Estimating Hurricane Storm Surge Heights in Galveston Bay and Affected Population

GEO 327G: GIS and GPS Applications in Earth Science

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Introduction and Problem: Populated areas along the Texas Coast are under constant threat from hurricanes. High winds and storm surges are capable of demolishing buildings and destroying residences. A storm surge is the rise in water associated with a hurricane. Storm surge heights are affected by many different factors including barometric pressure, bathymetry, coastal land formation, tides, wind speed, wind direction and width and depth of continental slope. I plan to calculate how many people along the Texas coast would be affected by a hurricane storm surge (category, 1, 2, 3, 4 and 5) hitting Galveston Bay. This plan will be carried out using Arc GIS version 10.2.

Data Collection: A model of each storm category was created using the Slosh Display Program developed by the National Weather Service. SLOSH models have been created for multiple US bays, for this project Galveston Bay, 2007, v4 was chosen. SLOSH can display MEOW's (maximum envelope of water) or MOM's (maximum of maximums), which can then be exported as a shapefile and brought into ArcGIS.

A MEOW is the maximum surge water height at every grid cell that is reached in any of several envelopes, where the envelopes are acquired by running the model on storms with the same category, forward speed, and direction of motion, but with tracks that are parallel to each other. A MOM is the maximum surge water height at every grid cell that is reached in any of several MEOWs, where the only constant is category (thus there are only 5 MOMs per basin, one per storm category). It is the composite of the maximum storm surge height for all hurricanes of a given category at every grid cell.

For this project MOM's were used and storm simulations were run with high tides (as oppose to mean tides), as these are the most conservative estimates of storm surge heights (Figure 1). A MOM shapefile was exported for each storm category (1, 2, 3, 4, 5).

Figure 1: MOM for category 3 hurricane at high tide (note storm surge is in feet)
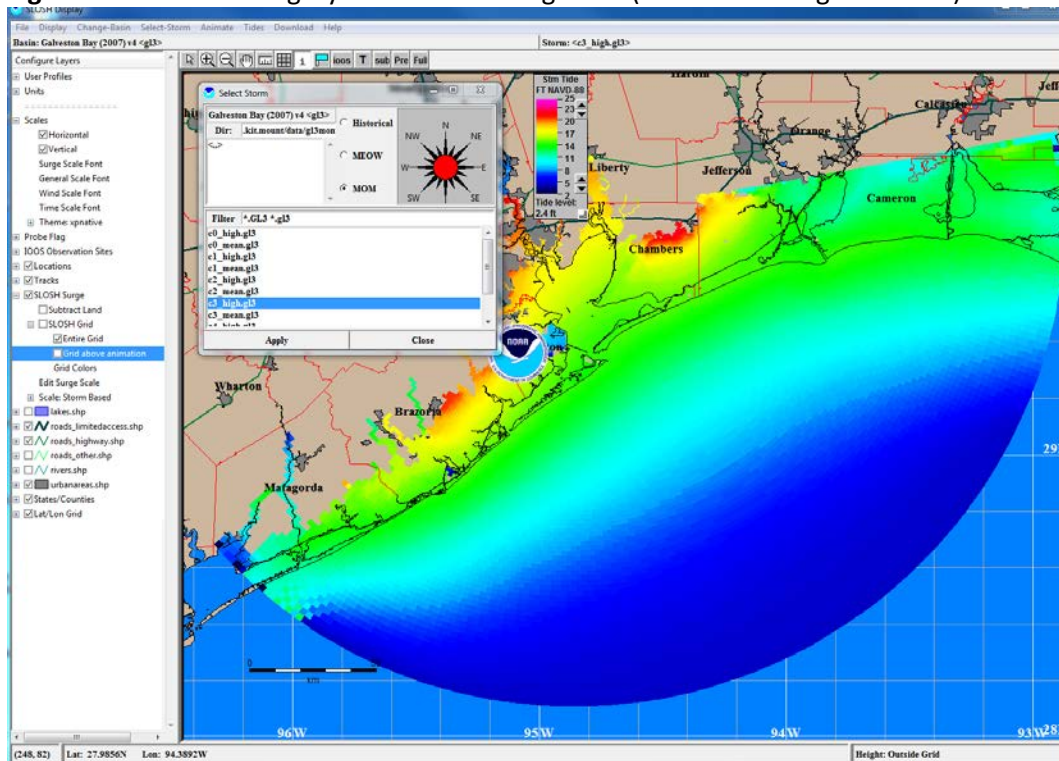
A shapefile of Texas, including county boundaries, was taken from http://www.tpwd.state.tx.us/gis/data/

A shapefile of Louisiana, including parish boundaries, was taken from http://louisianasiteselection.com/gis-data-download.aspx

Data on population, including the location of populated places and the number of people living there was taken from http://gis.ttu.edu/center/DataCatalog/Download.php?County=Galveston. One Shapefile, 'County Name' Populated Places Points (ESRI), was taken for each county of interest. Counties of interest include; Matagorda, Brazoria, Galveston, Harris, Chambers, Liberty and Jefferson.

The United States base map used to show the area of interest was acquired from http://www.census.gov/geo/maps-data/data/cbf/cbf_state.html

The bathymetry, US/Mexico boundary and North America political boundaries shapefiles were taken from http://www.cec.org/Page.asp?PageID=924&ContentID=2336

Procedure: I began by adding the MOM shapefiles to ArcMap (Figure 2). The spatial reference was unknown for these files and had to be assigned. This process was as follows; ArcToolbox > data management tools > projections and transformations > raster > define projection > geographic coordinate systems > North America > NAD 1983, (Figure 3). NAD 1983 was selected after viewing SLOSH Display Program to ESRI ArcGIS 101, a PowerPoint provided by NOAA explaining how to import SLOSH shapefiles into ArcGIS.

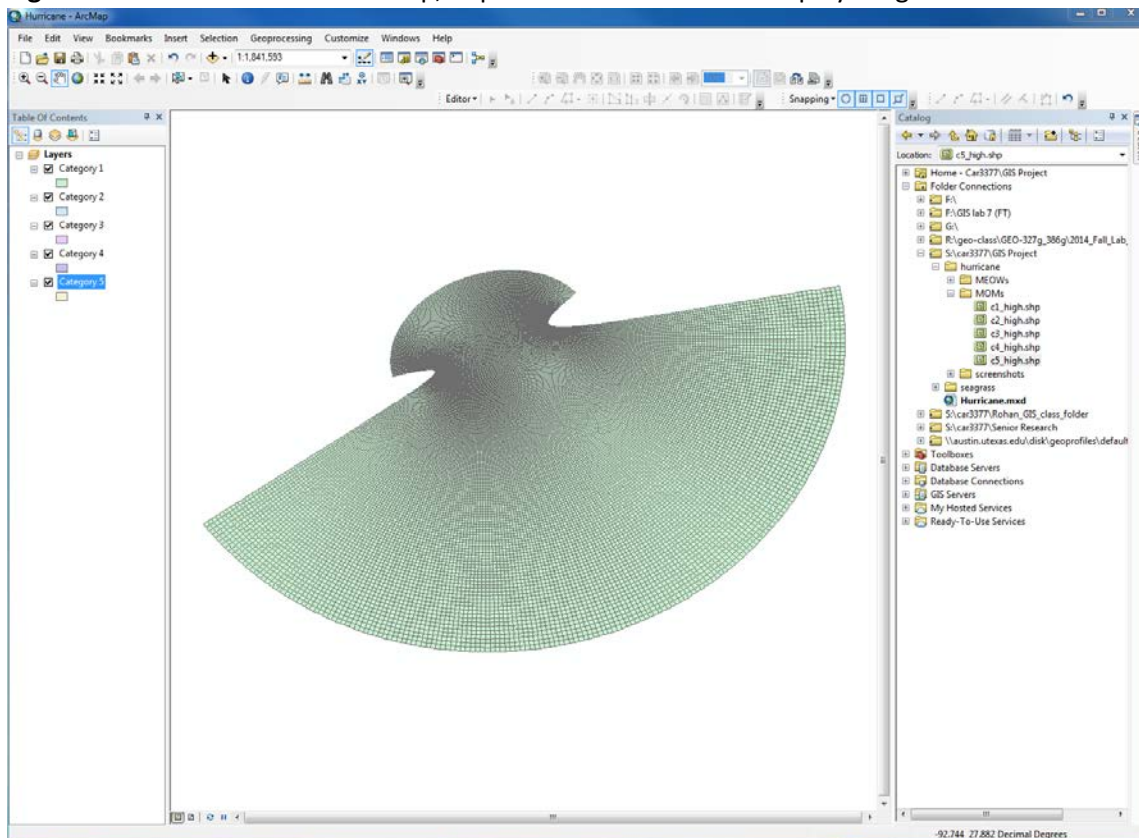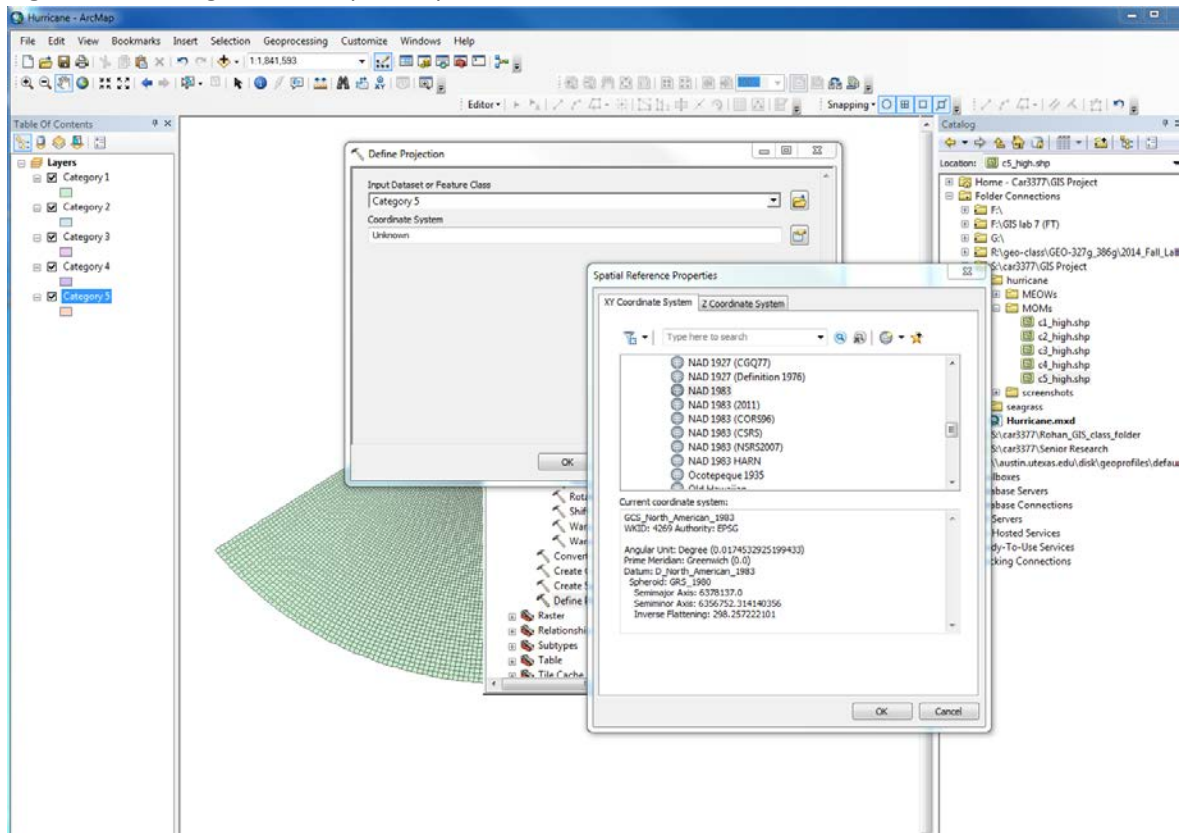**Figure 2:** Raw MOM data in ArcMap, imported from the SLOSH Display Program

Figure 3: Defining SLOSH shapefile spatial reference

To get a feel for the surge heights water depth was symbolized by color for each storm category layer. Process as follows; symbology > quantities > graduated colors > value: c1_high (an error message occurred, this was fixed by changing the sampling size, under the classification tab, to 500,000 to include all cells) > click 'classify…', create break values for every 2 feet of water (Figures 4 and 5). No data (99.9) polygons were made hollow with no outline since they were not of interest.

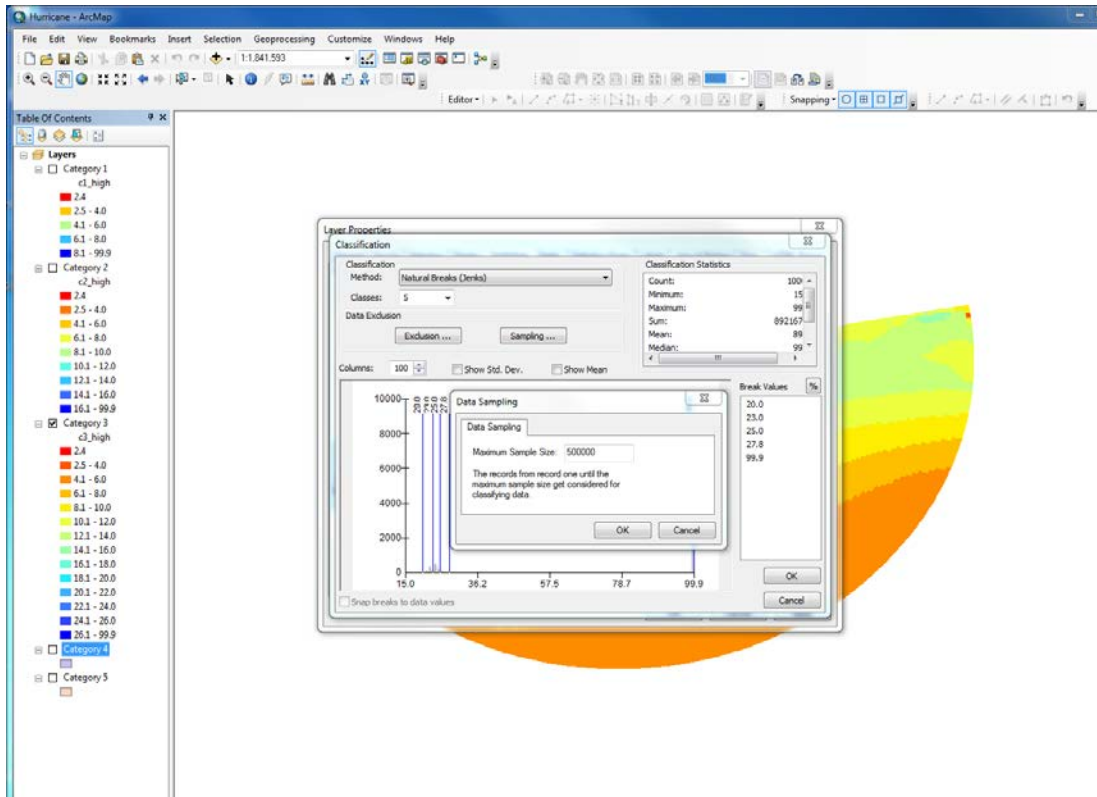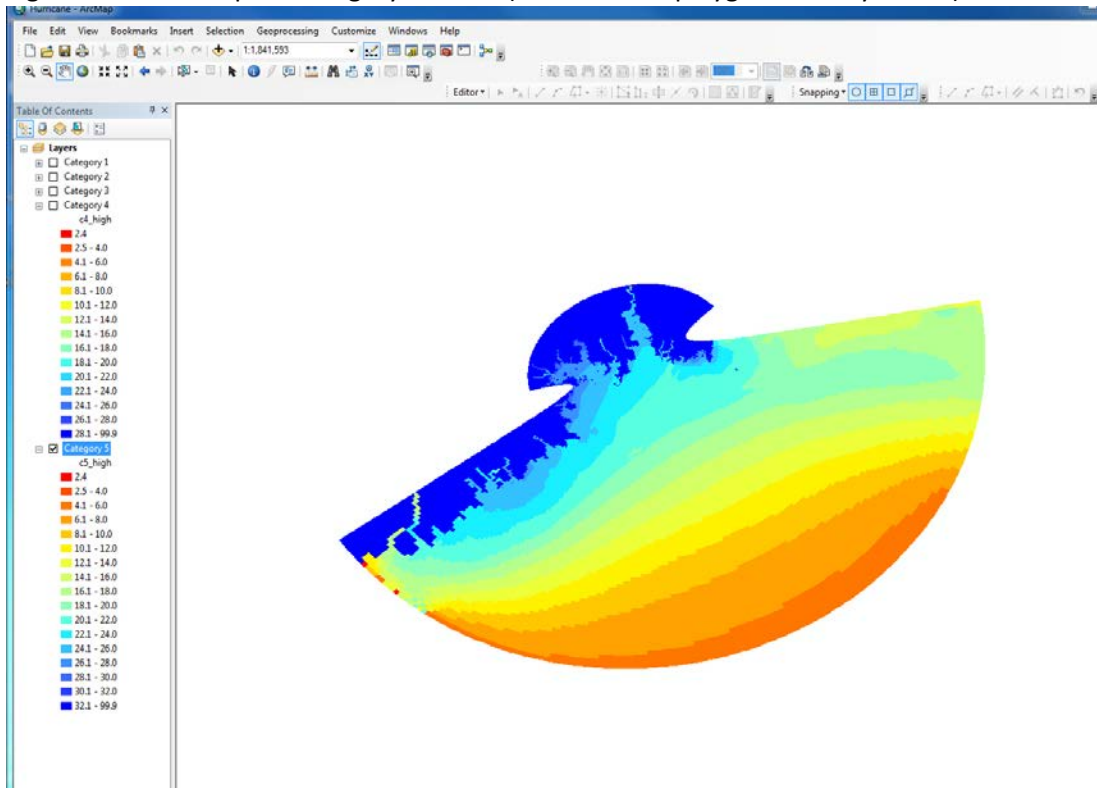**Figure 4:** Initial surge height classification

Figure 5: Color ramp for category 5 storm (note no data polygons are royal blue)

Next the Texas counties and Louisiana parishes layers were added. To obtain a darker state outline for Texas the dissolve tool was used to merge all Texas counties (Figure 6). This created a new layer that only contained an outline of Texas. The outline was made bold to help differentiate the Texas/Louisiana border. The same procedure was performed on the Louisiana parishes layer to obtain a Louisiana state outline.

Figure 6: Dissolving Texas outline
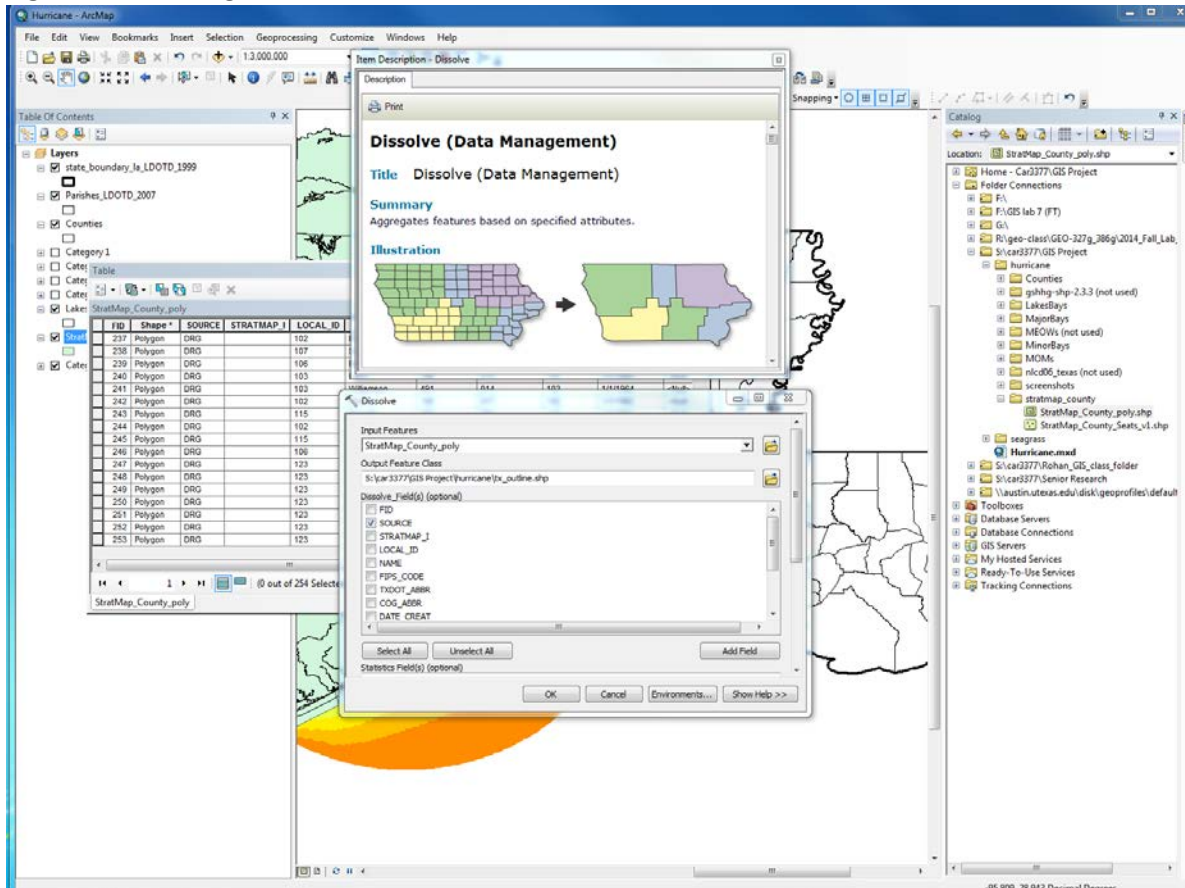
Because I wanted to overlay the surge water heights layer on top of all other layers it needed to be transparent. Doing this however made the water depth legend difficult to read as the colors on the legend were not be exactly the same as those on the map. To make the depths easier to identify I created a separate layer of just the outlines of the storm surge height intervals. This was done in 6 steps;

1) I used the select by attribute tool to choose the water height category of interest, Ex: "c5_high" >30 AND "c5_high" <= 32' (figure 7), note I continued to break water height into 2 foot intervals.

**Figure 7:** Selecting for specific water heights within a category 5 storm surge
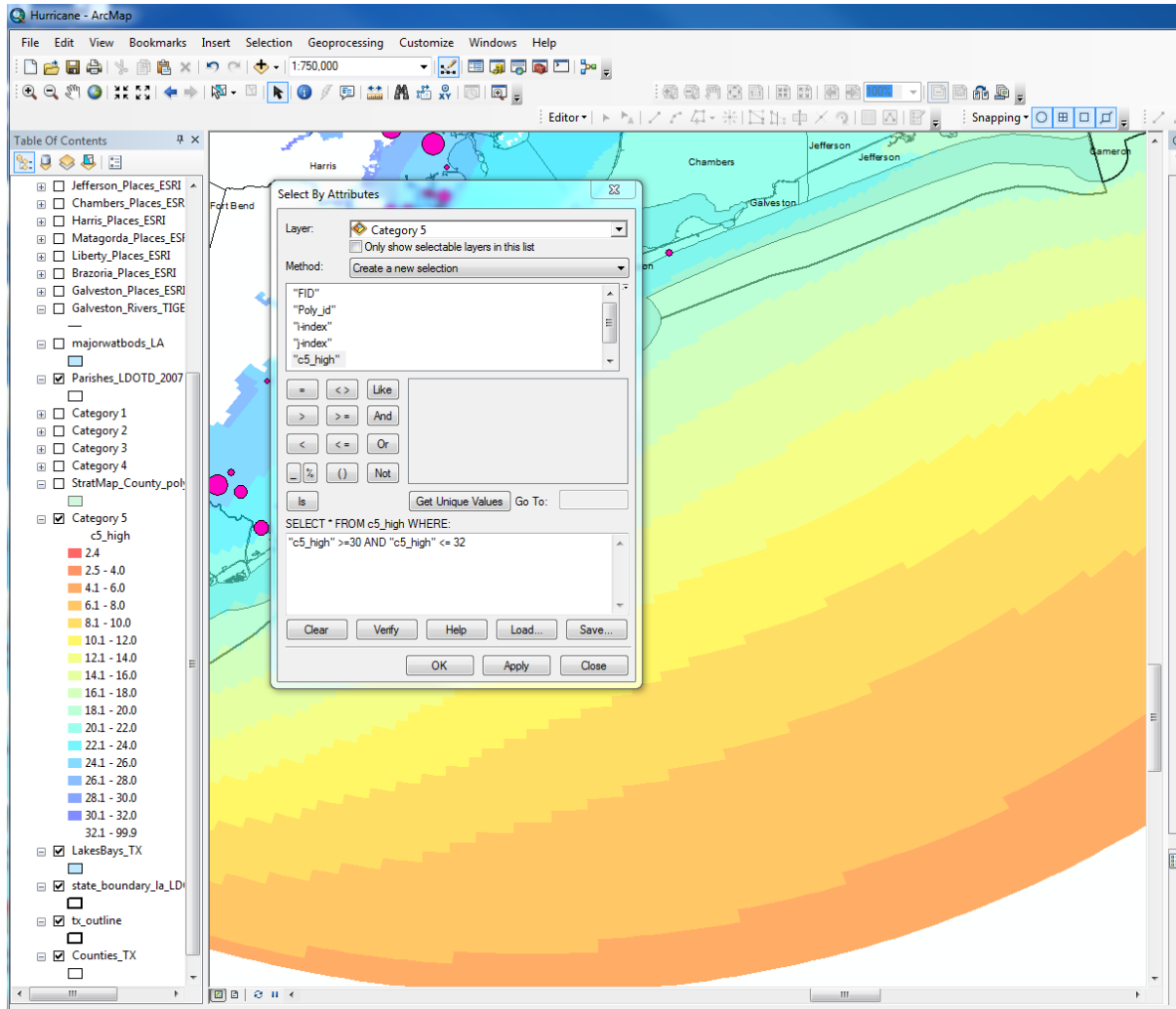
2) I made a new layer from the selected features (a new layer was made for each surge height interval excluding no data polygons).
3) Next I used the dissolve tool to create one larger polygon of the depth interval of interest (Figure 8).

**Figure 8:** Dissolving all polygons with water height >30 and =< 32 foot
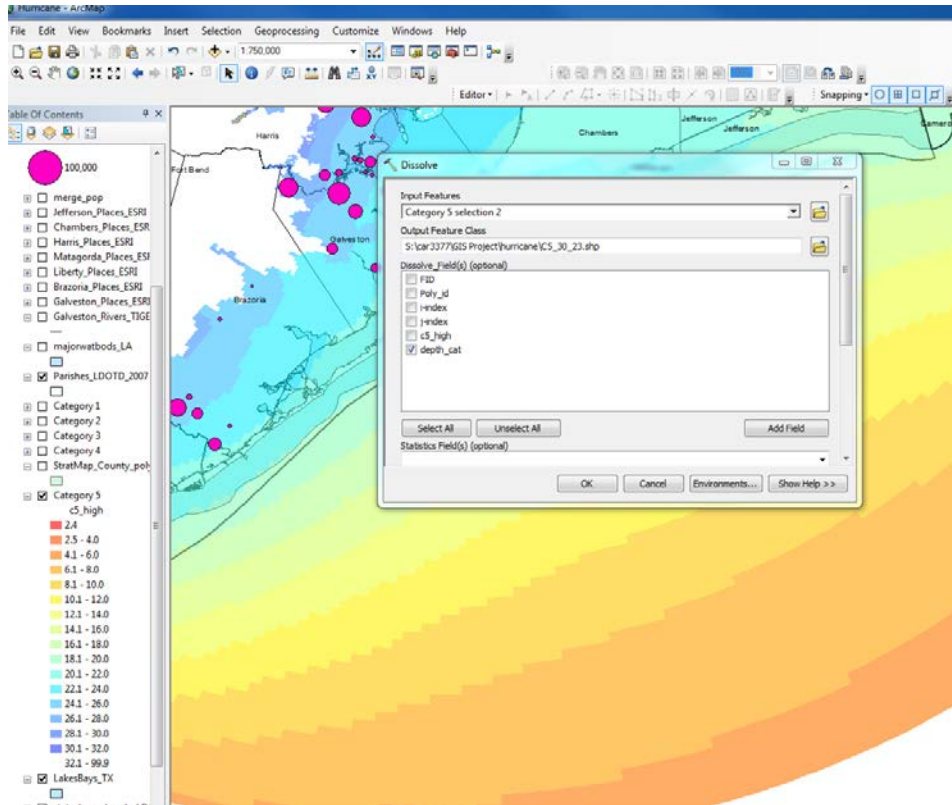
4) Once polygon layers were created for all surge height intervals they were merged back together to create one larger polygon showing surge heights in 2 foot intervals (Figure 9). This process was repeated for each storm category.

**Figure 9:** Merging all surge height intervals to create on polygon
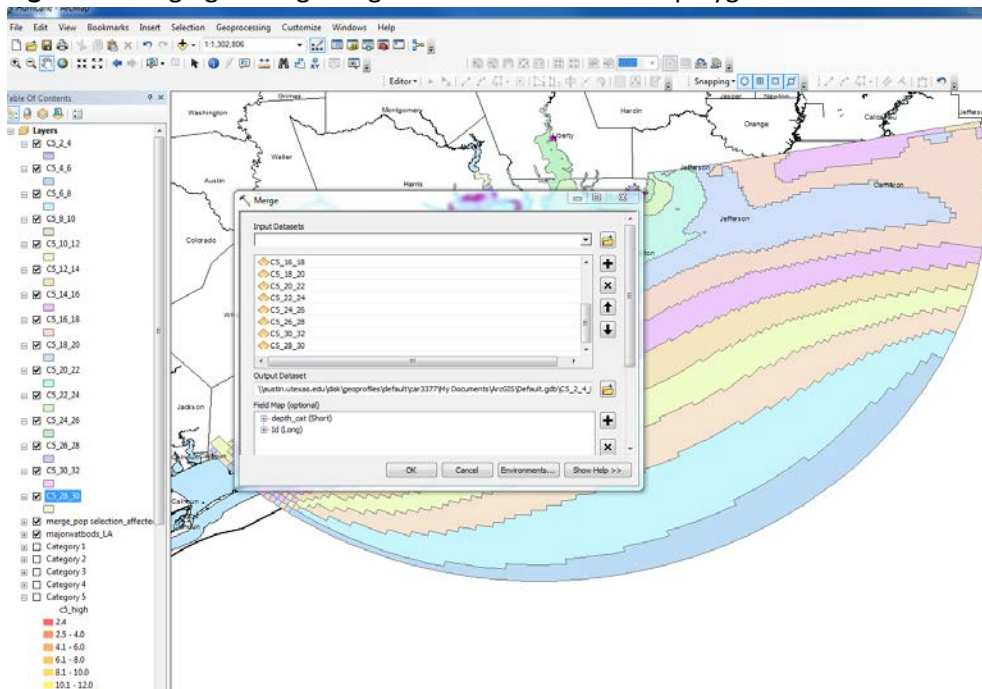
5) Next an attribute field (used to color height intervals) was created for each new, merged polygon layer (Figure 10). The greatest water height was input into the new attribute field to signify each intervals range.

**Figure 10:** 40% hollow, merged surge height intervals displayed along a color ramp
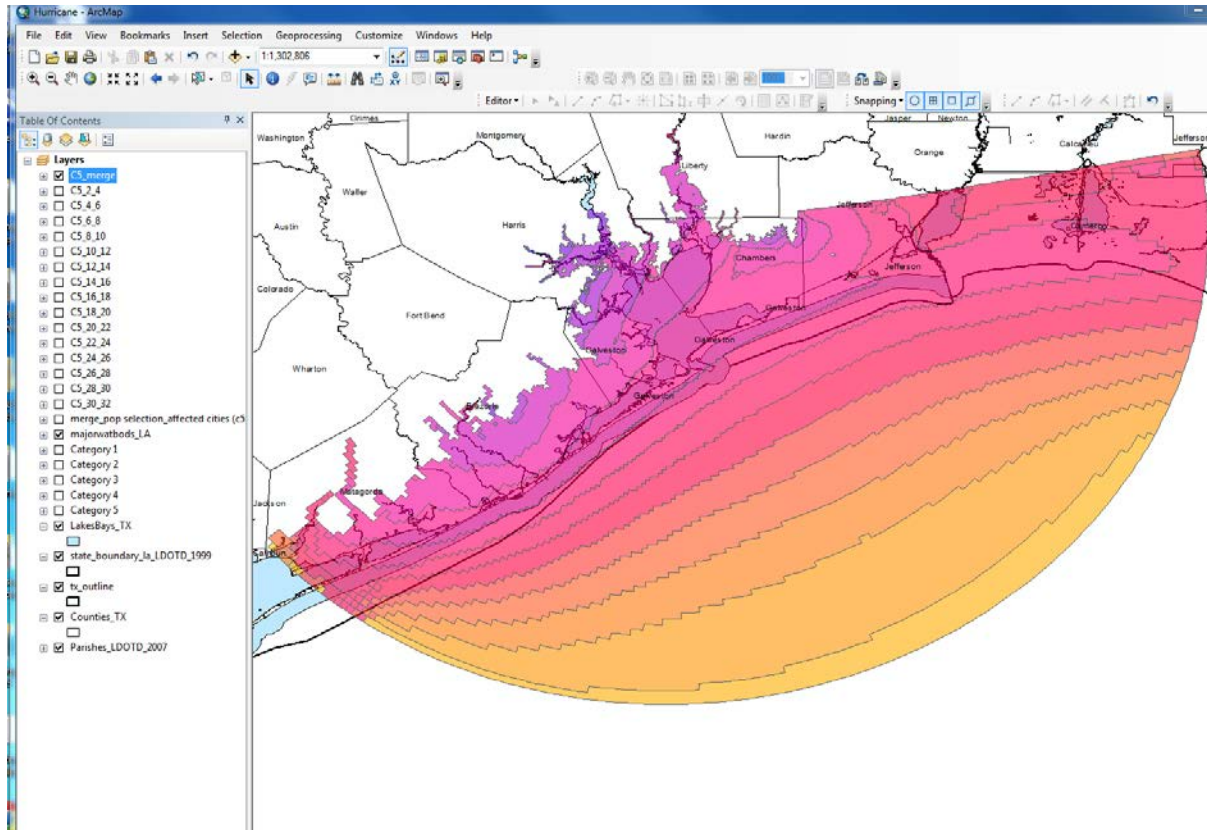
6) The layers were next make 40% transparent so county and state boundaries could be seen beneath them. To really differentiate between the surge height intervals a copy of the merged surge height interval layer was made hollow, 0% transparent, with thick, bright outline colors corresponding to the colors of the original surge height interval layer and placed on top of all other layers (Figure 11).

Figure 11: Outlined surge height polygon
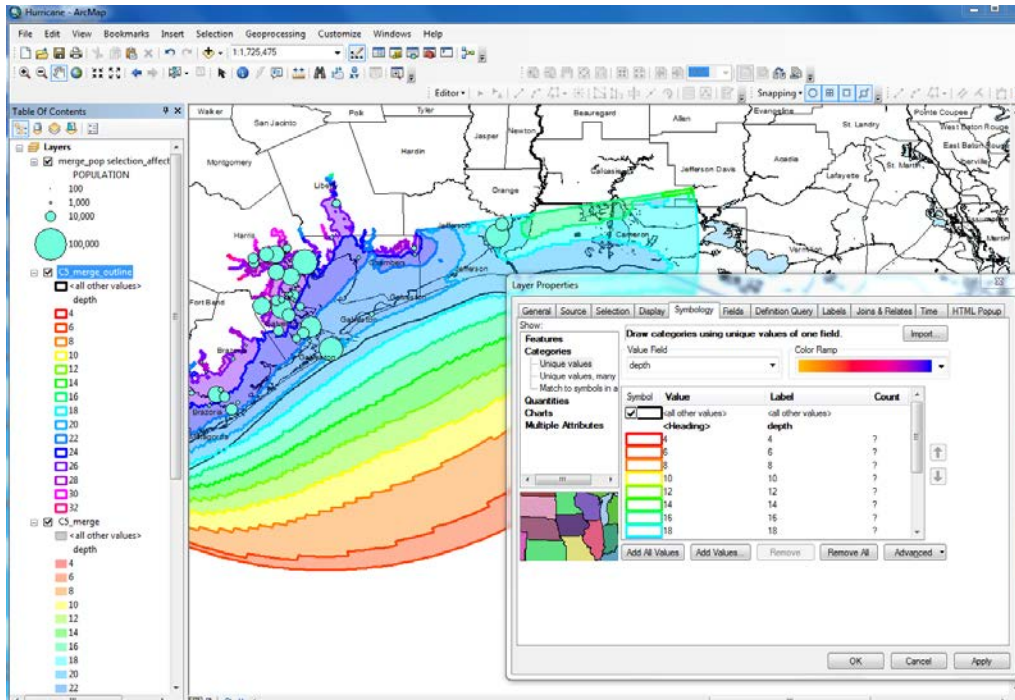
Since all storm categories then had the same water height intervals I assigned each interval a specific color (Figure 12). In this way legends would be consistent across all maps.

**Figure 12:** Setting water height interval colors
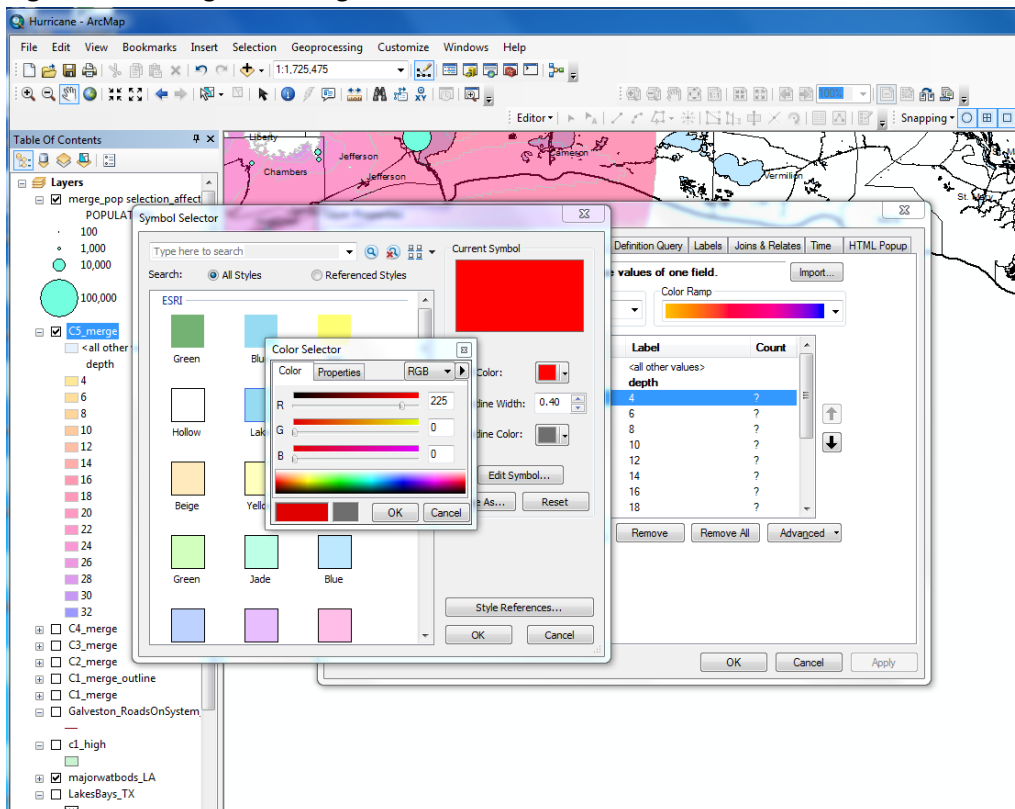
Colors for each surge water height interval (in R, G, B format) are as follows;

2-4; 255, 0, 0	12-14; 0, 255, 0	22-24; 0, 0, 255
4-6; 255, 66, 0	14-16; 0, 255, 128	24-26; 127, 0, 255
6-8; 255, 128, 0	16-18; 0, 255, 255	26-28; 169, 0, 207
8-10; 255, 255, 0	18-20; 0, 176, 255	28-30; 255, 0, 255
10-12; 128, 255, 0	20-22; 0, 128, 255	30-32; 255, 0, 127

Outline colors were set at the same time as polygon colors. This new, correctly colored, surge height interval layer was then copied (preserving color setting) and pasted on top of all other layers. It was made hollow, 0% transparent, with bold, colored outlines (the same colors as the corresponding semi-transparent surge height interval polygon). The first outlined polygon layer (along a color ramp) was then deleted.

After this a data frame for each storm category was created and the associated layers were pulled into each (Figure 13).

**Figure 13:** Data frames, one for each storm category, layout view
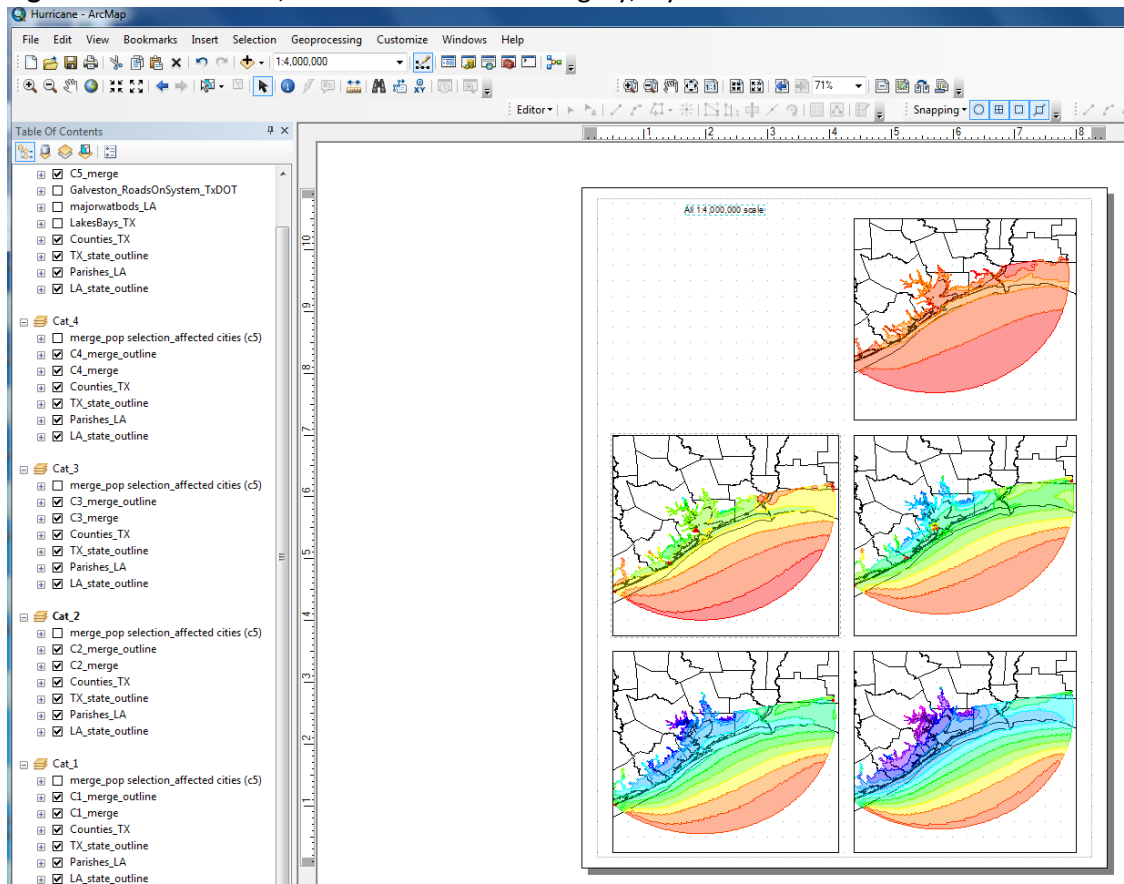
Next I needed to figure out how many people would be affected by the storm surge in each hurricane category. To do this I created a new map for each hurricane category and added the population layers for each county of interest and then merged them together to create one larger population layer. From here I selected by attribute for populated areas within the surge height polygon (Figure 14).

**Figure 14:** Selecting for populated places within surge height polygon
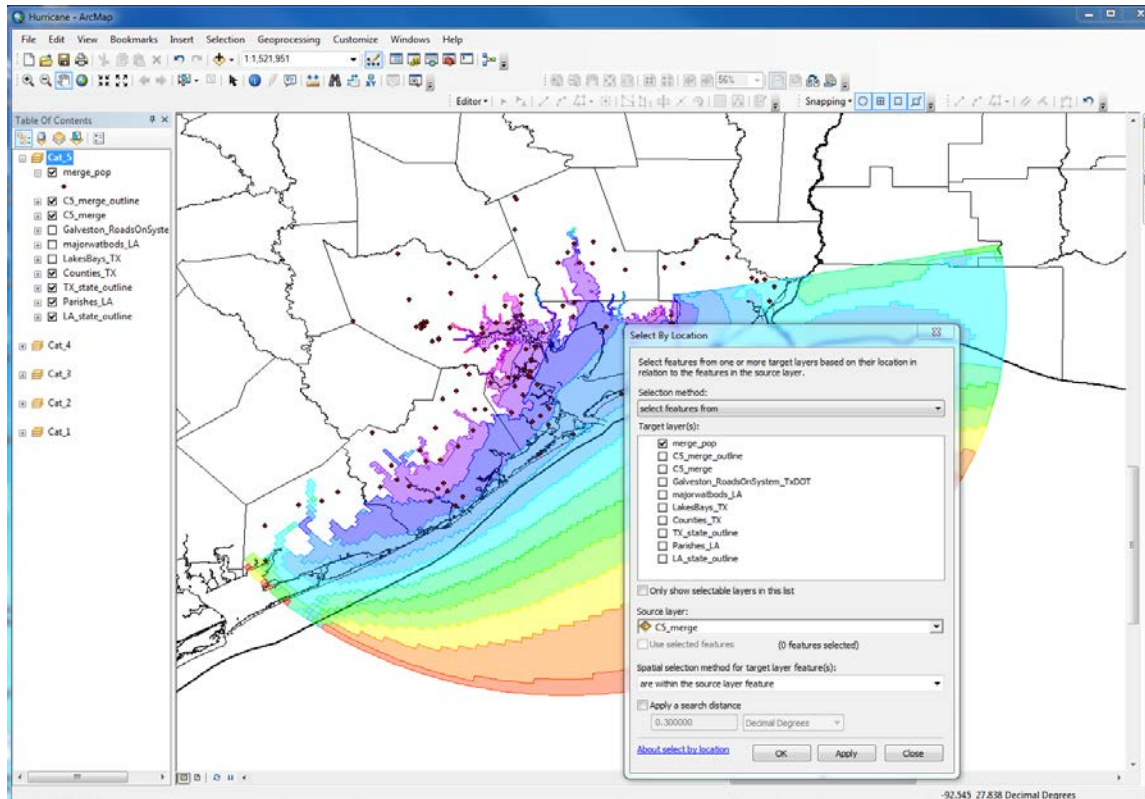
Then I created a new layer from the selected areas and displayed population with proportionality symbols (Figure 15)

**Figure 15:** Affected population displayed proportionality
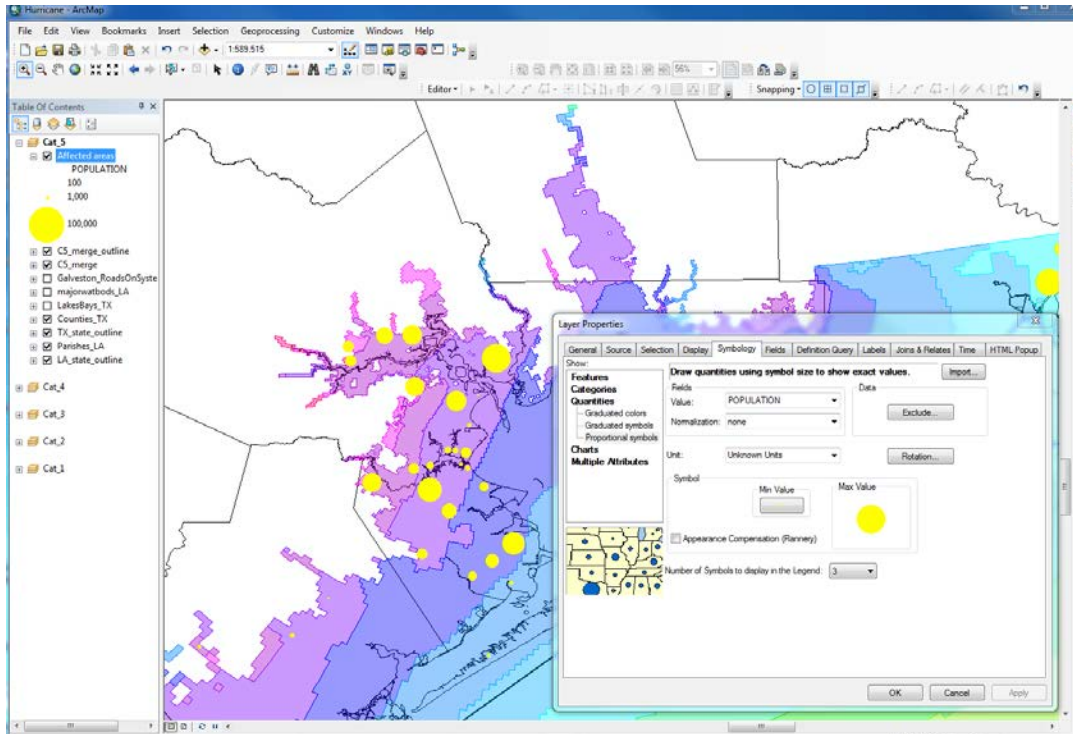
To differentiate land from water (but to avoid too much color that would take away from the surge intervals) I symbolized land as a 10% ordered stipple in the color 'mango'. I also added a bathymetry layer to round out the map (Figure 16)

**Figure 16:** Adding bathometry layer
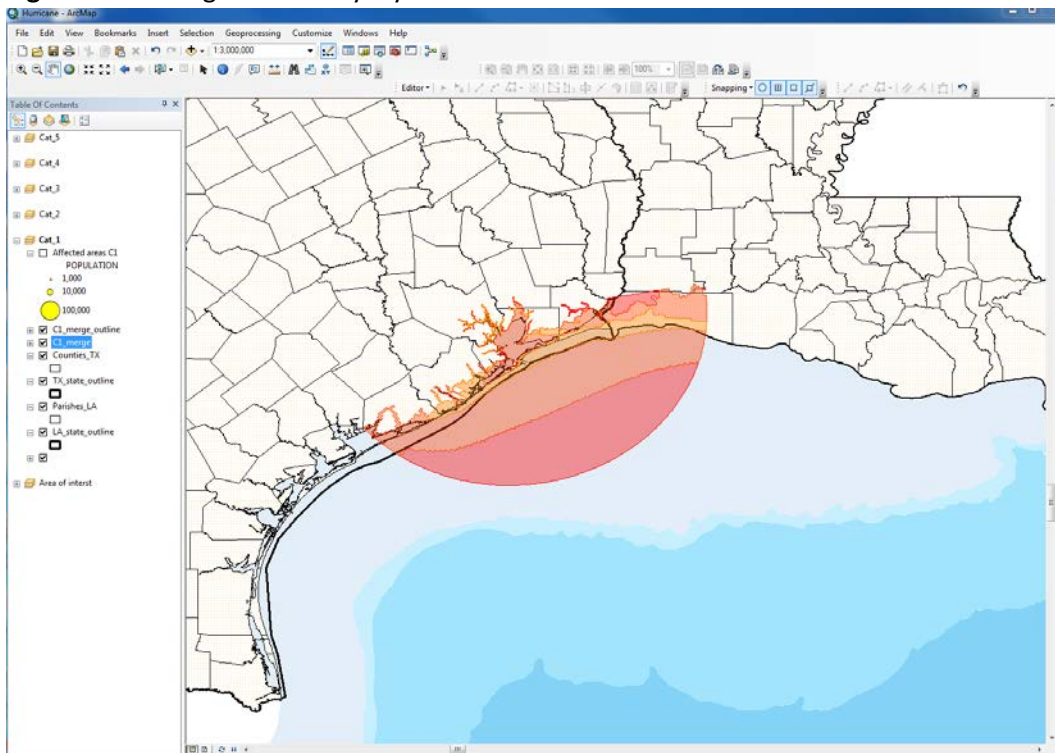
Next I added a data frame to each map to indicate the area of interest and pulled in the needed layers including the US/Mexico border and North America political boundaries shapefiles (Figure 17).

Figure 17: Area of interest
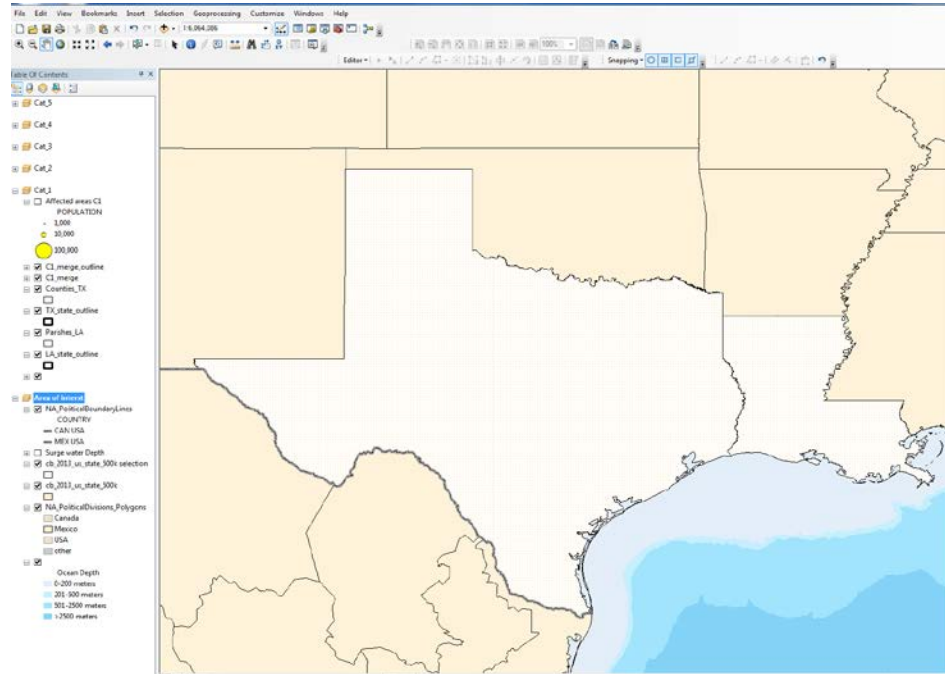
Lastly, to each large map, I added labels to the Texas counties of interest, a title, north arrow, scale etc. (Figure 18).

Figure 18: Putting final map elements together
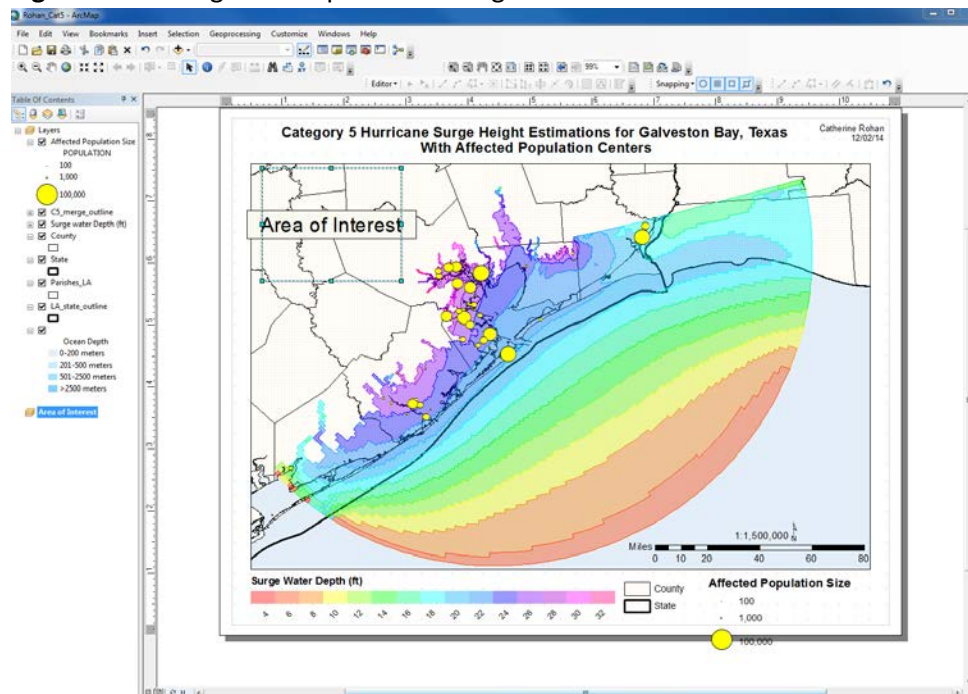
Results: The total population affected by each category of hurricane was found using the statistics tool under the population tab in the affected population attribute table (Figure 19)

Figure 19: Finding total affected population for a category 5 hurricane
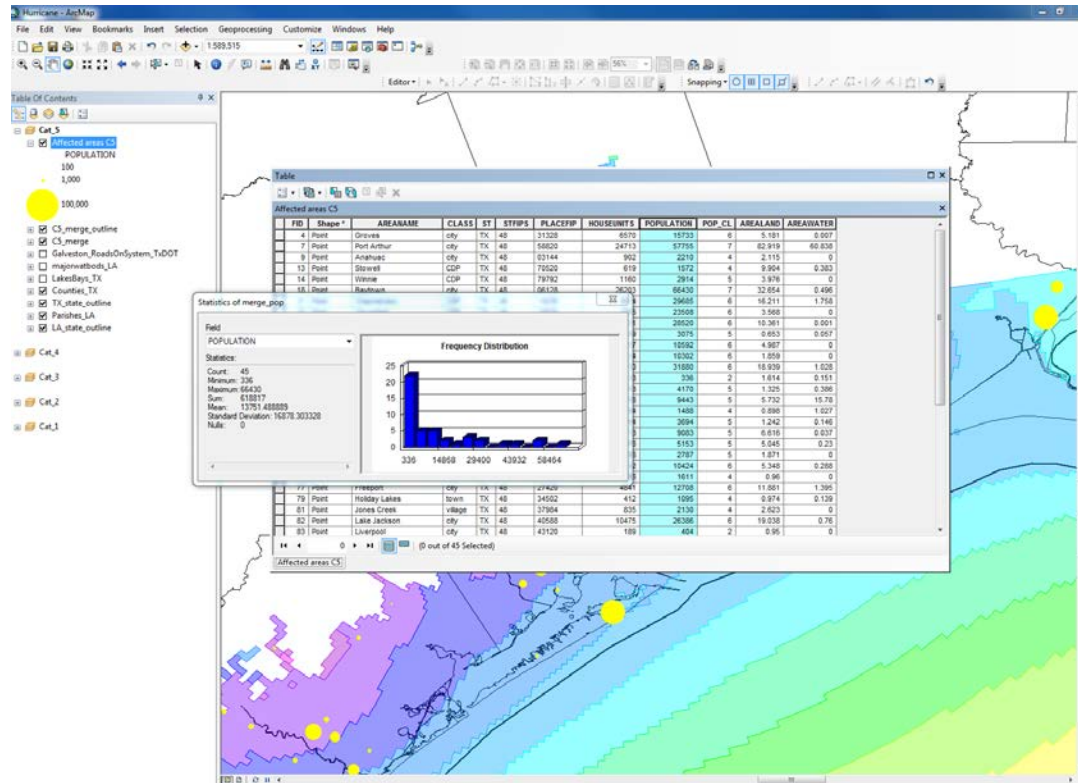
A summary of the total number of people affected by a hurricane, of a specific category, hitting Galveston Bay is displayed below.

Hurricane Category	1	2	3	4	5
People Affected	78,924	187,370	291,957	442,625	618,817

Data Presentation: completed maps below

It should be noted that these maps are only models. Additionally I was unable to find the year in which the population data was collected so these maps may not reflect current populations.

Figure 20: Map of all storm categories and hurricane surge height estimations

Figure 21: Category 1 storm surge height estimations with affected population centers

Figure 21: Category 2 storm surge height estimations with affected population centers
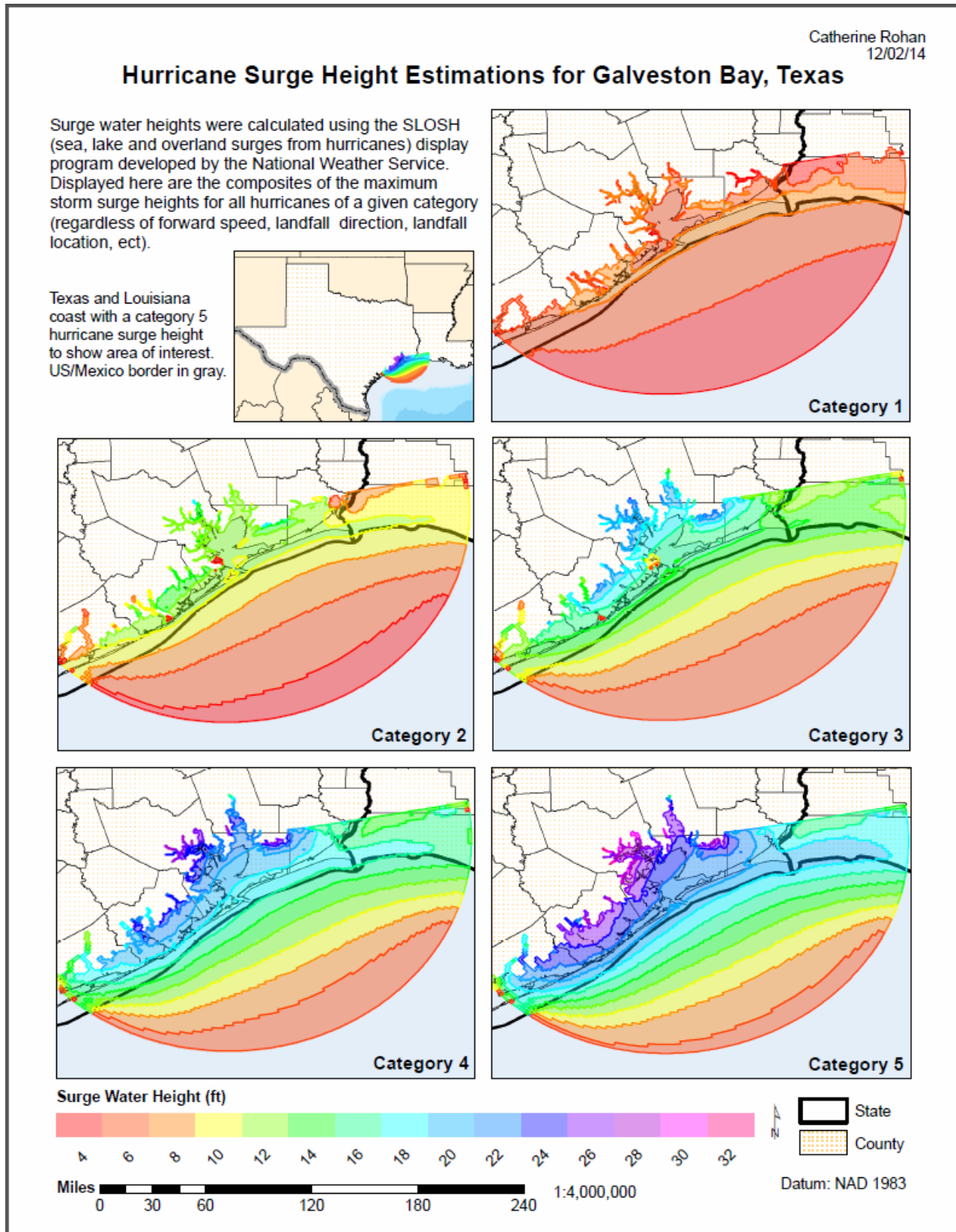
Figure 21: Category 3 storm surge height estimations with affected population centers
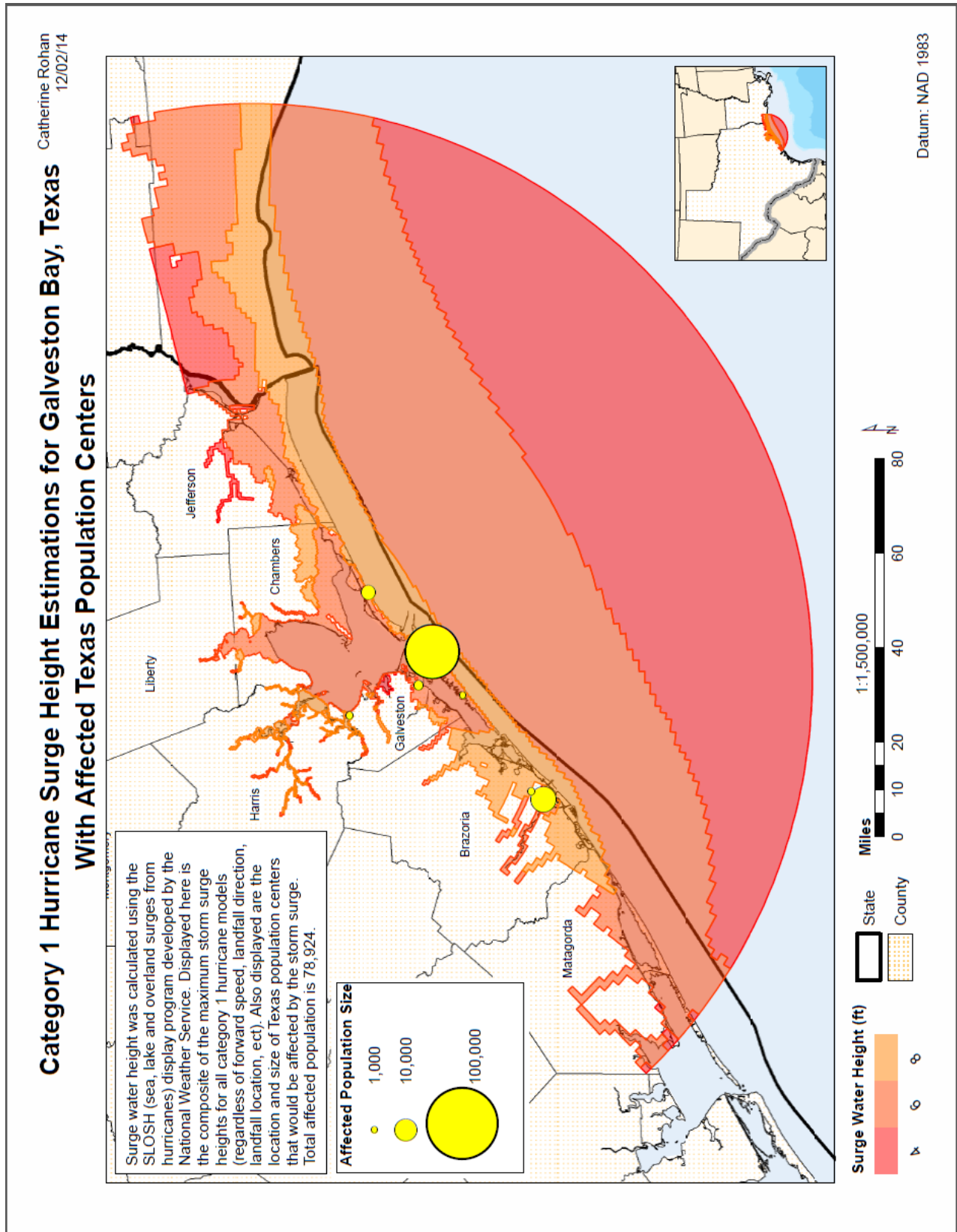
Figure 21: Category 4 storm surge height estimations with affected population centers
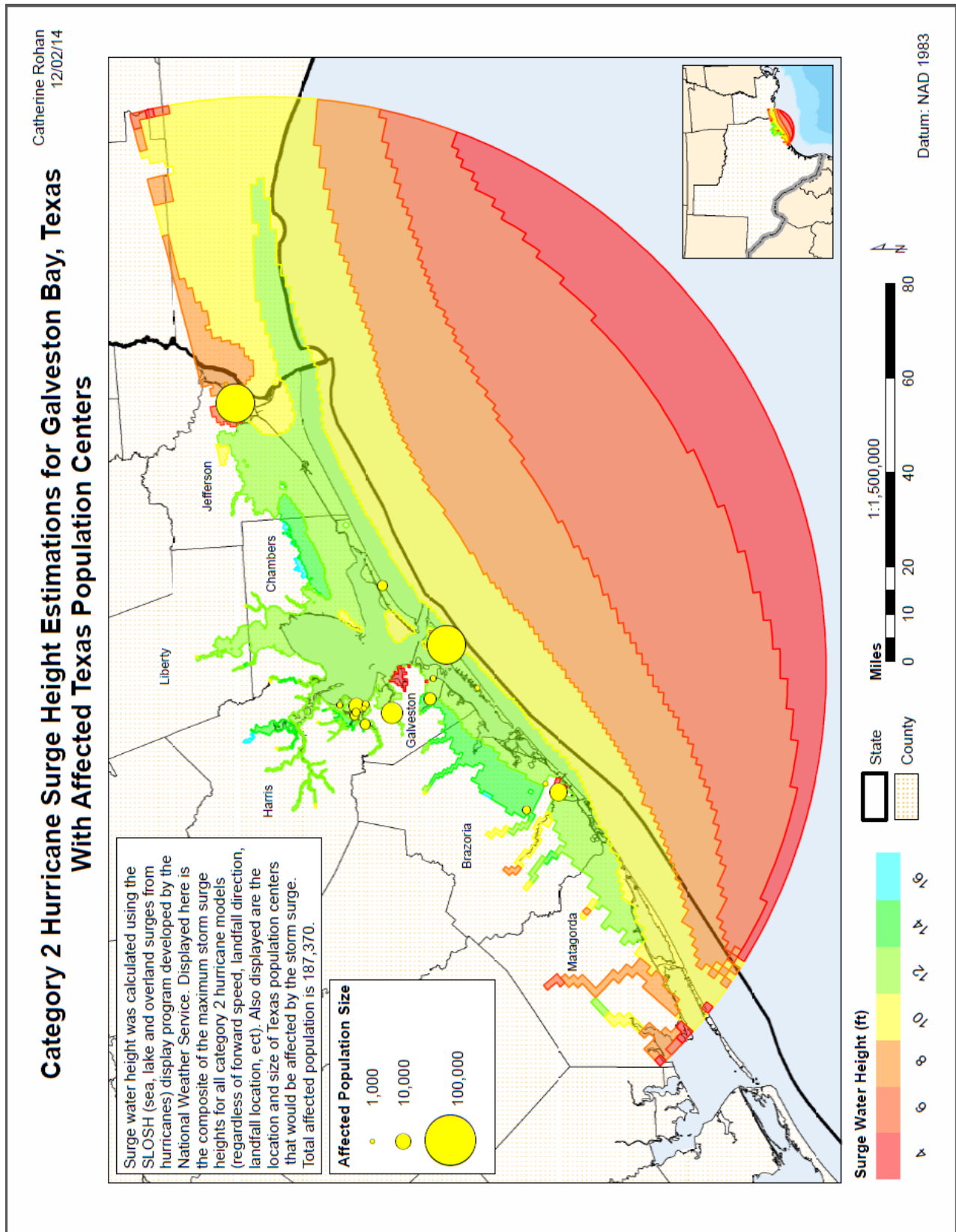
Figure 21: Category 5 storm surge height estimations with affected population centers
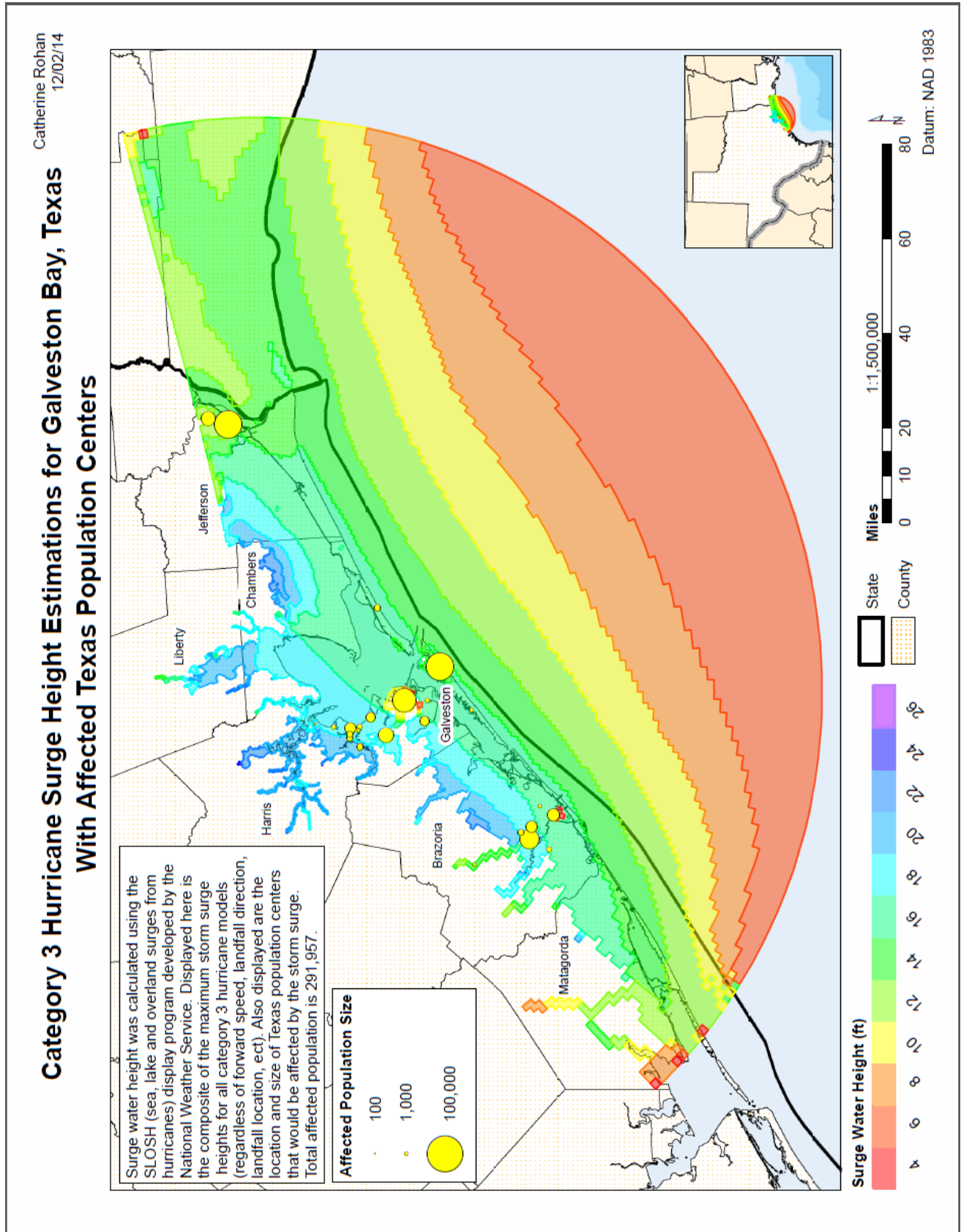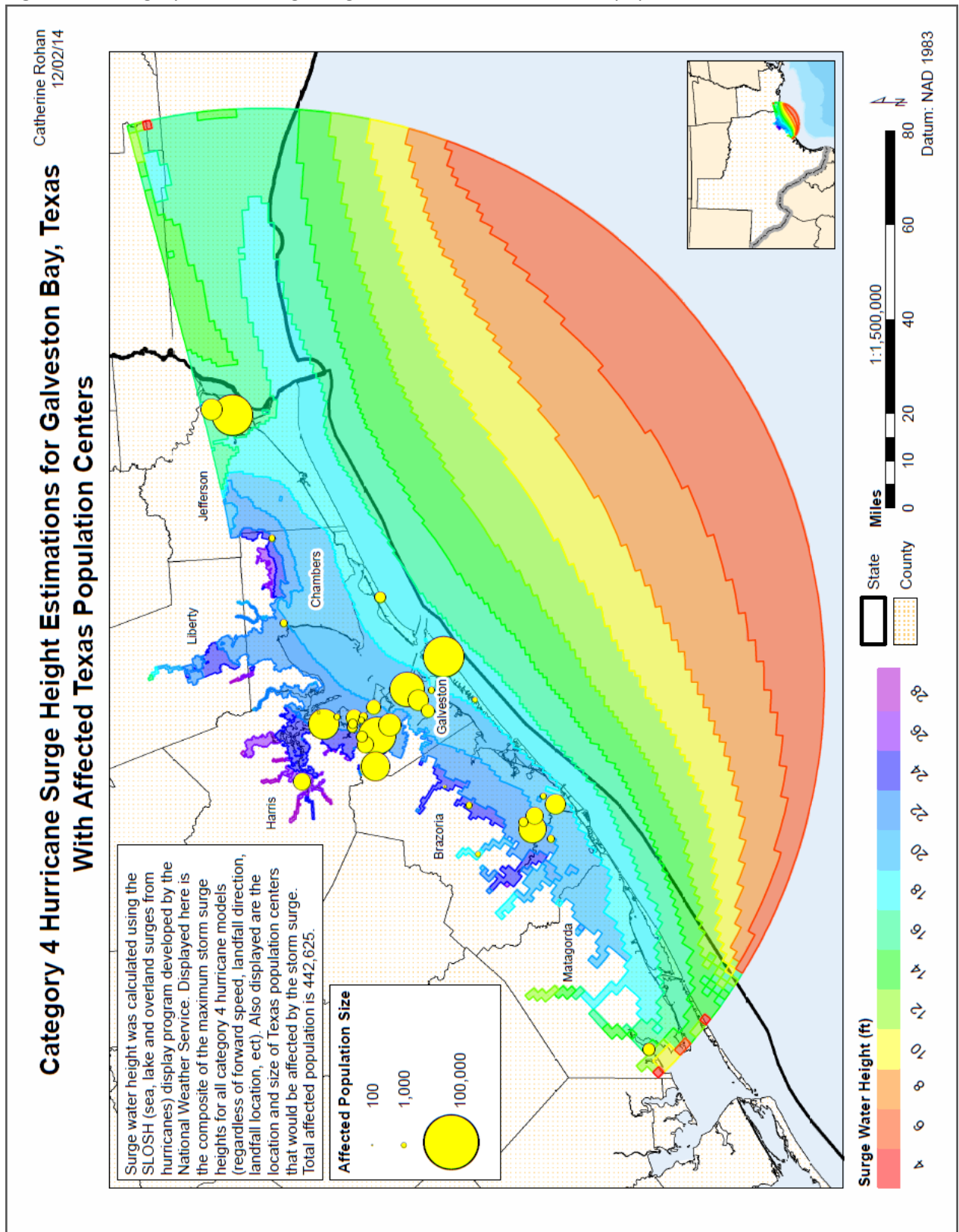

Category 5 Hurricane Surge Height Estimations for Galveston Bay, Texas
With Affected Texas Population Centers

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Surge water height was calculated using the SLOSH (sea, lake and overland surges from hurricanes) display program developed by the National Weather Service. Displayed here is the composite of the maximum storm surge heights for all category 5 hurricane models (regardless of forward speed, landfall direction, landfall location, ect). Also displayed are the location and size of Texas population centers that would be affected by the storm surge. Total affected population is 618,817.

Affected Population Size

100
1,000
100,000

Jefferson
Chambers
Liberty
Harris
Galveston
Brazoria
Matagorda

Surge Water Height (ft)

4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

State
County

Miles
0 10 20 40 60 80

1:1,500,000

Datum: NAD 1983