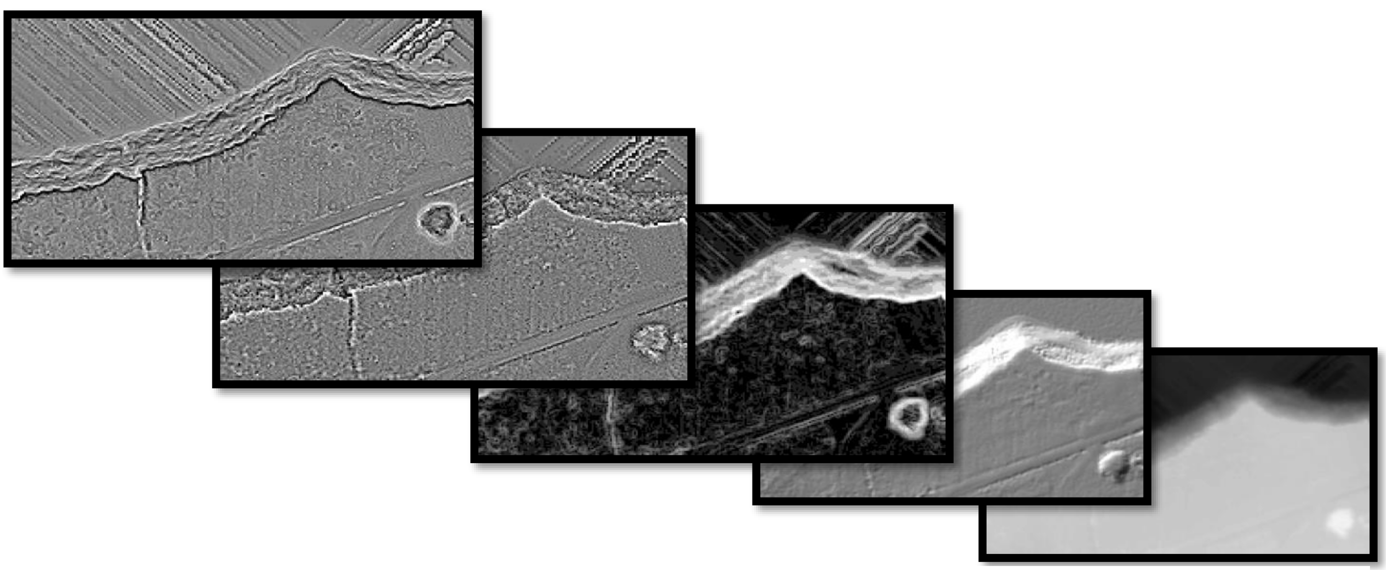

Figure 15 Conceptual layer stack

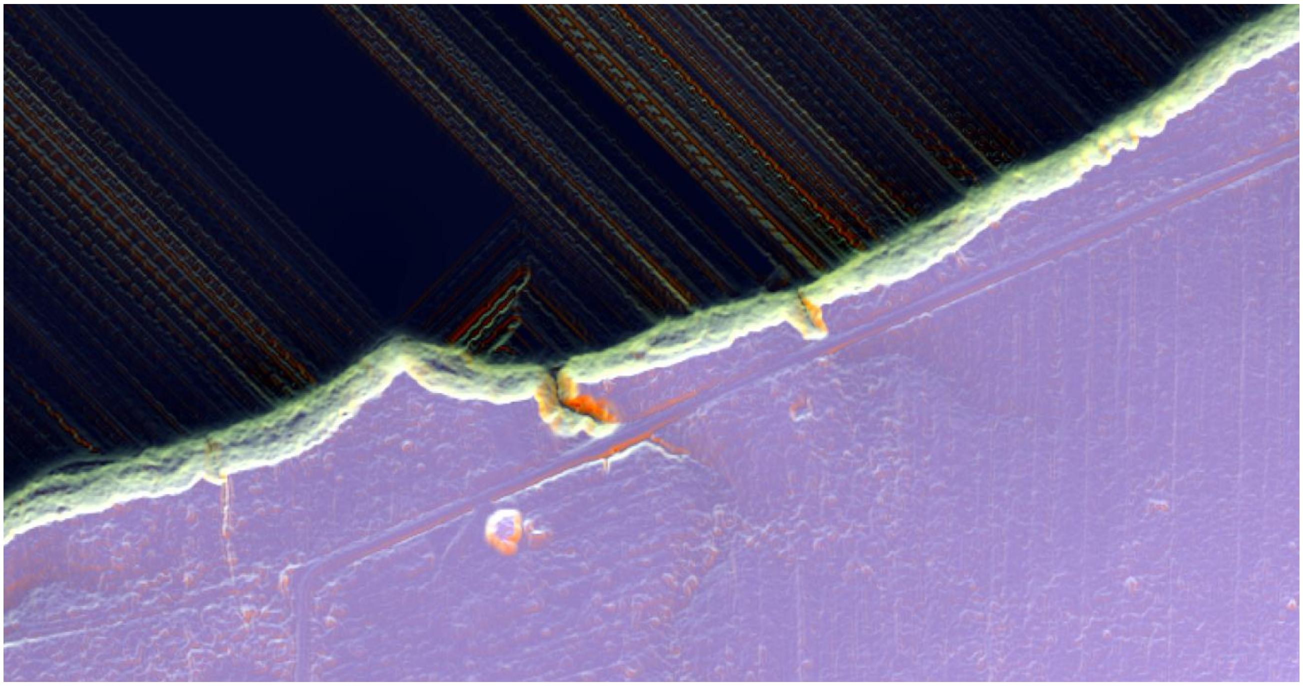

Figure 16 Visual layer stack

Object Based Image Analysis (OBIA)

The simplest approach to object based image analysis is called thresholding. The key to the success of this method was the selection of threshold values (or values when multiple-levels are selected). In Woolpert's implementation of OBIA for bluff crest line delineation, the following threshold values were used:

- Slope: > 38 degrees
- Hillshade: > 184
- Curvature: > 74
- Profile: < -3

In order to utilize these threshold values, Woolpert developed rulesets. Rulesets are a collection of logic-based queries that are created to group homogenous pixels or cells into objects. Ruleset development process also included the preliminary analysis of the input datasets in order to evaluate the efficacy of the rulesets.

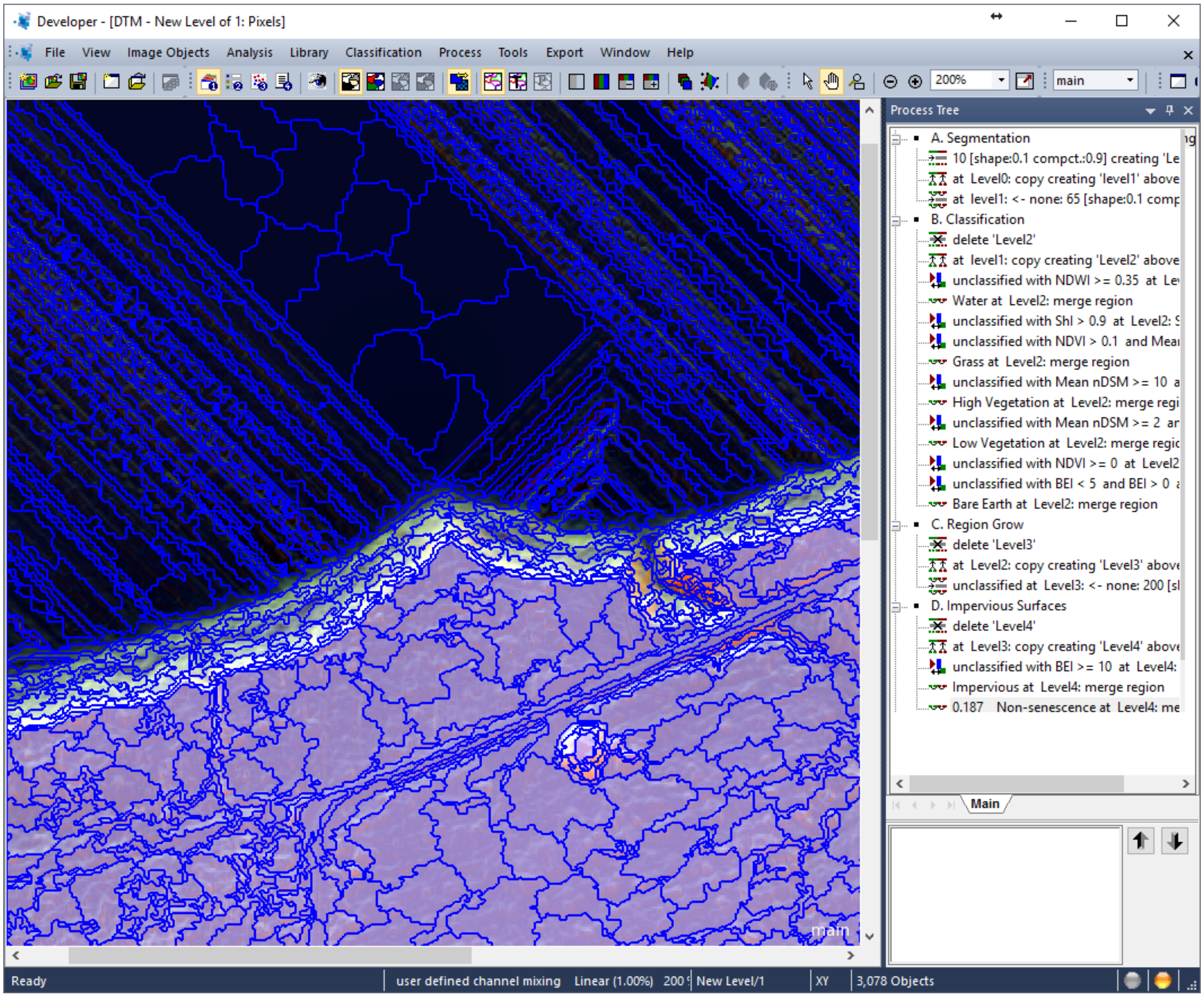

Figure 17 Object based image analysis in Trimble's eCognition

QA/QC and Manual Edits

Manual QC and edits were carried out in ArcMap which enables mapping, compilation and analysis of geographic information. The following steps were performed in ArcMap:

- After the crest bluff line were automatically extracted, the cartography team received this data in the form of shapefiles. The shapefiles are first imported into a geodatabase and processed to eliminate errors and ensure file continuity.
- Using cartographic workstations, Woolpert technicians then verify that the raw data meets or exceeds the applicable accuracy standards.
- Any voids in the data, over-runs, and dangling line work are edited.
- Tie edges between tile sheets are verified to ensure that the transition between all maps meet exactly.
- Exception reports are generated to flag any data that does not meet feature parameters.
- Where the data does not meet the target goal, it is manually edited and then reviewed.
- The resulting crest bluff lines were viewed and inspected while overlaid on top of the imagery to verify its completeness and to ensure that the vector data meets or exceeds the required accuracy standards.
- The final bluff crest lines were then subjected to a QC procedure to verify that all data is translated properly and that the final products meet all cartographic, aesthetic and other applicable standards.
- The lines were then attributed accordingly.

- The recession analysis was then carried out.

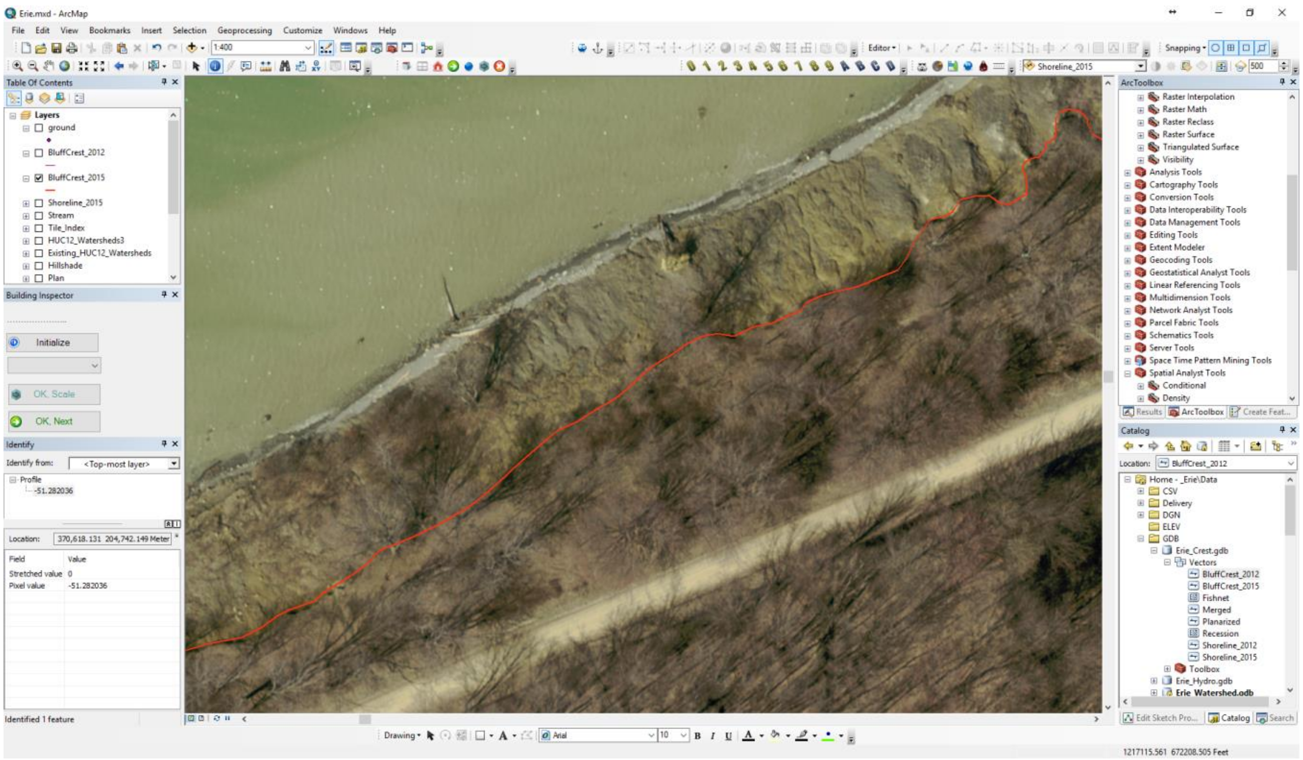

Figure 18 Editing in ArcMap environment

Results

Between the years 2012 and 2015, the Lake Erie shoreline experienced a total of 8,117.58 sq. ft. (0.19 acres) of total advance and 705,325.98 sq. ft. (16.19 acres) of total recession.

Quality Control and Acceptance Criteria

1. The bluff crest line was mapped with a horizontal accuracy consistent with 100 scale mapping. Supplementary mapping techniques were applied to improve the limiting RMS error from +/- 1 meters (consistent with 100 scale mapping) to +/- 0.5 meters or +/- ~20 inches
2. The overall vertical accuracy has a limiting error of +/- 0.1 meters.
   Note: Vertical map accuracy is defined as the RMS error in evaluation in terms of the datum for well-defined points. The height values for the crest line was defined directly from lidar dataset which was deemed to have limiting rms error of +/- 0.025 meters or +/- ~1 inch. This height accuracy is relevant where lidar pulse reflected off the top of the bluff. In the event that the lidar pulse was not coincident with the top of the bluff, the height was interpolated.

Delivery

1. Woolpert delivered a shapefile and/or Esri geodatabase.
2. All mapping was delivered in NAD83 Pennsylvania State Plane North HARN, U.S. feet horizontal and NAVD88 GEOID09 vertical.