Sedimentation in Aquilla Lake

Hill County, Texas

by Lorena Roque Martinez, GIS and GPS Applications in Earth Sciences (GEO 327G)

Introduction

The Texas Water Development Board (TWDB) is in charge of offering financial assistance, planning, technical services, information and education for the conservation and development of water for Texas. As a part of those responsibilities, the TWDB's Hydrographic Survey Program has completed 161 lake surveys since 1992.

These surveys give information on storage capacities, rates of sedimentation, and sedimentation levels within reservoirs. The lake surveys develop bathymetric maps and tables with capacities and surface areas for each elevation. To produce these deliverables, the TWDB uses a multi-frequency sub-bottom profiling depth sounder, most frequently called a multibeam. While mounted on a boat, the multibeam emits soundwaves and records the time it takes for the waves to travel from the instrument to the bottom of the lake floor and back to the receiver. The times recorded can then be translated to depths. While the boat follows pre-determined survey lines, usually 500 feet apart, the multi-beam receives bathymetry data while simultaneously, through GPS, tracking the location of the soundings.

Once data is collected for depths and location, a map is produced that connects all points of equal elevation and surface areas are calculated each tenth of a foot from these bathymetric lines. Once surface areas are calculated, volumes at each elevation are calculated using the formula:

$$V= (½) H (A_1 + A_2)$$

Where: V= volume of water,
H = difference in depth between two consecutive depth contours,
A_1 = area of the lake within the outer depth contour being considered,
A_2 = area of the lake within the inner contour line under consideration,

as described in Taube (2000).

Aquilla Lake is located in Hill County at river mile 23.3 of Aquilla Creek and approximately 7 miles southeast of Hillsboro, Texas. The lake has a drainage area of 252 square miles (Figure 1).
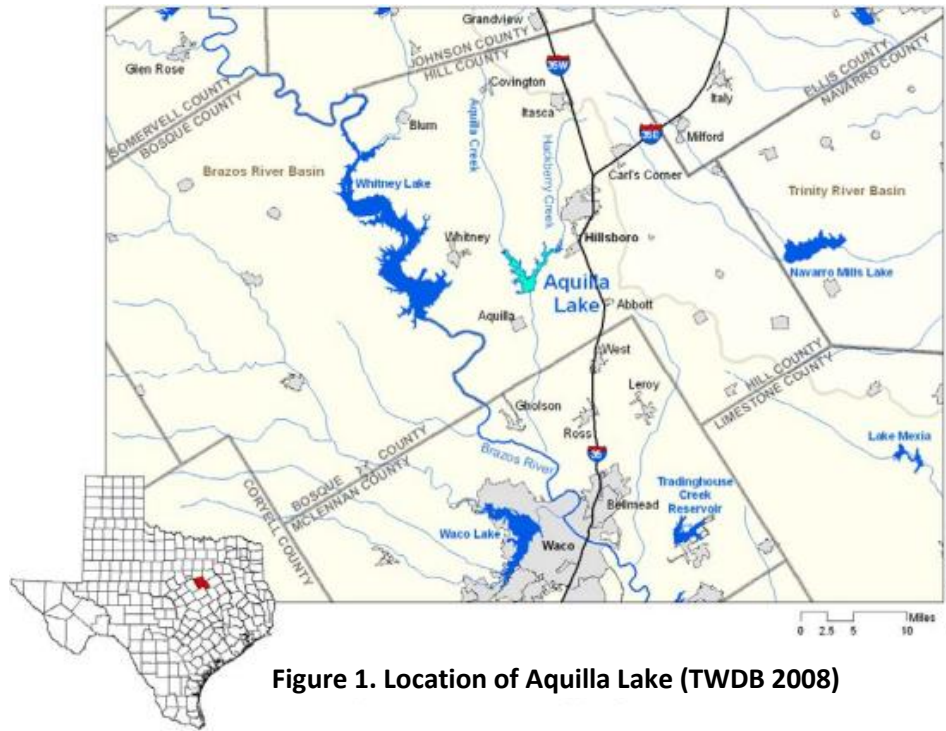

Figure 1. Location of Aquilla Lake (TWDB 2008)

Objectives

The specific objectives of this study area to (1) visualize sedimentation occurring in the lake from survey to subsequent survey and overall from earliest to latest survey and (2) to determine the percent error in calculating storage capacity directly from bathymetry data as opposed to the TWDB method described above. The method for visualizing sedimentation is to create bathymetry rasters for every survey and use the raster calculator to create a sediment thickness raster. The method to calculate storage capacities is to use the Surface Volume tool in the Spatial Analyst Toolbox to calculate the volume below the conservation capacity elevation (537.5 feet for Aquilla Lake). Aquilla Lake was chosen for this project as it is one of the reservoirs that has been surveyed the most. Aquilla Lake has been surveyed the years of 1995, 2002, 2008, and 2014.

With state population and water use projected to increase by 82% and 22%, respectively in 50 years (TWDB 2012) and the potential for droughts like the one in 2011 that brought about historically low reservoir levels (Scanlon 2013), estimates of reservoirs storage for water planning purposes are essential.

Data Collection

Both vector and raster data were used in this project to determine bathymetry and boundaries.

The TWDB offers shapefiles of all the survey data for free on their website. The dropdown menu for Aquilla Lake reveals all 4 surveys and their respective immediate download shapefiles.

http://www.twdb.texas.gov/surfacewater/surveys/completed/list/index.asp

The specific shapefiles used for each survey were:

- 1995
  - Boundary (polygon)- aql_lk_poly_interpolated.shp
  - Survey Points- Aquilla95_AEIDWpts4.shp
- 2002
  - Boundary (polygon)- Aquilla02_Lake95_edited.shp
  - Survey Points- Aquilla02_AEIDWpts.shp
- 2008
  - Boundary (polyline)- Aquilla08_1ftcontr.shp
  - Survey Points- Aquilla08_AEIDWpts.shp
- 2014
  - Boundary (polyline)- Aquilla14_375p5cont.shp
  - Survey Points- Aquilla14_AEIDWpts_4vol.shp

Data Preprocessing

Most of the work for this project was preparing the data for analysis. The boundary files had gaps and other topological errors that were corrected. The survey point files were converted to TIN files then finally to rasters in order to use the raster calculator to create sediment thickness maps. Detailed steps are described below:

1. All eight shape files had the same defined projection, NAD83 State Plane FIPS 4202. But none had the vertical datum specified so I defined them all as NGVD29, as specified in the survey reports by the TWDB (TWDB, 2009).

2. Polygon shapefiles for boundaries are needed to set processing extents and masks. However, the 2008 survey had no boundary, but did include a 1ft contour file. In order to create a boundary, I chose 538 ft as my contour because it was the closest to the conservation capacity elevation of 537.5 feet. I selected all 538 contour lines using the Select By Attribute window from the Attribute table (Figure 2), and exported the data. Now, I had a polyline shapefile of the contour I wanted.
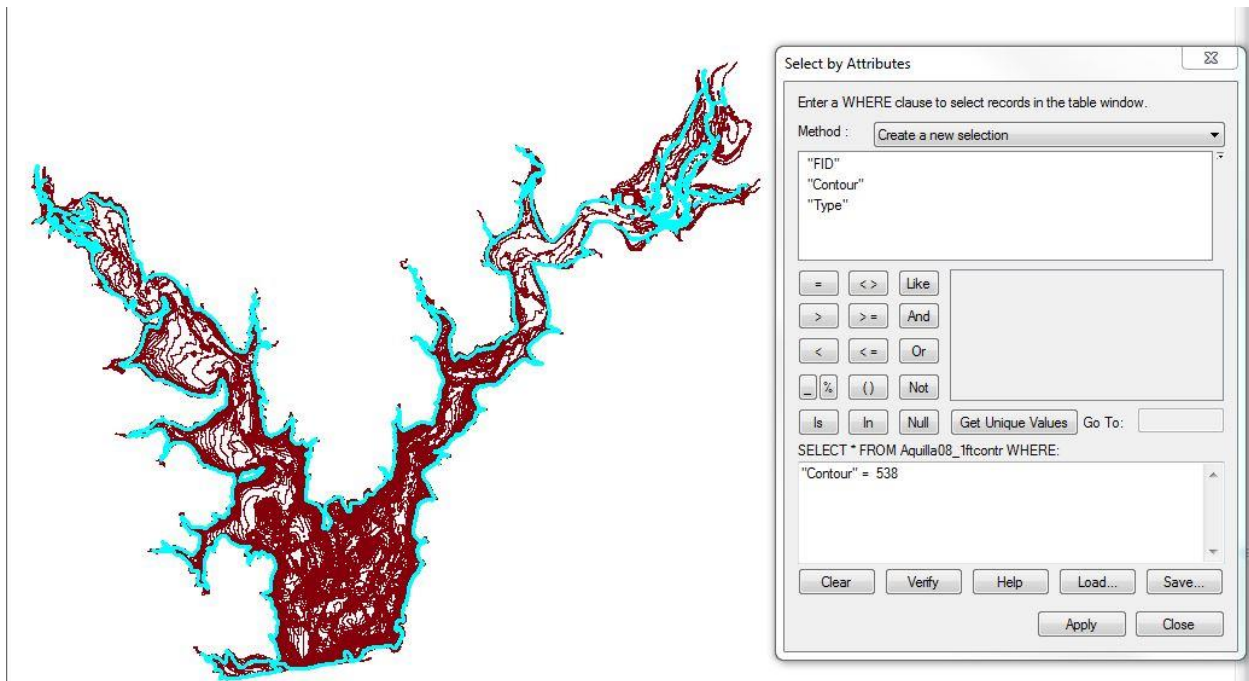
Figure 2. Selecting the 538 feet contour lines to export in order to create a polygon of the lake boundary.

3. Now that I had appropriate lines and polygon shapefiles for boundaries, I created feature datasets in personal geodatabases for each survey in order to ensure topology was enforced as some shapefiles had gaps and intersections. I had to do this before using the Feature to Polygon tool to make sure I would get the boundary file I needed.
    a. First, I created personal geodatabases for each survey year.
    b. Then, I created a feature dataset in order to enforce topological rules to make editing easier and error-free.
    c. Finally, I imported the polyline or polygon shapefiles for boundaries
4. Now that I had imported the boundaries, I created a new topology for each survey's feature dataset.
    a. For polyline boundaries, I added the rules in Figure 3. Figure 4 shows an error in the topology.

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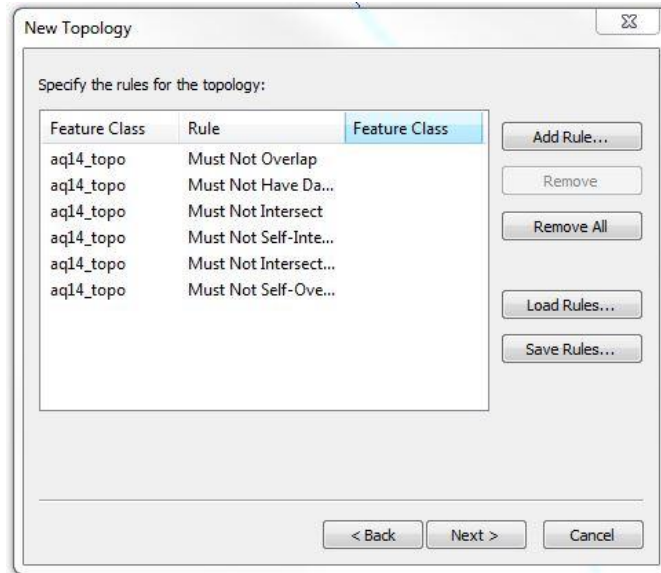
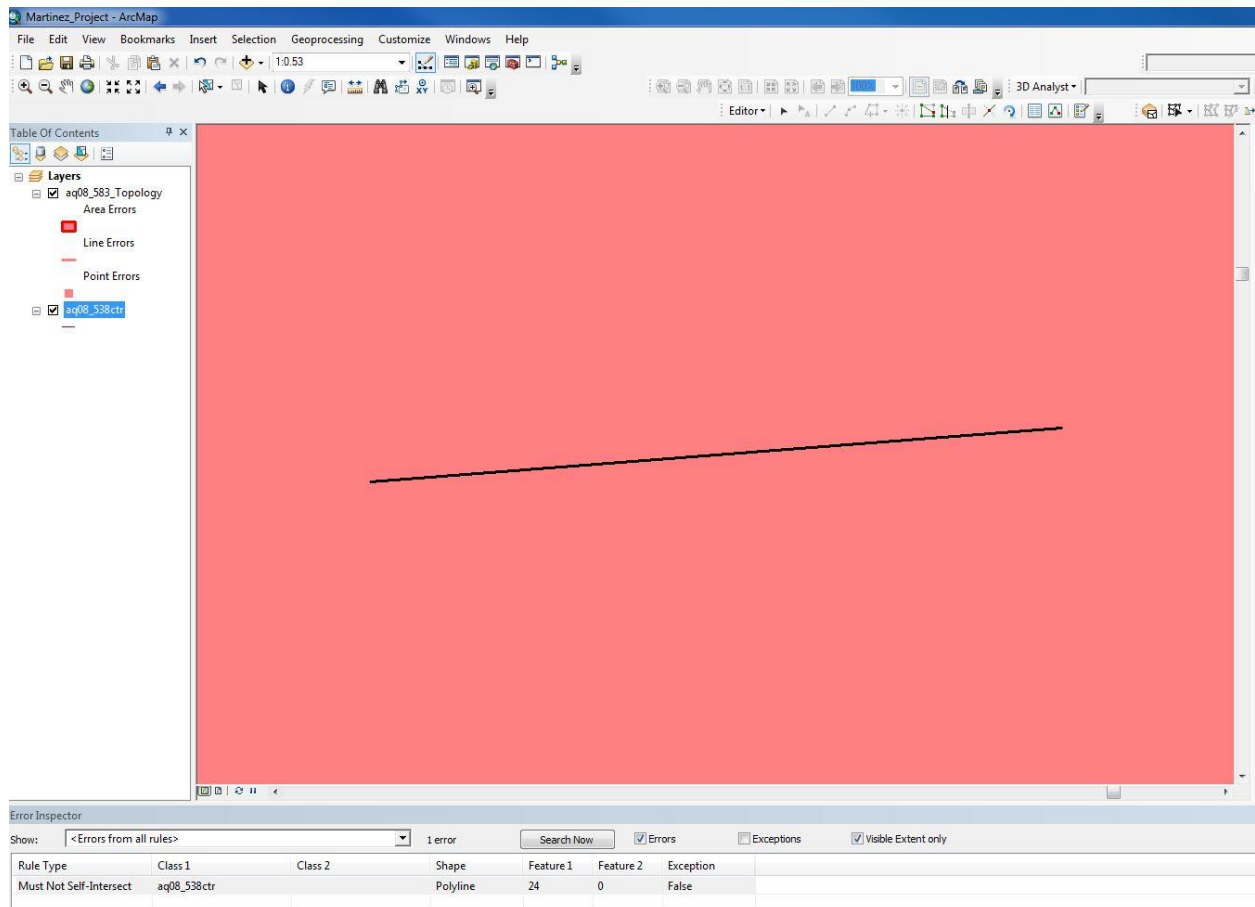**Figure 3. Topological rules added to polyline boundary files**

Figure 4. Topology error "Must Not Self-Intersect"

b. For polygon boundaries, I added the rules in Figure 5. And was able to detect little islands and delete them completely so as to have holes and none outstanding islands outside of the main boundary. Figure 6 shows the topology rules added to polygon shapefile boundaries. The topology tool was great for the polygon files as they often had islands, so I was able to delete them out by simply selecting the biggest polygon from the "Select By Attribute Table" and deleting the rest (Figure 6)
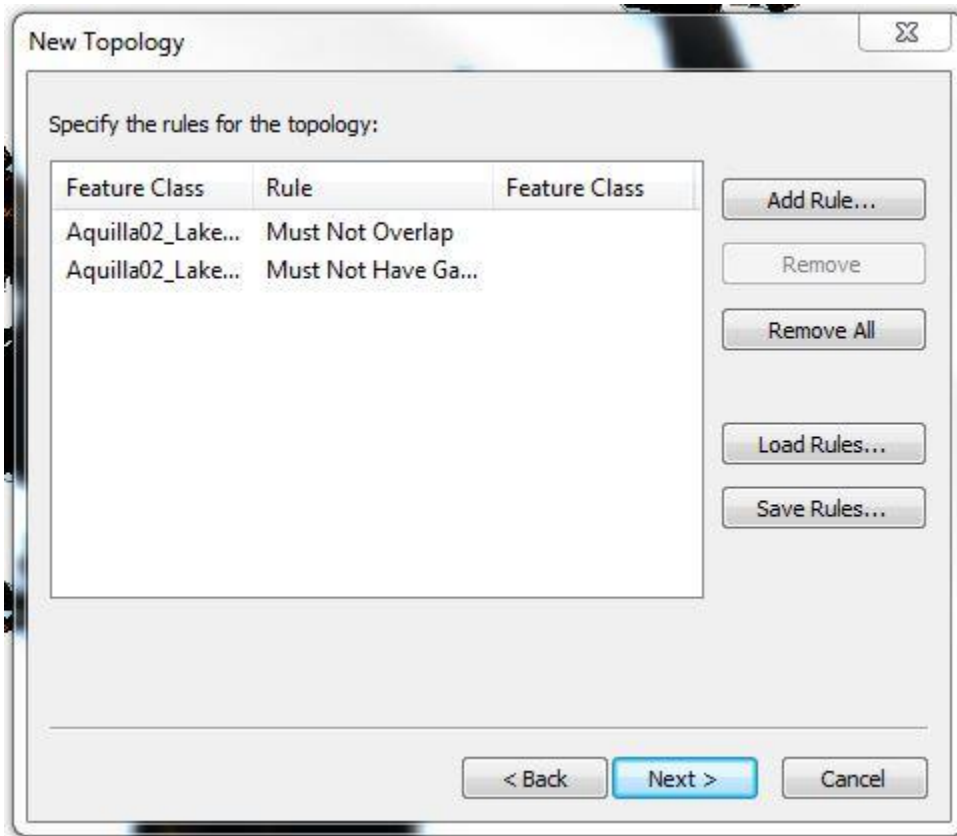
Figure 5. Topology Rules added for polygon boundary shapefiles.
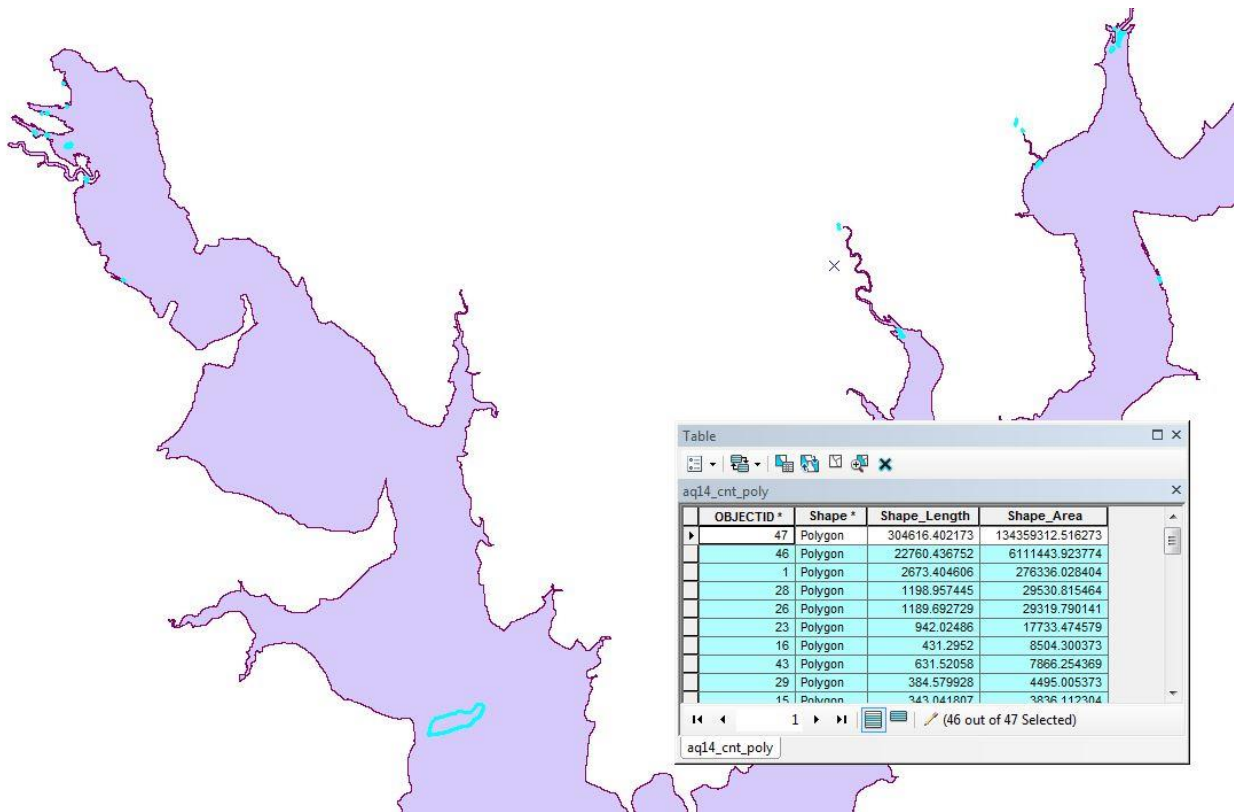
Figure 6. All polygons but the largest one (not selected) are deleted so as to have one polygonas the boundary with islands as holes.

5. After enforcing topology and fixing errors, the polyline boundary files could be converted into polygons using the Feature to Polygon tool.
6. Now that my boundaries were set, I could start working with the point files.
7. Create TIN from point files
   a. Using the Create TIN tool, I uploaded the point file needed and set my parameters as such:
      i. Processing extent: respective boundary polygon shapefile
      ii. Mask: respective boundary polygon shapefile
      iii. I also uploaded the boundary file to the input features in the tool in order to incorporate the boundary as "Mass Points", meaning TIN would use the boundary (really, a 537.5 elevation contour) as elevation points that would be imported as nodes (Figure 7). As an example, Figure 8 uses the boundary as masspoints while Figure 9 does not. Figure 8 bathymetry shows the island present while Figure 9 without the mask, does not.

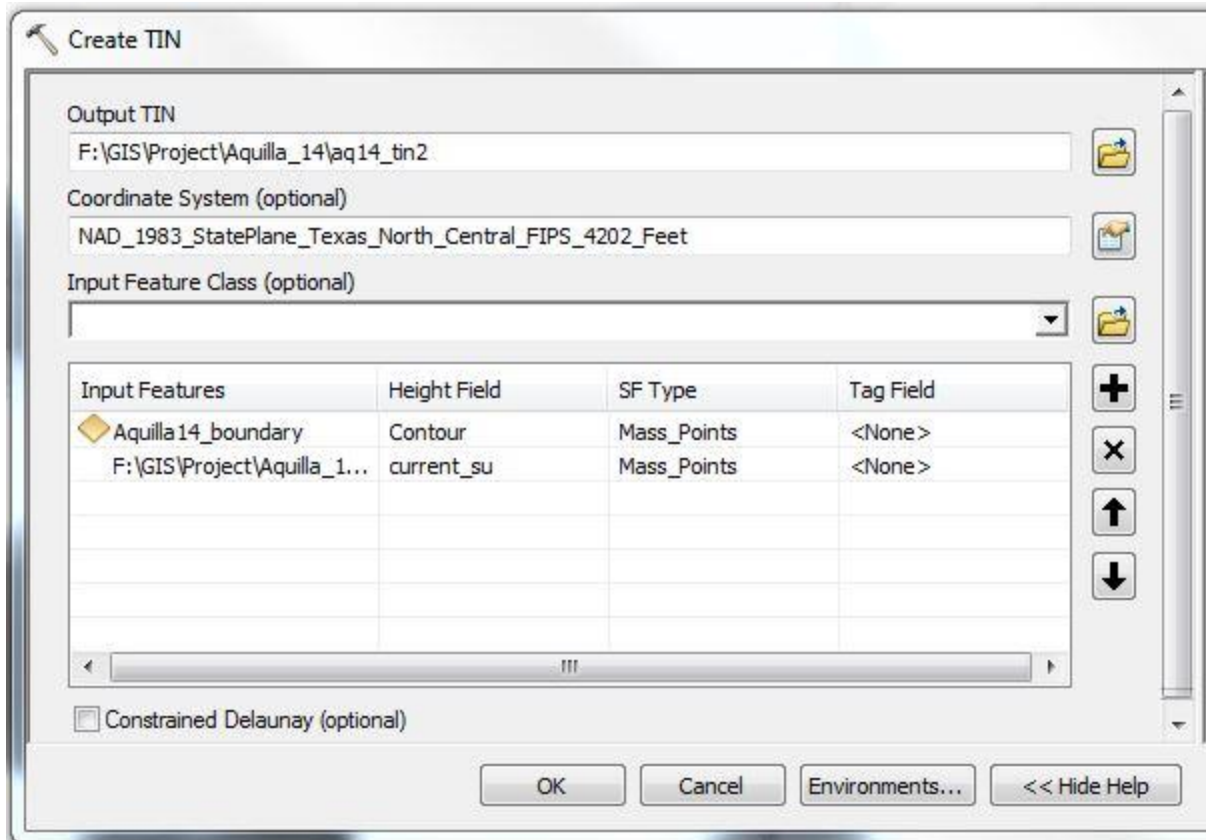Figure 10 shows a completed TIN for Aquilla Lake from survey year 2014.
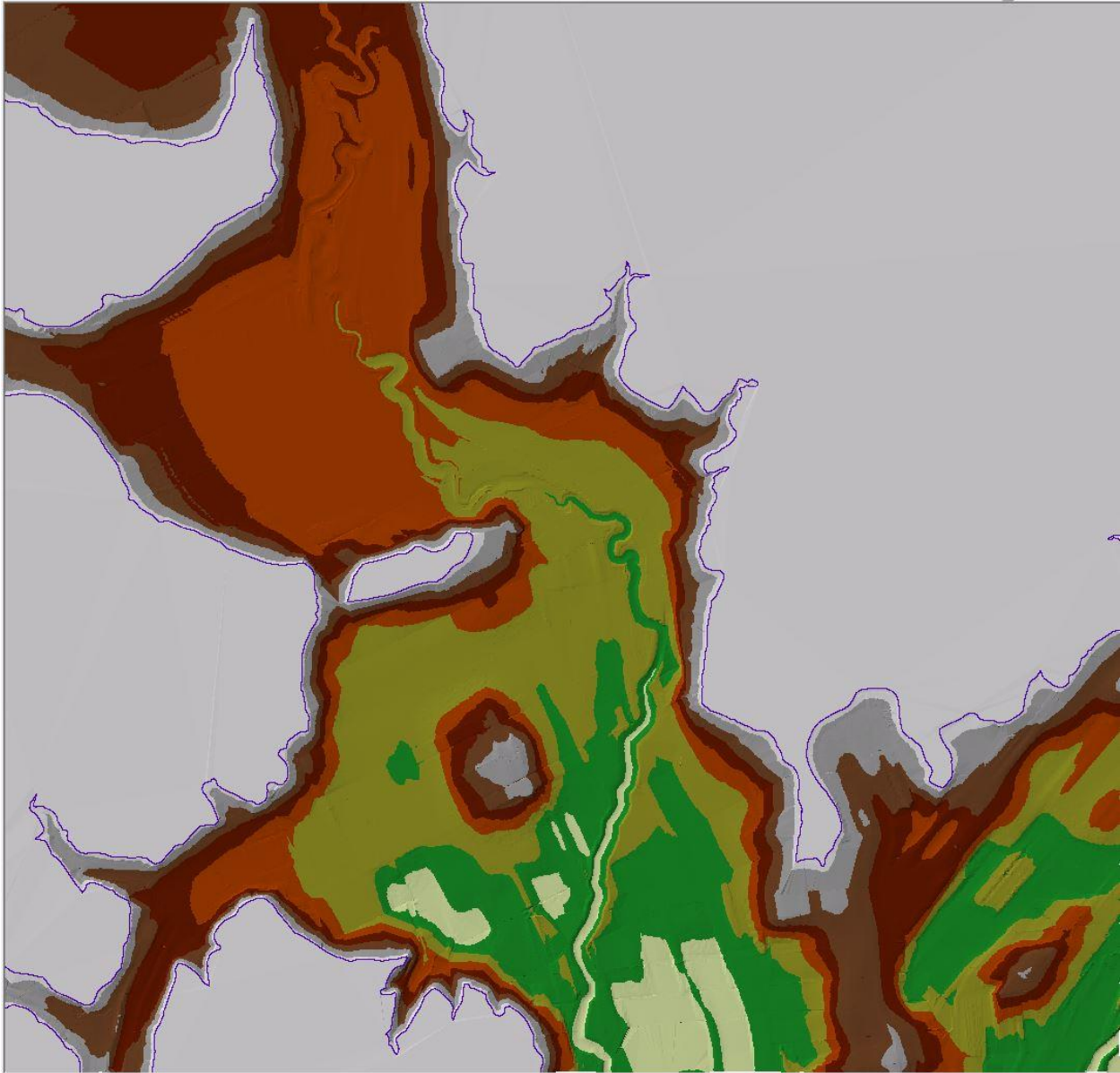
Figure 7. Create TIN set up

Figure 8. The boundary file is incorporated as mass points and appropriately excludes the island from the TIN
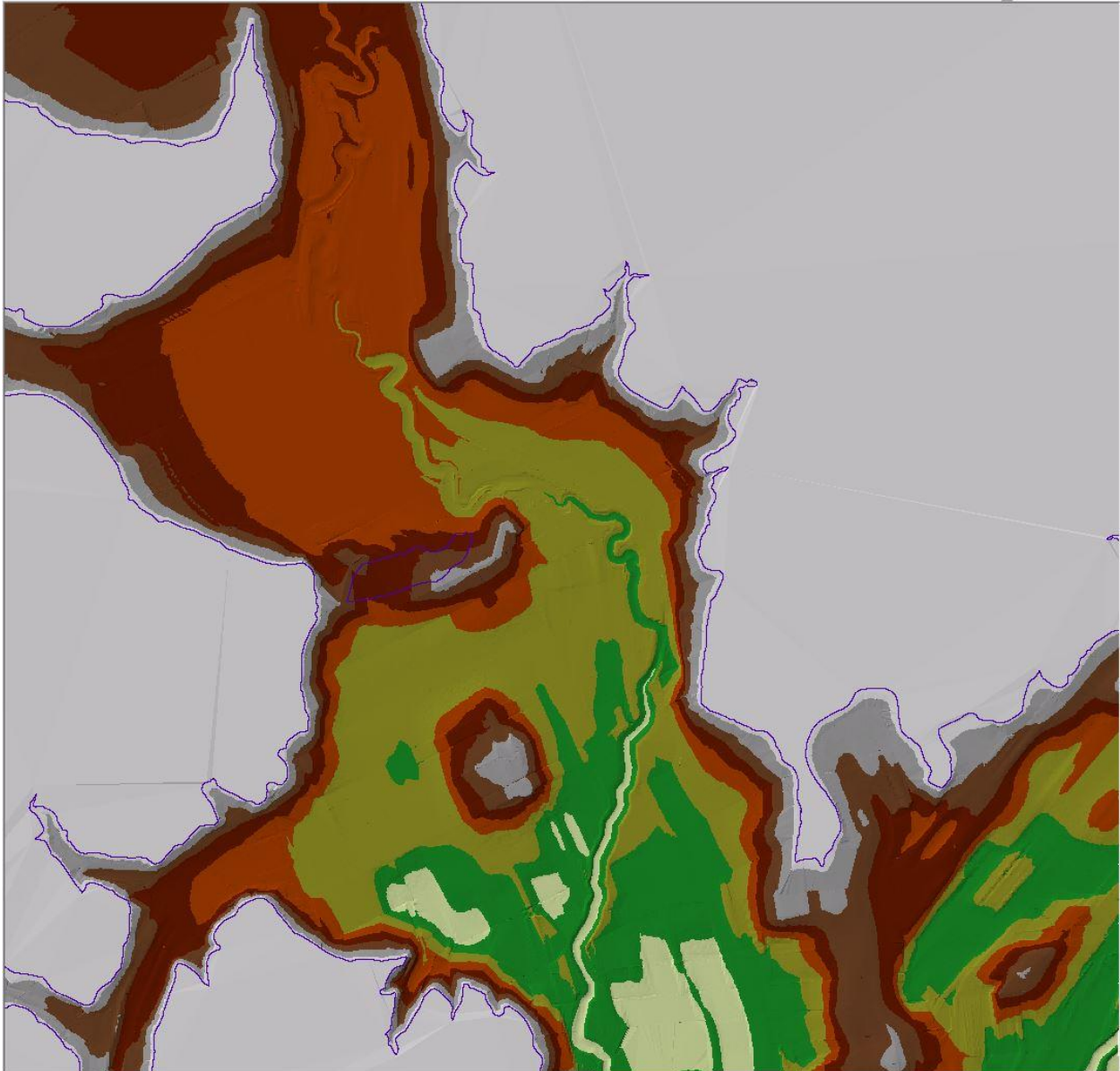
Figure 9. The boundary file is not incorporated as mass points therefore missing the island present.
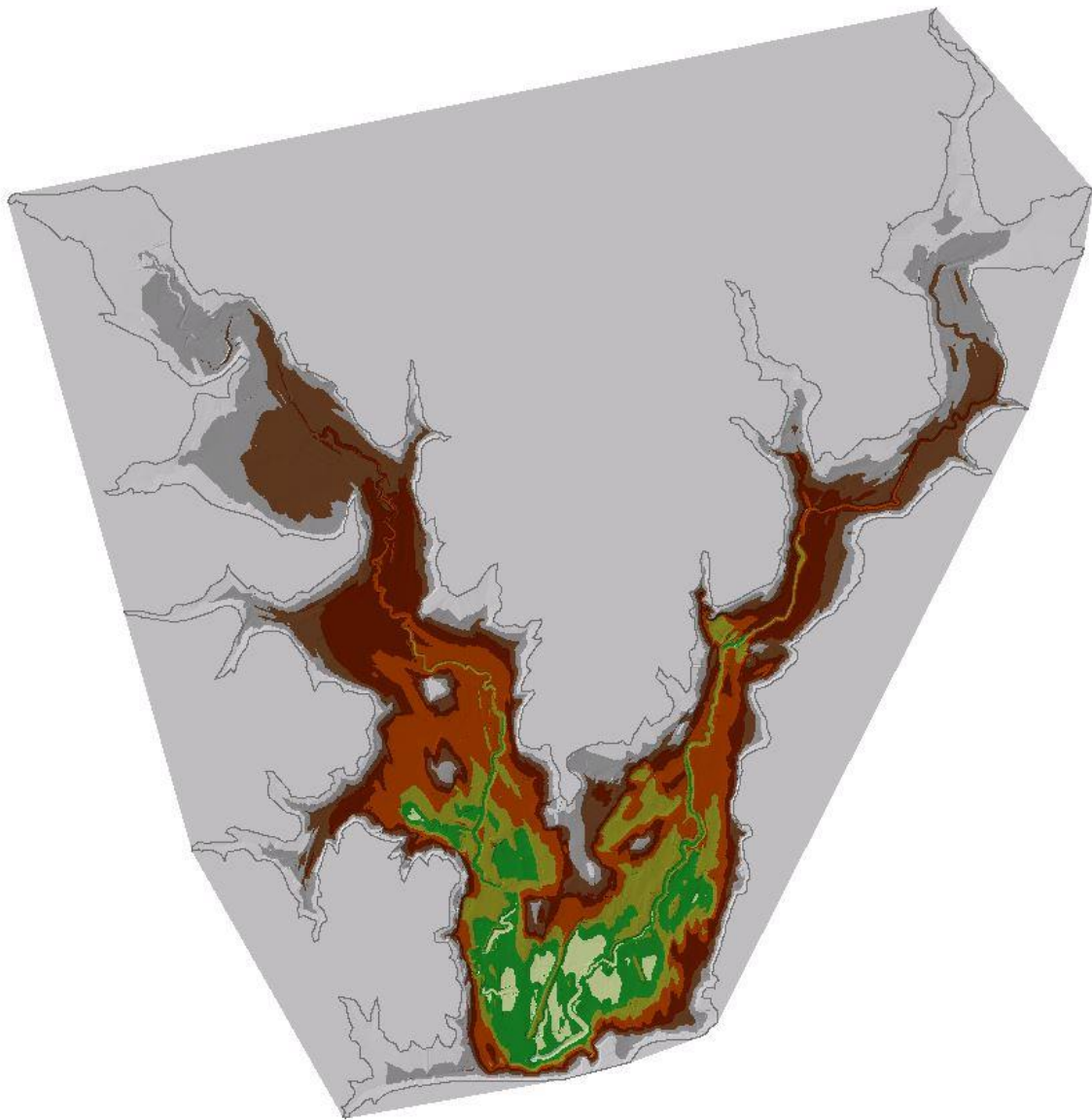
Figure 10. Completed TIN model for Aquilla Lake survey year 2014

8. Convert TINs to rasters.

   Parameters (Figure 11):

   a. Processing extent: respective boundary polygon shapefile
   b. Mask: respective boundary polygon shapefile
   c. Output data type: float
   d. Method: Linear
   e. Sampling distance: cellsize 10 feet

Figure 12 shows the raster with parameters specified above while Figure 13 shows default values. Figure 14 is the resulting raster for Aquilla Lake survey year 2014.
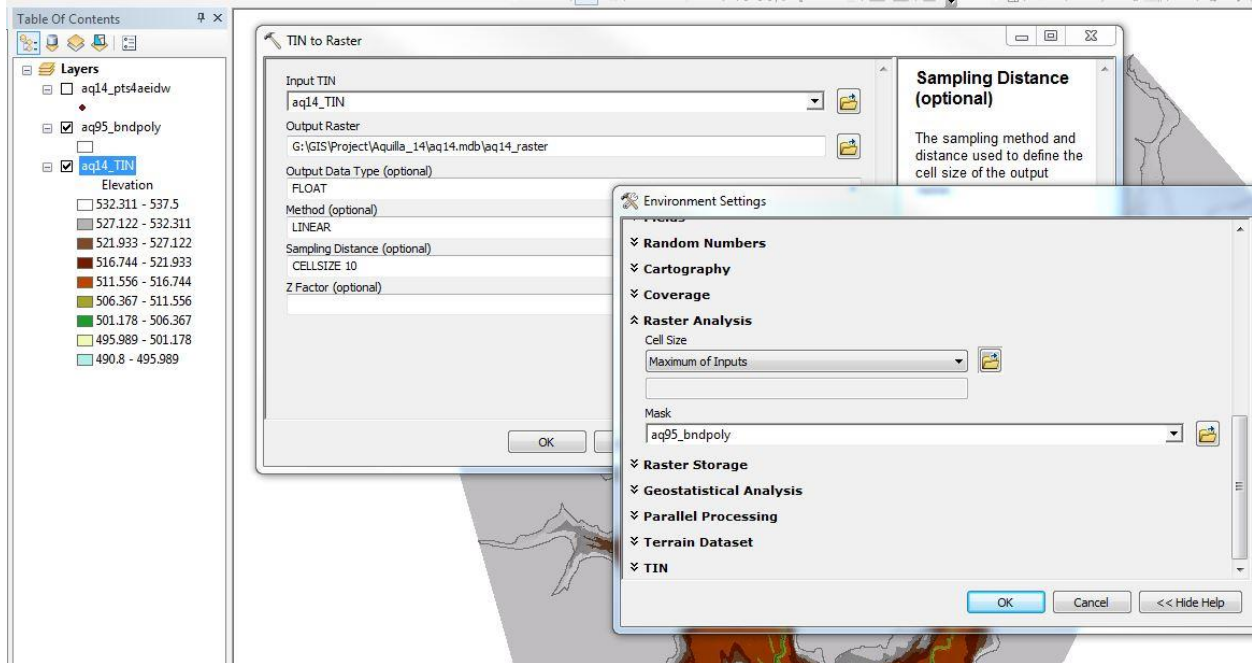
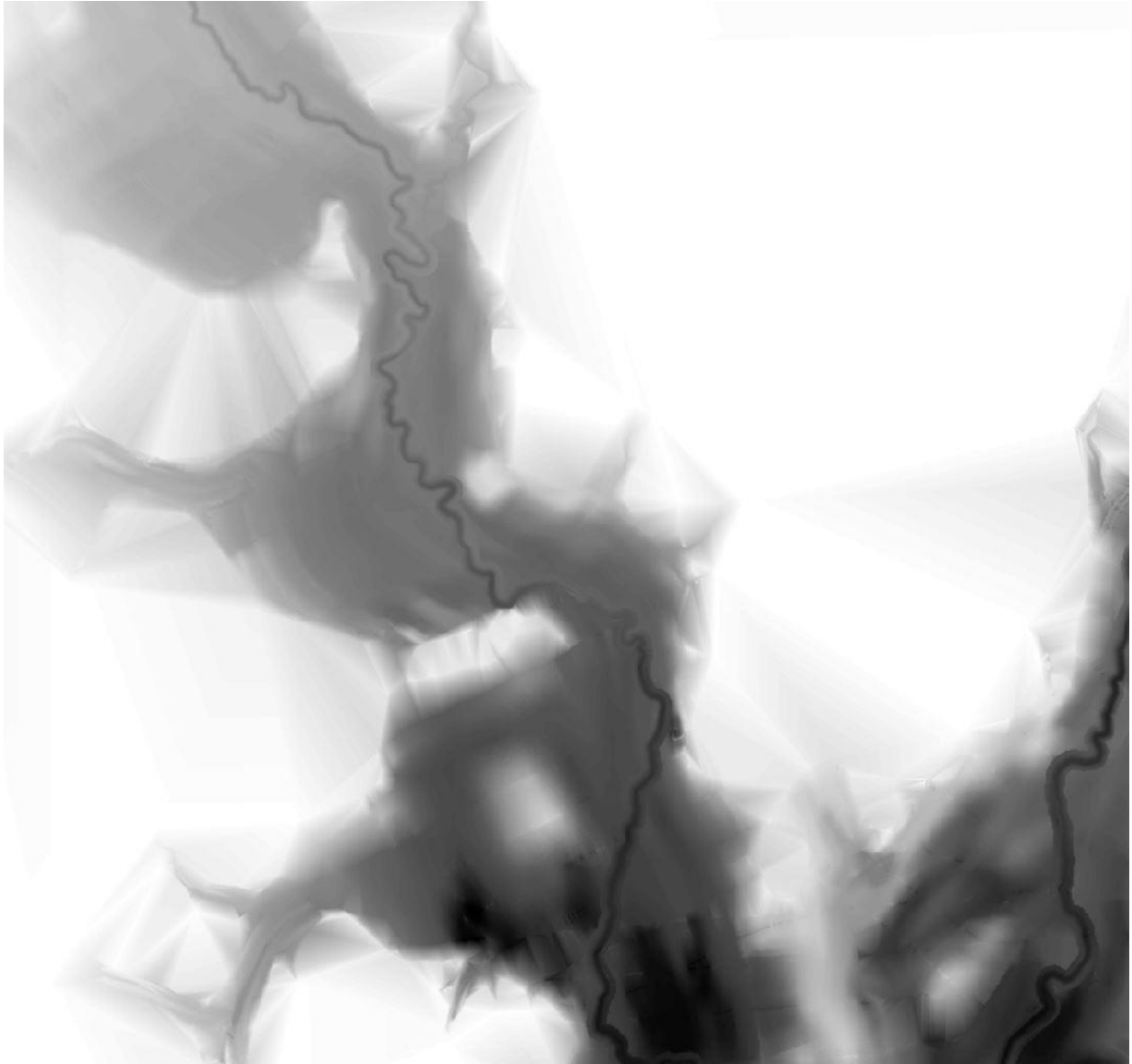**Figure 11. Parameters for converting a TIN to raster**

Figure 12. Cell size 10 feet raster showing very fine resolution

Figure 13. Default cell size 250 feet raster showing very coarse resolution
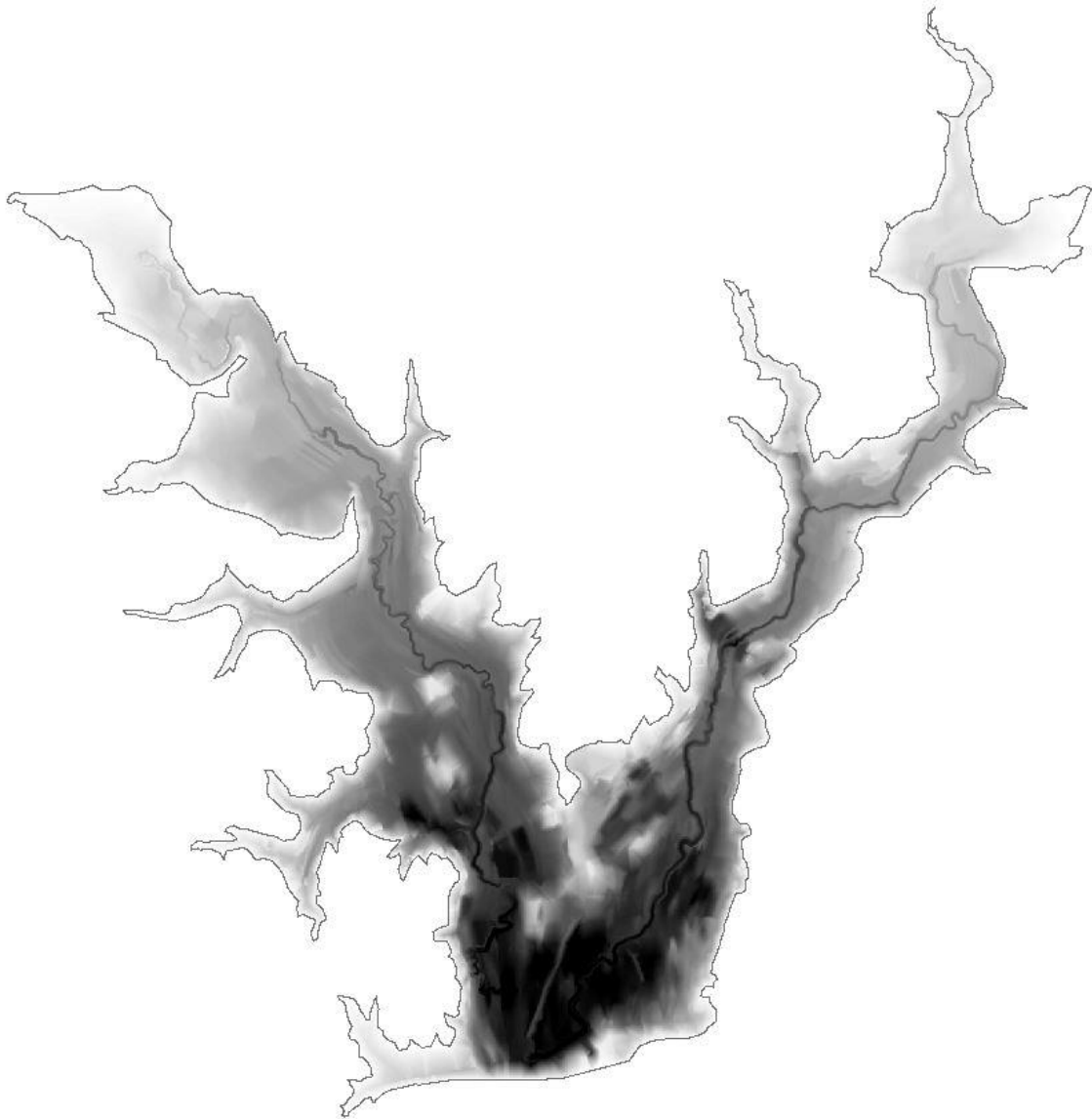
Figure 14. Aquilla Lake survey year 2014 raster

Data Processing and Analysis

All rasters are ready to be subtracted from each other using the raster calculator. I subtracted the latest survey from the earliest survey in order to get positive values for assumed decrease in bathymetric depth. The resulting sediment thickness maps are Figures 15, 16,17, and 18.
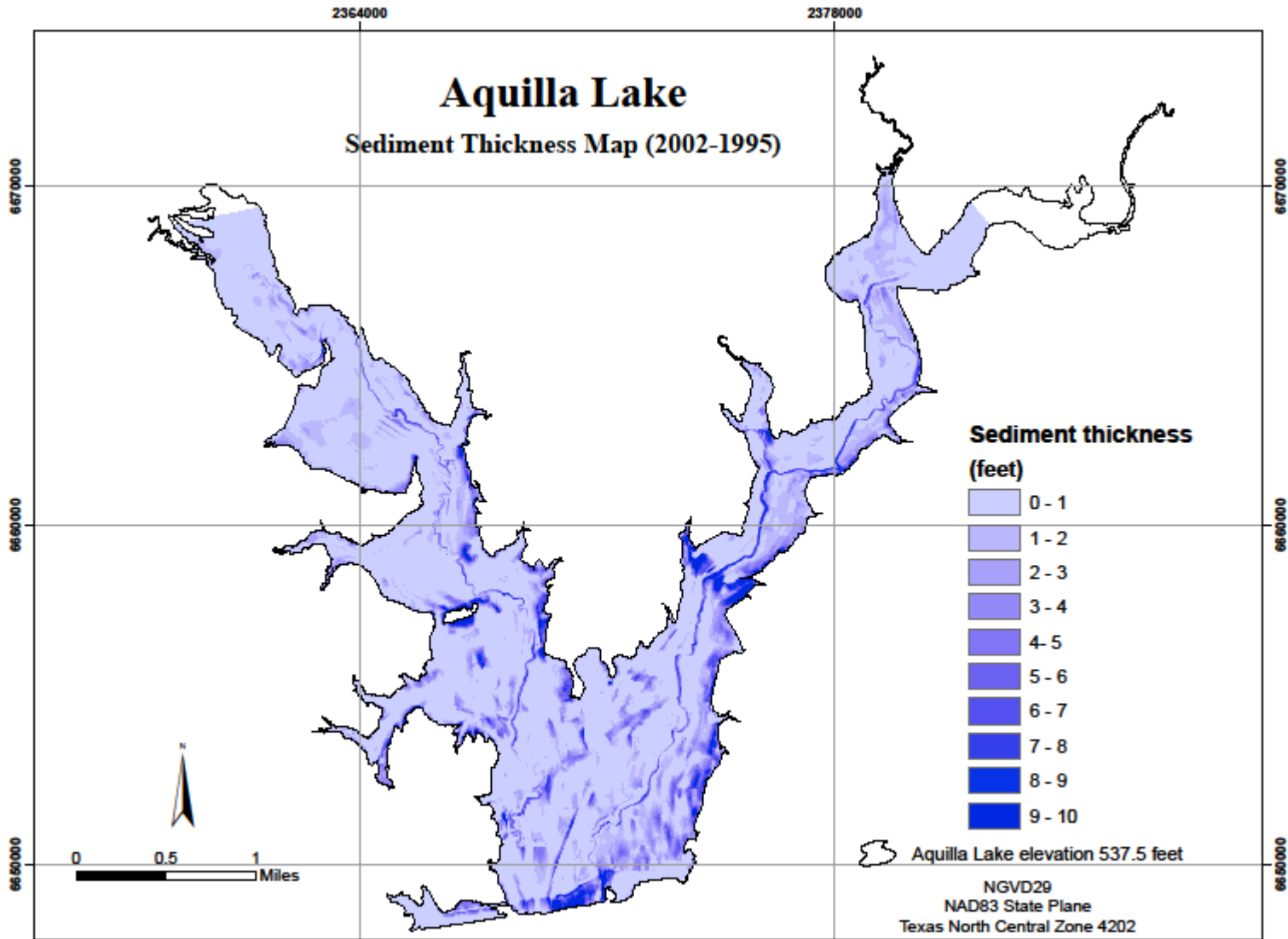
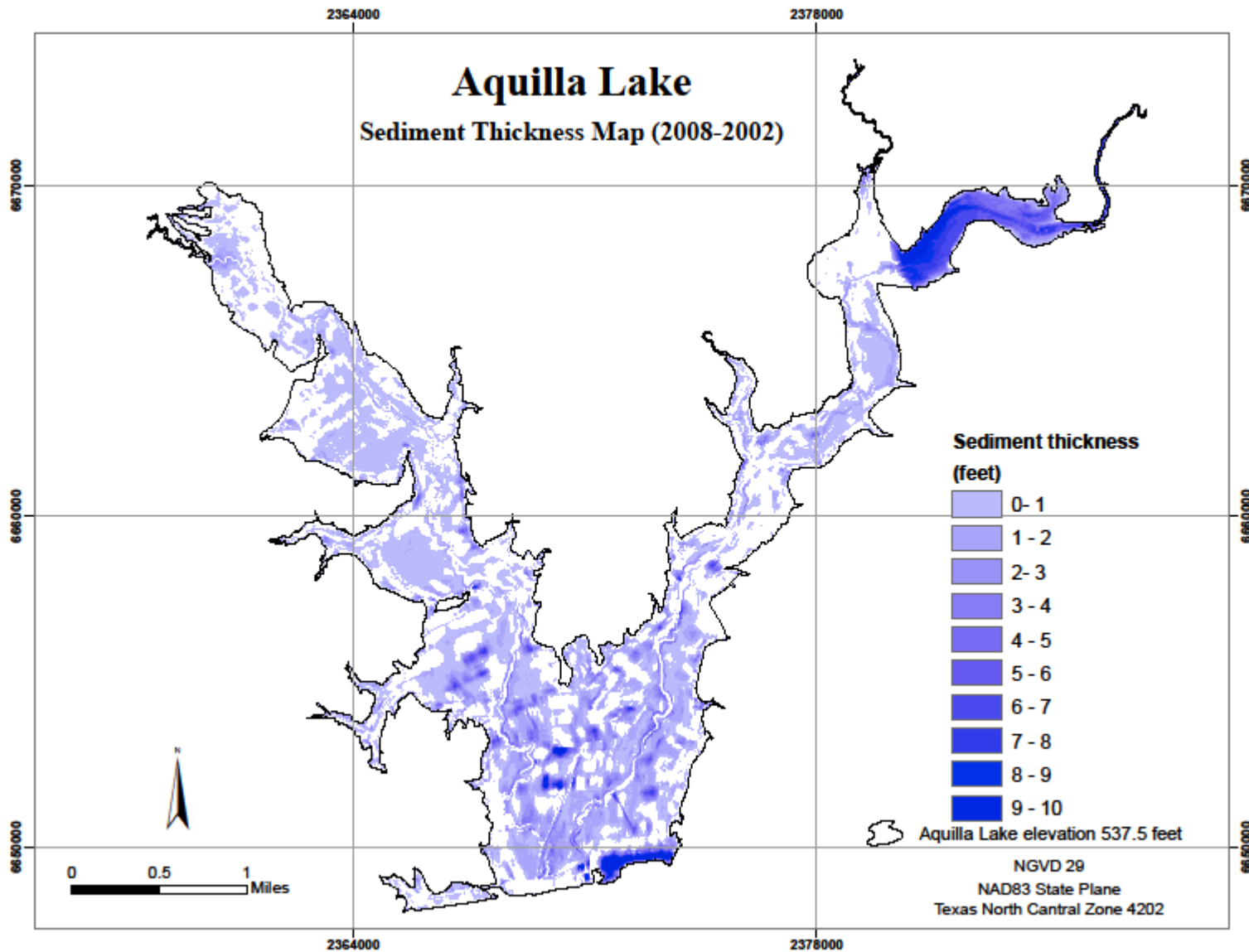Figure 15. 2002-1995 Sediment thickness map for Aquilla Lake

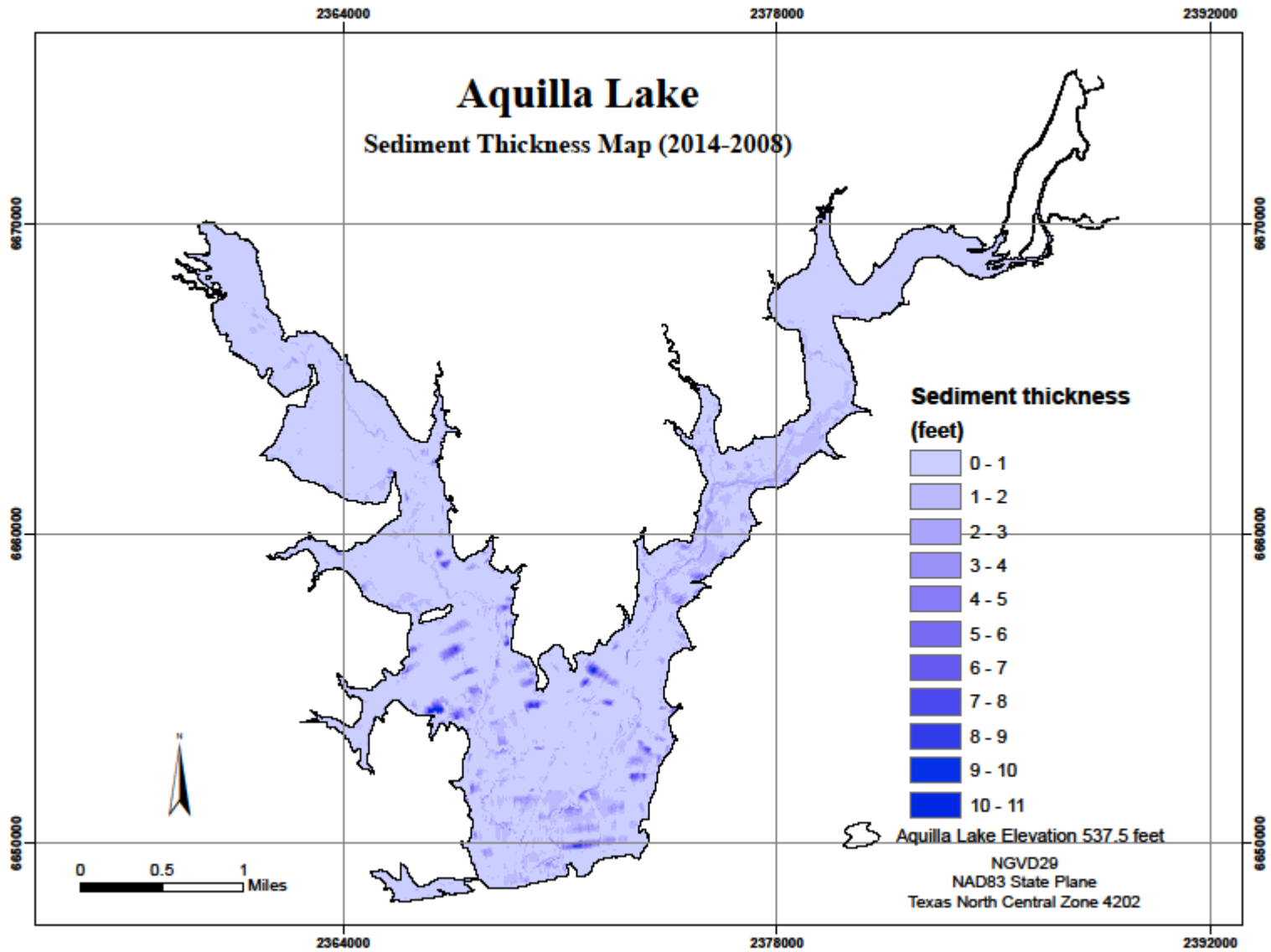Figure 16. 2008-2002 Sediment thickness map for Aquilla Lake

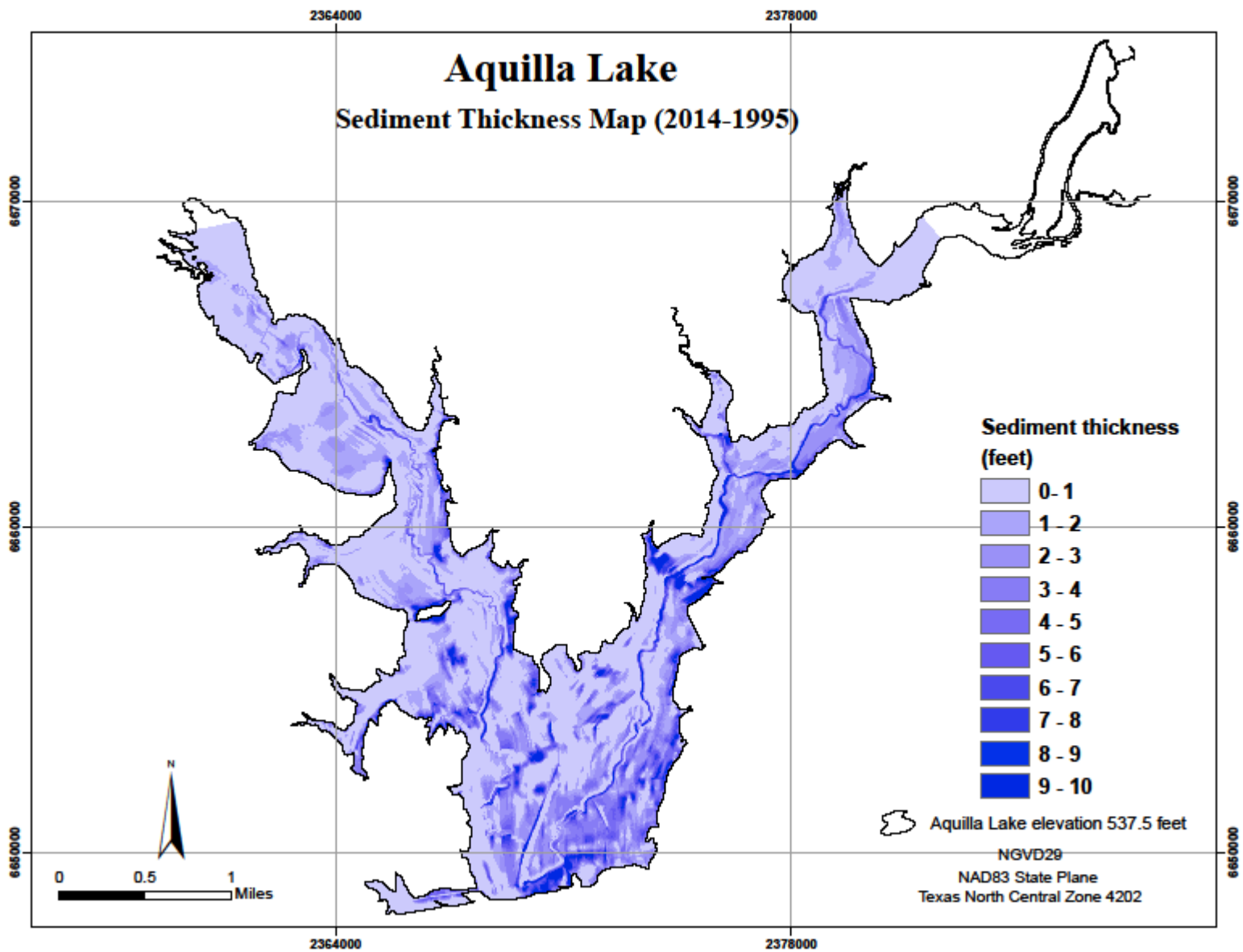Figure 17. 2014-2008 Sediment thickness map for Aquilla Lake

Figure 18. 2014-1995 Sediment thickness map for Aquilla Lake

The first objective was reached with creation of those maps. As for the second objective, to determine the percent error in calculating storage capacity directly from bathymetry data as opposed to the TWDB method, I used the Surface Volume tool to calculate the volume below 357.5 for each year. The resulting text file was in feet cubed so I converted it into acre-feet (Figure19)
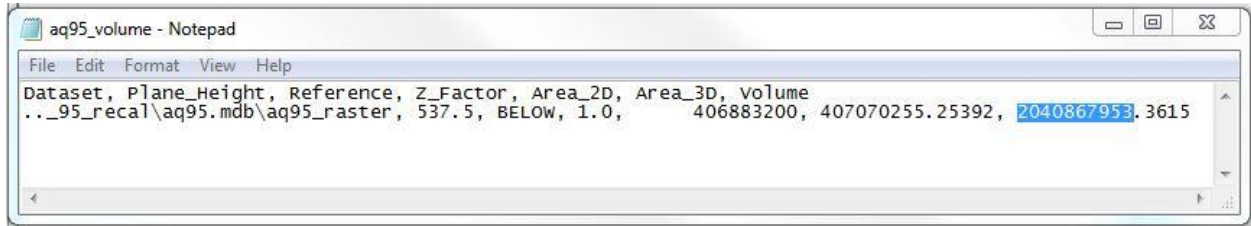

Figure 19. Surface to Volume tool result. Volume result is highlighted in blue in feet cubed.

Comparing the calculated volumes to TWDB data showed no significant error Table 1.

Table 1. Capacity results, differences and percent errors.

Aquilla Lake Survey Years				
	1995	**2002**	**2008**	**2014**
TWDB-Capacity (acre-feet)	46,853	45,824	44,568	43,279
ArcGIS-Surface Volume Tool (acre-feet)	46,852	45,916	44,552	43,280
Capacity difference (acre-feet)	1	92	16	1
Percent Error	0.00%	0.20%	0.04%	0.00%

Discussion

The sediment thickness maps did not turn out as expected and I propose it is because of a failure to identify the correct vertical datum. The point files from the TWDB did not include a metadata file so I was left to read the reports in where it was specified they were in NGVD 29. The resulting maps also had differences in available data at areas therefore resulting in missing data inside the boundaries.

Conclusions

My method to visualize sedimentation was flawed. However, using the Surface Volume tool proved to be a great and easy way to calculate volume with no significant error when compared to TWDB volumes.

References

Scanlon, Bridget R, Ian Duncan, and Robert C Reedy. "Drought and the Water–energy Nexus in Texas" *Environmental Research Letters* 8.4 (2013): 1-14.

Taube, C.M., 2000, Instructions for winter lake mapping. Chapter 12 *in* Schneider, James C. (ed.) 2000. Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

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Texas Water Development Board, Volumetric Survey of Aquilla Lake, March 2008 Survey, April 2009.