Water Resources to Develop Natural Gas from Shale Plays

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Project Goal

The goal of my project is to assess whether there is enough water available annually in the Black Warrior Basin to support both municipal water uses and shale gas extraction from prospective shale plays in the region.

Introduction & Background

Environmental Drivers for Natural Gas

Natural gas accounts for 25% of the United States' total energy consumption (Figure 1) to the tune of 23,775 billion cubic feet in 2011.[1] As compared to oil and coal, natural gas burns cleaner, emitting significantly lower levels of carbon dioxide and sulfur dioxide. Additionally, as U.S. energy demand increases due to population and economic growth, and concerns over the effects of greenhouse gas emissions on global warming build, many experts are looking to natural gas as a way to reduce the human impact on climate change while continuing to meet our growing energy needs.

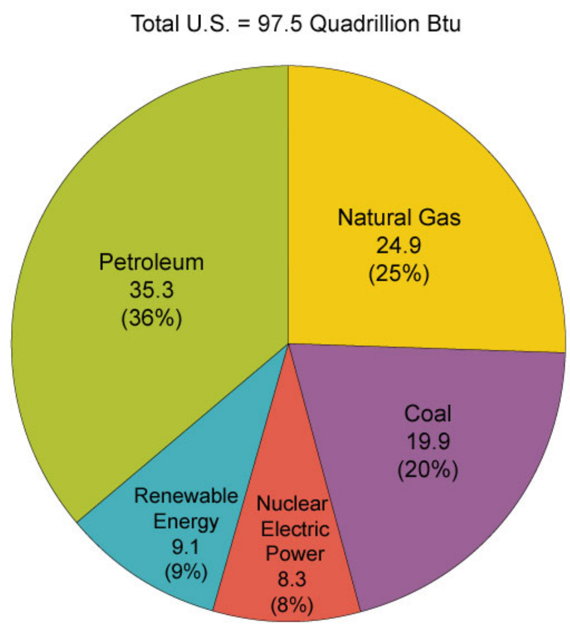
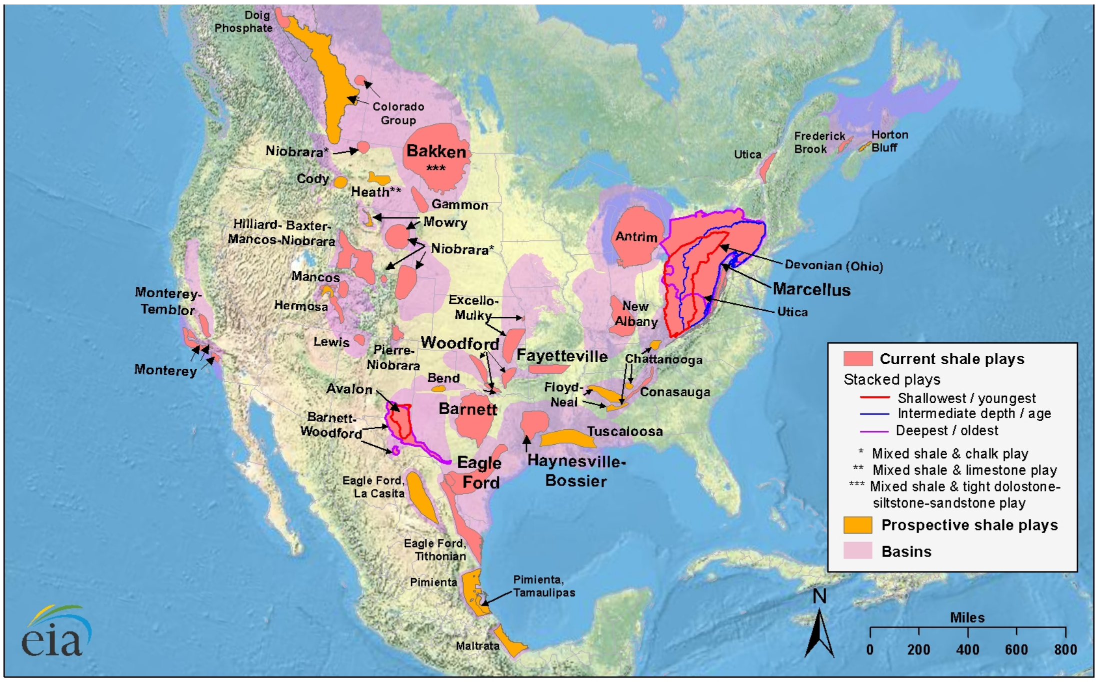


Figure 1: 2011 primary energy use by source in the U.S. given in quadrillion British Thermal Units (BTU) and percent of total usage.[2]

Economic and Political Drivers

In addition to the environmental benefits of natural gas, political considerations have also driven the U.S. to increase production and utilization of this energy source. Political and economic drivers for energy security and independence served as the impetus to explore for more domestic natural gas resources. The result was the discovery of an incredible abundance of natural gas trapped within shale formations—fine-grained sedimentary rocks—referred to as shale gas (Figure 2).

The U.S. Energy Information Administration (EIA) estimates that the U.S. has 482 trillion cubic feet of shale gas. An additional economic (and often political) driver for increased production in domestic natural gas is employment of more Americans and growth of the American economy.



Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Figure 2: EIA map of shale plays located in North America (updated May 2011).

Technology Improvements

Technology improvements over the last fifteen years in hydraulic fracturing ("fracking") and horizontal drilling have made shale gas extraction economically feasible. Currently, these technologies employ approximately one million gallons of highly pressurized water containing sand and chemical additives to fracture the shale formations in order to extract the shale gas (Figure 3).

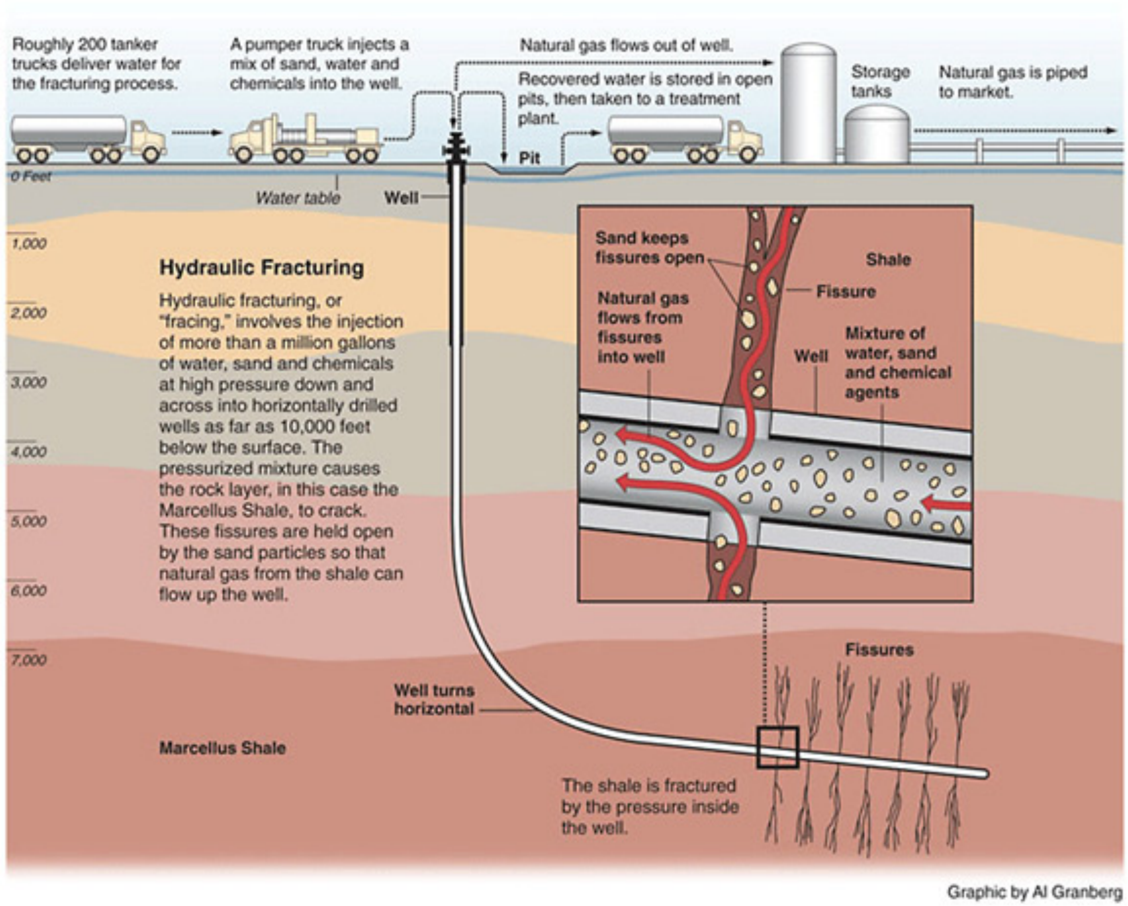


Figure 3: A schematic of the hydraulic fracturing and horizontal drilling techniques.[3]

Given the environmental benefits, economic and political drivers, and improvements in shale gas extraction methods, natural gas production is projected to rise by approximately 25% over the next thirteen years (Figure 4).

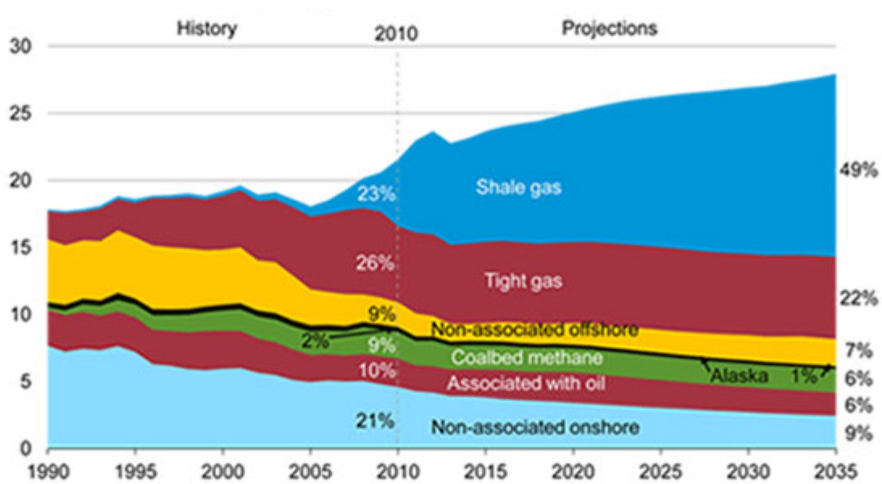


Figure 4: Historical and projected US natural gas production by type in trillion cubic feet per year.[4]

Environmental Concerns with Fracking

Using a million gallons or more per well to create fissures in the shale formation means that fracking is incredibly water intensive. Given this tremendous dependency on water, fracking may not be feasible in already water-stressed regions. Additionally, mixing the water with chemicals and sand produces large amounts of wastewater that must be dealt with either through wastewater treatment or deep well injection. The latter has led to small earthquakes near the injection sites. Surface spills can lead to surface contamination and, finally, issues with well integrity may lead to leaks that have the potential to contaminate nearby groundwater resources. While the environmental concerns are significant, my project focuses only on the water quantity impact of shale gas extraction.

The Black Warrior Basin

Located in eastern Mississippi and western Alabama, the Black Warrior Basin (HUC 031601) is approximately 40,000 km^2 and sits on top of a significant portion of the Floyd/Neal and Chattanooga prospective shale plays (Figure 5). There is an estimated 2.34 trillion cubic feet of shale gas underneath the basin.

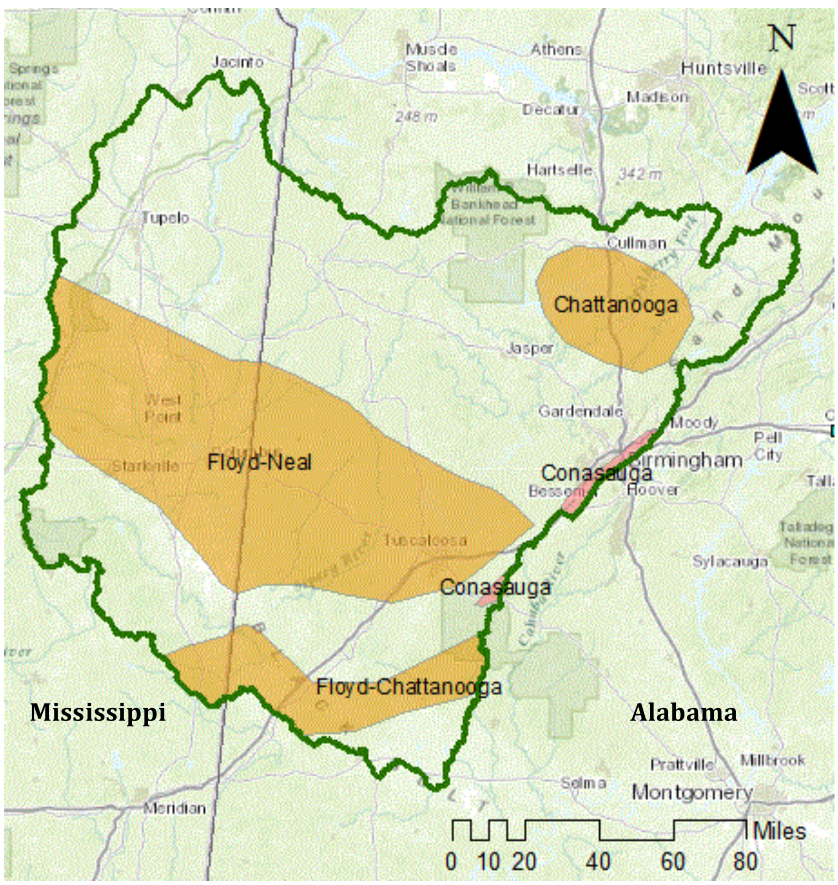


Figure 5: Shale plays clipped for the Black Warrior Basin region of Alabama and Mississippi.

Chattanooga and Floyd/Neal Shale Plays

The Chattanooga and Floyd/Neal shale plays are the two main plays within the Black Warrior Basin. The Floyd shale is often compared to the Barnett shale located in Texas because both a) have dense limestone layers above and below them and b) are similar in age.

Data and Methods

Extractable Shale Gas Amount

To determine the amount of annually extractable shale gas taking into consideration the basin's water availability and municipal water usage, the variables of the following equation needs to be inferred:

$$Extractable\ Gas = k(W_A - W_M)$$

where:

k = amount of shale gas extracted per cubic meter of water
W_A = water availability
W_M = municipal water usage

Water availability is determined by the following equation:

$$W_A = P - ET$$

where:

P = precipitation
ET = evapotranspiration

Water Availability

Two separate data sets were used to assess water availability of the Black Warrior Basin.

Data Set 1: 2011 monthly average data for precipitation and pan evaporation for 53 gauge stations located throughout the basin were obtained from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (Figure 6). The goal was to first sum the monthly averages to obtain average annual values and then apply the formula for water availability (see above) to calculate the annual water availability at each site. Then, these data would be interpolated within ArcGIS using the Thiessen polygon spatial interpolation method to give an estimate for the water availability over the region. Unfortunately, approximately 95% of the pan evaporation data was missing from the dataset. As such, only the estimated annual precipitation could be calculated (Figures 7 and 8).

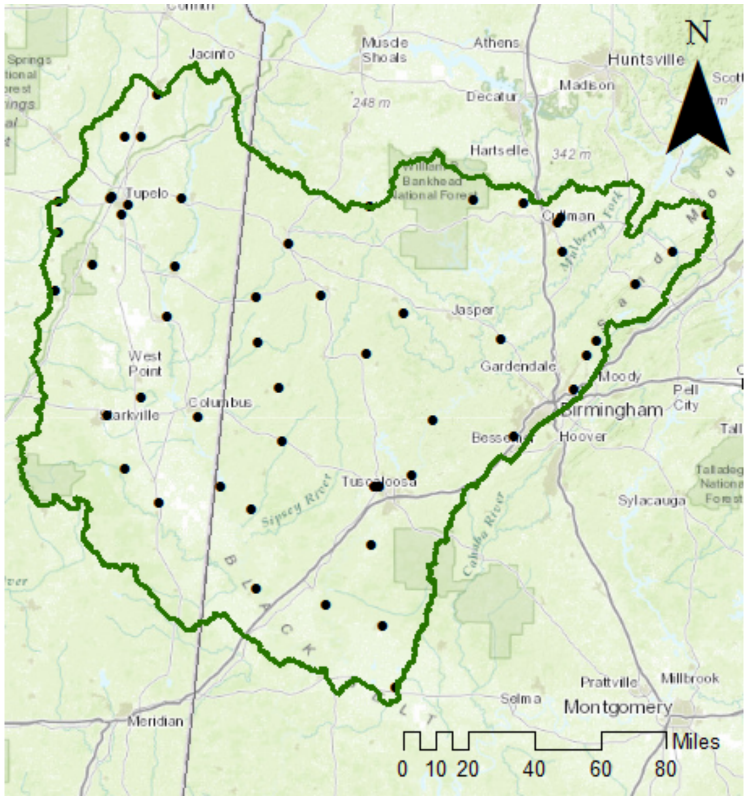


Figure 6: Gauge stations located within the basin.

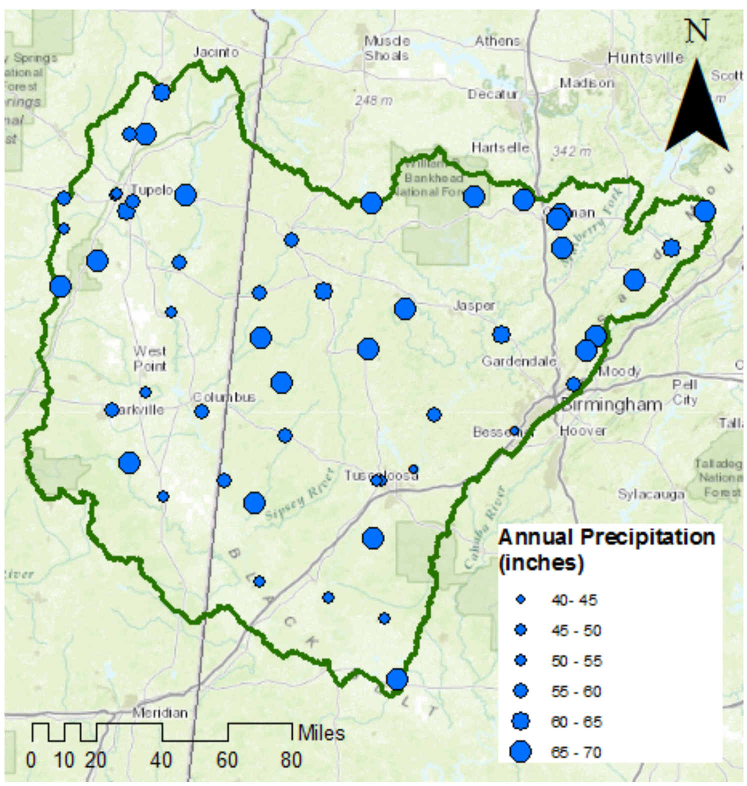


Figure 7: Average annual precipitation at each gauge site within the basin.

Based on this dataset, the Black Warrior Basin received a lot of rain in 2011, with averages across the gauges in the range of 1016–1778 mm (40–70 inches) of precipitation that year. Using the Thiessen polygon spatial interpolation method in ArcGIS (Figure 8), I determined the area received an estimated 63 km^3 of water over the year.

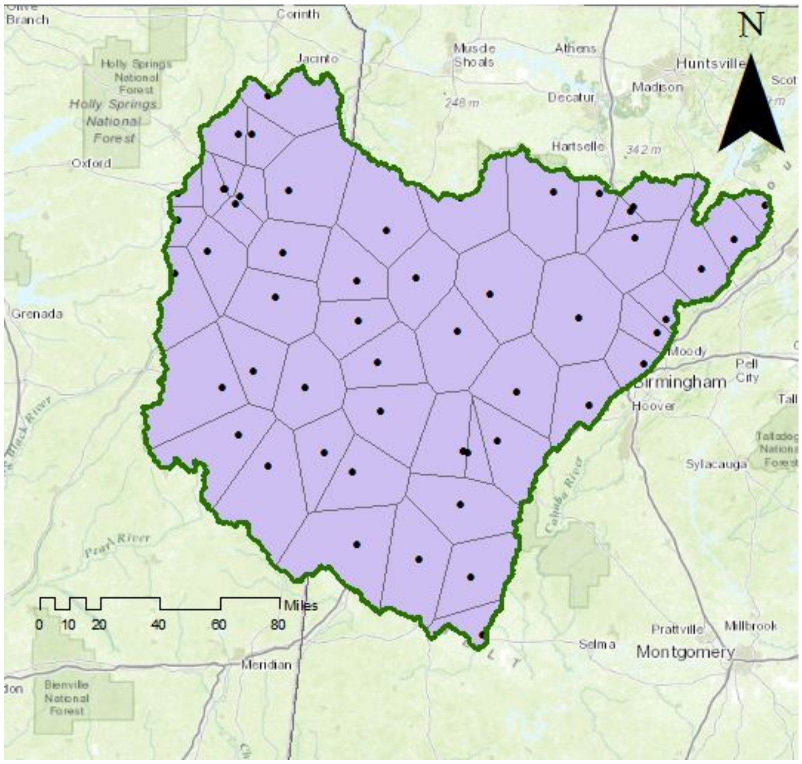


Figure 8: Thiessen polygon spatial interpolation based on data from the 53 gauges to estimate the total volume of water that entered the basin in 2011 due to precipitation.

Data Set 2: ArcGIS online has a map service entitled “Average Annual Available Water with Hillshade” that currently can only be imported into ArcGIS Desktop to overlay with other datasets but cannot be used with geoprocessing tools. I was able to obtain the map service’s raster dataset from Daniel Siegel at ESRI. The raster uses precipitation data from the 1981–2010 normal according to PRISM Climate Group and the evapotranspiration average over the MODIS’ period of record (2000-2010) for MOD16 MODIS Evapotranspiration Product. Using the Zonal Statistics as a Table geoprocessing tool, the annual average water availability for the region was estimated at 24.2 km^3. This value is an annual average water availability based on data spanning decades rather than just a single year’s worth of data like the NOAA dataset (Figure 9).

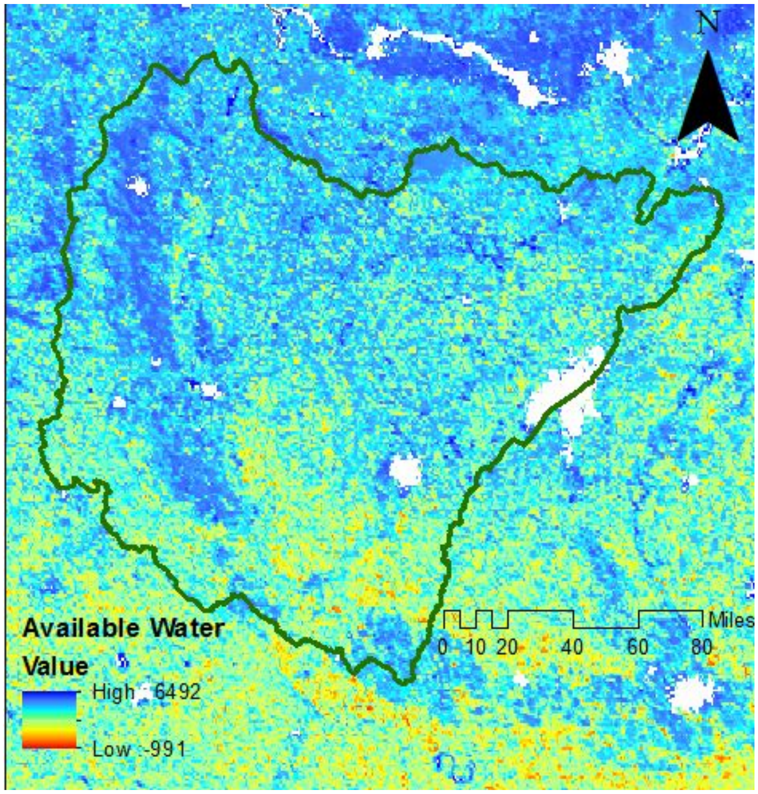


Figure 9: Water availability in millimeters per year. White areas represent urban regions in which water availability was not calculated.

Municipal Water Usage

The annual municipal water requirements can be calculated by the following equation:

$$W_M = (population)\left(\frac{avg.water\ usage}{person - day}\right)\left(\frac{365\ days}{year}\right)$$

To determine the population, 2010 census data for the United States was imported into ArcGIS and clipped for the Black Warrior Basin region. The population for each precinct within the region was summed to determine a population of approximately 1.6 million people. Next, I created a map of the population density by dividing each precinct's population by the area of that precinct (Figure 10).

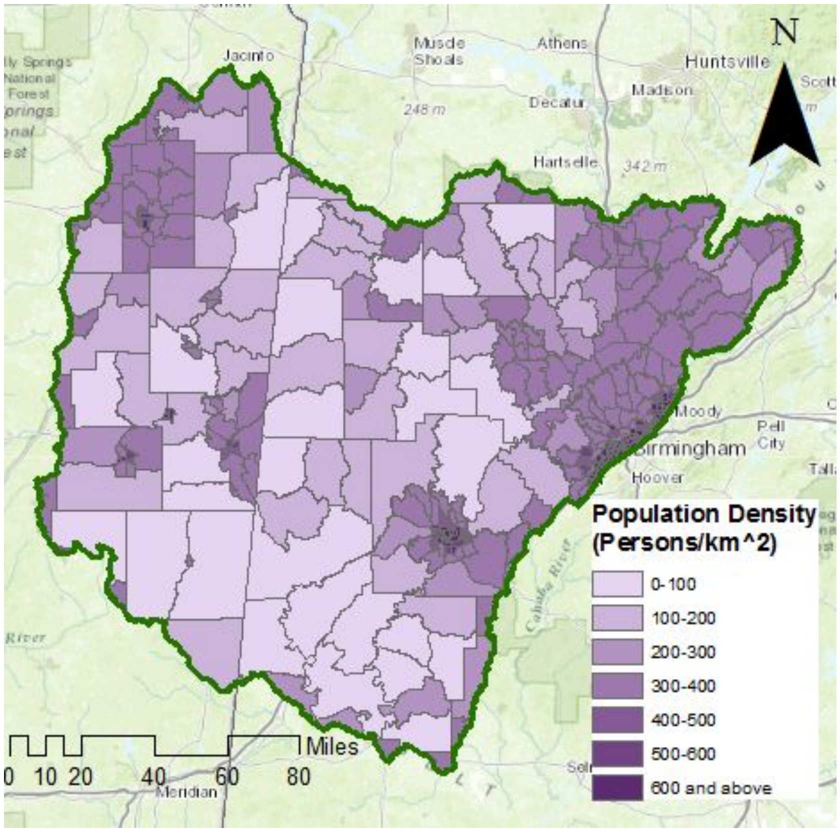


Figure 10: Population density over the Black Warrior Basin given by number of people per km[2].

The EPA estimates a four-person household uses 400 gallons of water per day.[5] As such, we can infer that the average person uses 100 gallons per day. To assess a worst-case scenario, I assumed 150 gallons of water used per person per day in the following calculation:

$$W_M = (1.6 \cdot 10^6 \; persons\,) \left(\frac{150 \; gallons \; of \; water}{person - day}\right) \left(\frac{365 \; days}{year}\right)$$

$$= \; 87.6 \; trillion \; \frac{gallons \; of \; water}{year}$$

$$W_M = 0.33 \; \frac{km^3 \; water}{year}$$

Amount of Shale Gas Extracted Per Unit Water

An estimate for the amount of shale gas that is extracted per unit water was made through an intense literature review for data. Since the Floyd/Neal and Chattanooga shale plays have not yet been exploited, I used data from the Barnett shale play, an active shale play with similar characteristics, as a proxy.

Nicot et al determined the total amount of water used for shale gas production in the Barnett shale play 2008 (Table 1).[6] Separately, the EIA estimated the amount of shale gas extracted from the Barnett shale play for that same year (Figure 11). Using these data, I calculated that approximately 1812 m^3 shale gas are extracted for every 1 m^3 water used. To put these values in perspective, one cubic meter of water serves one person for three days while ~2000 m^3 of gas can serve one person for one year.

Table 1: County-level 2008 net water use for the Barnett shale. In the box are the shale gas net water use by county.

2008 net water use			
total (Mm^3)[d]	GW (%)	SG (Mm^3)	SG (%)
120	13	3.4	2.8
35	45	10.4	29
21	49	2.2	10
453	5	6.3	1.4
14	42	2.7	19

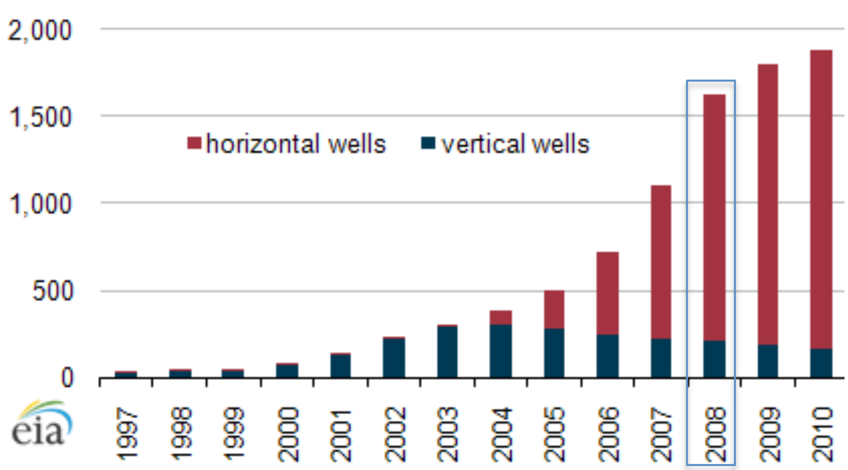


Figure 11: Annual Barnett Shale natural gas production by well type given in billion cubic feet (BCF). In the box is the gas production for 2008.

Results

Black Warrior Basin's Annual Extractable Shale Gas

Using the values derived from the analysis above, the maximum annual extractable shale gas for the region can be calculated as follows:

k = amount of shale gas extracted per m^3 of water = 1812 m^3 gas per m^3 water
W_A = water availability = 24.2 km^3 per year
W_M = municipal water usage = 0.33 km^3 per year

$$Annual\ Extractable\ Gas = 1812 \frac{m^3\ gas}{m^3\ water}(24.2\ km^3 - 0.33\ km^3)$$

$$Annual\ Extractable\ Gas = 43{,}252\ \frac{km^3}{year}$$

We can see that by only considering these three factors: k, W_A, and W_M, the region has a significant amount of water remaining that can potentially be used for fracking. Discussion on incorporating other heavy water users into the method appears in the Future Work section.

Discussion & Additional Considerations

Groundwater for Fracking

When I began my research for this project I set out to find groundwater data in the region. I chose this path initially because using groundwater nearby a gas well removes any dependency on surface water that may or may not be located anywhere nearby. Unfortunately, there was not enough data to conduct a complete assessment of groundwater availability. However, I was able to obtain information on the principal aquifers of the region (Figure 12). Additional data on geologic type, extent, and depth of the aquifers across the region along with average monthly groundwater level data would have allowed me to estimate the amount of groundwater available in the basin.

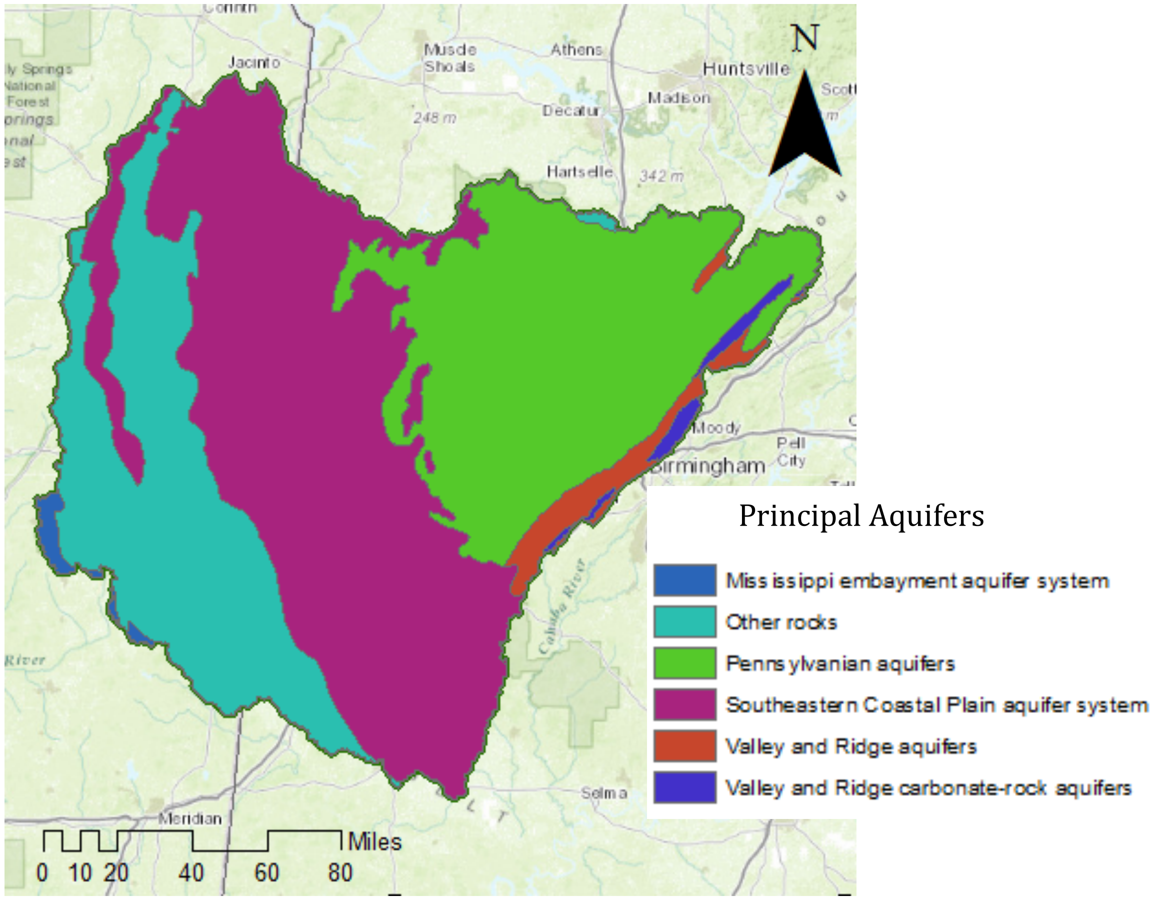


Figure 12: Principal aquifers in the Black Warrior Basin.

Gas Well Locations

Another critical variable that must be considered when determining where to place wells for fracking is human population density near potential sites. As such, identifying the populous areas that sit on top of or near the shale play is essential. By overlaying the shale plays on the population density map, we can see that Tuscaloosa sits on top of the eastern side of the Floyd/Neal shale play. Additionally, higher population density exists around the Chattanooga shale play near Birmingham in the northeast region of the basin.

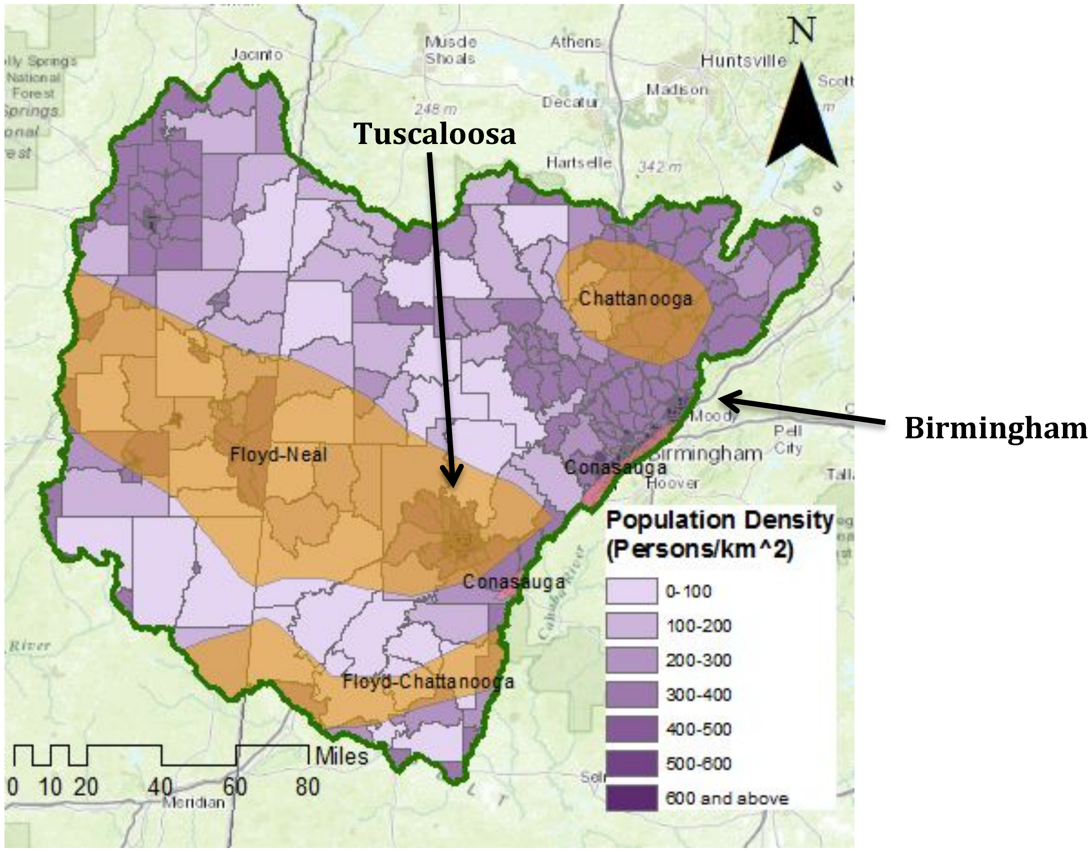


Figure 13: Shale plays overlaying population density over the Black Warrior Basin.

Lessons Learned

Data Acquisition Challenges

The biggest challenge I faced in executing this project was finding the necessary water usage for shale gas extraction and groundwater information. I suspect that difficulty in locating gas extraction's water consumption data is due to the fact that the overall shale gas sector is relatively young and, as such, a) there has simply not been enough time to collect a significant amount of data, b) the data is not yet publicly available, and perhaps most likely c) the regulatory environment for reporting water consumption used by gas companies has not kept up with the changes in the industry. I sincerely hope that the government regulations improve so that a better understanding of shale gas extraction's impact to water quantity, water quality, and other environmental issues can be properly investigated and understood. Similarly, given the importance of understanding our impact on the aquifers beneath us, I hope that groundwater information improves across the country, not just on a state-by-state basis. Additionally, to keep data content and formats consistent across states, groundwater data standards should be set at a Federal level.

Future Work

Additional Water Consumers

This assessment did not take into consideration other major water users of the region such as the agriculture sector and other water-intensive industries. Successfully assessing the water availability and municipal water usage gives validation to the approach, allowing as a next step to incorporate data from other heavy water users to determine how they will impact the maximum annual amount of extractable shale gas.

Apply Method to Other Prospective Shale Play Regions

Once the method incorporates other major water users of the region, the next step would be to apply it to another region of the country (or world) where a prospective shale gas play exists. Considerations that could impact the values in the extractable shale gas equation are:

- Who/what are the major water consumers/industries in the region? What are their water requirements?
- How does k (the amount of gas extracted per unit of water) vary as a prospective shale play's depth or hardness varies?

Once these variables are considered, application of this method should be fairly straightforward in the new region.

GIS Data Sources

1. Shapefiles for shale gas basin and play boundaries obtained at http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm
2. HUC 031601 2011 average monthly precipitation and pan-evaporation obtained at National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center. Retrieved November 2012.
3. "Average Annual Available Water with Hillshade" raster dataset obtained from Daniel Siegel at ESRI. Includes precipitation data from the 1981–2010 normal according to PRISM Climate Group and the evapotranspiration average over the MODIS' period of record (2000-2010) for MOD16 MODIS Evapotranspiration Product.
4. 2010 Census Demographic Profile 1 – Shapefile Format obtained at http://www.census.gov/geo/maps-data/data/tiger-data.html.
5. Principal US Aquifers map layer obtained at www.nationalatlas.gov.

Endnotes

[1] U.S. Energy Information Administration. *Natural Gas Monthly.* Table 2 (November 2012).

[2] U.S. Energy Information Administration, *Monthly Energy Review,* Table 1.3 (March 2012), preliminary 2011 data.

[3] Granberg, Al. "What is Hydraulic Fracturing?" Graphic. www.propublica.org.

[4] U.S. Energy Information Administration, *Annual Energy Outlook (2012).* June 2012.

[5] "Indoor Water-Use in the United States." EPA Watersense (June 2008): EPA-832-F-06-004.

[6] Nicot, Jean-Phillippe, et al. "Water Use for Shale-Gas Production in Texas, U.S." Environmental Science and Technology 46.6 (2012): 3580-3586.