

Brine Groundwater Contamination in the Gulf Coast Aquifer Due to 12m Sea Level Rise

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Problem statement

As the globe continues to warm and the population continues to grow, water scarcity is a real threat for many regions of the world. The sea level is projected to increase by roughly 3 meters by the year 2100 if carbon emissions are not controlled and reeled in. As the sea expands from melting ice reserves and warmer temperatures, coastal cities are at most risk.

Groundwater is a resource that is becoming increasingly less available due to increased withdrawal, growing populations, unsustainable practices and consumption, and ignorance. Most importantly, as the sea levels rise, aquifers along the coast are becoming contaminated by the high salt content of the ocean. This means that as the sea level rises, more money will be spent on treatment of the groundwater before consumption by humans. According to the EPA, a concentration of >12,000 mg/L of salt in groundwater is unacceptable, however the salt content of the ocean is 35,000 mg/L. Considering this threat, I chose to conduct some more research and focus my project on this phenomenon. Narrowing in on a section of the gulf coast aquifer in the state of Texas, I will explore the relationship between sea level rise and groundwater flow patterns to infer the susceptibility of groundwater to brine contamination. This project should have been conducted on a smaller scale if my intention was to maintain scientific integrity, however in order to infer a relationship given the data constraints, it was necessary to project a somewhat unreasonable sea level rise over a larger scale.

Layout

To explore this relationship, I obtained well data collected by the Texas water development board in which latitude, longitude, well depth, and water level data was given. I will use water level and well depth measurements to calculate head values. In hydrology, head is a measure of energy of the groundwater within an aquifer at the exact location in which the measurement was taken. With this information, I will produce a raster that will display a surface of the head values to infer the groundwater flow pattern in this area, with the knowledge that groundwater within an aquifer flows from high head to low head. Overlying a projected 15 meter, 12 meter increase with 3 meter high tide, increase in sea level from present day's sea level, I hypothesize that if the areas of highest head are submerged by the projected sea level, this would mean that the areas of lower head would be susceptible to brine contamination even if the elevation of the land is not below the new sea level.

Data collection

To obtain elevation data for my sea level raster along the Texas Gulf coast, I downloaded DEM data from EarthData

Source: <https://earthdata.nasa.gov>

Gathered well data which included depth of well and water level collected by the Texas Water Development Board:

Source: <http://www.twdb.texas.gov>

<http://www20.twdb.texas.gov/ReportServerExt/Pages/ReportViewer.aspx?%2fGWDB%2fWaterLevelsByAquifer&rs:Command=Render>

Texas counties and cities data:

<http://gis-txdot.opendata.arcgis.com/datasets/texas-county-boundaries>

<http://gis-txdot.opendata.arcgis.com>

Data preprocessing

Water level and well depth information was downloaded as an excel file, converted to a csv file and added to arcmap as a csv file. Latitude and longitude coordinates were included in the csv file, and were used to add give the point measurements spatial data (figure 2).

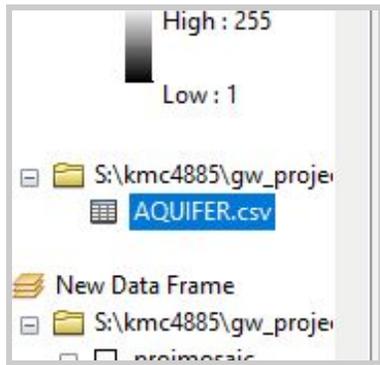


Figure 1: Well data csv file in ArcMap

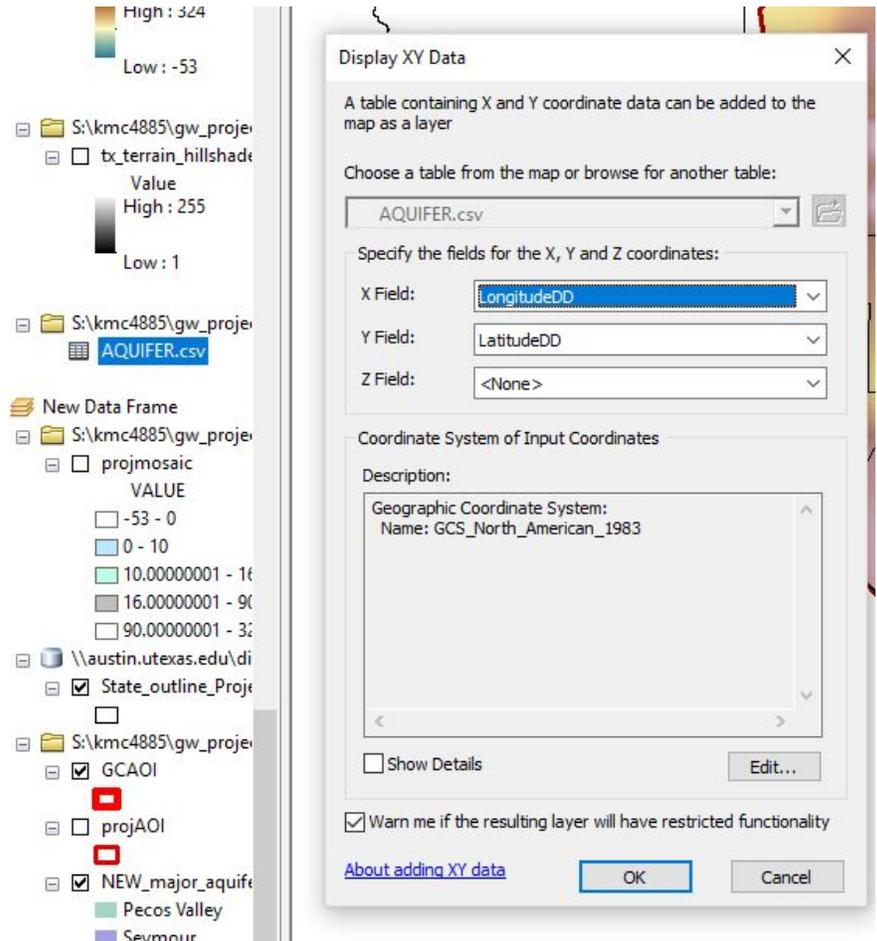


Figure 2: Adding XY data to point data from csv file

The default geographic coordinate system was GCS_North_American_1983 (figure 2), however early on I chose to project all data to a common projected coordinate system:

North_American_1983_Lambert_conformal_conic using the **project** (data management) tool for datasets and feature classes and **project raster** tool for rasters.

Property	Value
Raster Information	
Columns and Rows	279, 342
Number of Bands	1
Cell Size (X, Y)	0.0064544444, 0.0064544444
Uncompressed Size	372.73 KB
Format	GRID
Source Type	Generic
Pixel Type	floating point
Pixel Depth	32 Bit

Property	Value
Raster Information	
Columns and Rows	20824, 23271
Number of Bands	1
Cell Size (X, Y)	29.4578992, 29.4578992
Uncompressed Size	1.81 GB
Format	GRID
Source Type	Generic
Pixel Type	signed integer
Pixel Depth	16 Bit

Figure 3: Original raster settings when in geographic coordinate system of GCS_North_American_1983 (left) vs. when projected to North_American_1983_Lambert_conformal_conic (right)

Data processing and analysis

I. Selecting Area of Interest (AOI)

County boundary shapefile was downloaded, in which I chose a select few from the South Texas region.

3 factors influenced selection of AOI:

1. Resolution of DEM (30 x 30 meters); should be considered when deciding extent of analysis
2. Counties that had DEM data available
3. Whether county was in the Gulf Coast Aquifer; groundwater well data was only available for areas within the aquifer

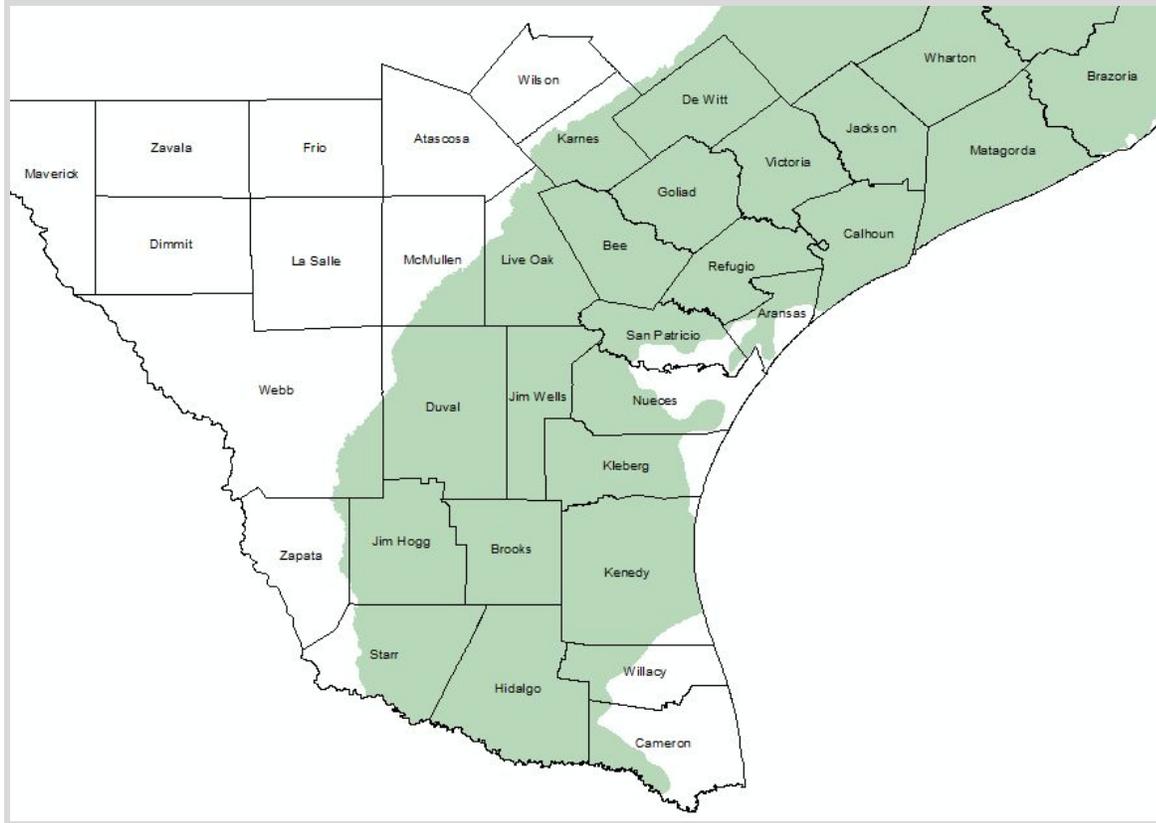


Figure 4: South Texas Counties within Gulf Coast Aquifer

Once AOI was selected, I used the **draw** toolbar to trace a polygon around the counties and part of the aquifer that would be included in the analysis. Polygon was then **converted to a feature class** which will be used for clipping all relevant layers to (figure 5).

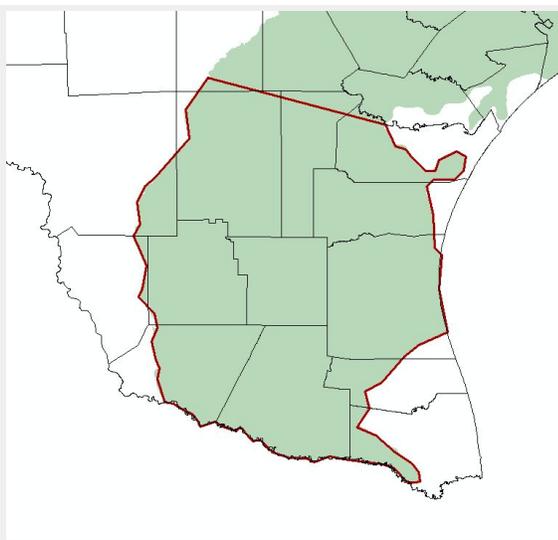
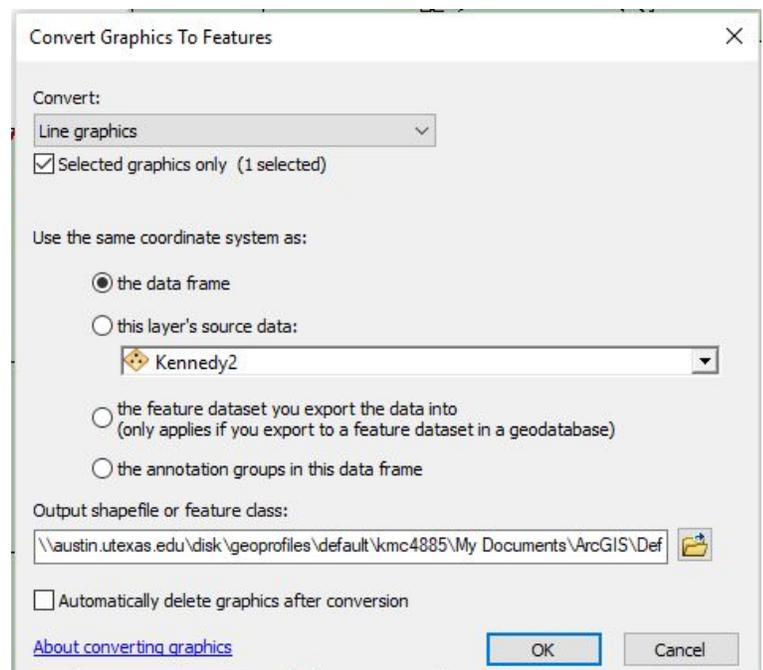


Figure 5: Converting polygon outline to feature class, defining AOI



II. Projecting Sea Level

DEM tiles were downloaded > **raster project** tool > and used **mosaic** tool (figure 7 & 8) to coalesce all tiles into one raster. This dem data will be used for the sea level - both current and projected

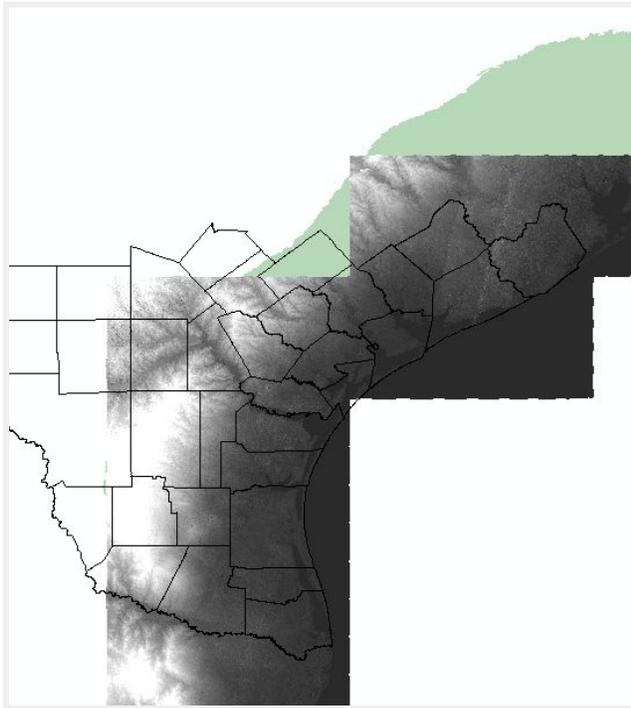


Figure 6: Mosaic of DEM data along the Coast

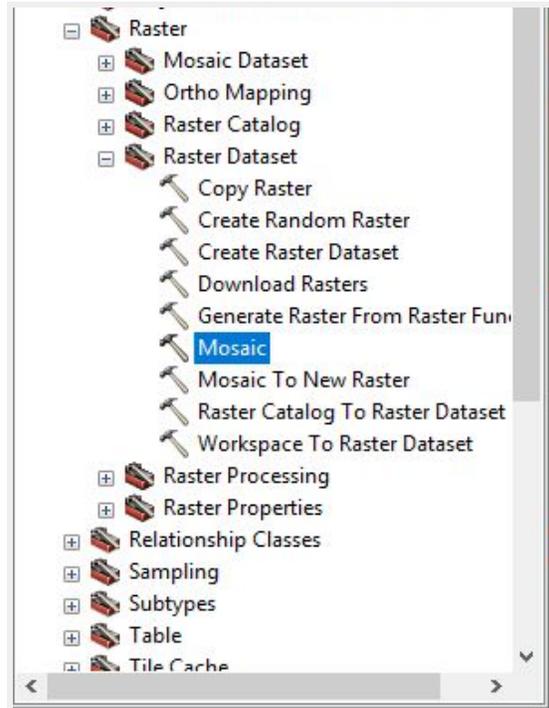


Figure 7: Location of Mosaic tool used in ArcToolbox

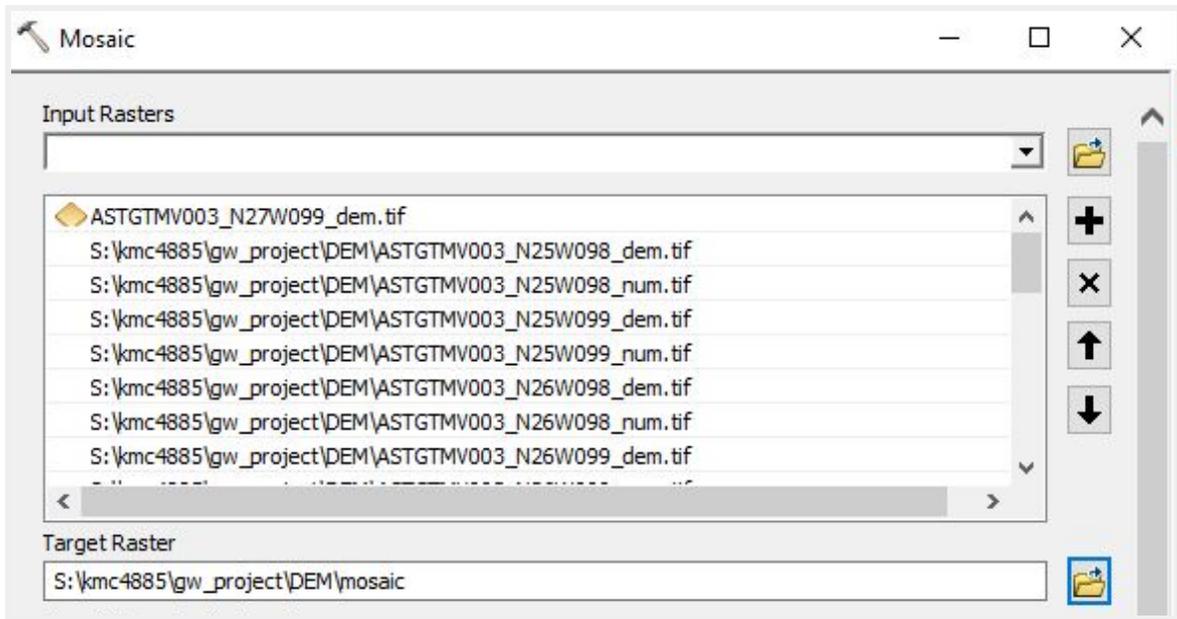


Figure 8: Using Mosaic tool to merge individual DEM tiles into one

Mosaic was then clipped to AOI2 (figure 10) that includes the Coast, unlike the first AOI, using the **extract by mask** tool.

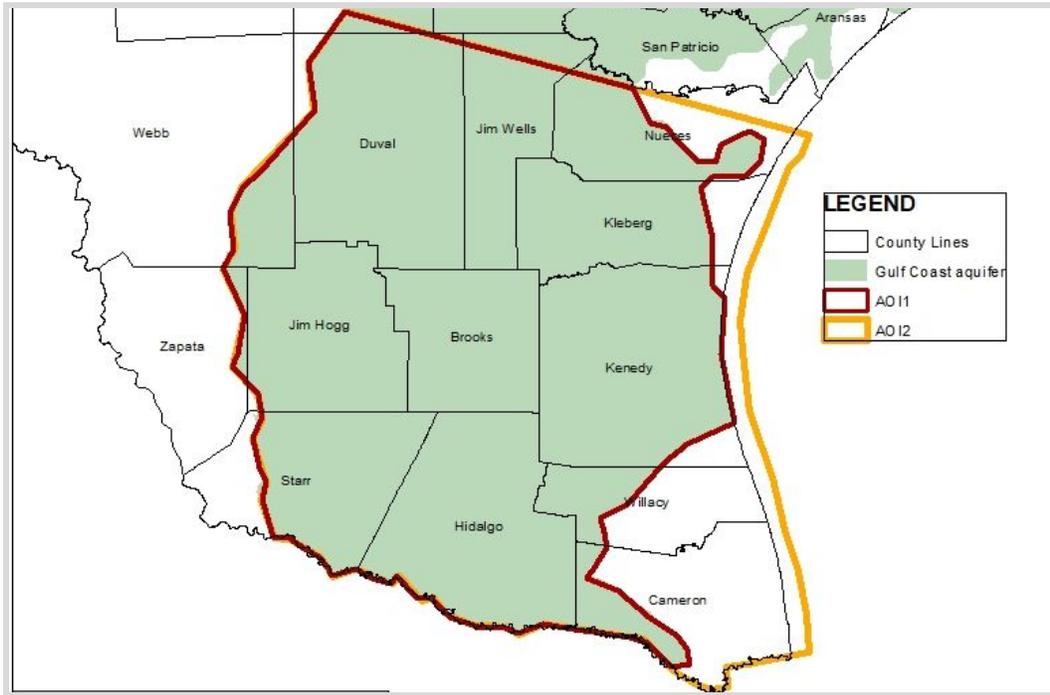


Figure 9: defining areas of analysis: AO1 and AO2

AO1 will define the area of analysis for groundwater head interpolated surface (figure 21) and AO2 defines the area of analysis for the sea level raster; since there was barely any well data exists outside of the aquifer, interpolating a groundwater flow raster based on head data would have to be confined to an area in which the points existed, or else resulting surface would be awkward.

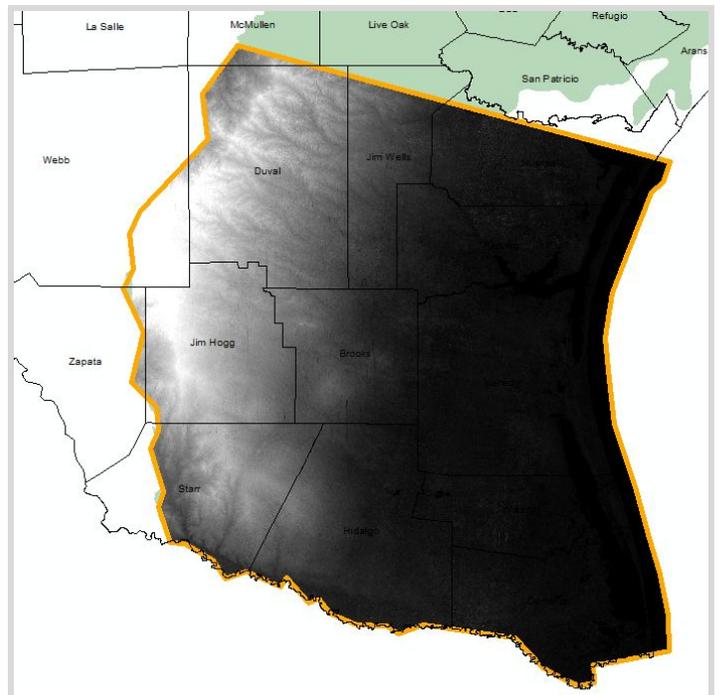


Figure 10: Mosaic Clipped to AO2 that includes the Coast to display the sea level

I then used **raster calculator** to make a statement that would generate a new binary raster, assigning a value of 0 if > 15 meters and a value of 1 if <=15 meters (figure 11). This method was repeated to make a new raster displaying the current sea level, + 3 meter high tide (figure 12).

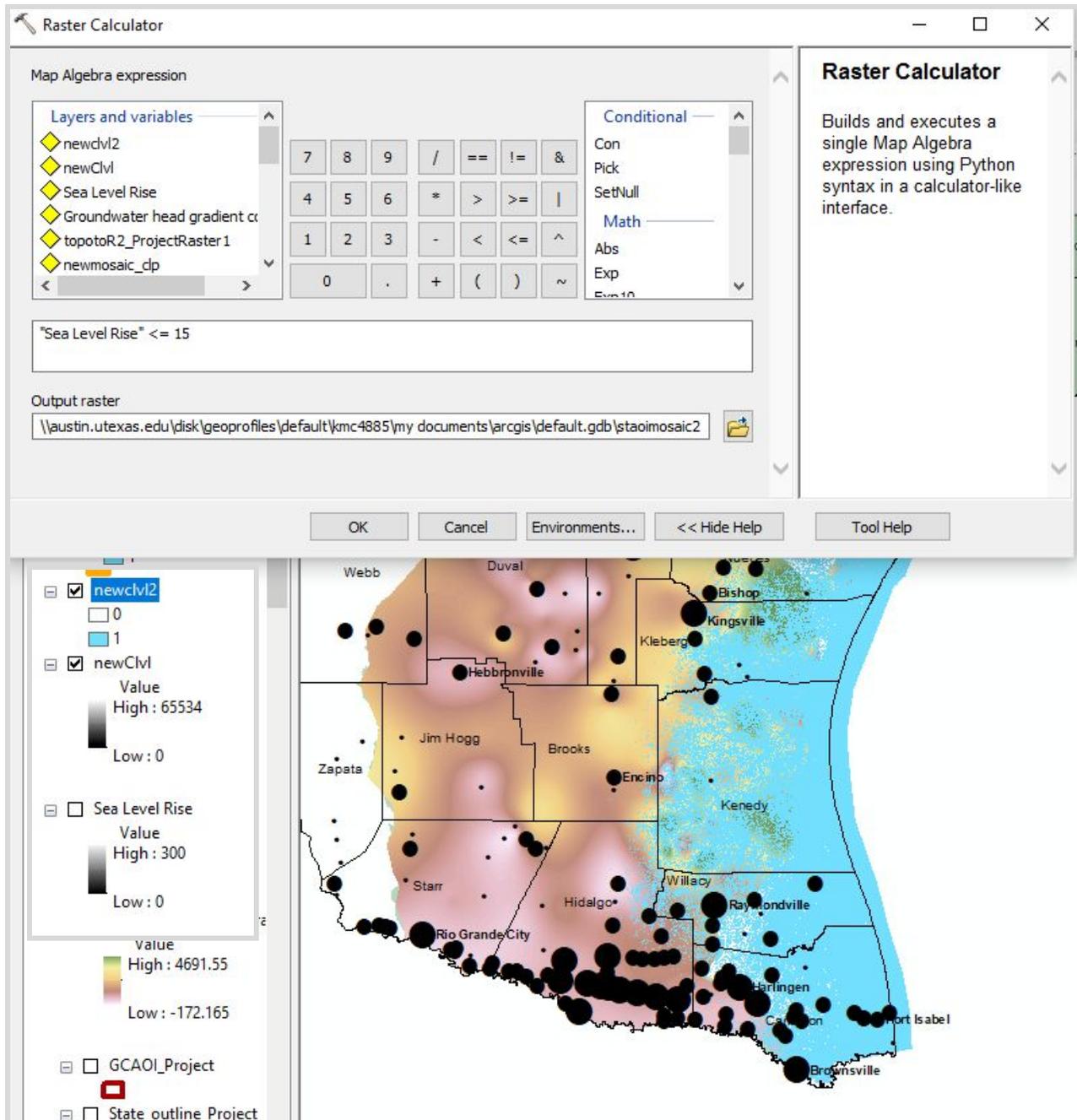


Figure 11: Raster Calculator code used to generate new raster displaying 12 meter sea level with 3 meter high tide

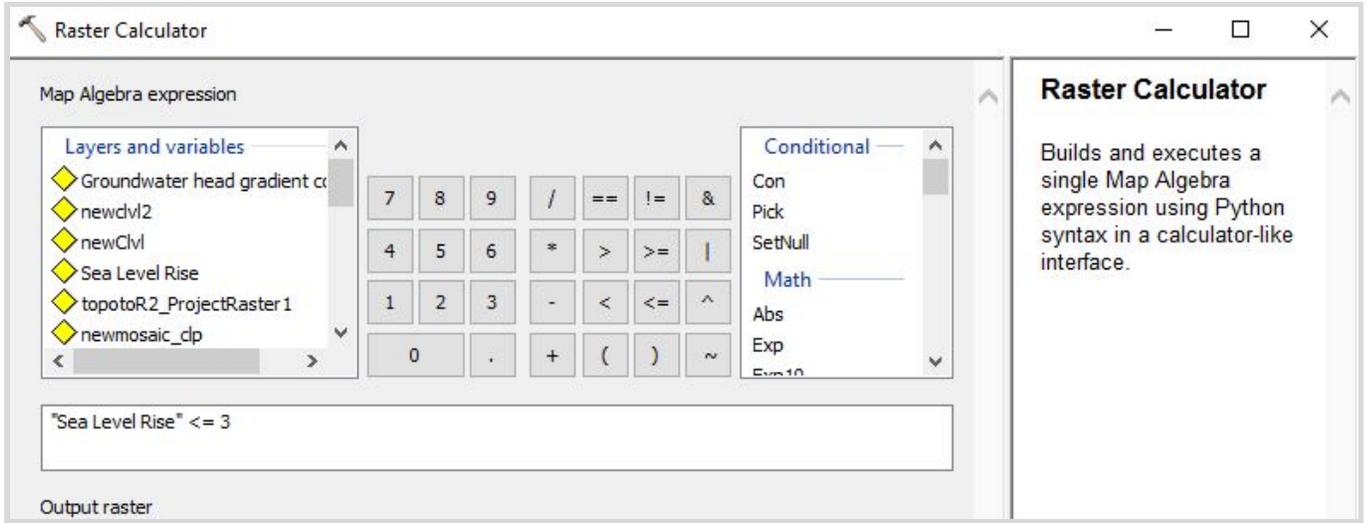


Figure 12: Raster Calculator code for generating new raster of 0 meter sea level with 3 meter high tide

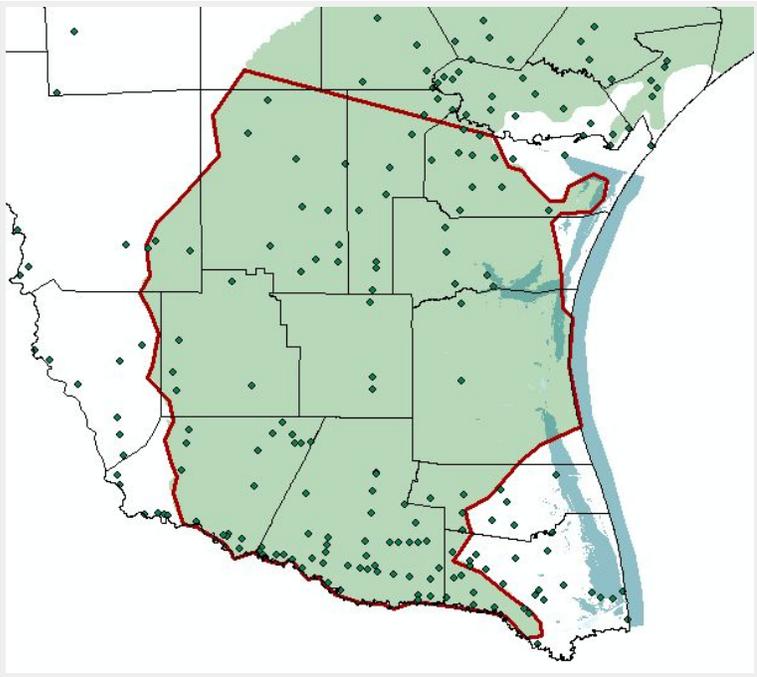


Figure 13: Current Sea level (+ 3 meter high tide)

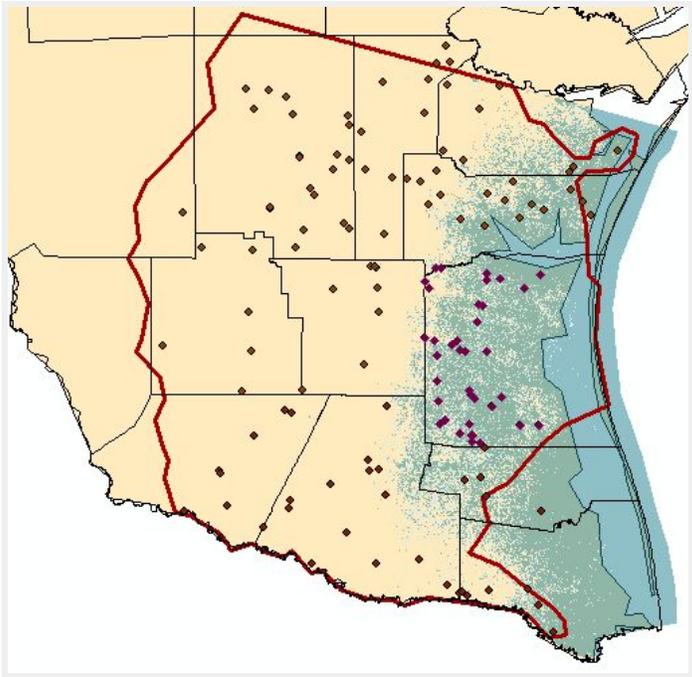


Figure 14: projected 12 m sea level (+ 3 m high tide)

III. Analyzing Groundwater Well Data

In the field of Hydrology, data collected from groundwater wells can be useful in determining flow direction of groundwater; groundwater flows along a hydraulic gradient as it flows from high head to low head. 'Head' is a measurement of the energy of the groundwater at the exact point in which the well is screened, or where the measurement is taken. Data was downloaded from the TWDB into one excel file > saved and brought into ArcMap as a csv file > given spatial reference (figure 2). I then add new fields in the attribute table for both water level and well depth. Description of data listed measurements in feet, so field calculator was used to convert the measurements of water level and depth into meters. I added a new field to calculate head, which is the absolute value of [water level - well depth] (figure 16).

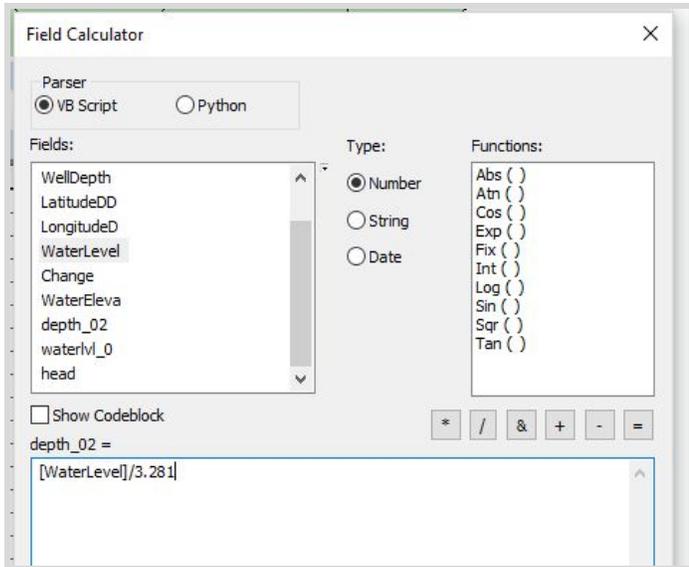


Figure 15: converting 'waterlevel' and 'wellddepth' from feet to meters ('waterlvl_0' and 'depth_02')

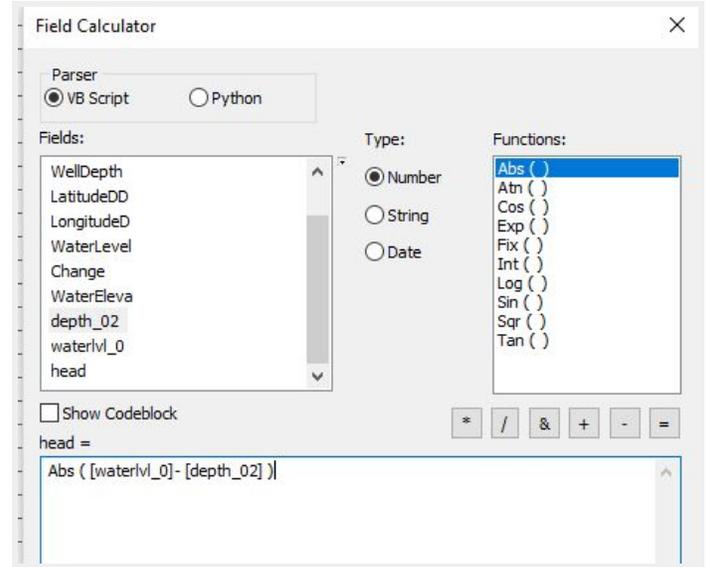


Figure 16: expression to calculate head

IV. Making Groundwater Contour Surface Using Head Data

Once head was calculated for each point, **topo to raster** tool was used to generate a "hydrologically correct digital elevation model" (1), or a smoothed surface displaying the point data as a dynamic surface.

Figure 17 shows the area of interest used.

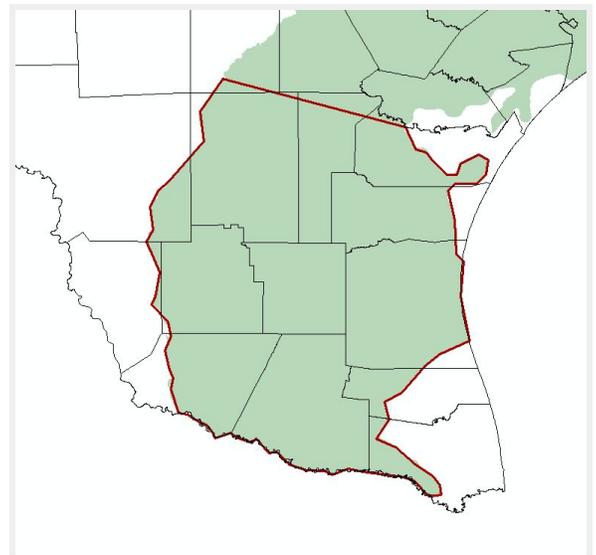


Figure 17: AOI chosen for best output

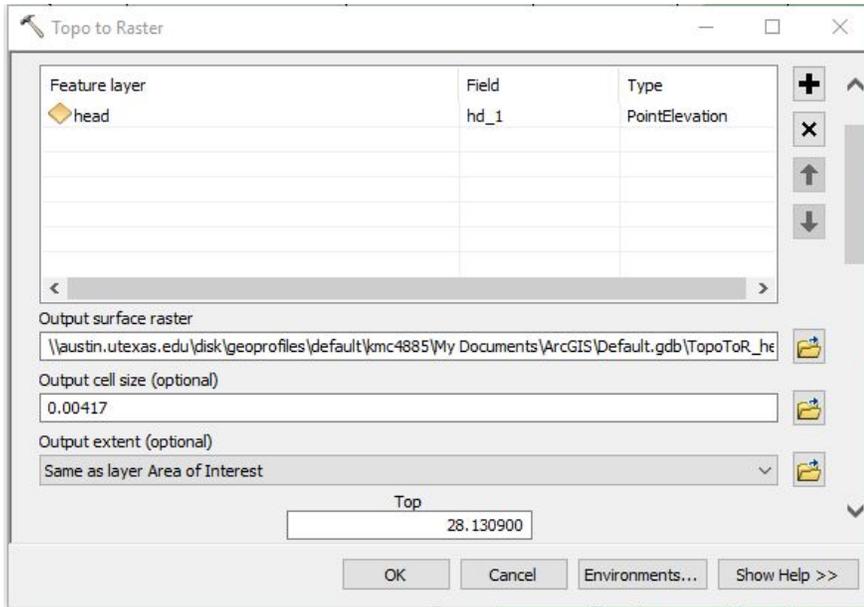


Figure 18: Topo to raster tool; 'type' had to be changed to "pointelevation" for tool to run

After running tool, used **extract by mask** tool to clip new raster to AOI1 (figure 19).

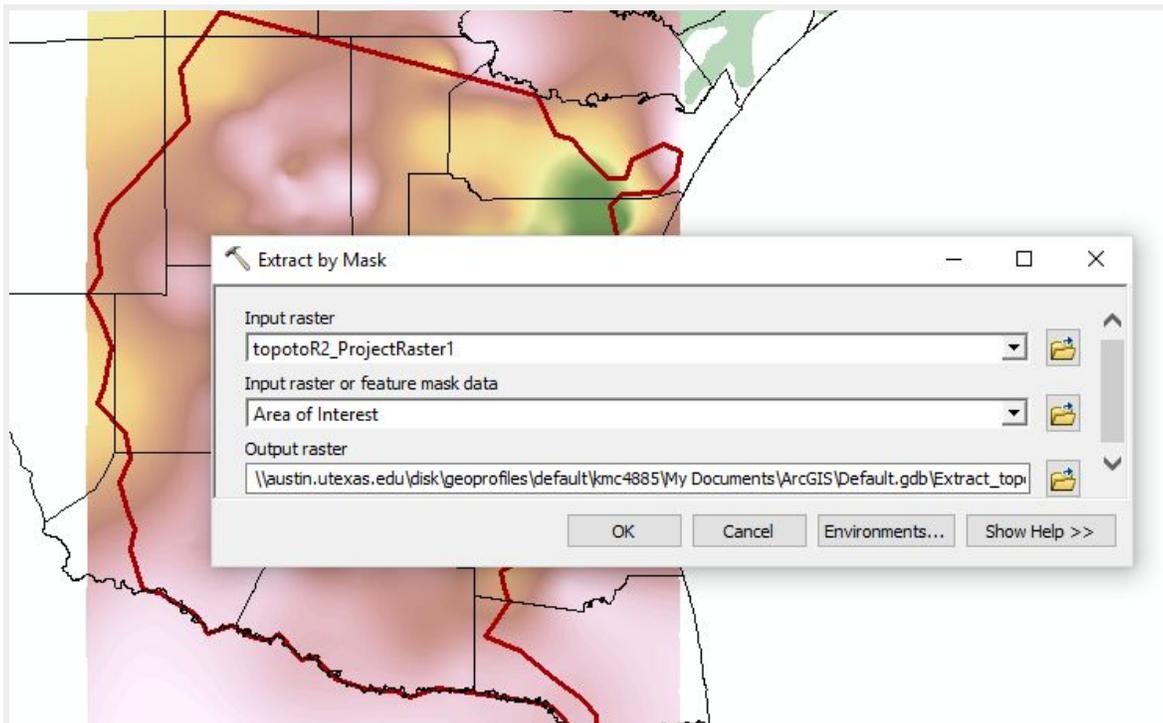


Figure 19: extract by mask tool

To symbolize, 'surface' color ramp was used and colors were inverted so color would run from green to red, symbolizing from high head to low head. The raster was then projected to North_American_1983_Lambert_Conformal_Conic using bilinear resampling technique (figure 20) given the product is now a digital elevation model of the point data and displays continuous data.

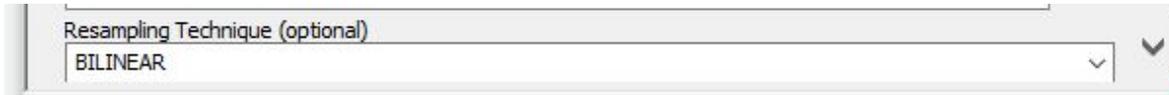


Figure 20: project raster tool

V. Analysis of Affected Populations

Shapefile of cities in South Texas was downloaded from the Texas department of transportation (txdot), then gradually symbolized by population to visualize the amount of people who will be affected by groundwater contamination and the consequences.

I proceeded to look up the general population cut off for a town and a city and symbolize accordingly (figure 22).

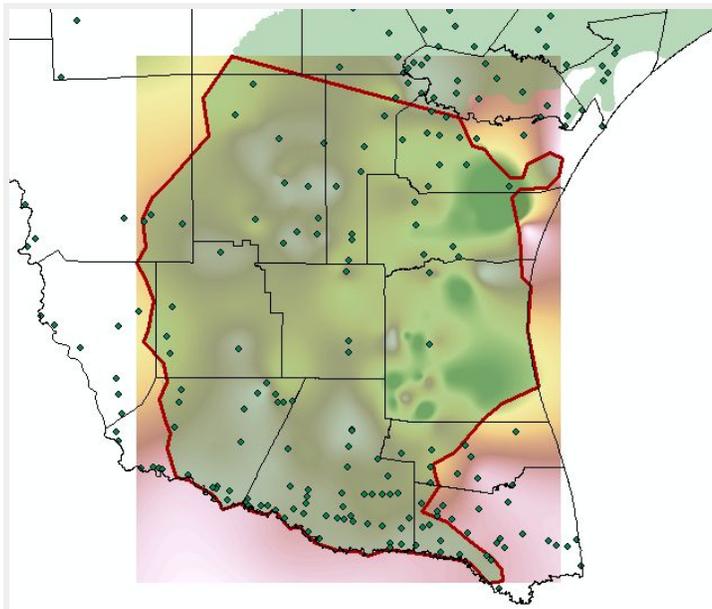


Figure 21: Cities in South Texas

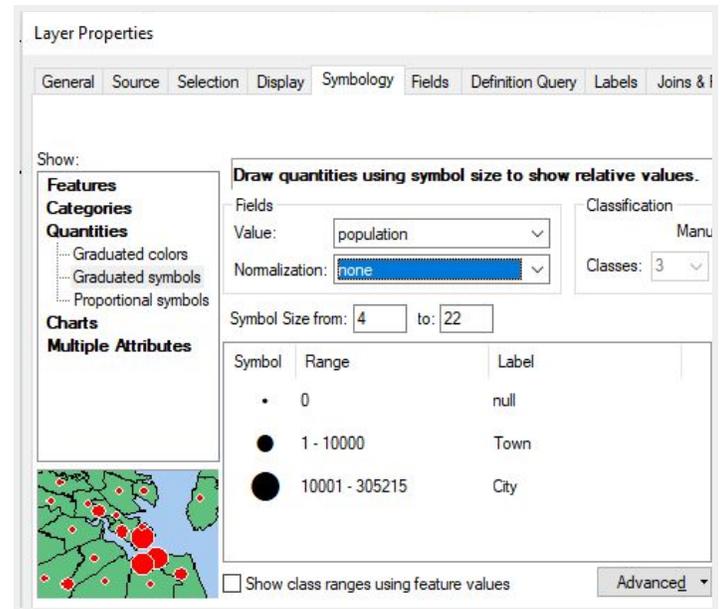


Figure 22: symbolizing cities by population size

Using the **labeling toolbar**, I chose to display a select few cities based on most recognizable names for context. I did this using **SQL query** and the code shown below in figure 23.

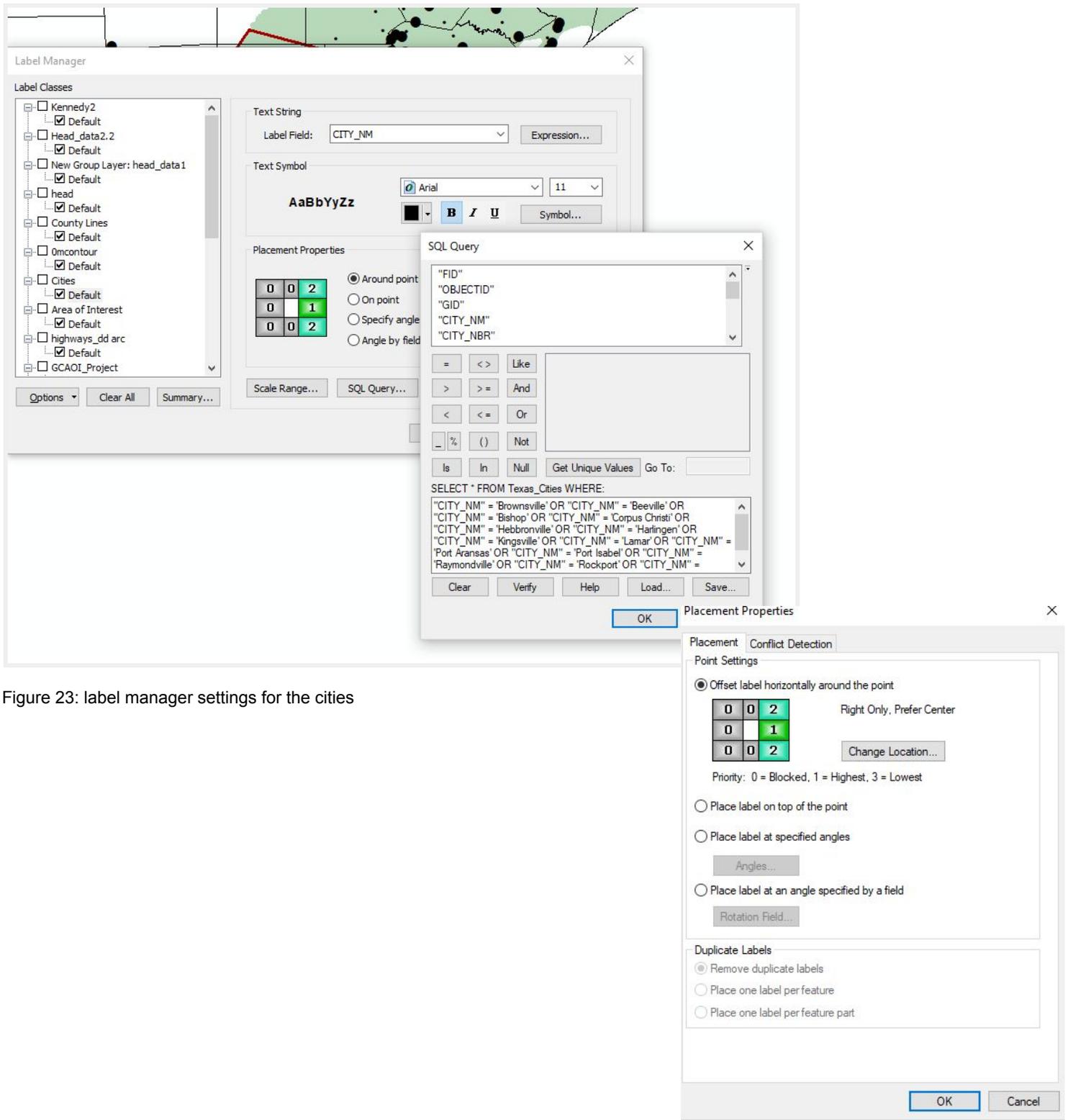
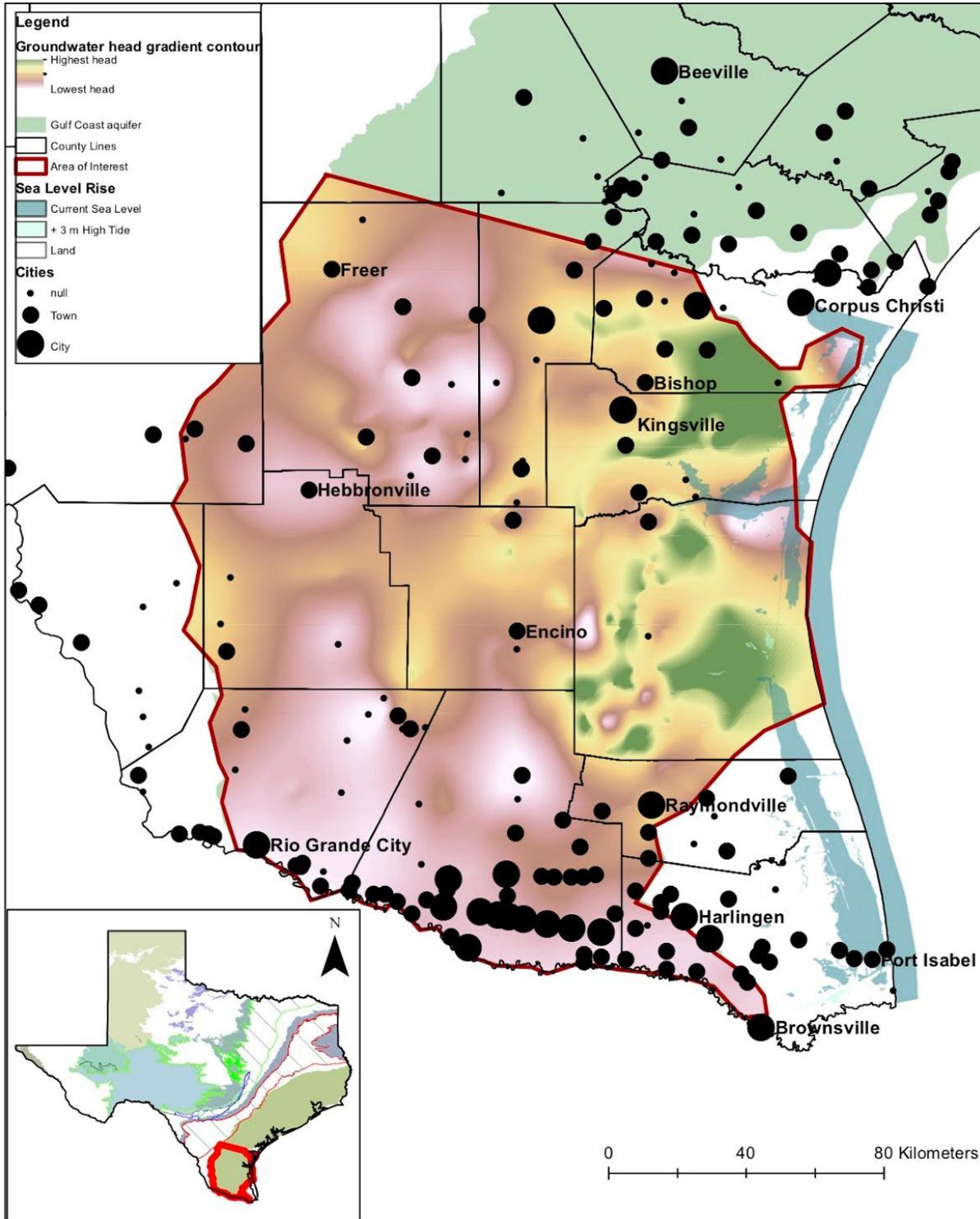


Figure 23: label manager settings for the cities

VI. Final Product

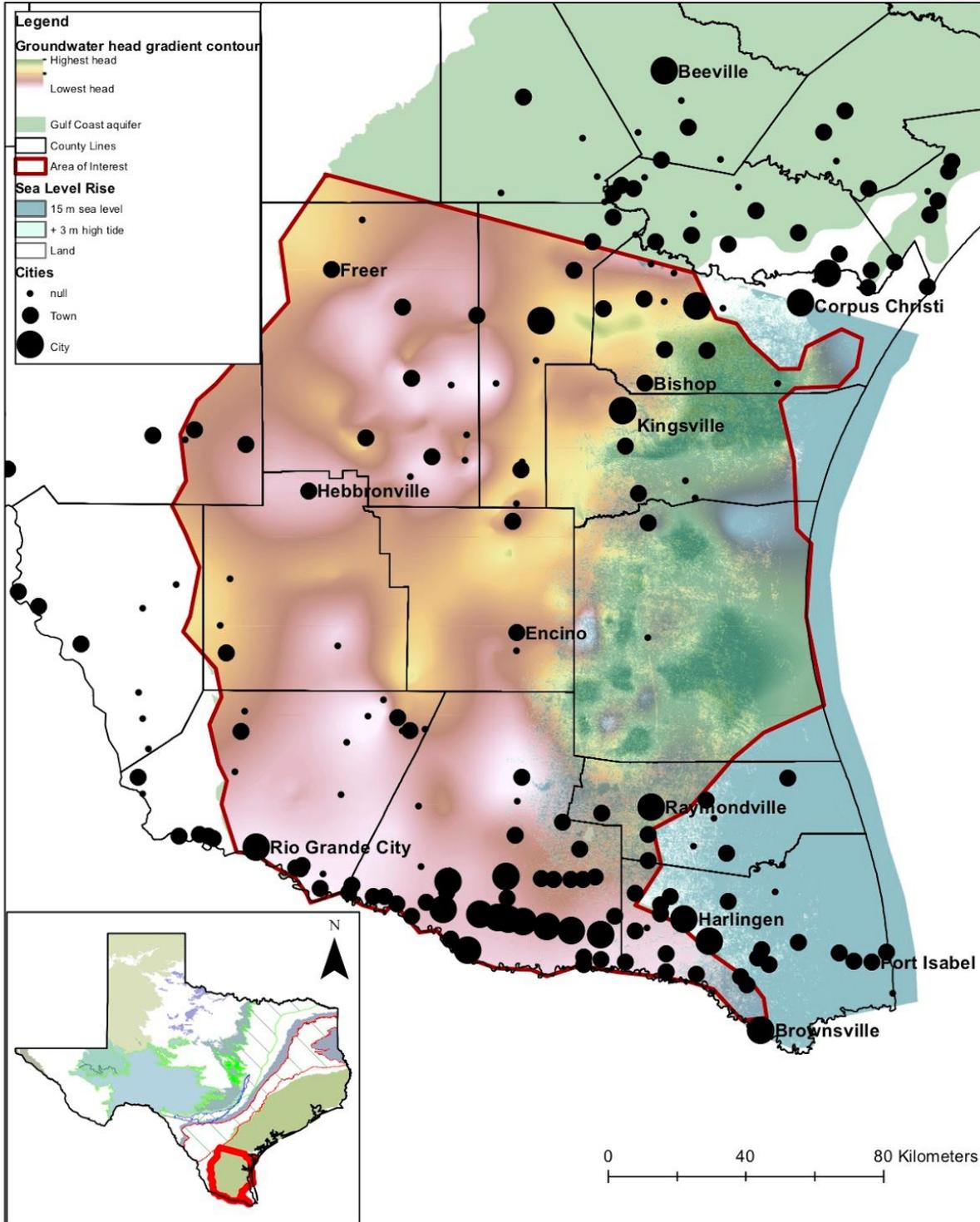
Current Brine Groundwater Contamination of Gulf Coast Aquifer

Kahne Cobarrubias
12.09.19



Brine Groundwater Contamination of Gulf Coast Aquifer Due to 15m Sea Level Rise

Kahne Cobarrubias
12.09.19



VII. 3D Model

To better visualize the way groundwater flows, I put the raster into ArcScene. The result, the figure below, can be considered analogous to topography for the sake of analysis; looking at the model below, areas of lowest head create low points similar to valleys, in which groundwater will flow towards along the hydraulic gradient.

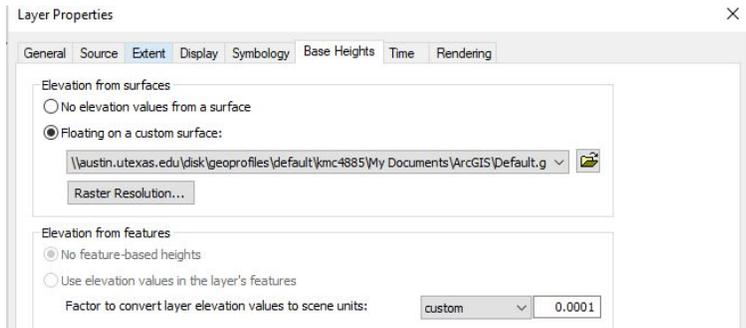
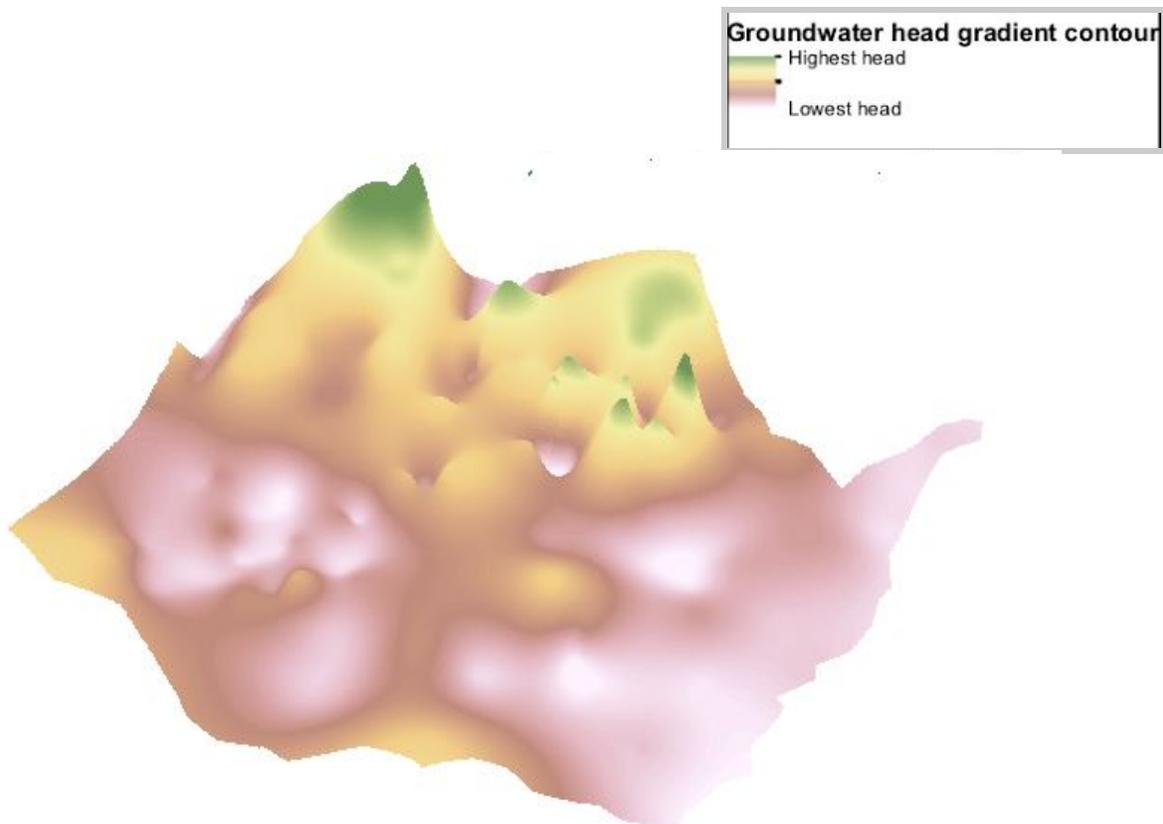


Figure 24: ArcScene settings for head gradient raster



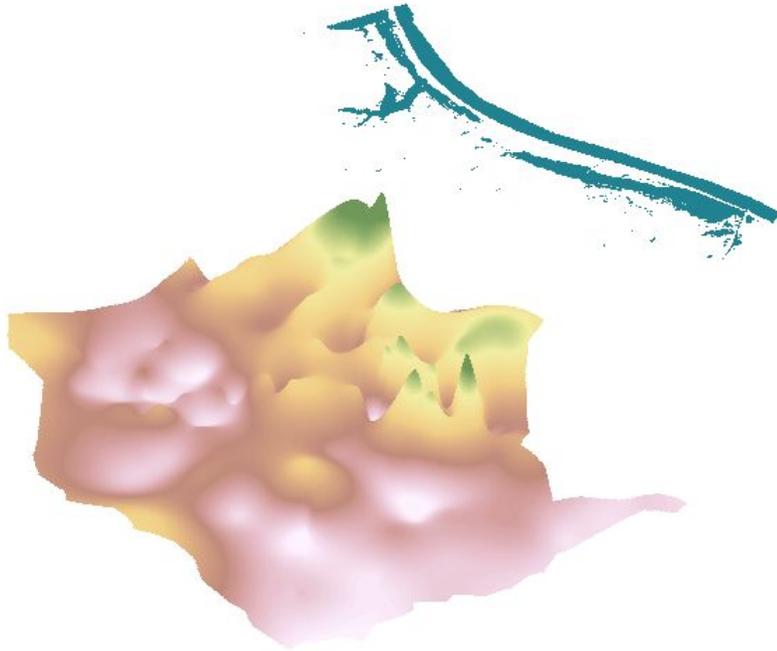


Figure 25: 3D model of groundwater flow with overlying current sea level

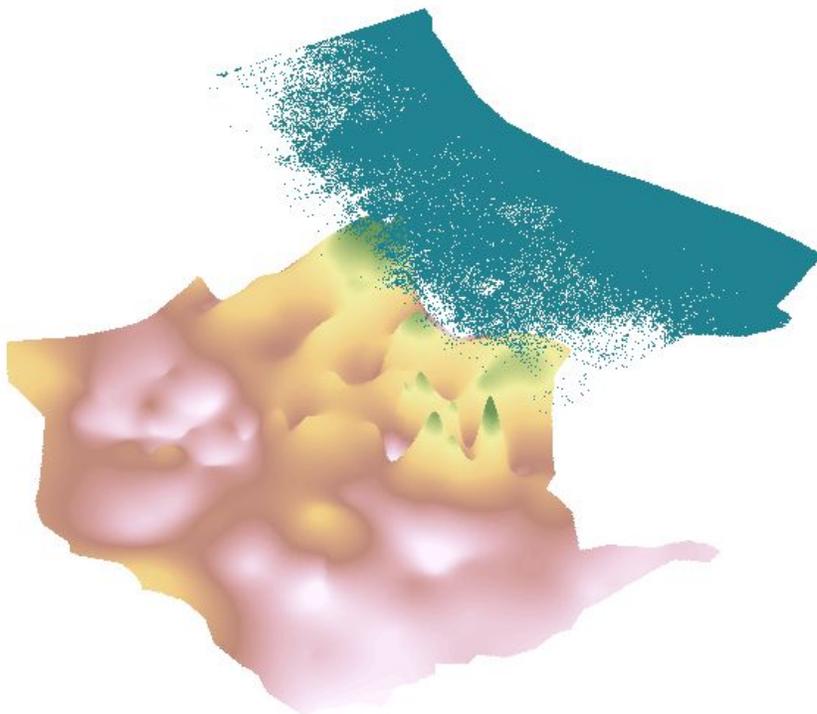


Figure 26: 3D model of groundwater flow with overlying 15 meter sea level rise

From this model (figure 26), it became obvious that if all of the high points are overlain by the sea level, then all of the areas down gradient of the highest head will be susceptible to contamination by seawater.

VIII. Conclusion

There are many factors that affect the relationship between groundwater flow and a rising sea level, that I did not account for, such as increased withdrawal due to population increase and the gradual nature of sea level rise; therefore people will have the ability to build better infrastructure in preparation, relocate, and find alternative water sources. Therefore, this project by no means seals the fate for these areas, however it does illuminate this relationship that is fundamental for preparation and mitigation protocols. Especially along the Coast, where most of the population currently relies on freshwater from the Gulf Coast aquifer, it is important to recognize the complexity of the environment and the resulting effects this will have on resource availability in the near future.

Works cited:

(MLA 7th edition)

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