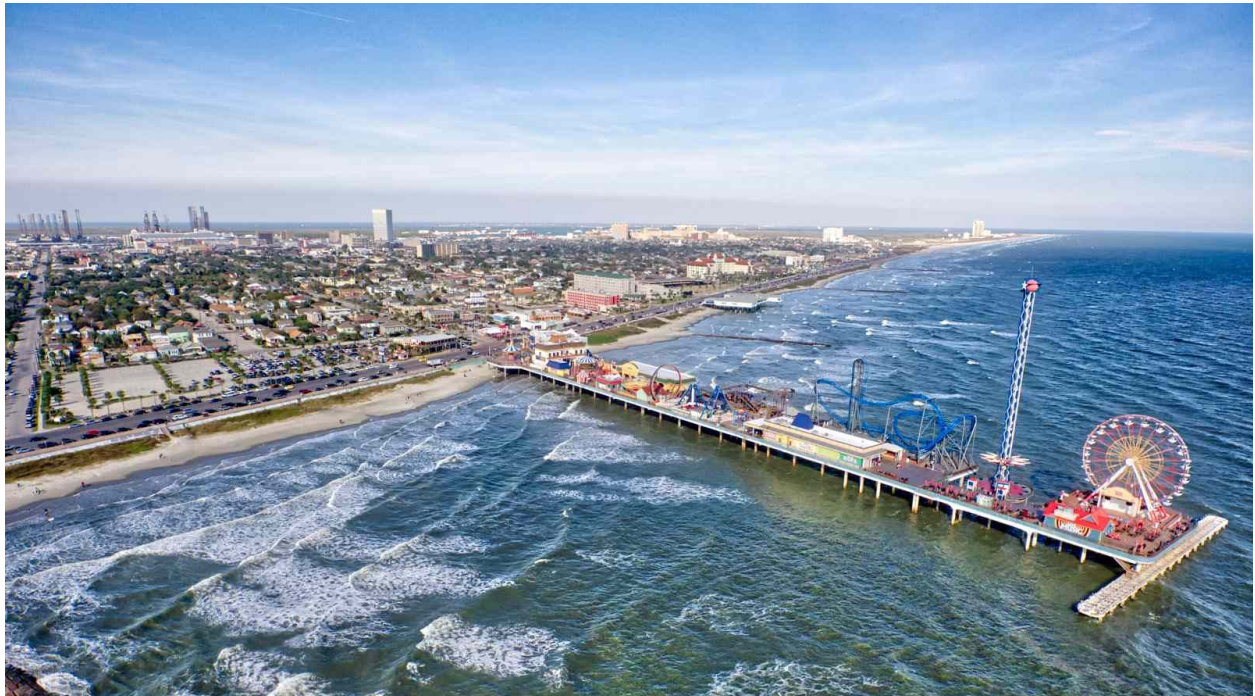


Effects of Sea Level Rise on the Texas Gulf Coast

An ArcGIS Suite Analysis



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GEO 327G: GIS and GPS Applications in Earth Science

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INTRODUCTION

Climate change is arguably the most important issue of our generation, and should be especially high on Texas's list of concerns as we approach the year 2100. One of the most pressing issues affecting Texas as a result of climate change is the potential increase in sea level associated with the expansion of water due to rising temperatures and the melting of the polar ice caps, which will increase the total volume of water in the oceans. Studies have shown that the rate of ice cap melting is accelerating and will definitely be the major contributor to sea level rise, even going to far as to predict higher sea levels than recent IPCC reports². Some reports show that after sea level rise as little as 3 meters (10 feet) coastal cities such as Galveston will be entirely underwater³.

This study seeks to use the ArcGIS suite to quantify the number of people that are estimated to be displaced as a result of sea level rise in the Galveston area of the Texas coast using 2010 U.S. Census population data. Applications of the methodology of this study can expand to other regions of the world, as 10% of the global population lives in coastal regions lower than 10 meters⁴.

DRIVING QUESTION

- How many people on the Texas Gulf Coast will be displaced as a result of increased sea level?
- This can be quantified through the quantity of people displaced as a result of increased sea level.

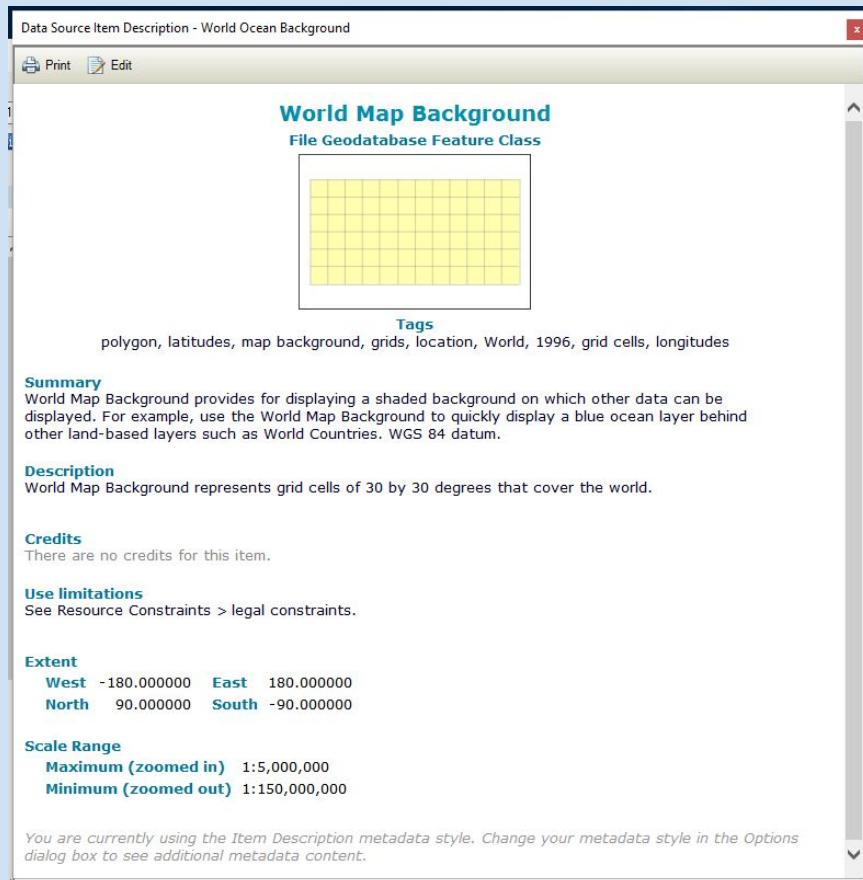
DATA INFORMATION

World Map Background

File name: World_Ocean_Background.lpk

Source: ESRI Website

Description: Blue ocean background for entire earth with 30 by 30 degree cells that form grid blocks



The screenshot shows a window titled "Data Source Item Description - World Ocean Background". The main content area displays the title "World Map Background" and "File Geodatabase Feature Class". Below this is a grid of yellow squares representing the 30x30 degree grid. The "Tags" section lists: polygon, latitudes, map background, grids, location, World, 1996, grid cells, longitudes. The "Summary" section states: "World Map Background provides for displaying a shaded background on which other data can be displayed. For example, use the World Map Background to quickly display a blue ocean layer behind other land-based layers such as World Countries. WGS 84 datum." The "Description" section states: "World Map Background represents grid cells of 30 by 30 degrees that cover the world." The "Credits" section states: "There are no credits for this item." The "Use limitations" section states: "See Resource Constraints > legal constraints." The "Extent" section shows: West -180.000000 East 180.000000 North 90.000000 South -90.000000. The "Scale Range" section shows: Maximum (zoomed in) 1:5,000,000 Minimum (zoomed out) 1:150,000,000. At the bottom, a note says: "You are currently using the Item Description metadata style. Change your metadata style in the Options dialog box to see additional metadata content."

GDEM Data for Texas Gulf Coast

File name: elevation_ASTER.tif

Source: USGS Earth Data

Description: ASTER elevation data for the Galveston area of the Texas gulf coast

Item Description - elevation_ASTER

Description Preview

Print Edit Import

elevation_ASTER.tif
Raster Dataset



Tags
elevation, Texas, gulf coast

Summary
ASTER elevation data for the Galveston area of the Texas gulf coast. WGS84 projection. Updated five days after collection, differs for different parts of the world.

Description
There is no description for this item.

Credits
Source: USGS Earth Data online

Use limitations
There are no access and use limitations for this item.

Extent

West	-96.827917	East	-91.488472
North	29.822083	South	28.591806

Scale Range

Maximum (zoomed in)	1:5,000
Minimum (zoomed out)	1:150,000,000

You are currently using the Item Description metadata style. Change your metadata style in the Options dialog box to see additional metadata content.

Texas State Outline

File name: txtrect.shp

Source: ESRI Data and Maps CD 3 - Western US

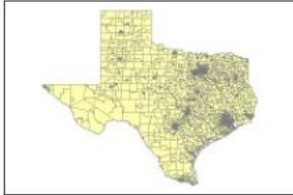
Description: 1990 census data for Texas, by census tract

Item Description - txtrect

Description Preview

Print Edit Upgrade Import

txtrect
Shapefile



Tags
There are no tags for this item.

Summary
For GIS class use

Description
1990 census data for Texas, by census tract. NAD83 projection.

Credits
From ESRI Data and Maps CD 3 - Western US

Use limitations
copyright 1999 ESRI Inc. all rights reserved.

Extent
West -106.645646 **East** -93.508131
North 36.500704 **South** 25.837377

Scale Range
Maximum (zoomed in) 1:5,000
Minimum (zoomed out) 1:150,000,000

You are currently using the Item Description metadata style. Change your metadata style in the Options dialog box to see additional metadata content.

Texas Cities

File name: Texas_Cities.shp

Source: Texas Department of Transportation

Description: Texas cities with 1990, 2000, and 2010 population data as well as district and county information. Cities updated according to 2010 census. WGS84 projection.

The screenshot shows a metadata window titled "Data Source Item Description - Texas_Cities". It contains the following information:

- Shapefile:** Texas_Cities
- Tags:** Texas, cities, population
- Summary:** Texas cities with 1990, 2000, and 2010 population data as well as district and county information. Cities updated according to 2010 census. WGS84 projection.
- Description:** There is no description for this item.
- Credits:** Source: Texas Department of Transportation
- Use limitations:** There are no access and use limitations for this item.
- Extent:**

West	-106.605960	East	-93.617237
North	36.499118	South	25.899394
- Scale Range:**

Maximum (zoomed in)	1:5,000
Minimum (zoomed out)	1:150,000,000

You are currently using the Item Description metadata style. Change your metadata style in the Options dialog box to see additional metadata content.

GENERAL METHODOLOGY

- A. Acquire data and match the datum
- B. Symbolize the elevation raster for easier visualization
- C. Create a coastline contour
- D. Lower the elevation of the original raster (raise sea level)
- E. Create new contour lines for lowered elevation rasters
- F. Clean up contour lines
- G. Create binary rasters
- H. Select cities for analysis
- I. Analyze data in Excel

DATA PRE-PROCESSING

A. Acquire data and match the datum

1. Download data from ESRI website (in the “Data and Maps” section)
 - a. “World Ocean Background”
2. Download GDEM ASTER Data from NASA
 - a. Used only Galveston area for processing time concerns (see **figure 1**).
3. Download Texas cities data from the Texas Department of Transportation
4. Import the Texas outline shapefile from Lab 1 data folder used during class (from ESRI data and maps).
 - a. This outline was not intended to be used at the resolution at which we are trying to use it, so the coastline was very jagged and not true to the actual nature of the coastline. In order to solve this problem, I created a coastline contour with the DEM elevation data (shown in section C) that served as the Texas coastline for purposes of seeing the changes that resulted from sea level rise.

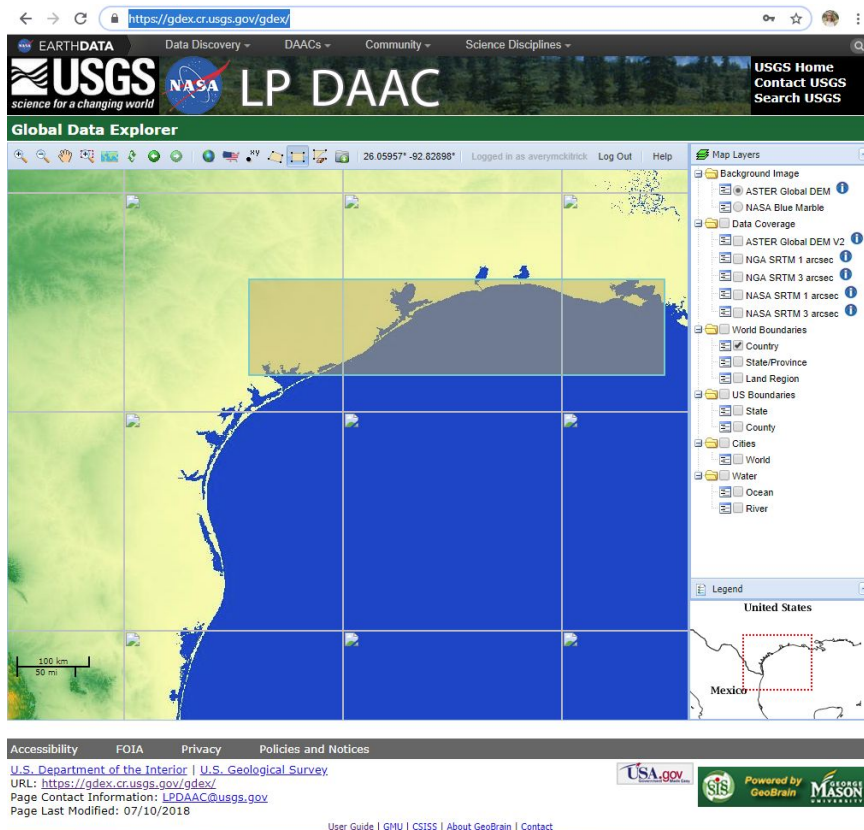


Figure 1: The USGS Earth Data site used to collect the coastal elevation data for analysis. A box had to be drawn around the area needed for analysis, which was difficult without state boundary lines.

5. Put all data into map file
6. Match datum so that it's the same across all data
 - a. State_outline: NAD83
 - b. World Ocean Background: WGS84
 - c. Elevation: WGS84
 - d. Texas Cities: WGS84
 - e. Only the state outline needs to be change using the “project” tool under data management
7. Project Texas state outline into new datum
 - a. Data management tools → Projections and Transformations → Feature → Project.
 - b. Export the new feature as state_outline_WGS84 (see **figure 2**).

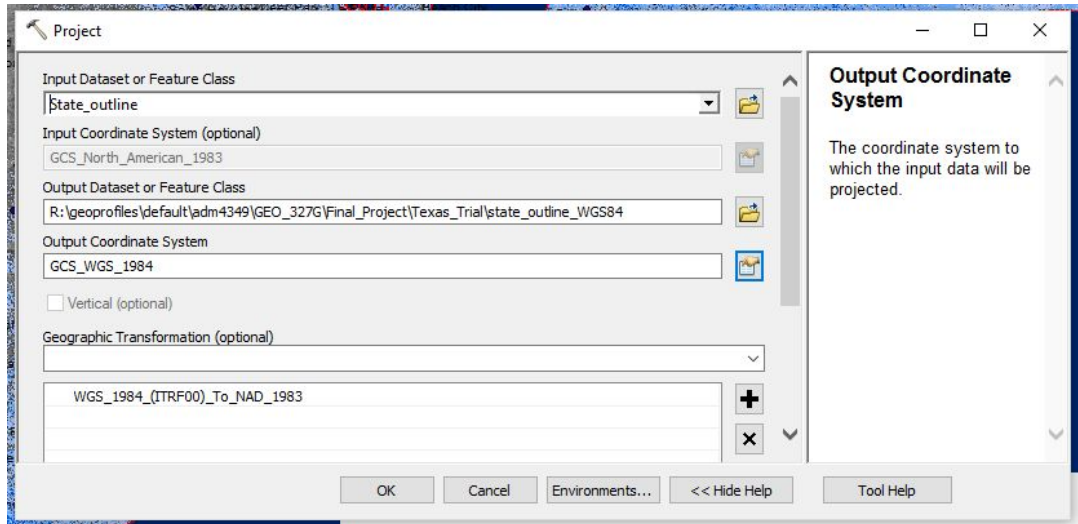


Figure 2: The projection tool used to change the projection of the state outline from NAD83 to WGS 84, the datum that most of the downloaded data had in common.

ARCGIS PROCESSING

B. Symbolize the elevation raster for easier visualization

This step could have easily been eliminated, however, I decided that it was easier to see the elevation differences using this symbology.

1. Change the symbology of the raster so that the stretch type is minimum-maximum. Edit the high/low values so that the high is 50 and the low is 0 for symbolization purposes (see **figures 3 and 4**).

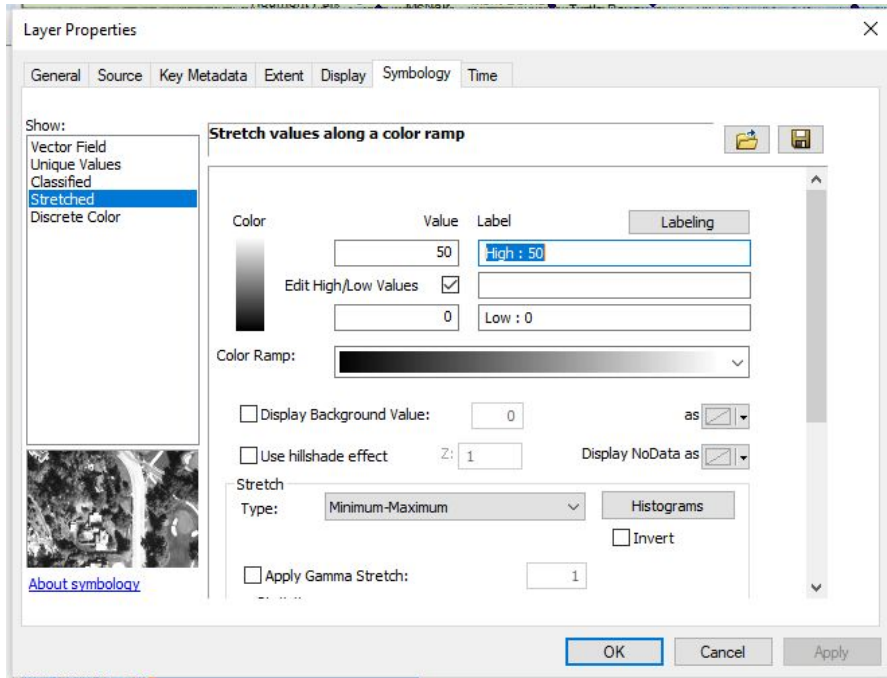


Figure 3: The symbology tab of the elevation layer properties. Switching the stretch type to “Minimum-Maximum” and editing the high low values will result in a more visually appealing raster.

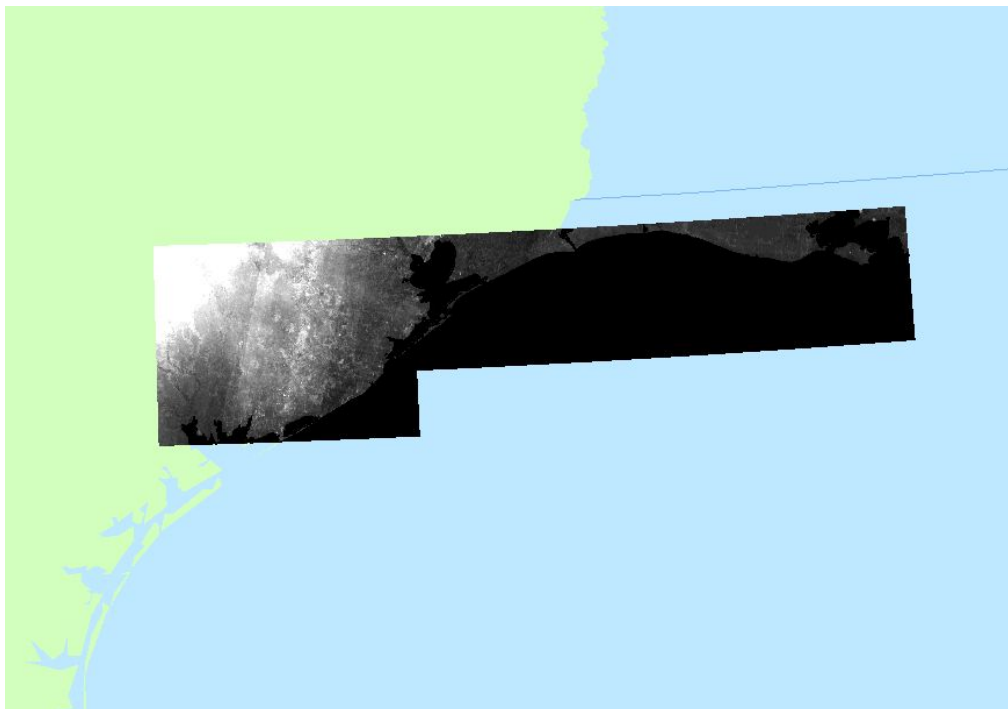


Figure 4: Final results of the raster symbolization step.

C. Create a coastline contour

1. Create a contour using this binary raster. This was done using the “Contour” tool under the spatial analyst toolbox.
 - a. Set the input raster to the “elevation_ASTER.”
 - b. Set an output. Name this new file “contour_ASTER.”
 - c. Set the contour interval to something higher than your highest value, so that one contour line will be created. I set mine to 5000 (see **figures 5** and **6**).

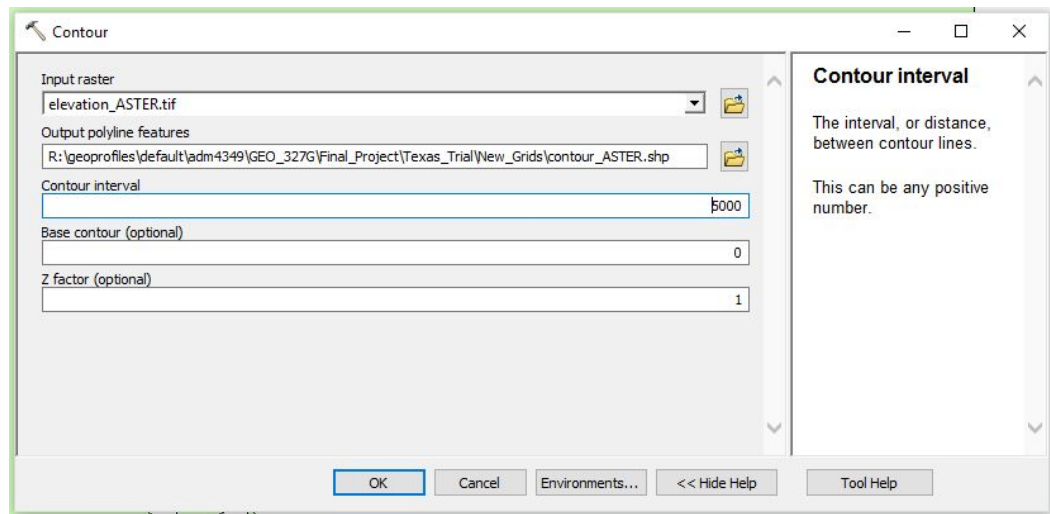


Figure 5: The contour tool used to create a single line that represents the present-day coastline of Texas.

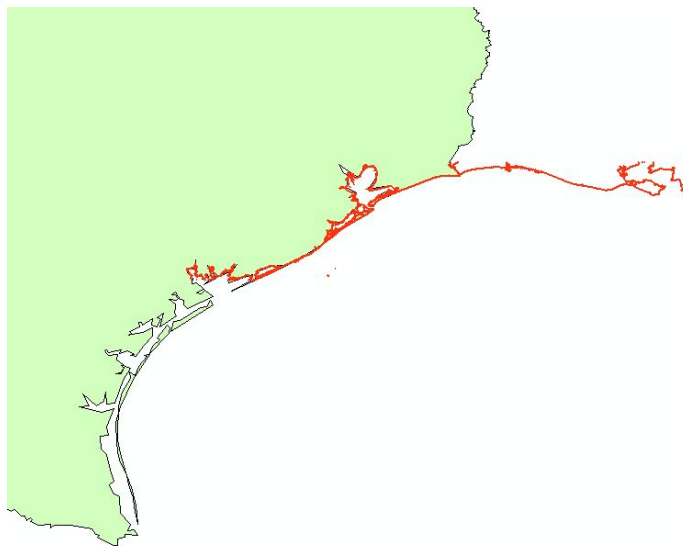


Figure 6: Results of the initial contour creation. The “Texas_Cities” layer has been removed for visualization purposes.

D. Lower the elevation of the original raster (raise sea level)

1. Lowered the whole elevation raster by amount that sea level was to be raised. I started with rising sea level by 1m.
 - a. Open the raster calculator again.
 - b. Use the following expression to lower all elevation values in the “elevation_ASTER” raster by 1 m:
 - i. “elevation_ASTER.tif” - 1” (see **figure 7**)

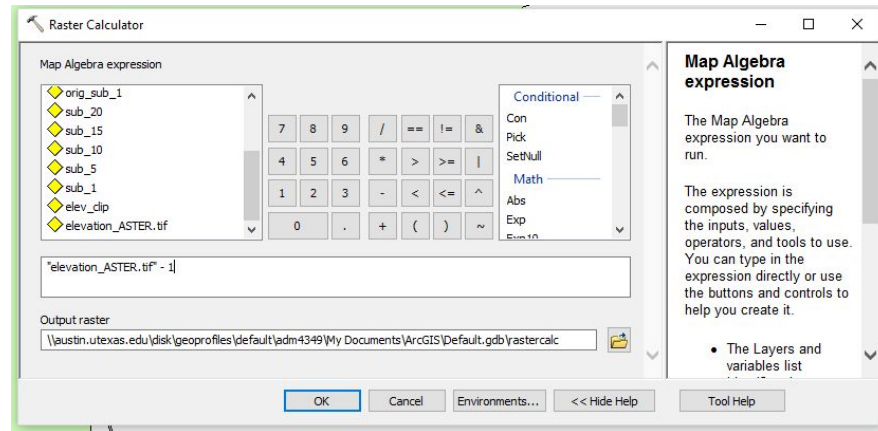


Figure 7: The expression used in the raster calculator to subtract 1 meter from the original elevation raster (which will then be used to show the effects of one meter sea level rise).

- c. Set the output as “orig_sub_1” to indicate that you are subtracting one meter from the original, unclipped elevation raster.
2. I repeated the above steps until I had subtracted 5, 10, 15, and 20 meters from the “elev_clip” layer. I named these “orig_sub_5,” “orig_sub_10,” “orig_sub_15,” and “orig_sub_20,” respectively to indicate that I was using the original elevation raster (before I had decided not to use the clipped elevation raster).

E. Create new contour lines for lowered elevation rasters

1. Use these “orig_sub_*” rasters to create contours as specified in the above section. I named these “contour_1,” “contour_5,” “contour_10,” “contour_15,” and “contour_20,” respectively (see **figure 8**).

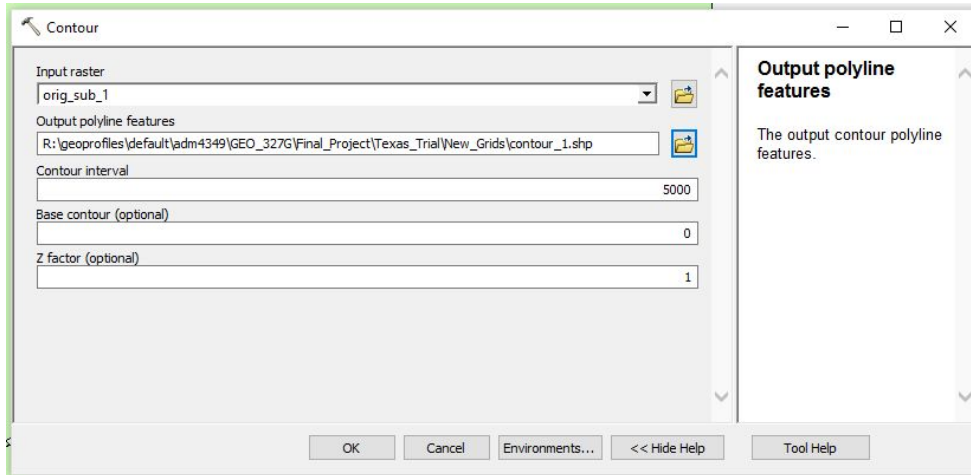


Figure 8: The contour tool used to create a contour that symbolizes the new shoreline after 1 m sea level rise.

F. Clean up contour lines

1. Add a new field in the attribute table of the contours. Call this field “Length_.”
2. Set the type as “Double,” the precision as “0,” and the Scale as “12” (see **figure 9**).

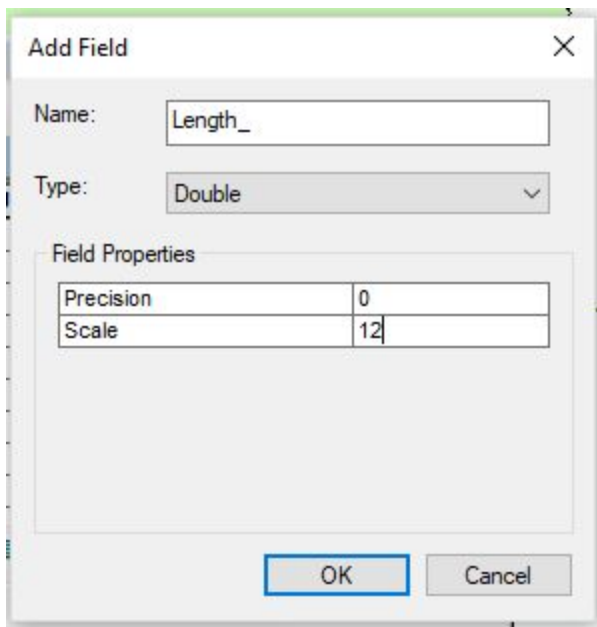


Figure 9: The box that should appear when attempting to add a new field to the contour line attribute table.

3. Right click the column header and click “calculate geometry.” The coordinate system will have to be one that uses meters and not decimal degrees in the horizontal, so WGS84 won’t work. For editing purposes, I’ve chosen the new coordinate system to be NAD83 Texas Centric Mapping System Albers.

4. Set the property as “Length” and units as “Meters [m]” (see **figure 10**).

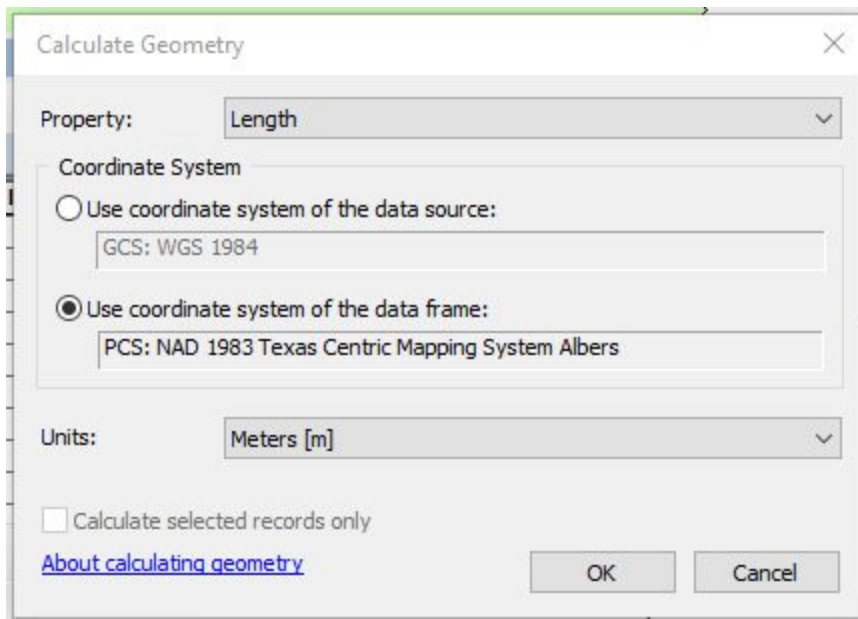


Figure 10: The box that results from calculating geometry of the new “LENGTH_” field in the contour attribute table. Note the new coordinate system used (or else the tool will not work).

5. Click “OK.”
6. Sort the table by ascending “Length_” values to get a feel for their range.
7. Do this for every contour, including the original “contour_ASTER” contour.
8. Begin an editing session.
9. Play around with the select by attribute tool using the shown query (the number included can be different) until it seems that the contour line is at least mostly continuous and reflective of the binary data. I’ve started here with 1000 meters, or 1 km (see **figure 11**).

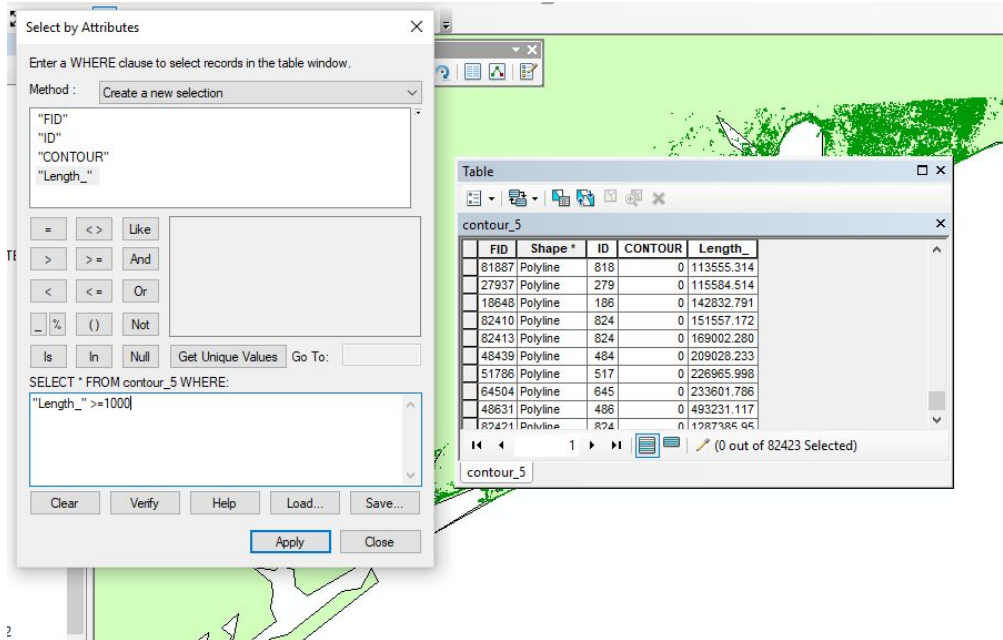


Figure 11: The method used for editing the contour lines. The SQL query used to the left helped to narrow down which contour lines should be deleted and which needed to stay.

10. When satisfied, use the black and blue “✕” symbol in the attribute table to delete the values that are too small to meaningfully contribute to the contour. For most of the contours, I found that only the last one to two contours were coherent and continuous.

G. Create binary rasters

1. Create a binary raster with the following conditional statement using the ASTER elevation layer. Name the output “bin_1.” This step will aid with the visualization of where the water is actually predicted to be.
 - a. Open the raster calculator again and input the following expression to symbolize all areas above (1) and below (0) sea level:
 - i. “Con(“orig_sub_1” <= 0,1) (see **figure 12**)
 - ii. The input layer would be changed based on which layer you wanted to create a binary raster for.
 - b. Repeat this step for all orig_sub_* rasters.

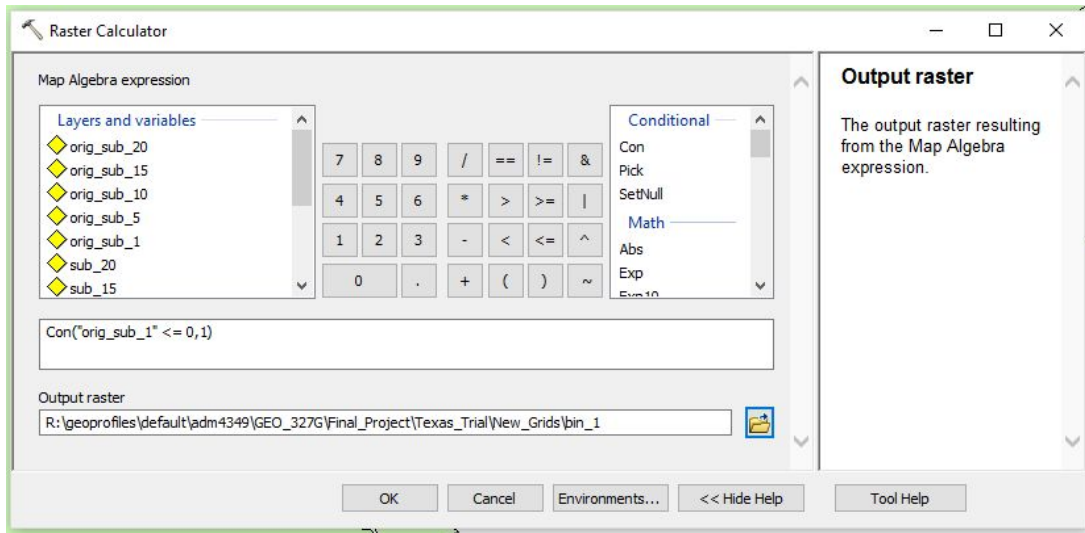



Figure 12: The raster calculator expression needed to create a binary raster.

H. Select cities for analysis

1. Export just the cities that are affected by the “bin_20” binary raster so that we can more easily find out the number of people affected based on population data from the 2010 census.
 - a. Use the selection tool to “Select by Lasso.” 
 - b. Draw a “lasso” as well as you can around the cities that are covered in the color you selected to symbolize “below sea level.” This is the maximum extent of cities that will be affected in out analysis (see **figure 13**).

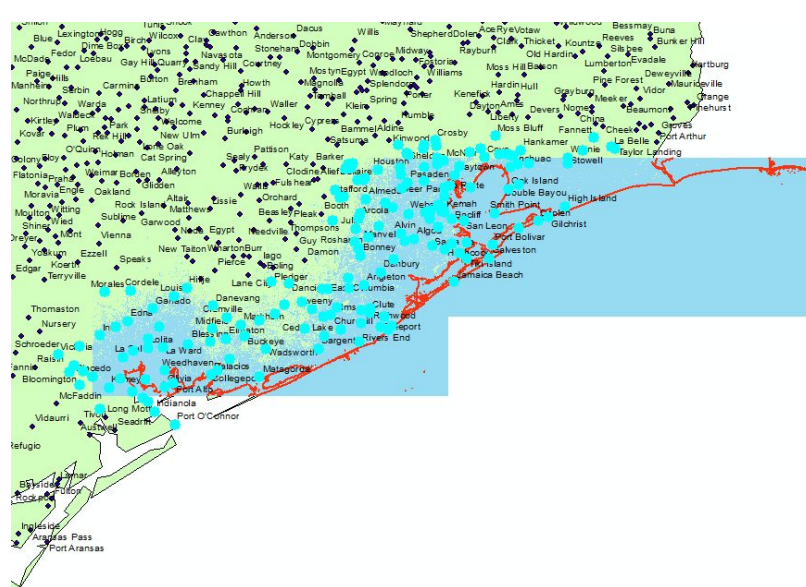


Figure 13: All cities that appear to be within reach of the “bin_20” raster were “lassoed” with the selection tool. These cities will be further perfected in the next few steps.

- c. I further modified these selections to include only what will be within the bounds of the original elevation raster by right clicking the “cities_select” layer, selecting the “Start Editing” option, and then holding down the shift key while selecting the remaining cities outside of the raster.
 - i. Remember to save edits frequently and to click “stop editing” when finished.
- d. Go to the table of contents and right click the “Texas_Cities” layer.
- e. Click “Data” and then “Export Data.”
- f. If not already chosen, select “Selected Features” as the export option. Set the output as “cities_select” (see **figure 14**).
- g. Click “OK” and add the layer to the map.

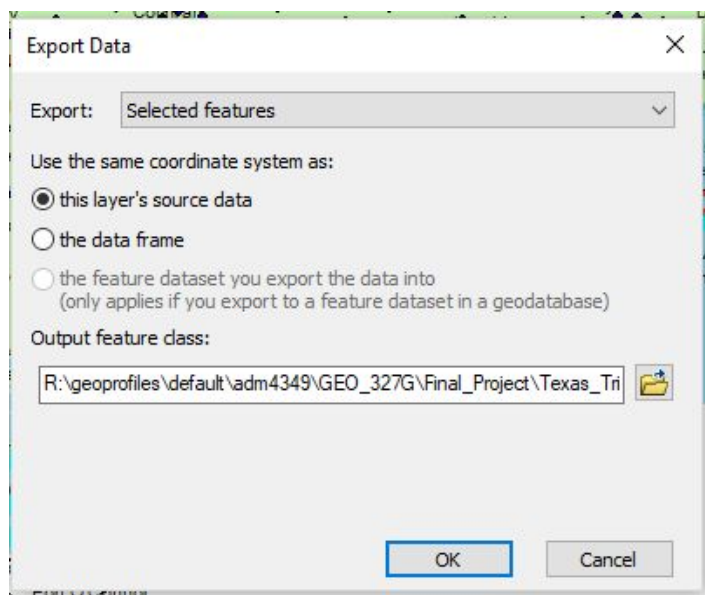


Figure 14: The Export Data window that can be used to create a new layer for the cities needed for analysis and none of the unnecessary cities.

- h. You can remove the “Texas_Cities” layer and only display the “cities_select” layer. This layer has only about 140 cities, compared to about 3000 in the original file (see **figure 15** for final results).

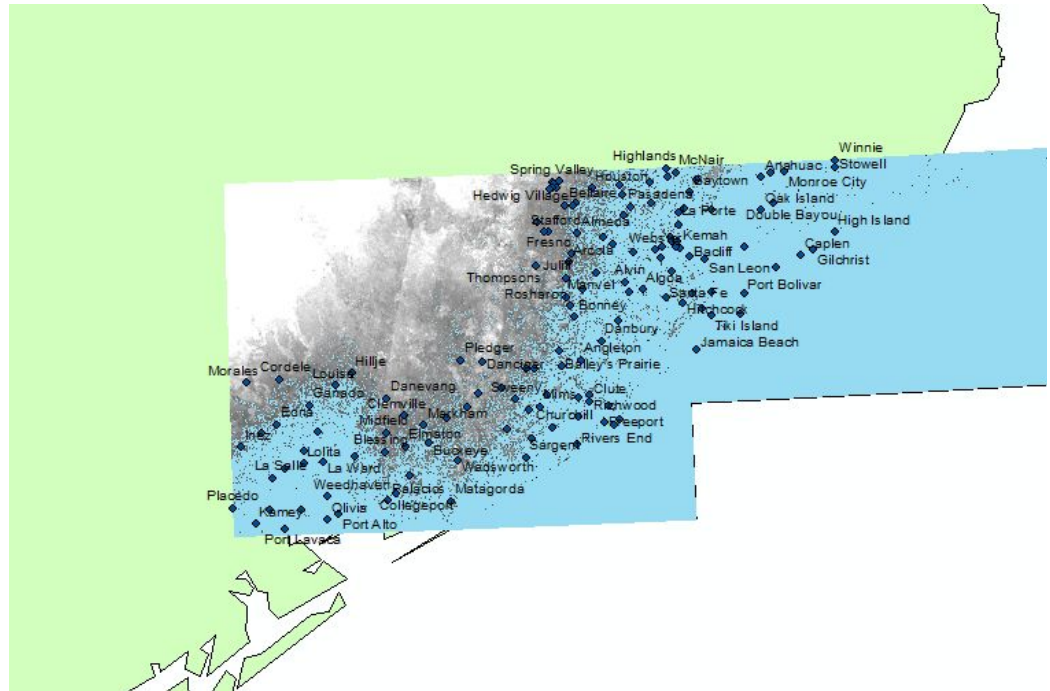


Figure 15: Display of the cities needed for analysis after selecting by lasso and using the editing feature.

I. Analyze data in Excel

Export Data

1. Open the attribute table for the “cities_select” layer.
2. Click on the arrow to the right of the white box button on the far left side of the attribute table.
3. Click export data.
4. Export “All Records” (see **figure 16**).
5. IMPORTANT: Save as file type “dBASE Table.” This will allow you to open the attribute table in Microsoft Excel (see **figure 17**).

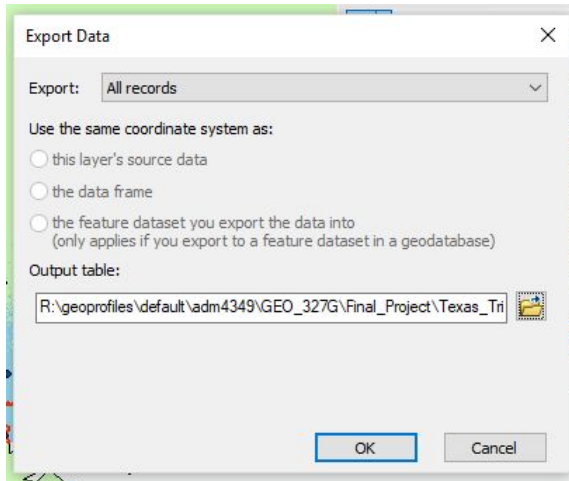


Figure 16: The window used to export data from the “cities_select” attribute table into a dBASE file, which will then be opened with Microsoft Excel.

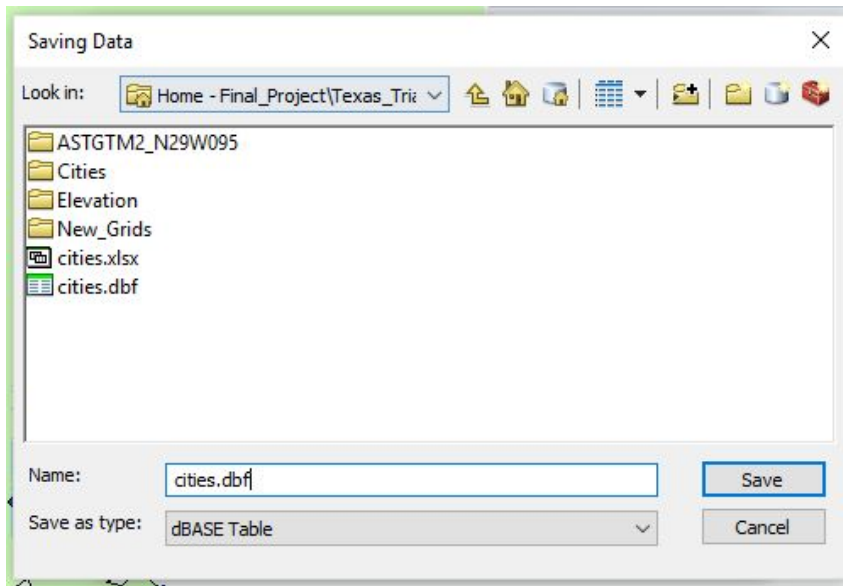


Figure 17: How the attribute table data should be saved. Note that the “Save as type” option will need to be changed.

6. Open a new Microsoft Excel sheet. Under “file,” click open, and the browse. Set the file type as “dBASE Files” and find the cities dBASE (see **figure 18**).

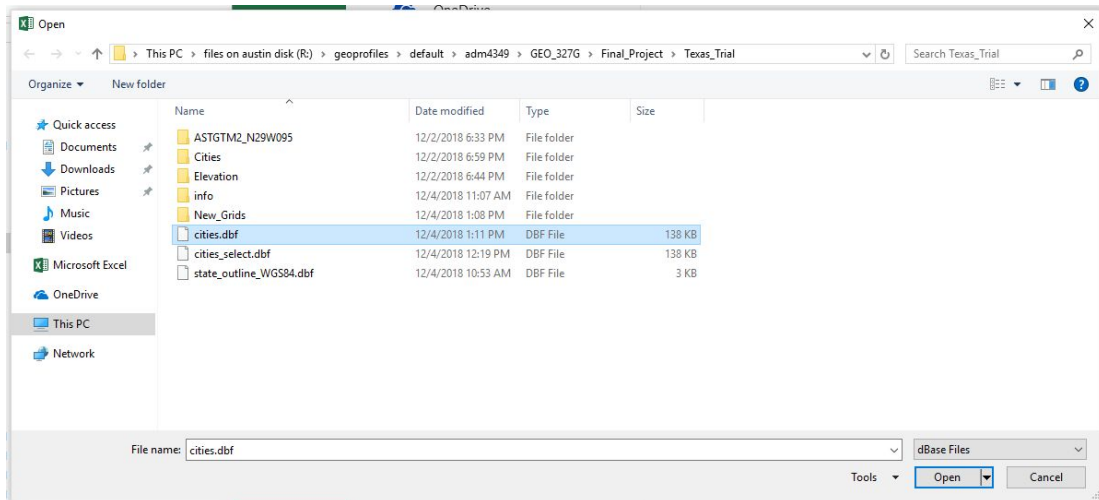


Figure 18: Where to find the cities.dbf file.

7. This will open a new Excel document. You can close the old one.
8. File and “Save As” “cities.” You can overwrite the old “cities” sheet.

Analyze Data

1. Delete all fields except “OBJECTID,” “GID,” CITY_NM,” and POP2010” by right clicking the column header and selecting “delete.”
2. In the top right corner, select “Sort & Filter” and then “Custom Sort...”
3. Sort by “CITY_NM” A to Z. This will sort the city names alphabetically so we can find them easier later, but the OBJECTID field will help us connect those values to the ArcMap values (see **figure 19**).

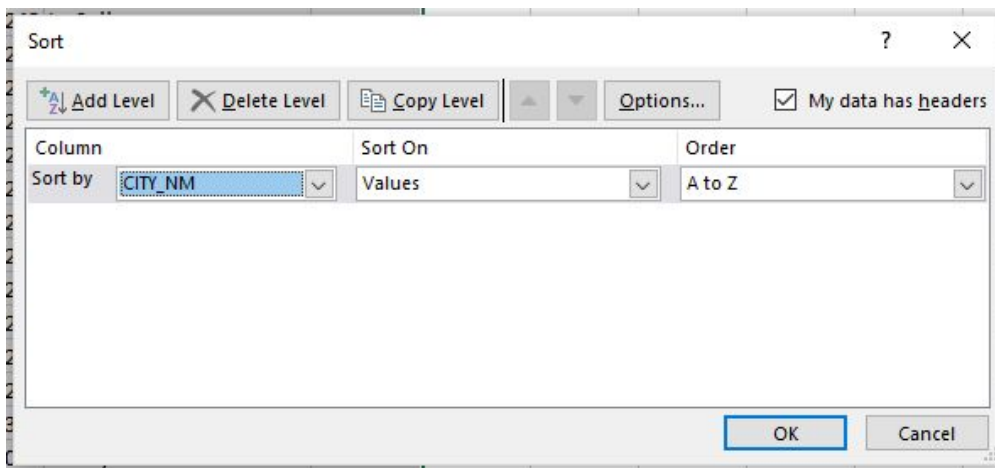


Figure 19: The “sort” function in Microsoft Excel is used to alphabetize the city names so that they can be found more easily.

4. Add fields bin_1, bin_5, bin_10, bin_15, and bin_20. Each time a city is in the “underwater” section of a binary file, indicate so in the excel sheet. I’ve used fill

colors so that it is obvious which cities are affected at which sea level. It may help to label features as you determine which are underwater. An example of the results of this analysis is shown below in **figure 20**.

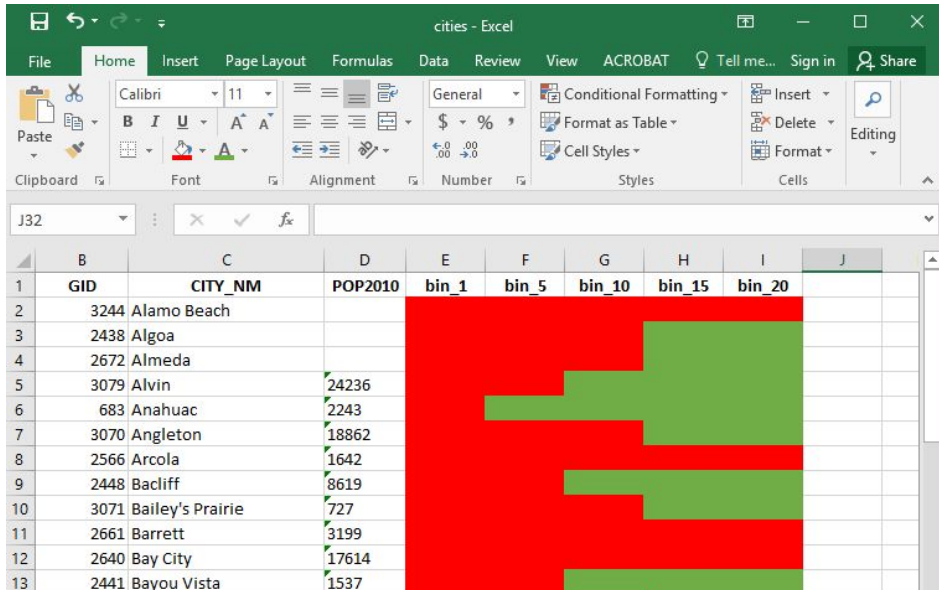


Figure 20: An example of what the table could look like once the cities have been found and analyzed for water coverage.

5. Use this information to determine how many cities are affected (and how that translates into percentages of the analyzed cities) as well as the number of people affected using the 2010 population data (as well as the percentage of the total) downloaded along with the other fields in the attribute table.
 - a. The cities that do not include population data are cities that were not included in the 2010 census.
 - b. An example table might look like the one shown in **table 1**, and another, similar table for population data.

Table 1: Table displaying the total number of cities in the affected area that will be underwater as a results of sea level rise, and what that translates to in terms of percent of the total cities analyzed (unfinished).

SEA LEVEL RISE	1 m	5 m	10 m	15 m	20 m
Number of Analyzed Cities Affected					
Percent of Analyzed Cities Affected					

TABLES & FIGURES

Table 1: Table displaying the total number of cities in the affected area that will be underwater as a results of sea level rise, and what that translates to in terms of percent of the total cities analyzed. *

SEA LEVEL RISE	1 m	5 m	10 m	15 m	20 m
Number of Analyzed Cities Affected	0	5	32	59	71
Percent of Analyzed Cities Affected	0%	3.60%	23.00%	42.40%	51.10%

Table 2: Table displaying the total number of people in the affected area that will be displaced as a results of sea level rise, and what that translates to in terms of percent of the total population analyzed. *

SEA LEVEL RISE	1 m	5 m	10 m	15 m	20 m
Number of Affected People in Analyzed Area Affected	0	12,475	374,146	757,334	946,326
Percent of Affected People in Analyzed Area Affected	0%	0%	12%	23%	29%

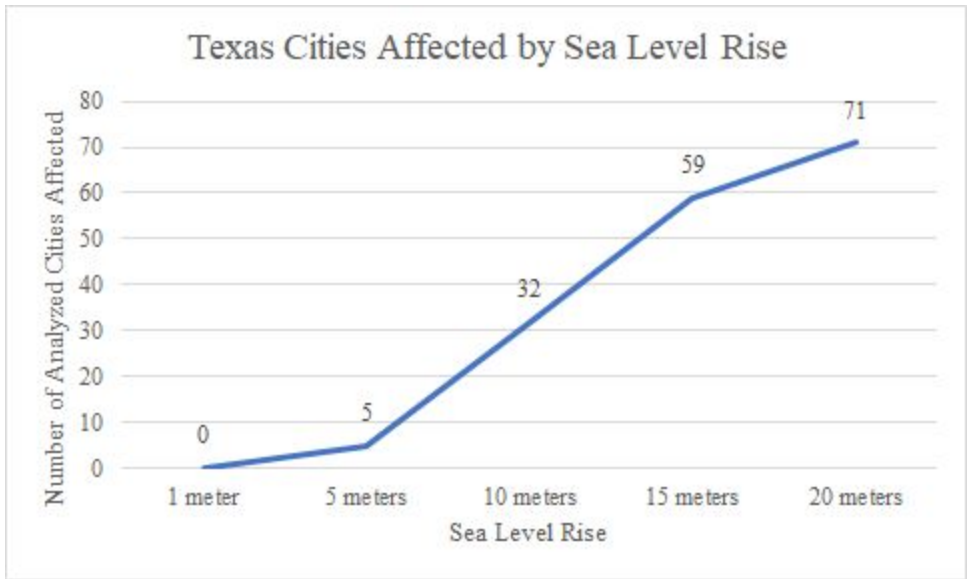


Figure 21: Figure graphically displaying the total number of analyzed cities in the affected area that will be underwater as a results of sea level rise. *

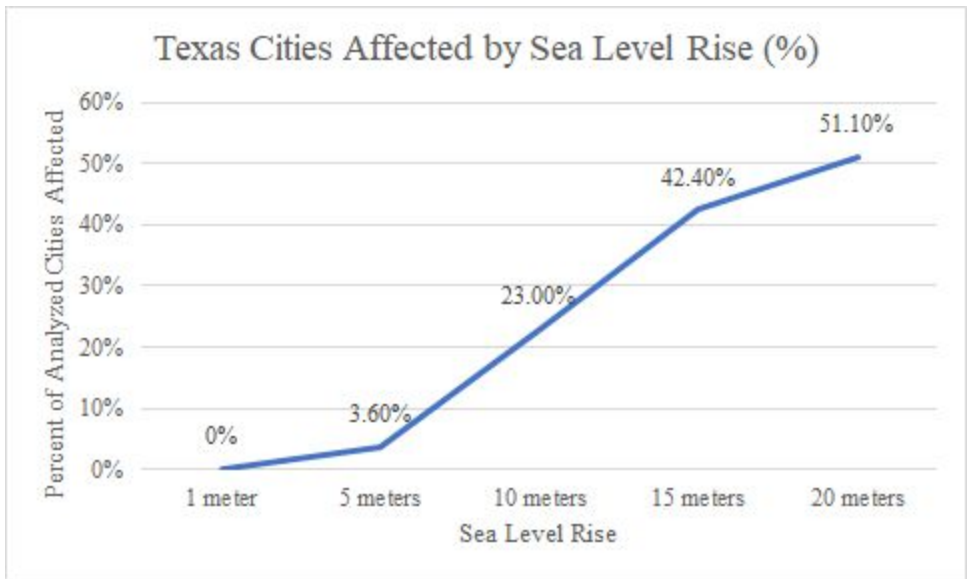


Figure 22: Figure graphically displaying the total percentage of analyzed cities in the affected area that will be underwater as a results of sea level rise. *

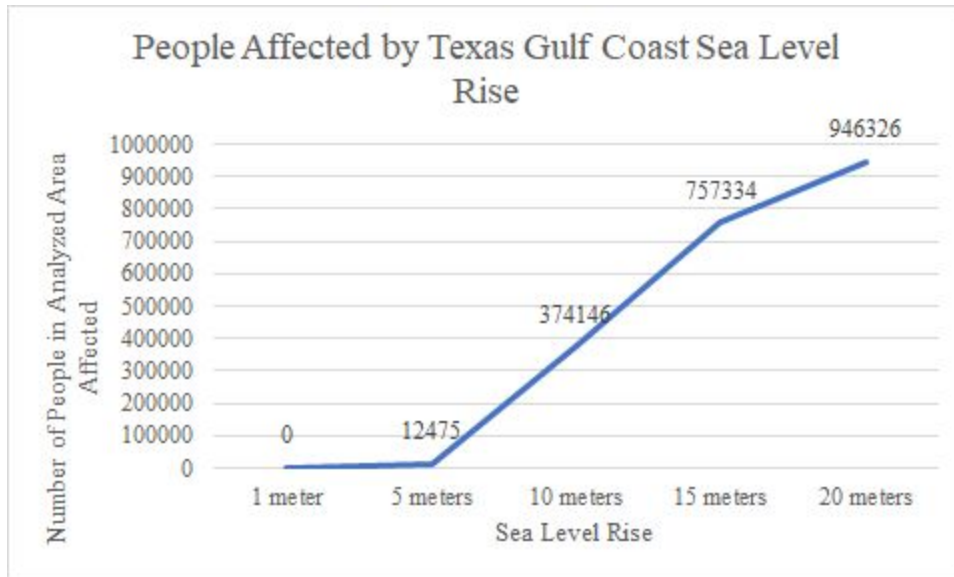


Figure 23: Figure graphically displaying the total number of people in the affected area that will be displaced as a results of sea level rise. *

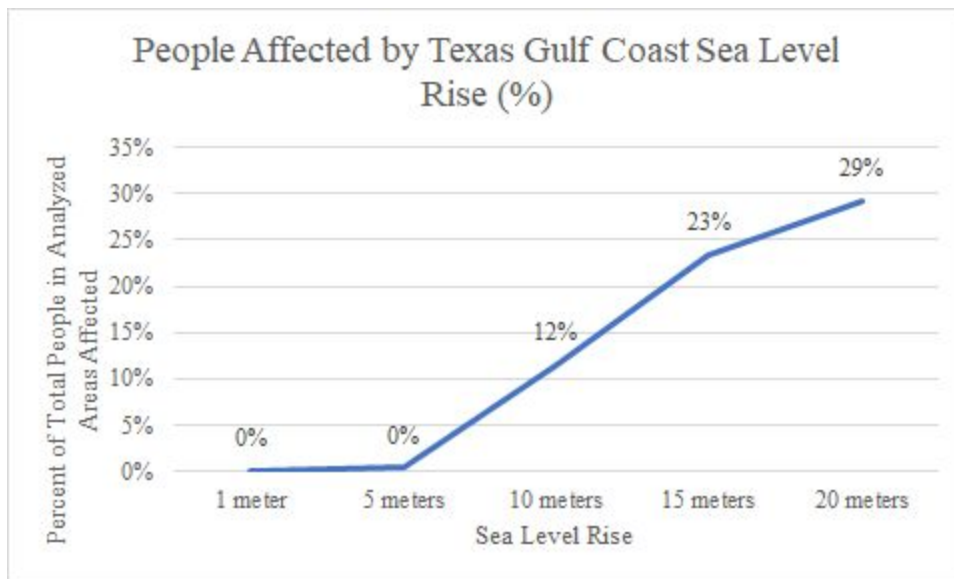


Figure 24: Figure graphically displaying the total percentage of analyzed populations in the affected area that will be displaced as a results of sea level rise. *

*These results were concluded based on which cities were below sea level at the rise amount given, and not necessarily if they were behind the contour line.

RESULTS & DISCUSSION

Based on the analysis of the 2010 population data available and the extent of the binary rasters created during ArcGIS processing, it can be concluded that

1. At 1 m sea level rise, no cities (and thus no Texans) will be affected
2. At 5 m sea level rise, 5 cities will be underwater and 12,475 Texans displaced
3. At 10 m sea level rise, 32 cities will be underwater and 374,146 Texans will be displaced
4. At 15 m sea level rise, 59 cities will be underwater and 757,334 Texans displaced
5. And at 20 m sea level rise, 71 cities will be underwater and 946,326 Texans will be displaced (**Tables 1 and 2**).

This data is a good general representation of the effects that a rise in sea level will have on the Texas Gulf Coast and the people who live there. However, this map did not account for the likely increase in population that each of these cities will face when the sea level is actually at the levels described. This was not accounted for due to the wide variation in predictions based on different factors taken into account, as well as the difficulty of getting that information based on several cities and towns, which would be required for this analysis. This model also did not account for the possibility, however unlikely, that Texas will learn to adapt to these changes in sea level and that the people will be able to continue living in these areas despite the increase in sea level.

If this project allowed for a more in-depth analysis of the problem presented, I would try to model the potential increase in population for each city and correlate these numbers for each moment in time when the sea level is predicted to be at the level indicated in the map. I would also spend more time finding elevation data that displays at a higher resolution, as the elevation data I used made it nearly impossible to create a decent-looking hillshade. There is also a possibility that the binary rasters would have been more legible if the elevation data had been of higher resolution. I also would have got elevation data over a larger area, likely along the entire Texas coast. This was not done for this run due to the time- and space-intensive nature of doing so. It would furthermore be useful to look at the actual area that would be underwater.

CONCLUSION

It was found through careful analysis that, as sea levels continue to rise, Texas will be partially underwater. This will affect hundreds of thousands, if not millions of people in the decades to come. Thus, it is essential that we mitigate and adapt to climate change as quickly as possible so that we are not caught by surprise when we can no longer return to the coast that once was.

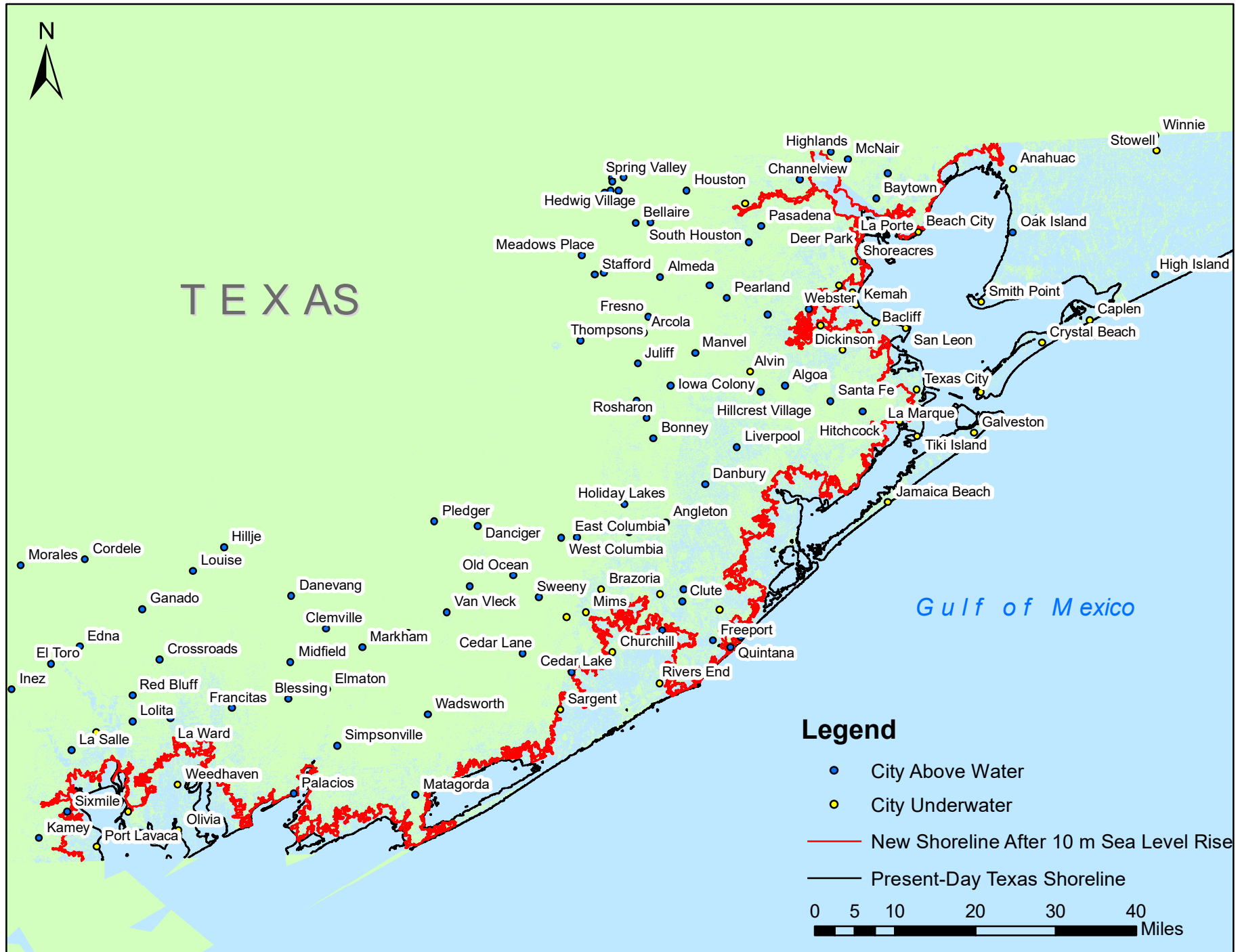
REFERENCES

1. Wise, Danno. "Attractions for Everyone on Galveston Island." TripSavvy, TripSavvy, 18 Oct. 2018, www.tripsavvy.com/attractions-on-galveston-island-1656862.
2. Rignot, Eric, et al. "Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise." *Geophysical Research Letters* 38.5 (2011).
3. Leatherman, Stephen P. "Coastal geomorphic responses to sea level rise: Galveston Bay, Texas." Barth and Titus (eds). op. cit (1984).
4. FitzGerald, Duncan M., et al. "Coastal impacts due to sea-level rise." *Annual Review of Earth and Planetary Sciences* 36 (2008).

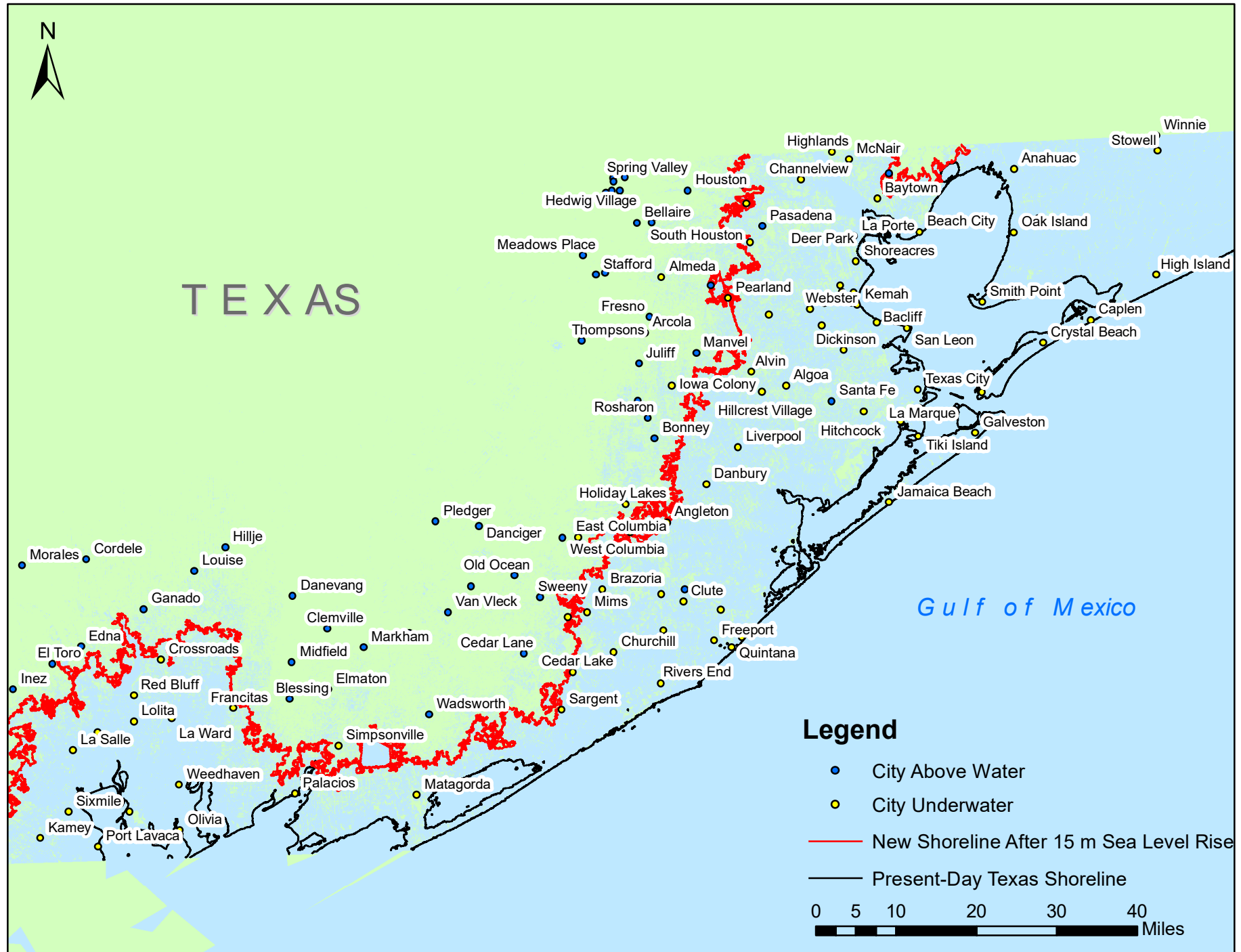
Texas Gulf Coast, USA After 5 m Sea Level Rise



Texas Gulf Coast, USA After 10 m Sea Level Rise



Texas Gulf Coast, USA After 15 m Sea Level Rise



Texas Gulf Coast, USA After 20 m Sea Level Rise

