Flow Analysis of Pintail Island, Wax Lake Delta

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Introduction

River deltas are dynamic ecogeomorphic systems that are home to almost 25% of Earth's population and a variety of endangered species, making them socially, ecologically, and economically significant. However, they also face environmental hardship due to sediment erosion, eutrophication, and habitat loss caused by urbanization, river- routing, and natural system fluctuations [1]. To resolve these issues, there is a need for a well-rounded understanding of delta system processes so policy-makers and water managers can make informed sustainable solutions that minimize unintended impacts on wildlife and the environment.

An enormous amount of information is involved in describing the connectivity between water, nutrients, sediments, energy, and biota in a deltaic system. To enhance the overall view, external disturbances caused by large storm events or anthropogenic activity must also be considered. Taken over spatial and temporal scales, a truly dynamic system emerges. Various aspects of delta formation and evolution have been studied using field experiments and numerical modeling including flow dynamics, morphodynamic evolution, and the effect of storm events [1].

An important aspect of delta evolution is the propagation of fluxes such as nutrients, sediments, and water. Channel flow and island flow constitute the flow of water in the deltaic system. While channel dynamics are relatively easily measured and studied, less is known about island hydrodynamics.

This report focuses on the island dynamics of Pintail Island in Wax Lake Delta (WLD). Shown in Figure 1, WLD is a natural delta located 140 km southwest of New Orleans. A self-organizing system, WLD is building land while many deltas are suffering major sediment loss [1]. There is little human interference, making it a "healthy" natural system and the ideal location to study delta dynamics.

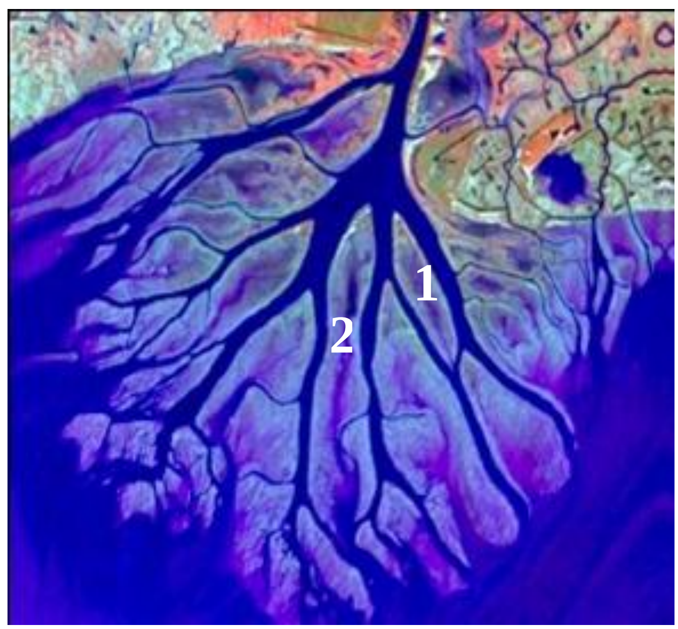


Figure 1: Satellite image of Wax Lake Delta. The "1" denotes Pintail Island and "2" Mike Island

This project concentrates on a tracer study conducted on Pintail Island. The tracer results are presented along with analysis into environmental forcings on the island through wind, tides, and channel flows. Pintail will also be compared to Mike Island (the "2" in Figure 1) to makes some estimations of locations for sensors on Mike for a future tracer study.

Data and Methods

The tracer studies were performed in May 2013. Sensors were organized within the island and rhodamine dye was released at an injection point to track how water moves across the island. One study was performed during a falling tide and one during a rising tide that became a falling tide. Water depth loggers and Acoustic Doppler Profilers were employed to capture water depth and velocities across the island. The tracer, velocity, and depth data along with sensor and injection locations were obtained from Matt Hiatt, who conducted the tracer tests. The tracer data was in the form of a time series while the velocity and depth data were measured in transects across the island during the rising tide and falling tide. Images were procured from USGS and from Bing Image Basemaps for input into ArcGIS. Wind and tide data were obtained from the NOAA Tides and Currents database through the LAWMA Amerada Pass station in Louisiana, located about 10.8 kilometers from Pintail Island, and deemed to represent conditions in the delta accurately.

Tracer data was processed and input into ArcMap. Sensor locations and injection points were input as coordinates into ArcMap using the NAD1983 UTM Zone 15 projected coordinate system. A time series was created for both the falling tide and rising tide studies to get a sense of tracer propagation and travel time on the island. Results were summarized in Microsoft Excel to confirm travel time and to observe any dispersion across the sensors. The depth transects for both studies and the velocity transect for the rising tide were input into ArcMap and interpolated using the Nearest Neighbor interpolation method using with a cell size of 3m to extend the values over the island. The velocity transect for the falling tide data is being processed and was not ready by the time of this report. The interpolations of depths and velocity were compared with the travel times found in the tracer analysis and wind and tide data to better understand environmental forcings in the delta.

For the analysis of Mike Island, a feature class dataset was created where the outlines of Pintail and Mike Island were traced by hand using the Editor toolbar to obtain the area of each island. An image of Wax Lake Delta, taken from the USGS Landsat image database, was input into ArcMap and georeferenced with the Bing Basemap provided in ArcMap. The NDVI function was employed in the Image Analysis window to obtain an estimation of the water area for the island. The areas were traced by hand using the Editor Toolbar and the resultant areas were compared for the 2 islands.

Results

Tracer Study

Figure 2 shows the arrangement of sensors for the two tracer studies. Table 1 presents some information about the two tests while Table 2 describes the distances from the injection points to the sensors in meters for both studies.

Table 1: Study information

Tracer Study 1: Falling Tide	Tracer Study 2: Rising Tide
Started 05/09/2013 16:43:00	Started 05/13/13 11:15:00
160 mL Rhodamine Dye Injected	310 mL Rhodamine Dye Injected

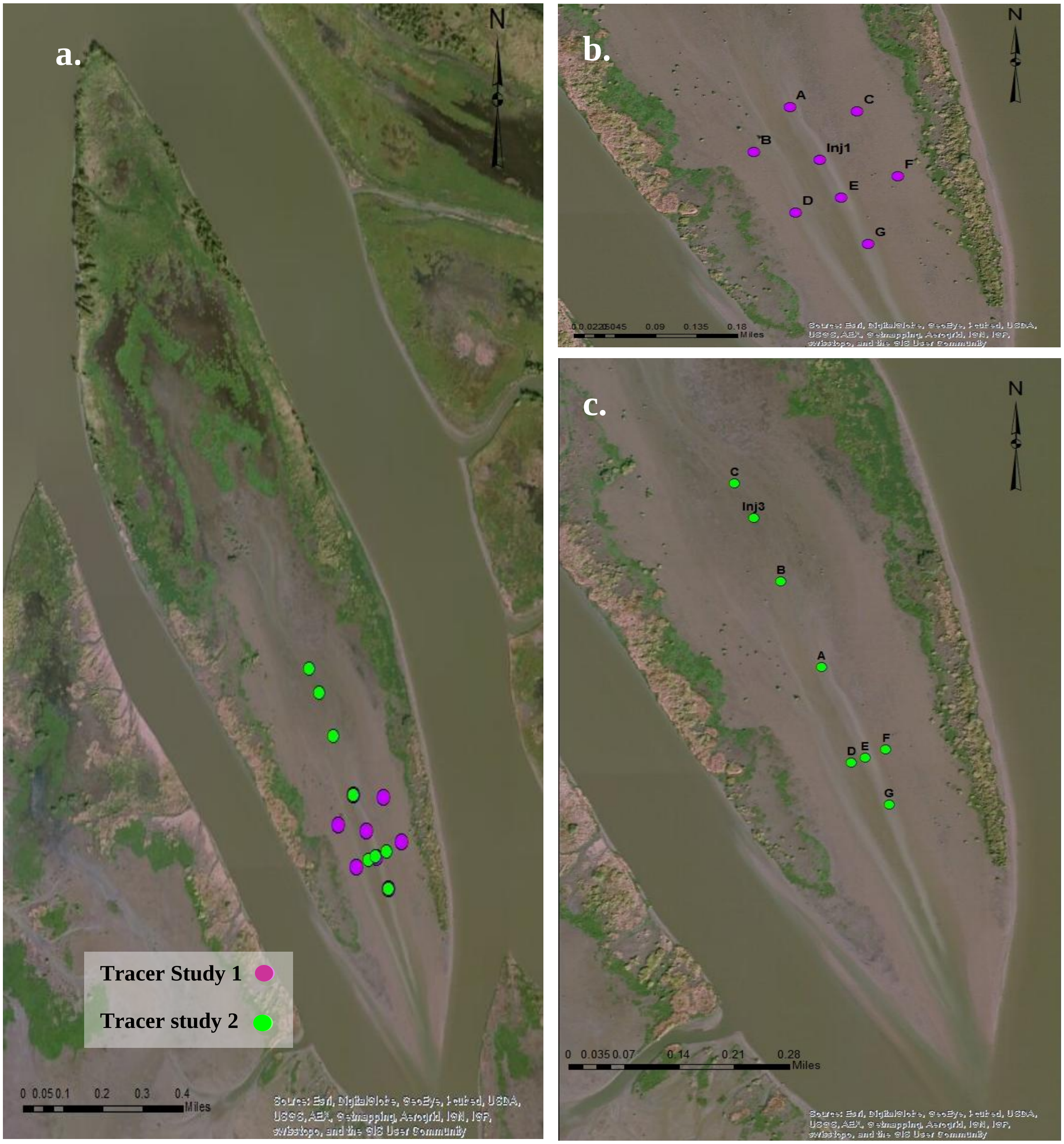


Figure 2: a) Sensor orientations for both tracer studies. b) Tracer study 1 orientation zoomed in c) Tracer study 2 orientation zoomed in

Table 2: Sensor distance from Injection

Sensor	Distance from Injection1 for Study 1, meters	Distance from Injection2 for Study 2, meters
A	115.62	321.57
B	102.95	136.49
C	112.96	76.96
D	111.8	519.87
E	82.96	519.59
F	125.63	621.37
G	184.25	518.6

As seen in Figure 2, the sensor orientations of the second tracer study covers more than twice the area of sensor arrangement 1; therefore the rhodamine concentration was also doubled for the second tracer test. The sensors had a detection limit of 200 µg/L; anything measured above that value is not considered accurate on a quantitatively, but the time to peak is considered reliable and was the parameter of interest in the study.

First Tracer Study: Falling Tide

The first tracer test was conducted during the limb of a falling tide as shown in the red circle in Figure 3. In the analysis, the time series information is expressed as a series of screen shots that show the time of peak of rhodamine detection for the sensors (Figure 4).

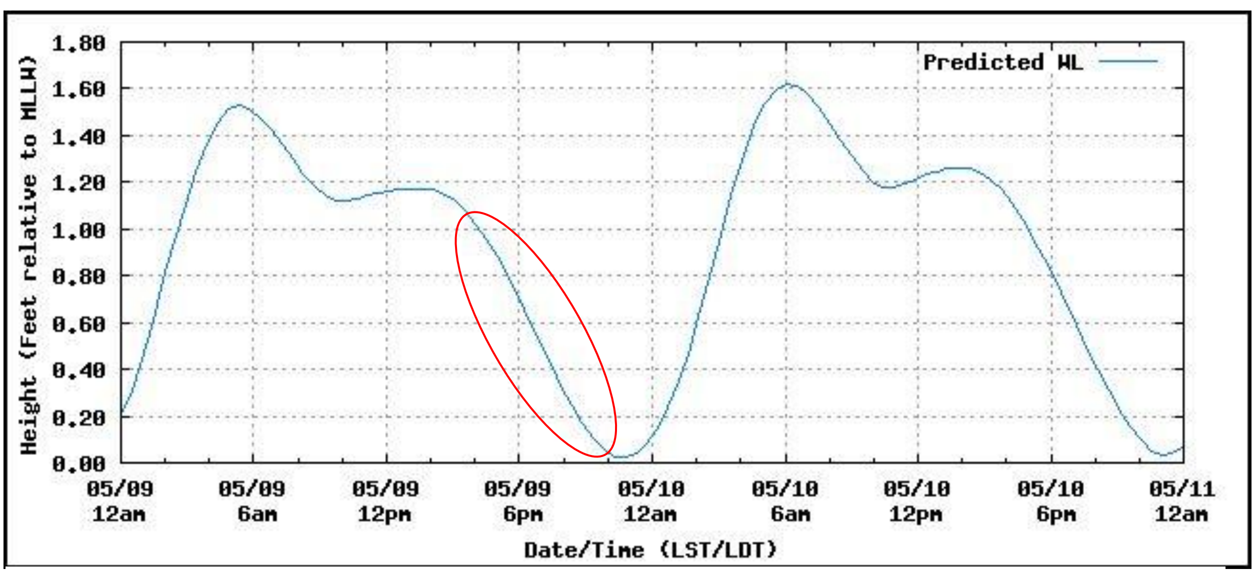


Figure 3: Tide predictions for 05/09/2013 obtained from NOAA for the LAWMA Amerada Pass Station, Louisiana

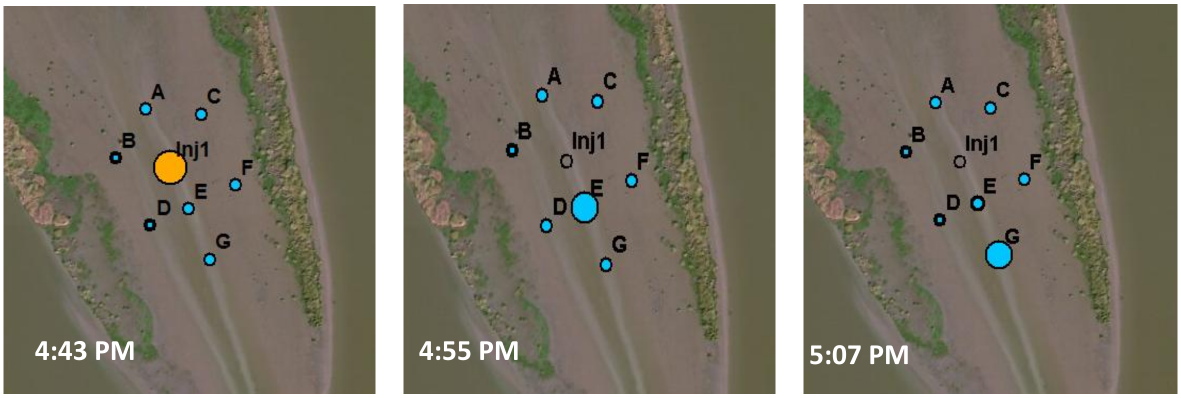


Figure 4. Map showing the time of injectio , detection by Sensor E, then Sensor G, for Tracer Analysis 1.

The tracer progressed down Pintail, through sensor E 12 minutes after injection, and through G around 25 minutes after injection as shown in Figure 4. The tracer seemed to follow a straight line indicating there was little or no lateral dispersion and sensors D and F did not detect Rhodamine. A summary of the study is presented in Figure 4. The presence of the relatively sharp peaks for both sensors E and G suggests water may travel as plug flow for a stable falling tide condition, meaning different parcels of water have little interaction as they propagate through the island. Analysis of Figure 5 reveals that for the duration of the test the wind speed and direction were relatively constant which reinforces that the system was stable and plug flow is likely.

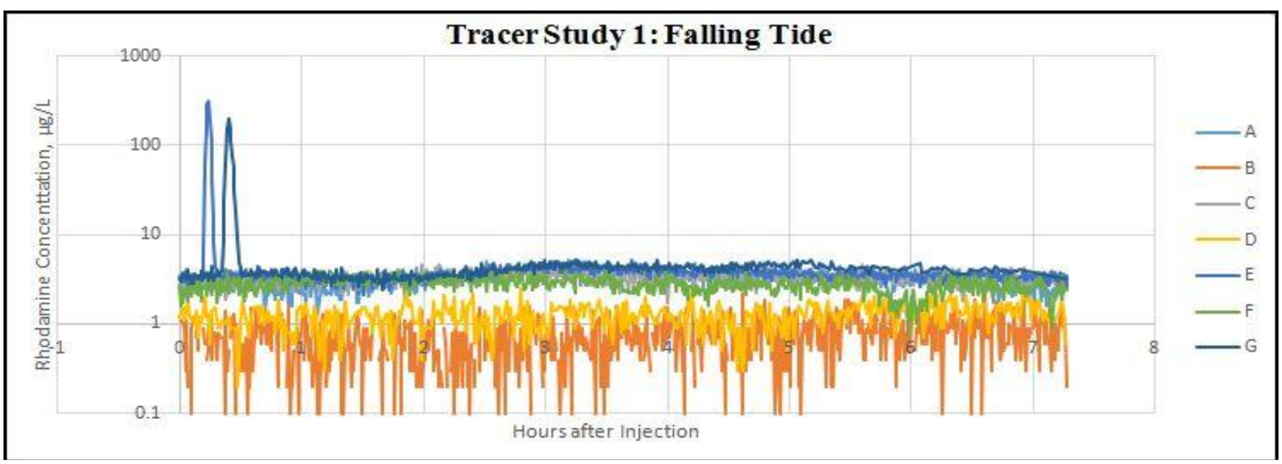


Figure 4: Summary of first tracer study

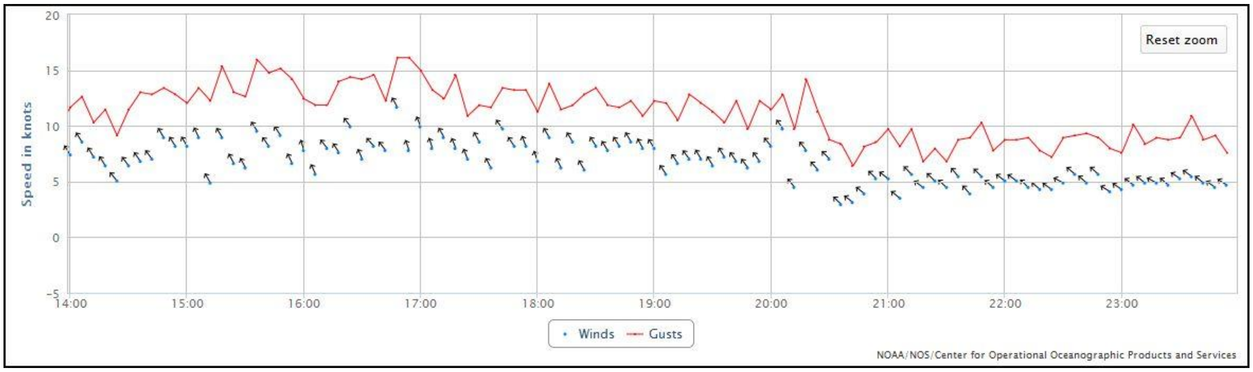
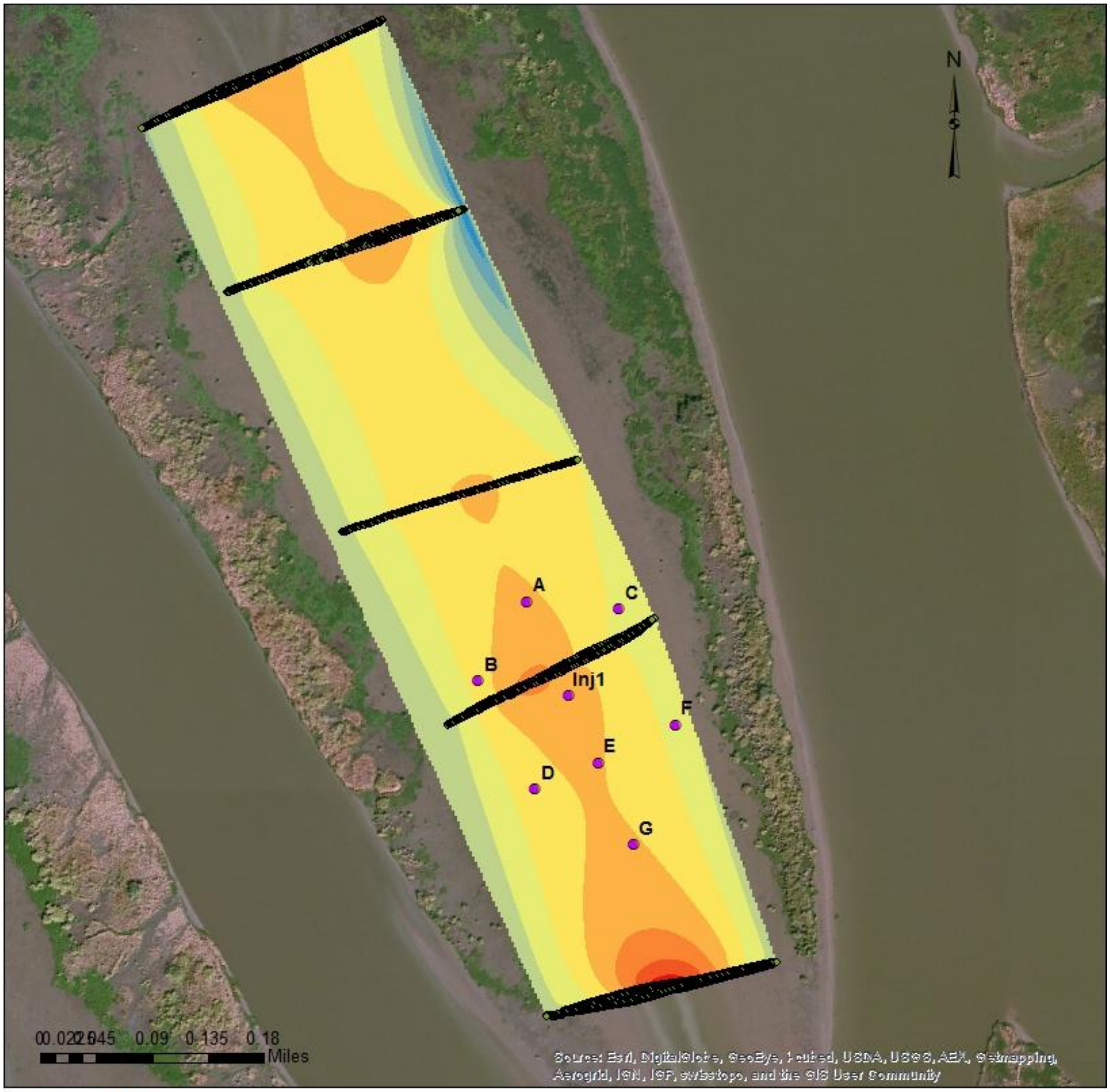


Figure 5: Wind speed and direction for the duration of the tracer test obtained from NOAA

Water depth surveys were taken across the island during a falling tide and are shown in Figure 6. The nearest neighbor interpolation of the data reveals that depths are highest toward the middle of the island going towards the outlet. Shallower depths were recorded closer to the edges of the island which is expected as the edges of the islands comprise both heavily vegetated land cover closer to the top of the island and submerged levees down the sides that direct flow. This can be seen in Figure 2a more clearly, where there is more “green” at the top of the island, however, there are times throughout the year where Pintail and the islands throughout WLD are much more inundated.

The distance between the injection and the outlet at sensor G is about 184 meters. Total rhodamine travel time from injection to G was about 25 minutes. The velocity, calculated as the distance from the injection point to G over the travel time, is about 12.9 cm/s. The velocity is relatively fast for an island that is situated more “inland” in a delta (as shown in Figure 1) [2].

A combination of channel morphology and environmental forces could contribute to the increased velocity in the channel. The depths shown in Figure 6 indicate that islands could essentially “channel” the flow toward the middle and with the additive effect of a falling tide versus a rising tide the velocity values are increased. Additional studies in island bathymetry would assist in this finding [2]. The directness of flow inspired the new orientation of sensors through the island for the second tracer study.



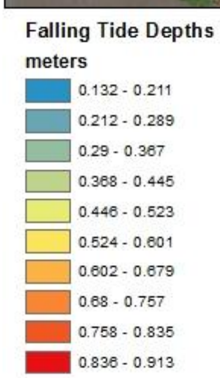


Figure 6: Interpolated depths over the channel using the nearest neighbor method. Acoustic Doppler Current Profilers measured depth and velocity across several transects throughout the island during a falling tide. The sensor orientation of tracer study 1 is also shown.

Second Tracer Study: Rising tide that transitioned to a falling tide

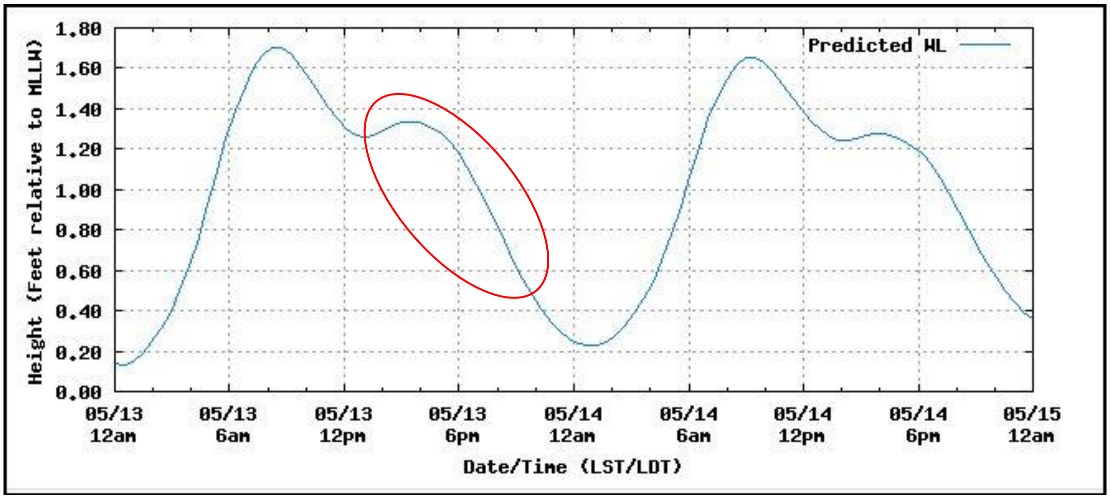


Figure 7: Tide predictions for the tracer test performed on 05/13/13. The red circle indicated the time of the test.

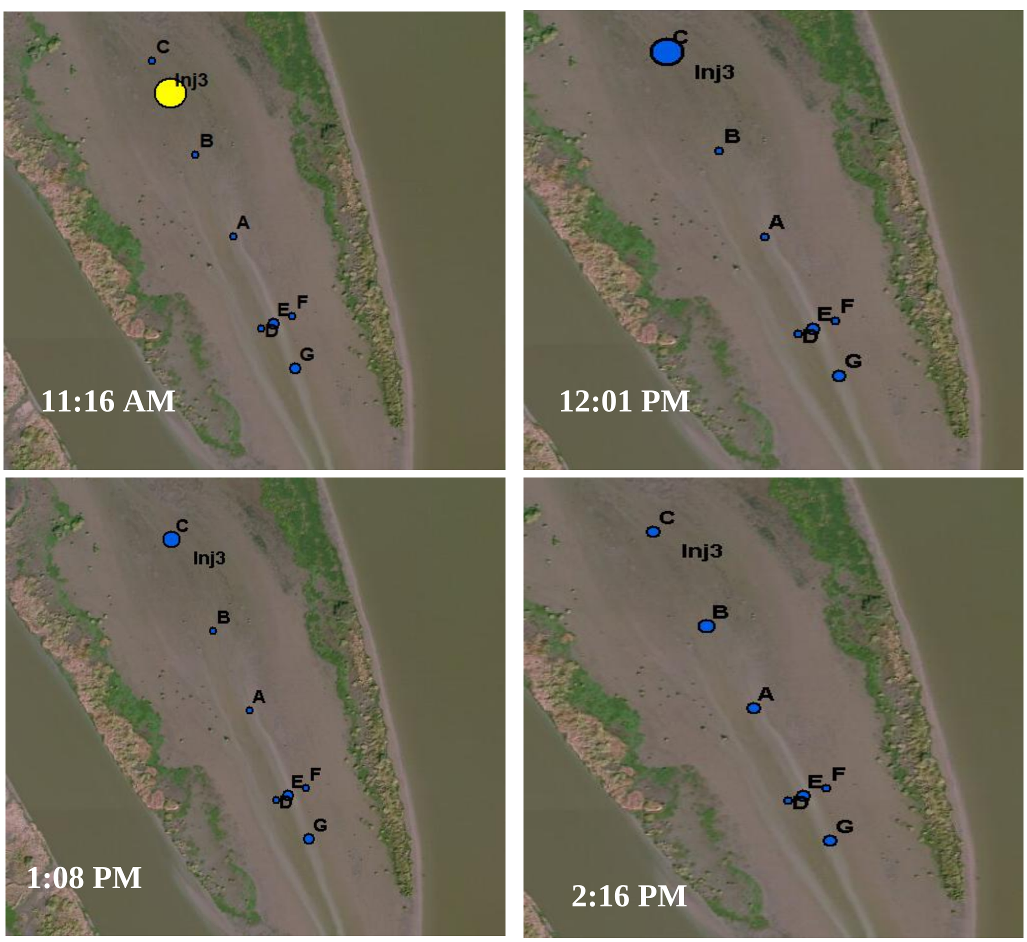


Figure 8: Time series screenshots of second tracer study

The second tracer study took place during a rising tide that transitioned into a falling tide as shown in Figure 7. The test began at 11:16AM and sensor C detected the peak rhodamine concentration 45 minutes later at 12:01PM. The tide begins to turn and the rhodamine begins to move down the island. Sensor C detects a second peak 66 minutes after the first peak (the third picture on the bottom left in Figure 8). Sensor B shows a small peak 181 minutes after initial injection.

Compared to the first tracer study, the tracer propagated much more slowly in this test, even though the distance between the injection and sensor C is shorter than that between the injection and sensor E in the first study. Figure 9 gives a summary of the duration of the study. There is much more dispersion than in test one and the evidence of the 2 peaks is shown for sensor C along with the much smaller peak at B. The figure also shows that sensors A, F, E, and G detected some rhodamine about 6 hours after injection.

The effect of the changing tide contributed to some dispersion as the rhodamine was traveling in one direction and then turned around. According to Figure 10, the wind was also moving perpendicular to the water surface during the time of study which may have contributed some dispersion.

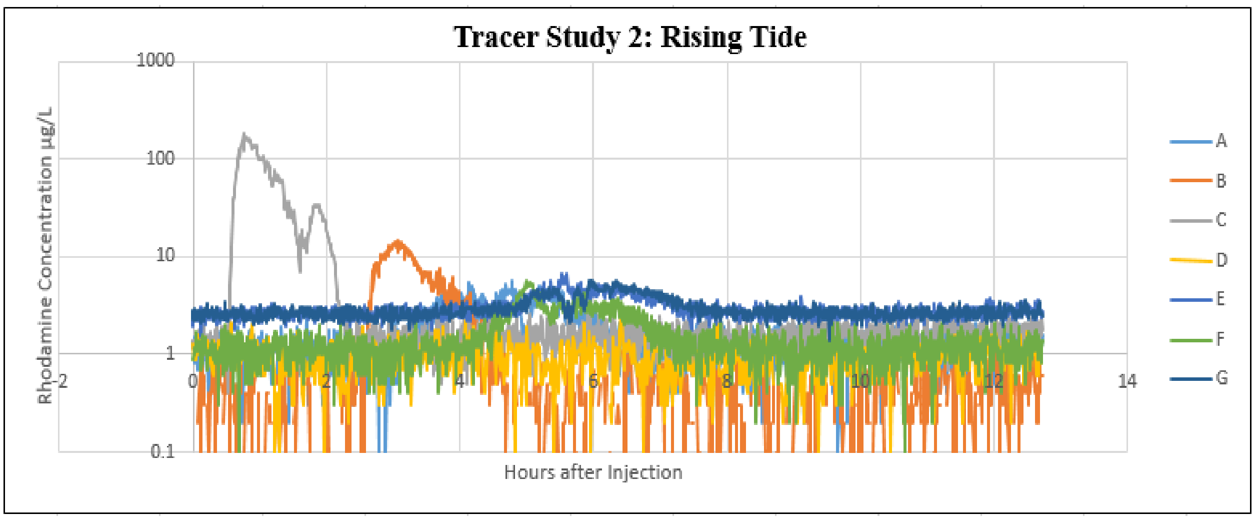


Figure 9: Summary of second tracer study

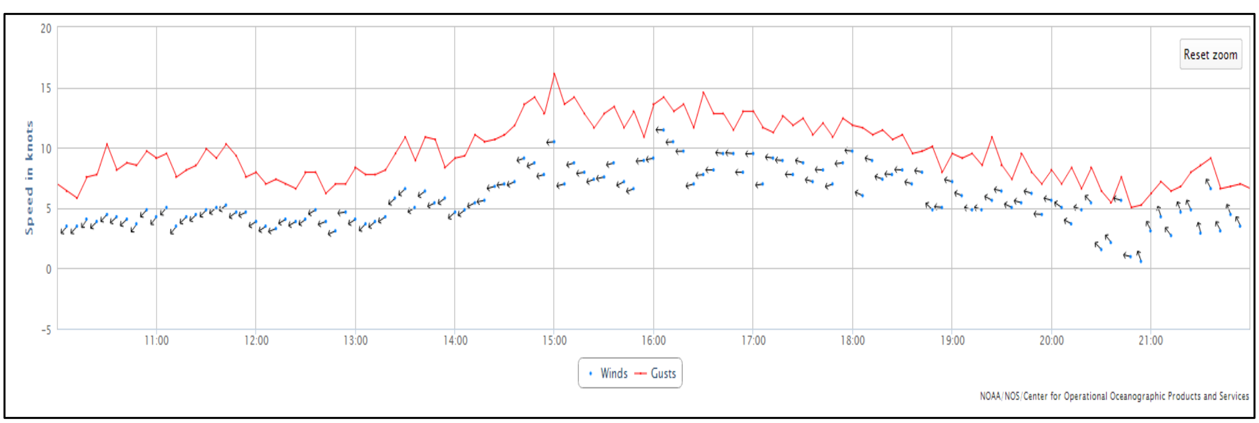


Figure 10: Wind speed and direction obtained from the NOAA wind and tides database for the date of 05/09/13.

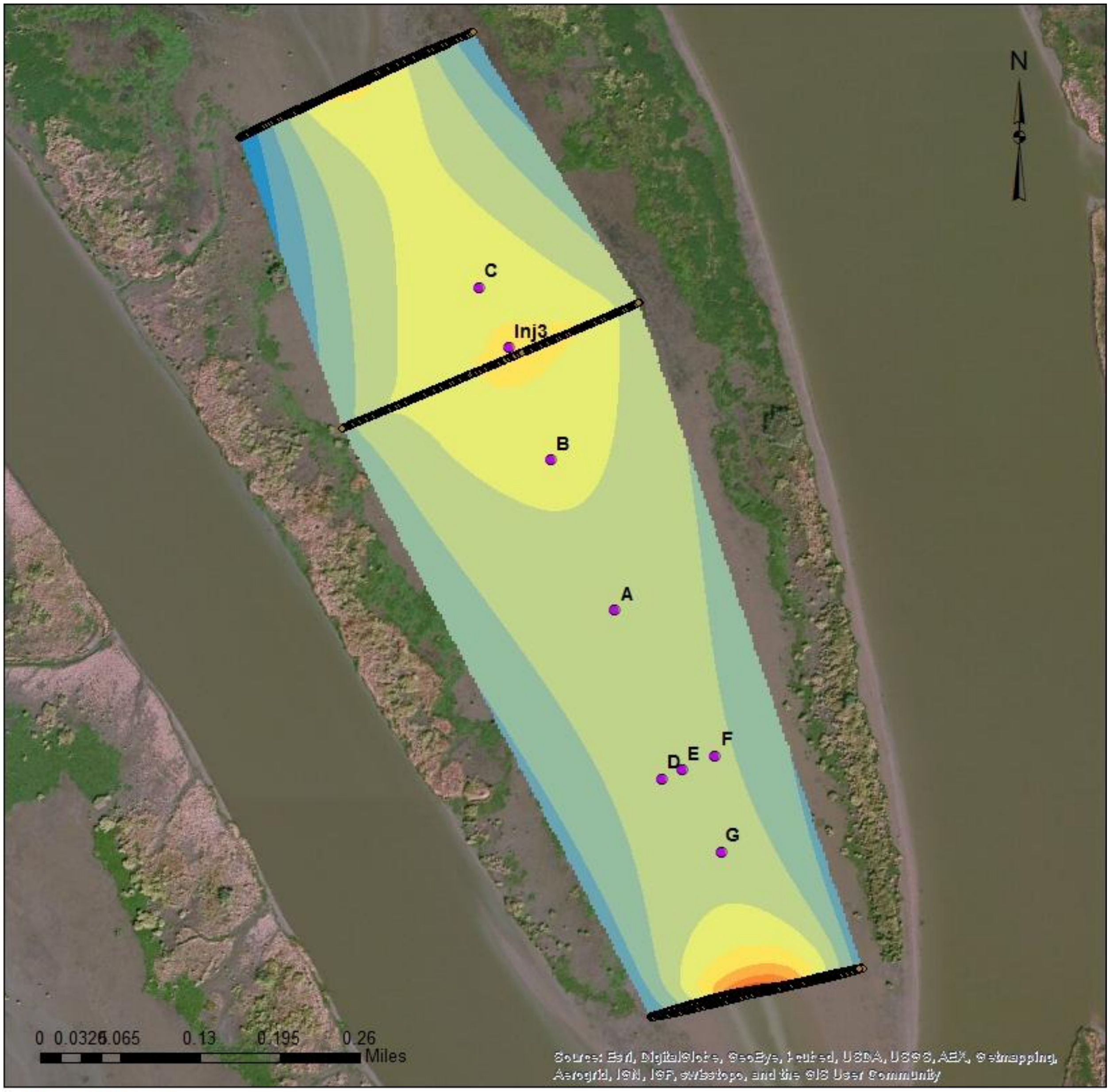


Figure 11: Interpolated depths over the channel using the nearest neighbor method for the second tracer study. Acoustic Doppler Current Profilers measured depth and velocity across several transects throughout the island during a rising tide. The sensor orientation of tracer study 2 is also shown.

Figure 11 shows the interpolation of the ADCP transects for a rising tide. Even though the second tracer test took place over a rising and falling tide, the depths are still indicative of the conditions of the beginning of the test. There are again the higher depths toward the outlet as the island joins the channels. The island sides also slope toward the middle reaffirming that regardless of tidal condition the middle of island is deeper than the sides.

The velocity measured for the first peak seen in sensor C is about 2.8 cm/s. This velocity if almost 6 times slower than the velocity in the first test. If velocity if calculated from the second peak of sensor C to the small peak at sensor B, the value is about 4.9 cm/s. By this time the island was in the falling tide condition which may explain the increase. However there was much dispersion through the test so velocities are more of an approximation.

Figure 12 shows the results of velocity measurements taken across the width of the island. The negative values indicate upstream flow while the positive values are downstream. The results show flow around sensor C moving upstream at a rate of 2.3-2.9 cm/s which agree well with the tracer study finding. The figure also shows an area toward the bottom right where large flows are leaving the island. This could be due to measurement error, or the presence of a small flume of water exiting the island while the tide is rising, which was not in the range of the sensors.

Conclusions

Both tracer tests show that Pintail Island is tidal dependent even though it not directly in contact with the ocean. The differences in flow velocity between the studies are attributed to tide conditions and wind direction. Results suggest that singular events such as storms could change the flow pattern for a time which would also effect nutrient cycling and sediment transport.

The tests indicate that island hydraulic residence time is highly variable which has several implications in nutrient cycling and delta evolution. If Delta islands are moving water and nutrients quickly through the system, there is likely a decrease in denitrification since plants and soils are not in contact with the water long enough for significant removal to occur. As seen in the Mississippi Delta, this could lead to an hypoxic zone that forms due to large nutrient outwash into the ocean. Understanding the island system processes will highlight the mechanisms that can prevent ecosystem degradation in coastal communities.

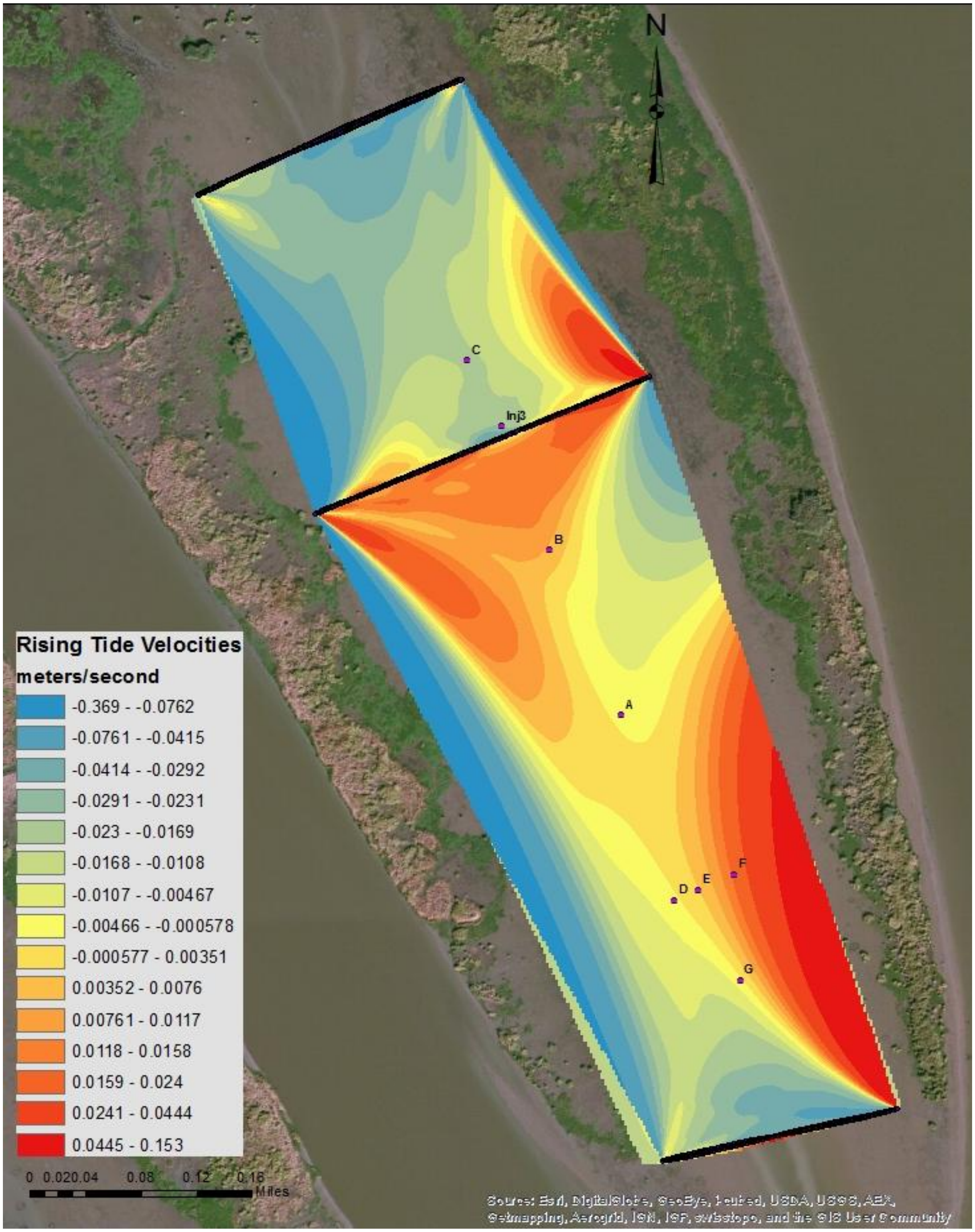


Figure 12: Interpolated velocities over the channel using the nearest neighbor method for the second tracer study in a rising tide. The sensor orientation of tracer study 2 is also shown.

Suggestions for Mike Island tracer study

The tracer studies on Pintail provided insight into island hydrodynamics and the relationship between the island and the surrounding channels and tides. Additional research includes investigating other islands to observe whether similar interactions exist such as those on Pintail or whether there are entirely different forces influencing the delta system. In this regard, this study investigated differences between Pintail and Mike Island to make informed suggestions for a tracer study on Mike Island.

Figure 13 shows hand drawn approximations of Pintail and Mike Island using the Editor toolbar in ArcGIS. Land area was taken from these approximations that include both the land and the water that inundate the islands and is also shown in Figure 13. Mike Island is about 5 times the size of Pintail Island and has a more variable structure with channels cutting though Mike in Figure 13 and Figure 1. Additionally, Mike is in direct contact with the ocean so it is expected that Mike will be even more tidally influenced than Pintail Island was.

A LANDSAT Image from USGS was downloaded and input into ArcMap. Using image analysis, the NDVI function or the Normalized Difference Vegetation Index was employed that calculates where vegetation occurs based on visible and infrared imaging. The NDVI function was used to distinguish vegetation from the water surface to get an approximation of the water area other than through pure observation. The image was georeferenced and overlaid over the delta from the Bing Basemap in ArcMap and traced using the editor toolbar to obtain a water area measurement. Figure 14 shows the USGS image pre and post processing using the NDVI. The results of the water area assessment are shown in Table 3.

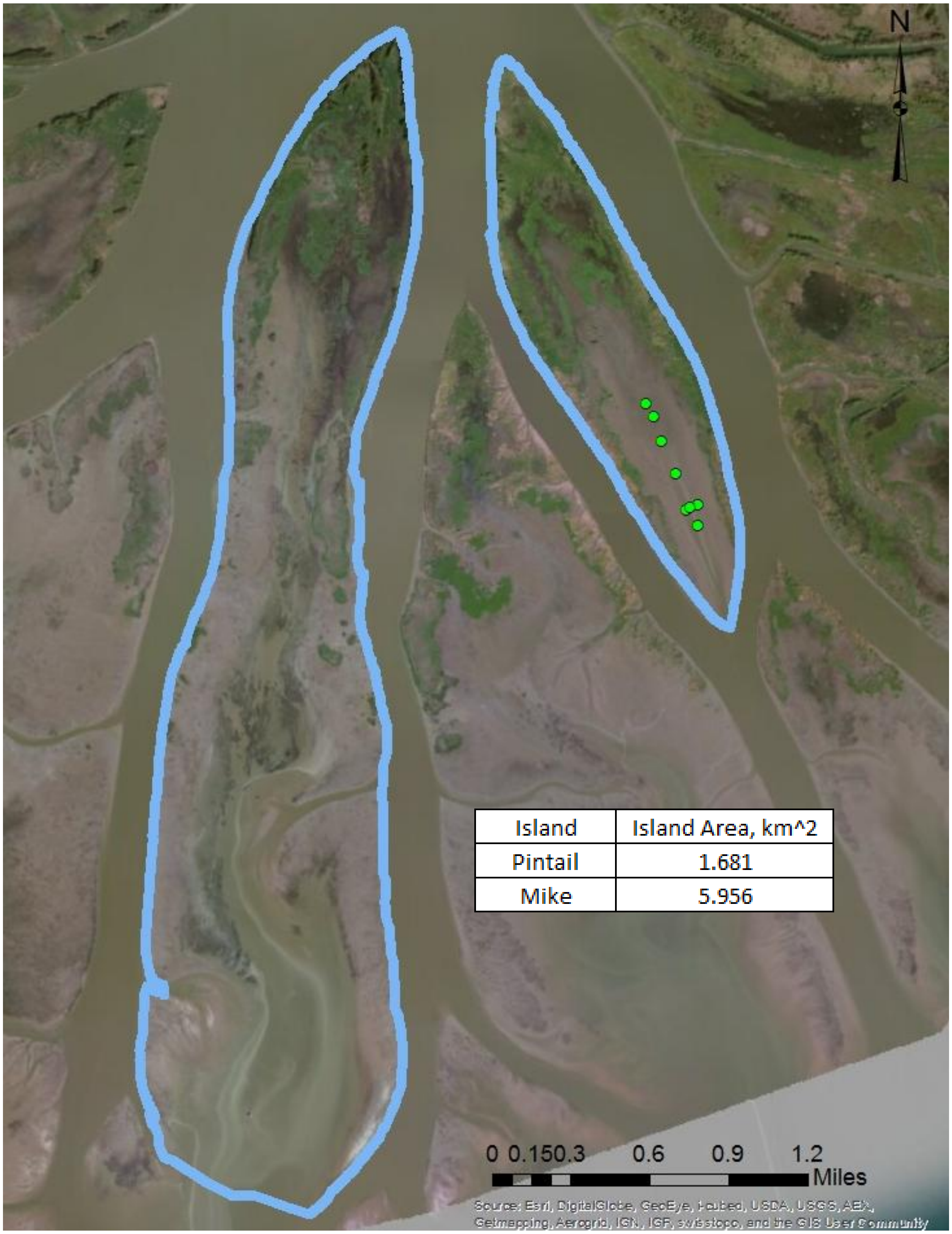
Table 3: Water Area for Mike and Pintail Island

Island	Water Area, km^2
Pintail	0.473
Mike	2.289

The results suggest that water area on Mike Island is about 5 times as much as on Pintail Island. For the study, the author recommends using more sensors throughout the length of the island. Ten sensors rather than seven would allow for additional capture of rhodamine and could cover the larger area of Mike. Sensors could be placed in a relatively straight path down the island with various sensors placed lateral especially toward the bottom as the island approaches the ocean. A suggested layout is provided in Figure 15.

Report Conclusions

This project showed the versatility in GIS in investigating and visualizing time-dependent delta studies to draw conclusions about the natural world. Information was able to be linked spatially and temporally in a visual medium that measured interactions between complex system processes.



Island	Island Area, km^2
Pintail	1.681
Mike	5.956

Figure 13: Mike Island on the left and Pintail Island on the right along with a table of land area calculated in GIS.

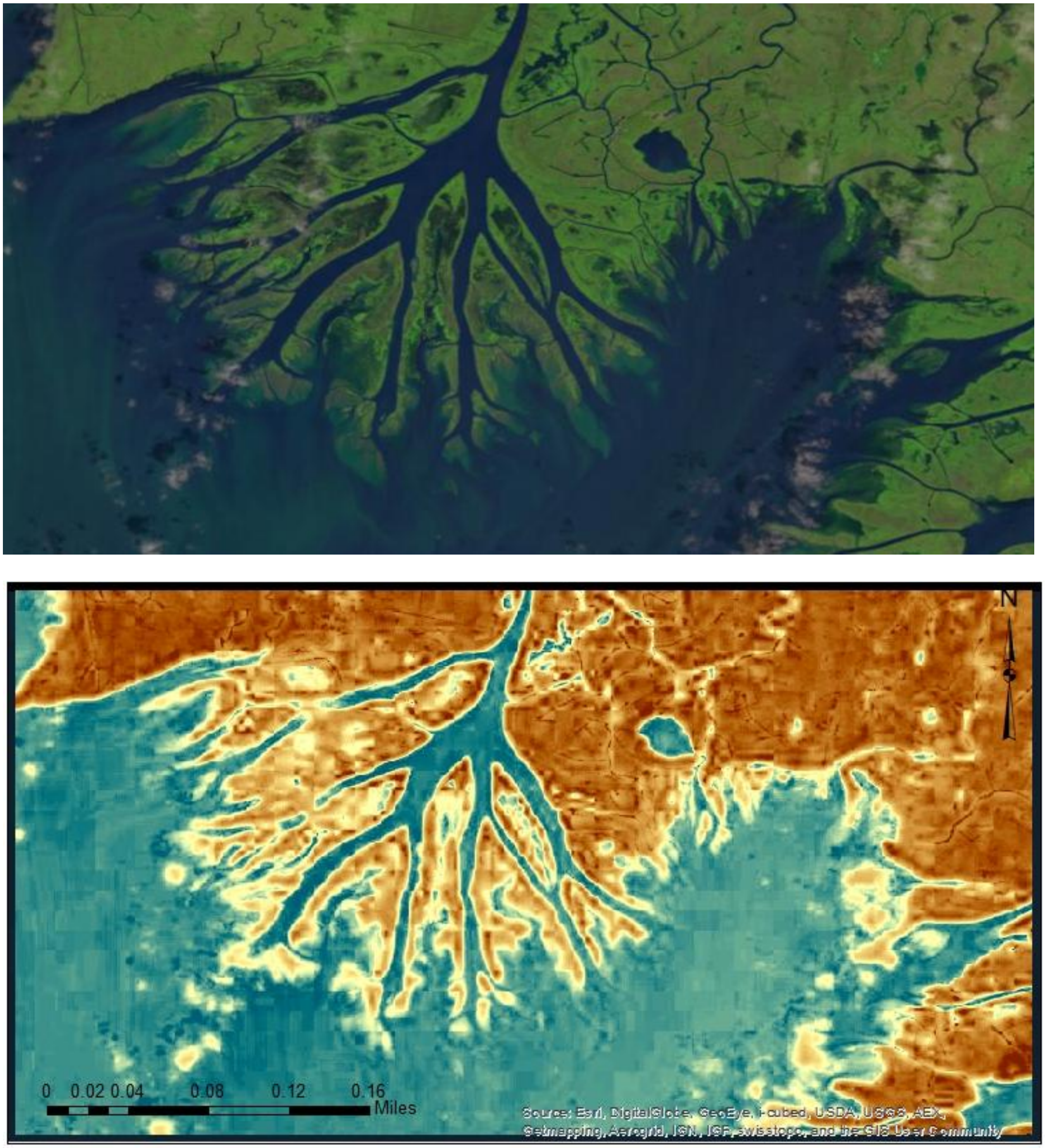


Figure 14: The top image shows WLD obtained from the USGS LANDSAT imagery. The bottom image shows the results of the NDVI analysis.

Figure 15: Suggested sensor locations for a Mike Island tracer study, shown as the white circles.

References

Images from the USGS LANDSAT http://landsatlook.usgs.gov/

NOAA Tides and Currents: http://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels

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Acknowledgements

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