



TECHNICAL REPORT
NO. 5099

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EXTRACTION METHODOLOGY

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JULY 2022

This work was supported through funding by the National Oceanic and Atmospheric Administration Regional Geospatial Modeling Grant, Award # NA19NOS4730207.



The Geospatial Education and Outreach Project (GEO Project) is a collaborative effort among the Geosystems Research Institute (GRI), the Northern Gulf Institute (a NOAA Cooperative Institute), and the Mississippi State University Extension Service. The purpose of the project is to serve as the primary source for geospatial education and technical information for Mississippi.

A VECTOR SHORELINE EXTRACTION METHODOLOGY

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INTRODUCTION

Digital descriptions of shorelines, in the form of vector polyline geospatial data layers, constitute an important input to many coastal geospatial data products used by coastal managers. Coastal environments are dynamic, and rapid updates of coastline location and configuration information from remote sensing and geospatial data products are critical for making sound decisions based on current conditions. Generating vector shorelines by tracing aerial photos or traditional “paper maps” by hand is time-consuming and labor-intensive. Many automated shoreline detection and extraction methods rely on advanced proficiency in processing airborne or satellite remote sensing products and are not easily reproduced using the geospatial data products and expertise available to most coastal managers. This report presents a method for deriving a vector coastline from a digital elevation model (DEM) with commonly used geospatial tools.

BACKGROUND

As shorelines evolve over time due to coastal processes, storms, and changes in land cover and land management practices, accurate updating of existing maps is important to guide development planning and coastal resource management. Revising maps to reflect the current location and configuration of the shoreline has been a challenge since the days of traditional surveying and cartography. In the last several decades, remote sensing and geospatial data products have rapidly increased the speed and decreased the cost of delivering accurate shoreline location information to coastal managers.

Many efforts to detect shorelines and shoreline change involve the use of satellite imagery and methods of grouping pixels by their different spectral properties to detect a feature or features in the landscape that can serve as a proxy for the true shoreline, sometimes referred to as a shoreline indicator. These methods include use of the Normalized Difference Vegetation Index, the Normalized Difference Water Index, various band ratio formulas (usually involving green and

NRI bands), Principal Components Analysis, supervised and unsupervised classification techniques, and other methods (Abdelhady et al. 2022, Al Fugura et al. 2011, Garcia-Rubio et al. 2014, Liu et al. 2011, Sekovski et al. 2014). More recently, LiDAR data obtained by aircraft and by unmanned aerial systems has been used to derive terrain models and elevation data has been used to produce a contour for use as a shoreline indicator (Harris et al. 2006, Lin et al. 2019, Yu et al. 2017). Most shoreline extraction literature addresses short (< 20 miles) sections of sand beaches rather than morphologically complex inshore environments comprised of marshes, beaches, bays, tributaries, tidal creeks, and developed (commercial, industrial, residential) areas.

Whether the shoreline indicator is derived from spectral segmentation or elevation data, even the best segmentation methods fail to produce an entirely reasonable vector shoreline. There are two types of errors in the vector line products derived from gridded data. One is irregularities, described as jitters, dithers, or saw-blade-like meanders in the line. This error occurs particularly in areas where the natural boundary between land and water (or dry and wet features) is ambiguous on the land surface and therefore in the raster data causing the resulting line to meander through relatively homogeneous pixels and indeterminate edge. If the shoreline indicator is a contour, the line meanders in flat areas where equal elevation values spread in all directions. The other source of error involves the detection of shoreline indicators disconnected from the shore. Examples of these include low and wet areas on land or raised and dry features (sand bars, marsh patches, boats) in the water. Few papers acknowledge these issues with the vector product (Harris et al. 2006, Liu et al. 2011, Di et al. 2003). Most descriptions of methods focus entirely on parsing the raster data or LiDAR point cloud to produce the best possible vector shoreline.

For those studies that address refining a shoreline vector, proposed methods include: editing the vertices, then selecting and deleting unwanted segments (Harris et al. 2006); selecting and deleting features based on a length threshold (Liu et al. 2011); and, adding shoreline-adjacent polygons representing homogeneous regions identified in the image segmentation process (such as tree shadows over water) back to the shoreline then accepting or rejecting these based on visual inspection (Di et al. 2003). Di et al. (2003) describe the latter process as “semi-automatic” since the polygons are created automatically in the segmentation process but must be individually accepted or rejected by the user. Liu et al. (2011) implemented an algorithm within an ArcGIS extension module called “Shoreline Extractor” and made it publicly available. This algorithm modifies bends of the shoreline by widening the narrow ones and removing the extraneous ones.

The shoreline extraction method presented here is novel in that it can be implemented with commonly available desktop GIS tools at a level of expertise typical of coastal managers and GIS analysts at state and county agencies. The method is appropriate for reducing extraneous vertices and line jitter in large, heterogeneous areas. The example presented here processes roughly 264 miles of shoreline in St Louis Bay, Mississippi which is a morphologically complex system consisting of the main bay, three major tributaries, extensive marsh, and residential

areas with modified water channels. The process is presented as a shoreline extraction from a LiDAR-derived DEM but could theoretically be applied in any geospatial process requiring rapid simplification of a complex vector polyline.

PROJECT GOAL, STUDY AREA, AND DATA SOURCES

The method presented here is intended to greatly reduce (as in by >80%) the amount of manual editing and subjective interpretation required to extract a reasonable vector shoreline from high-resolution digital elevation data. The vector shoreline output generated for this project was used as an input in the Virginia Institute of Marine Sciences Shoreline Management Model (Center for Coastal Resources Management 2022). The model generates recommended shoreline stabilization methods based on combinations of features described in the vector shoreline attribute table. It requires a vector shoreline that does not violate the following five topological rules: must not overlap, must not intersect, must not have dangles, must not self-overlap, and must not self-intersect.

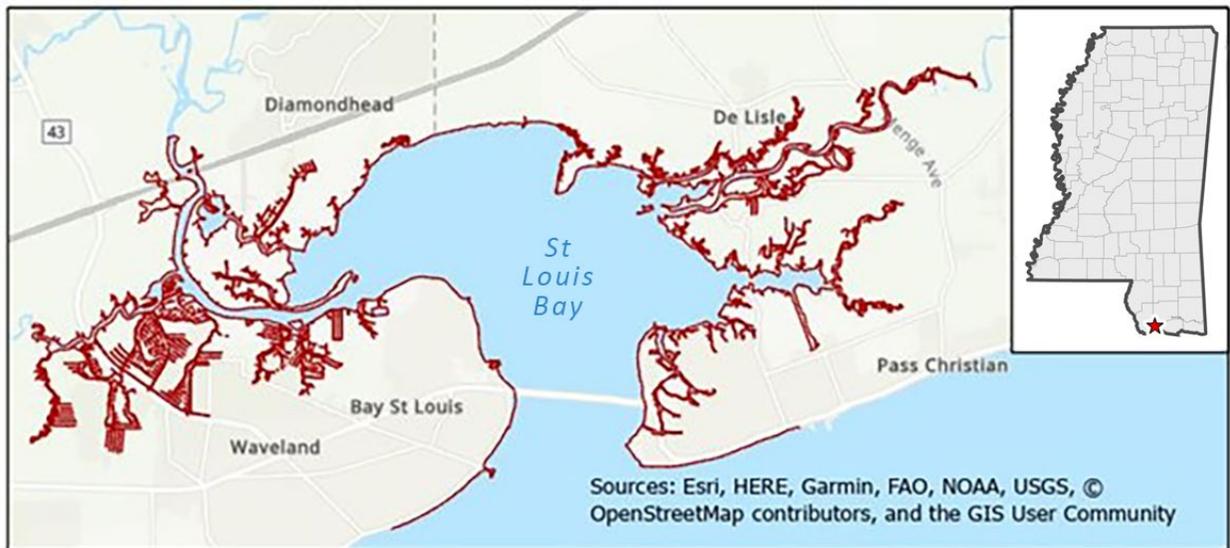


Figure 1: Project area of interest.

The area of interest is St. Louis Bay, a waterway located surrounded by Hancock and Harrison Counties on the Mississippi Gulf Coast (Figure 1). The main bay consists of about 4,327 ha (16.7 square miles) of shallow water, fed by the Jourdan River from the west and by the Wolf River and Bayou Portage from the east. The most accurate and comprehensive vector shoreline for this area currently available is the NOAA Composite (NOAA Shoreline Website 2016). The NOAA Composite stitches together shoreline location and configuration information from multi-temporal sources.

The vector shoreline created in this project is derived from the Mississippi Coastal QL2 LiDAR collected in 2015 by the Mississippi Department of Environmental Quality. The elevation data is available in a raster format with a horizontal resolution of 1.22 meters (4 feet) and an altitude resolution of 0.0001 meters (0.0039 inches). Imagery is not an absolute requirement for this process. County mosaics for Hancock (2012) and Harrison (2020) Counties (MARIS 2022) were used here to guide decisions, but Esri’s basemap imagery is adequate. All geospatial analyses and dataset creation were done in ArcGIS Pro 2.5 (Esri Inc. 2020), and all new data layers were written to a geodatabase as feature classes.

METHODS

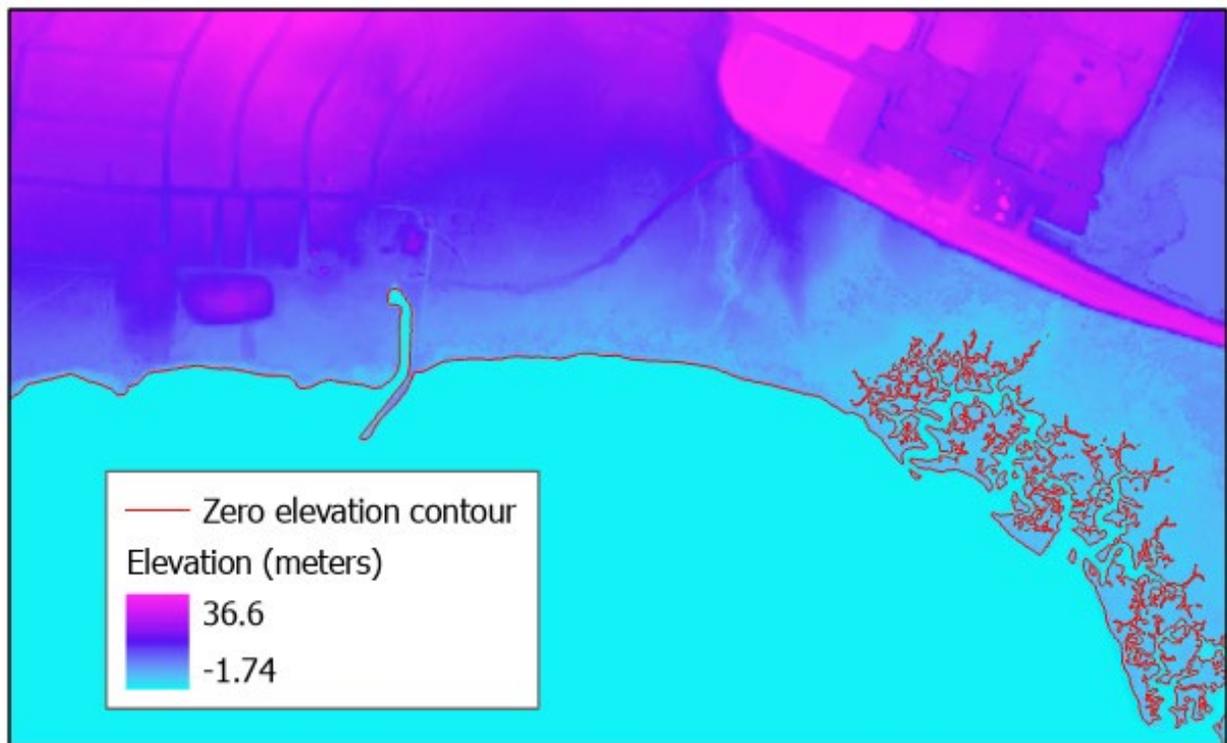


Figure 2: The 2015 LiDAR-derived DEM and the zero-elevation contour in St. Louis Bay. A contour used as a shoreline proxy is reasonable when the land-water edge is sharp, meandering, and jittery in transitional areas such as marsh.

Limitations of contours and vector lines

A contour interpolates a line passing through areas of equal elevation. A contour derived from a high-resolution digital elevation raster can trace outlines of fine-scale features such as emergent vegetation in water and depressions and drainage channels on land (Figure 2). If the goal of the project is to quantify near-shore land cover classes relative to linear segments of shoreline, simplification of these meanders will avoid overestimating linear amounts of classes characterized by patchy and highly dissected configurations. Additionally, a “reasonable” shoreline would describe a land-water edge that excludes small features that do not functionally

contribute to the shoreline. In digital elevation data, these features are depicted as small areas of above-zero values in regions of below-zero values, or the reverse, small areas of below-zero values in regions of above-zero values. These could depict small patches of grass in the water or small puddles of water on land and may be as small as a single pixel and may occur far from shore.

For this project, a zero-elevation contour line derived using the *Contour List* tool produced a feature class polyline describing 904 km (562 miles) of linear distance with 10,362 individual features. The NOAA Composite clipped to the same area describes 418 km (259 miles) with 342 features. The method described here is intended to render the more recent and more spatially precise information of the former with a simpler, more useful vector that resembles the latter. The method reduces the spatial complexity of the vector and the dimensionality of the data through a series of semi-automatic steps involving mass deletion to remove unwanted features while retaining wanted features.

One approach to refinement of the polyline would be to delete all line segments below a certain length threshold as suggested by Liu et al. (2011). In ArcGIS Pro 2.5, the *Contour List* tool output is written to the geodatabase as a feature class with a 'Shape_Length' field which can be used to guide a selection. A threshold that eliminates noise while retaining reasonable shoreline features can be difficult to determine in a large heterogeneous landscape, since many small features contribute to the functioning shoreline (Figures 3 and 4). Additionally, the contour derived from raster elevation data fails to cross open water at the raster's edge, leaving gaps on the many tributaries and tidal creeks.

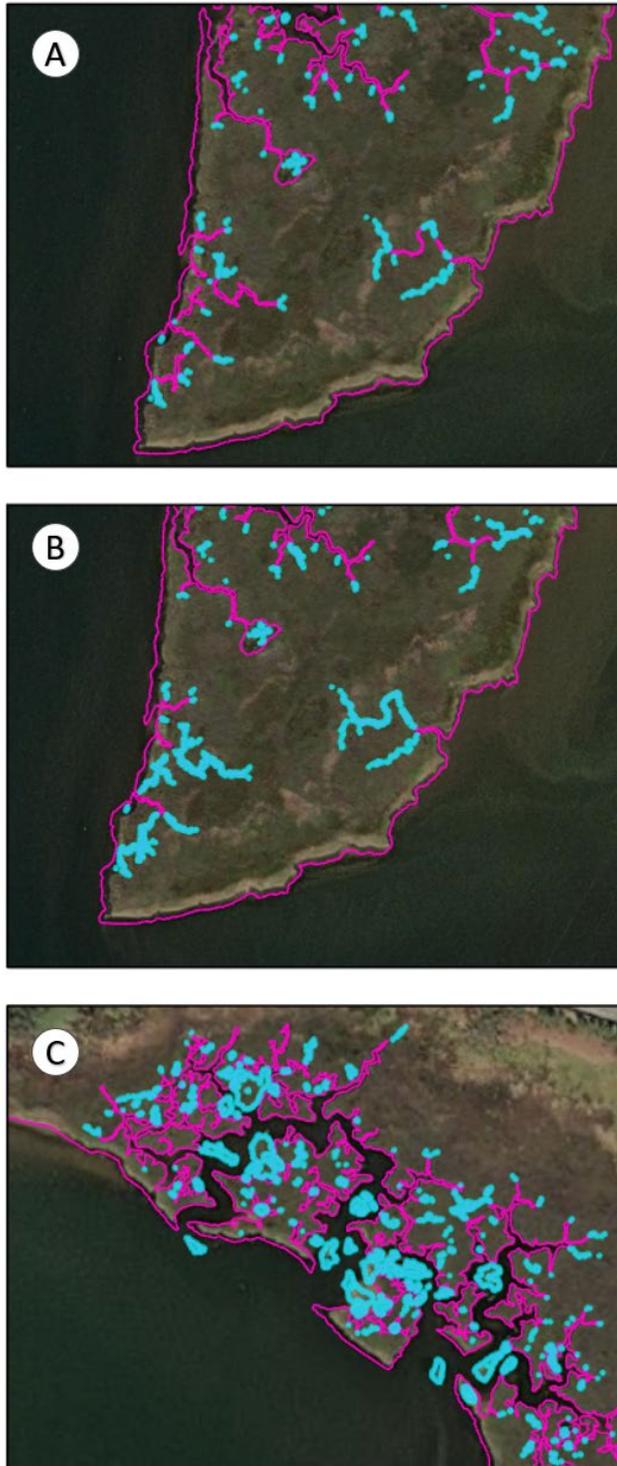


Figure 3: Choosing a feature length selection threshold for deletion of short features (units are feet): The selection of < 100 fails to capture all the small, unconnected inland features (A). The selection of < 750 adequately captures all the unconnected inland features in one area (B), but also captures small islands that contribute to the shoreline in another area (C). Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.



Figure 4: Choosing a feature length selection threshold for Inclusion of long features (units are feet): The selection of the 20 longest features (> 15,500) includes an unwanted, disconnected feature (A) and fails to include desired shorter features that contribute to the shoreline (B). Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Using polygons to describe elevation data

Transforming the rasterized elevation values into land and water polygons rather than an interpolated contour polyline as a first step creates better opportunities for semi-automatic editing through mass deletions of features. The first step is to transform the DEM, which contains continuous values, into a binary raster describing land and water as areas either above or below the shoreline proxy elevation, which in this case is zero. A new raster was created with below-zero values (associated with water) represented as zero and above-zero values (associated with land) represented as one. A polygon vector from the binary raster was then created using the *Raster to Polygon* tool with the “simplify polygons” option checked. The polygon output Feature Class attribute table contains a ‘gridcode’ field with values of zero and one associating the polygon features with water and land, respectively. Features with a gridcode value equal to one were selected and deleted, resulting in a “water” polygon.

Clipping the “water” polygon with a buffer of a legacy shoreline confines the dataset to near-shore features and cuts off tributaries and tidal creeks without creating gaps and dangles. This project used a 120-meter buffer of the NOAA Composite to clip the “water” polygon (Figure 5).



Figure 5: Polygon of below-zero elevation values derived from DEM (Top) and then clipped to 120-meter buffer of the NOAA Composite shoreline (Bottom). Image Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

With the dataset confined to an area in proximity to a legacy shoreline, small features can be batch deleted based on the shape area attribute. Before this step is attempted, it is important to ensure that all unconnected shapes are singlepart features. The Clip process transforms some singlepart features to multipart features in the output. In highly dissected marsh areas, numerous very small, disconnected shapes may exist in the output as a single feature with a cumulative shape area value much greater than any reasonable threshold for deletion. To eliminate these small shapes, they must be converted to single part features, each with its particular shape area value. This can be accomplished with the *Multipart to Singlepart* geoprocessing tool. Users can also select the multipart feature and use the Explode procedure (Edit > Modify Features > Divide > Explode) to transform the single multipart feature into many single part features. Once each single part feature has an independent area value, a mass deletion of the remaining scattered, small, and disconnected features can be achieved by

selecting the shape area attribute. The user should be aware that this step deletes “water” polygons, generally describing unconnected near-shore drainage areas. Islands are rendered in the larger “water” polygon as “donut” holes of negative space and are not affected by this step. A very small value can be used to eliminate a lot of noise. This project used the *Select By Attributes* option, to select features with an area of less than 100 square meters (1,076 square feet) to eliminate 5,896 of 6,104 features (97%).

Converting polygon to line for further edits

At this point, the land-water polygon can be converted to a polyline to remove more extraneous features. The part of the polyline that delineates the buffer of the legacy shoreline over the water surface must be deleted after splitting it at the point where it intersects the land-water edge represented by above and below zero elevation values (Figure 6). Then a mass deletion of small segments based on a selection by the length threshold attribute can be executed. Most of the small segments at this stage describe the “donut” holes, or small areas of above-zero elevation, in the larger water polygon. As with the shape area threshold previously, a small, conservative value can capture a large number of scattered features. In this project, a threshold of 50 meters captured 422 of 845 features (50%) but reduced the total length by only 1%.



Figure 6: After converting the polygon to line, the line is split at the two points where the buffer intersects the shore (A, Top, is one example), then all lines representing the buffer over the water surface are selected and deleted (Bottom). Image Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

The final step in the process is the creation of topology to check for violations of the five topological rules previously mentioned. For this project, the *Error Inspector* found less than twenty errors, all easily corrected by manual edits. A final visual inspection to eliminate any other non-shore features not eliminated by the mass deletions is recommended.

RESULTS

A zero-elevation contour derived from a 2015 LiDAR-derived DEM (four-foot spatial resolution) of St. Louis Bay, Mississippi generated a polyline describing a total distance of 904 km (562 miles) consisting of 10,362 features, a product too spatially complex and inclusive of non-shore areas for use in coastal management decisions. An alternative, semi-automatic process for vector shoreline extraction from the same DEM, comprised of ten steps summarized in Table 1, produced a vector shoreline describing 596 km (370 miles), a length reduction of 34%, and 1,479 features, a reduction of 86%.

Table 1: Summary of steps for extracting vector shoreline from DEM.

Step	Tool	Rationale
Convert raster to two classes above and below shoreline elevation value	Analysis > Raster Functions > Math > Logical > Greater Than	Necessary to create a "water" polygon
Convert Raster to polygon	Geoprocessing > Raster to Polygon	Product must be vector; polygons close the gaps characteristic of contour lines
Discard the "land" polygon features	Select based on gridcode attribute	These features generally do not contribute information about the shoreline
Clip the "water" polygon to a buffer of an old shoreline	Geoprocessing > Clip (Analysis Tools)	Confines Product to area historically recognized as shore. Also cuts off tributaries: no dangles, no need to hand draw
Ensure single part features	Geoprocessing > Multipart to Singlepart <i>or</i> Select feature > Edit > Modify Features > Divide > Explode	To delete features by the shape area attribute, each shape must have unique area value
Delete all features below a threshold area value	Select by shape area attribute and delete	Removes small features not connected to shoreline
Convert polygon to line	Polygon to Line	Line is the desired output format
Remove old buffer on water surface	Split the line at point where shoreline meets buffer, select additional segments, delete	The buffer is useful for cutting off landward tributaries, not useful over off-shore open water
Delete features below a length threshold	Select by length threshold attribute, delete	Further reduction of noise
Topology	Create a Feature Dataset and Topology in the Catalog. In the pane establish rules for no overlaps, intersects, or dangles.	Ensures "clean" shoreline output free of overlaps, intersects, or dangles

Although the process is not fully automated, it greatly reduces the on-screen digitizing, reducing both time and subjective judgment involved in tracing shorelines over imagery in large, spatially heterogeneous areas. The result can be obtained by any intermediate-level geospatial analyst with access to Esri software and is repeatable as new high-resolution digital elevation datasets become available. Given the basic nature of the operations, the procedure can be adapted to other software packages. The vector shoreline created for this project was used as an input to the Virginia Institute of Marine Science Shoreline Management Model with no modification of shape or configuration. Figure 7 shows key iterations and the vector shoreline output for the entire area of interest.

CONCLUSIONS

A vector shoreline was extracted from a high-resolution DEM. The method used an elevation value as a proxy shoreline and eliminated many fine-scale features in the vector linework representing unrelated areas of equal elevation. The process required no on-screen digitizing and no subjective interpretation of imagery. The only subjective elements of the process are the selection of area and length threshold values for mass-deletion of features and the selection of a distance value for buffering a legacy shoreline dataset. This process is a significant improvement over mass deletion of contour line features based on segment length alone because it 1) addresses issues caused by gaps in the line and 2) integrates deletion based on value thresholds with other steps iteratively.

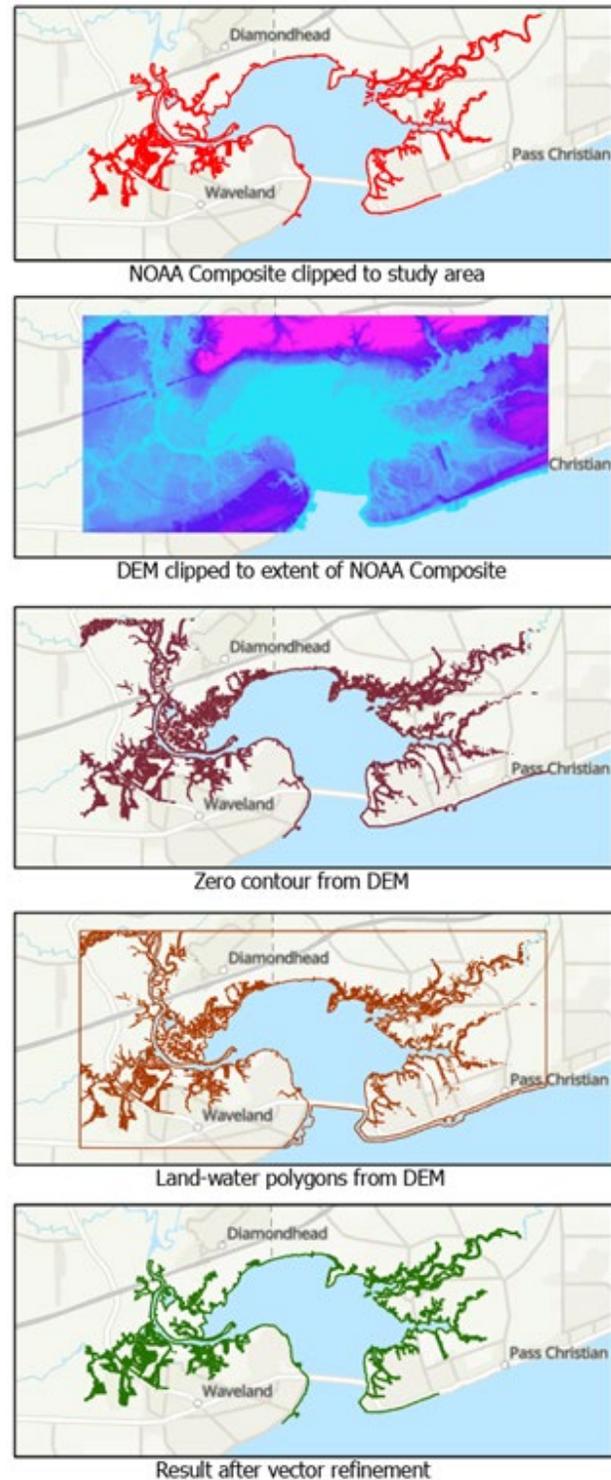


Figure 7: St. Louis Bay area depicted by input layers, iterations, and final result. Image Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Vector shorelines based on elevation data are only as accurate as the source of the elevation data. The DEM used in this project delineates marsh patches in a highly detailed way that corresponds strongly with recent imagery. The land-water edge detected in the narrow canals of highly developed areas is not so accurately described. Narrow canals in residential areas have multiple objects – trees, small structures, boats – that seem to cause the sensor to frequently detect above zero values (0-3 feet) over open water in an irregular pattern in narrow canals (Figure 9).

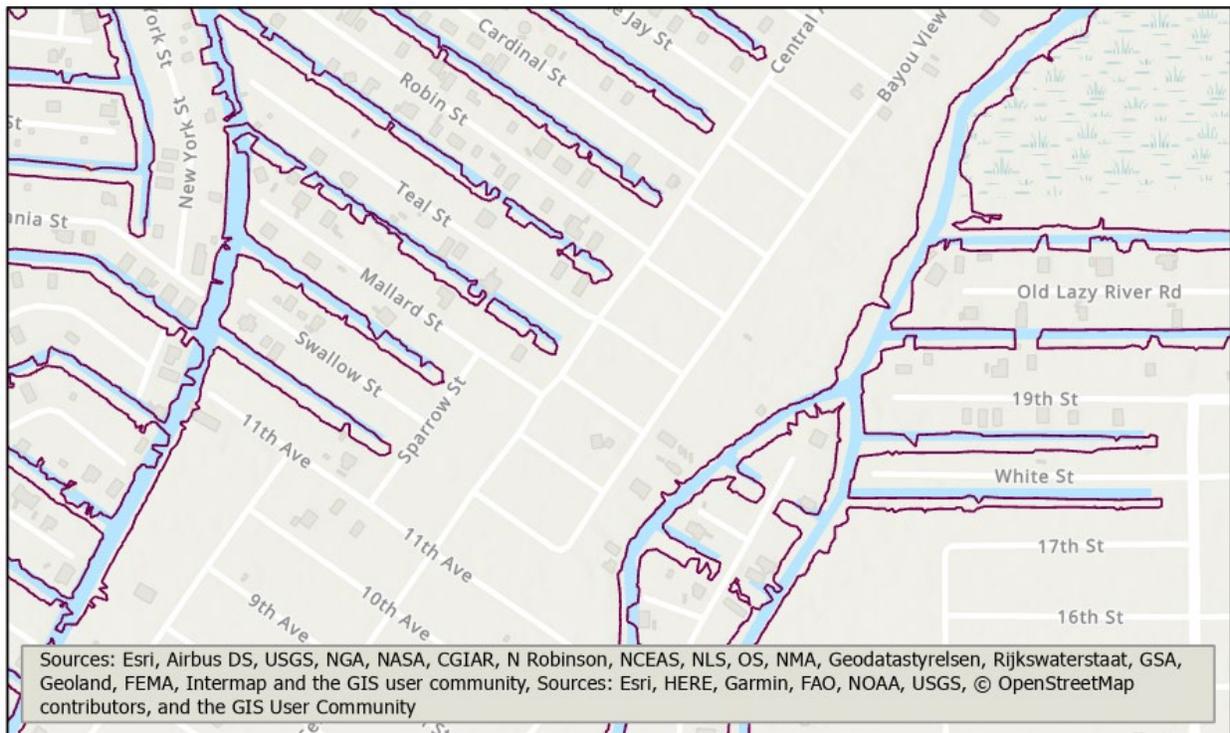


Figure 7: The process was unable to remove the meander of the line in areas with narrow canals.

Since shorelines are strongly associated with topography and LiDAR technology measures elevation, datasets derived from LiDAR have an advantage over imagery composed of spectral bands when it comes to shoreline detection. The increasing availability of surface elevation datasets derived from LiDAR has advanced the ability of coastal managers to update their shoreline maps. The process described here provides simple steps for reducing the noise in those high-resolution products.

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