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Hazard/Risk Assessment of the nitrate contamination in the Seymour aquifer

Introduction and Problem Statement:

The rural agricultural setting of the Rolling Plains in north-central Texas is a major agro-economic region that is strongly dependent on its groundwater resources. Substantial deterioration of the groundwater quality has been observed in the Rolling Plains which overlays the Seymour aquifer. The Seymour aquifer provides water to the Rolling Plains area for domestic, irrigation, livestock and municipality uses. However, irrigation accounts for approximately 90% of the water pumped from wells (Chaudhuri and Ale, 2014). The Seymour aquifer is a shallow unconfined aquifer and is one of the nine major aquifers in Texas. It consists of isolated areas of alluvium that are erosional remnants that were left scattered as discontinuous, physically and hydraulically disconnected clusters or "pods" (USGS, 2009). Concurrently, the groundwater of the Seymour aquifer is under threat of continuous elevated levels of nitrate concentrations which pose a growing health concern. The safe drinking water standard for nitrates set by the Environmental Protection Agency is 10 mg/L. The consumption of high levels of nitrates, specifically by infants less than 6 months of age, can cause methemoglobinemia or "blue baby's syndrome."   Because of health concerns and the prevalent use of groundwater for irrigation, it is critical to understand the dynamics of nitrates and their correlated sources (Chaudhuri and Ale, 2012).

Nitrate levels in groundwater require investigation, as they are a critical issue within the Rolling Plains region of Texas.   Using the ArcGIS software for analyzing, spatially, the components surrounding the nitrate contamination, the purpose of this project is to evaluate correlations between the land cover of cultivated crops, the nitrogen-fertilizer use by county, and the median nitrate levels in the groundwater of the Seymour aquifer by county.

Data Sources:

All of the data collected was able to store the applicable metadata associated with the downloaded files from the internet. The point data, downloaded and imported through Excel and into ArcMap, accompanied the GIS data. See "Data Preprocessing" for more info.

- **National Map Land Cover raster data (Conterminous US):**
  http://www.mrlc.gov/nlcd11_data.php; nlcd_2011_landcover_2011_edition_2014_10_10 is the compressed folder that is downloaded. Extracting the files from the folder allows for adding the raster file that shows the land cover usage in the conterminous United States with a pre-assigned color scheme. Value 82 is assigned to cultivated crops (i.e. agriculture).

- **Texas feature datasets from Lab 2 data**: *Quad75* – a 7.5' quad map extent of Texas

- **Major Aquifers shapefile**: http://www.twdb.texas.gov/mapping/gisdata.asp

- **Texas_counties shapefile from Lab 3 data**: Texas_counties.shp

- **State of Texas Boundary shapefile**: http://www.landsat.com/texas-free-gis-data.html

- **Water Quality report for Seymour Aquifer in regard to NO$_3$ concentrations in wells in the last 10 years**: http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp

- **County-level estimates of Nitrogen from Commercial fertilizer for the Conterminous United States, 1987-2006:** https://catalog.data.gov/dataset/county-level-estimates-of-nitrogen-and-phosphorus-from-commercial-fertilizer-for-the-1987-2006

Data Preprocessing:

One of the first and important steps to consider for this project, in analyzing the Seymour aquifer, is finding data that spatially relate to each other. Since the major components involve land cover usage, nitrate concentration well data, and fertilizer usage by county in the US, there were a few steps that would lead to the culmination of this data working together in ArcMap. The land cover data is sourced from the National Land Cover Database 2011 (NLCD2011) in a raster dataset of the conterminous US. Once the NLCD data is imported into ArcMap (Figure 1), the data needed for Texas only in relation to the land cover data is extracted for later analysis. The "Extract by Mask" tool was used in placing the *Quad75* (a 7.5' quad map extent of Texas) as the mask for the conterminous US land cover raster (Figure 2). The land-cover raster data of Texas is used later in the ArcGIS processing of this project.
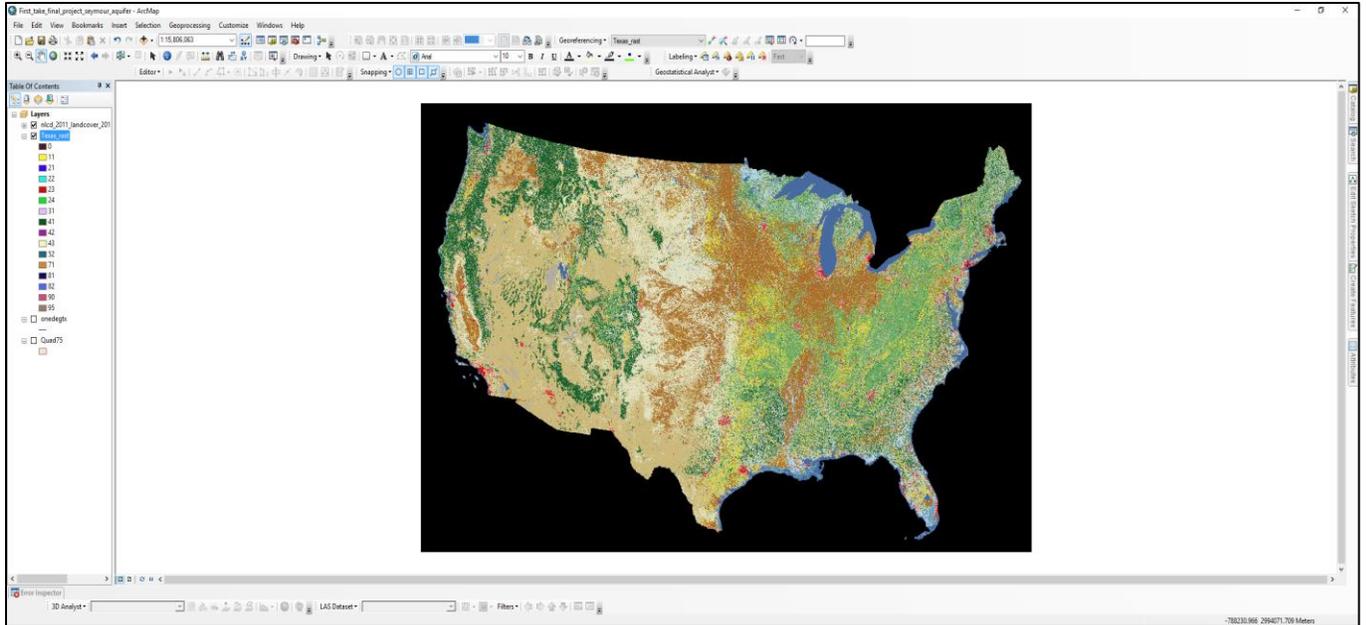
Figure 1. Land cover raster of the conterminous US.
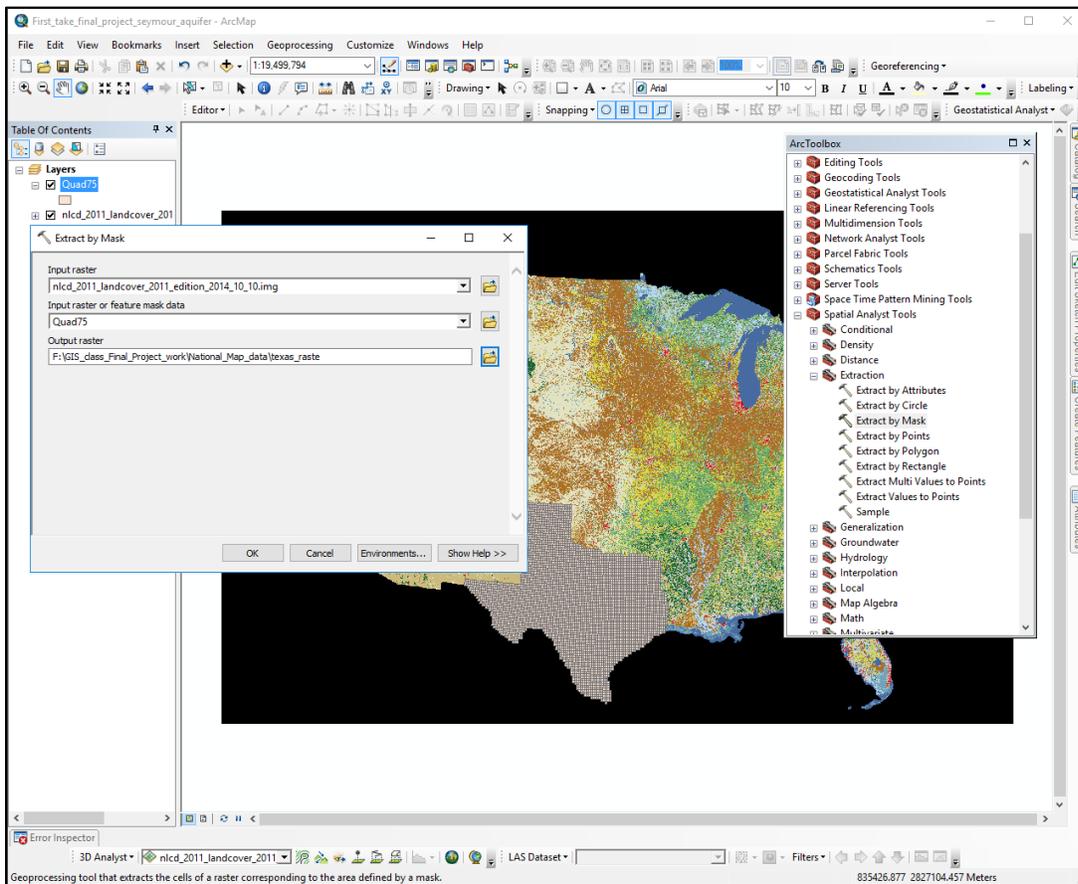
Figure 2. Extract by mask the Texas land cover raster data.

Next, the shapefiles of the Texas counties, the Texas boundary and the major Texas aquifers, imported into ArcGIS, are available for further manipulation and analysis.

The Groundwater Database of the Texas Water Development Board provides water-quality well data by contaminant and by aquifer. After selecting to search for well data by searching through "Water Quality by Aquifer", Figure 3 shows the necessary information needed to search for the nitrate well data in the Seymour aquifer of Texas.

Figure 3. Water quality data showing nitrate-nitrogen (nitrates) concentration levels observed through wells.

To extract the data, click on the "Export Drop Down Menu" and then click on "CSV (comma delimited)" to export to Excel. The latitude and longitude coordinates change to decimal degrees in Excel format. The pertinent information copied and pasted to a new Excel workbook, and subsequently imports into the ArcMap data frame. This information will include: ID number, County, WellDepth, Latitude, Longitude, and ParameterValue (Nitrate concentrations in mg/L) (Figure 4). Importing these nitrate concentrations as point data can now be achieved very easily. Now, click "Add Data" through ArcMap

and browse to the Excel file with the nitrate data for the Seymour aquifer (Figure 5). Right click on the "Nitrate data$" in the table of contents and click "Display XY Data". In the window that pops up, choose Longitude for the X field and Latitude for the Y field. Click OK and continue or accept through the warning message to suggest exporting the data as a shapefile or feature class (Figure 6). Now the point data displays and in the table of contents the layer of "'Nitrate data$' Events" can have its data exported as a feature class. In the "Export Data" window, choose All Features and the data frame's coordinate system and save as a feature class in the pre-made personal geodatabase created in ArcCatalog called "Seymour_aquifer_data.mdb" (Figure 7). The exported feature class can then be added to the data frame's table of contents and now displays in ArcMap as the nitrate point data that is needed for further analysis.

	A	B	C	D	E	F
1	ID	County	Well Depth (ft.)	Latitude	Longitude	Nitrate Contamination (mg/L)
2	1	Baylor	28	33.60833	-99.284167	26.69
3	2	Baylor	28	33.60833	-99.284167	3.71
4	3	Baylor	33	33.60445	-99.281667	38.96
5	4	Collingsworth	95	35.16556	-100.30639	13.72
6	5	Collingsworth	110	35.165	-100.30639	13.28
7	6	Collingsworth	110	35.165	-100.30639	10.4
8	7	Collingsworth	90	35.01111	-100.3775	120.86
9	8	Collingsworth	228	34.92028	-100.51445	12.22
10	9	Collingsworth	90	34.90333	-100.39722	52.68
11	10	Collingsworth	90	34.90333	-100.39722	68.18
12	11	Collingsworth	90	34.90333	-100.39722	37.1
13	12	Collingsworth	110	34.89333	-100.33417	100.94
14	13	Collingsworth	110	34.89333	-100.33417	113.33
15	14	Collingsworth		34.89	-100.28695	32.32
16	15	Collingsworth	120	34.85139	-100.23417	38.65
17	16	Collingsworth	120	34.825	-100.245	22.14
18	17	Collingsworth	55	34.79472	-100.01972	52.24
19	18	Collingsworth	55	34.79472	-100.01972	60.65
20	19	Fisher		32.82472	-100.17222	47.81
21	20	Fisher	55	32.81639	-100.1725	63.75
22	21	Fisher	55	32.81639	-100.1725	58.88
23	22	Foard	36	34.05583	-99.616112	0.89
24	23	Foard	36	34.05583	-99.616112	3.55
25	24	Foard	32	34.05417	-99.575278	11.95
26	25	Foard	32	34.05417	-99.575278	6.68
27	26	Foard	32	34.05417	-99.575278	13.5
28	27	Hall	101	34.70945	-100.72167	37.01
29	28	Hall	101	34.70945	-100.72167	42.94
30	29	Hall	70	34.67389	-100.68111	3.98
31	30	Hall	150	34.67111	-100.7	4.43
32	31	Hall	150	34.67111	-100.7	5.31
33	32	Hall	70	34.54889	-100.46417	17.89
34	33	Hall	75	34.32972	-100.84917	55.34
35	34	Hall	75	34.32972	-100.84917	26.34
36	35	Haskell	80	33.39	-99.728333	49.14
37	36	Haskell	80	33.39	-99.728333	57.99
38	37	Haskell	47	33.37028	-99.914167	50.47
39	38	Haskell	30	33.30556	-99.987778	222.24

Sheet1

Figure 4. Excel workbook format with the pertinent information regarding nitrate concentration data for the Seymour aquifer.
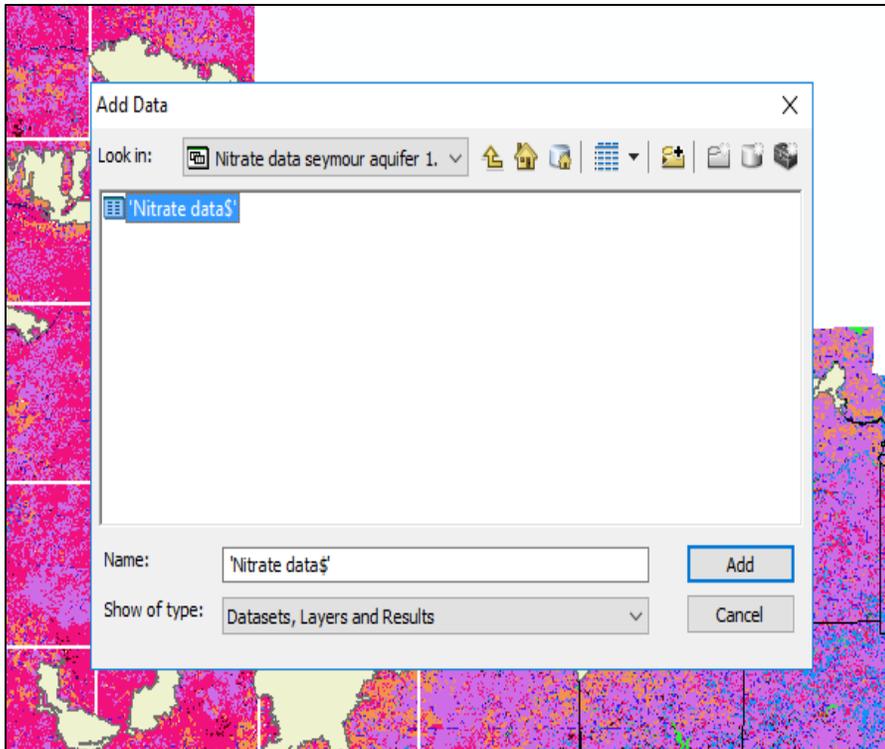
Figure 5. Adding the nitrate data via Excel and ArcMap.
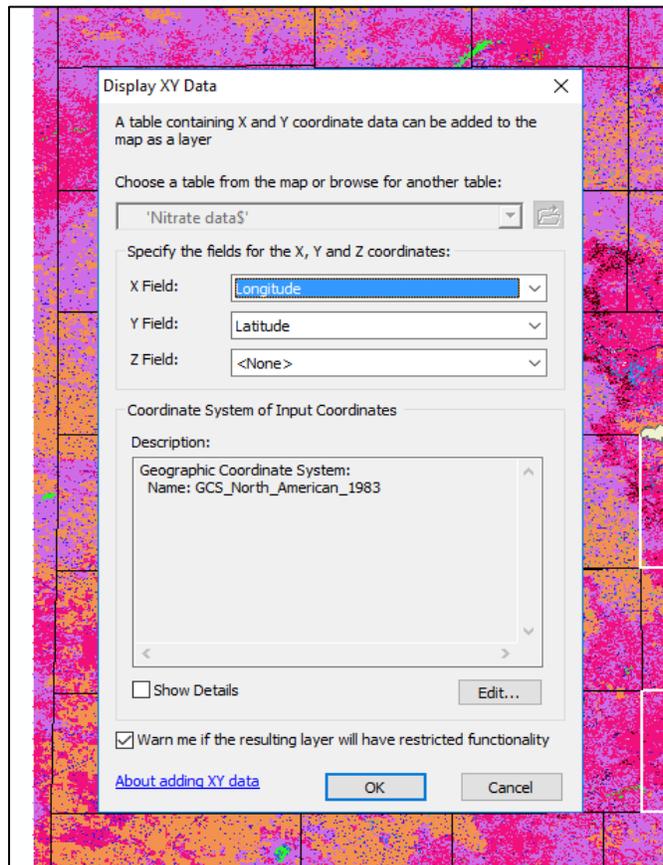
Figure 6. Displaying the XY data of the nitrate concentrations for converting into point data in ArcMap.
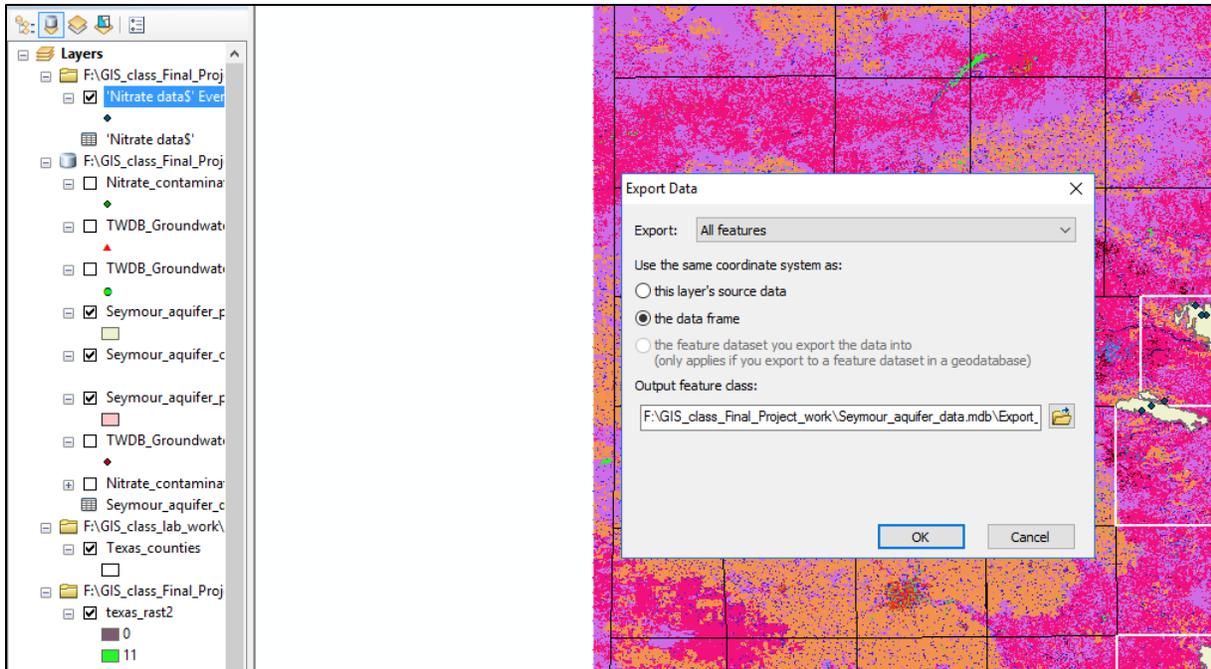
Figure 7. Exporting the point data regarding the nitrate contamination levels into a new feature class for ArcMap compatibility.

The nitrogen-fertilizer dataset can initially be found in the USGS catalog on data.gov in a Microsoft Access file for county-level estimates of nitrogen commercial fertilizers for the conterminous US. After downloading this file and unzipping the folder it is in, then I can access the Microsoft Access document and filter the data in the tables to view the farm and non-farm usage of nitrogen fertilizers in the respective counties of Texas that encompass the Seymour aquifer (Figure 8). This data from 1987-2006 for fertilizer use is broken into three time periods and their respective averages for each county. The 2000-2006 average amount of fertilizer per county is the most reliable as it is the most recent dataset used to correlate the best with the nitrate well data and the cultivated crops land cover in the respective counties. The averages of fertilizer use are used through ArcGIS processing as this data will be joined to the attribute table of the Texas counties that encompass the Seymour aquifer and the nitrate well data to be further analyzed.

	A	B	C	D	E	F	G
1	tblFarmNonfarmCountyNitrogen						
2	FIPS_ST	FIPS_CO	STATE	CO	farmN1987	nonfN1987	farmN
3	48	23	TX	Baylor	2144892	758	249
4	48	87	TX	Collingsworth	1683158	565	202
5	48	151	TX	Fisher	1314166	882	153
6	48	155	TX	Foard	846512	256	97
7	48	191	TX	Hall	998450	662	129
8	48	207	TX	Haskell	2878931	1271	338
9	48	253	TX	Jones	2284991	4151	272
10	48	263	TX	Kent	234813	112	28
11	48	275	TX	Knox	3609023	855	415
12	48	345	TX	Motley	765610	196	90
13	48	433	TX	Stonewall	601833	278	66
14	48	483	TX	Wheeler	1886400	1217	218
15	48	485	TX	Wichita	2117267	58968	267
16	48	487	TX	Wilbarger	3869488	3684	465
17							
18	Average farm N-fertilizer (tons):						
19	Counties	87_93 avg		94_99 avg		00_06 avg	
20	Baylor	2121151.1		2776040.0		1745581.6	
21	Collingsworth	1874532.7		3149573.5		2056249.0	
22	Fisher	1301362.3		1597557.3		1672352.1	
23	Foard	807557.4		1076278.5		1072083.3	
24	Hall	1333374.6		1976529.5		2047410.7	
25	Haskell	2917977.7		3125739.8		4710493.4	
26	Jones	2434447.4		3171223.5		3531817.7	
27	Kent	258439.9		251198.8		217175.0	
28	Knox	3467345.9		4288530.8		3446116.1	
29	Motley	780499.9		896332.3		799717.6	
30	Stonewall	504168.0		457726.8		485542.7	
31	Wheeler	1819880.4		1938389.0		1610382.0	
32	Wichita	2622128.6		2644324.7		2343106.4	
33	Wilbarger	4196188.0		4272611.0		3822347.9	
34							
35							
36							
37							
38							

Texas county data | **Seymour aquifer county data** | Farm averages for county data | (+)

Figure 8. Formatted Excel workbook showing the farm and non-farm fertilizer usage amounts in kilograms, not in tons, for the respective counties relating to the Seymour aquifer. The averaged time periods for farm fertilizer usage can be observed for time groups of 1987-1993, 1994-1999, and 2000-2006.

All of this data imported into ArcMap do not have the same coordinate system that they use to determine geographic location. The "Project Raster" (Figure 9) and "Project" (Figure 10) tools through the Spatial Analyst toolbox are used to project all of the necessary components in the table of contents to the same coordinate system of UTM NAD1983 Zone 14N due to the project location entailing that particular zone of Texas. This allows for all of the data to be compatible with each other correctly in a geographic sense and also in an ArcGIS sense.
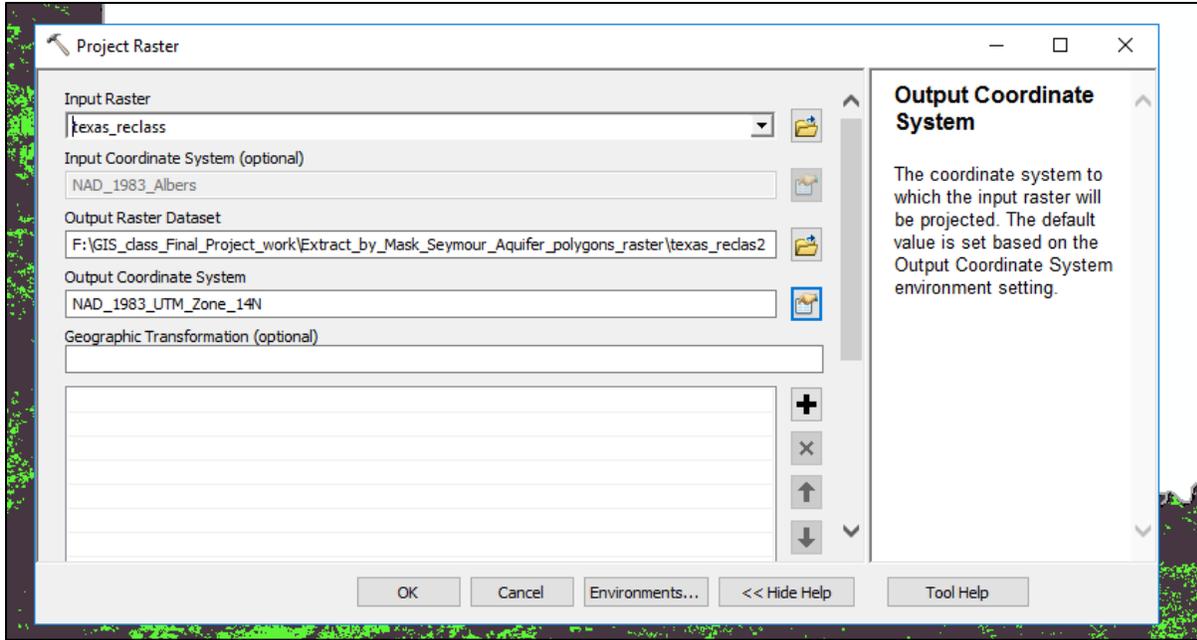
Figure 9. The use of the "Project Raster" tool for the land cover raster of Texas.
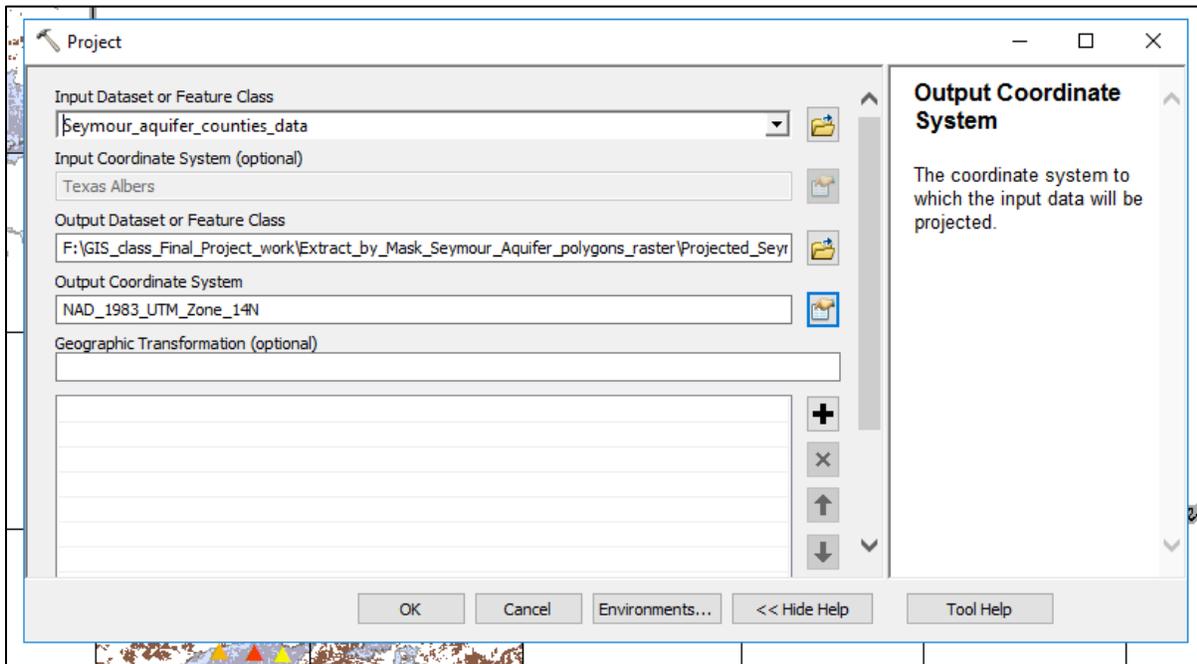
Figure 10. The use of the "Project" tool for projecting the uniform coordinate system to all non-raster files in ArcMap for a more accurate analysis.

ArcGIS Processing:

With all of the necessary data now imported and projected to a uniform coordinate system, UTM NAD1983 Zone 14N, the processing through ArcMap to manipulate the data for analysis of the Seymour aquifer and the respective counties encompassing it can begin. The extracted land cover raster, showing the various land uses in Texas, did not clip evenly to the actual Texas border, but showed areas of "no data" that would need to be taken care of for not only accuracy purposes of the analysis but visual ones as well. The imported Texas boundary shapefile was used as a mask for the Texas land cover raster data. Through the use of the "Extract by Mask" tool, the land cover raster data now fit smoothly to the Texas border and the Texas county lines (Figure 11).
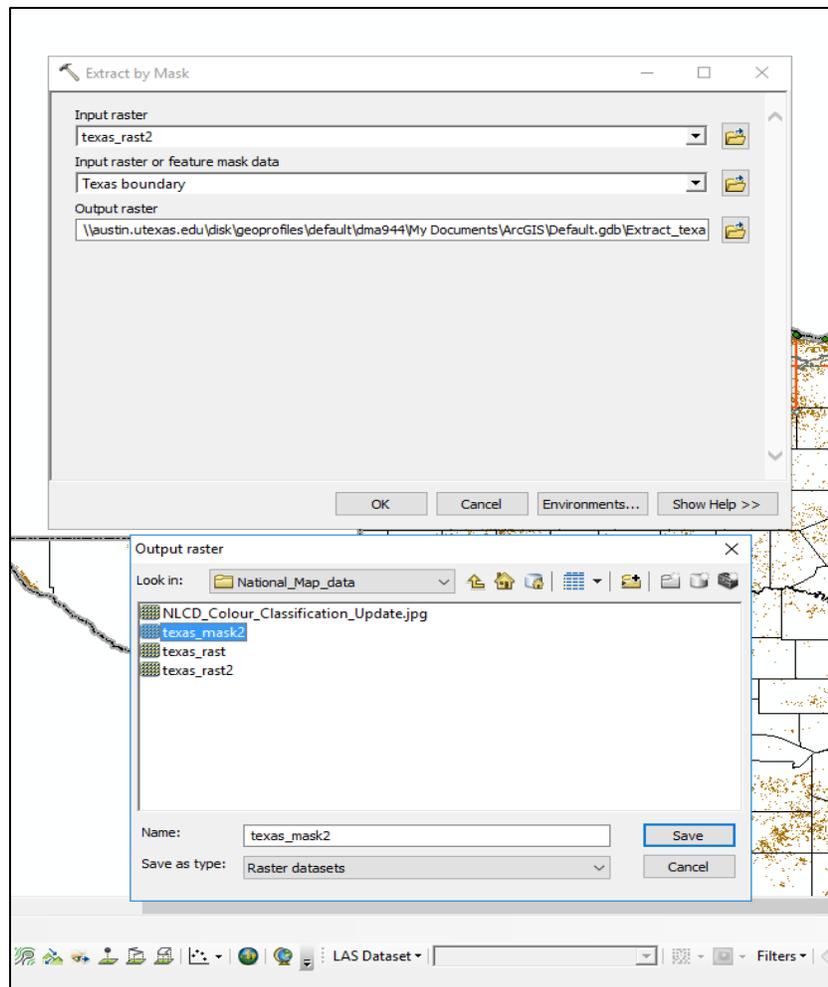
Figure 11. The "Export by Mask" tool used to constrain the funky border of the Texas raster to the Texas boundary itself. The use of the Texas boundary shapefile allowed for this to reach completion.

Next, the raster values used in the Texas land cover data indicating the different types of this land cover in Texas needed to be changed to show just two values. With one representing cultivated crops and the other representing all other land cover data, with the numbers of 1 and 0, respectively, they could be used to analyze more thoroughly the use of this agricultural data over the Seymour aquifer and its respective counties in Texas. This was done by the use of the "Reclassify" tool to assign these new values to the raster data's old values of land cover (Figure 12). Through this process, the data for land cover can now show agricultural usage in brown and everything else in the color white within the Texas boundary. The new, reclassified raster for Texas was then exported as a new raster file called "tex_reclass2" and added back into the table of contents. This new raster data for land cover in Texas is used later in the analysis for the respective counties land use in relation to the nitrate concentration values observed and the amount of nitrogen-fertilizer used per county.
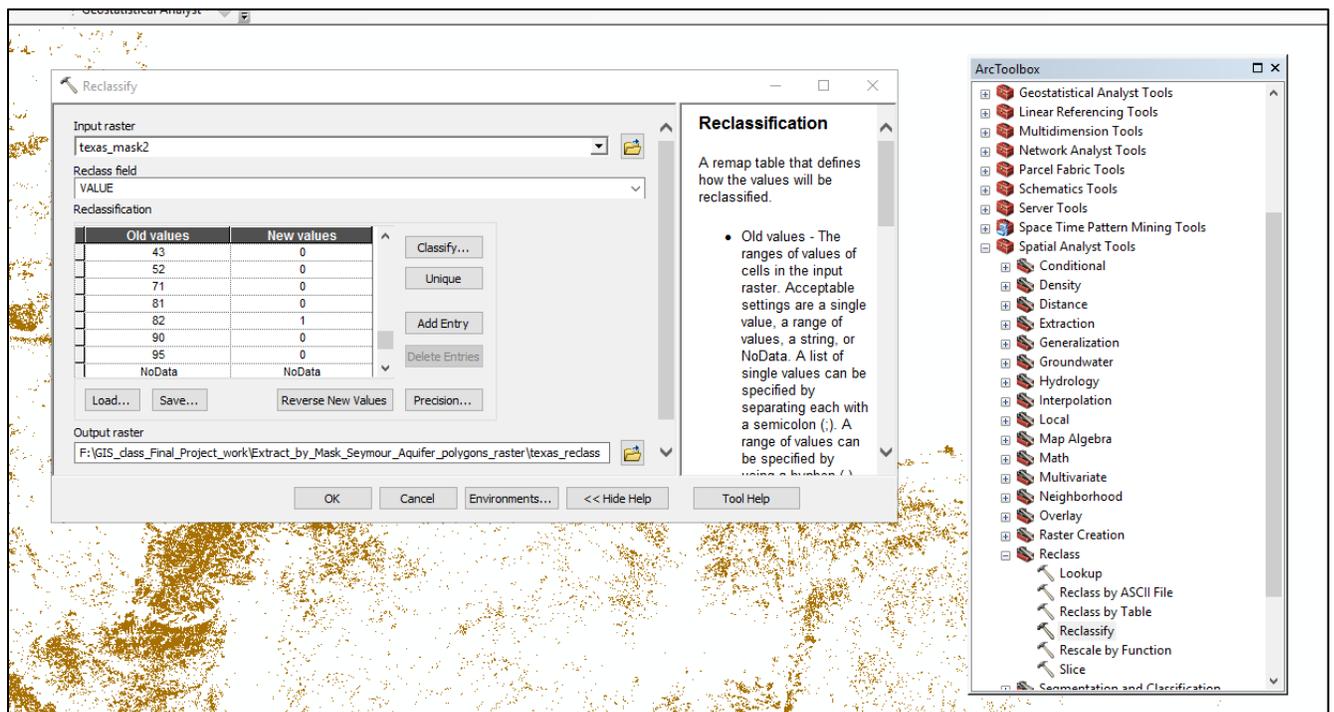
Figure 12. The "Reclassify" tool being used to better represent the land cover data in the Texas raster. The value of 1 represents cultivated crops and the value of 0 represents every other kind of land cover documented in the original raster dataset.

Since the land cover raster for Texas is now reclassified and organized, now the respective counties of Texas and the polygons representing the Seymour aquifer in Texas can be exported and added back into ArcMap as their individual feature classes. This process is fairly straight forward as the major steps in the path to these feature classes is to use "Select by Attributes" and/or "Select by Location" and then exporting these selected attributes as customized feature classes to the ArcMap

document. First, for the counties, using the "Select by Attributes" under the "Selection" tab at the top of ArcMap the specific counties can be selected using the criteria in Figure 13. Now that the counties needed to be analyzed are selected, I just right clicked on the "Texas_counties" shapefile in the table of contents and clicked "Data", then "Export data", and used the projected coordinate system for the source data. It was then added back into the table of contents as "Projected_Seymour_aquifer_counties_data".
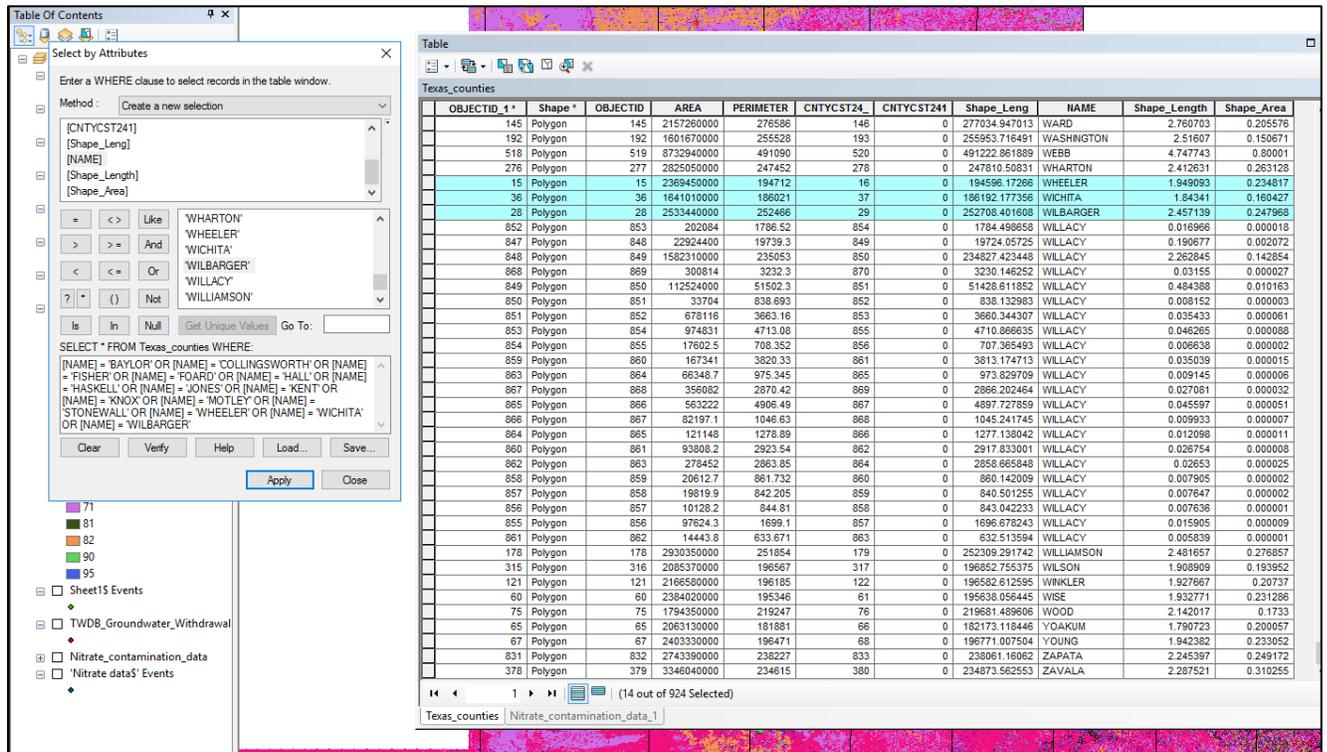
Figure 13. Selecting the correct counties of Texas for the exportation of this data for further analysis.

Second, for the Seymour aquifer polygons, the process is very similar in exporting these polygons as their own feature class. Now, instead, the selection process can be done through the attribute table of the "NEW_major_aquifers_dd" shapefile for the major aquifers of Texas. I right clicked on the shapefile in the table of contents and opened the attribute table and immediately right click on the field of "AQ_NAME" to "Sort Descending" for the purpose of ordering the aquifer polygons more readily for selection. The Seymour aquifer polygons can all be identified and selected (Figure 14). These selected aquifer polygons were then exported the same way as the "Texas_counties" but now named "Seymour_aquifer" in the table of contents.

Figure 14. Selecting the correct aquifer polygons that relate to the Seymour aquifer.

After organizing the Texas raster data for land cover, the respective Texas counties, and the specific polygons for the Seymour aquifer in ArcMap, now the nitrate concentration point data can be manipulated for further analysis. The point data was broken up into two categories of points in separate feature classes as safe and hazardous nitrate concentration data. The boundary condition for this point data is the maximum contaminant level (MCL) of 10 mg/L. The initial feature class of point data, "Nitrate_contamination_data_1" in the table of contents, was imported via Excel in Figure 4. Now, the interval of this data can be changed to that of 10 to signify the change in the concentration conditions from safe to hazardous. This was done by opening the properties of this file through the table of contents in ArcMap. I clicked on the "Symbology" tab and clicked on the "Quantities" section to give graduated colors to these values. To set this defined interval, through the "Classify" button, set the "Classification Method" to "Defined Interval" and the interval size being to 10 (Figure 15). This changes the range of groups that the nitrate concentration is represented by in the view of ArcMap. Next, through the process of exporting selected data, the nitrate values that are less than 10 mg/L were selected and exported as "Safe_nitrate_concentrations" to be a feature class with nitrate concentration

point data set at an interval of 10. However, the nitrate values equal to or above this boundary condition will have a defined interval of 50 due to the range of data observed in the Seymour aquifer. The process was the same when exporting this data set and setting this interval. This allowed for better representation of the nitrate data for visual purposes in the analysis. Now, there are two separate feature classes with nitrate concentration point data that differentiate safe and hazardous conditions of nitrates being observed in the Seymour aquifer within the respective counties.
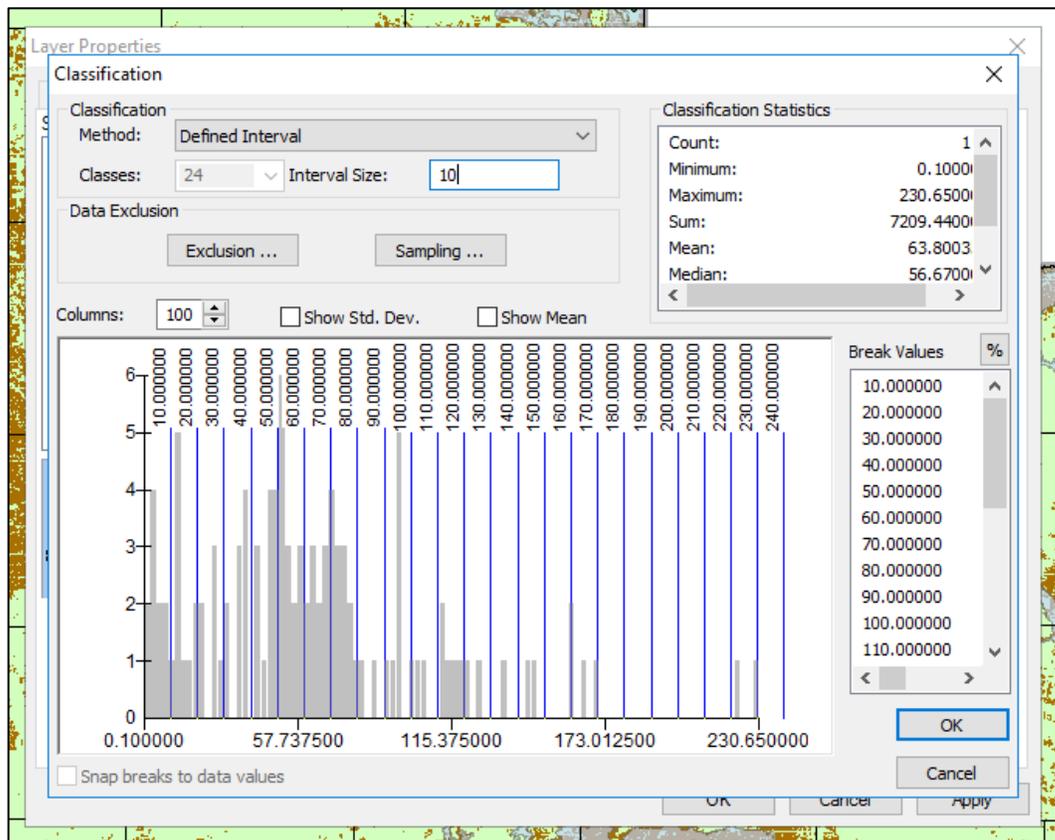
Figure 15. An example of setting the defined interval for the representation of the nitrate data in the table of contents and in the data view of ArcMap.

The next major step was now to join the data showing fertilizer usage, in kilograms, by county to each of the respective selected counties. By copy and pasting the information including the counties and the average amounts of nitrogen-fertilizers used on farms in the three specified time groups into a new Excel workbook, this data could be joined to the counties attribute table in ArcMap. Although, first I had to set-up the Excel table in the correct format. The cells with textual information were classified as text cells and those with numerical information were classified as being numeric (Figure 16). A very important step in finishing formatting the table in Excel was to capitalize the names of the counties to

match the format of the counties names in the counties attribute table in ArcMap (Figure 16). After this was done, then the Excel file was saved as a text file to be joined as such in ArcMap.

	A	B	C	D
1	Counties	87_93 avg	94_99 avg	00_06 avg
2	BAYLOR	2121151.14	2776040.00	1745581.57
3	COLLINGSWORTH	1874532.71	3149573.50	2056249.00
4	FISHER	1301362.29	1597557.33	1672352.14
5	FOARD	807557.43	1076278.50	1072083.29
6	HALL	1333374.57	1976529.50	2047410.71
7	HASKELL	2917977.71	3125739.83	4710493.43
8	JONES	2434447.43	3171223.50	3531817.71
9	KENT	258439.86	251198.83	217175.00
10	KNOX	3467345.86	4288530.83	3446116.14
11	MOTLEY	780499.86	896332.33	799717.57
12	STONEWALL	504168.00	457726.83	485542.71
13	WHEELER	1819880.43	1938389.00	1610382.00
14	WICHITA	2622128.57	2644324.67	2343106.43
15	WILBARGER	4196188.00	4272611.00	3822347.86
16				

Figure 16. The correctly formatted Excel workbook for the farm use of nitrogen-fertilizers. The cells containing text and numerical values were formatted as such and the use of capitalized county names needed for further importing into ArcMap.

By right clicking on "Projected_Seymour_aquifer_counties_data" in the table of contents and going through "Joins and Relates" to "Join…", the textfile of the fertilizer usage information could be imported to ArcMap. The necessary information needed for correctly joining this table to the counties feature class is seen in Figure 17, but the file selected to join in section 2 was not a CSV (comma-separated values) and instead was a textfile. Figure 18 shows the correct result through this joining process of importing this average fertilizer use to these specified counties. As it can be seen, the counties names match up in capitalization and order according to the fertilizer values assigned to these counties over the Seymour aquifer.
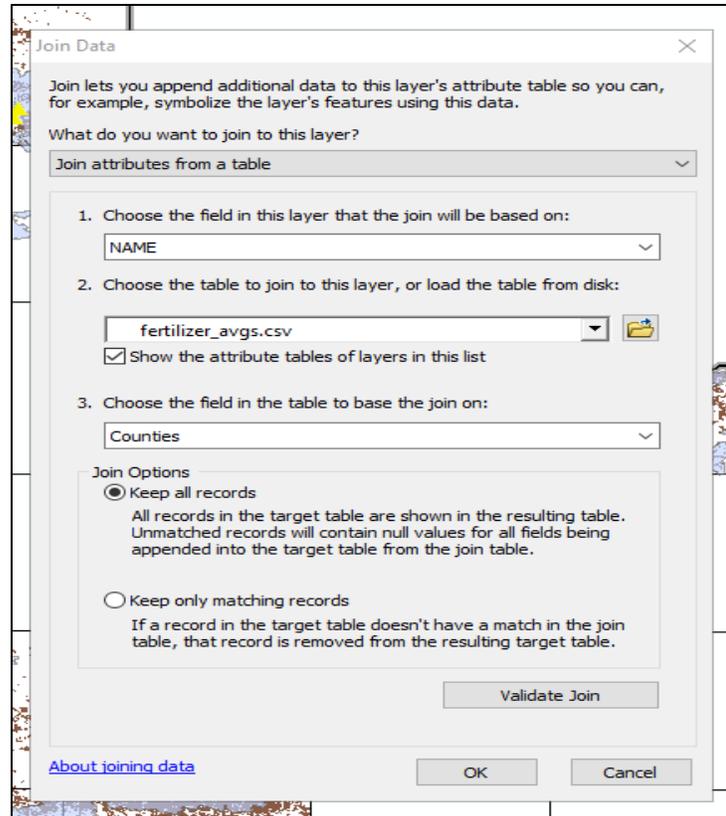
Figure 17. Joining the fertilizer usage data to the respective Texas counties, but as a textfile and not as a CSV file.

Figure 18. The representative result of joining the fertilizer usage table of data to the Texas counties feature class.

Now, the entire feature class of the "Projected_Seymour_aquifer_counties_data" can be exported as another feature class called "Fertilizer usage (kg)". The difference in the two feature classes is their symbology by how and what they are symbolizing in ArcMap with the other data sets. By opening the "Symbology" tab through the properties button of the "Fertilizer usage (kg)" feature class, the color scheme is organized to show a varying hazard level from green to yellow to red. This was done under the "Quantities" section, and then the "Graduated colors" subsection is selected. The necessary field to

show is the 2000-2006 average nitrogen-fertilizer since this will show a better representation of the correlation of data with the nitrate concentration data within the last 10 years and the land cover raster of agricultural coverage in Texas (Figure 19).
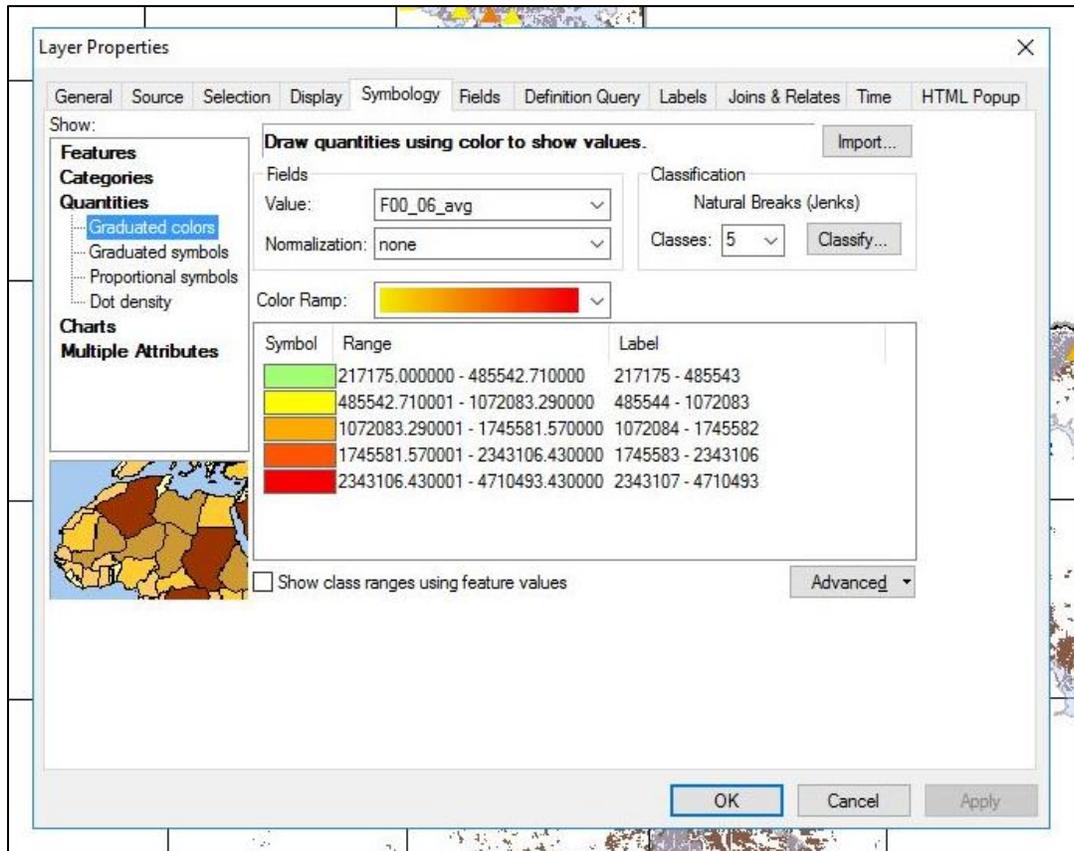
Figure 19. The correct path and necessary inputs to establish the color scheme observed for the fertilizer usage feature class.

The last important step in processing the data through ArcMap is extracting the data for agricultural coverage from the Texas land cover raster in the respective counties that are over the Seymour aquifer. This was completed with the "Extract by Mask" tool in the Spatial Analyst toolbox (Figure 20). All of the respective counties land-cover usage data was extracted so that the entire extent of agricultural coverage could be taken into account. By using the "tex_reclass2" raster as the imported file and the "Projected_Seymour_aquifer_counties_data" as the mask, the land cover data in the new raster file, named "county_aguse", is constrained to just the specified counties in the mentioned feature class. Now, the individual counties themselves would have their land cover data extracted as well, but from the "county_aguse" raster data (Figure 20). With all of the counties individual information for agricultural coverage, the areas of extent determined by cell value in the rasters can show the how much and the where of the major agricultural leaders over the Seymour aquifer.
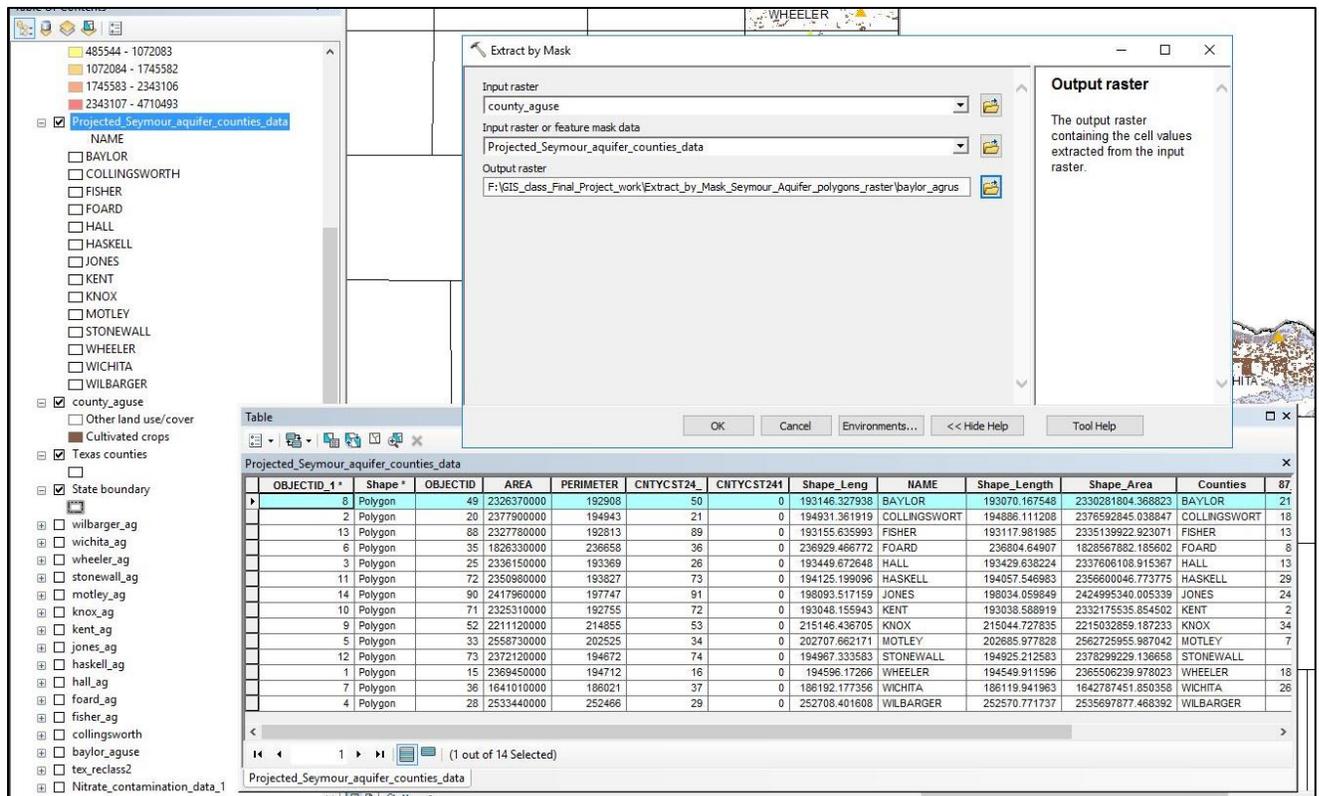
Figure 20. The use of the "Export by Mask" tool to individually, and all together, represent the land cover raster data for the respective counties of Texas over the Seymour aquifer.

Calculating the areas and percentages of these areas of agricultural and nonagricultural land cover was done through the attribute tables of the individual county raster files in the table of contents through ArcMap. I, first, opened up the attribute table of the "county_aguse" and then by clicking on the top left drop-down menu arrow of the attribute table, a new field of the table can be added. Figure 21 shows the necessary information needed for further calculating the areas of these rasters via the field calculator later in the analysis. The area units are set to square kilometers since these values in square meters would require more data to process and it would be visually distracting in the attribute table itself. As was done in Figure 21, the necessary information for the newly created percentage field is illustrated in Figure 22. Setting the value to being of "Float" allows there to be numerical values after the decimal place, which is not needed for the values of area calculated when it is on the scale of square kilometers. The values for the percentages of these areas, however, can show precision in just how much of the land is used for agriculture and how much is not over the Seymour aquifer.
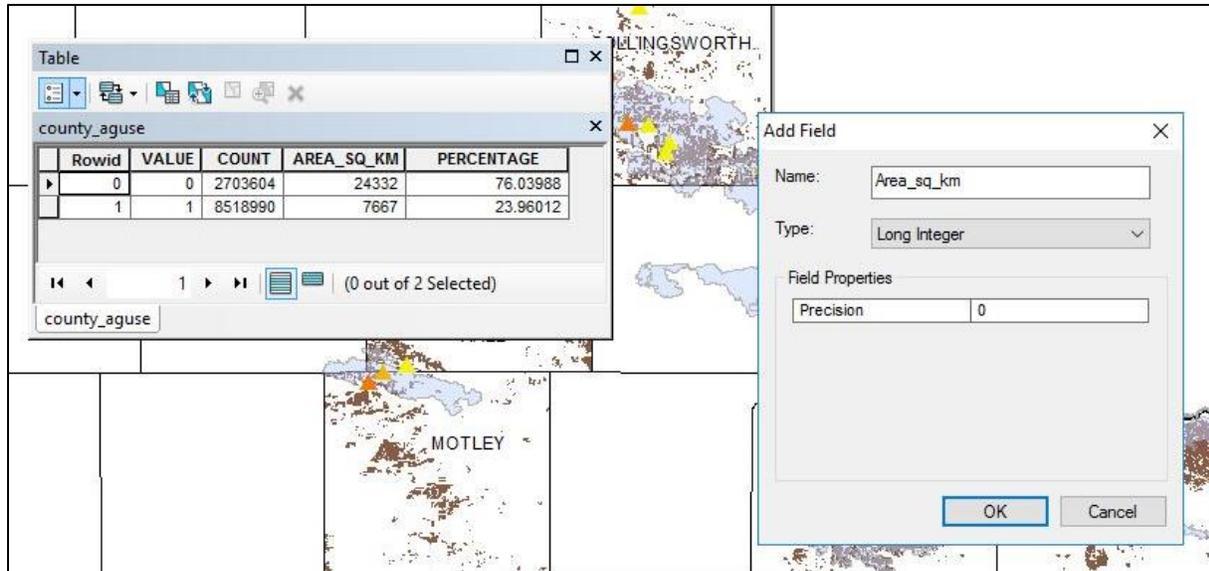
Figure 21. The process of adding the new field for representing the areas in square kilometers of the land cover raster data in the respective Seymour aquifer counties of Texas.
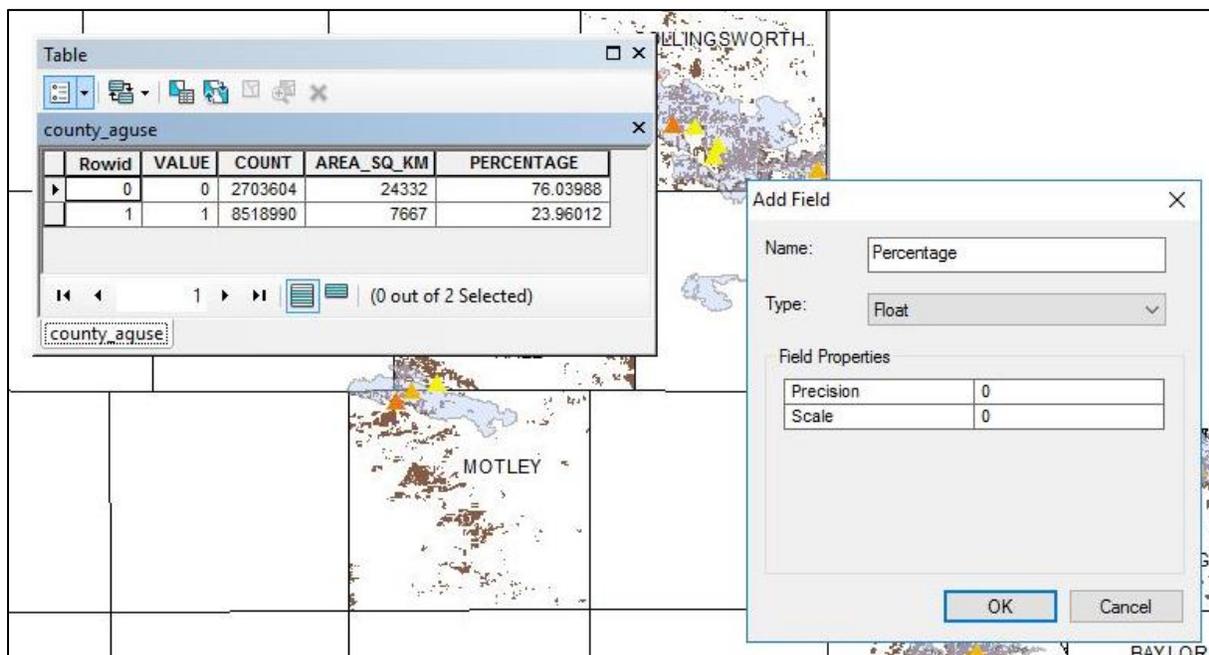
Figure 22. The process of adding the new field for representing the percentages of the land cover raster data in the respective Seymour aquifer counties of Texas.

Now, these values of areas and percentages were calculated. By right clicking on the "Area" or "Percentage" fields, the "Field Calculator" was utilized and thus the calculations for these fields accomplished. The conversion for calculating these areas in square kilometers would have to come from how much area a single cell in the raster takes up according to the cell size. This cell size is 30x30, so the area for one cell would be 900 m^2 and the equivalent value for that in square kilometers is 0.0009 km^2.

Through the use of this value the "COUNT" numbers for how many cells representing agricultural coverage were converted to areas (Figure 23). The percentages of these areas, calculated using the field calculator, were completed using the concept seen in Figure 24 for all of the individual counties and their agricultural coverage extent.
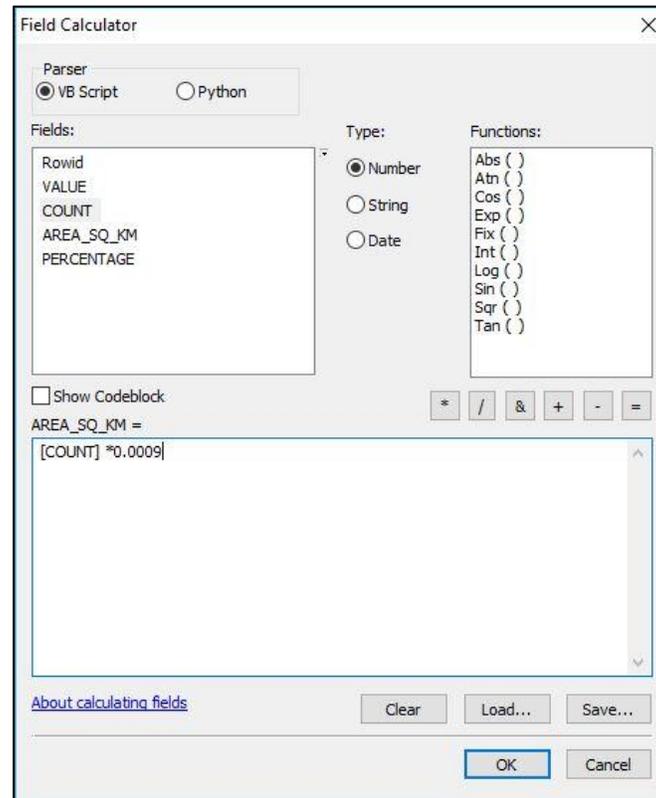
Figure 23. The conversion of the "COUNT" number of raster cells into area amounts in square kilometers via the use of the "Field Calculator".
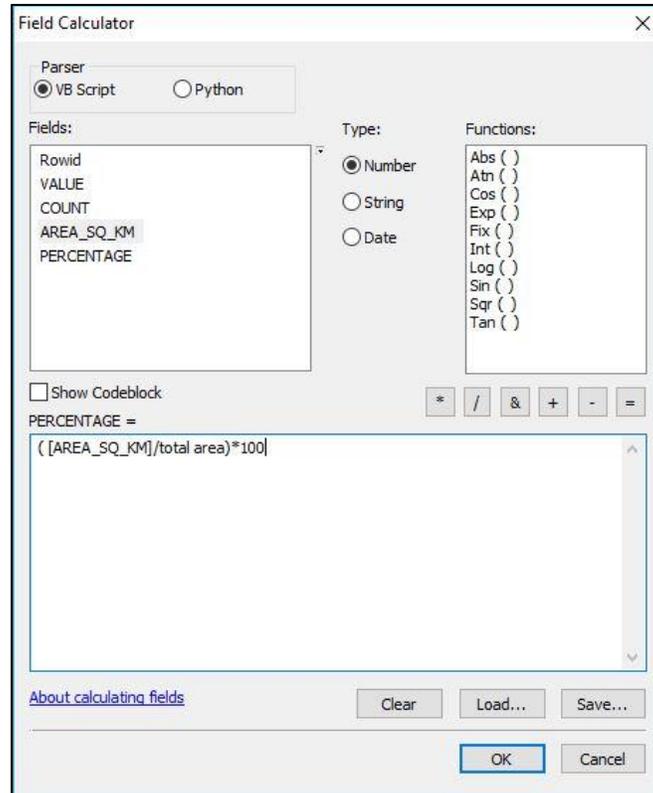
Figure 24. The conversion of the "AREA_SQ_KM" amounts into percentages for the land cover raster data in the respective Texas counties.

The important correlations of the various components of this analysis are seen through Figures 25 and 26. This progression of the different pieces of data being added to the field of view in ArcMap really shows how powerful this software can be through spatial analysis. In the "Data Presentation" section the final data table and map showing these final correlations and calculations can be observed. It is through this process that I have drawn conclusions from the analysis of these datasets regarding the hazards of nitrate contamination in the Seymour aquifer in relation to agriculture.
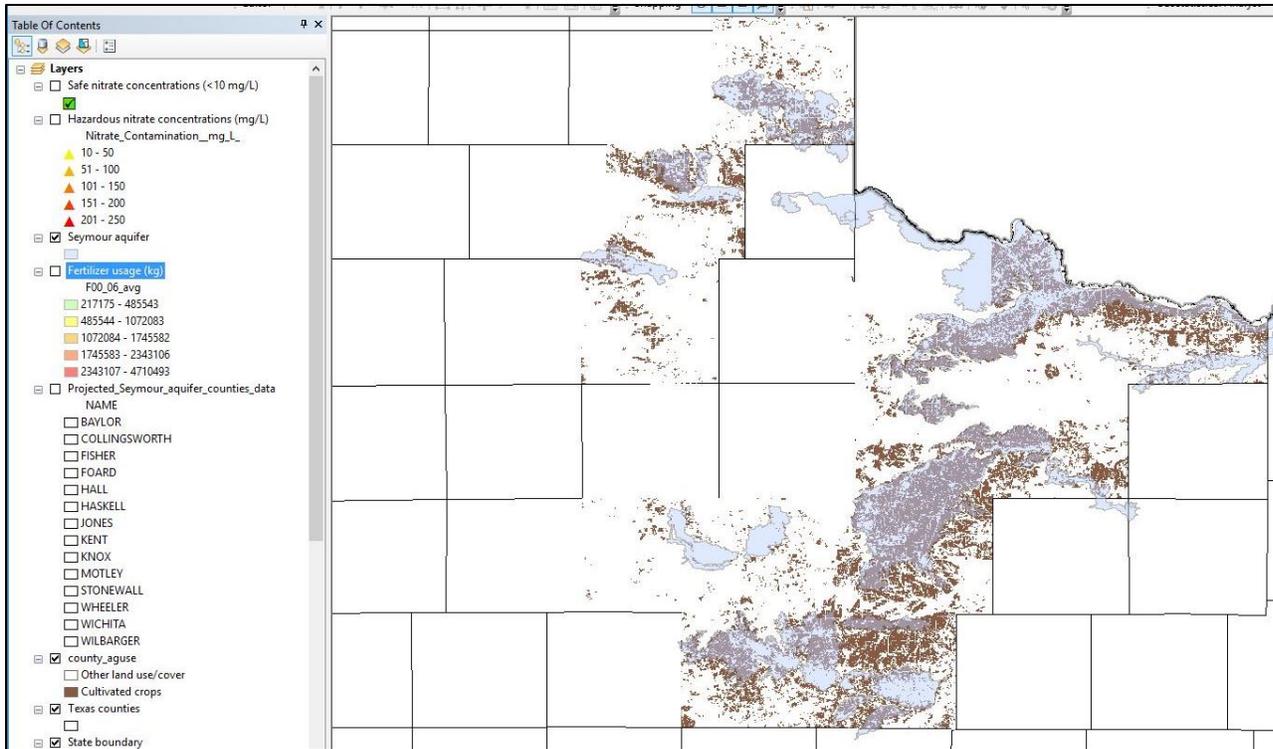
Figure 25. A snapshot showing the correlation of the Seymour aquifer polygons to the agricultural usage observed in the respective Texas counties.
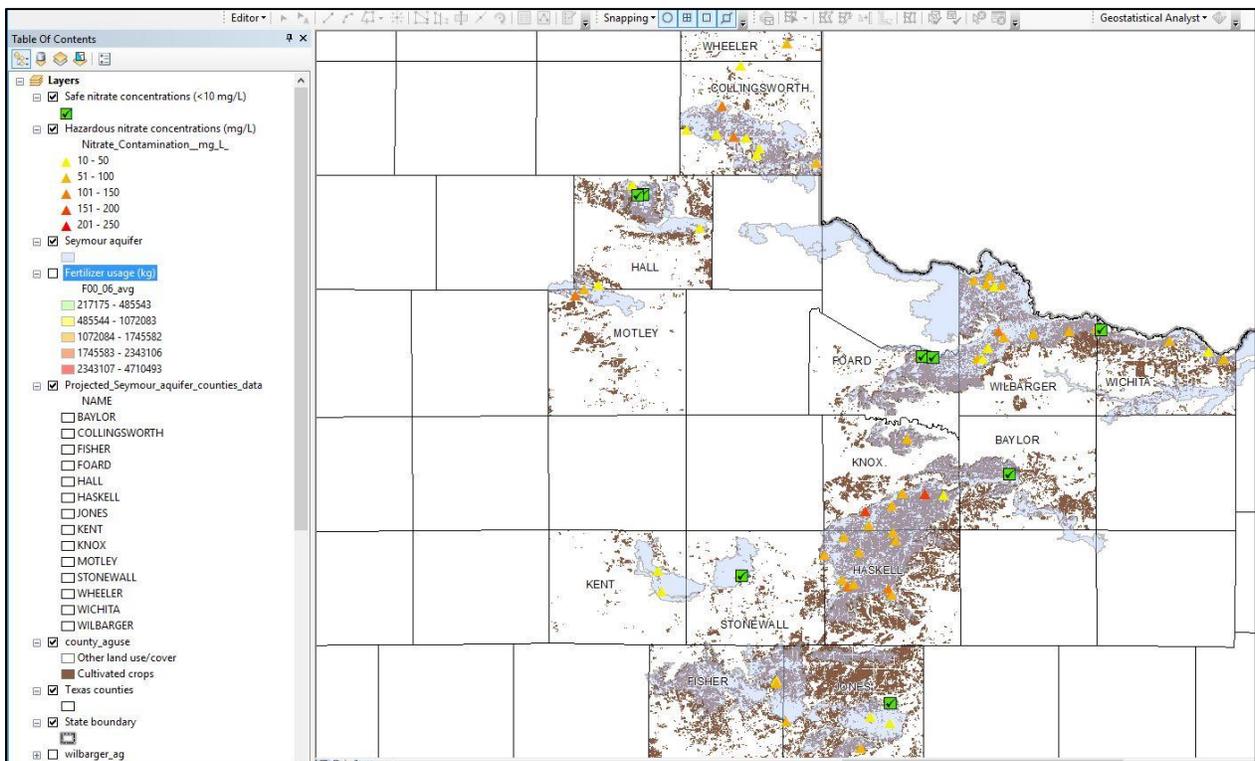
Figure 26. A snapshot showing a further correlation of the components shown in Figure 25, but with the addition of nitrate concentration data.

Data Presentation:

Table 1: Data showing the general relationship between N-fertilizer usage, the area of cultivated crops, and the average nitrate concentrations that are observed by county over the Seymour aquifer

County	N-fertilizer usage (kg)	Area of cultivated crops usage (km^2)	Area of cultivated crops usage (%)	Amount of fertilizer (kg)/Area of cultivated crops (km^2)	Average Nitrate (NO$_3^-$) concentration (mg/L) in the Seymour aquifer
BAYLOR	1,745,582	528	23	3,306	23.12
COLLINGSWORTH	2,056,249	450	19	4,569	49.91
FISHER	1,672,352	695	30	2,406	56.81
FOARD	1,072,083	370	21	2,898	7.31
HALL	2,047,411	538	23	3,806	24.16
HASKELL	4,710,493	1,154	49	4,082	90.75
JONES	3,531,818	1,129	47	3,128	40.34
KENT	217,175	78	4	2,784	27.61
KNOX	3,446,116	792	36	4,351	99.52
MOTLEY	799,718	209	8	3,826	124.1
STONEWALL	485,543	218	9	2,227	8.85
WHEELER	1,610,382	182	8	8,848	53.12
WICHITA	2,343,106	506	31	4,631	54.92
WILBARGER	3,822,348	817	33	4,679	68.07
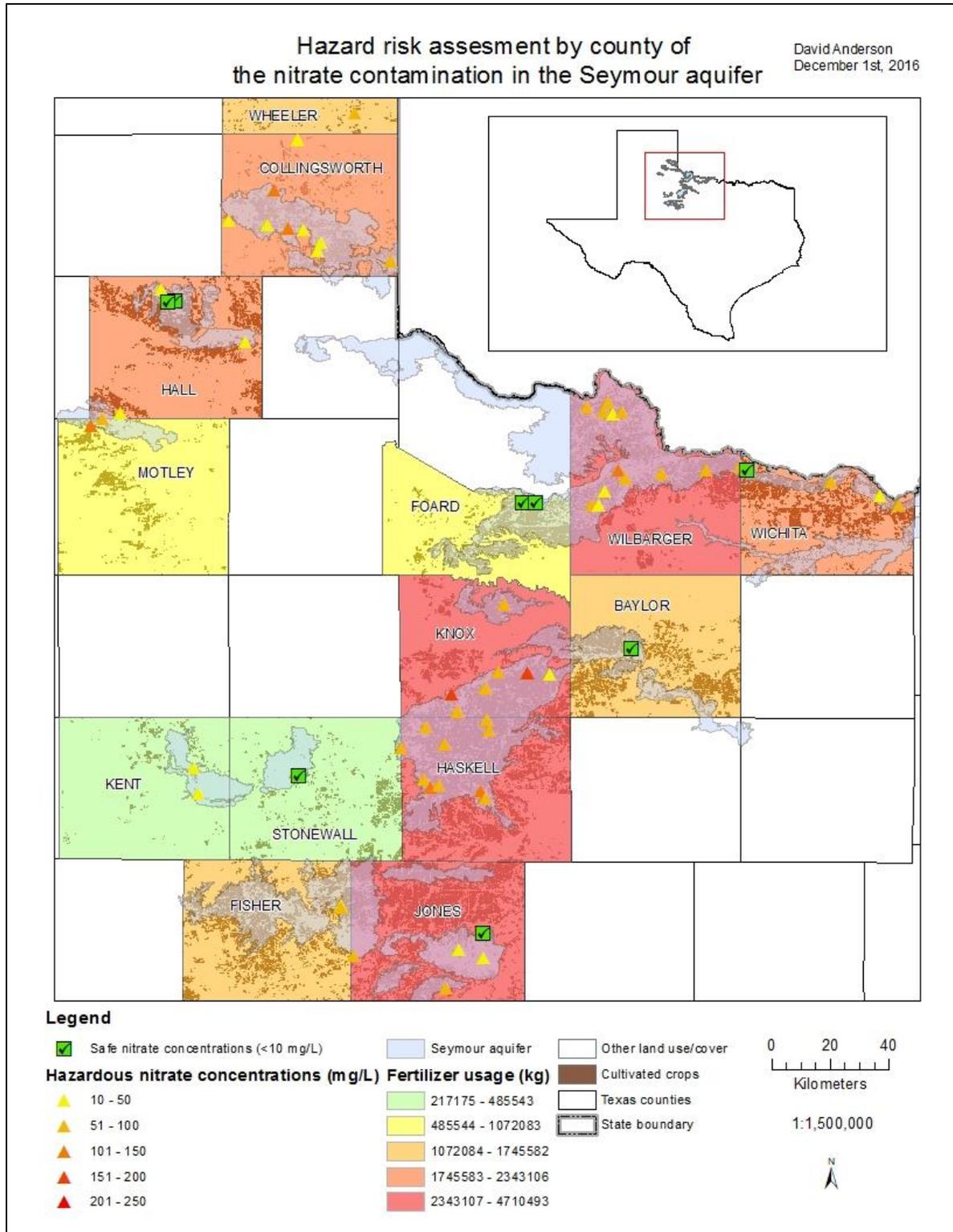
Figure 27: Final hazard/risk map showing correlations between fertilizer usage, the extent of the cultivated crops area, and nitrate concentrations in the Seymour aquifer in the respective counties in Texas.

Results :

By creating a hazard-risk map using ArcGIS, the land use cover of the Seymour aquifer area in the Rolling Plains of Texas was examined in relation to the quantity of fertilizer application and the resulting nitrate concentrations in the groundwater.   According to the project data, approximately 85% of the sampled wells had nitrate concentrations greater than the MCL limit of 10 mg/L of nitrate-nitrogen (nitrates). This result corresponds well with the decadal study of Chaudhuri and Ale (2014) where 82% of the observations of nitrate concentrations exceeded the MCL in irrigated agricultural lands in the 2000s (Chaudhuri and Ale, 2014).

According to Chaudhuri and Ale (2012), a rule of thumb when evaluating nitrate concentrations is that, counties with greater than 25% cropland will generally have concentrations greater than MCL levels.   In reviewing the calculated cropland percentages in Table 1, 6 of the 14 counties have percentages ranging from 30% to 49% cropland and the nitrate concentrations exceed the MCL. The cropland percentages and the exceedance of the MCL levels of the six counties are corroborated by the data from the 2007 USDA Census of Agriculture (USDA, 2007). Two counties, Foard and Stonewall, reflect low cropland and low nitrate levels of below 10 mg/L. Three counties, Kent, Hall and Baylor, had less than 25% cropland and hovered around 25 mg/L nitrate levels.   The outliers, Motley, Collingsworth and Wheeler have low cropland percentages ranging from 8% to 19% but nitrate levels exceeding the MCL.   The outlier exceptions could be a function of number of wells reported, well depth, type of fertilizer, type of planted crops, type of irrigation or dry land versus irrigated practices. The project data of eight of the counties reflect the rule of thumb of low and high nitrate concentrations versus their cropland percentages.

The highest risk counties in this project, based on nitrate concentrations of groundwater and percentage of fertilizer use per county area, are Haskell, Knox and Wilbarger. While Motley County has high values of nitrate and percentage fertilizer, it is suspect as an outlier, for reasons covered above, due to its low 8% cropland use calculated in the project. The lowest risk counties based on nitrate concentrations of groundwater and fertilizer use per county area are Stonewall and Foard. The project data shows positive correlated, observable trends of lower fertilizer application versus lower median nitrate concentrations and higher fertilizer applications versus higher median nitrate concentrations. Additionally, generally both trends correlate with cropland use.

Scanlon et al. (2003) findings suggest that nitrate concentrations of the groundwater in the Rolling Plains region of Texas result from agricultural practices. The pervasiveness of nitrates in the Seymour aquifer is not a debatable issue. While causes of the nitrate contamination are argued,

counter-measures concerning anthropogenic activities will lead to sound solutions in dealing with the reduction of nitrate concentrations.

Solutions:

The Seymour aquifer area requires a new way of thinking through a holistic approach and site-specific approach supported by ongoing water well monitoring and assessment aligned with specific counter measures in agricultural practices and nitrogen management. Nitrogen is the most important nutrient that maximizes crop production (Hudak, 2000). However, over-fertilization and over-irrigation are threats to the groundwater as both are sources of nitrate-nitrogen (nitrates). The DeLaune et al. (2013) study tested the hypothesis that irrigated cropland would be able to utilize nitrate present in the irrigation water as a source of nitrate towards the crop nitrogen requirements. The study involved three different irrigation systems cropped to cotton. By using the nitrate concentration found in the irrigation water and applying it to the nitrate concentration required for productive lint yields, a significant reduction occurred in the nitrogen fertilizer requirement. The irrigated water nitrate concentration made the difference and there was no reduction in lint yields in the cotton (DeLaune et al., 2013). The concept of "nitrogen crediting" is the reduction of fertilizer additions as the nitrate sources within the irrigation system counts toward the nitrogen needs of the crops. When done properly, this is a sound agronomic practice and a cost savings for the grower. One example in the Seymour aquifer, where fertilizer applications occur, includes both irrigation well water and residual soil-nitrate water credits. Based on 0.60/lb cost of nitrogen fertilizer, a farmer growing crops on 120 acres realized a savings of $2,260 on water- well nitrate value and $2,520 on soil-nitrate water value. The total savings in fertilizer costs for the 120 acres is $4,780 (DeLaune et al., 2013).

The conveying of information to the communities of the Seymour aquifer regarding the seriousness of nitrate contamination and its effects on the community is essential. Educating and working with the growers on the concept of "nitrogen crediting" will result in the creation of efficient fertilizer plans. The optimal goal is to minimize nitrate leaching to the groundwater and maximize the crops use of fertilizer. With "nitrogen crediting" implemented, growers will understand by using their "free nitrogen", an immediate savings occurs concerning fertilizer costs. Disciplines nutrient management and nitrogen crediting will save growers money and protect the groundwater resources.

Conclusions:

   Using ArcGIS processing, the hazard risk assessment observed in Figure 27 shows a positive correlation existing between the application of fertilizer on cropland and the median nitrate concentrations in the groundwater of the Seymour aquifer. Additionally, a negative impact exists between agricultural fertilizer practices and the groundwater nitrate concentrations. To counter the negative impact of agricultural fertilizer practices, "nitrogen crediting" is an inexpensive option, which allows for the reduction of excessive over fertilizing as an enhancement for crop production and saves the growers money in fertilizer costs. The reduced fertilizer use will contribute to the reduction of nitrate leaching into the groundwater and lead to a higher water quality in the Seymour aquifer.

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