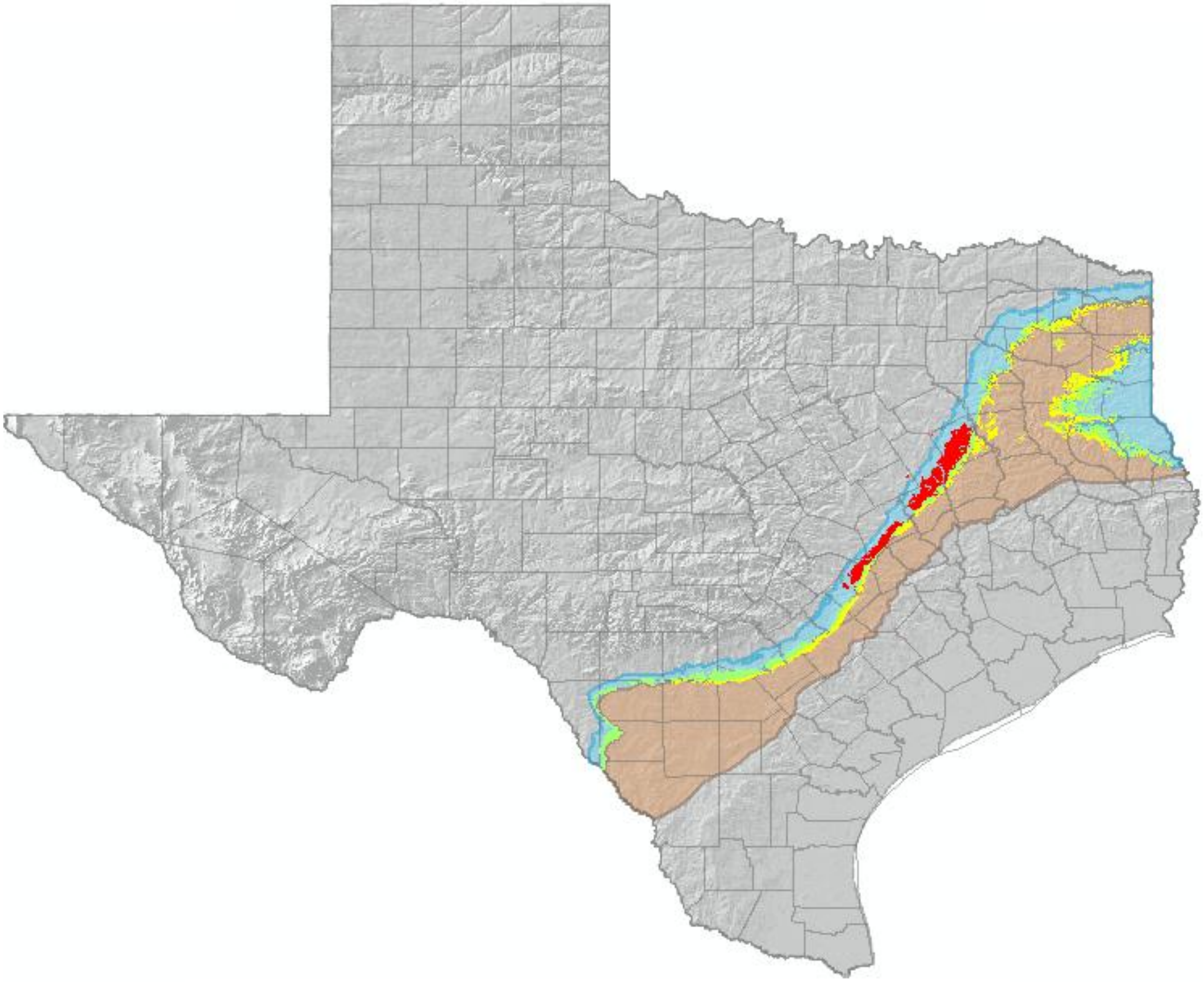
An Attempt to Study the Water Quality Effects of Lignite Strip Mining in Texas



A report by L. Joy Mercier

For GIS for Water Resources

On Friday, December 2, 2011

Introduction

The possibility of generating "acid mine drainage" is a common worry associated with mining operations in general—and strip mining in particular. Acid mine drainage is characterized by the presence of low pH, high metal cation concentration surface waters in associate with mine production. Strip mining in Texas has the potential to generate acidic waters due to the exposure of previously buried materials to atmospheric, oxidizing conditions. Most economic lignite seams in Texas are associated with the Carrizo Group and are overlain by the Wilcox Formation (as well as the Reklaw Formation where it has not been eroded away). Both the lignite deposits and the overlying Wilcox and Reklaw Formations are rich in sulfide minerals such as pyrite.

Overview of Strip (Surface) Mining of Lignite in Central and East Texas

To prepare an area for strip (surface) mining, unconfined and confined aquifers within the target area are desaturated and depressurized, respectively. The overburden —i.e. the unconsolidated and loosely-consolidated sediments overlying the targeted geologic formation or seam— are excavated. Once the target layer is exposed at the surface of the open pit or rolling line, it is removed and transported to nearby power plants to generate electricity. In Texas, newly excavated sediments and soils are mixed together to create a relatively homogenous soil. Materials, such as mulch, ash or lime, are often added to the sediments in an attempt to improve post-mining plant growth. The homogenized sediments are placed in the previously excavated pit (for a rolling line-type operation).

Reclamation of the mined land proceeds in phases. The land is contoured to approximate the pre-mining topography and appropriate vegetation is planted to promote post-mining land use (wetlands, hardwood forest, row crop farming, etc.), and the disturbed ground resaturates. Once state and federal regulations regarding key hydrochemical and geochemical variables (including a stable pH of at least 6) are satisfied, the reclaimed land is released from bond and can be sold by the relevant mining company.

Background: Geology of Lignite Deposits and Previous Research

Near-surface lignite deposits in Texas are primarily associated with the Calvert Bluff Formation of Wilcox Group and lie within the recharge zone of the prolific Carrizo-Wilcox aquifer. The presence of low pH seeps has delayed the release of some post-mining lands from bond and raised concerns that mining activities have compromised local water quality.

Lignite seams within the Wilcox Group as well as the younger Reklaw Formation (where present) are rich in reduced sulfide minerals such as pyrite. Surface mining causes both short- and long-term changes to the hydraulic characteristics of the area. In the short-term, aquifer dewatering can change hydraulic gradients and ground water flow paths (Sukhija et al. 1996). In the long-term, reclaimed land acquires a new permeability distribution (Hangsen et al. 2005). Furthermore, the process of removing the overburden to mine the economic lignite seams can change the redox conditions of the overburden, causing the oxidative solution of sulfide minerals, a drop in pH, and an overall increase in TDS (Holzmer 1992, Samborska and Halas 2010, Venburg 1983, Woessner et al. 1979).

While other lignite mines have been studied in Texas (Ayers 1987a and 1987b, Breyer 1987, Cagle 2007, Palmquist 1987), none have been as well-studied as the Big Brown Mine. Early work on the spoil characteristics and soil chemistry of the Mine was completed by Angel (1973), Askenasy (1977), Lentz (1975), and Hons (1978). Lentz (1975) interprets the depositional system of the lignite seams as fresh-water swamps and marshes formed as interlevee floodbasins between meander belts, and he correlates variations in the general depositional setting with changes in sulfate concentration in the lignites. French (1979) and Dutton (1985, 1986, 1990) discuss the hydraulic properties and chemical composition of the vadose zone while Hewitt (1990) and Holzmer (1992) focus on the (re-)saturated zone.

A recent study by Shaw (2006) indicates that surface waters in Texas naturally undergo a depression in pH as they interact with the Carrizo Sandstone and Reklaw Formation, both of which are "overburden" overlying the lignite seams of the Wilcox Group. But researchers tend to tackle the issue of lignite strip mining's effects on water quality using single mine location case studies. As a result, there has not been a systematic attempt to quantify the influence of the pyrite-rich Reklaw Formation on ground and surface water in undisturbed systems then to test relevant water quality parameters from undisturbed and mined locations for statistical significance.

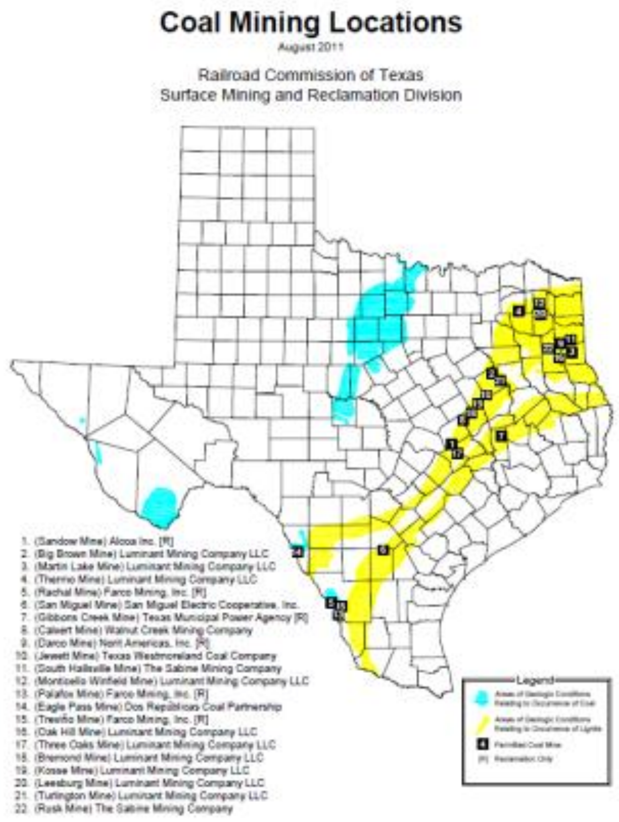
Hypothesis and Project Objectives

My hypothesis is that the process of removing and replacing the overburden alters the redox conditions of the overburden. Where the Reklaw and underlying formations were not exposed prior to mining activities, this process results in the oxidation of pyrite (and other sulfide minerals), producing a drop in local surface and shallow groundwater pH.

In this study, my objectives are to use ArcGIS to investigate the spatial relations between mapped areas of lignite surface mines and outcrops of the Reklaw Formation and Carrizo Sandstone in central and east Texas. After collecting relevant geospatial data together into one map, I assess the suitability of mapped lignite mines to test my hypothesis. Finally, I will select one mine and compare the production history of the mine with local surface and ground water data to test for a correlation between surface mining activity and water pH.

Step One: Collecting the Data

Data for this project was collected from a variety of sources. Unfortunately, I was unable to take advantage of the CUAHSI's user-friendly program for data discovery, HydroDesktop, due to an unusual situation. (Namely, my internet-enabled computer is a MacBook, which is not compatible with HydroDesktop, whereas the Windows-based computer that runs ArcGIS and ArcCatalog cannot access the internet.) Therefore, I developed my map by searching for and downloading data using the Geospatial Data Gateway server maintained by the USDA and then supplementing this data by manually searching the USGS, TWDB, and RRCT websites. While this data discovery method was time-consuming, it had the benefit of forcing me to become acquainted with the websites and data resources of numerous government agencies. Table 1 below summarizes the data set names, characteristics, and publishing government agency for the data uses in this study.



(Left) Figure 1. Screen shot of Railroad Commission of Texas (SRM Division) Coal Mining Locations Map

Most geospatial information was available as (vector-format) shapefiles. However, the Railroad Commission of Texas (RRCT) does not provide GIS-formatted files for the locations of lignite mines. Therefore, I obtained this information from an online pdf publication by the Surface Mining and Reclamation Division (SMRD) of the RRCT. I used the screen-capture function to isolate an image of the map of Texas lignite mines (Figure 3). I imported this screen shot into my geodatabase as a raster. By identifying the latitude and longitude coordinates of a number of county vertices, I was able to georeference the screen shot. Finally, I created a new feature class, called "LigniteMines." Then, I created an Excel table with the FID, name, Production_Start, Production_End, Pre_1976_Production_Start, and Active features. After importing this table into ArcGIS, I used the Join function to combine the temporal production information in the table with the geospatial information in the shapefile.

Unfortunately, there was not as much publically-available surface and ground water data as I had originally anticipated. Because I could not run HydroDesktop on my MacBook, I had to manually download the time series data for the USGS stream monitoring sites that I selected for this study. I downloaded this information as ASCII text files, converted them to Microsoft Excel files, and then cleaned up the format of the files so that they could be imported into ArcGIS. The stream gauging data that I obtained using this method covered the relevant time span (2004 to present). However, I discovered that water quality data was not collected at either of these sites after 2000 despite the presence of an active mine just upstream of the stations. Because of this lack of publically avaialable data, I was ultimately unable to test my hypothesis.

Table 1. Summary of geospatial and geotemporal data analyzed for this study

Name	Description	Publishing Agency	Selected Data for Present Study
Coal Mining Locations (August 2011)	PDF map of lignite mines in Texas	RRCT: SMRD	XY locations of active, proposed, and reclamation-only lignite mines in Texas
TX_Coal	Excel workbook with annual lignite mine production from	RRCT: SMRD	Years of production and amount produced annually for mines from 1976 to 2009
USGS Streamflow Stations	Point shapefile	USGS	XY location of steam gaging stations in central and east Texas
TWDB Well Location Grid	Point shapefile	TWDB	XY location of wells in central and east Texas
National Hydrography Dataset (NHD) geodatabase	Geodatabase containing point, line, and polygon shapefiles and associated attribute tables		Flowlines for streams in central and east Texas and HUC8, HUC10, and HUC12 for watershed delineation
National Scale Geology by State	Polygon shapefile	USGS (via GDG)	Extraction of Wilcox Group and Carrizo and Reklaw and Formations
Major Aquifers of Texas	Polygon shapefile	TWDB	Extraction of the Carrizo-Wilcox Aquifer outcrop (recharge) and confined polygons
Minor Aquifers of Texas	Polygon shapefile	TWDB	Comparison of minor aquifer spatial overlap with the Carrizo-Wilcox Aquifer
Major River Basins of Texas	Polygon shapefile	TWDB	Background imagery of major river basins of Texas (viz. the Colorado and Brazos river basins)
Existing Reservoirs	Polygon shapefile	TWDB	Names and locations of existing reservoirs and lakes in central and east Texas
Texas Hillshade	Shapefile (generated from processed DEMs)	TWDB	Background imagery of Texas topography
NRCS Counties by State	Polygon shapefile		Texas counties
Geographic Names – Populated Places	Shapefile	GDG	Texas cities as points
TIGER 2010 Primary Roads by State	Shapefile	GDG	Display major highways (e.g. I-35) for visual orientation/location
Major Ecoregions of Texas	Polygon shapefile	GDG	Major ecoregions
USGS 08109700 Middle Yegua Ck nr Dime Box, Tx and **USGS 08109800 E Yegua Ck Nr Dime Box, Tx**	ASCII text file	USGS	Time-series of stream gauging data
“ ”	ASCII text file	USGS	Time-series of water quality data

TWDB: Texas Water Development Board
USGS: U.S. Geological Survey
GDG: Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/)
RRCT: Railroad Commission of Texas
SMRD: Surface Mining and Reclamation Division

Step Two: Investigate spatial relationships between lignite mines and geologic features

My hypothesis is that the process of removing and replacing buried Reklaw Formation and Carrizo Sandstone overburden alters the redox conditions of the overburden, causing a measurable drop in pH in local streams and wells. To test this hypothesis, I needed to locate a lignite mine just downdip (southeast) of Carrizo and Reklaw outcrops since these units dip towards the Gulf Coast. To do this, I mapped the recharge (outcrop) and confined portions of the Wilcox aquifer, which is composed of rocks that underlie the units of interest. I also mapped three units from the state geologic map: the Reklaw Formation (Er), the Carizzo Sand (Ec), and the Calvert Bluff Formation (EPAc) (which contains the lignited seams). Figures 2 and 3 (below) show the location of the lignite mines in central and east Texas considered for this study.

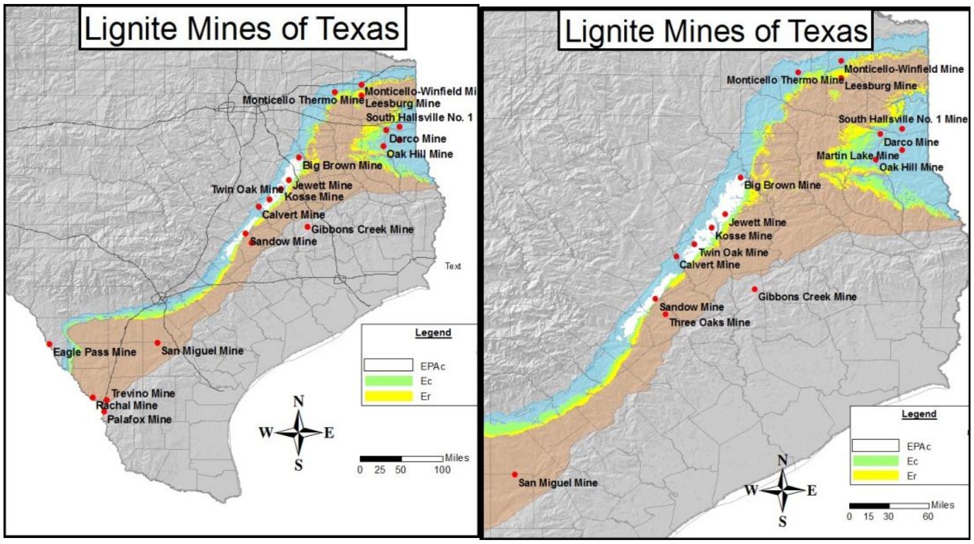
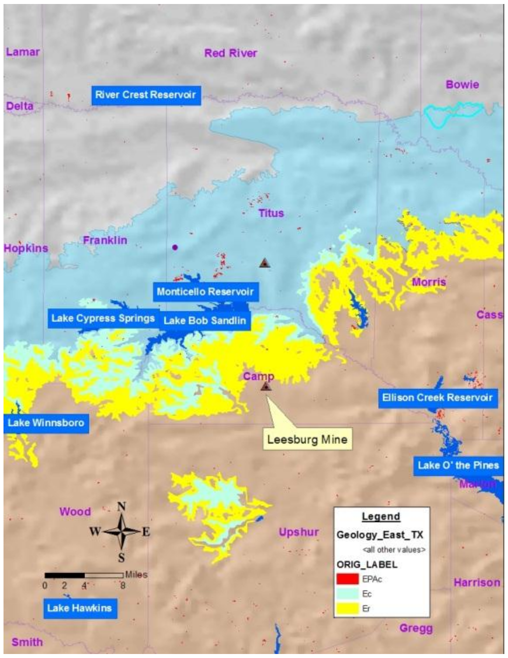


Figure 2 (left) and Figure 3 (right). The location of lignite mines and the orientation of the Wilcox Aquifer and overlying geologic units such as the Carrizo Sandstone and the Reklaw Formation.

The Leesburg Mine in northeast Texas (Figure 2) seemed perfectly situated for this study, and I falsely reported that the Leesburg Mine would be the focus of this study in my 10/25/2011 project update. However, review of the LigniteMine attribute table revealed that, though this location is not yet being actively mined though it is permitted as a lignite mine.

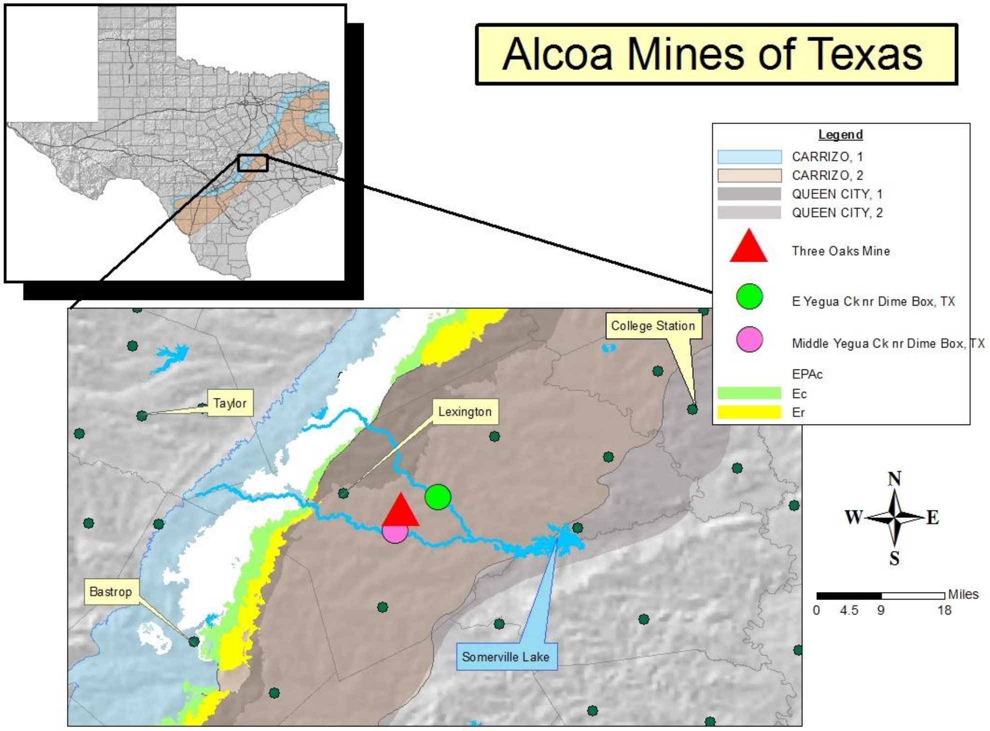


(Left) Figure 4. Map of northeast Texas indicating the location of Leesburg Mine and proximity to geologic units.

Step Three: Select a "case study" lignite mine

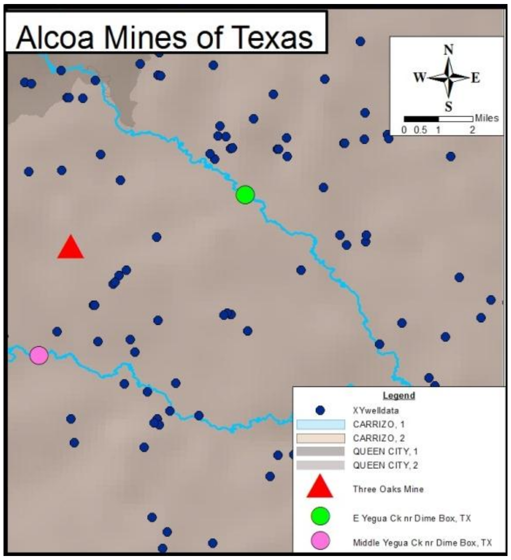
The mine ultimately selected for this study is Three Oaks Mine (Figure 5), originally owned by Alcoa, Inc. but now owned by Luminant Mining Company LLC. Three Oaks Mine has been active since 2005. To the north, the Sandow Mine (another Alcoa, Inc. mine) was active since before 1976 until 2005. Using the Measure tool in ArcGIS, I found that the Three Oaks Mine is approximately 11 miles downdip of the outcropping Reklaw Formation. The Queen City Sand, which overlies the Reklaw Formation and constitutes a minor aquifer in Texas, is exposed for 5.5 miles of the intervening distance until it is buried (confined) by younger clay sediments. Thus, I conclude that the Reklaw and underlying geologic units were sufficiently buried in the region of Three Oaks Mine that they were in a reducing (oxygen depleted) environment prior to mining operations.

(Below) Figure 5. Map illustrating the location of Three Oaks mine in east central Texas, Lee County.



Step Four: Download Time Series Data for Wells and Stream Monitoring Stations

The next step in this study was to visualize possible sources of water quality data, and then to download that data from the appropriate website(s). Because I know that the Lower Colorado River Authority (LCRA) maintains a very useful database describing surface water quantity and quality, I first checked to see if the LCRA has any monitoring loctions near the mine. Unfortunately, though near the groundwater divide that separates the Colorado and Brazos River Basins, Three Oaks Mine is located in the Brazos River Basin (map not included in this report), which is managed by a different river authority.



(Above) Figure 6. Possible water monitoring sites near Three Oaks Mine.

Using my USGS Streamflow Stations and TWDB Well Location Grid (which is actually a shapefile and not raster), I identified a dozen nearby wells and 2 USGS stream monitoring sites near the Three Oaks Mine. Unfortunately, the TWDB had only driller's well logs for the nearby wells and not water quality data.

Step Five: Use ArcGIS to test for a temporal correlation between mine production and water pH

The two stream monitoring sites maintained by the USGS have been used primarily for stream gauging (discharge) measurement. As a result, while adequate stream gauging data exists for the period of Three Oaks Mine activity (red bar in Figure 7), water quality data has not been gathered from these sites in a decade. This discovery was very disappointing as time limitations prevented me for selecting a new "case study" location.

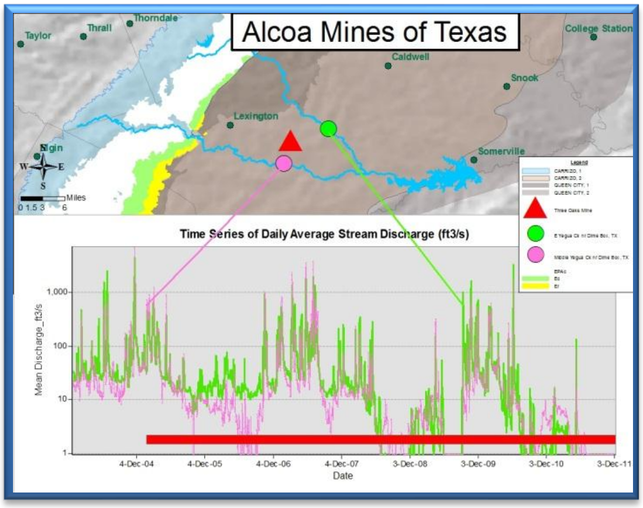
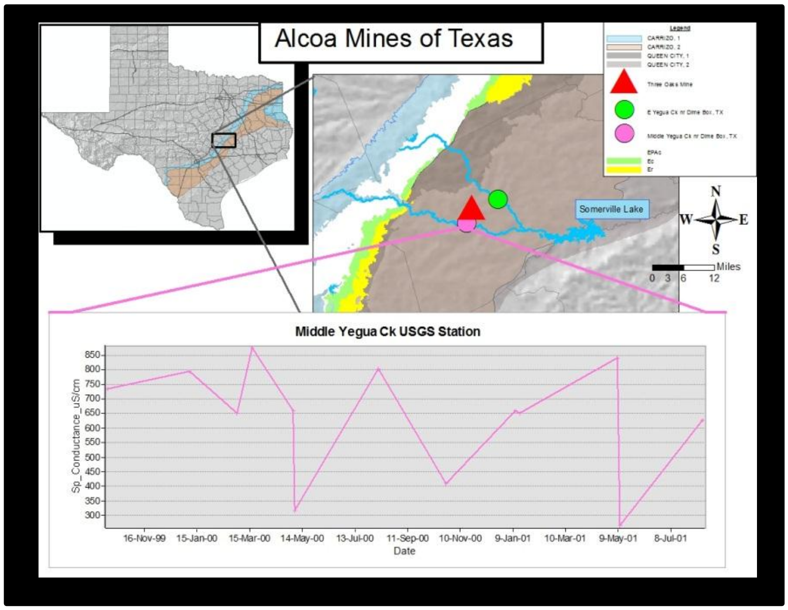
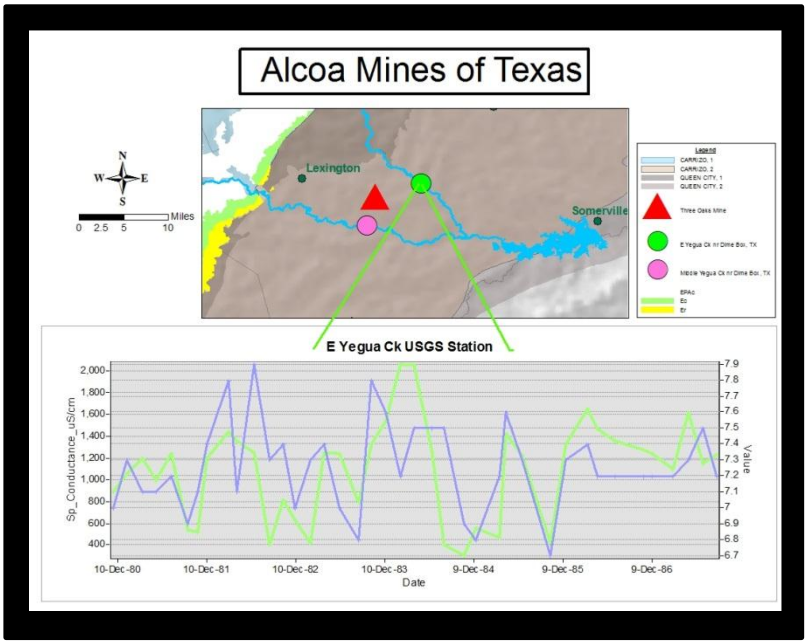


Figure 7. Stream discharge as measured at each of the USGS sites.





Figures 8 (top) and 9 (bottom), depicting the water quality data available for the selected USGS stream monitoring sites.

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