

# Modeling Sea Level Rise Along the Texas Gulf Coast:

Using Raster Data to Understand Climate Change  
and Population Dynamics in ArcGIS



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## 1. Problem Formulation

The Gulf Coast region of Texas is a highly populated area where petroleum collection and processing, fishing, and tourism all play a vital role to the success of the Texas economy. Due to its location along the coast (and thus its low elevation), most of the people living and working in this region are regularly at risk of flooding from seasonal hurricanes in the summer. While these storms present an immediate problem, there is a more long-term issue that threatens the Gulf Coast: sea level rise as a result of climate change.

Sea level rises from the combined effects of the thermal expansion of ocean water and the melting of land-based ice (i.e., glaciers and polar ice sheets) due to increasing global temperature. While this isn't the first time in Earth's history that sea level has risen from increased temperatures, the part that is concerning is the rate at which it is rising (Church and White, 2011). In a worst-case scenario, sea level is projected to rise by at least two meters (and possibly more) by 2100, (Rignot et al., 2011; Hansen et al., 2016) displacing a significant portion of the world's population (~10% of the global population lives in regions with elevations less than 10 meters (Fitzgerald et al., 2008)). Two meters in 80 years may not seem like much, but consider the fact that sea level has risen 120 meters to its current position since the end of the last glacial maximum ~21,000 years ago (Lambeck et al., 2014). This is an average of 350 years for a 2 meter rise, compared to today's projection of 80 years for an equivalent rise; in other words, sea level is rising about four times faster than it has since the last glacial maximum.

This realization is what motivates my study to understand how rising sea level will affect my home and possibly displace my family in the near future. **My aim is to map new possible coastlines according to sea level rises of 1-3 meters, 5 meters, and 10 meters, and estimate a corresponding population displacement for each rise, respectively. By assuming a constant rate of sea level rise (1 meter every 40 years), each map will allow us to predict when we can expect certain areas to become inundated, and the rate at which populations become displaced.** The results can be quantified as a measure of people displaced per "stage" of sea level rise. This information can be used to help communities understand their future hazards and mediate the associated risks of sea level rise, as well as prepare for life in a dramatically different environment from the one that exists today.

## 2. Data Collection

The first step is to acquire all the data necessary to perform this analysis. This includes DEMs from LiDAR raster data for the area of interest (from the USGS National Map), a shapefile containing points of Texas cities and population data from the 2010 Census (from the Texas Department of Transportation), a county outlines shapefile (from the USGS National Boundary Dataset), and a river shapefile and state of Texas hillshade (both from the Texas Water Development Board) to provide environmental context and use as a base map, respectively.

Figure 1 provides an example of what data collection from one of these download portals is like.

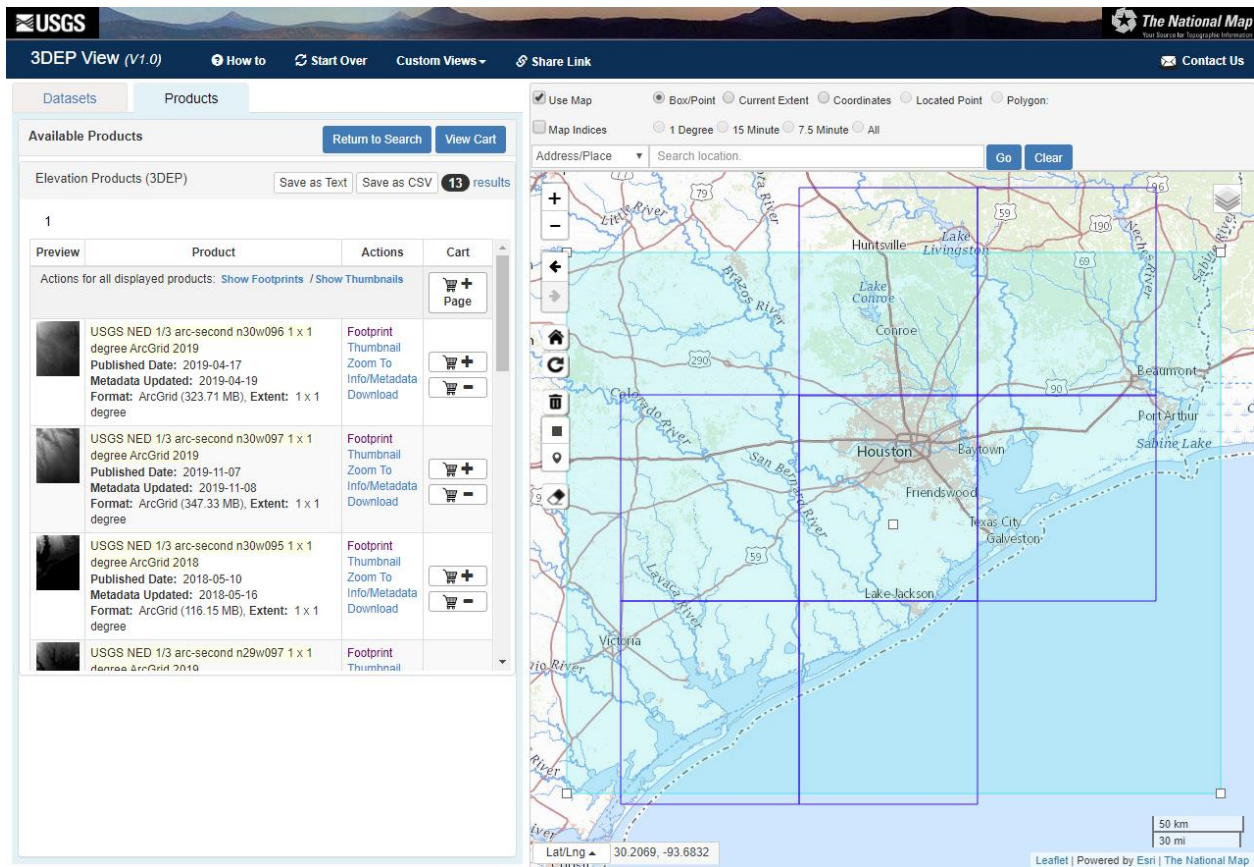
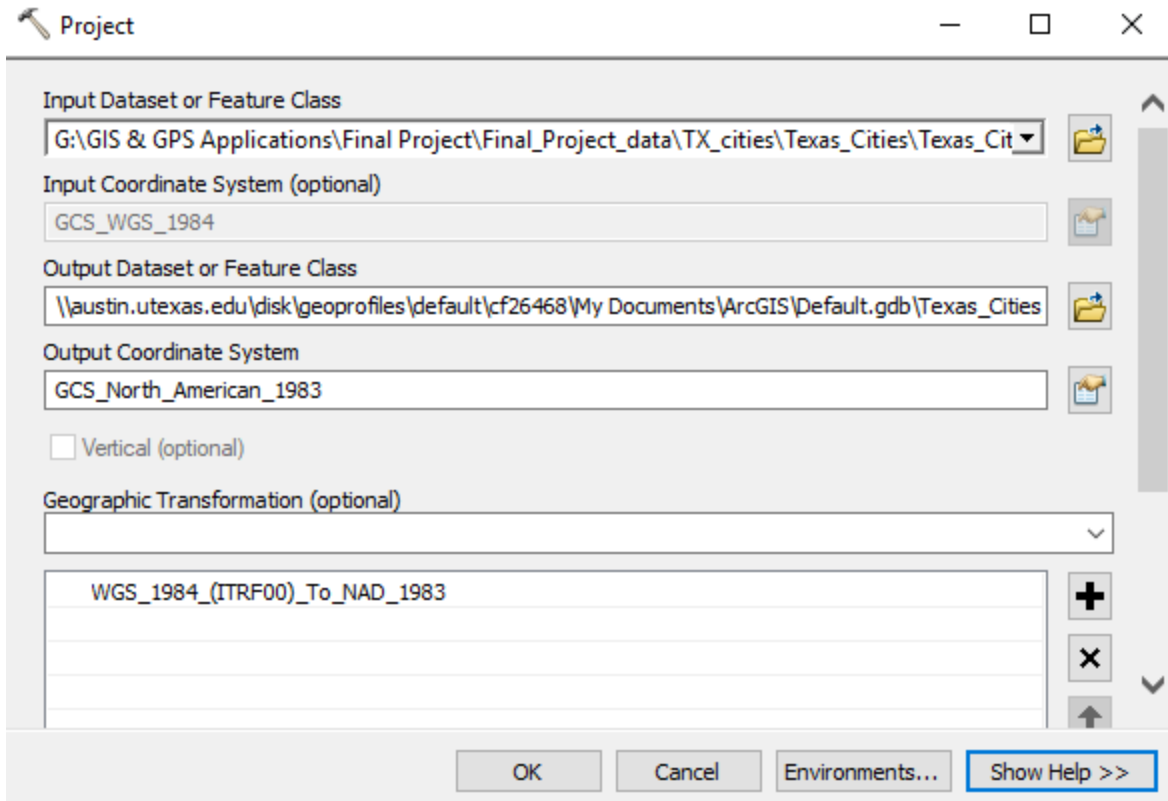


Figure 1. The USGS National Map Download portal. The map window shows footprints of the 1/3 arc-second DEMs that comprise the area of interest. Selecting the “Info/Metadata” link next to each footprint opens a new tab containing metadata for each file (along with a download link for the metadata file). Selecting the “Download” link downloads a zipped file which I later extracted into a folder made for all my DEM files within a larger project data folder. File organization and a consistent naming method for files is crucial to quickly and easily finding and processing the data in ArcMap.

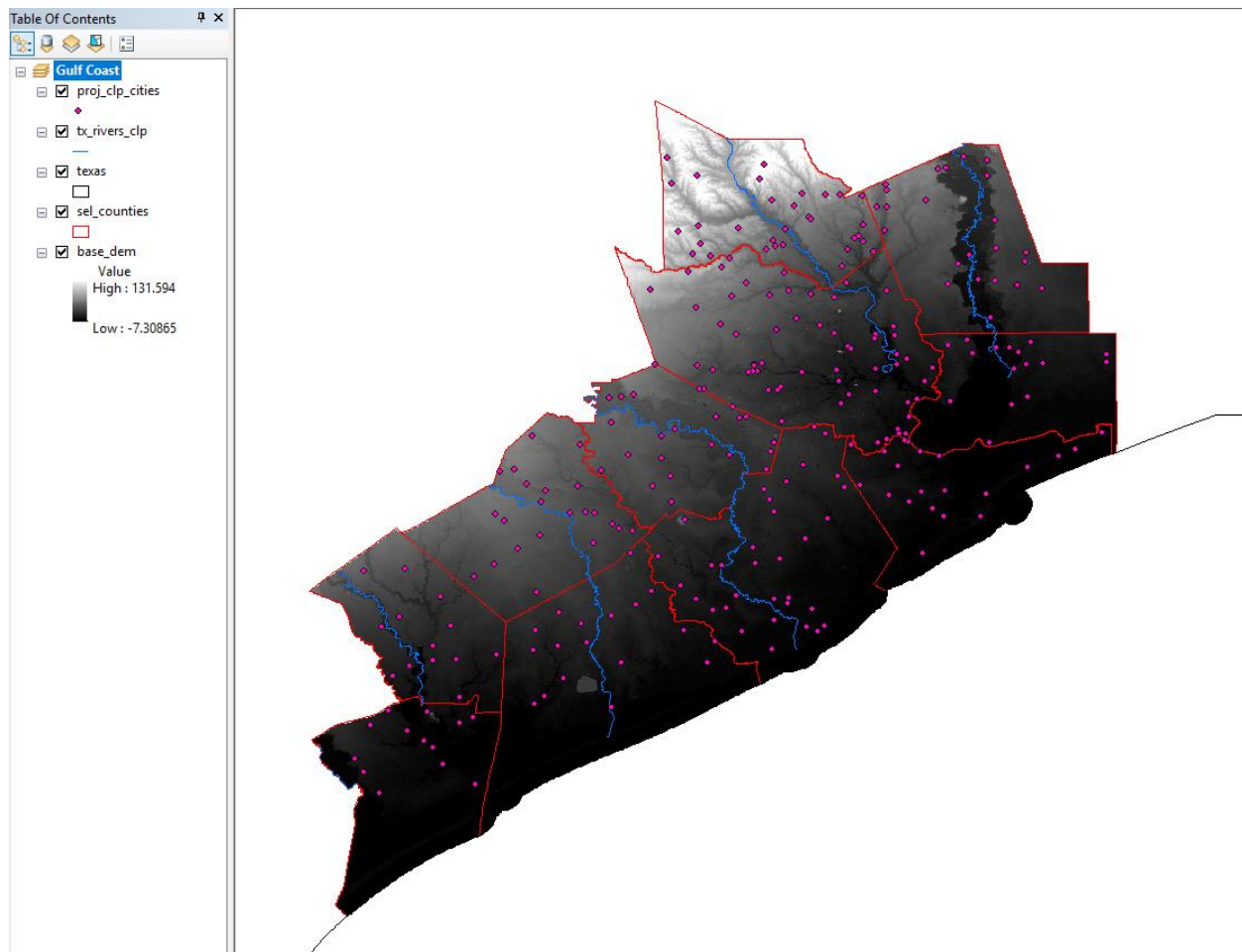
### 3. Data Preprocessing

Once all the files were downloaded and organized in their respective folders (I assigned a new folder for each “theme”), I loaded all the data into ArcMap. The first thing to do once all the data is imported into ArcMap (and arguably the most important) is to make sure the datums agree. Fortunately, only the cities shapefile datum did not conform with the rest; it was in WGS84 instead of NAD83. I used the “Project” tool (Data Management > Projections and Transformations > Project, Fig. 2) and added the now properly projected cities feature into the Table of Contents, and removed the old copy.



**Figure 2.** Using Project to convert the cities shapefile into the proper datum. Without this step, the cities would not be in the correct location with respect to the rest of the features on the map (including the coastline). This would affect the sea level rise interval at which certain coastal cities would become submerged.

Another problem with the data is that the DEMs are not represented on a uniform scale; each raster has a different high and low value, which would affect the symbology of the elevation and my calculation of sea level across the area of interest. I used the “Mosaic to New Raster” tool (Data Management > Raster > Raster Dataset > Mosaic to New Raster) to stitch all the DEMs together into one large dataset with a uniform high and low. The shapefile download from the Department of Transportation of counties includes an outline for the state of Texas which I simply loaded into the map window. I then used the Select by Location function to select the counties of interest which fall entirely within the mosaic (Brazoria, Calhoun, Chambers, Fort Bend, Galveston, Harris, Jackson, Liberty, Matagorda, Montgomery, and Wharton counties) and got an outline of these counties. This important new feature will be the cookie cutter we use to clip the rest of our data. **Figure 3** shows the final result of this preprocessing.

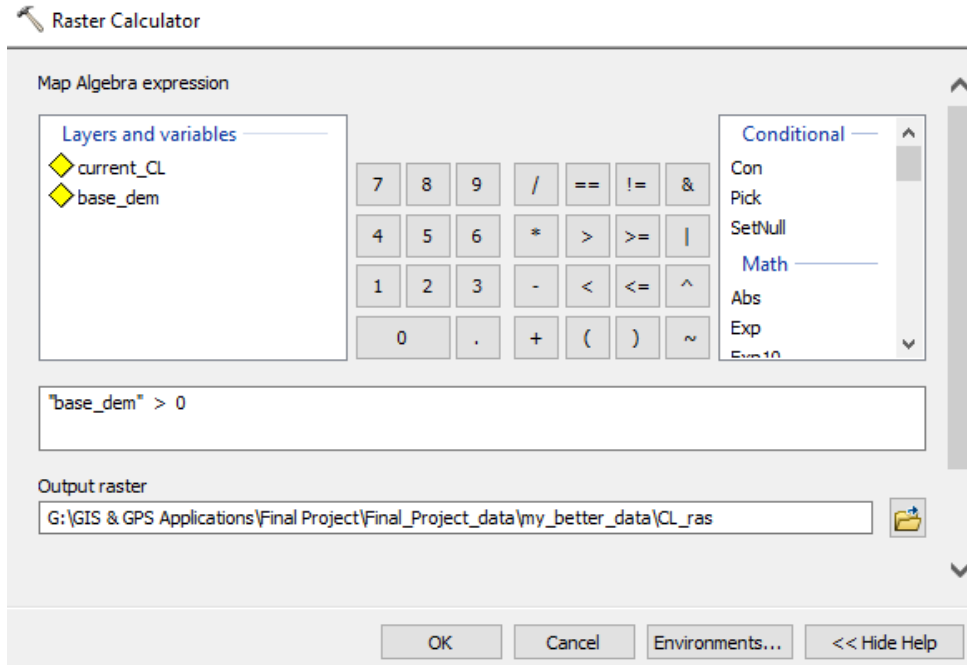


**Figure 3.** The final result of all data preprocessing. Note that the DEM raster conforms to one gradient with a uniform high and low (get comfortable during this step; such a large dataset takes several minutes to process). “sel\_counties” is the feature I used to clip the cities, rivers, and base DEM; I made this feature by using the Select by Location function under the “Selection” tab to choose the counties near the coast that were entirely contained within the DEM. Once I reached this step, I was ready to begin putting together rasters to represent different sea level rises.

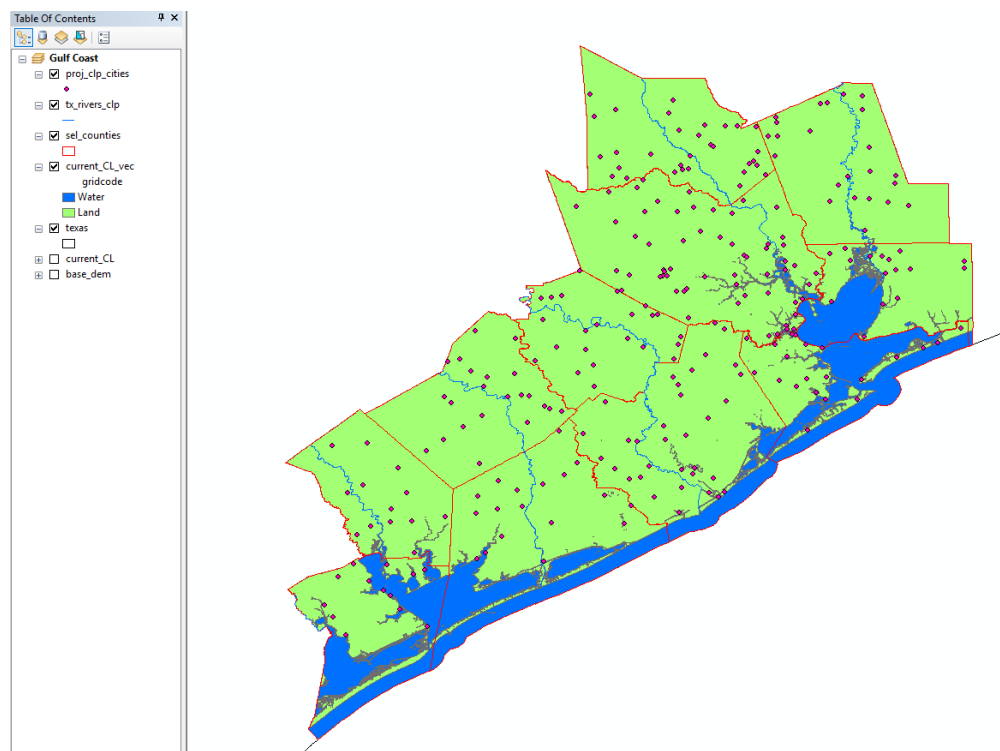
#### 4. ArcGIS Processing

Now that all of the data is contained within the area of interest, we can begin representing elevation. This dataset still does not include a coastline, which is what we are trying to map. The all-important “Raster Calculator” tool (Spatial Analyst > Map Algebra > Raster Calculator) is very useful here; note that you must have the Spatial Analyst extension enabled to use this tool. **Figure 4a** shows the expression in the tool to return the intended output raster that represents a very detailed present coastline. I then used the “Raster to Polygon” tool (Conversion Tools > From Raster > Raster to Polygon) to convert this output raster into a vector polygon feature. Be sure to choose “Value” under the “Field” field, and check the simplify polygons box to simplify the polygons into smoother shapes. **Figure 4b** shows the result of this vectorization.

a)



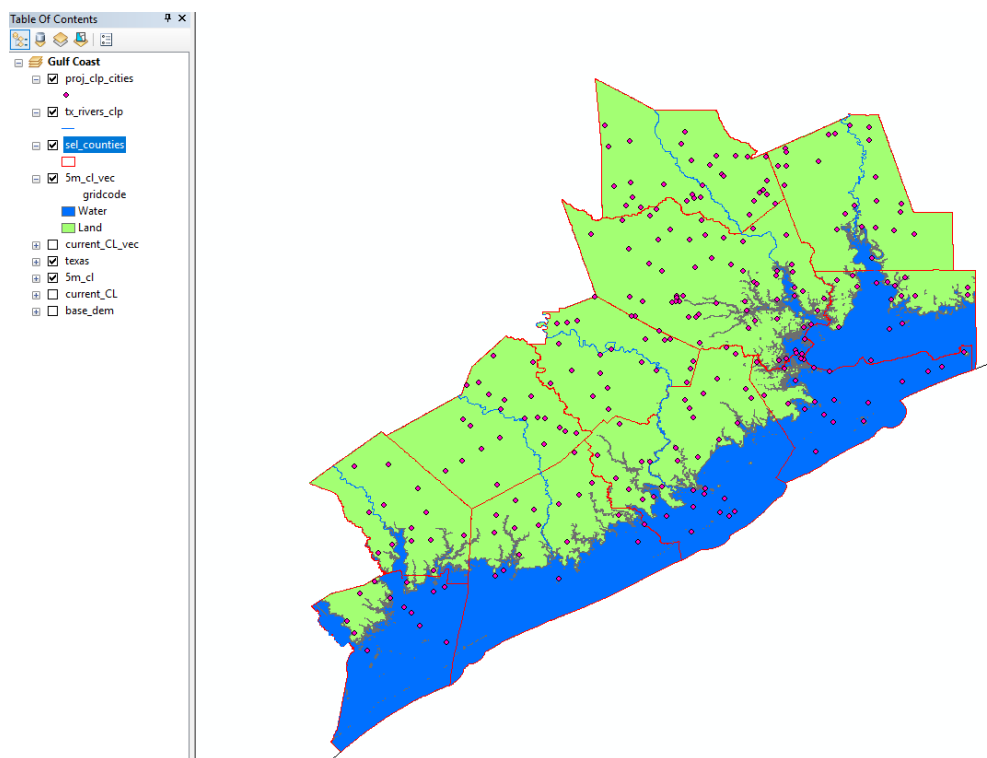
b)



**Figure 4. a)** Raster Calculator showing the expression which returns a raster showing the cells which are greater than 0 (i.e., cells which correspond to land) and less than 0 (i.e., cells which correspond to water), and **b)** the result of using Raster to Polygon to vectorize the output raster from **4a**. This represents the current coastline of the area of interest along the Gulf Coast. Note the number of cities that lie right on the coastline; these are highly at risk of sea level rise.

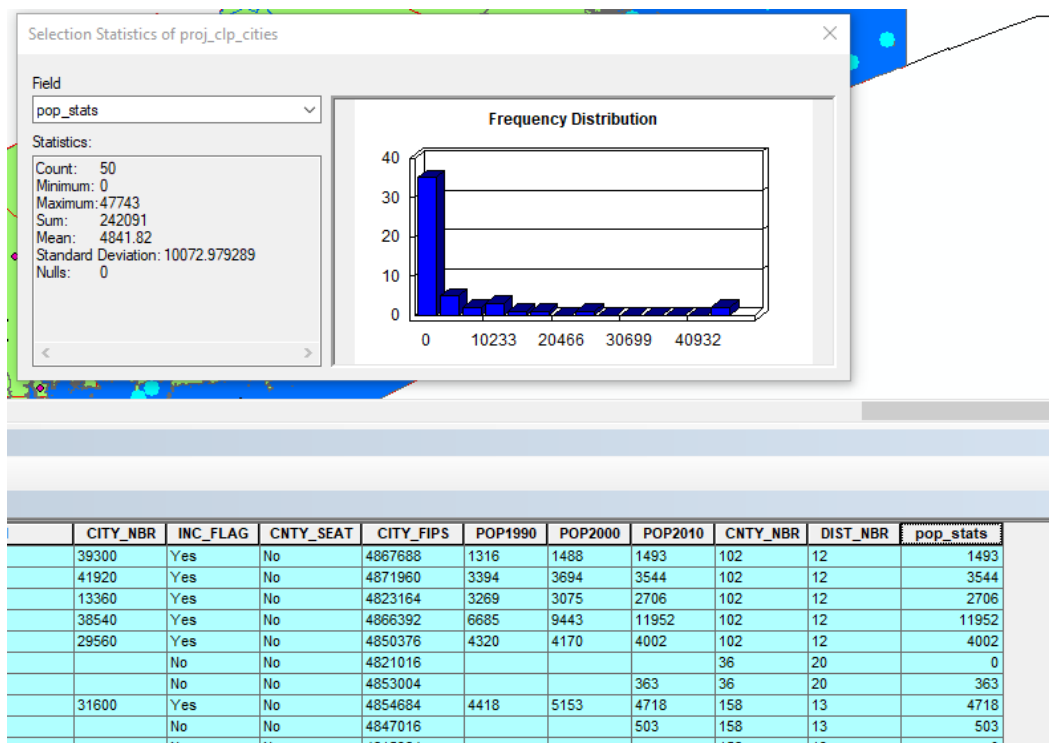
The procedure to obtain new coastlines for each stage of sea level rise (remember, we want a coastline corresponding to a rise of 1 meter, 2 meters, 3 meters, 5 meters, and 10 meters) is very similar to the way we got the current coastline. The only difference is the expression plugged into Raster Calculator. If “base\_dem > 0” returns a representation of the cells which are above and below an elevation of 0 (i.e., sea level), then “base\_dem > 1” should return the cells which are above and below an elevation of 1. Sea level rising by 1 meter moves the “0 elevation” boundary up by one meter; by using the Con function in Map Algebra we can find an outline of where this condition holds true, and this is how we will model sea level rise for each interval. This method has its limitations, a discussion of which follows at the end of the report. For the scope of this project, however, this should be an appropriate approximation of how we can expect the coastline to change over time as sea level rises at its current, constant rate.

I performed this set of steps (using Raster Calculator, then vectorizing the output raster) five more times to get the coastline that results from shifting sea level up by 1-3 meters, 5 meters, and 10 meters by using the appropriate rise interval in the Raster Calculator expression. The final maps that represent these sea level rises are included in **Figures 8-12**; for the simplicity’s sake in the remainder of the report, we will look at a rise of 5 meters as our exemplar, but note that the analysis that follows was repeated for each interval of sea level rise. **Figure 5** shows the result of raster calculation and vectorization for a 5 meter sea level rise.



**Figure 5.** The expression “Con(“base\_dem”, 1, 0, “VALUE > 5.0”) returns a raster that gives a value of 1 in cells where the “VALUE” field of “base\_dem” is greater than 5, and a value of 0 in cells where it is less 5. Vectorization gives a smoother image of a coastline risen by 5 meters.

It is clear to see that multiple cities lie on elevations of less than 5 meters, and are now submerged underwater. Our goal is to find out the total population of people living in all of these submerged cities; this gives us the number of people that would be displaced for a sea level rise of 5 meters. Using the expression "SELECT FROM 5m\_cl\_vec WHERE: "gridcode" = 0" in the Select by Attribute function selects all water polygons within the vectorized 5 meter sea level rise shapefile. Then I exported this selection into a new shapefile and added it to the map. Now I can run Select by Location to find all cities that are contained within these water polygons. My next step would be to right click the field "POP2010" in the selected records of the cities attribute table, but this cannot be done because (for some reason) POP2010 is classified as a string value rather than a numeric value. A quick workaround is to simply add a new field and use "Field Calculator" to populate it with values from POP2010, making sure to classify the new field as numeric. Finally, I can right click the new field's header and choose "Statistics" to find the total population of all cities with population data that fall within the water polygons: 242,091 people. This value (along with the values for population that falls within the water polygons for a 1 meter, 2 meter, 3 meter, and 10 meter rise) will go into a table that records the increasing number of displaced people as sea level rises. **Figure 6** shows the summary statistics of the cities inside the 5 meter water polygons.



**Figure 6.** The summary statistic window for the cities that fall within the 5 meter sea level rise. The sum value of 242,091 is the total number of people living in these selected cities, and this value will be analyzed against rising sea level along with the other population values for the rest of the intervals. The field "pop\_stats" is the new field I added and populated with the values from "POP2010".

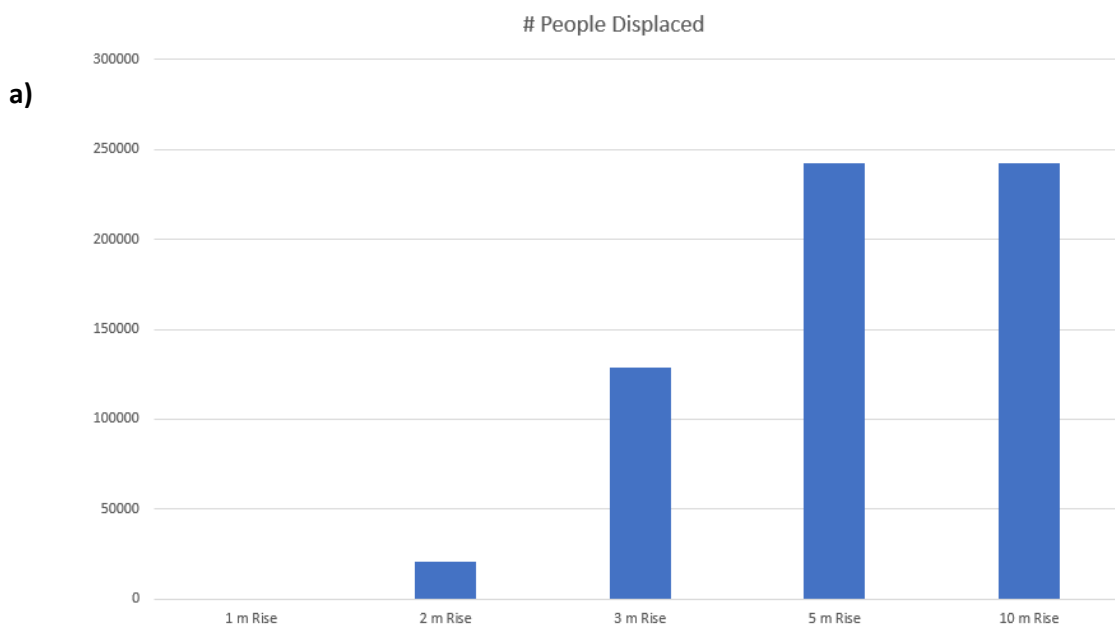


## 5. Data Presentation

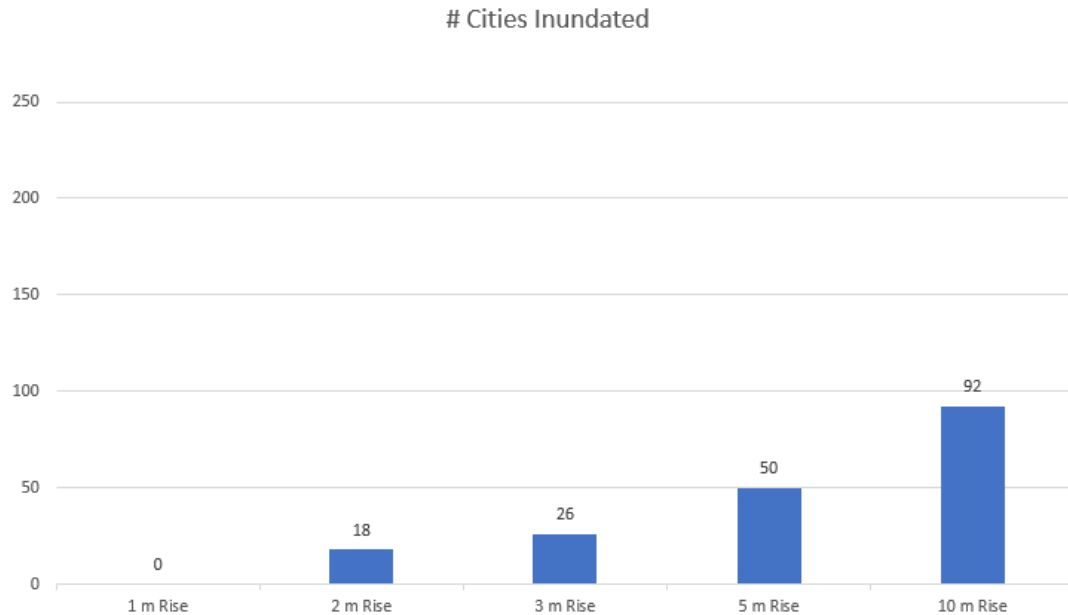
**Table 1** reflects the results of following through with the process of vectorizing the output raster of our calculation and selecting the cities that are contained within the water polygons for each sea level rise interval. The same data is graphed in **Figure 7**.

	1 m Rise	2 m Rise	3 m Rise	5 m Rise	10 m Rise
# People Displaced	0	20,798	128,428	242,091	242,091
# Cities Inundated	0	18	26	50	92
% of Total Cities	0	6.6	9.6	18.4	33.8

**Table 1.** Populations displaced, number of cities submerged underwater, and percentage of total cities ( $n = 272$ ) within the area of interest that become submerged. Some more limitations of the dataset are revealed here; number of people displaced doesn't increase from a 5 meter rise to a 10 meter rise even though the number of inundated cities almost doubles. This is because many of the smaller cities within the area of study did not come with census data in the attribute table.



b)

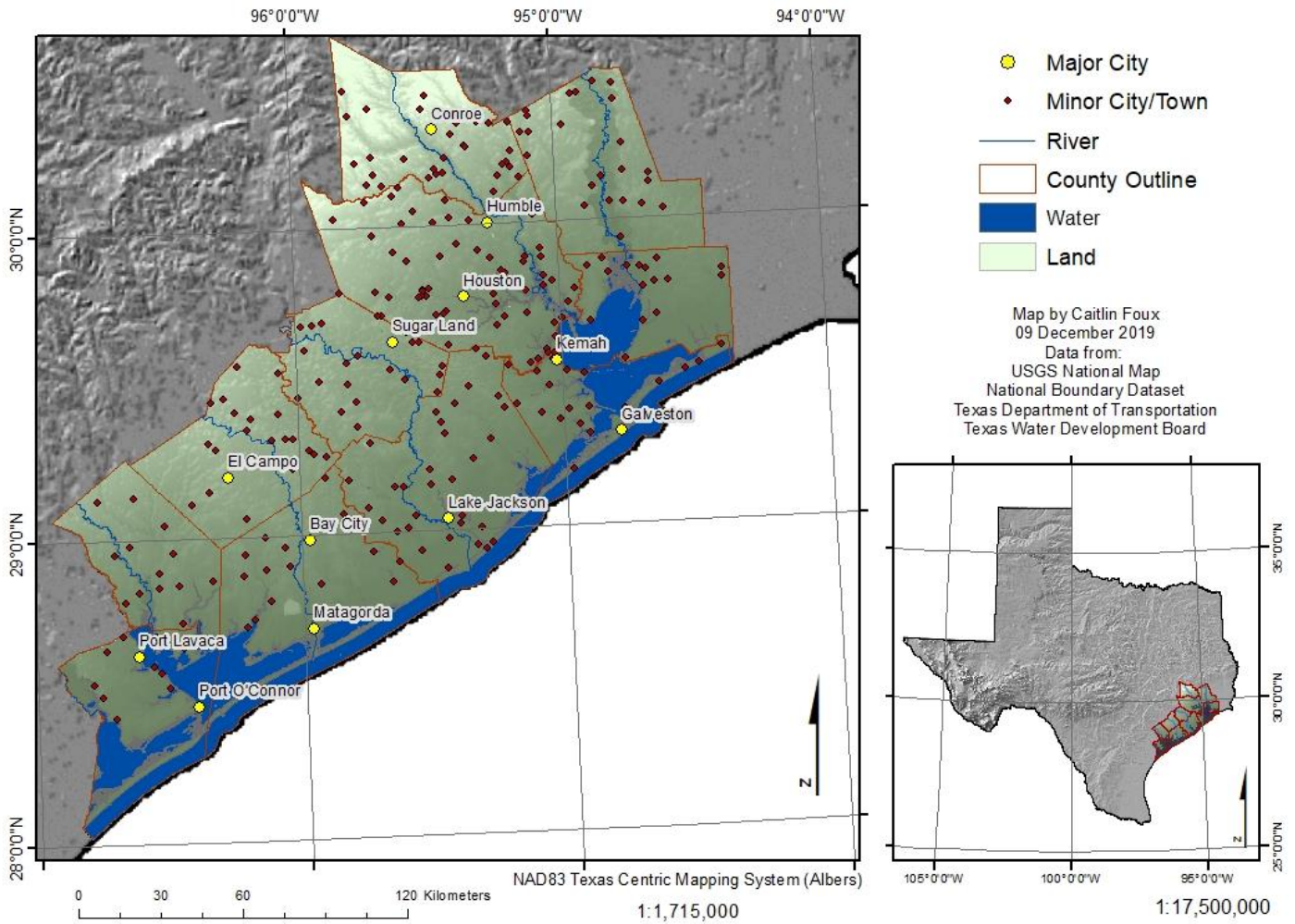


**Figure 7. a)** Number of people displaced per interval sea level rise. This data is not entirely accurate due to a lack of population data for every city in the dataset. **b)** Number of cities inundated per interval sea level rise. Plotting sea level rise this way provides a more inclusive view of the number of communities that will be affected, but takes away the ability to understand the number of people displaced with every sea level rise.

**Figures 8-12** are a collection of maps which detail the progressive sea level rise along the Texas Gulf Coast in the context of amount of land inundated and as a changing coastline. An in-depth discussion of these maps is presented in the following section. In order to put these maps together, I had to project all the data into a projected coordinate system (as all of our analysis so far has been performed on data that has only been assigned a datum, not a XY coordinate system). I chose the Texas Centric Mapping System (Albers) because it uses the NAD83 datum that all of my data are already in and there is little areal distortion. I mapped the area of inundated land by using Raster Calculator to subtract the current sea level DEM (**Fig. 4b**) from each of the sea level rise DEMs (**Fig. 5**) to get the difference between the two (i.e., the area where water overlaps between the two rasters). From here, putting together the maps is simply a matter of choosing a visually effective and pleasing color and symbology scheme that is readable on a letter-size page. I have chosen to make each of my maps full-size to maximize readability and clarity.

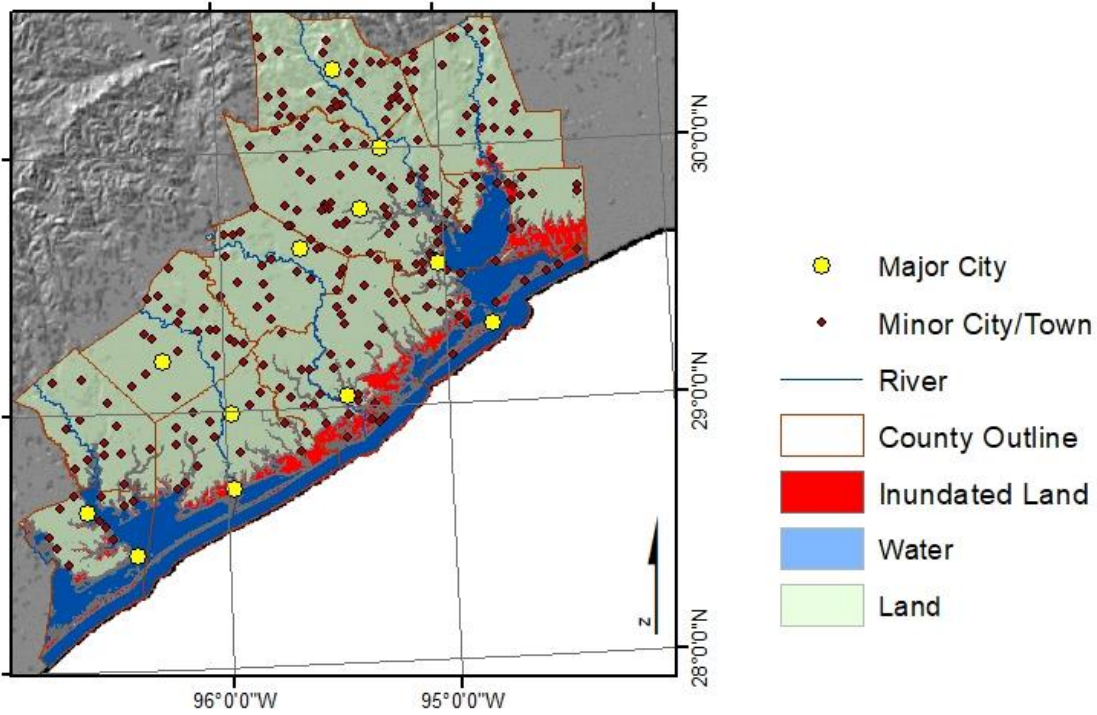
I chose not to represent the changing coastline for a sea level rise of 1 meter because no cities become submerged for a sea level rise of this magnitude, thus there is no displaced population.

## Central Texas Gulf Coast: Area of Study

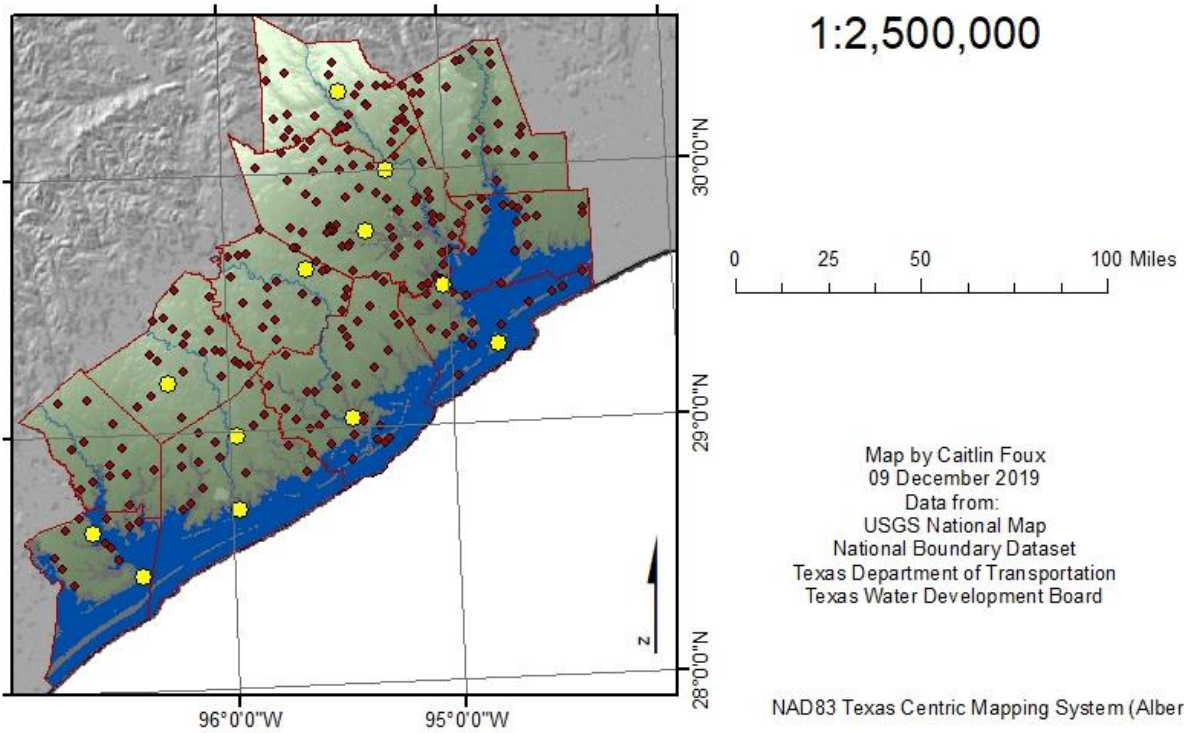


**Figure 8.** Map showing the location of the area of study along the Texas Gulf Coast. Cities important to Texas economy are symbolized in yellow. Total number of cities is 272.

## Two Meter Sea Level Rise

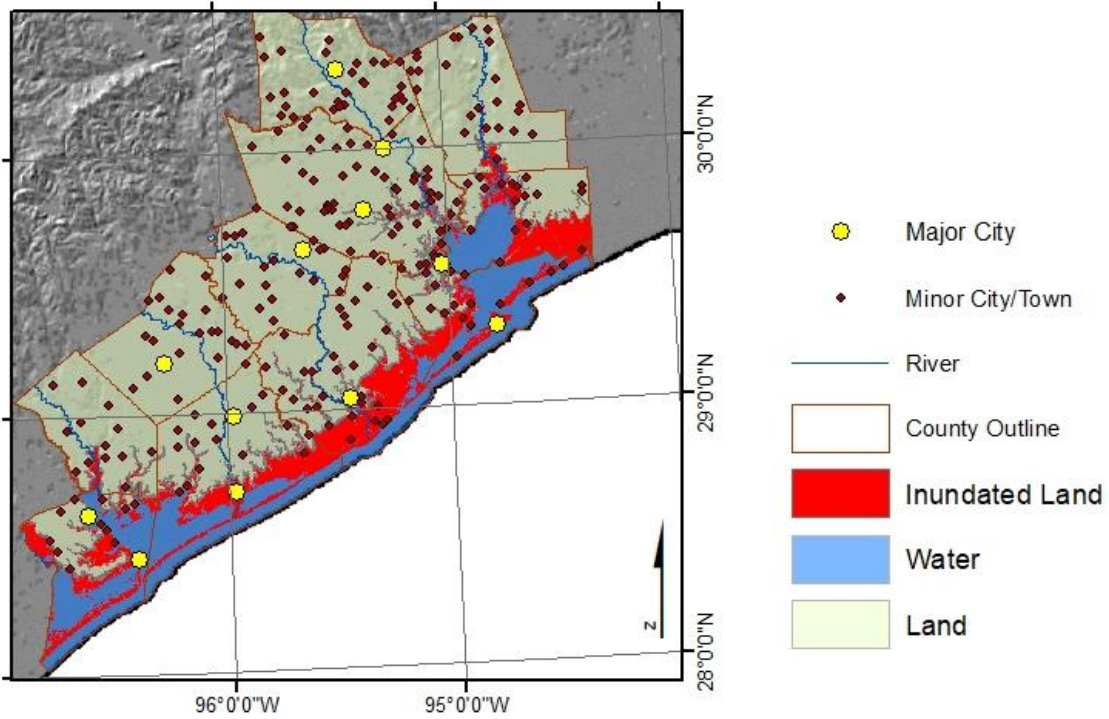


## New Coast Line in 2100

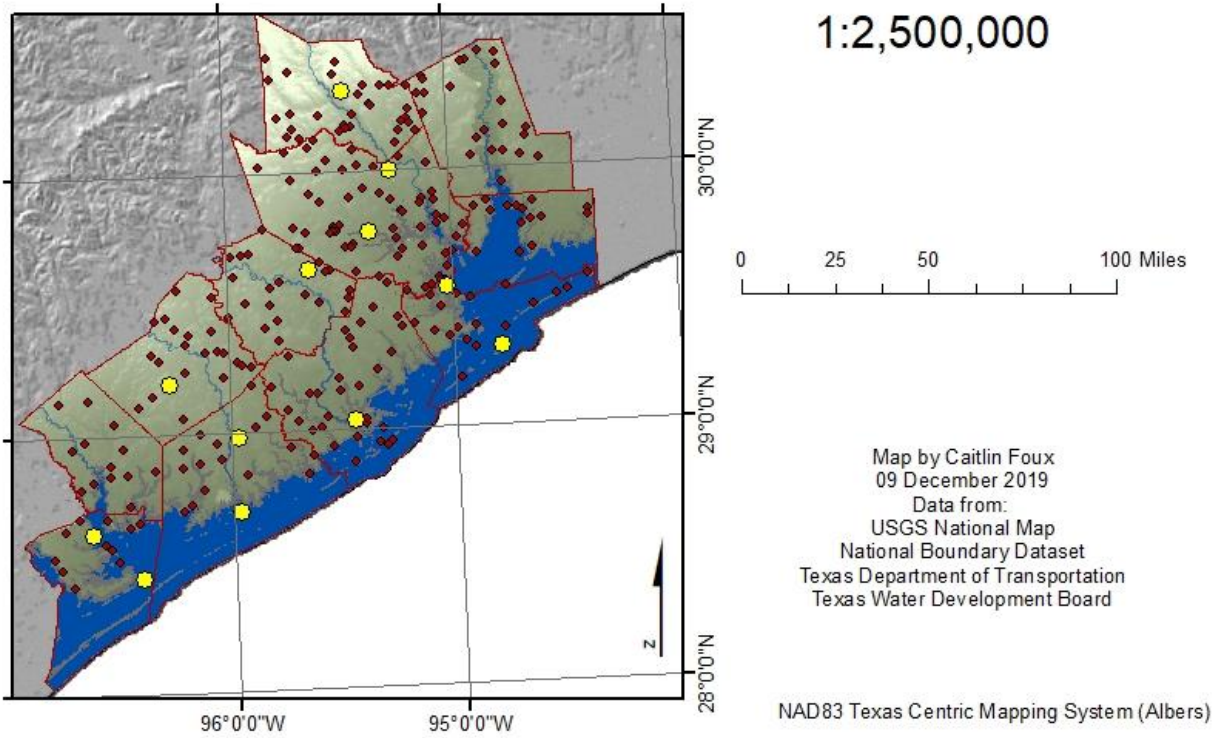


**Figure 9.** Maps showing the area of land that becomes submerged by a 2 meter sea level rise, and the resulting new coast line that can be expected by 2100 if sea levels continues at today's constant rate.

### Three Meter Sea Level Rise

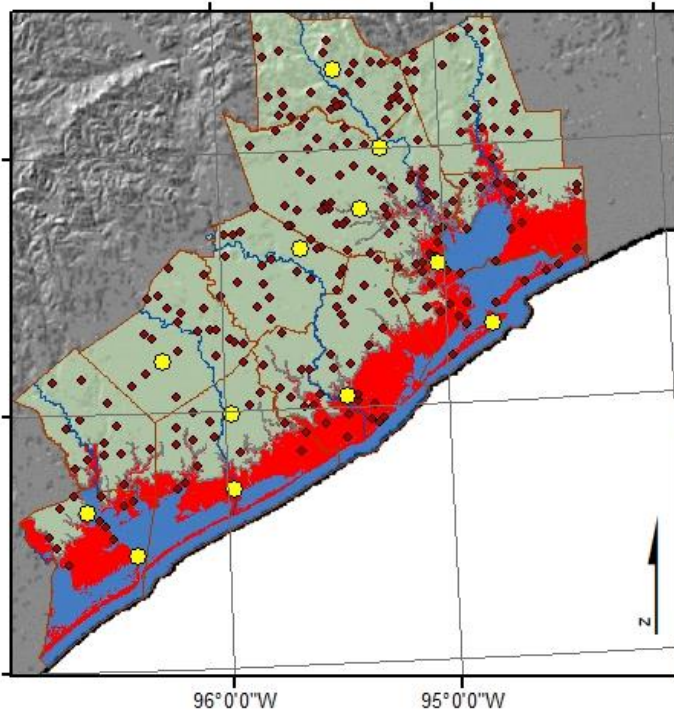


### New Coast Line in 2140



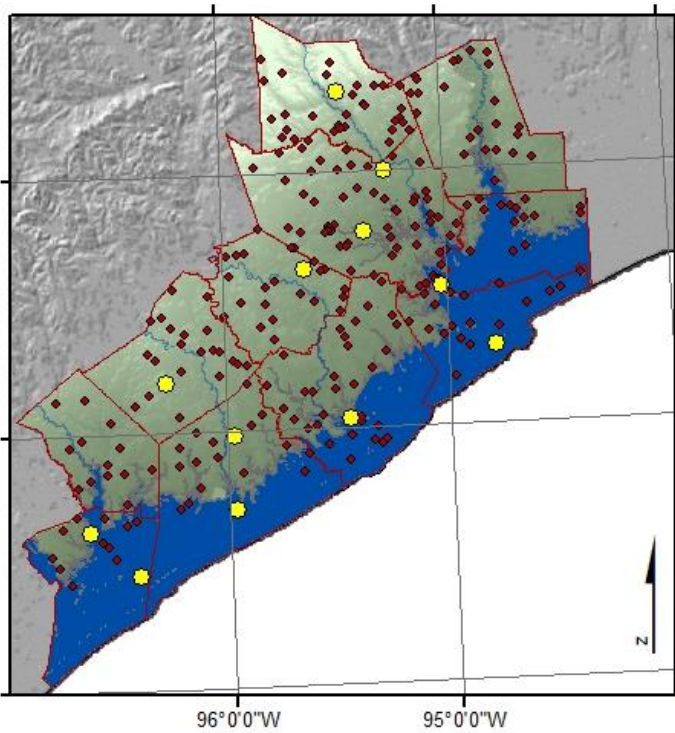
**Figure 10.** Maps showing the area of land that becomes submerged by a 3 meter sea level rise, and the resulting new coast line that can be expected by 2140 if sea levels continues at today's constant rate.

### Five Meter Sea Level Rise



- Major City
- Minor City/Town
- River
- County Outline
- Inundated Land
- Water
- Land

### New Coast Line in 2220



1:2,500,000

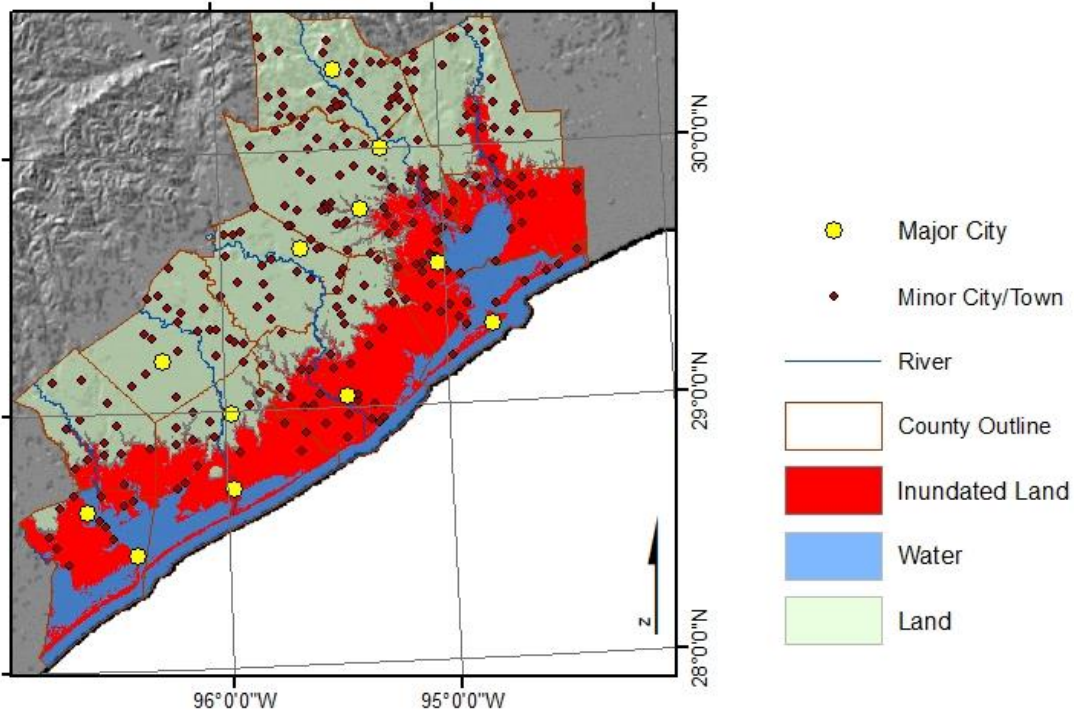
0 25 50 100 Miles

Map by Caitlin Foux  
09 December 2019  
Data from:  
USGS National Map  
National Boundary Dataset  
Texas Department of Transportation  
Texas Water Development Board

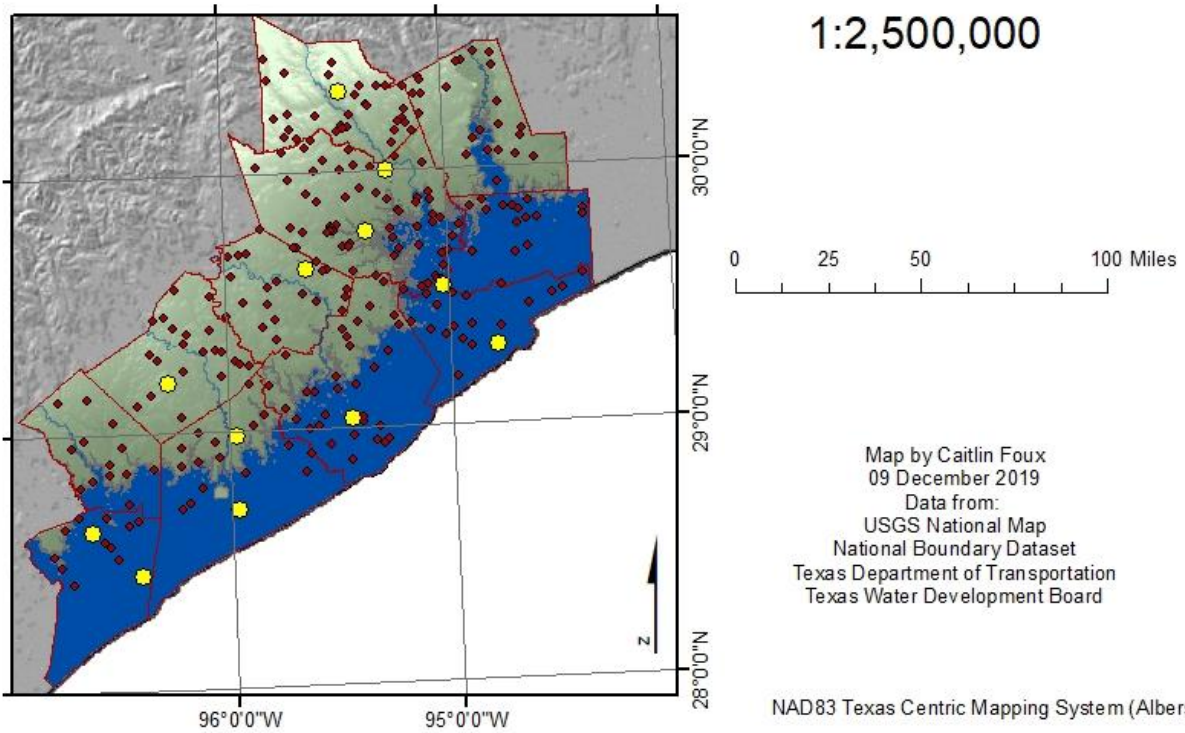
NAD83 Texas Centric Mapping System (Albers)

**Figure 11.** Maps showing the area of land that becomes submerged by a 5 meter sea level rise, and the resulting new coast line that can be expected by 2220 if sea levels continues at today's constant rate.

### Ten Meter Sea Level Rise



### New Coast Line in 2420



**Figure 12.** Maps showing the area of land that becomes submerged by a 10 meter sea level rise, and the resulting new coast line that can be expected by 2420 if sea levels continues at today's constant rate.

## 6. Discussion

To recap, my original goal was to map new possible coastlines for sea level rises of particular magnitudes (1-3 meters, 5 meters, and 10 meters) along the Texas Gulf Coast at specific points in the future, given that the current rate of sea level rise remains at the constant rate of today's 1 meter rise every ~40 years. I also set out to understand these environmental changes in the context of population dynamics to get an estimate of population displacement caused by these changes in terms of people displaced per interval sea level rise.

As mentioned previously, I chose not to include a map showing the sea level rise for one meter because, as it turns out, a rise of this magnitude does not result in any displacement. Even a lack of data here can be useful though; we can estimate that there is a minimum of one meter of vertical space separating the coast from people living at the lowest coastal elevations; if it takes 40 years for sea to rise by this much, then we have at least until 2060 until communities are seriously at risk of flooding and displacement.

In 2100 we predict a sea level rise of two meters. At this point, 6.6% of the total number of cities becomes inundated, displacing ~20,000 people. Herein lies the first crucial limitation of the study. Choosing to map sea level rises by the meter returns a fairly coarse temporal resolution for understanding how people will begin to be affected by rising sea level, and a more thorough understanding of the nature of this sea level rise requires its mapping on a finer (centimeter) scale. The data for this type of analysis exists; in fact, the resolution of my DEMs are likely capable of this type of fine-tuned analysis, but in the interest of simplicity and time management I chose to stick with a coarser temporal resolution.

From a rise of three meters all the way to ten meters, the coast begins to change dramatically; most of Galveston goes underwater first, and the bay area southeast of Houston moves further inland. Matagorda, Port O'Connor, Port Lavaca and Kemah now lie under shallow ocean water as well, and the characteristic protected bays and lagoons disappear as the barrier islands get washed away. By 2420 (corresponding to a ten meter sea level rise), new features begin to form; a long bay reaches inland on the far northeast side of the study area, and many cities present just 400 years earlier are now submerged and (hopefully) abandoned.

An important complication is the fact that in the real world, the rate of sea level rise would almost certainly not remain constant. However, modeling the factors that control the rate of sea level change and including them in this analysis are beyond the scope of this assignment, so I decided to approximate it as remaining constant at a fixed rate through time. In addition to simplifying real world processes, it must be noted that the forces that shape the Texas Gulf Coast will likely continue to do so in the future, thus affecting the nature of the landscape that forms; that is, the new coastline will not be solely dependent upon the amount that sea level rises.

As for issues with the data itself, two major sources of concern surround the significant lack of population data. Not only are these population counts almost ten years old, they are also absent for consequential amount of the cities I included in the analysis. As a result, the number of people displaced as a result of sea level rise in these models are without a doubt severe



underestimates. The other problem lies in the intervals with which I chose to model sea level rise. The significant jump in the number of people displaced between 2 and 3 meter sea level rises is almost 100,000. Clearly, some big changes are happening in places where people reside, and as described before, the temporal resolution that these rise intervals suggest is not fine enough to disentangle the nuances of population displacement in these circumstances.

Despite the numerous inconsistencies, complications, and limitations of this particular case study, it is still clear to see that the people living along the Gulf Coast of Texas will be facing a significant hazard in the near future, and studies like these can help us understand how to prepare for and handle the environmental risks associated with climate change not just on the Gulf Coast, but in any densely populated coastal communities.

## 7. References

- Church, J. A., and White, N. J. (2011). Sea-Level Rise from the Late 19th to the Early 21st Century. *Surveys in Geophysics*, 32(4-5), 585–602.
- Fitzgerald, D.M., Fenster, M.S., Argow, B.A., Buynevich, I.V. (2008). Coastal Impacts Due to Sea Level Rise. *Annual Review of Earth and Planetary Sciences* 36: 601-647.
- Hansen, J., Sato, M., Hearty, P., Ruedy, R., Kelley, M., Masson-Delmotte, V., Russell, G., Tselioudis, G., Cao, J., Rignot, E., Velicogna, I., Tormey, B., Donovan, B., Kandiano, E., von Schuckmann, K., Kharecha, P., Legrande, A. N., Bauer, M., Lo, K. (2016). Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous. *Atmospheric Chemistry and Physics*. 16 (6): 3761–3812.
- Lambeck, K., Rouby, H., Purcell, A., Sun, Y., Sambridge, M. (2014). Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. *Proceedings of the National Academy of Sciences of the United States of America*. 111 (43): 15296–15303.
- Rignot, E., Velicogna, I., van den Broeke, M.R., Monaghan, A., Lenaerts, J.T.M. (2011). Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters* 38 (5).
- U.S. Geological Survey, 20190417, USGS NED 1/3 arc-second n30w096 1 x 1 degree ArcGrid 2019: U.S. Geological Survey.
- U.S. Geological Survey, 20191107, USGS NED 1/3 arc-second n30w097 1 x 1 degree ArcGrid 2019: U.S. Geological Survey.
- U.S. Geological Survey, 20180510, USGS NED 1/3 arc-second n30w095 1 x 1 degree ArcGrid 2018: U.S. Geological Survey.
- U.S. Geological Survey, 20190731, USGS NED 1/3 arc-second n29w097 1 x 1 degree ArcGrid 2019: U.S. Geological Survey.
- U.S. Geological Survey, 20190613, USGS NED 1/3 arc-second n29w096 1 x 1 degree ArcGrid 2019: U.S. Geological Survey.

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U.S. Geological Survey, 20180618, USGS NED 1/3 arc-second n31w095 1 x 1 degree ArcGrid  
2018: U.S. Geological Survey.

U.S. Geological Survey, National Geospatial Technical Operations Center, 20191112, USGS  
National Boundary Dataset (NBD) in Texas 20191112 State or Territory Shapefile: U.S. Geological  
Survey.