

Bathymetric and Hydrodynamic Analysis of Wax Lake Delta

I. Introduction

A. Motivation

The ability to explain and predict how any physical system behaves is paramount in understanding how that system will impact society. River deltas warrant such rigorous analysis for several important reasons. Deltas foster a home for almost a quarter of the global population and provide a unique habitat in which both plants and animals can thrive. Additionally, deltas exhibit a fragility which suggests an even greater significance in understanding their mechanics, as a change in a delta's structure could have significant societal and ecological impacts.

The significance of delta research is well-recognized by the scientific community, especially as it relates to the geological significance of deltas and delta restoration [Paola, 2011]. However, most delta research assesses a delta as a network of channels, while ignoring inter-channel flow. Recent studies have suggested that water transport through deltaic systems is not achieved solely by means of channels; rather, field observations suggest that flow leaks into delta islands and prevents the conservation of water fluxes in the channel network [Hiatt, 2013]. Thus, the traditional open channel flow (OCF) model, which operates under the assumption that flow is confined to channels, is likely insufficient to describe how water propagates through a delta [Parker, n.d.]. The development of a more robust model is necessary to account for unconfined flow conditions which observations suggest.

In order to determine how deltaic systems might depart from the OCF model, data need to be collected and analyzed. ArcGIS provides an appropriate venue for mapping and analyzing data collected from the field. More accurate and more complete bathymetric information can be developed, which can lead to hydrodynamic data of similar quality. This

data can then be used to develop better modeling techniques for describing the unconfined nature of deltaic flow propagation.

B. Location

For this project, my focus was on various physical aspects of the Wax Lake Delta (WLD). The delta, located on the Gulf of Mexico southwest of New Orleans, was accidentally created as a result of a flood-control project in the Atchafalaya River basin [Paola, 2011]. Since then, extensive sediment deposition has made the WLD a topic of study in deltaic growth; in fact, it has been a focus of research at the University of Texas at Austin, within the Delta Dynamics Collaboratory (DDC). WLD, depicted in Figure 1, is hydraulically connected to the

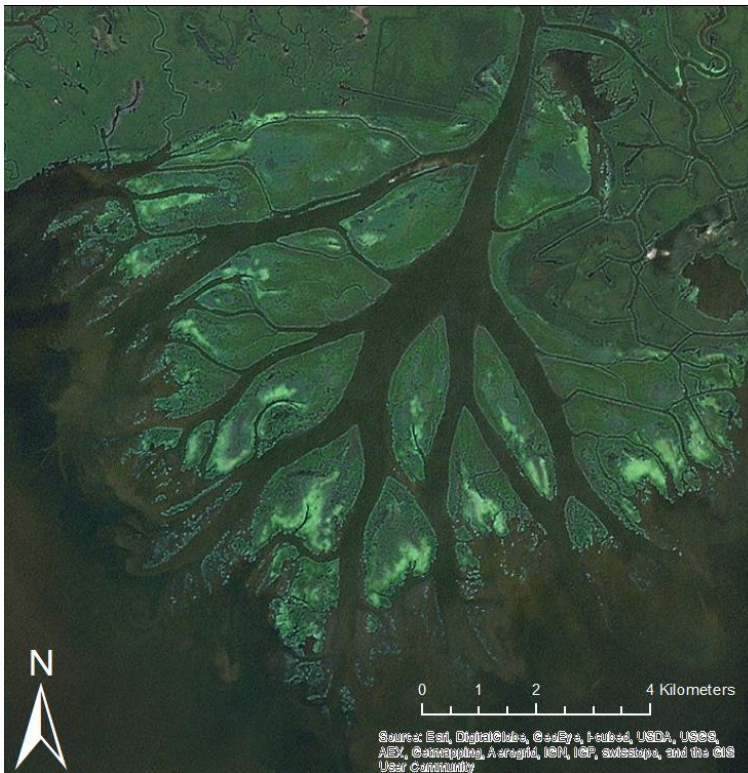


Figure 1: Satellite image of Wax Lake Delta, fed by a canal from the Atchafalaya River (not shown) and emptying in the Gulf of Mexico.

Atchafalaya River via a canal, and has experienced over 100 km² of deltaic growth since the canal's creation [Paola, 2011]. Figure 2, obtained from the United States Geological Survey (USGS) [USGS, 2005], shows WLD and its relative position along the Louisiana Gulf Coast, along with coastal land loss and gain, both past and projected; WLD is the western of the two green areas in the central region of the map. The importance of WLD (in addition to the Atchafalaya Delta, located adjacently east) is easily seen through its juxtaposition with the rest of the coast, which has undergone a net loss of land, and is expected to continue this trend.

Coastal Louisiana Land Loss

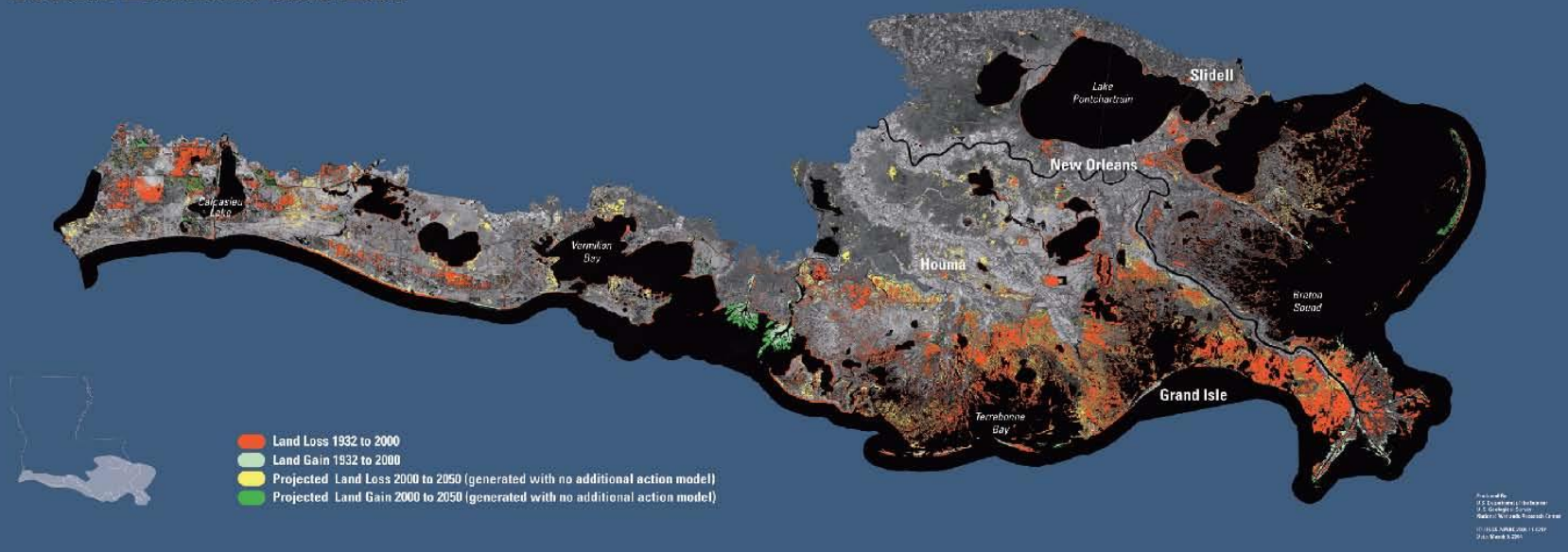


Figure 2: Past and project land loss and gain for coastal Louisiana, provided by USGS. Green areas are especially significant, as they are expected to exhibit future growth. WLD is the western of the two green areas.

II. Data

A. Transect Data

In order to develop a bathymetric profile of WLD, water depth information was acquired from DDC members. These data was originally obtained from the United States Army Corps of Engineers (USACE), who performed a hydrographic survey of WLD in 1999. The data was uploaded using the NAD83 datum and the Universal Transverse Mercator (Zone 15) projection. The nine transects surveyed, consisting of 2,310 points, are shown in Figure 3.



Figure 3: USACE transects across WLD. Satellite imagery used as basemap.

Deeper readings are depicted with blue dots, while the highest elevations with red dots. Transects are spaced 800 meters apart, and are generally oriented orthogonally to flow through the delta [Shaw, 2013].

It is important to note, however, that this orthogonal orientation is not (and cannot be) maintained throughout the entirety of the delta. This is especially noticeable with the eastern channels, which run nearly parallel to the transects. Such orientation proves problematic with interpolation, and requires special care that is discussed in the following section. Another aspect of the data that should be mentioned is the discrepancy between the transects and the

satellite imagery at the downstream areas of the delta, evidenced most egregiously by the southernmost transect. The deepest data points of the transect are located southeast of the channel, according to the basemap. This is almost certainly due to the dynamic nature of the downstream areas of river deltas (the USACE transects are almost 15 years older than the satellite imagery). An attempt to rectify this inconsistency is discussed in the following section, though the hydrodynamics primarily governing flow through the delta is that which occurs in the upstream sections, not downstream of the major channel bifurcations. These upstream transects match the satellite imagery fairly well, giving values of -0.5 meters to -1.0 meters to most of the channel borders (these values are dependent on a vertical datum, and therefore are somewhat arbitrary).

B. Unutilized Data

There were two main data sets related to Wax Lake Delta bathymetry that I refrained from using. The first set was gathered by John Shaw of the DDC, but primarily consists of data located downstream of the delta itself (see Figure 4), and is thus not particularly useful in determining the delta's bathymetry. While some of these data include useful channel depth data (the red and teal routes in Figure 4), most of the delta is not covered; therefore, this data set was not employed. Further work in mapping WLD's bathymetry will likely utilize data along these routes for a more complete depth profile.

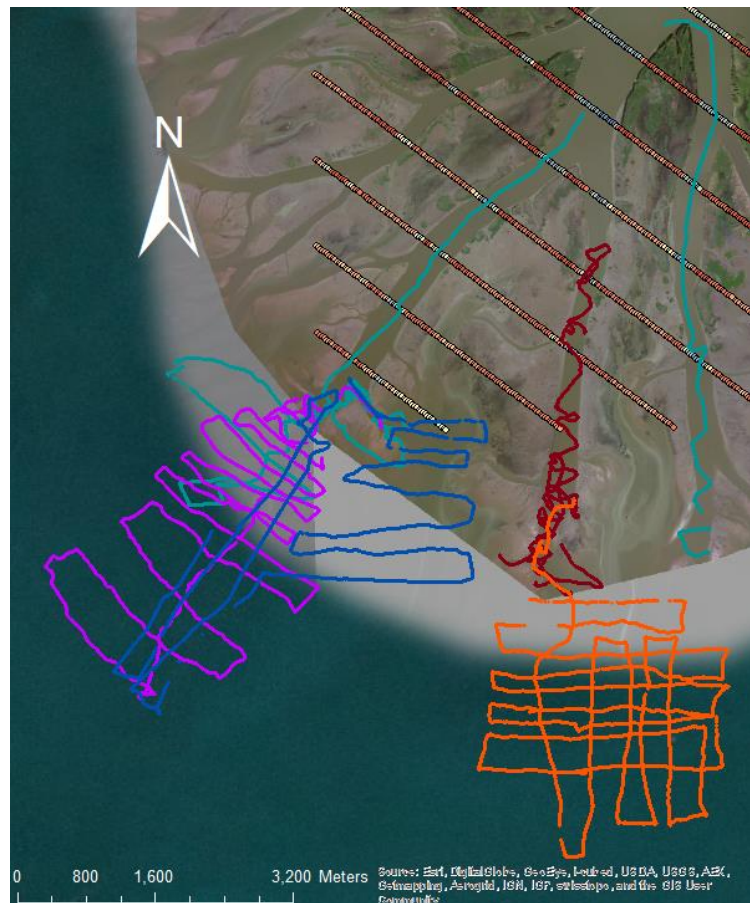


Figure 4: Depth data was collected along these routes by John Shaw. Depth along these routes is not shown; the colors only indicate the different routes along which data was collected.

The second data set not used consists of LIDAR data. While “green LIDAR” is available for the extent of the delta, the error introduced by the incomplete penetration of the water surface has not yet been eradicated, causing submarine depth values to be uncertain. The DDC and others are working on the processing of these data, which will give great insight into WLD’s bathymetry.

III. Interpolation Analysis

A. Initial Interpolation

The first interpolations were performed without any processing of the transect data. Four rasters were created, each using a different interpolation tool provided by ArcGIS’ Spatial Analyst. The four bathymetric rasters are presented in Figure 5. The parameters of each tool

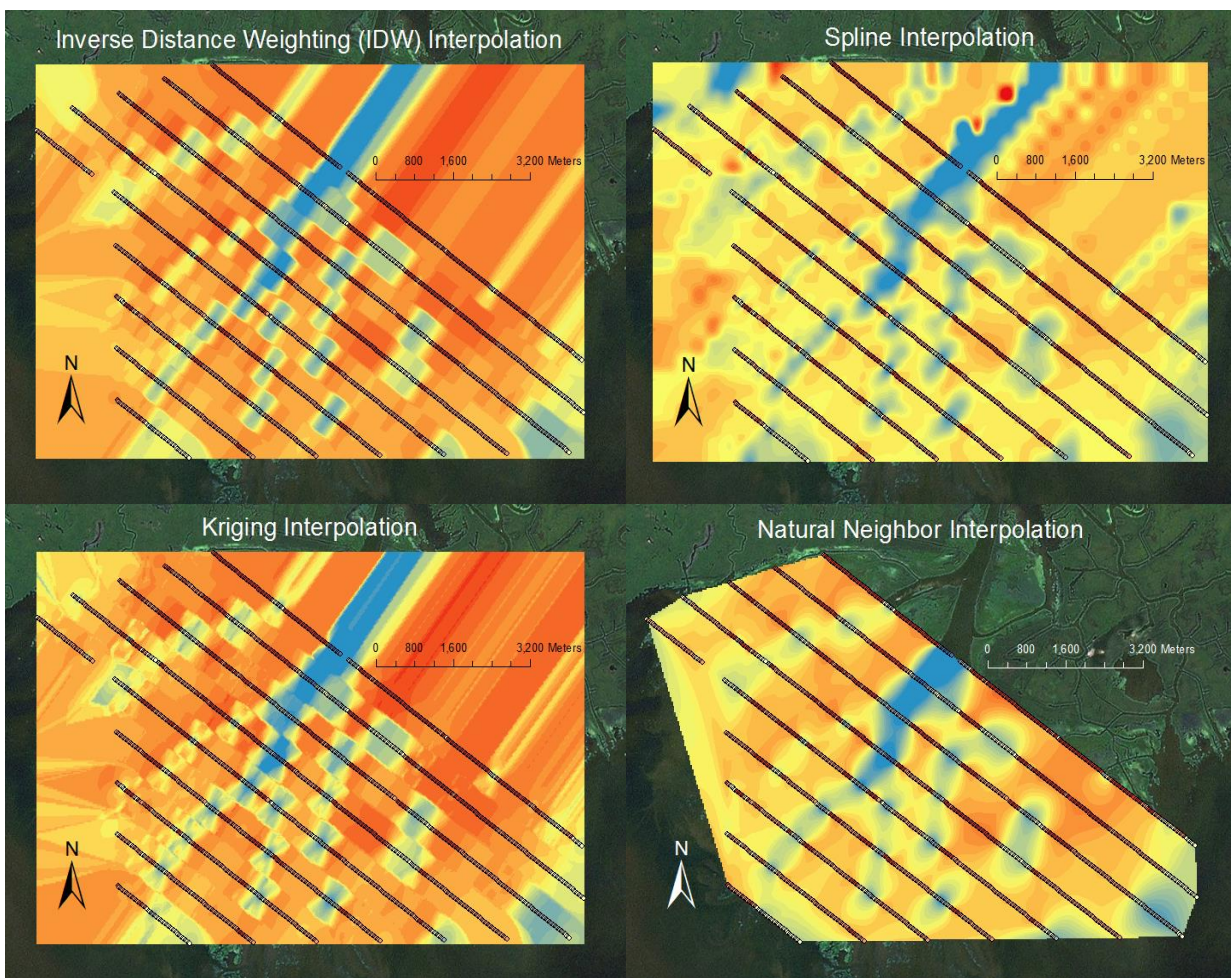


Figure 5: Four interpolation methods available from Spatial Analyst. Blue represents greater depths, while reds represent higher elevations.

were varied to create the most reasonable interpolations. Due to the linear nature of the transect data, two of the methods—inverse distance weighting (IDW) and kriging—give unsatisfactory results. The rasters are created by interpolating the data in only one direction, such that channels appear very “choppy” and unnatural. The spline and natural neighbor interpolations, on the other hand, appear much more natural, with the natural neighbor method in particular indicating most clearly the flow pathways and outlet points.

The natural neighbor interpolation, however, lacked much of the detail required for hydrodynamic analysis. Channels, especially those flowing nearly parallel with the transects, are not properly represented, with some not apparent at all. Furthermore, inlet and outlet points are not well-defined.

B. Interpolation Improvements

Significant pre-processing, therefore, proved necessary to develop an accurate bathymetric map. The first attempt involved defining channel boundaries, which resulted in

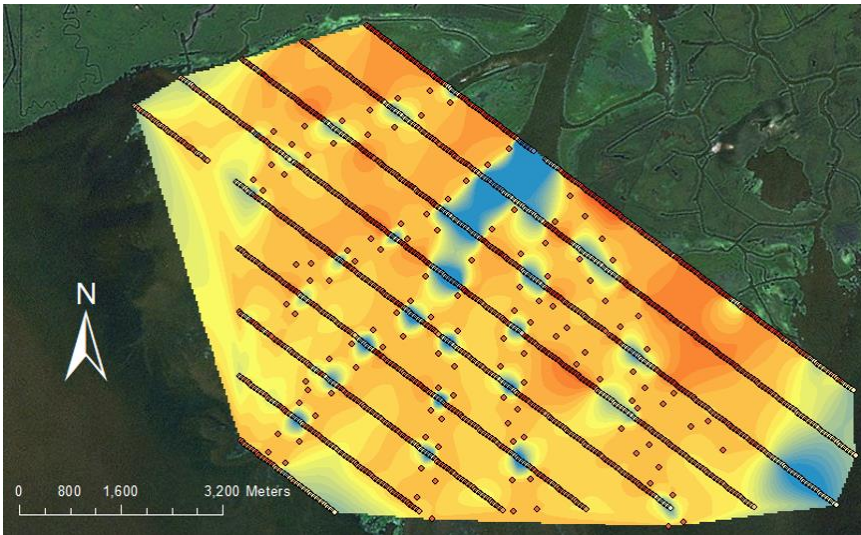


Figure 6: A nearest neighbor interpolation of the transects with channel boundaries. Other interpolation methods yielded results no better than this.

the raster depicted in Figure 6. Clearly, this method is not an improvement of the initial interpolation, as all locations within channels, other than those near transects, are determined to have the same depth as the boundaries.

Subsequent attempts encompassed a more robust approach, based on several motivations and utilizing more reliable methods. First, depths between transects (both in the channels and in the islands) were estimated assuming linear gradients between transects in directions parallel to channel flow (Figure 7), thus utilizing both the transect data and the satellite imagery from ArcGIS. Second, the two inlets in Figure 6 were combined upstream through extrapolation based on the satellite imagery and knowledge from field work done by

the DDC. Third, in order to provide better definition for the western outlets, depths were estimated based on the imagery and the ends of the downstream transects

To enhance the bathymetry further, an iterative process was used, alternating between interpolations and the addition of data points to the depth feature class. Points were added in the channels and the islands in order to smooth out the main channels, more accurately represent channel widths (Figure 8), and represent inter-island channels. Some transect points were deleted to more easily

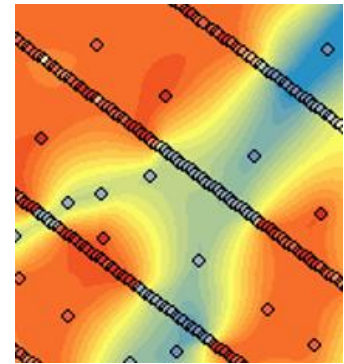


Figure 7: Depth was assumed to vary linearly along channel directions.

allow channel routing (Figure 9) and to better reflect the more recent basemap imagery. After each significant alteration, the newly-interpolated bathymetry

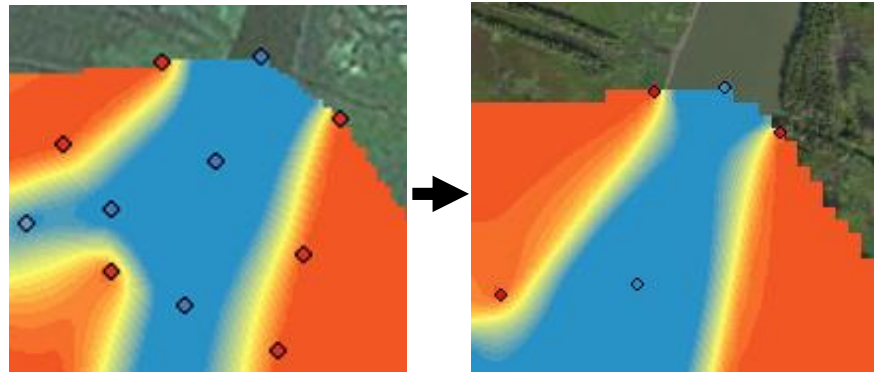


Figure 8: Experimentation with point placement was necessary before channel widths were satisfactorily accurate.

was assessed to determine if the previous change was effective and what future amendments should be made. After approximately twenty-five iterations, 425 points were manually added, and a final bathymetry raster was created, shown in

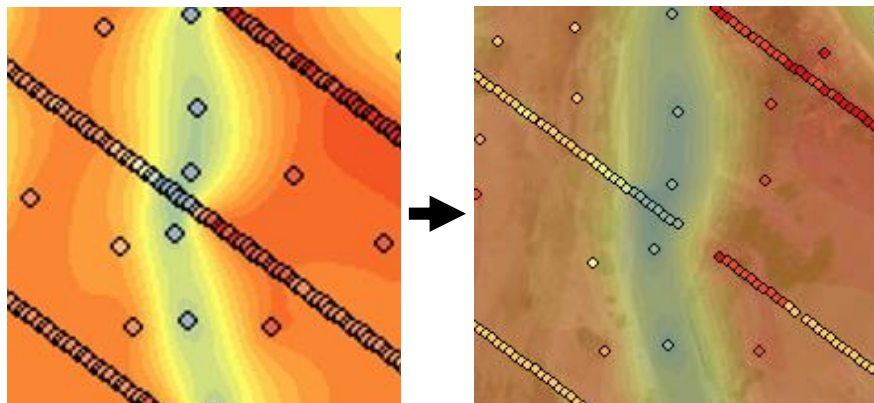


Figure 9: Due to the non-orthogonal orientation of the channel, deletion of transect points was necessary to reflect satellite imagery (shown in second image behind partially transparent bathymetry raster).

Figures 10 and 11. Figure 10 shows the bathymetry with the data points; Figure 11 shows the bathymetry at 50% transparency for comparison to the satellite imagery.

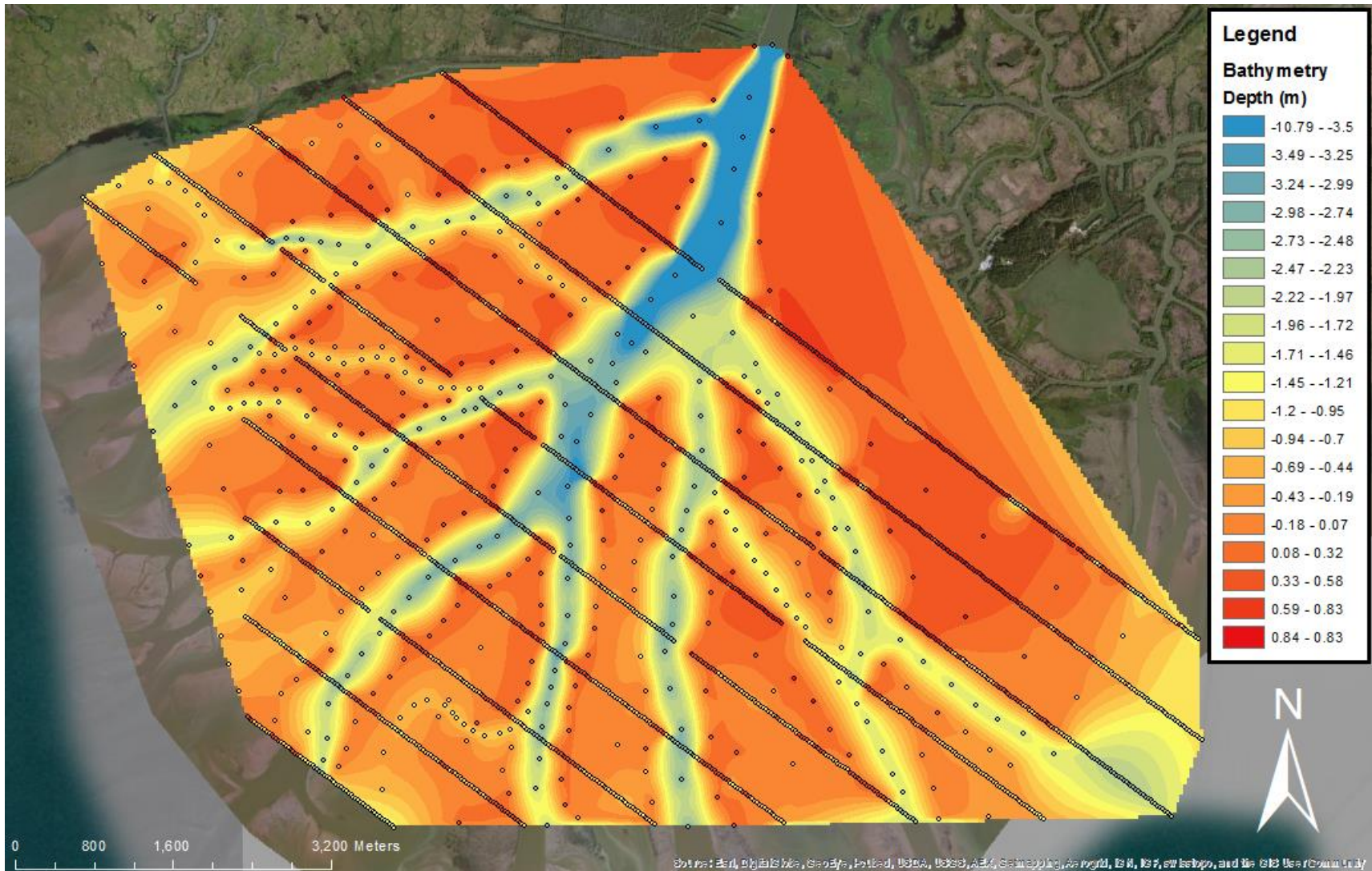


Figure 10: Final bathymetry raster of WLD with all 2,695 data points (2,270 transect, 425 manual).

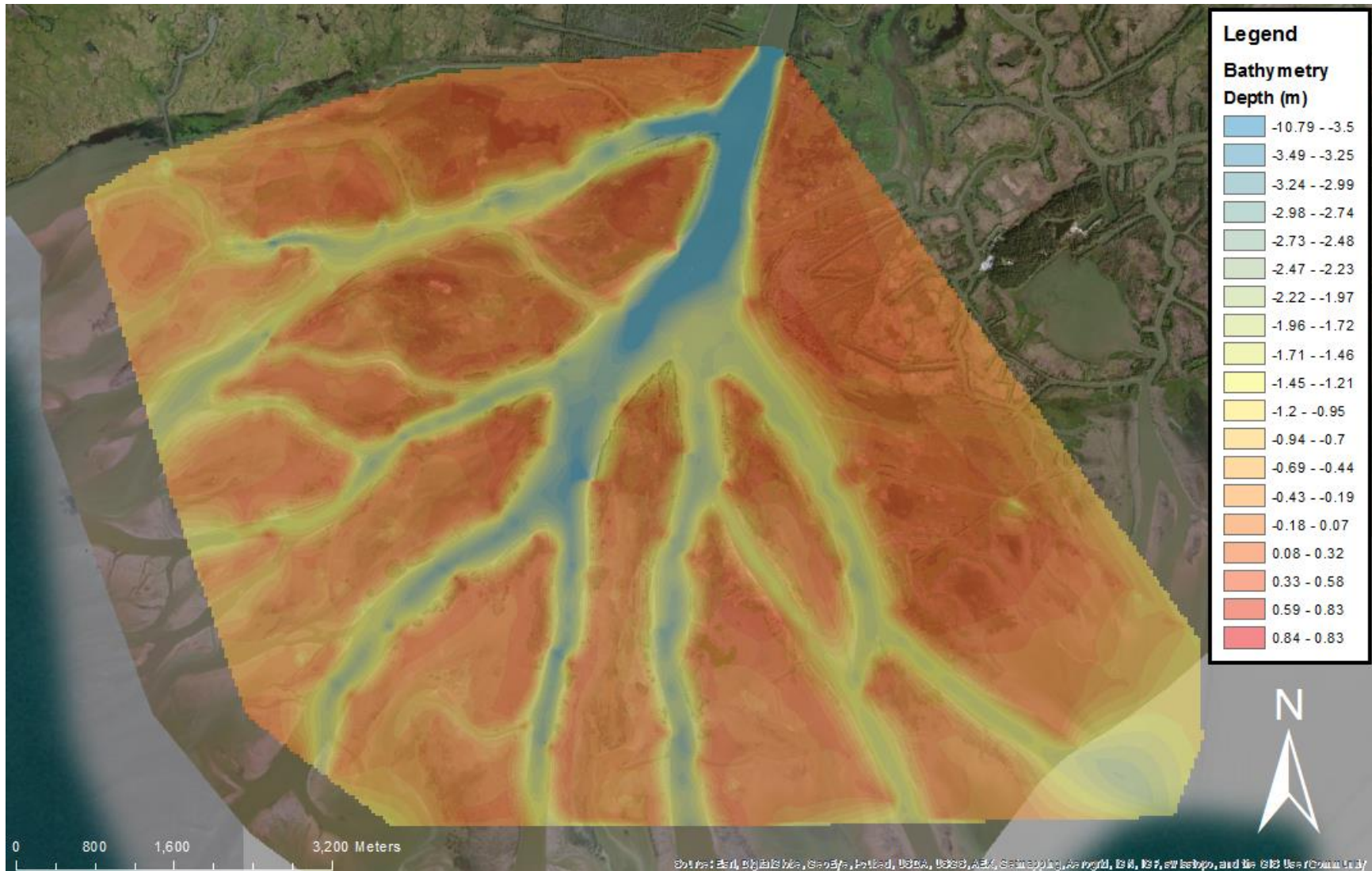


Figure 11: Final bathymetry raster of WLD at 50% transparency.

C. Interpolation Accuracy Analysis

In order to determine the accuracy of the above interpolation, two feature classes were created in order to estimate the size of the delta islands. The first set of islands was traced using the new bathymetry, where the depth is equal to -1 meter. This depth was chosen because it appeared to give the most accurate island borders for the majority of the delta; Figure 12 depicts the bathymetric contours, highlighting the -1 meter contour. Since this contour doesn't

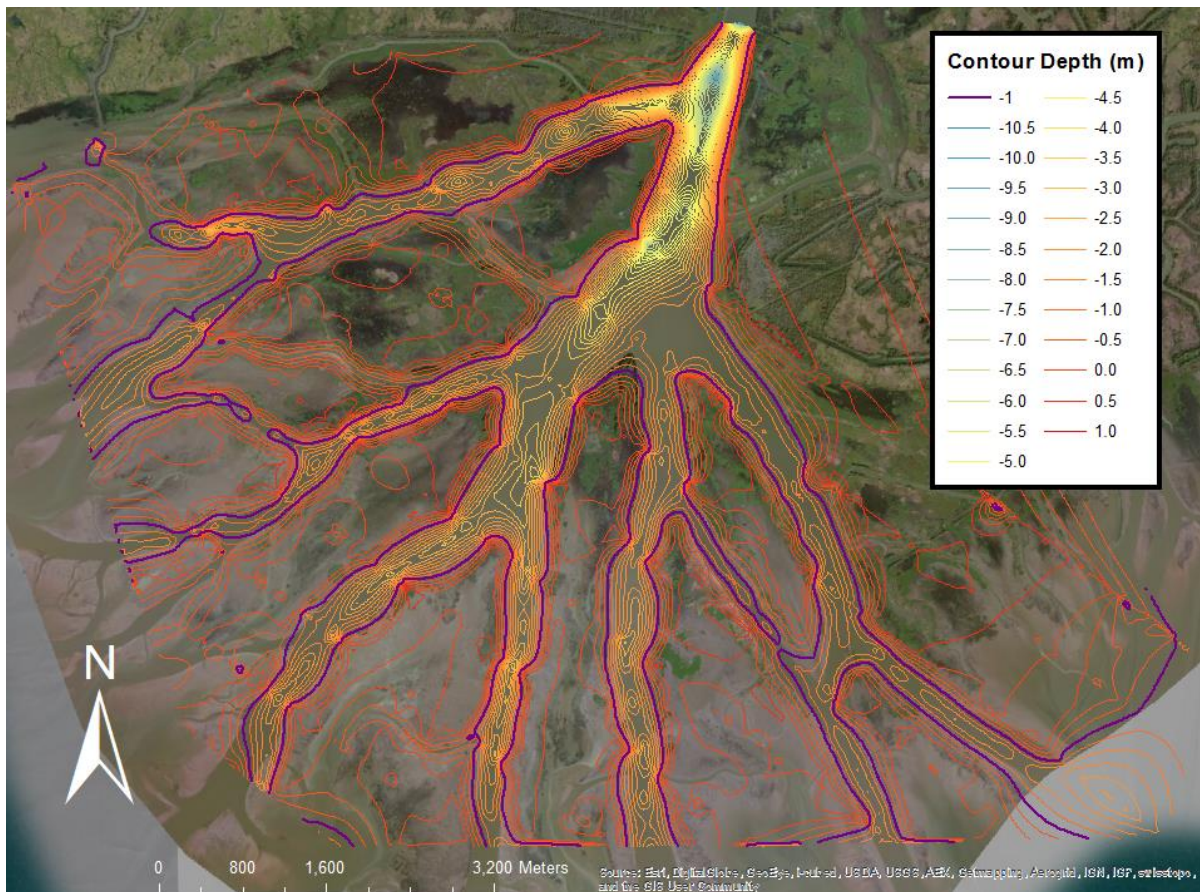


Figure 12: Contour map of WLD's bathymetry. The purple contour, representing -1 meter depth, was chosen for island extraction.

define all the islands, especially through shallow channels and the areas farthest downstream, the satellite imagery was used to supplement the island boundaries. For the second feature class, the satellite imagery was used exclusively. Both feature classes, which consist of the thirteen islands that are completely or mostly within the interpolated bathymetry, are shown in Figure 13. Comparing the areas of the two sets of islands will give some indication of how

well the bathymetry compares with the satellite imagery. This comparison is demonstrated in Figure 14; island areas and percent discrepancies recorded in Table 1.

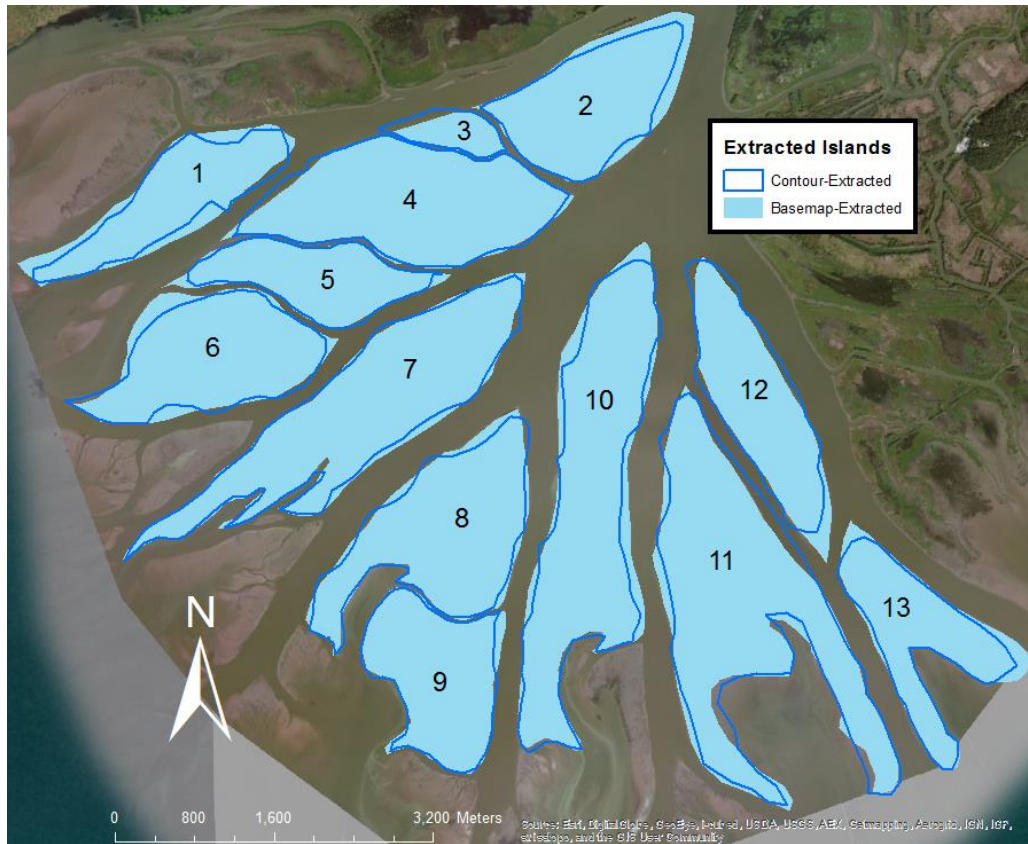


Figure 13: Islands extracted using both the contours and satellite imagery basemap provided through ArcGIS.

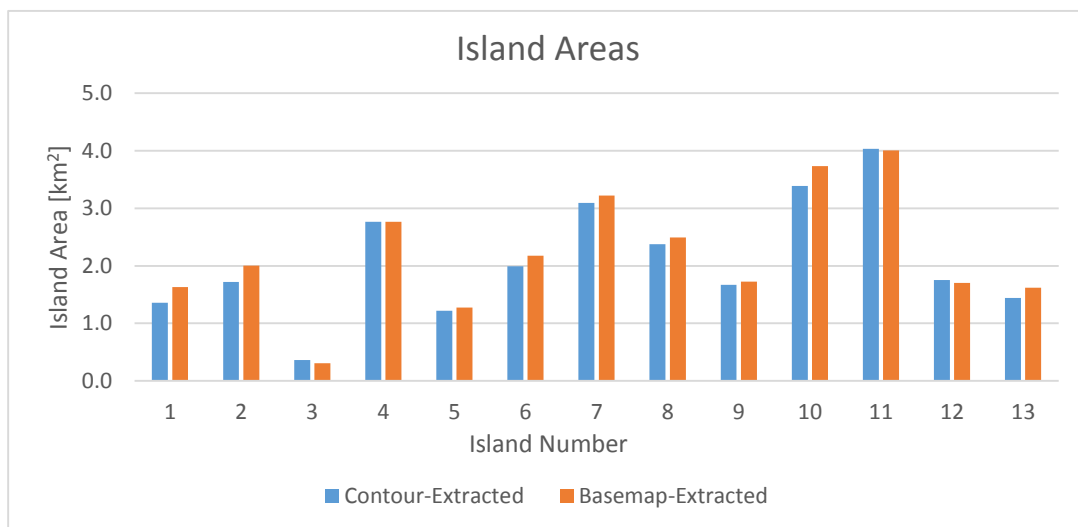


Figure 14: Bar chart demonstrating area of islands extracted with bathymetric contours and the satellite imagery.

Table 1: Island areas and percent discrepancies for both extraction methods.

		Island Number												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Areas [km ²]	Contour-Extracted	1.359	1.720	0.361	2.765	1.221	1.992	3.094	2.377	1.670	3.385	4.031	1.752	1.440
	Basemap-Extracted	1.633	2.005	0.305	2.764	1.274	2.177	3.220	2.494	1.727	3.731	4.003	1.701	1.621
Discrepancy [%]		16.74	14.23	-18.16	-0.03	4.18	8.51	3.90	4.69	3.30	9.28	-0.70	-3.00	11.18

The average discrepancy is 4.16%. Some larger discrepancies correspond to islands where interpolation required many extrapolated data points (1, 2, 6, and 13). It is important to note that similar island size does not necessarily correspond to similar island shape, which could negatively affect bathymetric data. Furthermore, there are other metrics that should be considered when determining appropriateness or accuracy of a given bathymetry. Finally, this method only compares the interpolated data to the satellite imagery, not necessarily the actual characteristics of the delta.

IV. Hydrodynamic Results

Hydrodynamic data was calculated using a reduced complexity model (RCM) developed by Man Liang at the University of Texas. This numerical model employs a “weighted random walk” to probabilistically determine flow patterns through systems based on its physical characteristics. In this case, morphodynamic processes such as sediment transport were ignored, and the WLD bathymetry was used to determine hydrodynamic data only [Liang, 2013]. Several of the interpolation motivations discussed above were conducted to facilitate the RCM compatibility, such as creating a single entrance point and clearly defining the outlets.

The final bathymetry was exported from ArcGIS as a .tif file and was uploaded to the RCM, which Man Liang ran. The resulting hydrodynamic data, consisting of water speed and direction, are displayed in Figure 15.

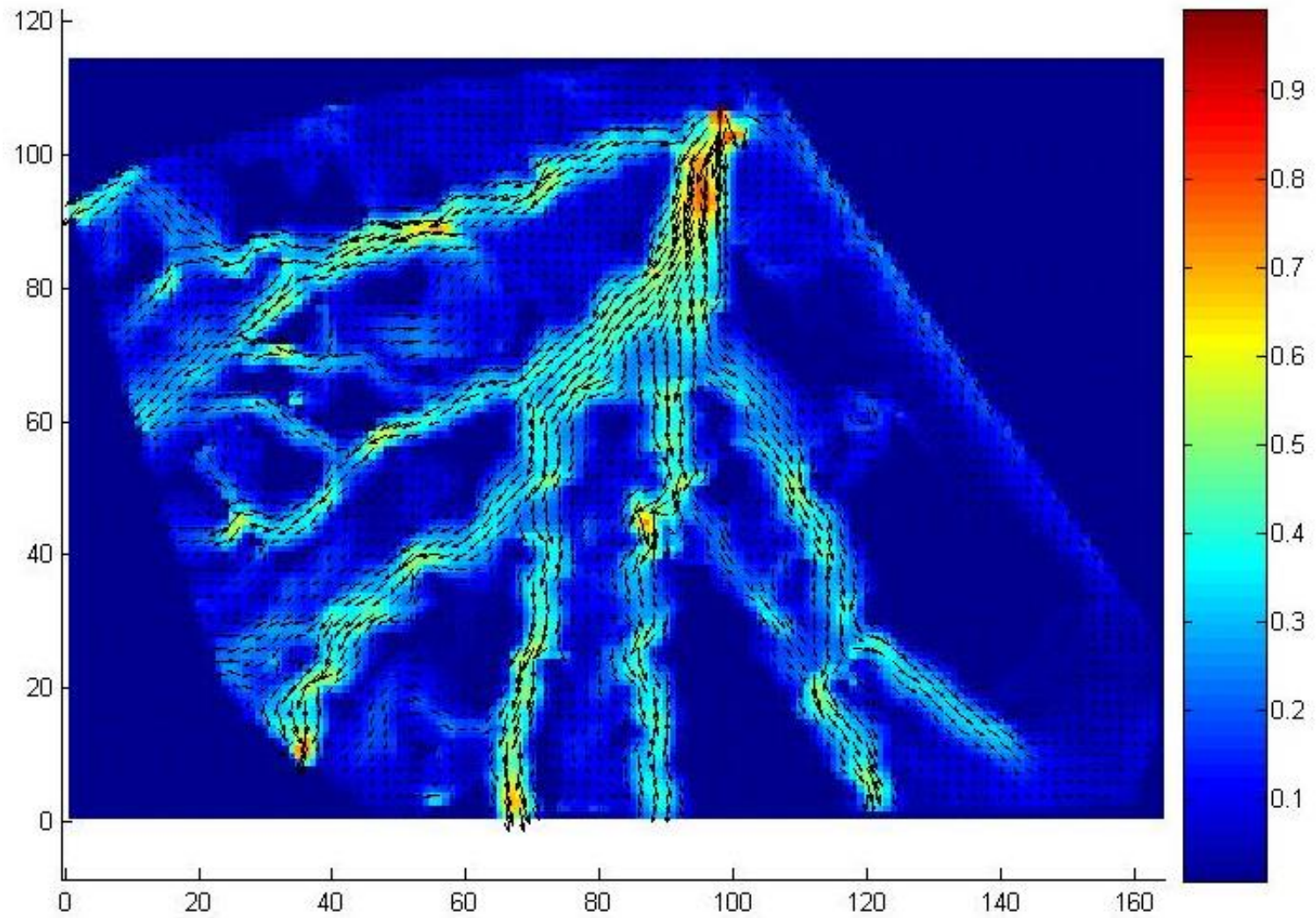


Figure 15: Hydrodynamic data, as produced by Man Liang's reduced complexity model. The values on the right side correspond to velocities in meters per second. Scaled velocity vectors are included. Distance units along the axes are arbitrary.

V. Discussion

A. Potential Improvements

Several improvements could be made to enhance WLD's bathymetry, and thereby increase the quality of the hydrodynamics. First, a greater number of data points, especially those in directions orthogonal to the transects, would clarify the channel depths immensely. The data collected by John Shaw would be the first step, but more information could be collected in future field work. If the errors inherent in the "green LIDAR" can be eliminated, WLD's bathymetry could be known with a high degree of certainty.

More experimentation on existing and interpolated data points could also improve the bathymetry. This could include higher detail within the islands, especially related to inter-island channels. Better characterization with respect to channel banks (sheer or gradual) could also more accurately reflect reality. Additionally, work could be done to update the downstream transects, which have undergone substantial change since USACE's 1999 survey.

Finally, the hydrodynamics given by the RCM could be mapped with ArcGIS, which would be a better platform for analysis and interpretation than the images output by the RCM.

B. Conclusion

Overall, ArcGIS is an effective instrument with which to extract and analyze bathymetric profiles. While there is inherent error with any interpolation method, especially when using limited data, the tools and resources provided by ArcGIS can dramatically improve our understanding of complex systems like deltas.

It is also important to note that the bathymetry is not the sole contributor to a system's hydrodynamics. Environmental factors such as wind and tides have been shown to have a nontrivial impact on the hydrodynamics of river deltas [Geleynse, 2013]. Nevertheless, bathymetry is the primary cause of flow propagation, and is essential in understanding how these systems function.

VI. References

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