GIS in Water Resources – Class Project Report

Brackish Water Recharge Potential in Texas

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1. Introduction

Brackish water is defined as groundwater with salinity levels higher than fresh water, but lower than salt water. Brackish groundwater originates from a mixture of fresh and sea water or rainfall that seeps into the ground where minerals within the subsurface react with water, thus increasing Total Dissolved Solids (TDS). The moderately salinity of brackish water makes it a prime resource to apply desalination, especially now that membrane technology has improved enough to become economically viable with water costs ranging from $1.50/Kgal to $2.75/Kgal (LBG-Guyton Associates, 2003.

Texas entities have recently taken an interest in brackish water, with the Texas Water Development Board having already identified brackish groundwater production zones in a few aquifers in 2016 and the state having already legislatively mandated identification in the rest of the aquifers by 2022. Austin has also acknowledged brackish water desalination as an option in the near future since the Water Forward program has suggested using desalination in the next water treatment as part of the 100 year water plan. An estimated 880 trillion gallons of brackish water exists underneath the surface of Texas, However, it is important to note that reverse osmosis in desalination involves flushing a waste stream of brine, effectively flushing a large portion of water away. The increased interest is a direct result of the increasing Texas population and depleting fresh water supplies.

Groundwater in general has already been a major challenge for the state of Texas to manage and regulate as a "mysterious and occult" natural resource. It is difficult to understand what truly occurs beneath the surface, but using information from multiple sources can provide a prediction of how groundwater can be sustained for human consumption. Brackish groundwater in particular is a new regulatory challenge as interest grows, and must be mapped and characterized to help future decision regarding this potential water supply for human consumption and minimal environmental impact. For instance, determining water rights for water below a property is difficult due to The lack of direct measurements to characterize groundwater raises the importance to define the resource as extensively as possible. In this project, I collect and create maps with datasets describing different variables for groundwater recharge potential such as slope, land cover, lithology, drainage density, and precipitation. Each variable is weighted based on relative importance and summed to obtain a value describing recharge potential in Texas areas known to have wells of brackish water. With this information, evaluation of groundwater potential for every city in Texas becomes possible.

2. Methods

To produce project deliverables, ArcGis Pro, Microsoft Excel, and Python are used for their data processing, calculation, analysis, and visualization applications. A detailed walkthrough of project procedures is described in the following subsections and depicted in Figure 1 below.

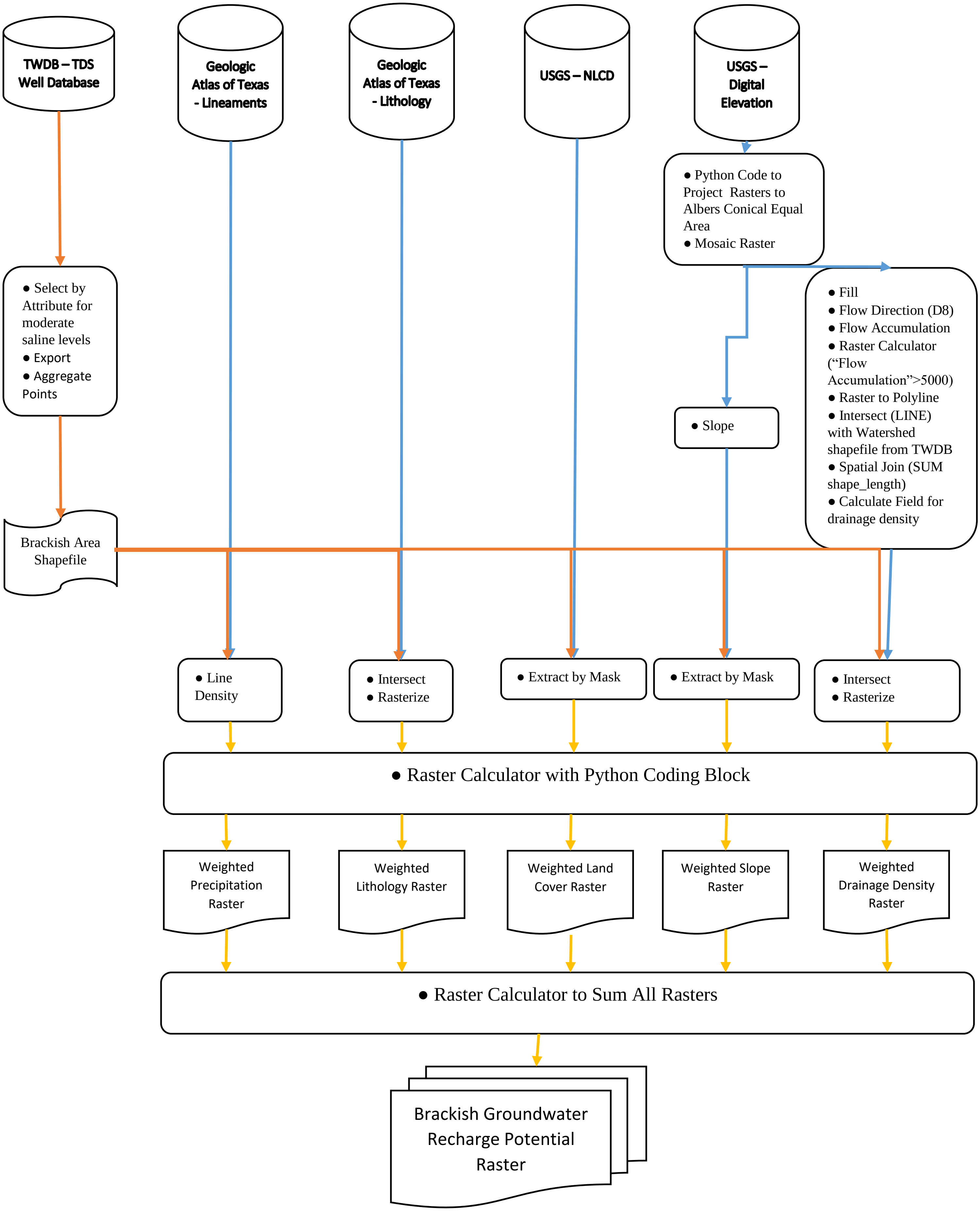


Figure 1. Project Procedure for Objective 1

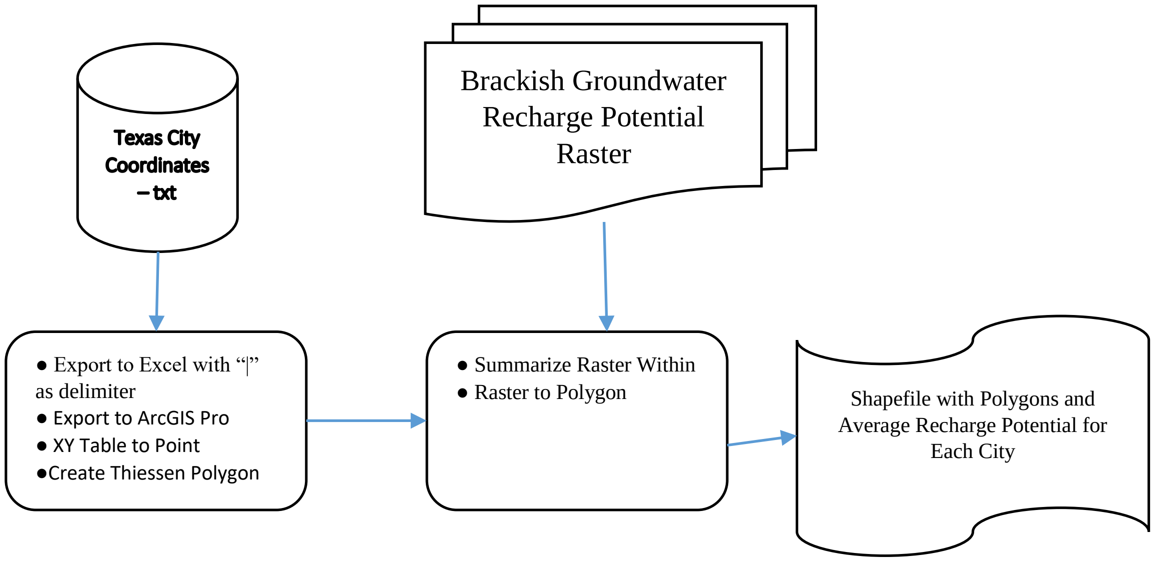


Figure 2. Project Procedure for Objective 2

The study region is the entire state of Texas, but the target area can be narrowed by selecting wells containing moderately saline water between 1000 and 10,000 mg/L of total dissolved solids (TDS). The defined brackish groundwater area of Texas if depicted in Figure 3. The map bears close similarities to the brackish water area defined by TWDB, except for the area along the Gulf Coast. It is assumed that this is an error in the map produced here since the Gulf Coast Aquifer is supposed to be the largest groundwater sink in Texas. This makes sense since seawater contact is another means by which brackish groundwater is produced. Perhaps the upper part was excluded due to high salinity.

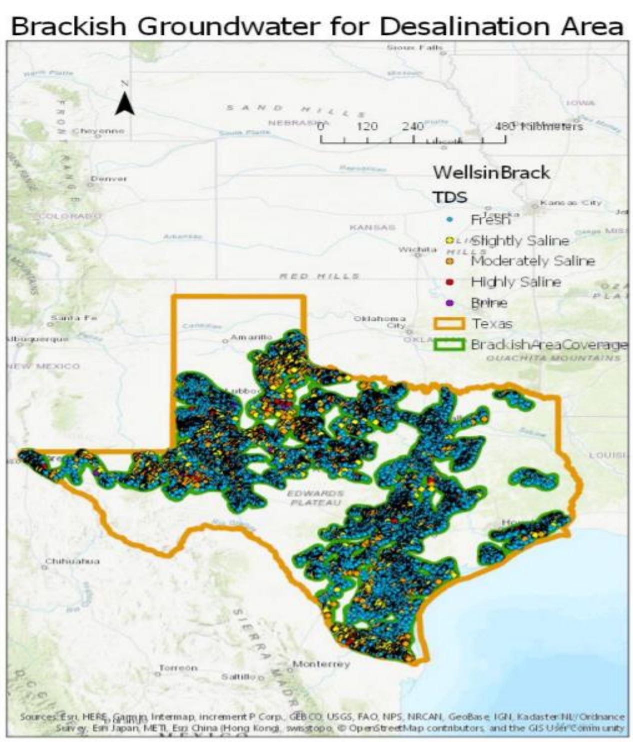


Figure 3. Brackish Water Coverage in Texas

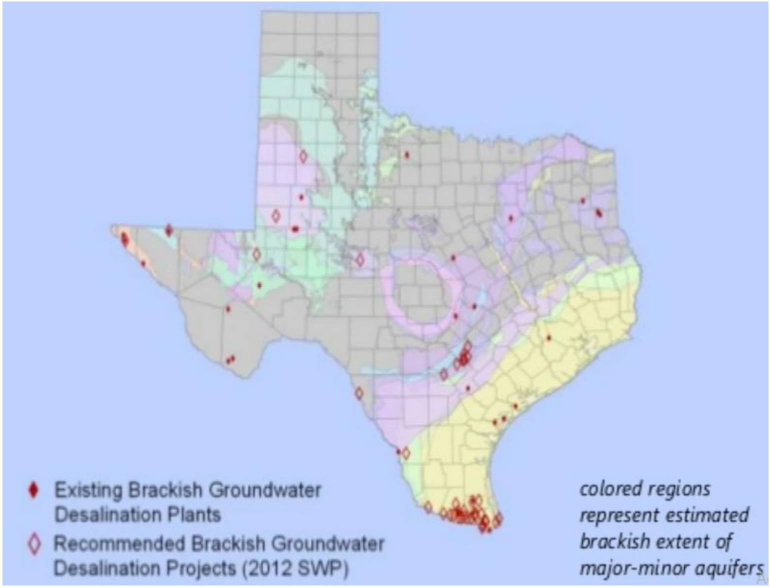


Figure 4. Brackish Water Coverage from TWDB

The weighted model used to determine the groundwater recharge potential comes from literature (Shaban et al., 2006). Converting values of significant variables to represent a new dataset describing trends on a map is a common practice in GIS. The particular weighted model used to describe brackish groundwater recharge is shown in Table 1, factoring in lithology, land cover, lineament density, slope, and drainage density.

Table 1. Weighted Model of Groundwater Recharge

Factor	Domain of Effect	Assigned Weight
Lineaments Density	5-6 (km-1)	20
	4-5	16
	3-4	13
	2-3	10
	0-2	6
	0	0
Drainage Density	6-10 (km-1)	9.75
	4-6	7.5
	2-4	5.25
	0-2	3
	0	0
Lithology	Gravelly Sand	30
	Slate/Schist	24
	Other Metamorphic Rock	15
	Marble/Dolomite	6
	Igneous Rock	3
Slope Gradient	0-10	15
	10-20	12
	20-35	9.75
	35-60	7.5
Land use/Cover	Water	16.25
	Agriculture	12.5
	Bare Land	8.75
	Forest	5
	Building	2.5

Lithology plays a role in the percolation of water as different rock formations with varying porosities can influence how water travels in the subsurface. Although there are investigations that consider lithology negligible by referring to lineament and drainage density as functions of primary and secondary porosity, including the data provides greater certainty. From Table 1, it is clear that the impact of lithology on groundwater recharge potential increases with porous and permeable media, such as gravel, but decreases with smooth and cohesive rocks such as igneous rock. As show in Figure 1 the lithology shapefile was retrieved from the Geologic Atlas of Texas (GAT) by the Texas Natural Resources Information System as a joint project with USGS Texas Water Science Center. Figure 3 presents the raw geology dataset and the resulting assigned weight of geology towards recharge potential.

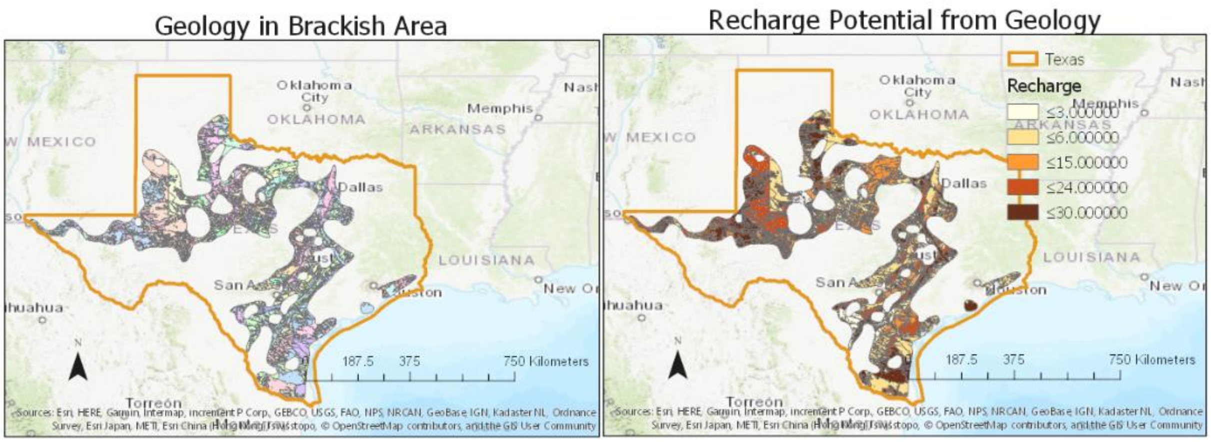
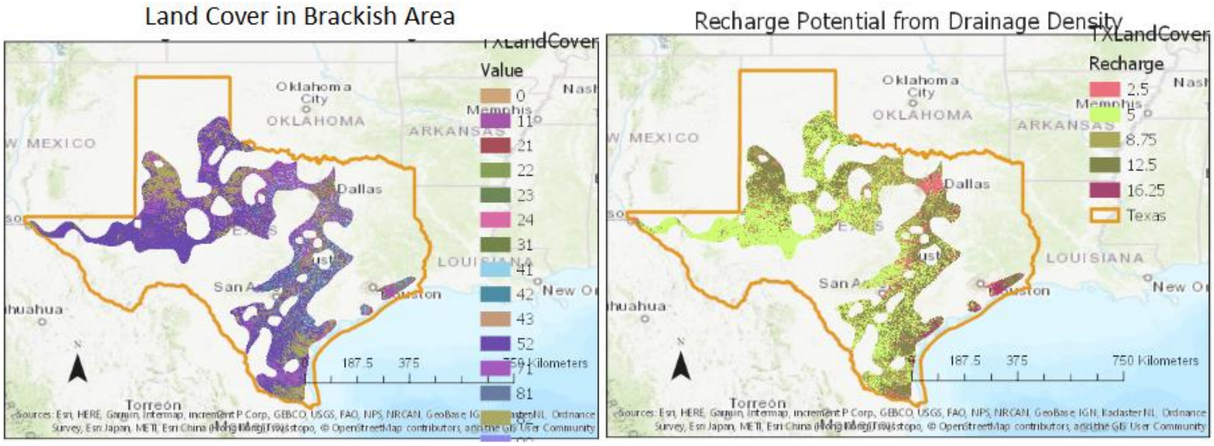


Figure 3. Geology in Groundwater Recharge

Land cover data gives an impression of the soil deposits, residential area distribution, water demand, and vegetation in an area and how these factors affect the ability for water to enter the subsurface. All these factors impact the evapotranspiration, runoff, and surface permeability. For instance, Table 1 suggests developed areas greatly reduce groundwater recharge potential; likely because infrastructure is designed to drain water into city water systems rather than lost to the subsurface. On the other end of the spectrum, areas with water greatly increase recharge potential due to the large availability of water that can permeate the surface. The land cover raster was obtained from the National Land Cover Database (NLCD) that was obtained from the United States Geologic Survey (USGS).



Lineaments are linear geologic formations and are commonly faults where water can easily pass into, thus supplementing groundwater recharge. However, some cases can slow the flow of groundwater. Overall, the model used in this project suggests that faults create a net increase in the ability for water to enter the ground. The lineaments were taken from the Geologic Atlas of Texas. In addition to lineament density and recharge potential weight, Figure 5 includes the lines of the original lineament polylines.

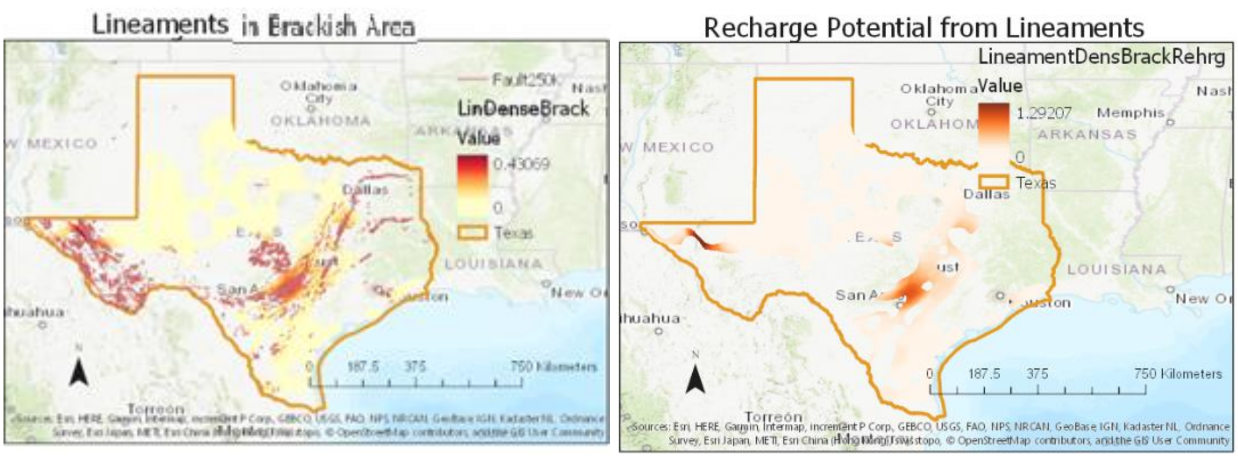


Figure 5. Lineaments in Groundwater Recharge

Slope mainly impacts recharge as steep terrain results in less time for water to permeate the surface. Table 1 shows how greater slopes result means lower recharge potential. The slope was calculated with the Slope geoprocessing tool with the National Elevation Dataset from USGS as the input.

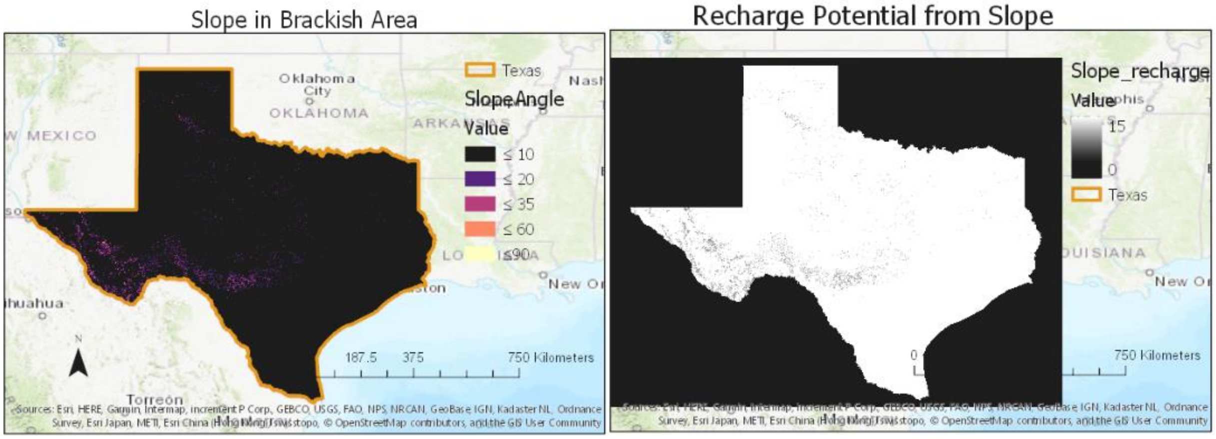


Figure 6. Slope in Groundwater Recharge

According to Table 1, the weighted recharge potential is directly proportional to drainage density. This correlation results from an increase in the amount of rivers, similar to bodies of water increase potential from land cover. Furthermore, a larger drainage density means less distance is required for rainfall to travel to a stream, meaning less time spent as runoff just as lower slope resulted in less time as runoff. Additionally, drainage density can indicate how prone to flooding an area is and floods can pick up clay sediment, thus increasing permeability. Like slope, drainage density calculation started with the Digital Elevation Model (DEM) for Texas, which then fed into the flow direction and flow accumulation geoprocessing tools to yield delineation of flow streams. The polylines were then broken at the boundaries of all watersheds and the length of polylines within were divided by the respective watershed area.

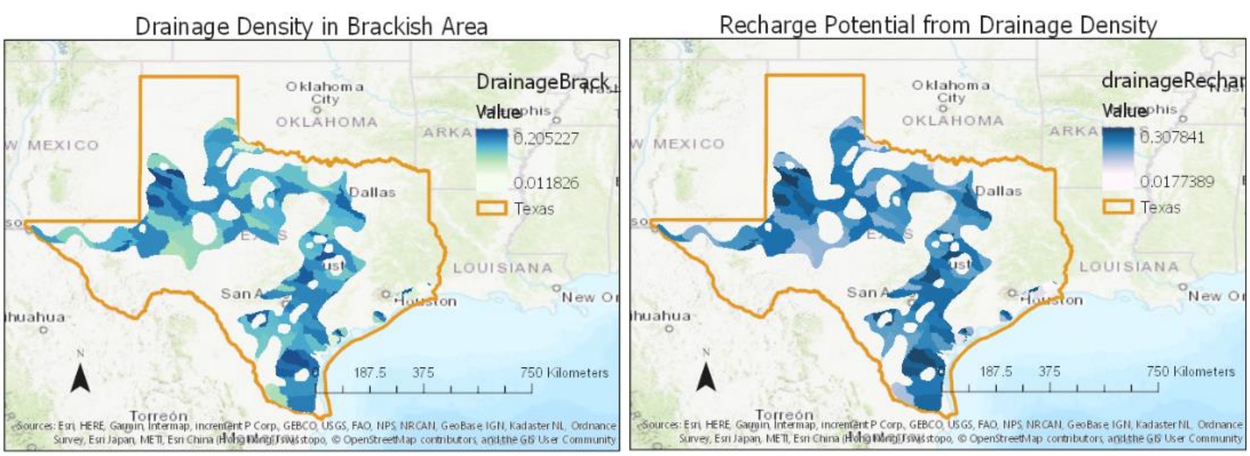


Figure 7. Drainage Density in Groundwater Recharge

3. Results

Once all the recharge potentials from each contributing factor are rasterized and mapped, the total groundwater recharge potential can be calculated from the model equation (Yeh et al., 2009):

$$P_r = LD_w + DD_w + LG_w + SG_w + LC_w \tag{1}$$

Where LD_w is lineament density, DD_w is drainage density, LG_w is lithology, SG_w is slope, and LC_w is land cover. The entire data processing can effectively be described by Figure 8, where each square is one cell of the raster with a corresponding value. Figure 9 displays the final result of the model.

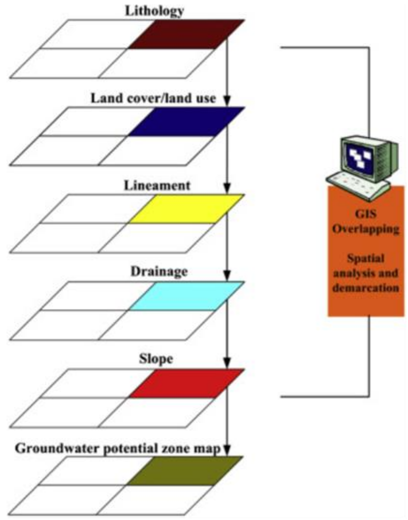


Figure 8. Weighted Recharge Model

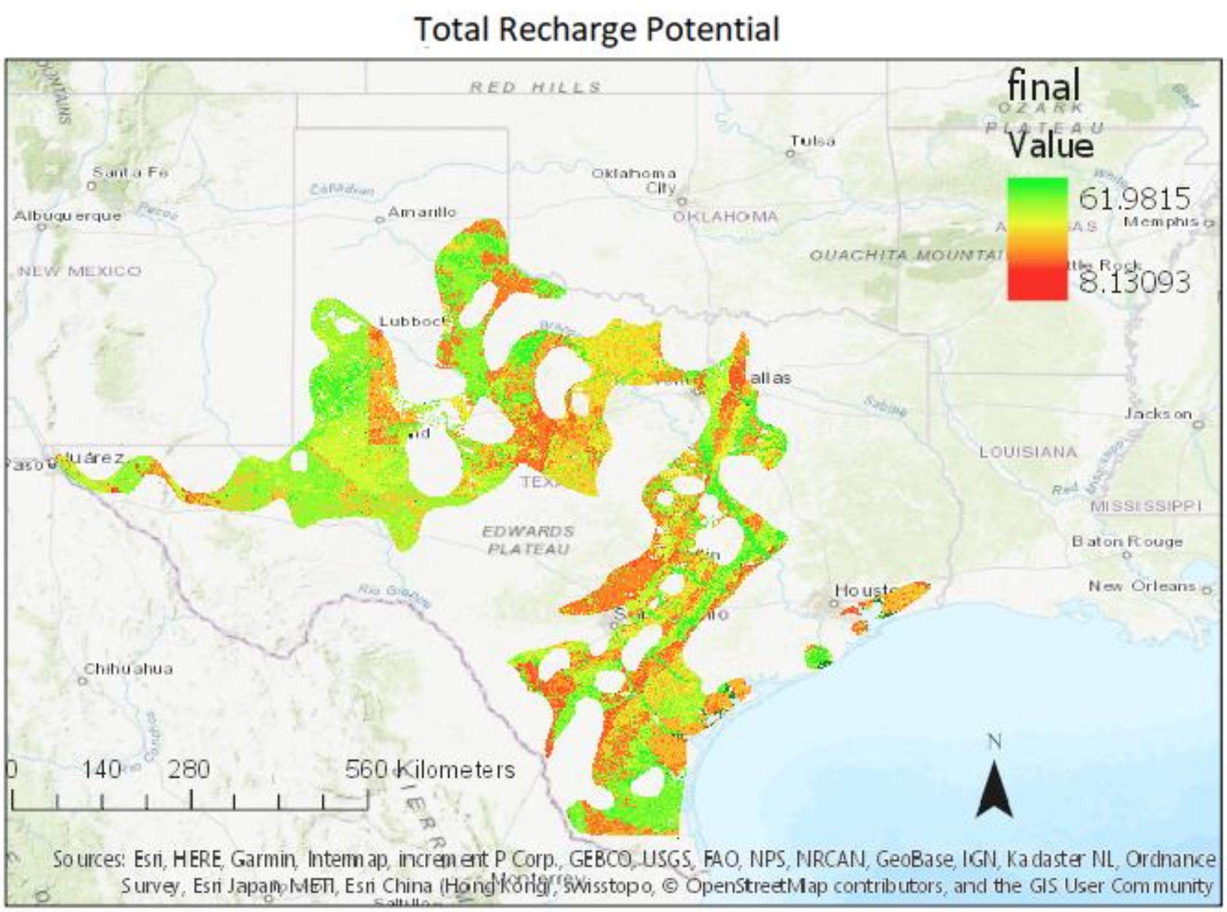


Figure 9. Total Recharge Potential

Based on the map, West appears to have the greatest potential for groundwater recharge, which is good since that area struggle with water issues. However, this raises the question of why precipitation was not included in the literature model since rainfall is generally where groundwater originates. Another interesting point was the low recharge potential around the San Antonio area, which relies heavily on groundwater and even utilizes desalination. However, further research revealed that recharge in the area is primarily from groundwater underflow from the west (Arnow, 1963). The biggest contributors that differentiated between high and low potential areas were land cover and lithology, whereas slope contributed to the final potential value but did not vary greatly across the state except for small areas. lineaments and drainage density appeared to minimal impact on final values, despite having the same magnitude as densities calculated in past exercises. Although lineament density only contributed up to 1.3 units of recharge potential, I believe it influenced the value of lithology, as the Trans-Pecos Texas area has high permeability earth overlain the lineaments.

After converting city coordinate data from a text file into Excel and again into ArcGIS Pro, the points were used to create Thiessen polygons. The groundwater potential can then be averaged within each polygon to describe the extent a city could use brackish groundwater as a water supply. Figure 10 displays the Thiessen polygons overlaid across Texas and Figure 11 displays the polygon representing Austin. The bar chart shown in Figure 12 displays the groundwater potential for a select few cities that may have the water demand to tap into this resource. This secondary objective of determining recharge potential needs refinement as the project was done with the Texas raster as the top priority. Mainly, the areas need to be defined in a broader way, instead of having Round Rock and Austin as two separate water users. Initially, the plan was to find GIS data for water municipalities or some other representation to define a metropolitan area. However, the cities were the easiest since a text file with coordinate data was available and would supply enough cities to create Thiessen polygons of reasonable sizes.

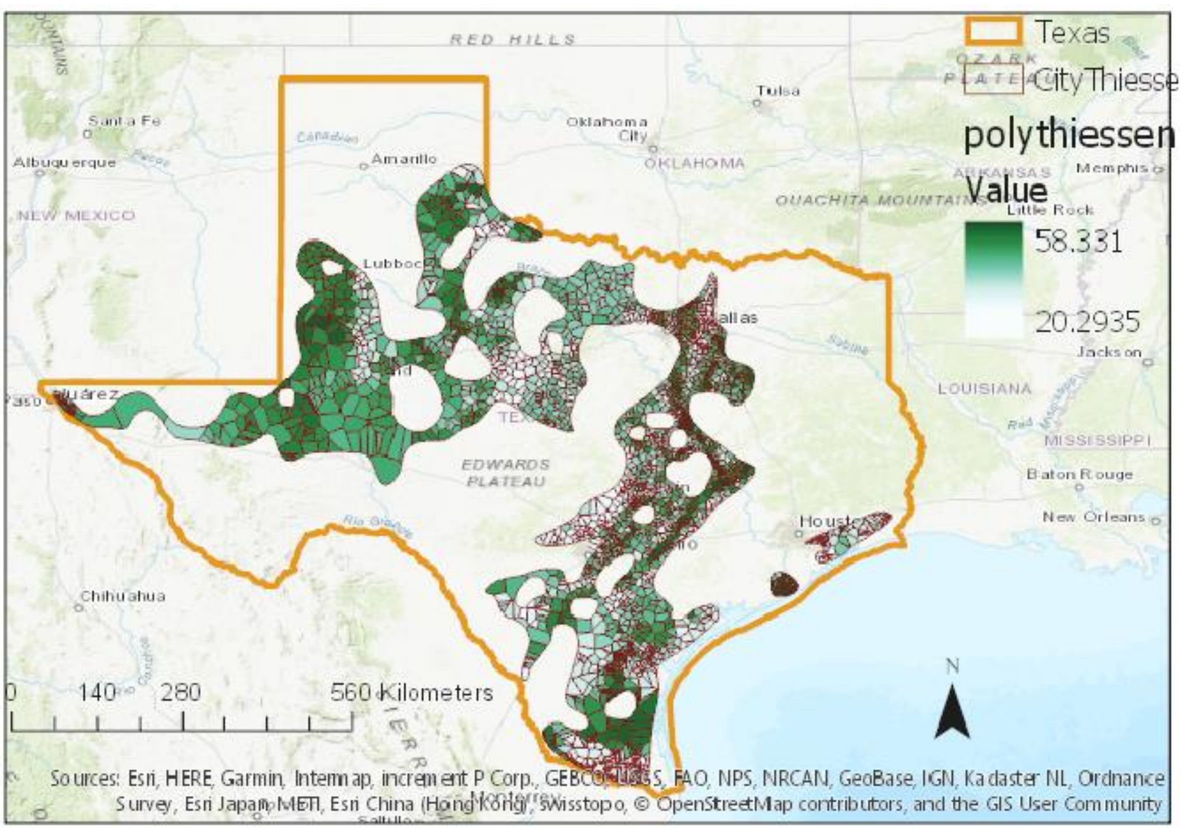


Figure 10. Groundwater Recharge Potential for Individual Cities

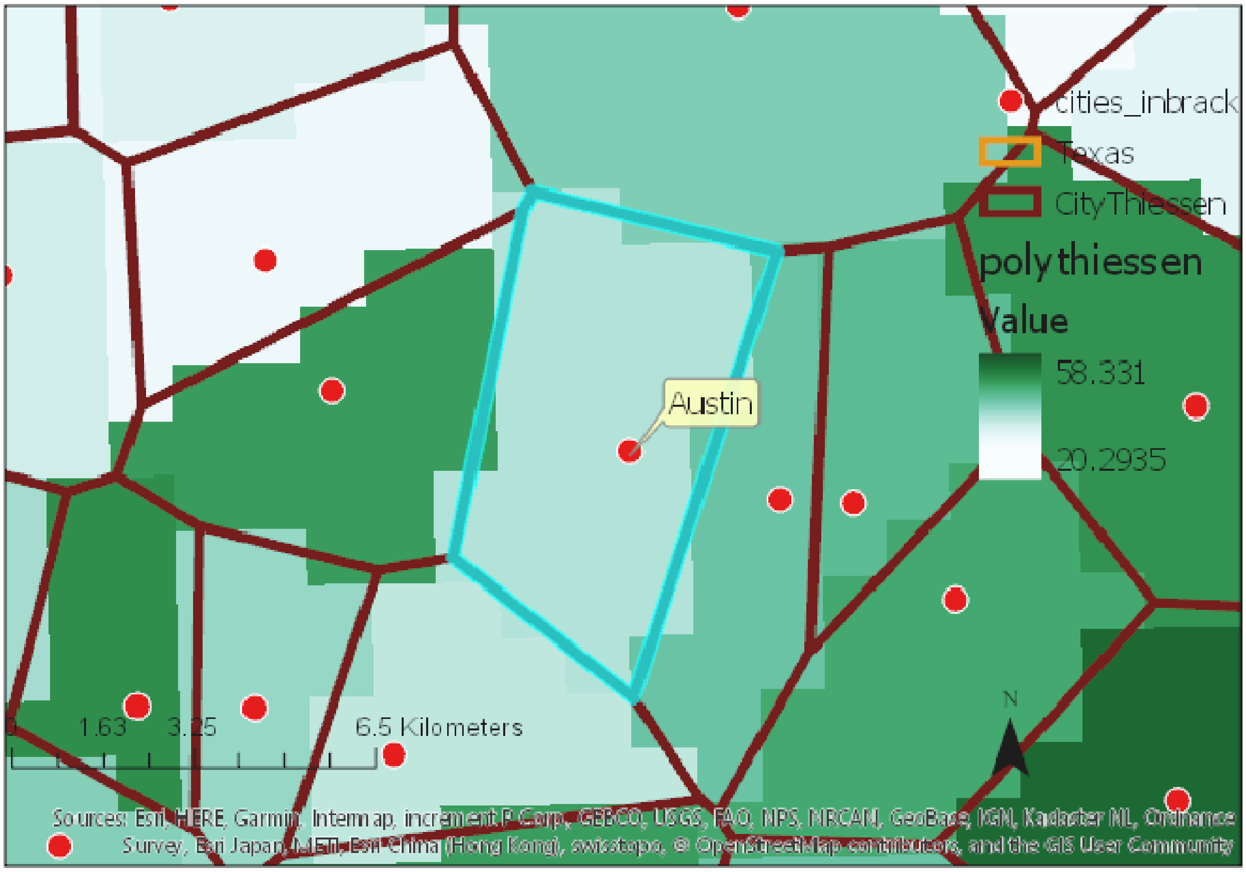


Figure 11. Thiessen Polygon for Austin

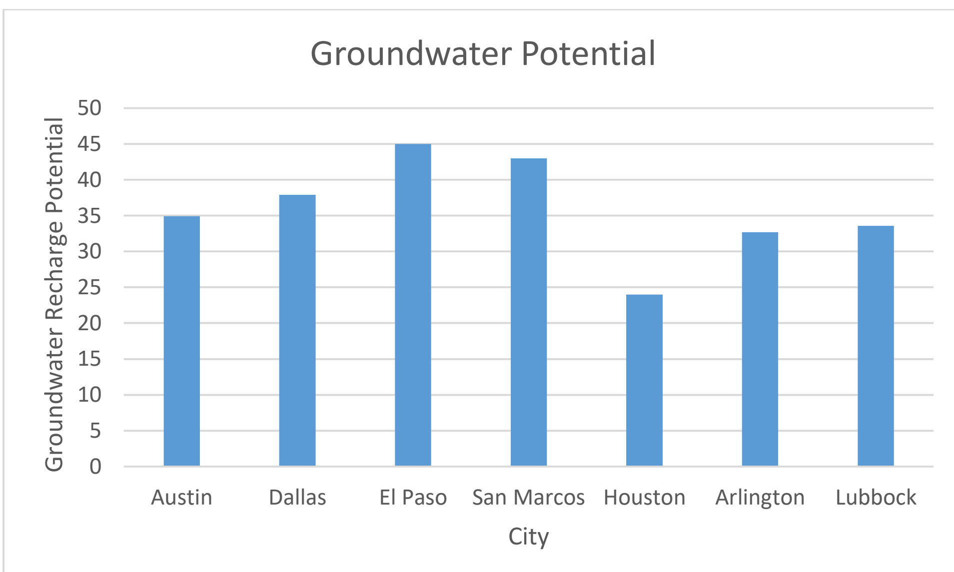


Figure 12. Groundwater Potential in Select Texas Cities

4. Conclusions

As said before, groundwater alone has proven a difficult resource to manage and regulate, so it is difficult to draw conclusions about how to move forward with the massive resource that is brackish groundwater. However, it is clear that the resource is there when needed. Austin has a moderately high recharge potential so the next brackish water desalination plant that Austin Water plans to construct should be a good buffer to the water supply. El Paso will also have the opportunity to access brackish water as it has a relatively high recharge potential and may need to rely on it heavily in an area that is arid and has a competing water user across the border.

With regards to the primary objective of building the brackish groundwater recharge potential raster, future work will involve considering more variables that may also impact recharge such as precipitation or soil. For the secondary objective, refinement of the Thiessen polygons for Texas cities will be necessary, either by finding another data set to apply the recharge raster or potentially by merging and averaging city polygons of interest, like Austin, with adjacent polygons to be more representative of the coverage that Austin Water utility provides.

Appendix A. Code

Land Cover Reclassify

Recharge =

```
Reclass(!Value!)
```

Code Block

```
def Reclass(Value):
    if (Value == 11 or Value == 90 or Value == 95):
        return 16.25
    elif (Value == 81 or Value == 82):
        return 12.5
    elif (Value == 31 or Value == 71):
        return 8.75
    elif (Value == 52 or Value == 41 or Value == 42 or Value == 43):
        return 5
    elif (Value == 21 or Value == 22 or Value == 23 or Value == 24):
        return 2.5
```

Lithology Reclassify

```
def ReClass(!RockUnit!):
a=("Qq" , "Qd" , "Qap" , "QT" , "Pvc" , "Pw" , "Kl" , "Kw" , "Ks" , "Kf" , "Ey" , "Ej" , "Ttr" , "Tscg" ,
"Tcg" , "F S" , "Qal" , "Qtf" , "Qbi" , "Qsd" , "Qds" , "Qs" , "Qt" , "Qcg" , "Qli"
b=("Qu" , "T-qu" , "Qw" , "Qo" , "Ql" , "Qh" , "Qf" , "Qg" , "Qc" , "Ke" , "Eb" , "Ec" , "Tsc" , "Tl" , "Tli"
, "Qcd" , "Qeo")
c=("Qaf" , "Py" , "Ps" , "Pn" , "Po" , "Pp" , "PA" , "Pa" , "Mf" , "Mg" , "Kt" , "Ko" , "Kd" ,"Kb" , "IP" ,
"Ew" , "Ek" , "EPA" , "Eh" , "Ei" , "Ty" , "Td" , "Tgd" , "Tmz" , "Tcv" , "Ql" , "Qa" , "Tfo")
```

```
d=("Qao" , "Pt" , "Pr" , "Pq" , "Pg" , "Ph" , "Pb" , "Pc" , "Pd" , "Og" , "Oh" , "Oc" ,"Mo" , "MD" , "MO" ,"Kp" , "Ky" , "Kn" , "Kl" , "Kg" , "Ka" , "Es" , "Er" , "Eq" , "Ed" , "Jm" , "Jz" , "Qb" , "Qu" , "Jlc" , "Kwt" , "Kae" , "Km" , "Tsi" , "Tgd" , "Tfo" , "Qbf" , "Qla"  , "QTu" , "Tg" , "Qam" , "Qas" , "Qbm")
e=("Pj" , "Pl" , "Pm" , "Pe" , "Ot" , "Of" , "OEdd" ,"Km" , "Mc" , "Kh" , "Ki" , "kk" , "Kc" , "Esb" , "El" , "Em" , "Ee" , "EO" , "Tm" , "Tla" , "Tgc" , "Tc" , "Tcgl" , "Tj" , "Tjw")
    if any(x in RockUnit for x in a):
        return 30
    elif any(x in RockUnit for x in b):
        return 24
    elif any(x in RockUnit for x in c):
        return 15
    elif  any(x in RockUnit for x in d):
        return 6
    elif  any(x in RockUnit for x in e):
        return 3
```

Batch Project Rasters

```
import arcpy, sys
InFolder = r"F:\New folder\elevation_NED30M_tx_3641694_01\elevation"
OutFolder = r"F:\New folder\texaselevation"
OutSR = arcpy.SpatialReference(26914)
arcpy.env.workspace = InFolder
for Ras in arcpy.ListRasters():
    arcpy.AddMessage("Projecting " + Ras)
    arcpy.ProjectRaster_management (InFolder + "\\" + Ras, OutFolder + "\\" + Ras,OutSR)
arcpy.AddMessage("Projecting complete")
```

References

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Ashworth, J., Albright, J., & Herrera, J. (2016). Far West Texas Water Plan (United States of America, Texas Water Development Board, Region E).

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H.F. Yeh, C.H. Lee, K.C. Hsu, P.H. ChangGIS for the assessment of the groundwater recharge potential zone. Environ Geol, 58 (2009), pp. 185-195

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