Carbon Dioxide Storage Volume Potential in the Permian Basin, West Texas, USA

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Problem Statement

Quantifying the potential carbon dioxide (CO_2) storage volume of a carbon sequestration sedimentary basin is essential for demonstrating to the United States Environmental Protection Agency (EPA) Underground Injection Control (UIC) program that the chosen storage site is viable for storage of the estimated volume of CO_2 from a chosen source. Being able to quantify the volume of storage will assist UIC injection permit applicants in successfully obtaining a Class VI injection permit. This project demonstrates a simplified methodology for estimating the CO_2 storage potential within a defined geographic area, and specifically answers the following question:

What is the volume of available CO_2 storage in the saline formations of the Permian Basin?

In order to answer this question, I will use the Map Algebra tool in ArcGIS along with different data sources to calculate a volume. To estimate a storage volume I could use a combination of the following data types:

1. Elevation OR Potentiometric Surface (~800m below this surface is the top of supercritical CO_2 storage window). Top of storage window can be improved if data on geothermal gradient can be found.
2. Base of fresh water (According to UIC rules, injection of CO_2 cannot occur in formation fluids where there is <10,000 TDS)
3. Top of basement in the Permian Basin (this will be the depth limit for CO_2 storage)
4. Area of the storage unit (this area will be defined by geologic structure and/or boundaries of chosen Texas counties where storage will take place)

These data sources are used to solve the following simplified equation:

(Top of storage window - Top of basement) * area of storage unit * efficiency factor (found through porosity thickness) = potential volume of storage

More specifically for this report I focused on Midland County and Midland Basin, as the city of Midland will provide excellent sources of CO_2 for potential storage.

Data Collection

SOURCE NAME	URL	SPATIAL REFERENCE	RESOLUTION	BRIEF EXPLANATION
Texas Counties	https://gis-txdot.opendata.arcgis.com/datasets/8b902883539a416780440ef009b3f80f_0	GCS_WGS_1984		Polygon shapefile of Texas County boundaries
Elevation	https://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View#/	GCS_North_American_1983	(0.00027777778, 0.00027777778)	30 meter DEM elevation data for West Texas. Higher resolution is available, but takes too long to download.

Top of Basement	https://www.beg.utexas.edu/resprog/permianbasin/gis.htm	GCS_North_American_1927	(0.018,0.018)	Precambrian basement structure grid interpolated from contours
Geothermal Gradient	https://www.beg.utexas.edu/resprog/permianbasin/gis.htm	GCS_North_American_1927		Geothermal Gradient contour lines (contoured every 0.1°F/100ft)
Midland Basin Outline	https://www.eia.gov/maps/pdf/PermianBasin_Wolfcamp_EIAReport_Oct2018.pdf			Digitized outline of the Midland Basin (a subpart of the Permian Basin)

Data Preprocessing

For this project, data preprocessing is not a major part of the workflow. The data outlined above is made usable for the goal of this project through different ArcGIS processing schemes. The separate elevation DEMs will need to be merged, which is explained in the ArcGIS Processing section. The Midland Basin outline image needs to be georeferenced and digitized, which is explained in the ArcGIS Processing section. And finally all these raster layers will need to be clipped to the Midland Basin outline and used with Raster Algebra techniques to obtain a storage volume.

ArcGIS Processing

The ArcGIS scheme appropriate for this study is explained in the following eight steps.

1. Set Up ArcMap

To set up ArcMap I clicked the “Add Data” button and selected “Add Basemap…” to add the imagery basemap for visualization purposes (Figure 1).

I also clicked the “Add Data” button and added the TxDOT county shapefile to my map. This sets the coordinate system of my Data Frame as WGS_1984_Web_Mercator_Auxiliary_Sphere (Figure 1).

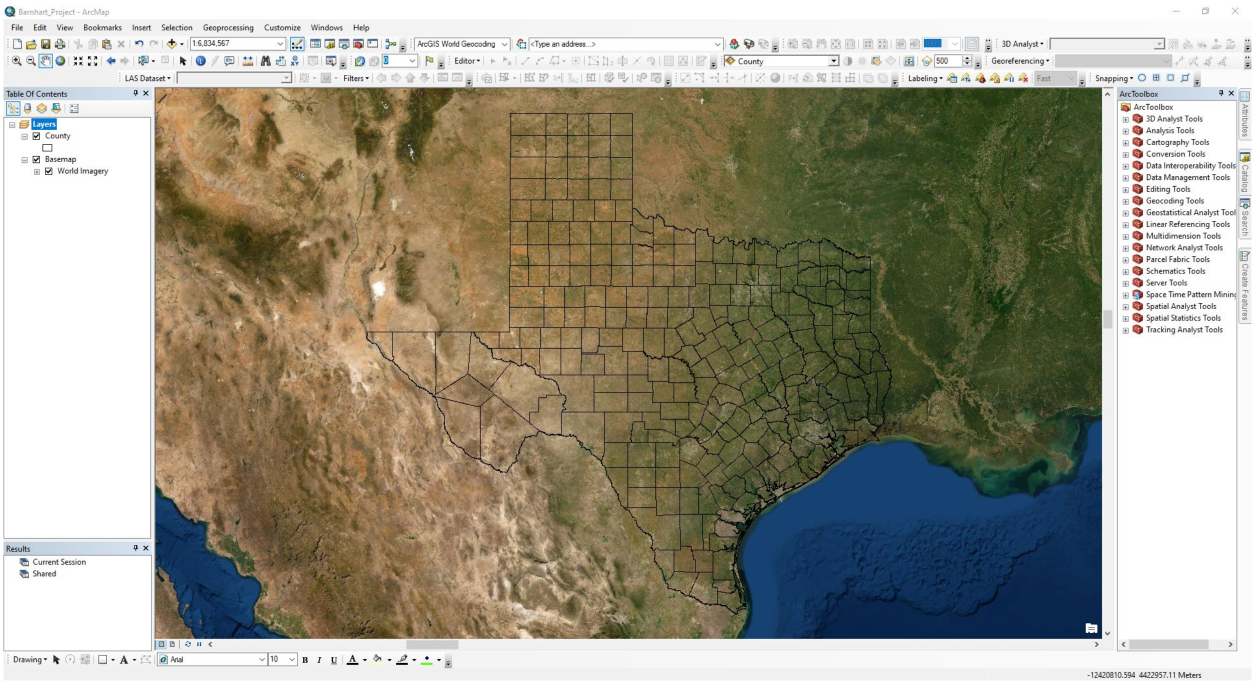

Figure 1: Adding a Basemap and County Outlines

2. Georeference and Digitize the Midland Basin Outline

The goal of this step was to georeference and digitize the Midland Basin outline, which will be used as the area in the subsequent volume calculations. I clicked the “Add Data” button to add the major structural and tectonic features in the region of the Permian Basin image from the EIA Permian Basin Wolfcamp Shale Play Geology Review to the map.

Then I went to the “Georeferencing” tool bar and selected “Fit to Display” for the image I want to georeferenced (Figure 2).

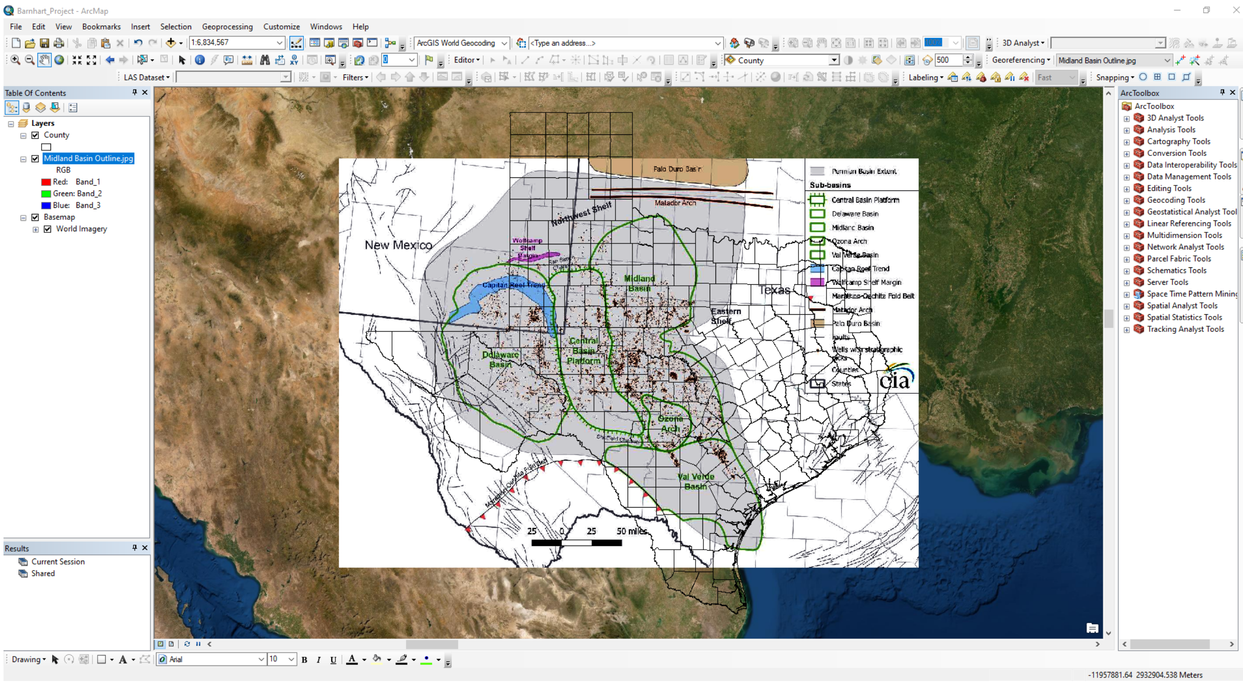

Figure 2: Fit to Display the Permian Basin Map Image

I double-clicked on the Midland Basin Outline in the Table of Contents (TOC) to open the "Layer Properties" window. Then I clicked on the "Display" tab and changed the transparency to 60% to make georeferencing easier (Figure 3).

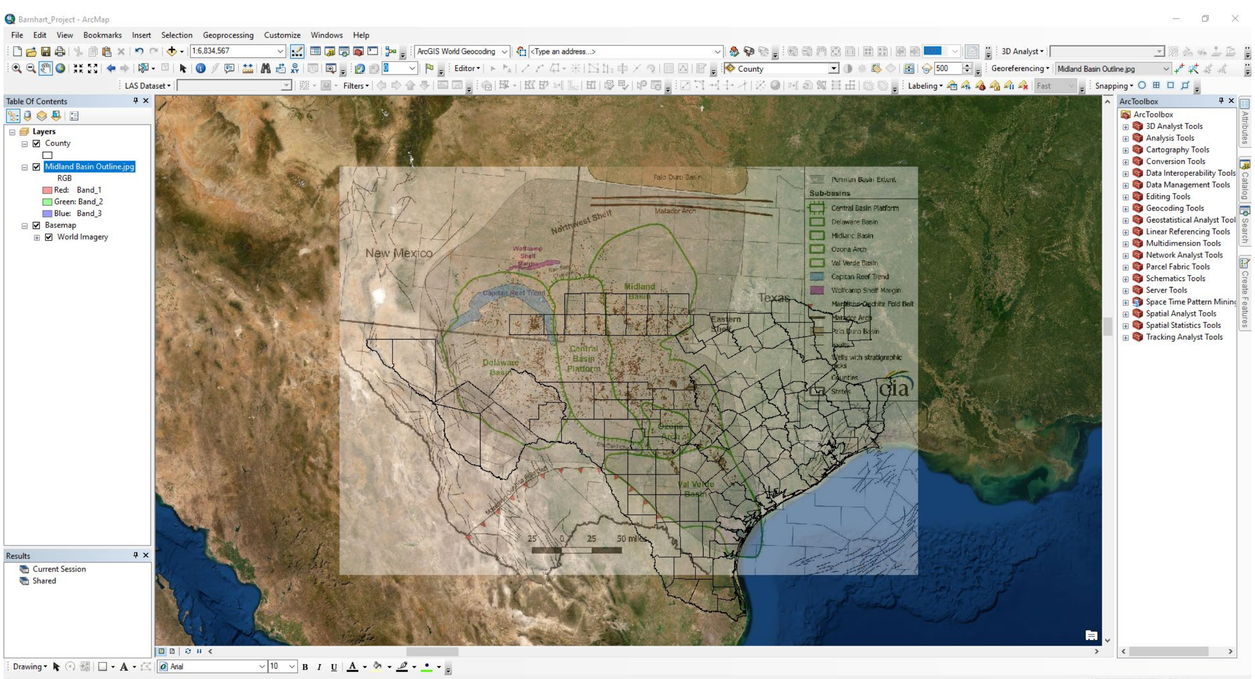

Figure 3: Adjusting Map Image Transparency

Then I clicked on the “Add Control Points” button in the “Georeferencing” toolbar and began the process of georeferencing. I added 5 control points, and because I only want a rough outline of the Midland Basin accuracy is not severely important. In order to georeference I toggled on and off the display of the image and County outlines while adding control points, and toggled on “Vertex Snapping” in the “Snapping” toolbar (Figure 4).

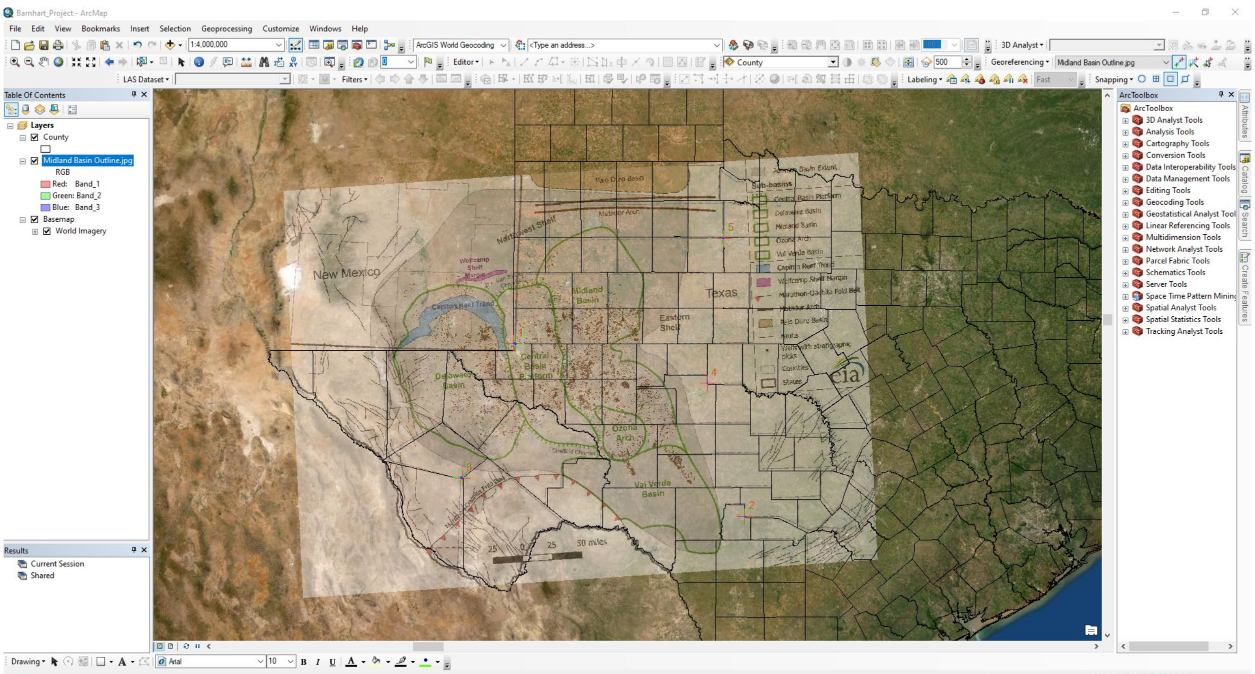

Figure 4: Adding Control Points to the Map Image

Then I selected “Update Georeferencing” in the “Georeferencing” toolbar.

To outline the Midland Basin, I went to “Catalog,” right-clicked my home folder, and selected “New > Shapefile.” I named this shapefile “Midland Basin,” and set the “Feature Type” as “Polygon.” I also set the coordinate system to be WGS_1984_Web_Mercator_Auxiliary_Sphere (Figure 5).

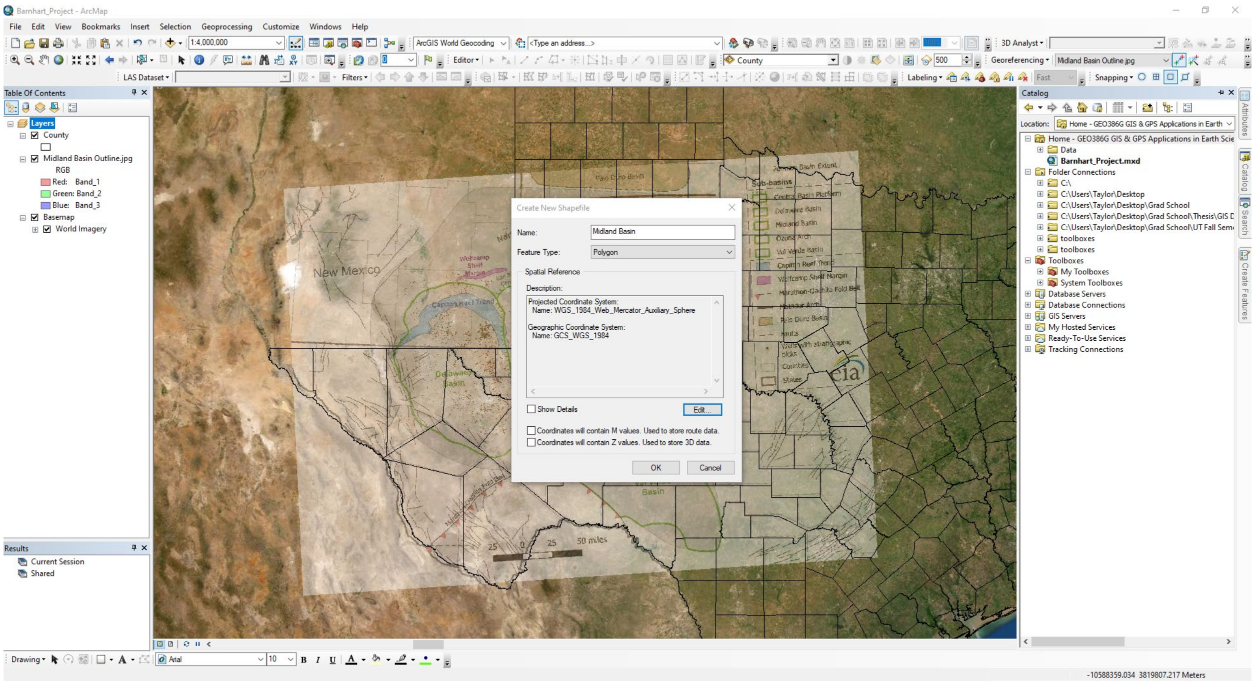

Figure 5: Create New Shapefile to Digitize Midland Basin Outline

To digitize the Midland Basin I right-clicked on “Midland Basin” in the TOC and selected “Edit Features > Start Editing.” Then I went to the “Create Features” tab to check that I had “Midland Basin” selected and began tracing the outline of the Midland Basin. Once I finished I went to the “Editor” toolbar and selected “Save Edits,” then “Stop Editing,” (Figure 6).

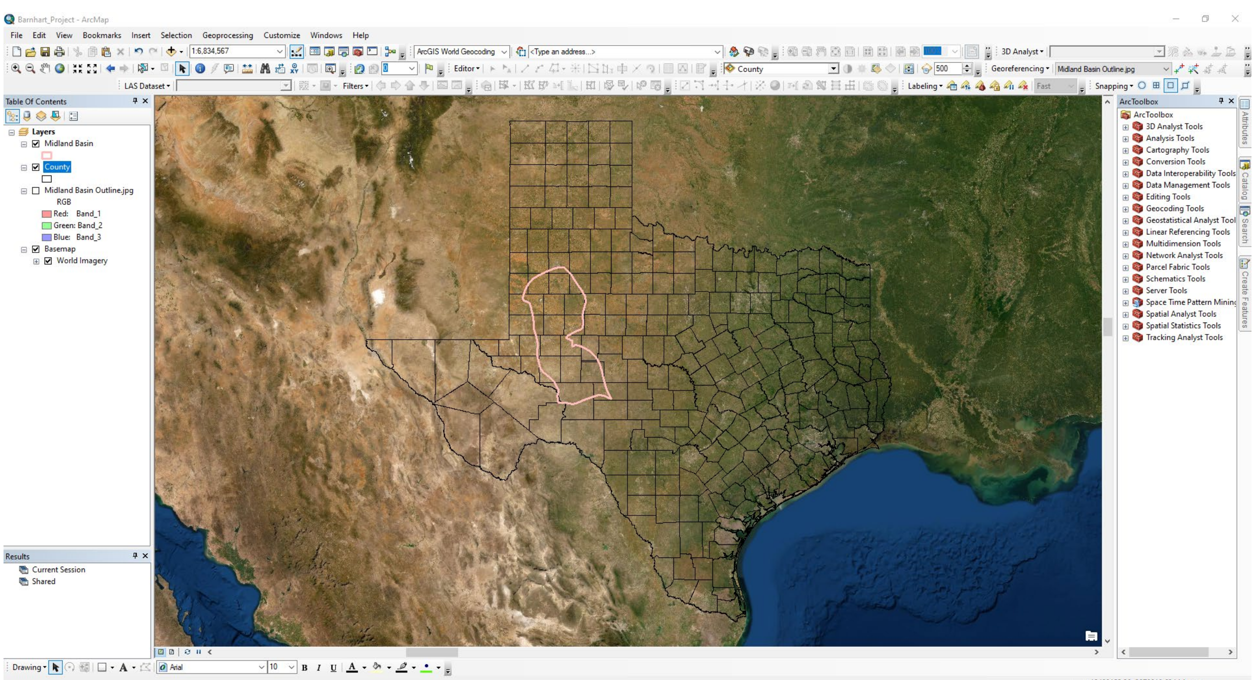

Figure 6: Midland Basin Outline Feature

To calculate the area of Midland Basin I right-clicked on the “Midland Basin” outline layer in the TOC and selected “Open Attribute Table,” then I clicked on the “Table Options” button and clicked “Add Field” to add a float type field called “Area.” After that I right-clicked on the “Area” field and selected “Calculate Geometry” to calculate the area of the Midland Basin in m^2. This number came out to be 49,856,000,000 m^2 (Figure 7).

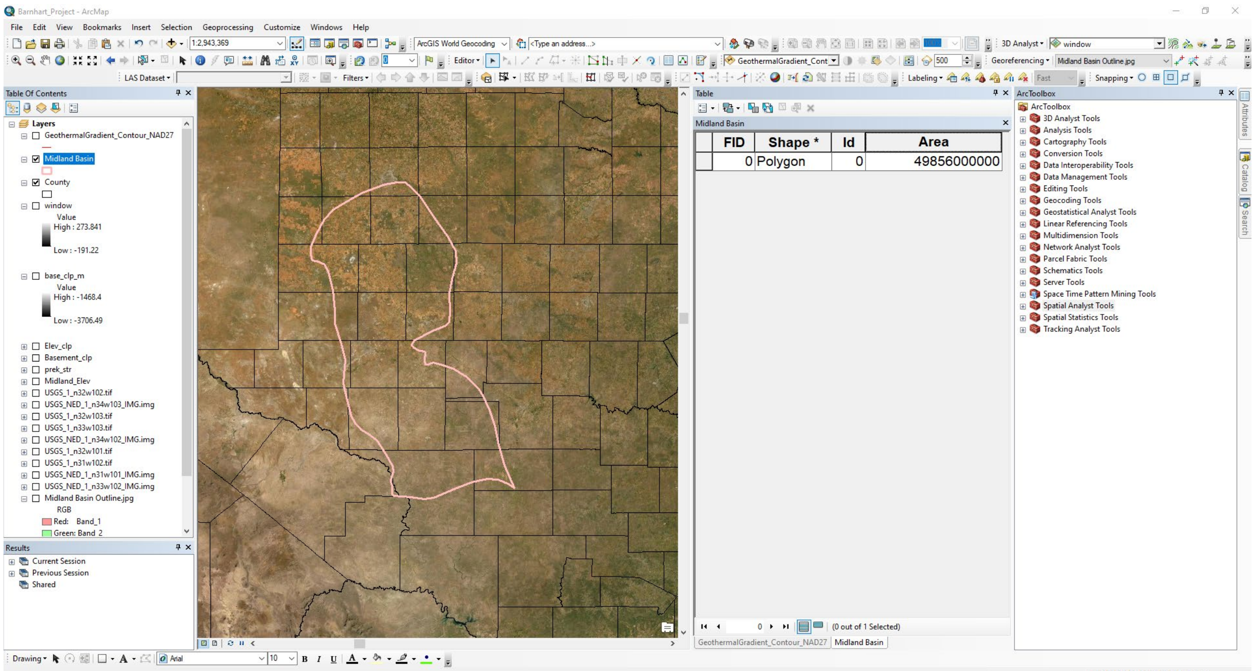

Figure 7: Midland Basin Area Calculation

3. Mosaic to New Raster Separate DEMs and Extract by Mask

I first loaded all of the applicable 30 meter DEMs to my map (Figure 8).

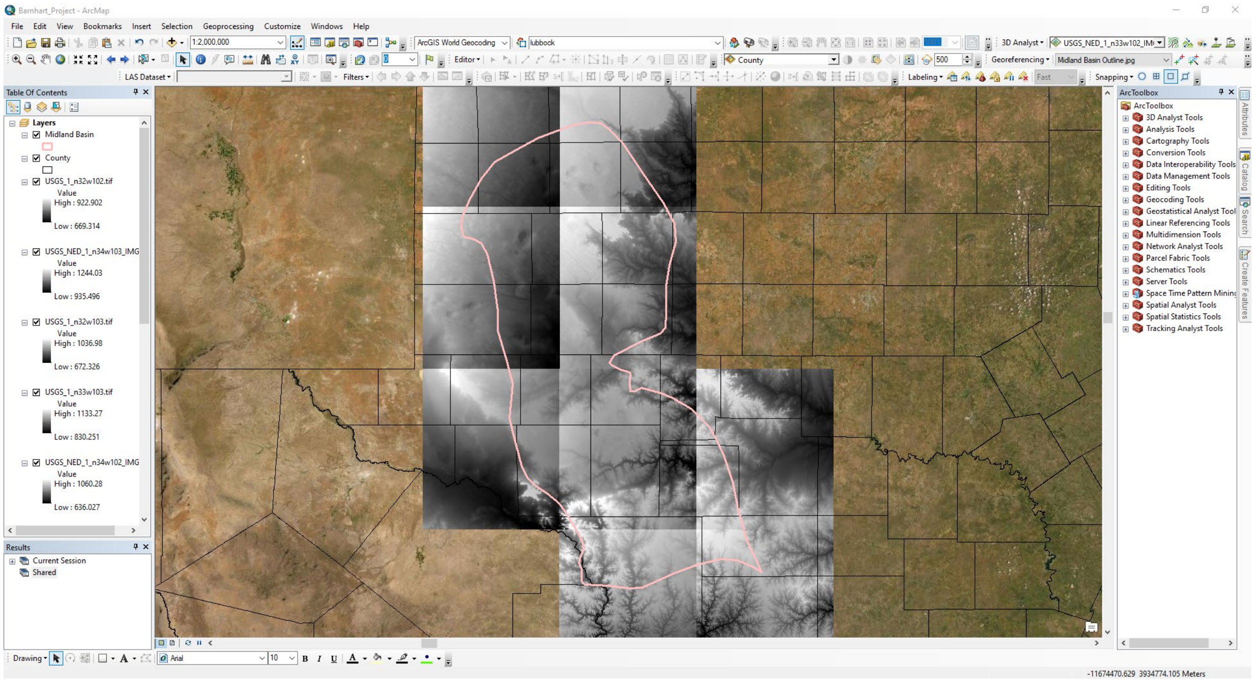

Figure 8: 30-Meter DEM Elevation Data

Then I combined these separate raster files into one single raster using the “Mosaic to New Raster” tool. This tool is in “Data Management Tools > Raster > Raster Dataset.” The “Input Rasters” are all the individual rasters, the “Output Location” is my home folder, the “Raster Dataset Name with Extension is “Midland_Elev,” the “Pixel Type” is “32_Bit_Float,” and the “Number of Bands” is 1 (Figure 9 & 10).

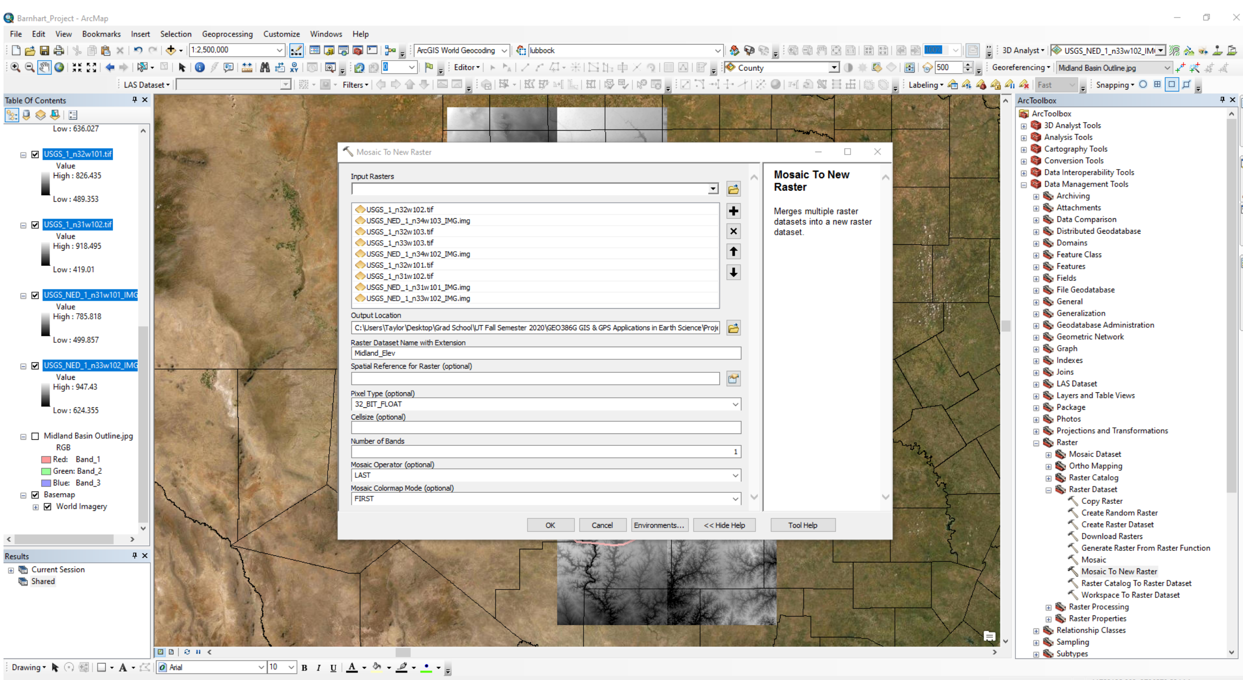

Figure 9: Mosaic to New Raster the 30-Meter DEMs Set-Up

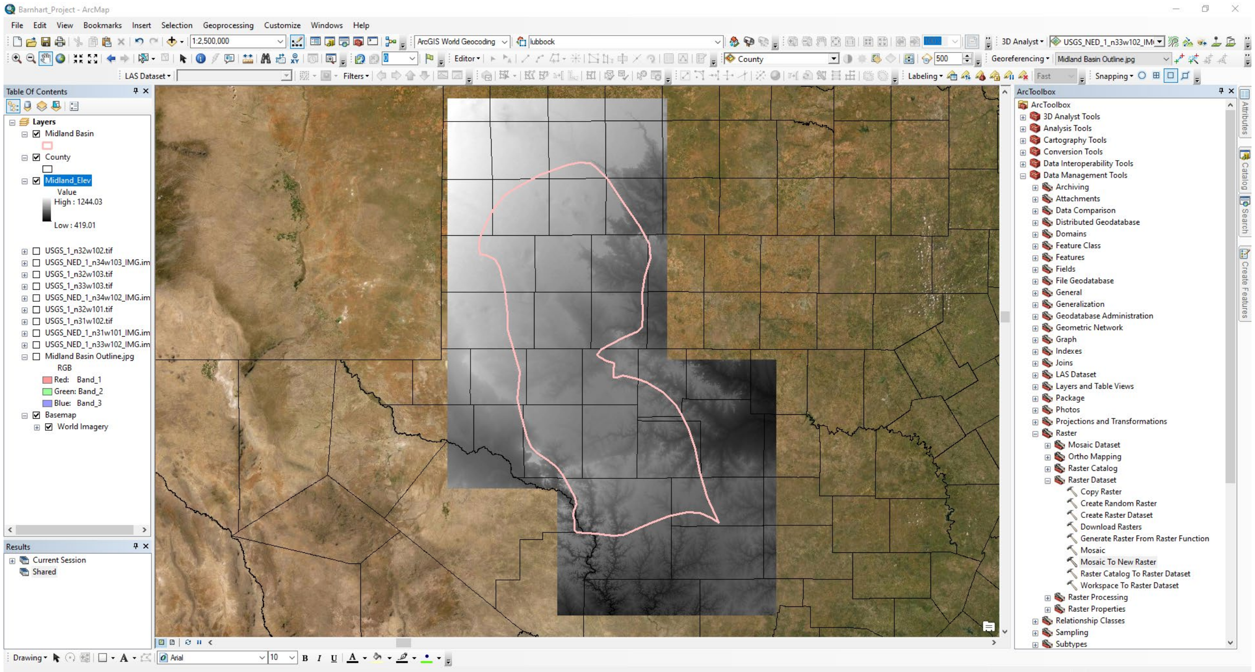

Figure 10: Mosaic to New Raster the 30-Meter DEMs Result

Then I used the “Extract by Mask” tool in “Spatial Analysis Tools > Extraction” to obtain only the elevation values within the Midland Basin outline. The “Input Raster” is the new “Midland_Elev” raster, the “Input Raster or feature mask data” is the “Midland Basin” outline, and the “Output Raster” is “Elev_clp,” (Figure 11).

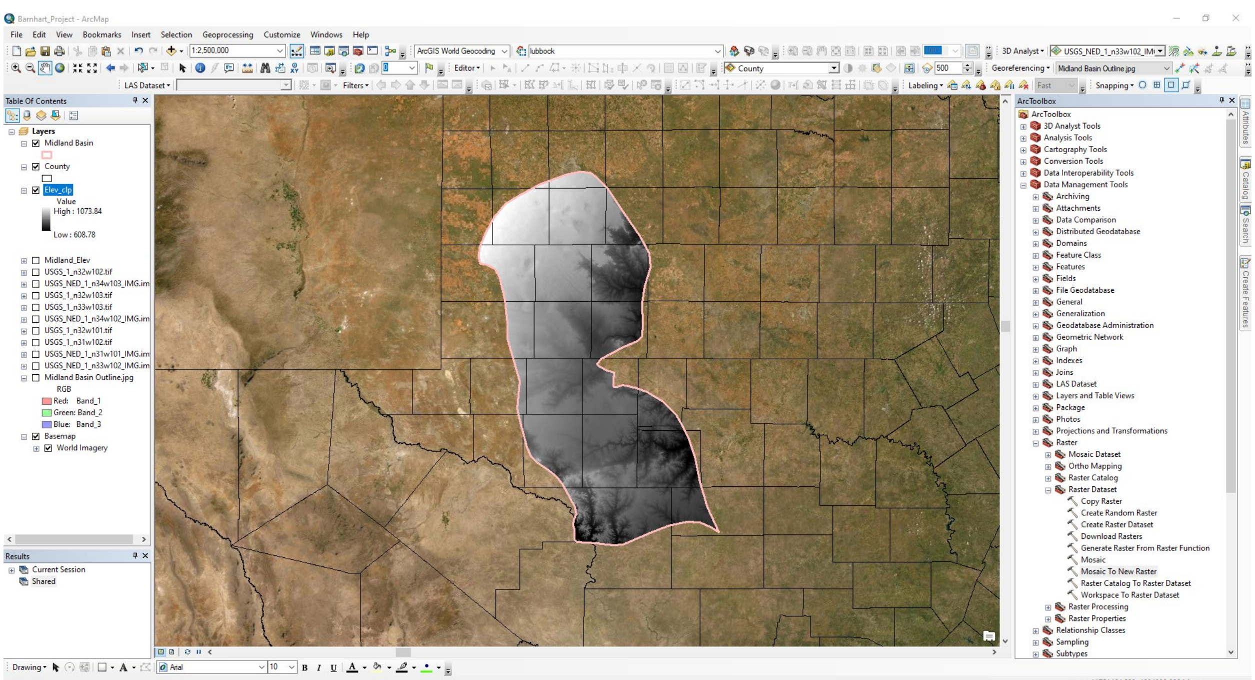

Figure 11: Extract by Mask the 30-Meter DEM Mosaic

4. Mask Precambrian Basement layer

I clicked the “Add Data” button to add the “prek_str” raster file to the map (Ruppel, et al., 2005) (Figure 12).

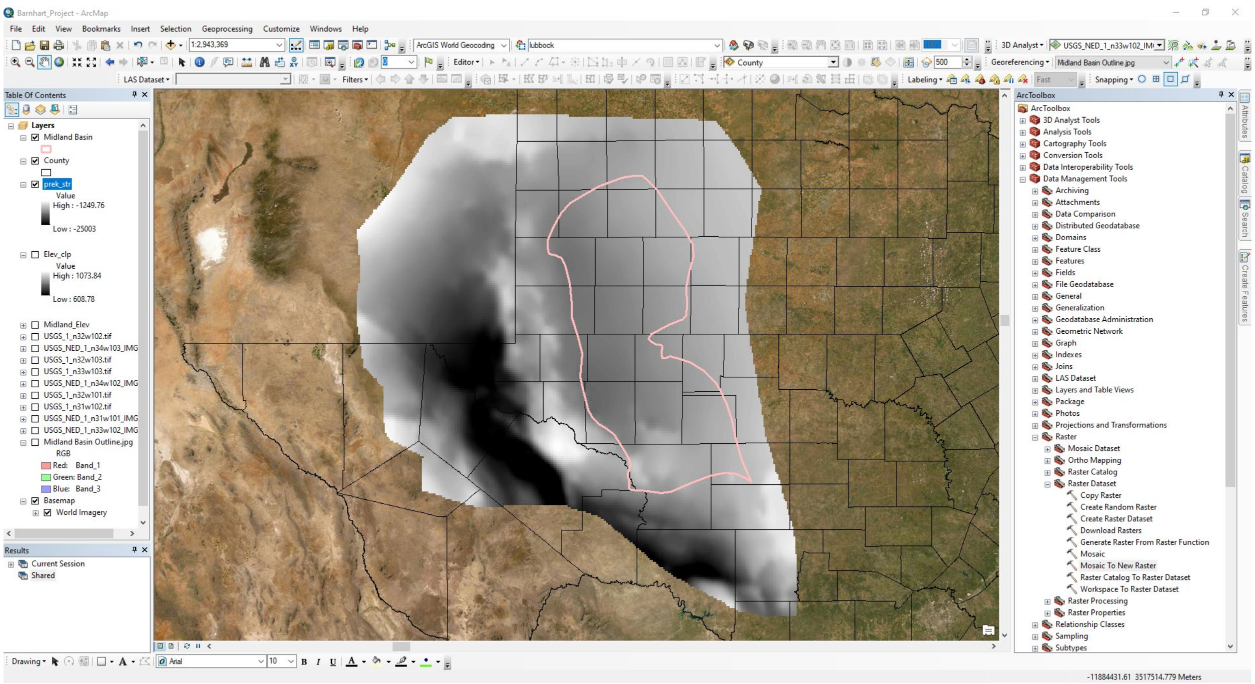

Figure 12: Loading the Precambrian Basement Layer

Then I used the “Extract by Mask” tool in “Spatial Analysis Tools > Extraction” to obtain only the elevation values within the Midland Basin outline. The “Input Raster” is the “prek_str” raster, the “Input Raster or feature mask data” is the “Midland Basin” outline, and the “Output Raster” is “Basement_clp,” (Figure 13).

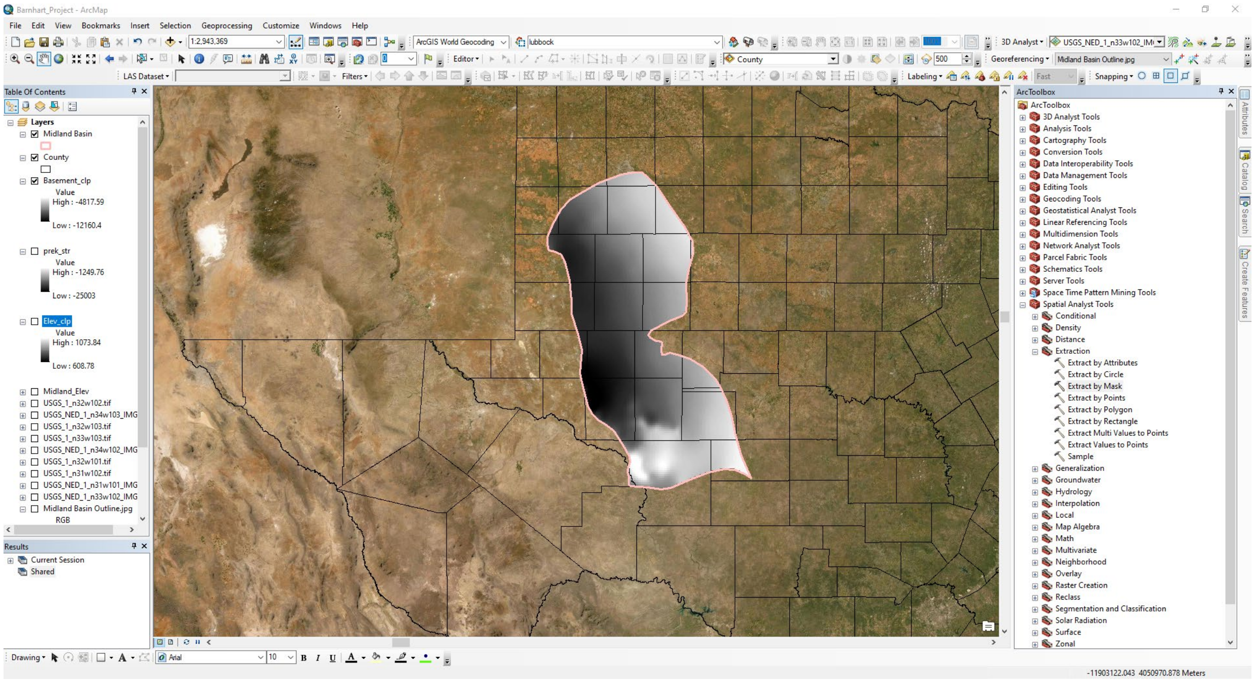

Figure 13: Extract by Mask the Precambrian Basement Raster

Then I used the “Raster Calculator” tool in “Spatial Analyst Tools > Map Algebra” to convert this raster from feet to meters using a conversion factor of 0.3048. The new output raster was named “base_clp_m,” (Figure 14).

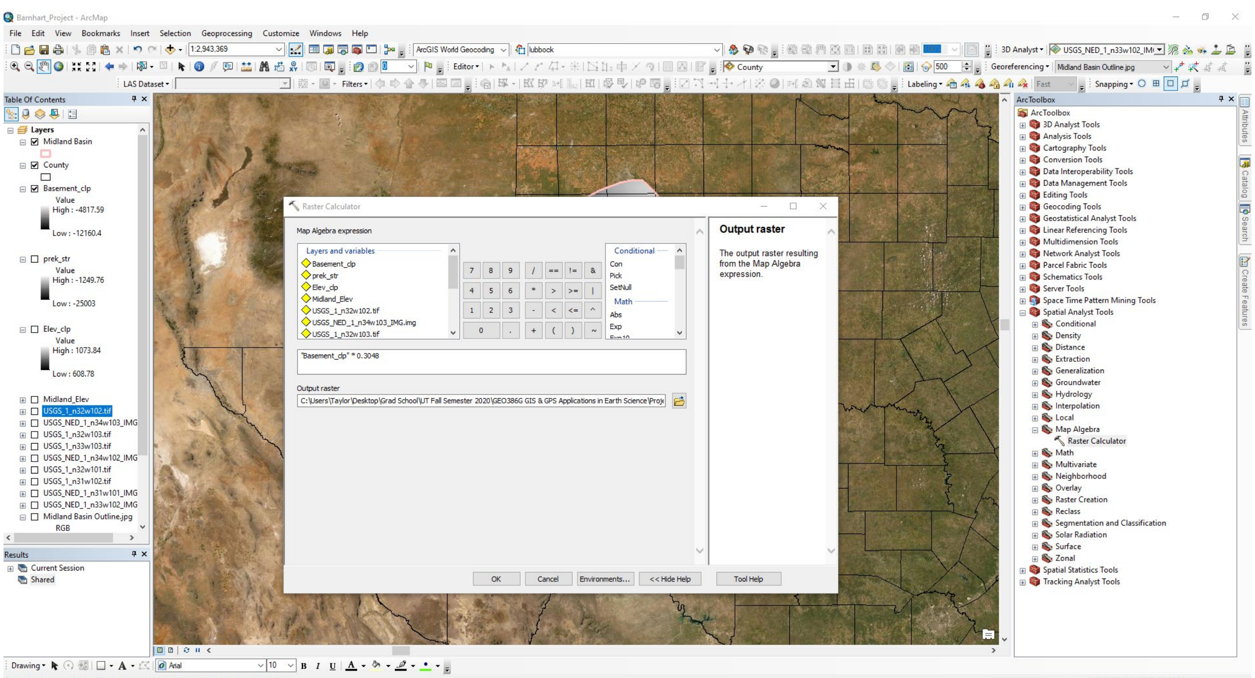

Figure 14: Raster Calculator to Covert Precambrian Basement From Feet to Meters

5. Calculating Storage Window From Elevation Data and Resampling

The storage window for supercritical CO_2 is nominally 800m below the surface, so to find this I used the “Raster Calculator” tool in “Spatial Analyst Tools > Map Algebra” to subtract 800m from the “Elev_clp” raster. The new “Output raster” is called “window,” (Figure 15).

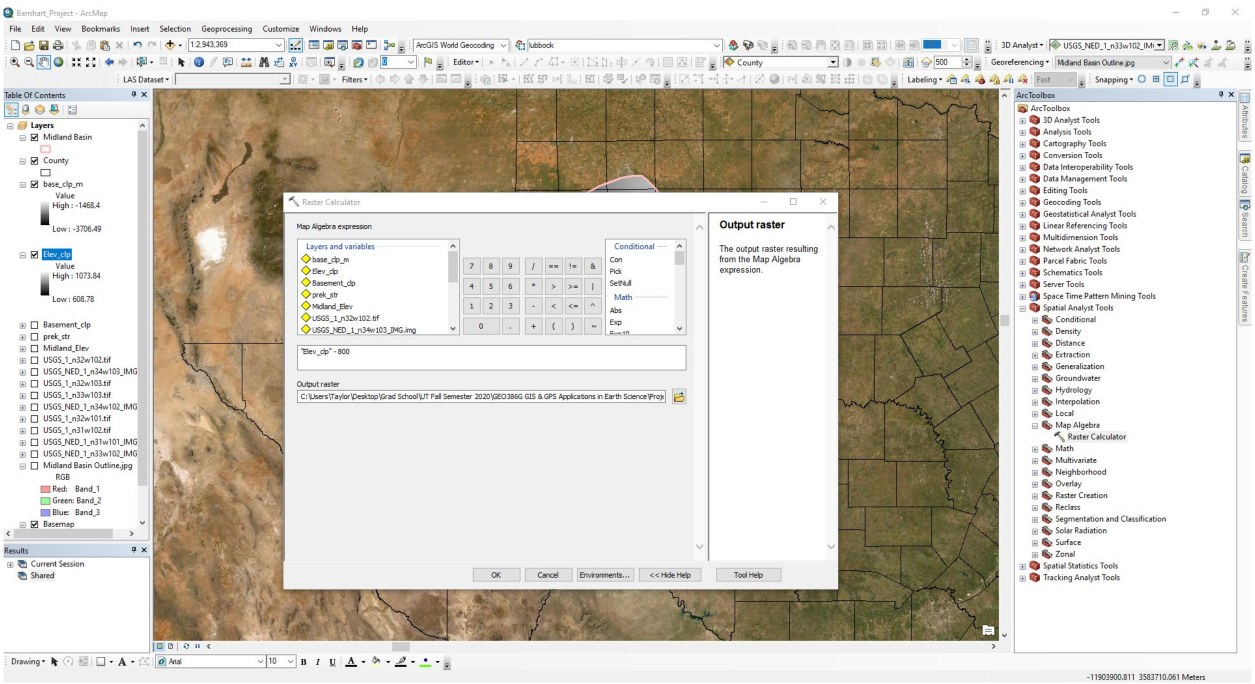

Figure 15: Calculating CO2 Storage Window From Elevation Data

Next this storage window needed to be resampled so that the cell size was the same as the depth to basement raster layer, which would allow for the use of the “Cut Fill” tool for calculation of the volume.

I went to “Data Management > Raster > Raster Processing > Resample,” and used the “window” raster as the “Input Raster,” named the “Output Raster” as “window_” and set the new cell size to the same as “base_clp_m” (0.018,0.018) (Figure 16).

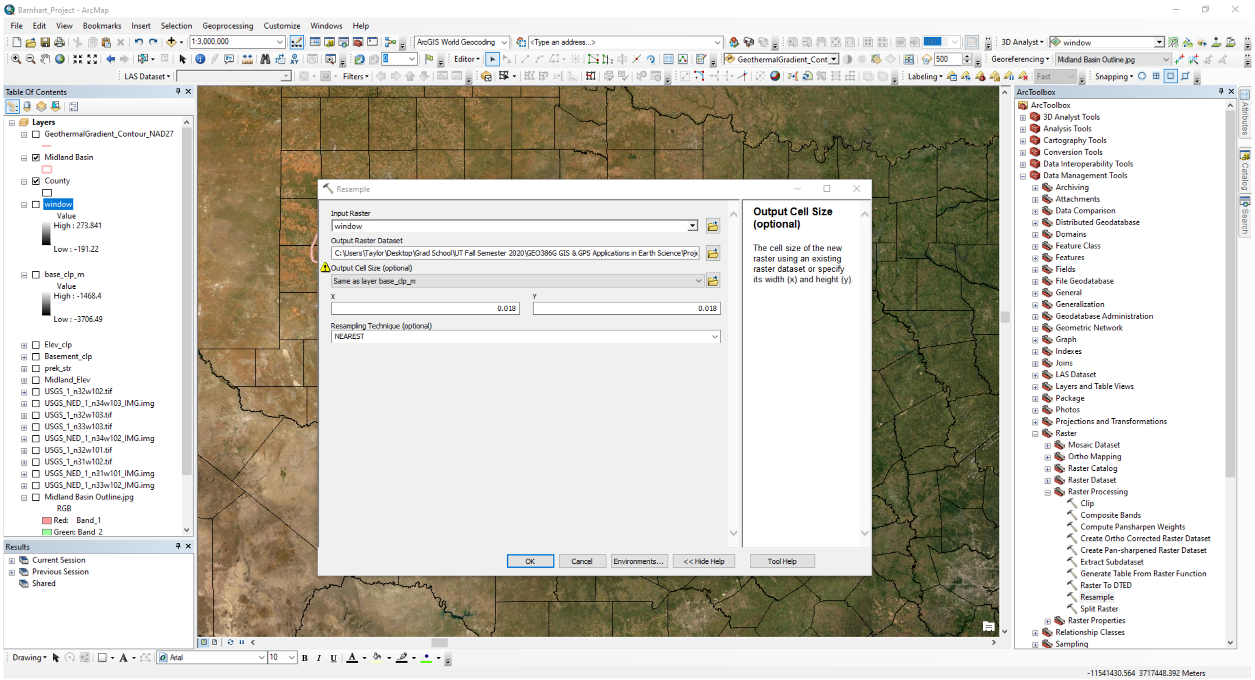

Figure 16: Adjusting the Cell Size of the Precambrian Basement Layer with Resampling

6. Projecting Rasters for the Cut Fill Tool

The goal of this step is to project the rasters into UTM so that the (x,y) units are the same as z (meters) for the “Cut Fill” Tool. In order to use the “Cut Fill” tool in the next step, I used the “Project Raster” tool in “Data Management Tools > Projections and Transformations > Raster > Project Raster,” to project the storage window and base rasters into NAD 1983 HARN UTM Zone 14N (Figure 17).

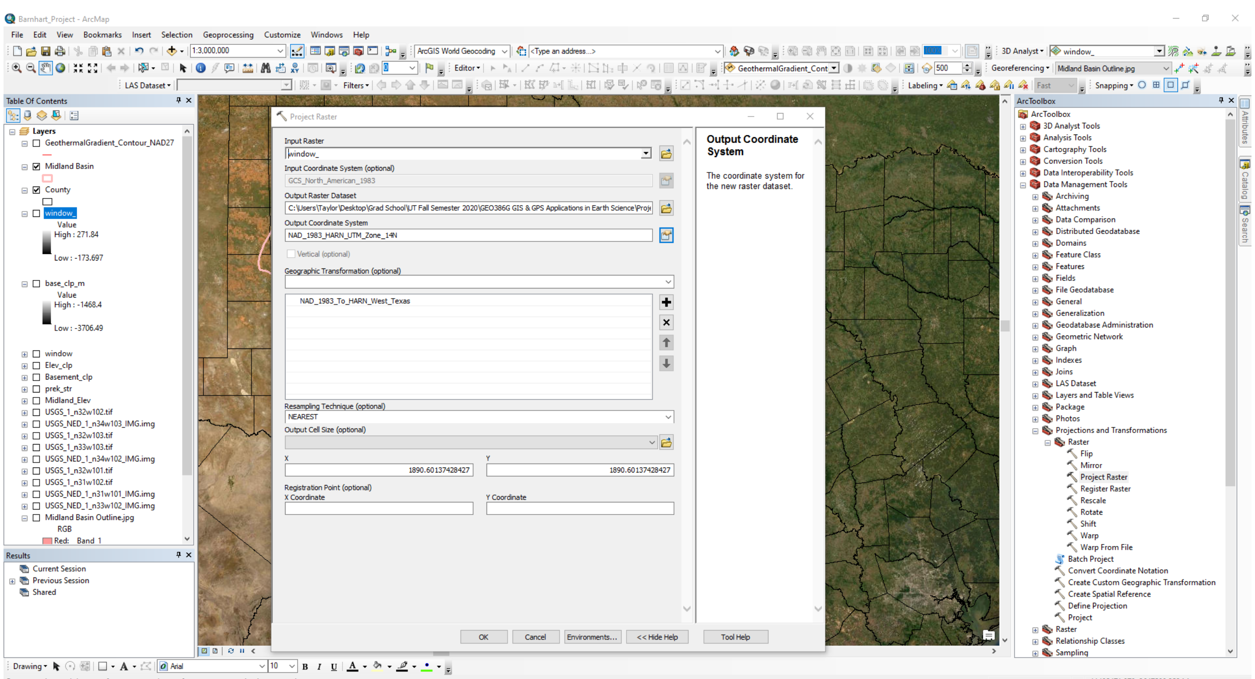

Figure 17: Projecting Each Raster Layer into UTM Coordinates

7. Cut Fill to Determine Storage Volume

I used the “Cut Fill” tool in “3D Analyst Tools > Raster Surface > Cut Fill” to estimate the volume between the top of storage window and the bottom of storage window. Since the UTM coordinates are in units of meters, no Z factor was applied (Figure 18).

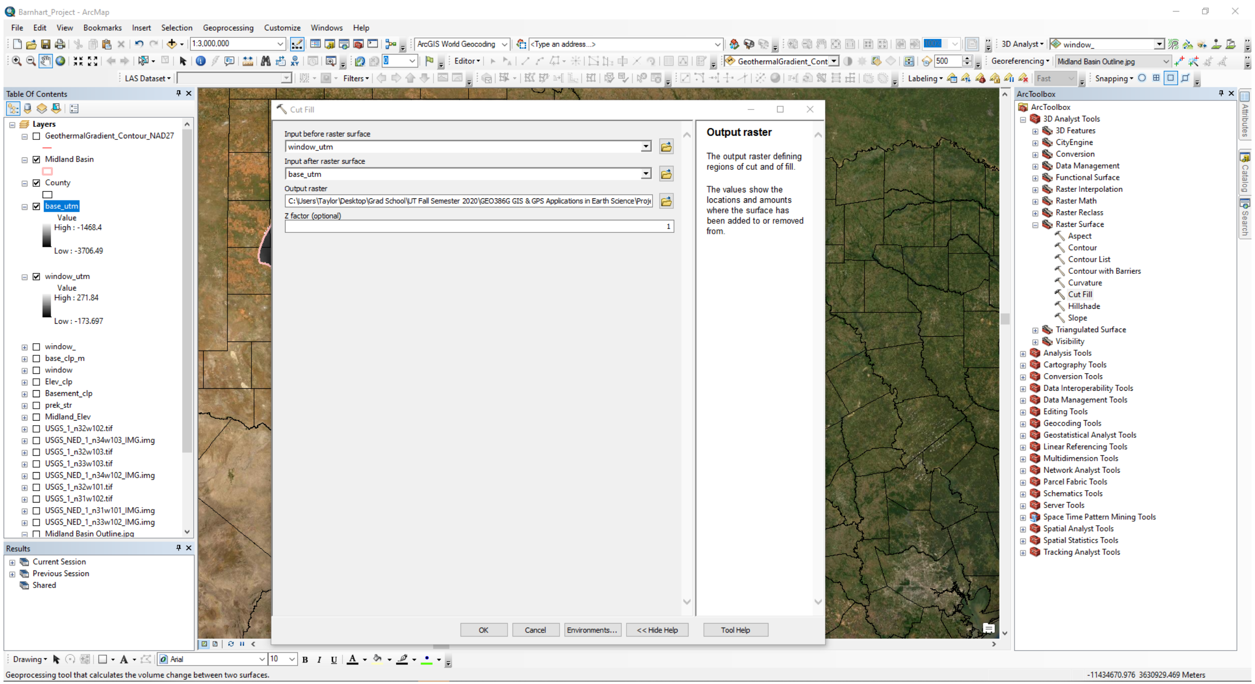

Figure 18: Volume Estimation Using the Cut Fill (With Projection) Tool Set-Up

The resulting layer showed that the volume of storage for CO_2 is a maximum of 98,623,678,886,299.03125 m^3 (Figure 19).

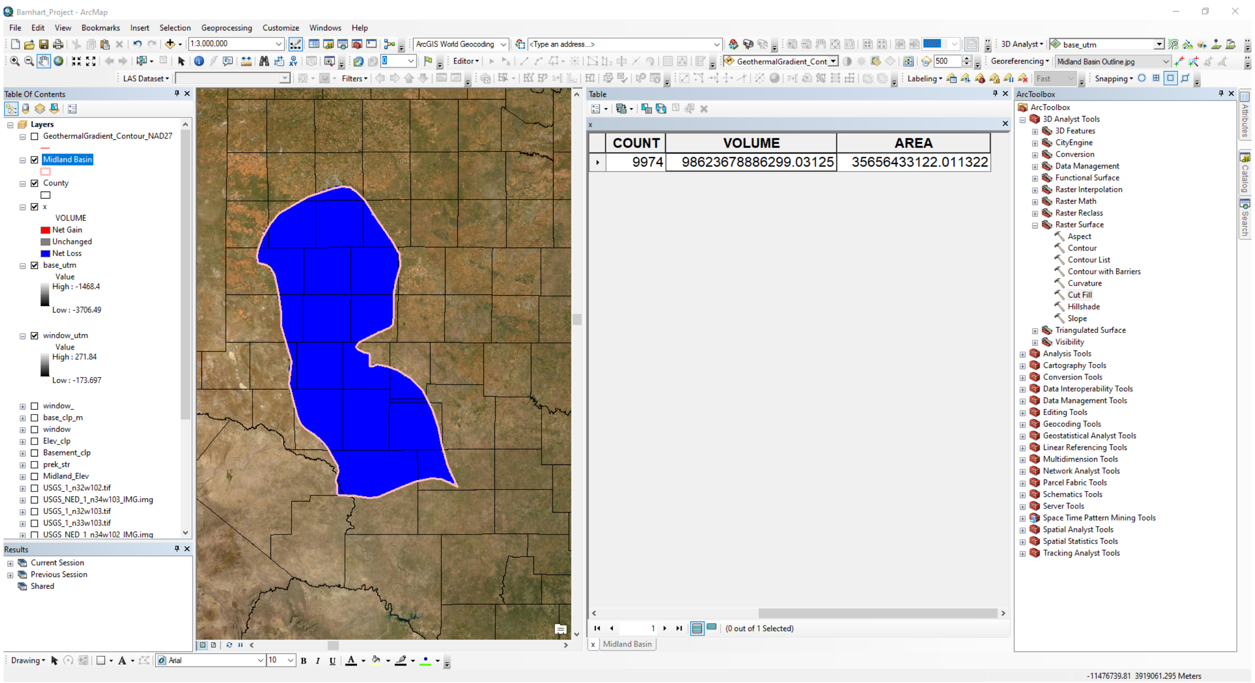

Figure 19: Volume Estimation Using the Cut Fill (With Projection) Tool Results

An alternative way of calculating this volume without projecting the raster layers is to use the Z Factor to convert decimal degrees (DD) to meters (m) (1 DD = 111,000 m) (Figure 20).

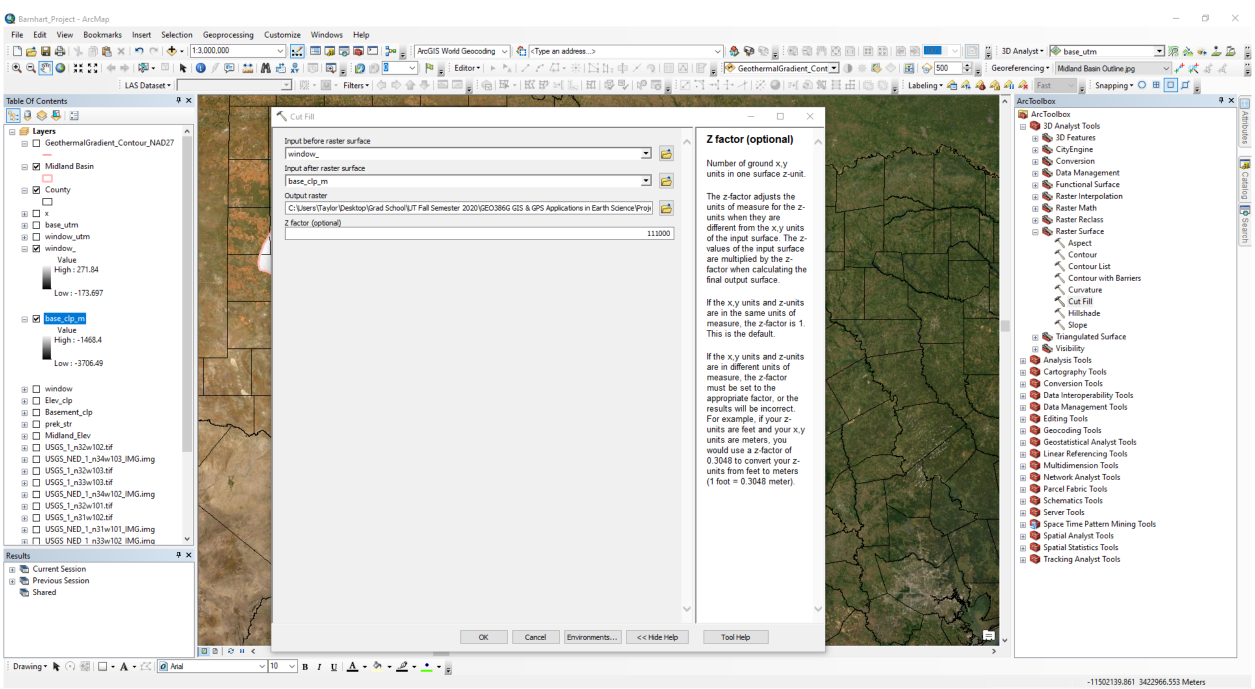

Figure 20: Volume Estimation Using the Cut Fill (With Z Factor) Tool Set-Up

The resulting layer showed that the volume of storage for CO_2 is a maximum of 1,043,052,398.092222 m^3 (Figure 21).

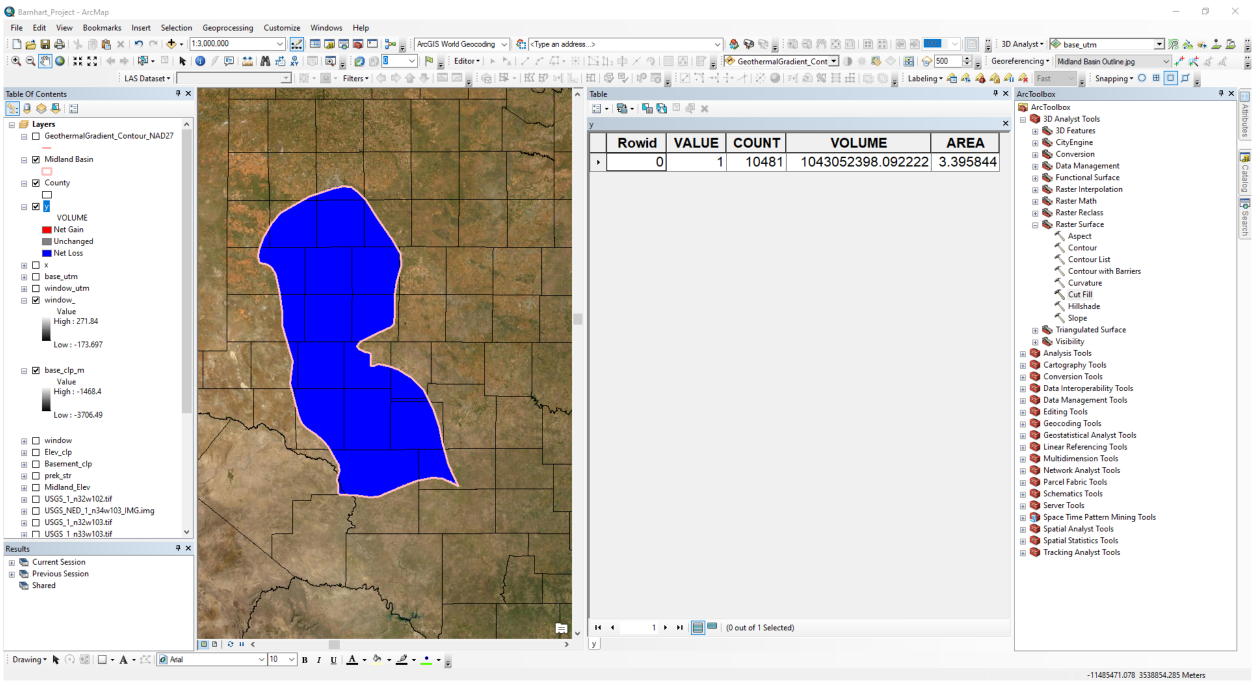

Figure 21: Volume Estimation Using the Cut Fill (With Z Factor) Tool Set-Up

The more accurate result will be with projecting into UTM coordinates, since the conversion from DD to m is a rough approximation, so the volume of maximum storage is 98,623,678,886,299.03125 m^3.

8. Applying an Efficiency Factor

The average porosity of the Wolfcamp Formation in the Midland Basin is 6.0% (U.S. Energy Information Administration, October 2018). This porosity was used to apply a rough efficiency factor to the previously calculated CO_2 storage volume in order to get a more accurate estimation. The following formula was used:

$$S_e = S * e$$

Where S_e is the storage estimate after applying the efficiency factor, S is the original storage estimate, and e is the efficiency factor, which in this case is the porosity of the Wolfcamp Formation.

$$S_e = 98{,}623{,}678{,}886{,}299.03125\ m^3 * 0.06 = 5{,}917{,}420{,}773{,}177.941875\ m^3$$

Data Presentation

The results of this project indicate that there is the potential for $5{,}917{,}420{,}773{,}177.941875\ m^3$ of CO_2 storage within the Midland Basin of the Permian Basin in West Texas, USA. The map (Figure 22) below shows the approximate height of the storage window in the Midland Basin (difference between the top of the CO_2 storage window and the depth to the Precambrian basement).

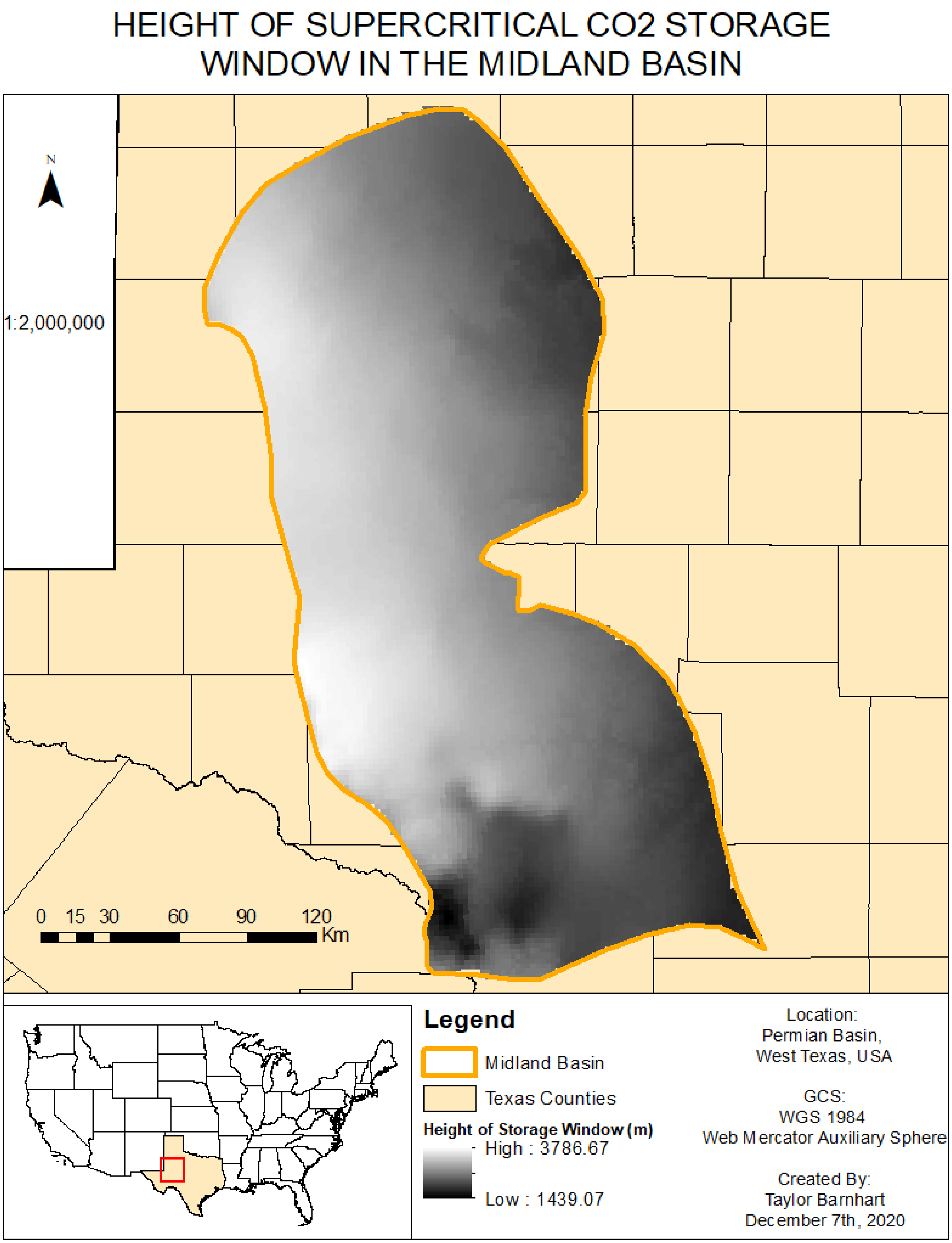

Figure 22: Final Map of Height of Storage Window in the Midland Basin

Discussion

This calculated storage potential volume for CO_2 is realistically an over-estimate for potential storage. This is because I did not include factors, such as permeability, and formation heterogeneity, which will ultimately impact the amount of CO_2 that is able to be stored. The porosity factor applied is generalized for a wide range of stratigraphic facies within the Midland Basin as well. The volume calculated can be further improved with more precise data for each of the pertinent aspects necessary to calculate volume. Including geothermal gradient and potentiometric surface would potentially change this estimated volume, since these factors may influence the supercritical CO_2 storage window top. Further refinement of this storage volume potential could take place by converting this value to tons of supercritical CO_2, but this varies as temperature and pressure vary and would require more in-depth calculations. Higher resolution elevation data as well as higher resolution data for the depth to Precambrian basement would also improve this estimation. This process for estimating volume of storage can and should be further applied to other areas of the Permian Basin, such as the Delaware Basin. This will further expand the estimate for storage potential.

Bibliography

Ruppel, S. C., Jones, R. H., Breton, C. L. & Kane, J. A., 2005. *Preparation of Maps Depicting Geothermal Gradient and Precambrian Strucutre in the Permian Basin,* Austin, TX: Bureau of Economic Geology.

U.S. Energy Information Administration, October 2018. *Permian Basin Wolfcamp Shale Play Geology Review,* https://www.eia.gov/maps/pdf/PermianBasin_Wolfcamp_EIAReport_Oct2018.pdf: s.n.