

Tunneling in Austin: Subway Routing using Geology, Population and Engineering Properties in ArcGIS

Problem formulation

The aim of this project is to perform a suitability analysis for a subway system in Austin, TX and come up with preliminary routes while looking at the geology, population and engineering feasibility of tunnel construction.

The motivation for this project comes from my experience with poor traffic conditions in Austin and an interest in Tunnel Construction. Patterson (2012) very convincingly gives reasons as to why Austin does not have subway systems yet, despite favorable geology of the Austin Chalk for a tunnel (Wallis, 2011). The major reasons are political more than anything else. While the political actions may proceed at a slow pace, as an engineer, performing a preliminary feasibility study of such a network using the powerful tool GIS is feasible.

My analysis is based on suitability analysis using raster datasets. I have come up with an equation that links population density, geological formations and presence of faults to give a simple suitability factor for tunnel construction. Looking at this final suitability raster, I trace out a possible pathway of a subway line with logical justification, and present it as my deliverable.

The planning of such a major infrastructure project requires careful consideration of a multitude of factors. I realize that the work done for this project is a preliminary step in a very complex problem solving process. For the sake of this project I have kept the analysis very simple and added on complexity one at a time.

I have divided the problem statement into the following tasks:

1. Collect the data on geology, population (by zip code), and orthophotos.
2. Decide the working area (according to zip code) and clip all the relevant shapefiles to this area.
3. Convert the geology, population density, and fault shapefiles to rasters. The more involved steps in converting the population density shapefiles to raster using IDW interpolation scheme is explained later in the report.
4. Reclassify the rasters using an equation and conduct a suitability analysis for the subway lines.
5. Analyze the high suitability zones and use point and line feature classes to draw the routes of the subway with logical justification. Store these features in a personal geodatabase.
6. Present the final subway system as a map.

Data collection

Datasets collected along with sources:

1. Geology of Austin from the Young and Garner Map – JGB Shared Files. Physical Address:
R:\geo-class\GEO-327g_386g\2016_Lab_data\Lab_1_data\Austin_Geo

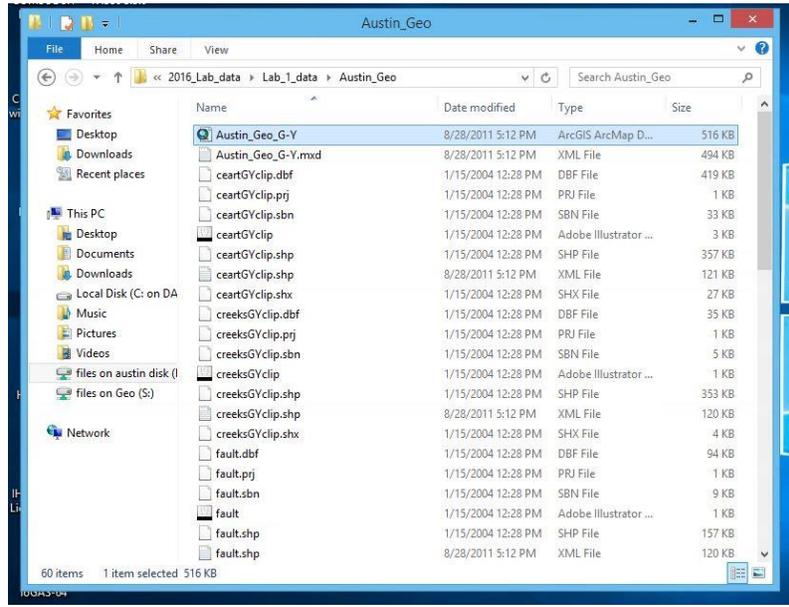


Figure 1: The Garner and Young Austin Geologic Map Files obtained from the JGB Shared Files Network

Kept the following shapefiles and deleted the rest – Roads, Balcones Faults, G & Y Geology

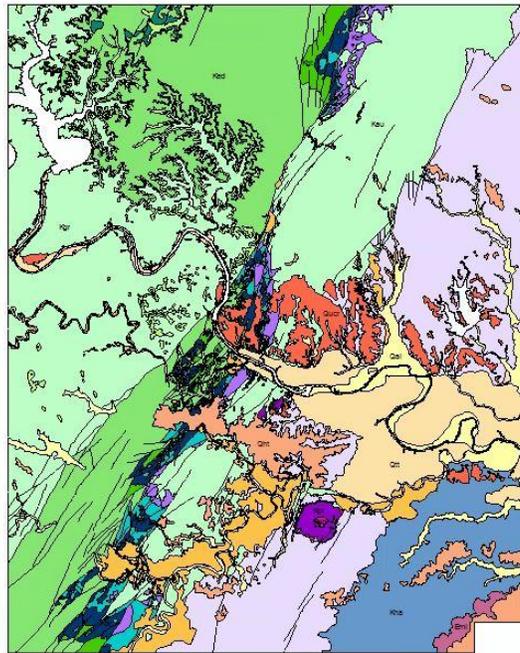


Figure 2: The Garner and Young Austin Geologic Map

2. Zip code Shapefiles of Austin – Zipcode tab from the City of Austin website for GIS/Map Downloads as shown in Figure 3. Web Address: ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html

Watershed Regulation Areas	metadata	Polygon	12/17/2014
Watersheds	metadata	Polygon	04/15/2013
ZIP Codes	metadata	Polygon	01/13/2010
Zoning Cases	metadata	Polygon	Monthly
Zoning Districts	metadata	Polygon	Monthly
Zoning Ordinances	metadata	Polygon	Monthly

Figure 3: The zip codes tab on the City of Austin website

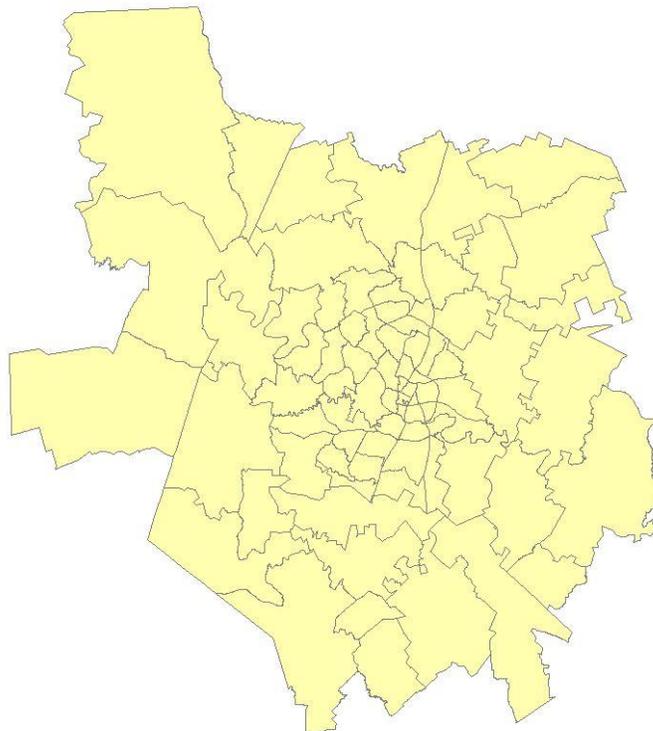


Figure 4: The zip codes shapefile for Austin

3. Orthophotos of Austin – Texas Natural Resources Information System (TNRIS) Website.

Web Address: <https://tnris.org/data-download/#!/quad/Austin%20East>
<https://tnris.org/data-download/#!/quad/Austin%20West>
<https://tnris.org/data-download/#!/quad/Jollyville>

<https://tnris.org/data-download/#!/quad/Pflugerville%20West>
<https://tnris.org/data-download/#!/quad/Pflugerville%20East>
<https://tnris.org/data-download/#!/quad/Manor>
<https://tnris.org/data-download/#!/quad/Montopolis>

The Digital Orthophoto Quarter Quad (DOQQ) Imagery is obtained from the TNRIS website for Austin East, Austin West, Jollyville, Pflugerville West, Pflugerville East, Manor and Montopolis quadrangles. The 2014 National Agriculture Imagery Program 1m NC/CIR are used.

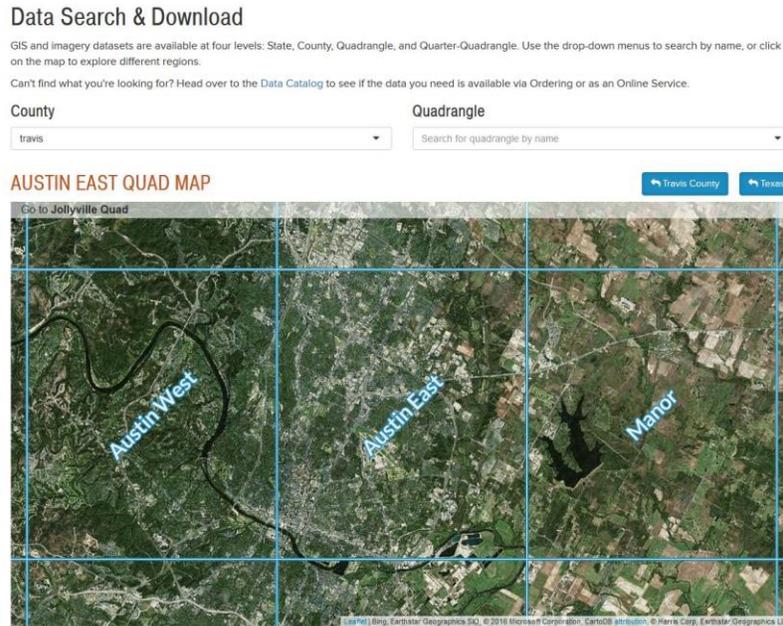


Figure 5: The TNRIS Data download website for different quadrangles

DIGITAL ORTHOPHOTO QUARTER QUAD (DOQQ) IMAGERY

These orthophotos follow the standard USGS Quarter Quad Grid.

1 - NW Quarter-Quad	2 - NE Quarter-Quad
2015 Texas Orthoimagery Program 50cm NC/CIR info	2015 Texas Orthoimagery Program 50cm NC/CIR info
2014 National Agriculture Imagery Program 1m NC/CIR info	2014 National Agriculture Imagery Program 1m NC/CIR info
2012 National Agriculture Imagery Program 1m NC/CIR info	2012 National Agriculture Imagery Program 1m NC/CIR info
2010 National Agriculture Imagery Program 1m NC/CIR info	2010 National Agriculture Imagery Program 1m NC/CIR info
2008 Texas Orthoimagery Program 50cm NC/CIR info	2008 Texas Orthoimagery Program 50cm NC/CIR info
2005 National Agriculture Imagery Program 2m NC info	2006 National Agriculture Imagery Program 2m CIR info
2004 National Agriculture Imagery Program 1m CIR info	2005 National Agriculture Imagery Program 2m NC info
1996 Texas Orthoimagery Program 1m CIR info	2004 National Agriculture Imagery Program 1m CIR info
	1996 Texas Orthoimagery Program 1m CIR info
3 - SW Quarter-Quad	4 - SE Quarter-Quad
2015 Texas Orthoimagery Program 50cm NC/CIR info	2015 Texas Orthoimagery Program 50cm NC/CIR info
2014 National Agriculture Imagery Program 1m NC/CIR info	2014 National Agriculture Imagery Program 1m NC/CIR info
2012 National Agriculture Imagery Program 1m NC/CIR info	2012 National Agriculture Imagery Program 1m NC/CIR info
2010 National Agriculture Imagery Program 1m NC/CIR info	2010 National Agriculture Imagery Program 1m NC/CIR info
2008 Texas Orthoimagery Program 50cm NC/CIR info	2008 Texas Orthoimagery Program 50cm NC/CIR info

Figure 6: The TNRIS DOQQ Imagery tab

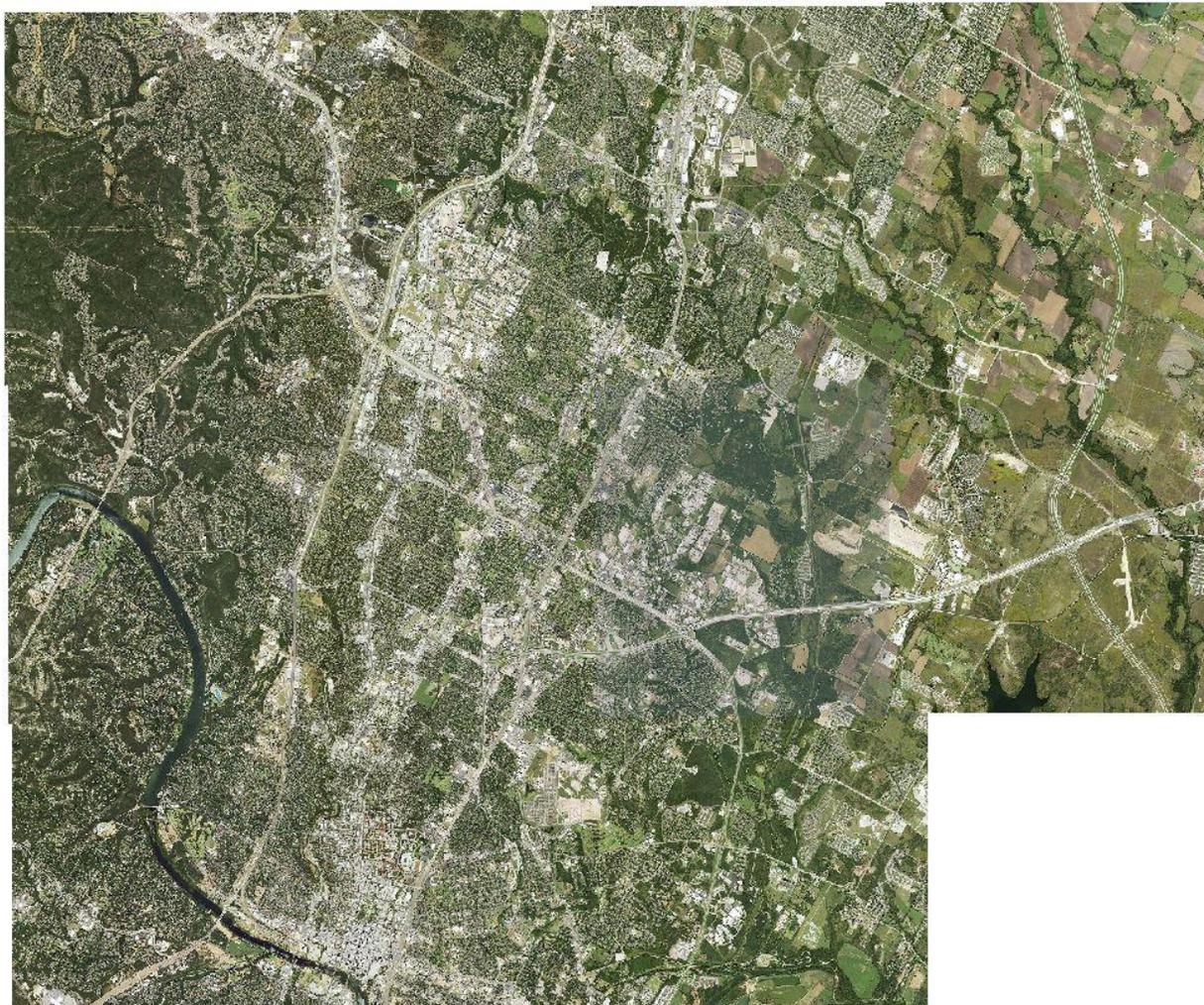


Figure 7: Orthophotos used in the analysis

4. Zip Code Population Data – City of Austin Planning and Zoning Department’s Demographic Data Library. The DTI2040 Forecast: Delphi-Trends-Imagine Austin 2040 Population and Employment Forecast by zip code is used from the spreadsheet.

Web Address: <http://www.austintexas.gov/page/demographic-data>

Population Histories and Forecasts

- [Austin, Travis County, and Metropolitan Austin population history and forecast - 1940-2040](#)
- [Detailed City of Austin population history: 1840 to 2016](#)
- [DTI2040 Forecast: Delphi-Trends-Imagine Austin 2040 Population and Employment Forecast](#)
- [DTI2040 Methodology](#)

Figure 7: The DTI2040 Forecast Tab on the City of Austin Planning and Zoning Department’s Demographic Data Library

All the data is stored with the projected coordinate system of UTM NAD 83 Zone 14N. The units are in meters. The following figure shows the snapshot of the final ArcCatalog Tree.

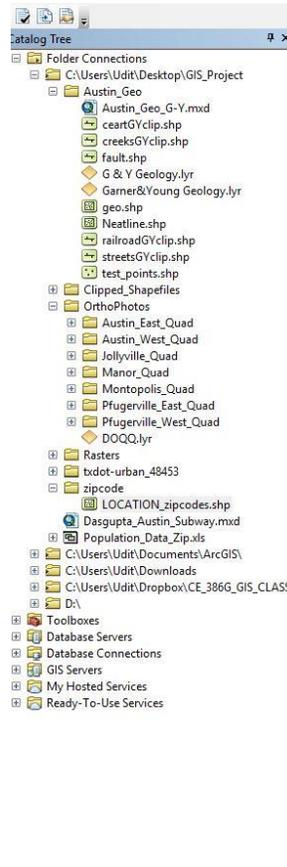


Figure 8: The Final ArcCatalog Tree for this project showing the data collected

ArcGIS processing

Step 1: Data Collection into ArcMap

- All the data specified above is added as layers to ArcMap.

Step 2: Choice of the extent of the area of the study and clip all shapefiles to this area.

The select by lasso tool is used to choose the zip codes to be under study. Zip codes cover majority of the Austin region. Only the north of the river is considered to keep the analysis simple.

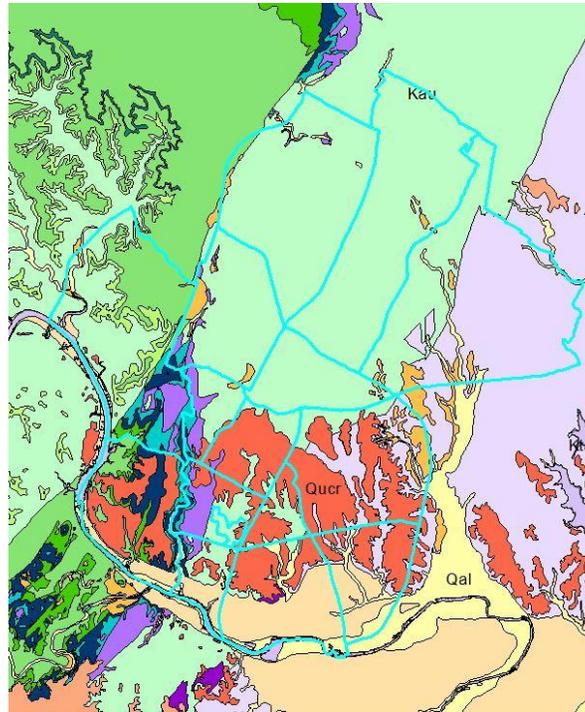


Figure 9: Selection by lasso to choose area of study

Once selected, I extract the data through the table of contents to a new shapefile called Zipclp. This becomes our area of study.

The clip tool under Analysis toolbox is used to clip all the shapefiles to this new area. An example snapshot is shown below.

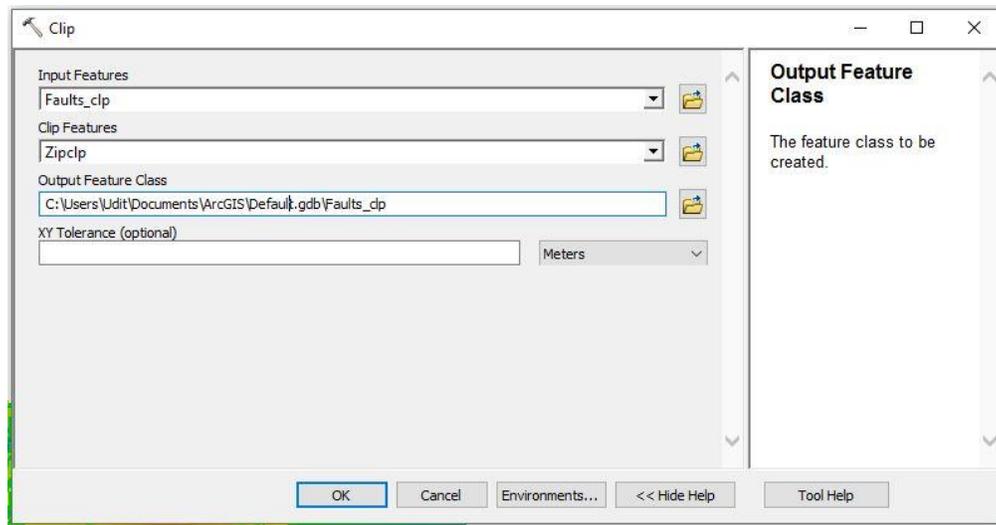


Figure 10: Snapshot of clip tool used with Zipclp as the clipping features

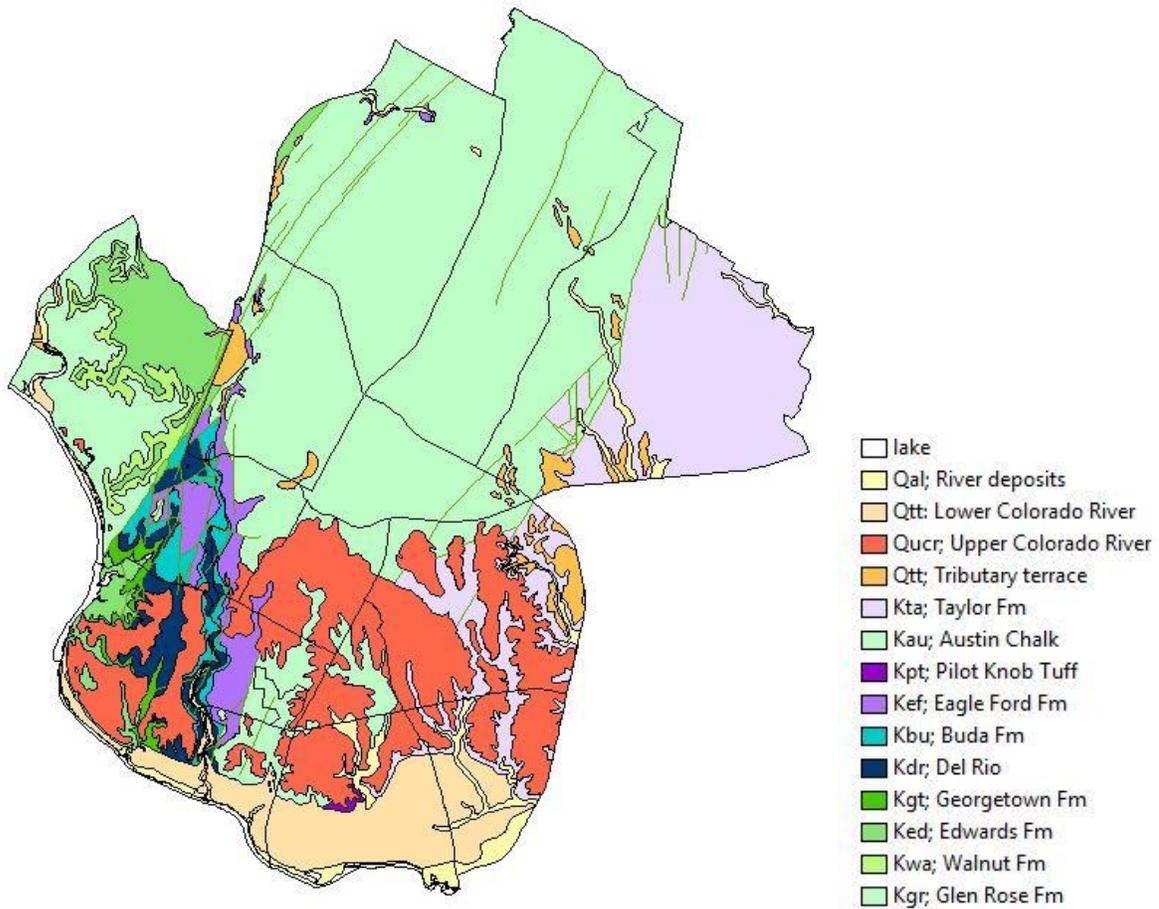


Figure 11: Clipped Geology, Zip Codes and Faults

Step 3: Link Population Data to Zipcode layer.

The population data is obtained for each of the zipcodes from the City of Austin website. A new field called population is created in the value attribute table for Zipcpl. Then in Editing mode, the values are taken from the excel sheet as given in the figure below.

DTI 2040 Population and Employment Forecast								
by ZIP CODE(1)								
ZIP Code	2010	2015	2020	2040	2010	2020	2040	Jurisdictional
	Populati	Population	Population	Population	Employment	Employment	Employment	
78701	6,851	13,369	16,394	29,722	64,407	81,003	115,307	1.000
78702	21,263	24,890	28,100	36,180	10,596	14,046	21,174	1.000
78703	19,652	21,218	23,115	30,435	13,757	18,220	27,792	1.000
78705	30,762	34,065	36,557	42,541	22,089	24,219	28,618	1.000
78712	460	474	487	544	5,092	5,316	5,779	1.000
78721	11,526	12,306	13,174	16,266	4,236	5,615	8,466	1.000
78722	5,907	7,237	8,213	11,163	1,716	2,275	3,429	1.000
78723	28,245	34,356	39,282	52,638	10,682	14,173	21,390	1.000
78731	25,708	26,415	27,130	32,160	16,819	20,489	28,076	1.000
78751	13,416	14,765	15,509	21,315	14,542	17,456	23,476	1.000
78752	21,332	22,809	25,536	37,752	20,752	25,907	36,565	1.000
78753	42,269	44,604	47,114	56,769	18,723	23,735	34,093	1.000
78754	12,654	16,265	19,975	34,727	18,462	23,246	33,135	1.000
78756	7,896	9,080	10,183	14,470	17,391	21,287	29,339	1.000
78757	21,730	24,073	25,847	33,925	16,406	22,588	37,842	1.000
78758	49,448	53,069	56,251	69,816	39,724	47,024	68,155	1.000
	965,605	1,059,680	1,152,559	1,574,742	561,834	697,051	1,010,453	

Figure 12: DTI 20140 Population Forecast Data by Zip Code

A new attribute is created called Population_Density. This is calculated using the field calculator under the drop down menu when you right click on the attribute title. Note Area of the polygons are in km².

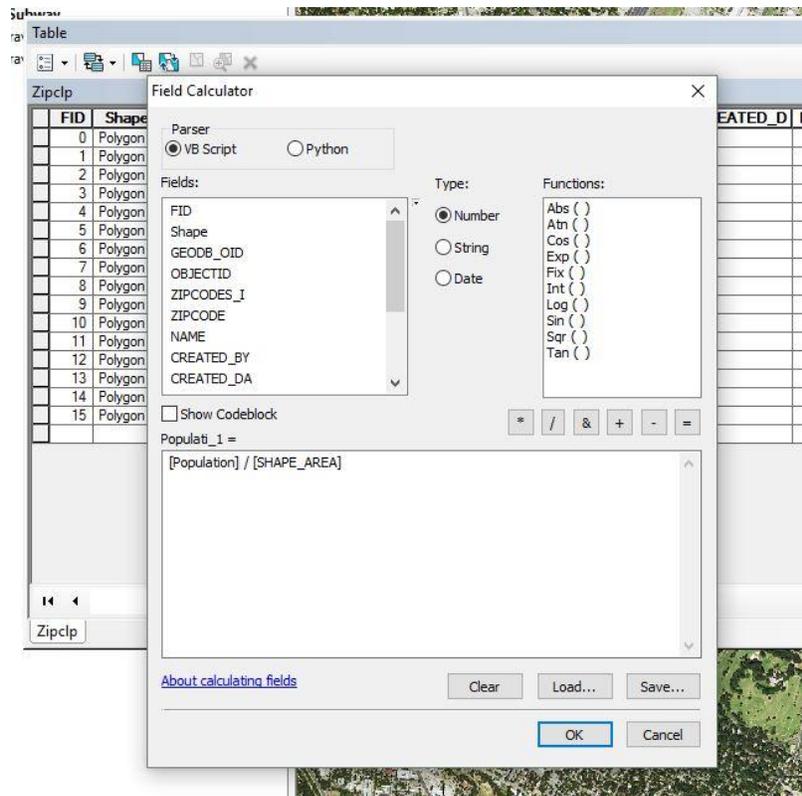


Figure 13: Field Calculator to find population density

MODIFIED_D	SHAPE_AREA	SHAPE_LEN	Population	Population Density
	34.28478	30.022277	34727	1012.9
	4.438125	9.829848	14470	3260.4
	18.143458	16.804918	52638	2901.2
	0.750953	5.451414	544	724.4
	6.728488	10.934037	21315	3167.9
	13.654477	16.19612	30435	2228.9
	3.504169	8.844701	11163	3185.6
	9.384098	12.967089	16266	1733.4
	13.241323	15.159985	36180	2732.4
	25.406196	24.279202	32160	1265.8
	13.333311	15.455932	33925	2544.4
	8.093359	13.15753	37752	4664.6
	27.427593	28.116576	56769	2069.8
	5.152867	15.706094	42541	8255.8
	24.963804	20.974493	69816	2796.7
	4.417677	10.506047	29722	6728

Figure 14: Population Density Calculated

Step 4: Conversion of Geology, Fault and Population Density Shapefiles to Rasters.

Before converting to rasters, the environment settings are changed geoprocessing tab in the menu bar. The Zipclp file is changed to a raster using the feature to raster tool keeping zipcode value as the rasterizing attribute. This raster will serve as the mask in all our raster creation.

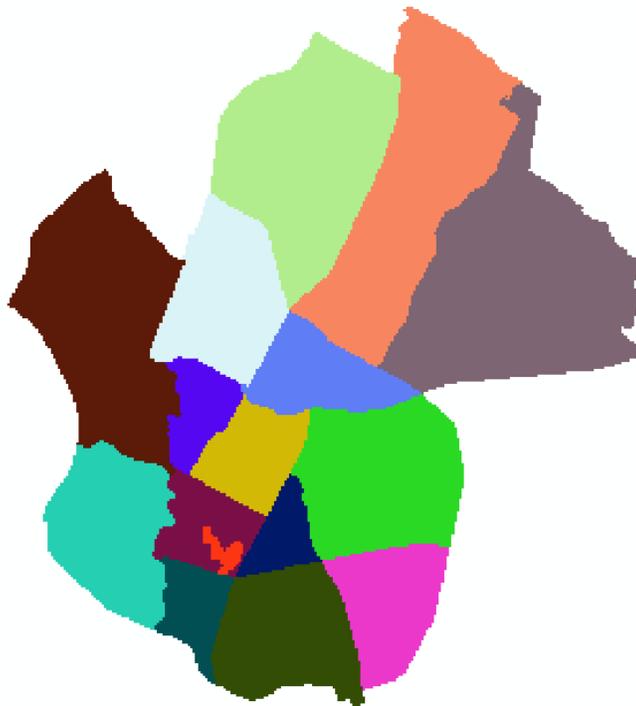


Figure 15: Zipcode Raster

Under environment settings, the Cell size (in Raster Analysis) is set to Maximum of Inputs. Also, the mask is set to Zipcode_Raster.

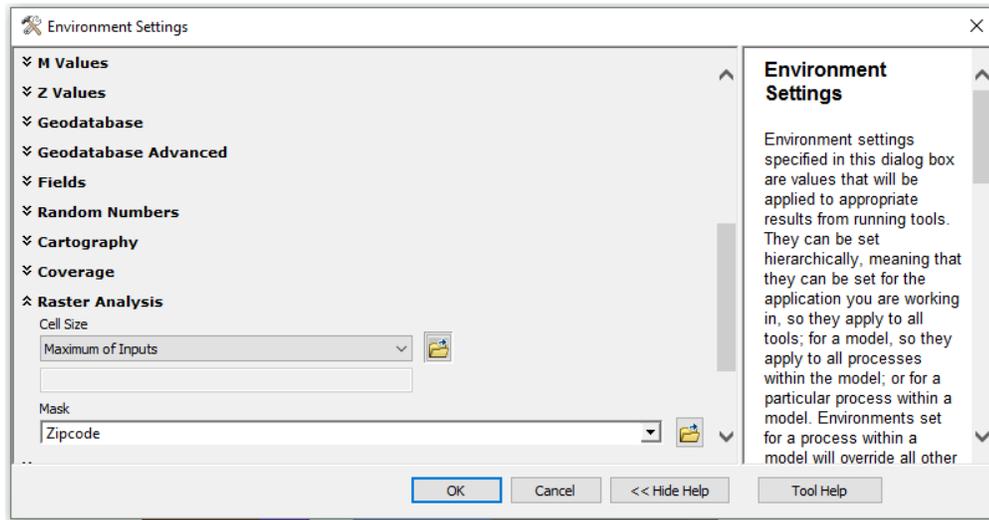


Figure 16: Environment Settings for Raster Analysis

The processing extent is set to Union of Inputs, so that parts of the new raster don't get over clipped. The raster is snapped to Zipcode_Raster

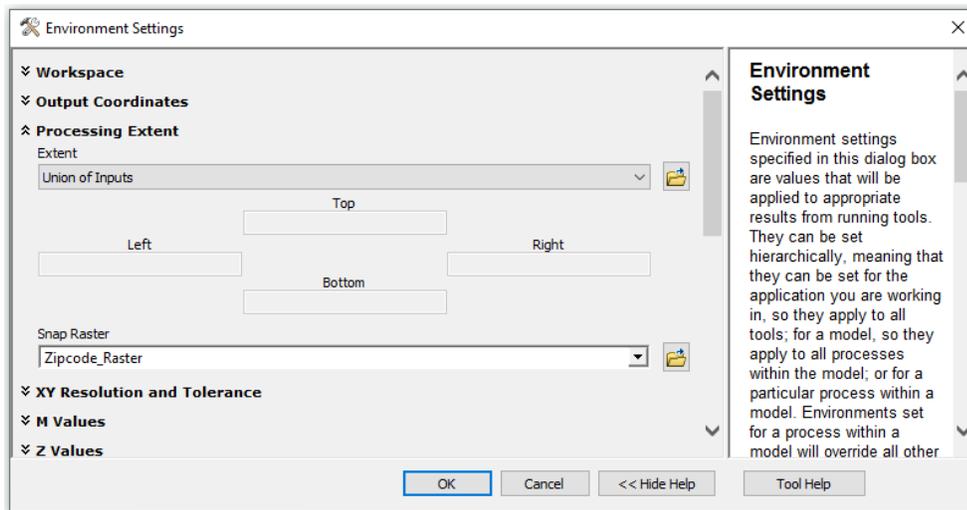


Figure 17: Environment Settings for Processing Extent

- Faults to raster

To obtain the Faults raster a new attribute is added to the Value attribute table of the shapefile called Raster. All the values are set to 1, indicating a fault present. Then the Feature to Raster Tool is used to create the Fault Raster.

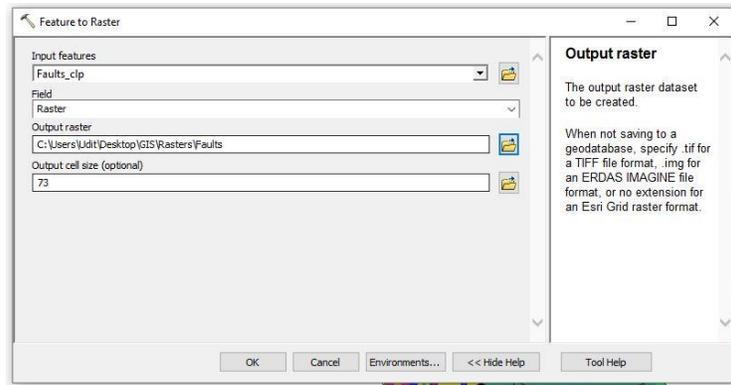


Figure 18: Features to Raster Tool to obtain Faults Raster



Figure 19: Faults Raster

- Geology to raster

The geology shapefile is converted to a raster using the feature to raster tool. An attribute called symbol is used to rasterize it as it is a unique attribute for every geologic formation. The final Raster is shown below. Then the raster is joined to the Original Geology Shapefile table so as to obtain the names of the formations in the symbology.

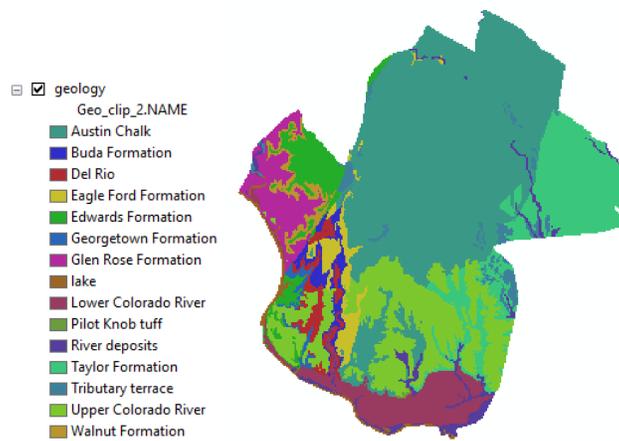


Figure 20: Geology Raster

- Population density to raster

To obtain the population density raster the following steps have to be followed:

- Create a new shapefile using the Feature to Point tool for Zipc1p. This will generate points at the centroid of the zip code regions and give it the population density for the zip code as an attribute.

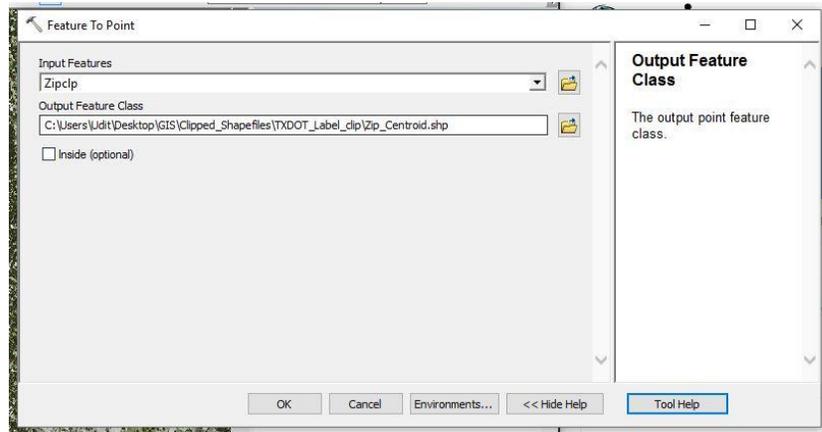


Figure 21: Feature to Point Tool

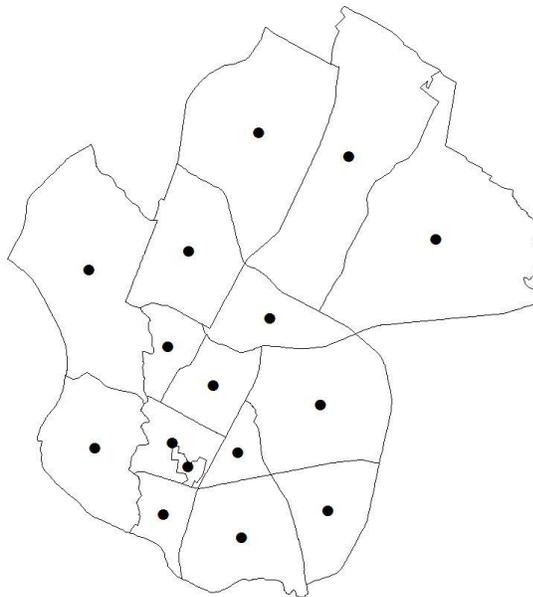


Figure 22: Zipcode Centroid Shapefile

- This new Point dataset is used to create a raster using the IDW (Inverse Square Distance Interpolation) tool under Spatial Analyst. The inputs are shown in the figure below

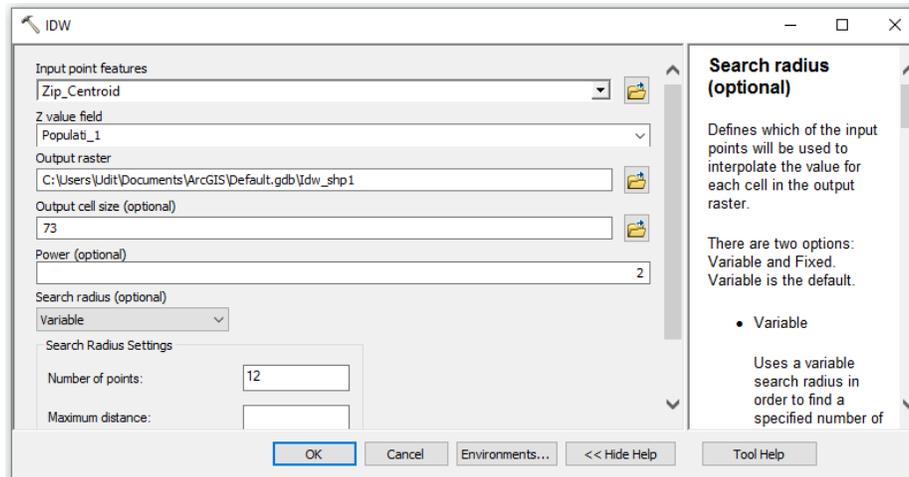
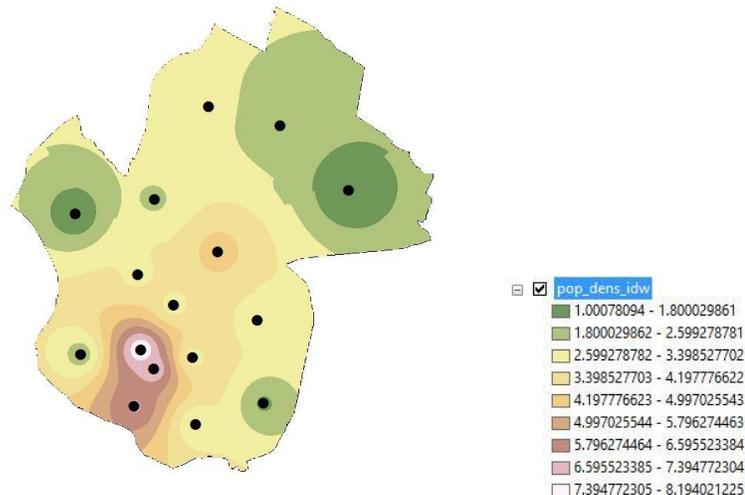


Figure 23: IDW Tool

Figure 24: Population Density Raster (Units persons/km²)

Step 5: Reclassification of rasters for suitability ranking

I went through multiple Geotechnical Baseline Reports for Tunnel Projects (The Waller Creek Tunnel and the Lockheed Shaft) and got an idea of the suitability of the geology of Austin for Tunnel construction (Fugro, 2011; Brierly Associates, 2006). The geologic formations in our area of study are River Deposits, Lower Colorado River, Upper Colorado River, Tributary Terrace, Taylor, Austin Chalk, Pilot Knob Tuff, Eagle Ford, Buda, Del Rio, Georgetown, Edwards, Walnut and Glen Rose. On reading through Chapter 2 of the Guidebook to the Geology of Travis County by Young (1977) I classified the formations into three groups based on engineering properties – Limestone, Claystone, Alluvium.

- Limestones are the most competent Rock Mass for tunneling and therefore I assign a value of 3 as the best.

- Claystones can be tunneled into but pose the major construction issue of shrink/swell behavior. Hence, I assign the value of 2.
- Alluvium deposits are loose material which can be cut into easily but do not have the best excavation support capabilities. Hence, they are assigned a value of 1.
- Lakes are assigned a value of 0, so as to not be a part of the analysis.

The limestones are Austin Chalk, Buda, Georgetown, Edwards, Walnut and Glen Rose.

The claystones are Taylor, Eagle Ford and Del Rio.

The alluvium deposits are River Deposits, Lower Colorado River, Upper Colorado River, Tributary Terrace, Pilot Knob Tuff (Not really alluvium, but classified here as the extent is almost negligible and should not majorly affect the analysis).

The reclassification is done using the Reclassify Tool under spatial analyst.

The reclassification of the geology layer is done using the values. The value field is checked against what formation it is using the value attribute table of the raster.

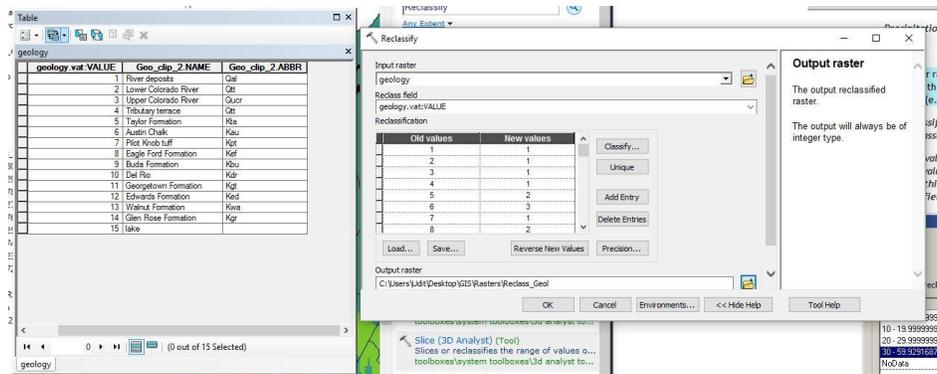


Figure 25: Reclassification snapshot of Geology Layer

The Reclassify tool is also used to change the NoData values in the Faults raster to 0.

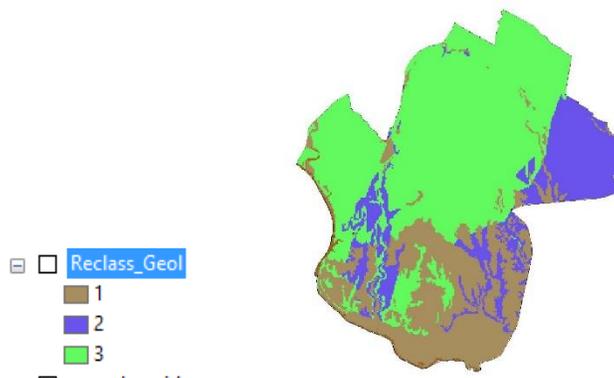


Figure 26: Reclassified Geology Raster

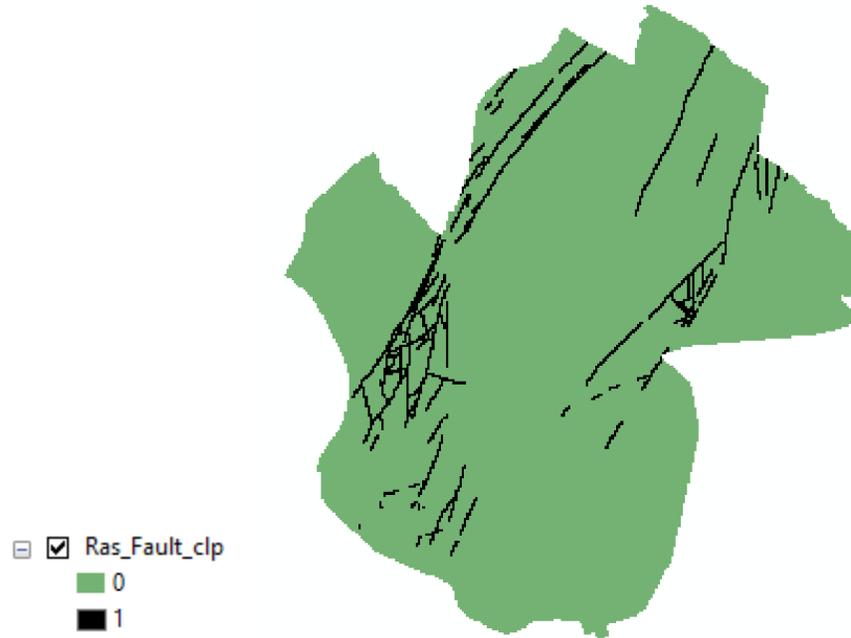


Figure 27: Reclassified Raster for Faults

Step 6: Combine rasters to obtain final Raster Map for suitability ranking

To be able to rank the suitability of the rasters, I've come up with an equation where the suitability factor 'S' depends on the population density (P), the underlying geologic formation (G) and the presence of faults (F).

$$S = w_1 * (P/P_{\max}) + w_2 * (G/G_{\max}) + w_3 * (1-F)$$

Where:

S = Suitability Factor ranging from 0 to 100

P = Value dependent on Population Density

G = Value depending on Geology (Reclassified Raster)

w_1 = Relative weight of P with regards to S

w_2 = Relative weight of G with regards to S

w_3 = Relative weight of F with regards to S

From the GBR's, I discerned that the success of the subway system depends strongly on how many trips it can generate. Maximizing the number of people that are in close proximity to it is crucial. The geology poses constructability issues which are part of the uncertainty of the site. Finally faults pose issues such as water seepage problems and mix face conditions and add to the risk of the problem. The geology problems are of concern, but there are engineering techniques to deal with them as construction takes place. But if the subway is ill planned with regards to ridership then the investment put in will be wasted.

To get a uniform value ranging from 0 to 100, we normalize both population density as well as the geology raster value by the maximum values. Presence of a fault is indicated by 1, so (1-F) means higher rank if there is no fault present.

In order of relative importance, $w_1=80$; $w_2=10$ and $w_3=10$.

The Raster Calculator tool under the spatial analyst toolbox is used to create the final raster using the three reclassified rasters.

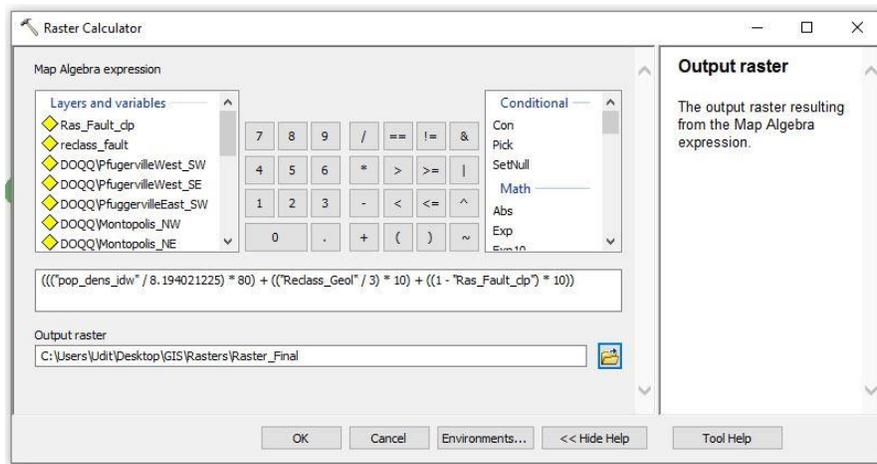


Figure 28: Raster Calculator used to create the final raster

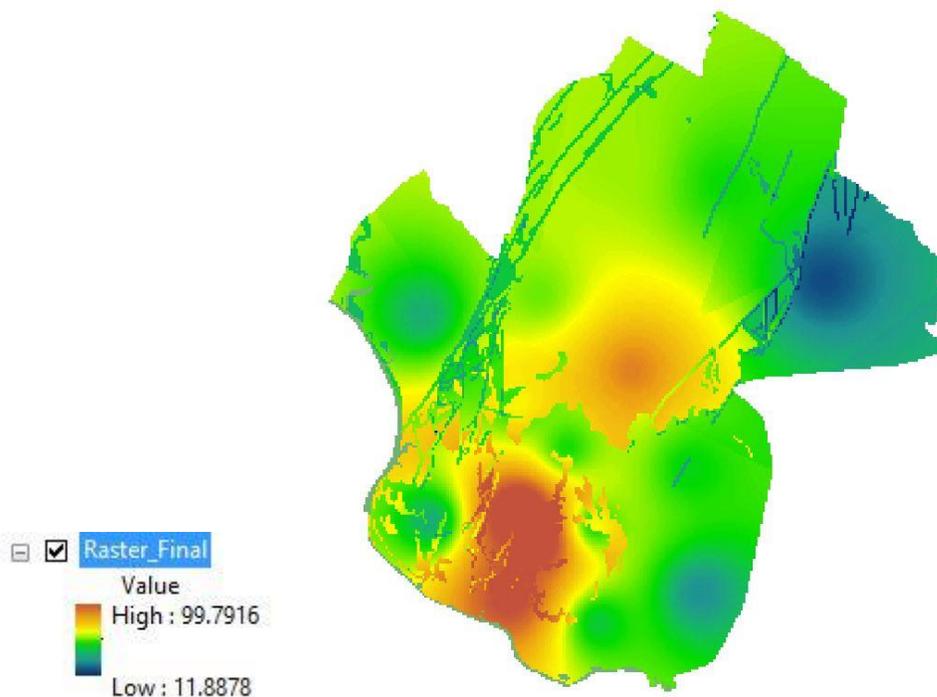


Figure 29: Final Suitability Raster



Figure 31: Using the OrthoPhoto and Road Network to find Domain (Near the J.J. Pickle Research Campus (Point in cyan))

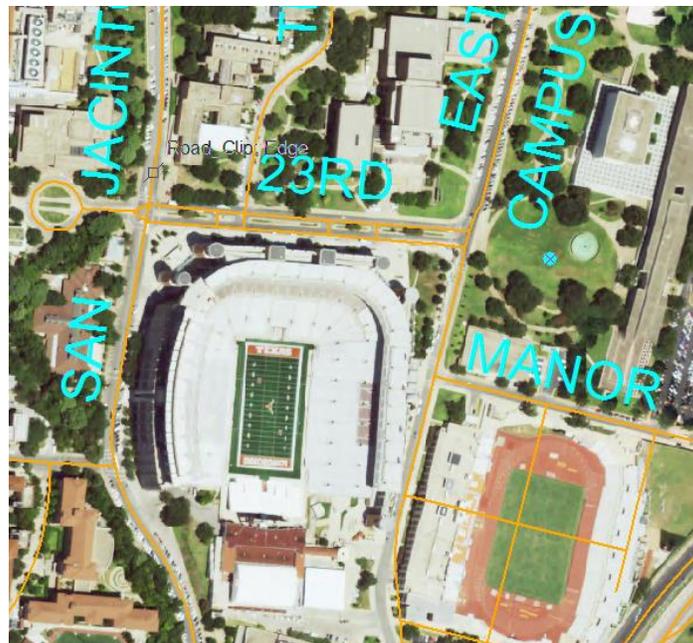


Figure 32: Putting down the UT station



Figure 33: Putting down the Downtown Station

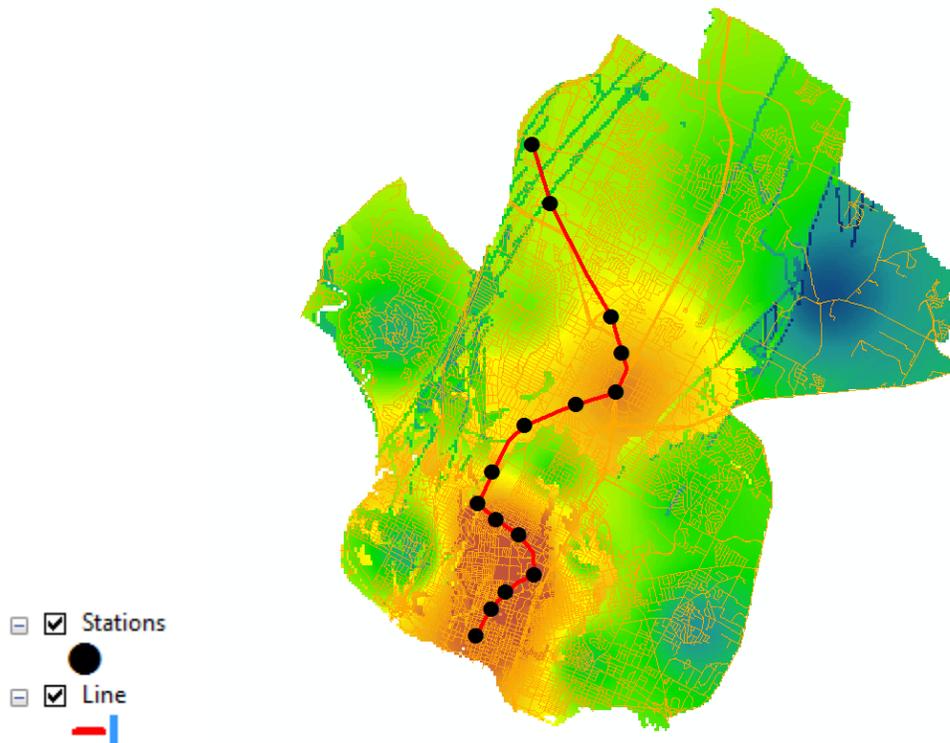


Figure 34: Final Alignment

Data presentation

From the analysis above, we obtain a subway system alignment using a suitability analysis. The following map shows the tunnel alignment with the final raster on the left and the orthophoto view on the right. There are 15 stations chosen starting from Downtown to Domain.

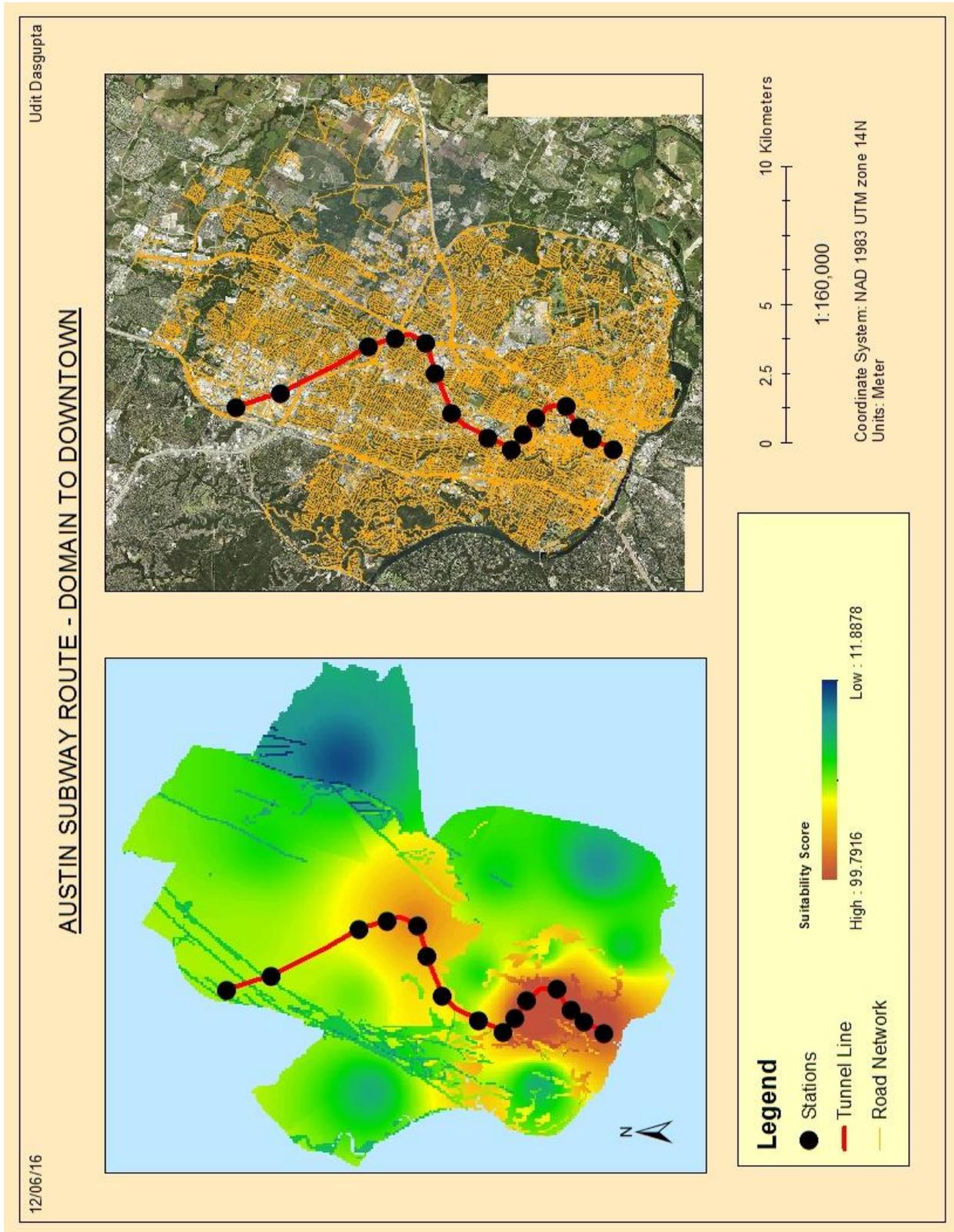


Figure 35: Final Map of Subway Layout

Conclusion

The planning of such a major infrastructure project is multifaceted and multiple stakeholder interests have to be considered. While this study simplifies the entire process and presents a bare schematic of the engineering involved, a more informative study would be a complete feasibility analysis with costing and estimation of the construction costs, and decision analysis to choose between different possibilities. Additional planning would involve adding more lines to the network and expanding it to the suburban areas of Austin.

Overall, I believe there is value in this study and it fits well with the theme of the class as both Tunneling and Geotechnical construction are strongly dependent on the underlying geology and GIS would be a crucial tool for the planning of such a project.

References

Young, K. (1977). Chapter 2, Guidebook to the Geology of Travis County
Retrieved from: <https://www.lib.utexas.edu/geo/ggtc/ch2.html>

Patterson, L. (2012, November). Why Texas Doesn't Have Subways.
Retrieved from: <https://stateimpact.npr.org/texas/2012/11/21/why-texas-doesnt-have-subways/>

Wallis, P. (2012, April). Tunneling to ease flooding in Austin.
Retrieved from: <http://www.tunneltalk.com/Waller-Creek-Apr11-Austin-Waller-Creek-flood-tunnel.php>

Brierly Associates. (2006). Geotechnical Baseline Report (GBR) for the Lockheed Shaft for the City of Austin. Retrieved from:
<ftp://ftp.ci.austin.tx.us/RobinField/Lockheed/Geo%20Tech%20reports/Geotechnical%20Baseline%20Report.pdf>

Fugro Consultants. (2011). Geotechnical Baseline Report (GBR): Wastewater Line Relocation at Waterloo Park Waller Creek Tunnel Inlet Facility, Austin, Texas.
Retrieved from:
ftp://ftp.ci.austin.tx.us/WPDRHHM/Waller_Design_Competition/Tunnel/Inlet_Facility_Waterloo_ConformedPlanSetandManual/GeotechReports/GBR_WW-LN-RELOCT.pdf