

CE 394K.3  
Term Project Report

# 3-D Underground Representation of Barnett Shale, TX

Prepared by Weili Lin  
Instructed by: Dr. David Maidment  
Environmental and Water Resources Engineering  
University of Texas at Austin  
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# 1. Introduction

## 1.1 Barnett Shale, TX

The Barnett Shale is a geological formation located in the Bend Arch-Fort Worth Basin in north Texas. The formation underlies the city of Fort Worth and underlies 5,000 mi<sup>2</sup> (13,000 km<sup>2</sup>) and at least 17 counties. Due to different research interests and objectives, the geologic boundary of Barnett Shale is defined in different ways. Based on the objectives of this project, the boundary of Barnett Shale is taken from the shapefile provided by U.S. Energy Information Administration (US EIA) <sup>[1]</sup>, shown in figure 1.

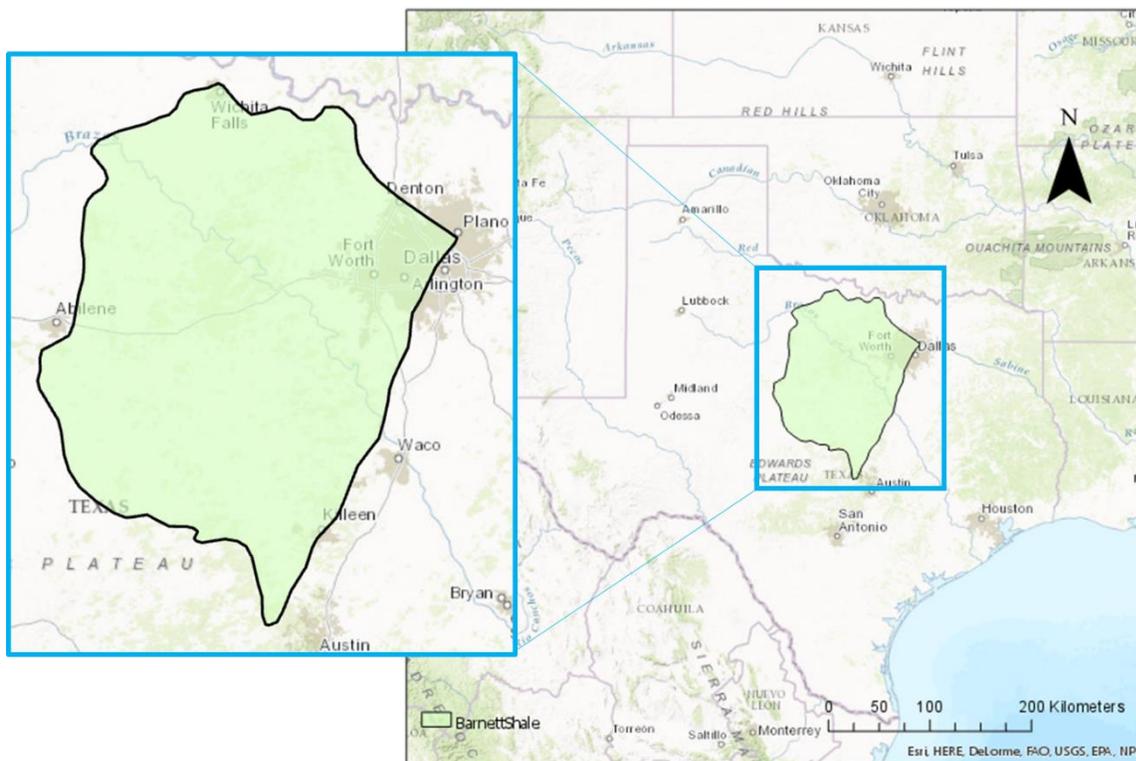


Figure 1 Geological Location and Formation Boundary of Barnett Shale

## 1.2 Barnett Shale Exploitation and Groundwater Contamination Potential

The Barnett Shale experiences rapid growth of exploitation in recent years. Based on the Texas Railroad Commission Production Data Query System, the average oil production in Barnett Shale from 2008 to 2015 was over 2500 barrels per day, average total natural gas production was over

4500 million cubic feet per day from 2008 to 2016. It was estimated that over 15,000 oil and gas wells drilled and hydraulic fractured in Barnett Shale by 2007 [2].

The production increase of the Barnett Shale oil and gas can be attributed to the development of horizontal well drilling and hydraulic fracturing. Hydraulic fracturing is a well stimulation technique in which a pressurized liquid is pumped down into a well and fractures the shale formation in the lateral well, which helps to release the shale oil and gas, thus greatly increase the production rate. But the Barnett Shale formation (actually any of the shale formations) is deeper than the shallow aquifer, so the oil/gas production wells drilled has to be appropriately cased to protect the groundwater resources, shown in figure 2. Moreover, the fluid used in hydraulic fracturing consists of chemicals that potentially contaminate groundwater resource as they remain and spread underground, due to a well leak or improper fluid handling. These chemicals can be antibiotics, organic surfactants, etc., which are toxic to human, other living creatures and harmful to the environment.

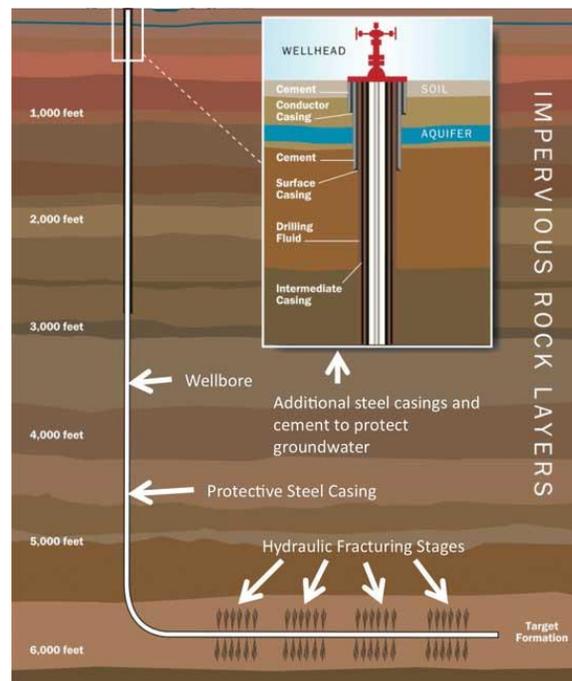


Figure 2 Illustration of a Horizontal Well for Hydraulic Fracturing [3]

### 1.3 Project Objectives

This project describes the data and method to construct a digital three-dimensional (3-D) model for the area of Barnett Shale (Figure 1). The primary objective is that visualization and accurate

representation of underground information can help future studies and engineering practices. For example, if a leak is detected in a hydraulic fracturing wells, it will be easier to figure out which aquifer the contamination is threatening and where the contamination will potentially goes. The secondary objective is to serve as an example for underground representation, and enhance similar studies in other areas.

## 2. Data Sources and Software Requirements

### 2.1 Data Sources and Explanation

This project utilized the major and minor aquifer features provided by Texas Water Development Board (updated in January 2014). Other basic databases, datasets used shown in Table 1 below.

Table 1 Database and Datasets Used in Project

| Database       | Dataset                   | Source         | Use in this Project   |
|----------------|---------------------------|----------------|---|
| GWDB           | WellMain Table            | TWDB           | Each well identified by a State Well Number. Provides well geological location and reference, well type, well depth and land surface elevation.                                 |
| BRACS Database | Stratigraphic Description | TWDB           | Each Well identified by a WellID. Provides well geological location, well depths, land surface elevation, BRACS geophysical well logs, stratigraphic description.               |
| -              | NED30                     | ArcGIS Service | <a href="http://elevation.arcgis.com/arcgis">http://elevation.arcgis.com/arcgis</a> . National Elevation Dataset Provides Digital elevation model (DEM) in 30 meter resolution. |

\*TWDB: Texas Water Development Board

GWDB: Groundwater Database

BRACS: Brackish Resources Aquifer Characterization System

The WellMain central table describes the location of wells and their properties, including county located in, well type, the corresponding aquifer, well depth and land surface elevation. The WellMain table is linked with additional tables describing information on the well construction, measurements of water levels and water quality taken at the wells. The stratigraphic data in the

BRACS Database describes the strata observed along a borehole, usually documented in drilling logs and later classified into geologic/hydrogeologic units.

The total number of wells from GWDB is 139,155. Based on the description of GWDB online, the wells in the database represent less than 10 percent of the wells that actually exist in Texas. TWDB estimates that between 1.35 and 1.5 million wells have been drilled in Texas since 1900. Actually the data available are very sparse both in space and time <sup>[4]</sup>. Each well, as an individual entity, usually are drilled far apart from one another. The information is sparse in time because the groundwater conditions are considered to relatively constant, and well samplings require tremendous efforts so they are carried out infrequently.

## 2.2 Software and Toolbox Requirements

This project is carried out using ArcGIS 10.3.1 (ArcMap and ArcScene). ArcHydro Groundwater Toolbox, provided by Aquaveo and ESRI, was used for subsurface data manipulation and feature display. ArcHydro Groundwater Toolbox is only compatible with ArcGIS 10.3 or lower versions. The ArcHydro Groundwater Toolbox includes three toolsets, Groundwater Analyst, MODFLOW Analyst, Subsurface Analyst. For full function of ArcHydro Groundwater Toolbox, the license for Subsurface Analyst is needed.

In this project, the Groundwater Analyst was used to import a variety of datasets (Well, BoreholeLog table, Boreline, Cross-Sections) into the geodatabase. The Subsurface Analyst was used to create Borepoints and then Georaster. It was also used to create two-dimensional (2-D) cross sections.

## 3. BoreholeLog Table and BoreLine

### 3.1 Well Feature Points in Barnett Shale

Although each well is actually a three dimensional feature, it is represented as a single point in a two-dimensional map. Well feature points were created using the Display XY Event tool in ArcGIS.

From the GWDB, there are around 13,470 wells (number would change slightly for different geologically intercepting method) in the Barnett Shale, all uniquely identified by Texas State Well Number. However, the Well Logs are stored in the BRACS Database, with each well assigned a unique WellID. Based on BRACS Database, there are only 4086 wells located in the Barnett Shale, with only a dozen wells having Texas State Well Number. During these 4086 wells, only 62 wells that have stratigraphic data are selected and represented, the comparison is shown in Figure 3 below.

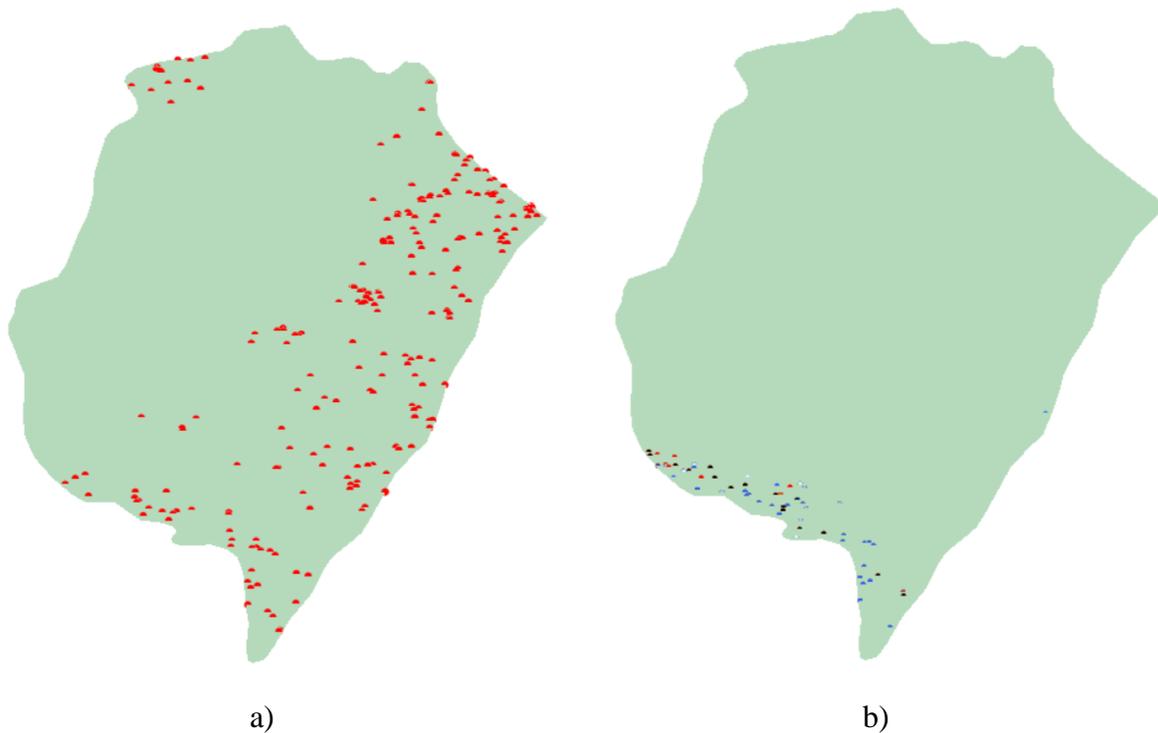


Figure 3 Barnett Shale Documented Wells (Shown in 2-D Map.)

a). Barnett Shale Wells from BRACS Database.

b). Barnett Shale Wells from BRACS Database with Well Logs.

As is shown in the maps, the Wells are distributed widely. The scarcity of the available subsurface well data, especially those with Well Logs, will requires large amount of interpolations and may actually invalidate the final results.

### 3.2 Barnett Shale Elevation

The Land Surface Elevation raster were created using the NED30 datasets (in unit of meter), then this feature raster is cut into a rectangle area encircling the Barnett Shale area, by using the Clip (Data Management) geoprocessing tool (in ArcGIS Pro). So the digital elevation model is created for the Barnett Shale, shown in Figure 4 below. The DEM raster was loaded into ArcScene and displayed three-dimensionally by choosing the layer base heights to float on its own layer surface, shown as Figure 5.

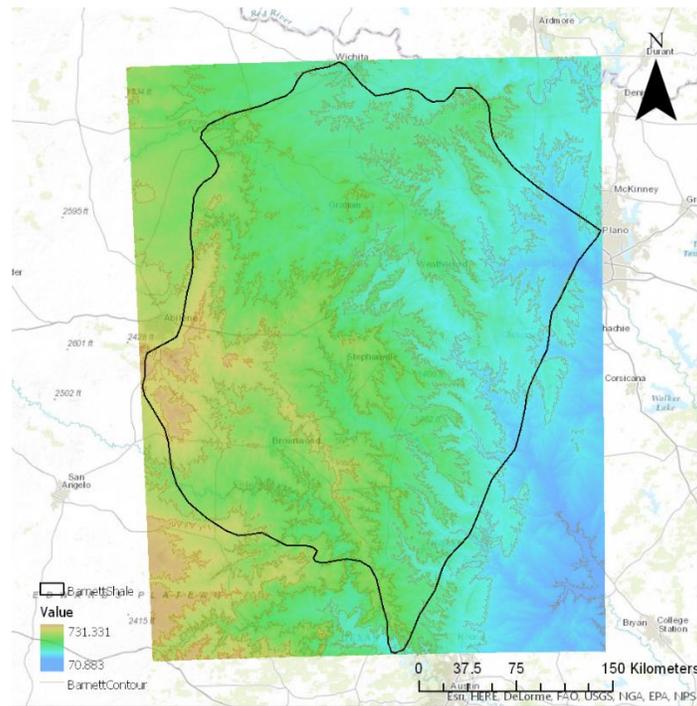


Figure 4 DEM of Barnett Shale (2D)

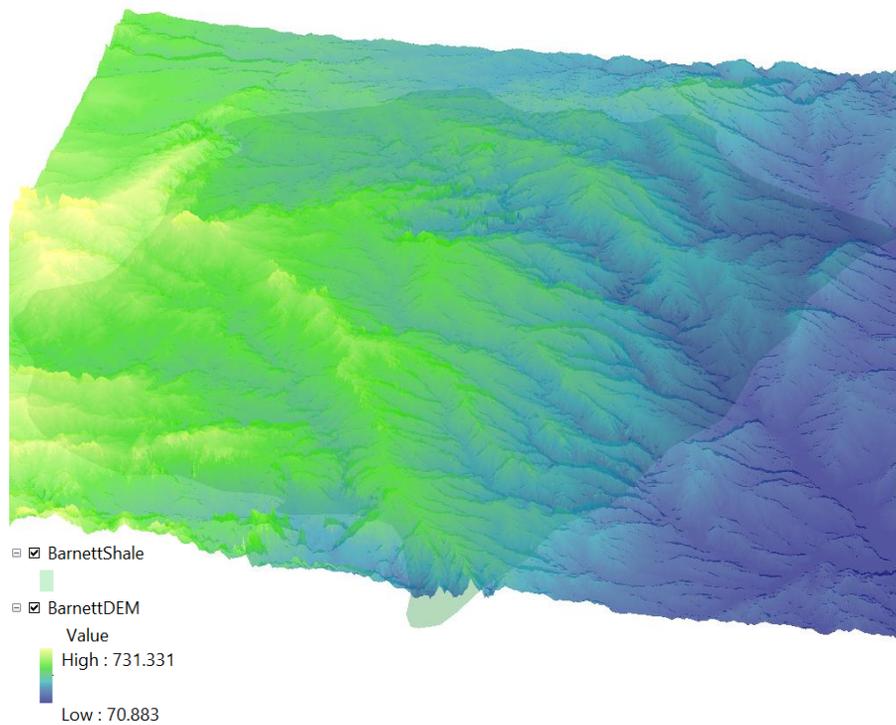


Figure 5 DEM of Barnett Shale (3D, Vertical Exaggerated 50 Times)

The land surface elevation is significant in the accurate representation of the subsurface information, because the subsurface data are usually obtained by the samples extracted from wells, and the elevation of the wellhead should correspond to the land surface elevation.

The above two figures show that the Barnett Shale is generally higher in the west and lower in the east. The change of elevation is more than 650 meters.

### 3.3 BoreholeLog Table

The BoreholeLog table was constructed using the data in Barnett Shale from BRACS Database (number of which is 4086), including the well longitude, latitude and unique identifier WellID. Then the wells with available stratigraphic data were identified and selected, this step was done manually. The stratigraphic data and description include the strata group name, FromDepth, ToDepth. Later on, each kind of strata group were assigned a HGUID and HGUCODE. The TopElevation and BottomElevation were calculated using land surface elevation subtracted by the depth. The part of a BoreholeLog table is shown in Figure 6.

| BoreholeLog |         |           |         |         |            |           |            |       |                   |         |          |             |  |
|-------------|---------|-----------|---------|---------|------------|-----------|------------|-------|-------------------|---------|----------|-------------|--|
| WellID      | RefElev | FromDepth | ToDepth | TopElev | BottomElev | ElevUnits | Material   | HGUID | HGUCode           | LogType | TopElevM | BottomElevM |  |
| 7221        | 1445    | 0         | 246     | 1445    | 1199       | <Null>    | Material 1 | 1     | Ellenberger Group | <Null>  | 440.436  | 365.4552    |  |
| 7221        | 1445    | 246       | 360     | 1199    | 1085       | <Null>    | Material 2 | 12    | Aquifer           | <Null>  | 365.4552 | 330.708     |  |
| 7241        | 1354    | 0         | 300     | 1354    | 1054       | <Null>    | Material 1 | 1     | Ellenberger Group | <Null>  | 412.6992 | 321.2592    |  |
| 7241        | 1354    | 300       | 600     | 1054    | 754        | <Null>    | Material 2 | 12    | Aquifer           | <Null>  | 321.2592 | 229.8192    |  |
| 7251        | 1383    | 0         | 116     | 1383    | 1267       | <Null>    | Material 1 | 1     | Ellenberger Group | <Null>  | 421.5384 | 386.1816    |  |
| 7251        | 1383    | 116       | 605     | 1267    | 778        | <Null>    | Material 2 | 12    | Aquifer           | <Null>  | 386.1816 | 237.1344    |  |
| 7261        | 1345    | 0         | 217     | 1345    | 1128       | <Null>    | Material 1 | 1     | Ellenberger Group | <Null>  | 409.956  | 343.8144    |  |
| 7261        | 1345    | 217       | 400     | 1128    | 945        | <Null>    | Material 2 | 12    | Aquifer           | <Null>  | 343.8144 | 288.036     |  |

Figure 6 Part of BoreholeLog Table

Each row of the BoreholeLog table represents an interval of a well. The FromDepth value of the highest interval should be 0, while ToDepth value of the lowest interval should be equal to the total depth of the well. Also, the ToDepth of an upper interval should equal to the FromDepth of the lower interval.

The BRACS Database is available as a Microsoft Access file, but I am personally not familiar with coding, and I have tried other ways to automatically extract the borehole stratigraphic data but failed, so I have to enter the data one by one manually, which took me large amount of time. I finally sorted the data of XX wells with their stratigraphic data.

### 3.4 BoreLine Feature

After the successful construction of Well BoreholeLog table, I started to use the ArcHydro Groundwater Toolbox to import and datasets into geodatabase.

In ArcScene, first of all, I used the Create Blank AHGW Geodatabase tool available in the Groundwater Analyst toolset. Well feature, Boreline feature, BoreholeLog table, HydrogeologicUnit table were created in the database. Next, the well feature was imported using Arc Hydro GW | Text Import command in the AHGW Toolbar. Then the BoreholeLog table was imported in similar way, by mapping each field correspondingly. After importing the HydrogeologicUnit table, all the data needed for building boreline features were prepared.

To build the boreline features, ArcMap was used instead of ArcScene. The Borehole Editor provided in the AHGW Subsurface Analyst was used to view borehole log data for individual wells. Use HGU Color Manager to set the color for each hydrogeologic unit.

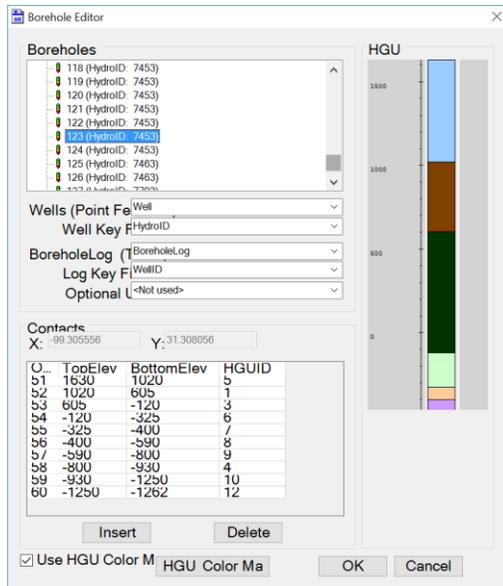


Figure 7 Example of Borehole Editor Interface

Create Borelines tool in the AHGW Tools | Subsurface Analyst | Features toolset was used to create the 3-D Borelines. After changing the symbology, the layout looks like below.

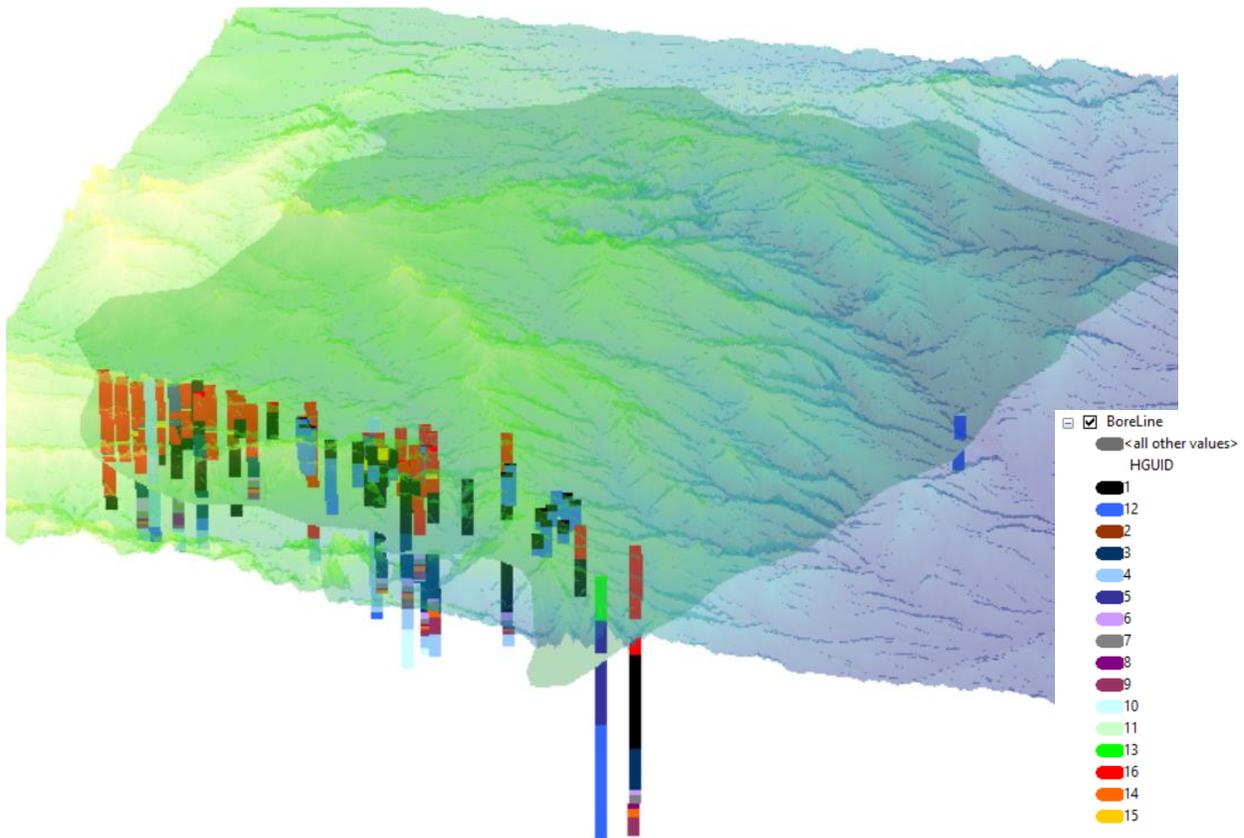


Figure 8 3-D Underground representation of BoreLines (3D, Vertical Exaggerated 50 Times)

If look close enough, we can see the BoreLines wellhead elevation may not be exactly the same with the NED30 elevation (which is the BarnettDEM raster in the above map), that is because the elevation data in the BRCAS Database may not be exactly the same with the NED30.

#### 4. GeoSection, BorePoints and GeoRasters

The attempt to create 2-D cross section was given. This started with sketching SectionLine features using the Editor toolbar and Straight Segment tool, one of the section line was drawn at the north of Barnett Shale, shown in Figure 9 below. This Section Line lies within the Hickory Aquifer, so the 2-D cross section can help to understand the aquifer and relevant formations better.

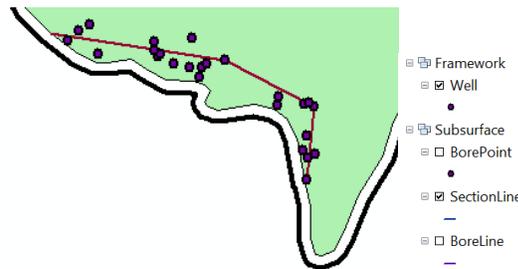


Figure 9 Example of a Section Line at South of Barnett Shale

After preparing the SectionLine and assigning HydroID, XS2D Wizard was run to create a new cross section. But it requires license of ArcHydro Groundwater | Subsurface Analyst Toolset to do so. So I didn't get it done.

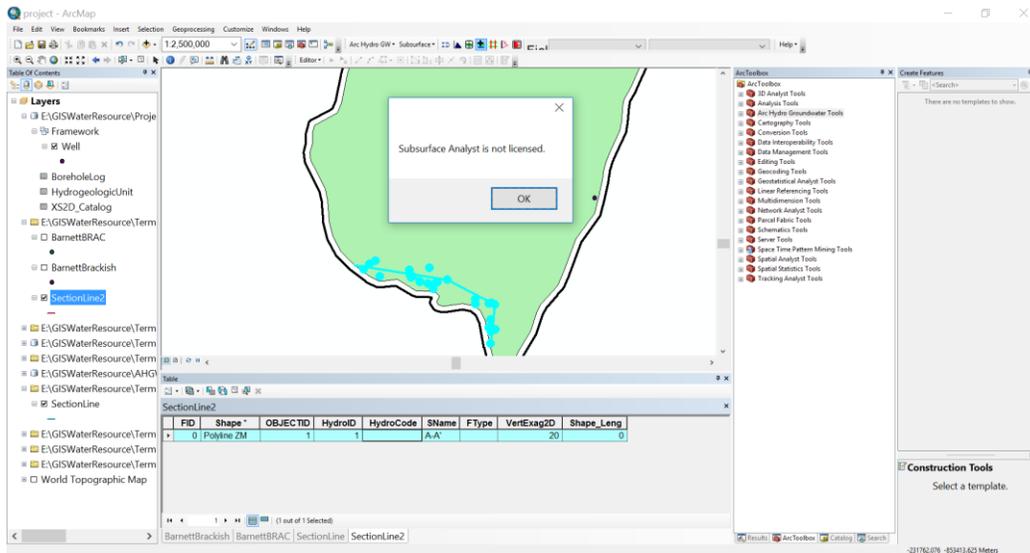


Figure 10 Failure to Run XS2D Wizard

There is same requirement with the BoreholeLog Table To Points tool located in the Subsurface Analyst | Features toolset.

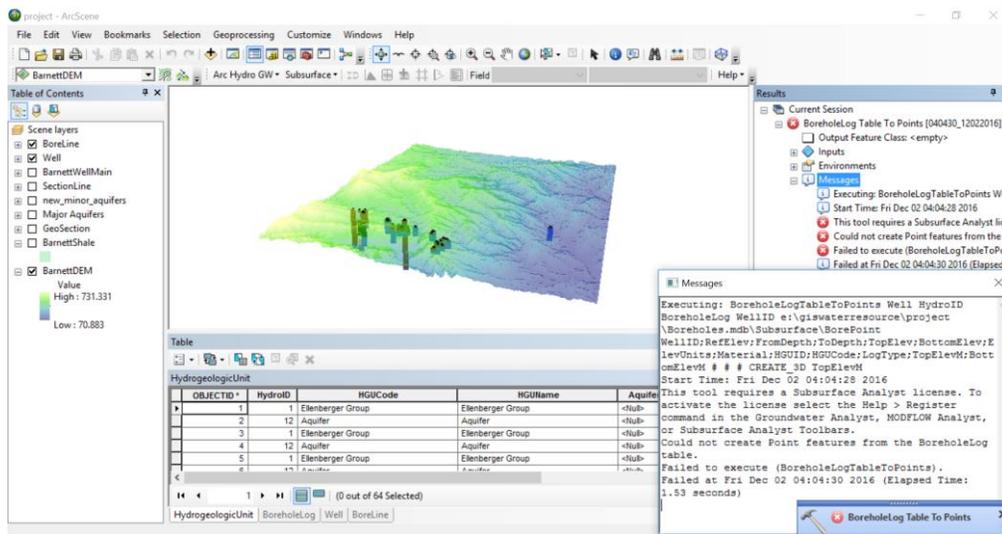


Figure 11 Failure to Create BorePoint Features

## **5. Conclusion and Future Work**

### **5.1 Challenge Encountered**

The first challenge was the difficulty of finding the needed data. The subsurface databases, including the stratigraphic data were described to be obtained from the Groundwater Database in Texas Water Development Board <sup>[5]</sup>, however, I were only able to obtain the stratigraphic data from the BRACS Database. Moreover, due to lack of programming knowledge, I may have failed to obtain all the data available.

The second challenge was the unexpected license requirement for ArcHydro Groundwater | Subsurface Analyst Toolset. I didn't find this out until the very late of my project, and I was left no time to obtain a license and carry on with the rest of my work, which was trying to construct GeoSection, BorePoints feature and then GeoRasters.

### **5.2 Conclusion of Present Work**

Based on the underground data obtained currently, the BoreLines features are created and represented three-dimensionally in ArcScene, shown in Figure 8.

### **5.3 Future Work**

After the license of ArcHydro Groundwater | Subsurface Analyst Toolset is obtained, I should carry on with the construction of GeoSection, BorePoints and GeoRaster.

First of all, two-dimensional cross sections can be built (Figure 12) and the information should be assemble to create an overall image of the Barnett Shale area.

Table 1.--Stratigraphic and Hydrogeologic Framework of Part of the Coastal Plain of Texas

| Era              | System             | Series                      | Stratigraphic Units                       | Hydrogeologic Units   | Selected Faunal Markers   | Remarks   |   |
|------------------|--------------------|-----------------------------|---|---|---|---|---|
| CENOZOIC         | Quaternary         | Holocene                    | Alluvium                                  |   |   |   |   |
|                  |                    | Pleistocene                 | Beaumont Clay                             | Chicot aquifer  |   | Quaternary System undifferentiated on sections.                             |   |
|                  |                    |                             | Montgomery Formation                      |   |   |   |   |
|                  |                    |                             | Bentley Formation                         |   |   |   |   |
|                  |                    |                             | Willis Sand                               |   |   |   |   |
|                  | Tertiary           | Pliocene                    | Goliad Sand                               | Evangeline aquifer  |   |   | Goliad Sand overlapped east of Lavaca County.   |
|                  |                    | Miocene                     | Fleming Formation                         | Burkeville confining system   | <i>Potamides matsoni</i><br><i>Bigennerina nodosaria</i> var. <i>directa</i><br><i>Bigennerina humblei</i><br><i>Amphistegina</i> sp. | Oakville Sandstone included in Fleming Formation east of Washington County. |   |
|                  |                    |                             | Oakville Sandstone                        |   |   |   |   |
|                  |                    |                             | Upper part of Catahoula Tuff or Sandstone | Jasper aquifer  |   |   | <i>Discorbis nomada</i><br><i>Discorbis gracilis</i><br><i>Heterostegina</i> sp.<br><i>Margulinina idiomorpha</i><br><i>Textularia mississippiensis</i> |
|                  |                    | Catahoula Tuff or Sandstone | Catahoula confining system (restricted)   | Catahoula Tuff designated as Catahoula Sandstone east of Lavaca County.                   |   |   |   |
|                  |                    | Anahuac Formation           |   |   |   |   |   |
|                  |                    | "Frio" Formation            |   |   |   |   |   |
|                  |                    | Surface Frio Clay           |   |   | Subsurface Vicksburg Group equivalent   | Anahuac and "Frio" Formations may be Oligocene in age.                      |   |
|                  |                    | Oligocene(?)                | Jackson Group                             |   | Fashioning Clay Member  |   | Not discussed as hydrologic units in this report.   |
|                  |                    |                             |   | Calliham Sandstone Member or Tordilla Sandstone Member                                    |   |   |   |
|                  |                    |                             |   | Whitsett Formation  |   |   |   |
|                  |                    |                             |   | Dubose Member   |   |   |   |
|                  |                    |                             |   | Deweesville Sandstone Member  |   |   |   |
|                  |                    |                             |   | Conquista Clay Member   |   |   |   |
|                  |                    |                             |   | Dilworth Sandstone Member   |   |   |   |
|                  | Manning Clay       |                             |   |   |   |   |   |
|                  | Wellborn Sandstone |                             |   |   |   |   |   |
|                  | Eocene             | Claiborne Group             | Caddell Formation                         | <i>Textularia yeguaensis</i><br><i>Eponides yeguaensis</i><br><i>Ceratobulmina extima</i> |   |   |   |
|                  |                    |                             | Yegua Formation                           |   |   |   |   |
|                  |                    |                             | Cook Mountain Formation                   |   |   |   |   |
|                  |                    |                             | Sparta Sand                               |   |   |   |   |
| Weches Formation |                    |                             |   |   |   |   |   |
| Queen City Sand  |                    |                             |   |   |   |   |   |
| Reklaw Formation |                    |                             |   |   |   |   |   |
| Carrizo Sand     |                    |                             |   |   |   |   |   |
| Paleocene        | Wilcox Group       |                             |   |   |   |   |   |
|                  | Midway Group       |                             |   |   |   |   |   |

Figure 12 Stratigraphic and Hydrogeologic Frame Example [6]

Secondly, BorePoint features need to be created and then a Georaster can be created.

## Reference:

- [1] *Shapefiles for basin and play boundaries*. <<https://www.eia.gov/maps/maps.htm>>.
- [2] Freyman, Monika. *Hydraulic fracturing & water stress: Water demand by the numbers*. Ceres (2014): 49-50.
- [3] Suchy, Daniel R., and K. David Newell. *Hydraulic fracturing of oil and gas wells in Kansas*. Kansas Geological Survey, 2011.
- [4] Strassberg, Gil, Norman L. Jones, and David R. Maidment. *Arc hydro groundwater*. Esri Press, 2011.
- [5] Pantea, Michael P., and James C. Cole. *Three-dimensional geologic framework modeling of faulted hydrostratigraphic units within the Edwards aquifer, northern Bexar County, Texas*. US Geological Survey, 2004.
- [6] Baker, Ernest T. *Stratigraphic and hydrogeologic framework of part of the coastal plain of Texas*. No. 77-712. US Geological Survey, 1977.