Modeling Hydrostratigraphy and Geochemical Analysis of the Rocker-B Ranch Aquifers

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Abstract

The Rocker-B Ranch spans over Irion and Reagan counties in West Texas. Recent drilling on the Rocker-B Ranch could pose a threat to fresh water aquifers if oil wells are improperly completed, allowing brackish water to migrate upwards. Thus, fresh water sandstone and carbonate aquifers could mix with high amounts of evaporate salts (e.g., primarily anhydrite, gypsum and halite) originating from deeper Mesozoic and Paleozoic formations. This cross-contamination could cause an increase to the total dissolved solids (TDS) concentrations of groundwater in the freshwater aquifers of the Cretaceous Edwards-Trinity, Antler Sands, and shallower Quaternary Aquifers such as the Leona and Alluvium aquifers. Increases in TDS can be observed from chemical analysis of the major ions (e.g., major 8's) such as Ca2+, Mg2+, Na+, K+, HCO3-, SO42-, Cl-, and Fl-. Aqueous geochemical data from multiple borehole sites for each aquifer have been placed into a GIS database for geochemical analysis and modeling to chemically fingerprint each aquifers' chemical characteristics. Groundwater chemistry in the areas in and around the research site will also be evaluated. The final product will be an interactive database to be given to the ranch manager as a tool to aid in managing the ranch's natural resources.

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Project Introduction

The Rocker B Ranch is one of the biggest oil producing sites in the United States and spans over two counties; Reagan and Irion. The ranch was donated to the Texas Scottish Rite Hospital for Children and most of the proceeds from oil production go to the hospital (Nolen, 2007). The ranch is also actively used for working cattle by modern day cowboys and providing an old western environment to guests.

There are over 20 aquifers in Texas that provide for drinking water, irrigation, and oil related activities (Sansom, 2008). In 1923 oil was discovered in Regan County at the famous Santa Rita Well No. 1 site (Ashworth, 1989). This lead to mass oil booms in the 1920's and 1940's until oil prices were dropped in the early 1980's by heavy oil producing countries in the Middle East which caused an oil bust to West Texas' oil production. Most of the water used for unconventional hydrocarbon recovery now comes from both the Edwards-Trinity and the Dockum aquifers. The Dockum formation is in

the Triassic period and is formed with red sandstones and shale that come from a fluvial depositional environment (Bradley, 2003). This aquifer is an artesian system with an impermeable layer both above and below it. It provides moderately saline water, due to a small amount of evaporative beds and is primarily used for hydrocarbon recovery (Ashworth 1998). The Trinity and Washita groups are separated by the Fredericksburg Group which is predominately limestone and dolomite; this is where the Edwards limestone is that provides drinking water to some wells around Regan and Upton.

Every ground water system is bound to have a unique aqueous chemistry due to how the aquifer is recharged, the type of rock that is embedded around and the chemical alterations of water as it flows through the system (Singh, 2012). The dissolution and cation exchange of carbonate rock could leave concentrations of major ions in groundwater such as Ca+2, which makes the water quality poor concerning human consumption yet adequate enough for agricultural and industrial uses (Bradley, 2003). It is possible to model mineral phase changes to track major and minor ions using different programs such as PHREEQC. From there it is possible to track these minerals and find out where they formed, track flow and see if the water mixes with other aquifers (Singh, 2012).

The study site (view Figure 1) is in an arid to semi-arid region with average yearly rainfalls between 13 to 19 inches and temperatures that range between 95o F and 28o F. The average gross evaporation of lakes is 81 inches per year which is over five times the amount of yearly average rainfall (Ashworth, 1989).

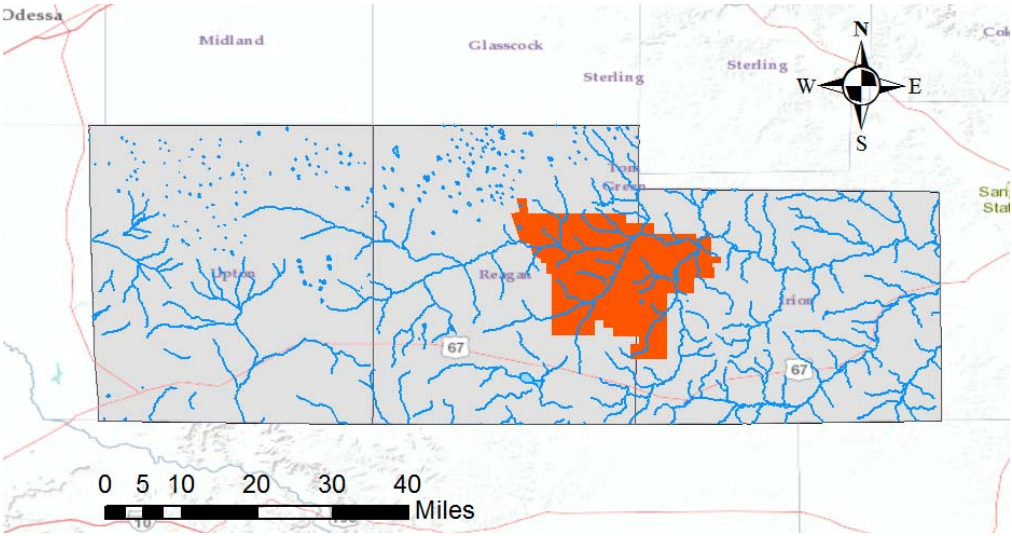

Figure 1. Map of Regan, Irion and Upton Country with ranch boundaries.

Geological and Hydrogeological description

The study area covers three major basins; the Central Basin Platform in the southwestern corner of Upton county, the Midland Basin, centered between Upton and Reagan counties, and the Eastern Shelf located at the north eastern part of Reagan county and the south western part of Glasscock county. The Permian has a synclinal structure caused by the dissolution of evaporites of older Paleozoic aged strata. The syncline (see Figure 2) has been filled in with excess Triassic aged rock underlying younger Cretaceous rock. The Permian and other Paleozoic aged strata are formed from marine carbonates and evaporites that accumulated in the Permian Basin. The Triassic aged strata contains the Dockum Group that is made of three separate parts; the lower Dockum contains red shale and siltstone, the middle Dockum holds iron oxidized sandstone and shale, and the youngest contains iron oxidized shale siltstone and sandstones. An aquaclude is naturally formed between older Paleozoic and younger Triassic through the Dockum Group by the impermeable shale and clay that acts as a barrier between the water from Permian and Triassic aged formations (Ashworth 1989). The primary evaporite minerals of the Permian are halite, NaCl, gypsum Ca(SO4)·2H20 and anhydrite, Ca(SO4) (Bumgarner 2012).

The Cretaceous can be broken down into three different groups; the Trinity, Fredericksburg and the W ashita groups. The Trinity holds the Antlers Sand, this unit contains fine to medium grained sized quartz sand and small amounts of iron oxidized shale within sandstones. The Trinity provides a moderate amount of fresh to slightly saline water (Walker 1979).

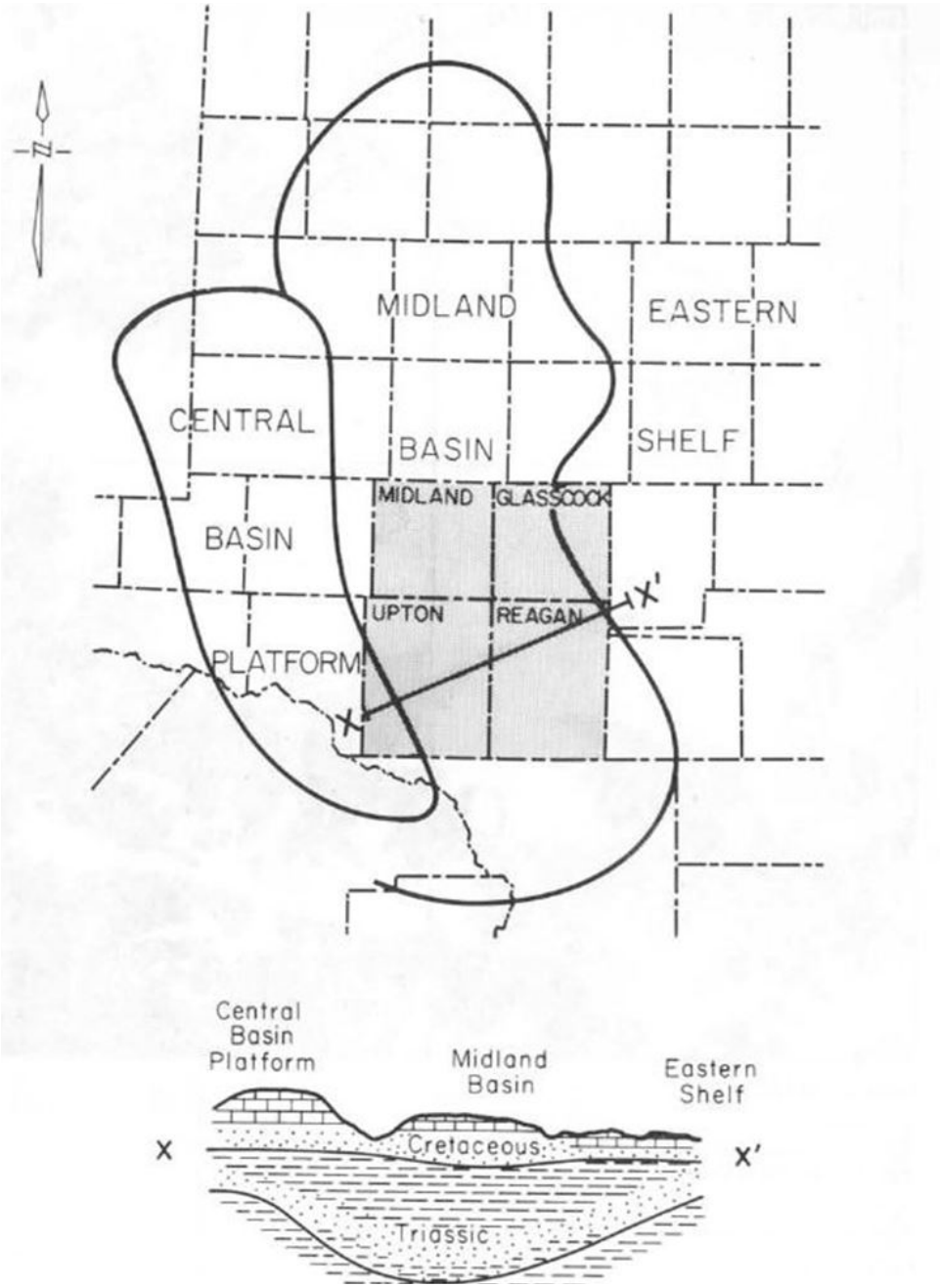

Figure 2. Cross section of Regan and Upton counties adapted from Ashworth, John B., and Prescott C. Christian. 1989.

The Fredericksburg and the Washita group provides a small amounts of water and is made up of large limestone beds, marl, and nodular limestone. The bulk of the Cretaceous and its water baring formations in this region are better known as the Edwards-Trinity aquifer. The Ogallala aquifer is the most important aquifer in the United States, it spans from South Dakota all the way to the pan handle of Texas. Tertiary in age, the Ogallala (or High Plains) aquifer provides drinking and agricultural water to many states and is vital to the United States' economy (Sansom, 2008). Although the Ogallala is not actually in the study site, it should be noted that fresh water from this aquifer laterally flows into the Edwards-Trinity Aquifer and helps to maintain less total dissolved solids on the water (Ashworth 1989). Table 1 shows stratigraphic chart of the site.

The aquaclude that separates water from Permian and the Dockum also provides a barrier for the geochemistry's in each aquifer. If the impermeable layer were to lose its integrity from faulting and or fracturing, then it the saline waters from the Permian could rise into the Dockum and even through to the Edwards-Trinity aquifer. A United States Geological Survey (USGS) reports that as of 2012, Pecos County; which is just to the west of the study site has encountered this very same issue. Massive amounts of faulting have occurred as a result of basin and range extension causing the system's impermeable layers to fracture all along the aquaclude. Though since there are massive faulting events, there has not been an issue with the separations of the two age's water due to the fact that there is still pressure in the sub surface, and that the saline water in the Permian (in this case the Rustler formation) is much denser than that of the Dockum and the Edwards-Trinity. Over use of the Edwards-Trinity and the Dockum have caused those waters to be replaced with the waters from the Rustler formation and now renders those aquifers susceptible to saturations of high salinity (Bumgarner, 2012).

SYSTEM	GROUP	FORMATION		LITHOLOGY
Quaternary		Alluvium		Caliche, sand, clay and gravel
Tertiary		Ogallala		Gravel, silty sand, and caliche
Cretaceous	Washita	Buda		Clay, marl, and limestone
	Fredericksburg	Edwards	Segovia	Limestone, and dolomite
			Ft. Terrett	
	Trinity	Antler Sands		Sandstone, with bedded shale layers
Triassic	Dockum			Red shales, sandstones, and siltstones
Permian	Whitehorse			Marine Carbonates and evaporites

Table 1. Generalized Stratigraphic Chart (Harris and Ward, 2012)

Methods

Well data information has been collected from the Texas Water Development Board (TWDB). Well information is divided by county and further divided by aqueous chemistries, aquifer elevations, and other information. The water chemistry date for Regan, Irion, and Upton counties are used to make multiple two dimensional maps representing the difference in sulfate, bi carbonate and chloride for four different aquifers; the White Horse (Fig 3), Dockum (Fig 4), Antler Sands (Fig 5), and Edwards-Trinity (Fig 6). The reason for modeling the sulfate, bicarbonate and chloride as opposed to any of the other major ions are because these three are the most important in regards to driving the water quality in the area since these three are anions, this is due to the dissolution of limestone and dolomite into carbonate, gypsum into sulfate, and halite into chloride as depicted below. After carbonate has been dissoluted from limestone or dolomite, a hydrogen atom is added from water forming bicarbonate. Calcium, magnesium and sodium are cations and are also in ground water but those ions are expected to be due to the geology of the region.

Carbonate and calcium is a product of limestone dissolution:

$$CaCO_3 \leftrightarrow Ca^{2+} + CO_3^{2-}$$

Carbonate and Magnesium is a product of dolomite dissolution:

$$CaMg(CO_3)_2 \leftrightarrow Ca^{2+} + Mg^{2+} + 2CO_3^{2-}$$

Sulfate is a product of gypsum ($CaSO_4$) dissolution:

$$CaSO_4 \leftrightarrow Ca^{2+} + SO_4^{2-}$$

Chloride can be produced due to evaporation or halite dissolution:

$$NaCl \leftrightarrow Na^{+} + Cl^{-}$$

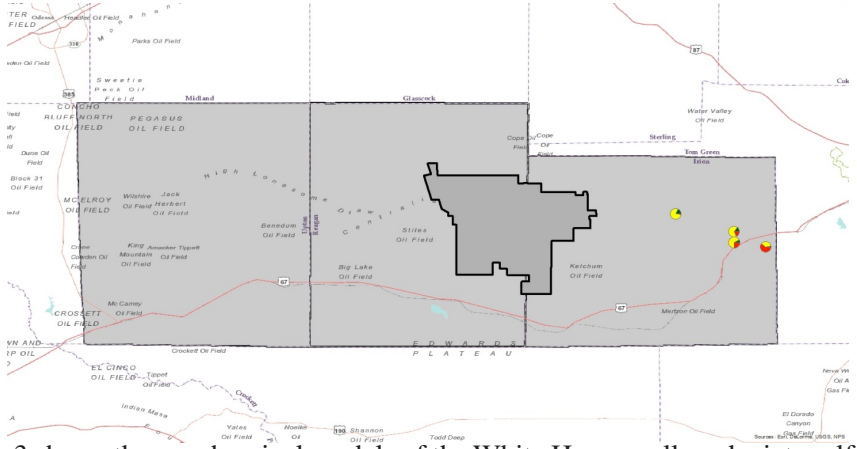

Figure 3 shows the geochemical models of the White Horse; yellow depicts sulfate, red depicts chloride and green depicts bicarbonate.

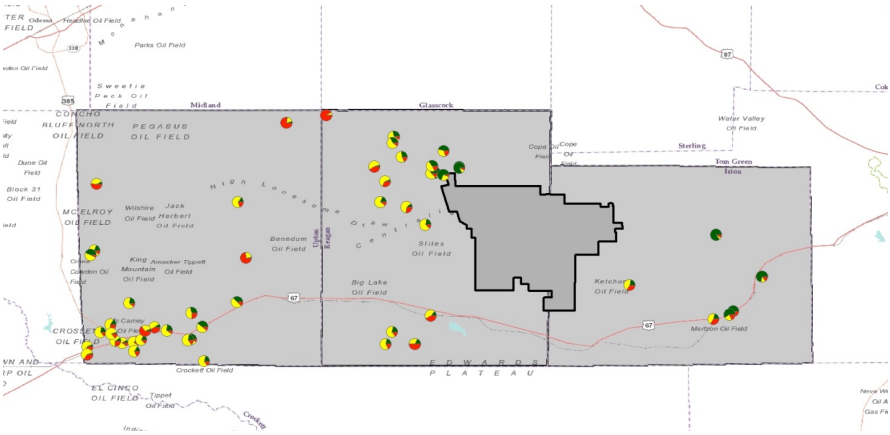

Figure 4 shows the geochemical models of the Dockum; yellow depicts sulfate, red depicts chloride and green depicts bicarbonate.

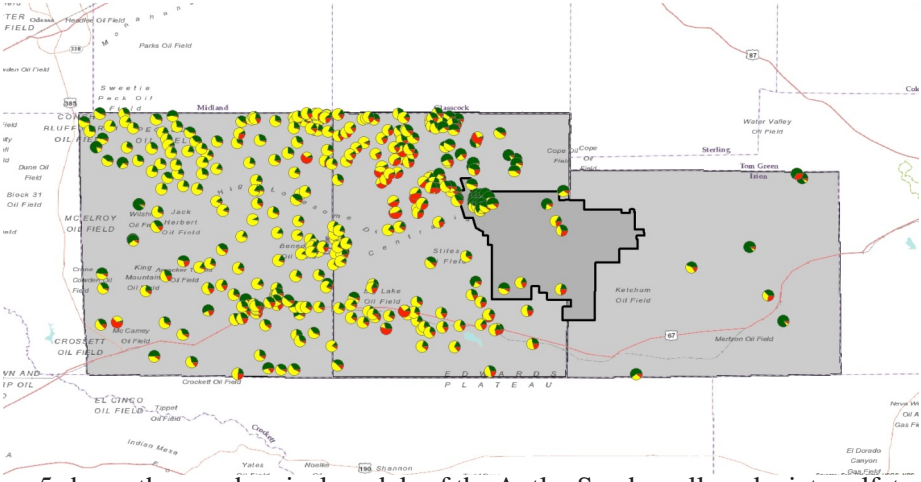

Figure 5 shows the geochemical models of the Antler Sands; yellow depicts sulfate, red depicts chloride and green depicts bicarbonate.

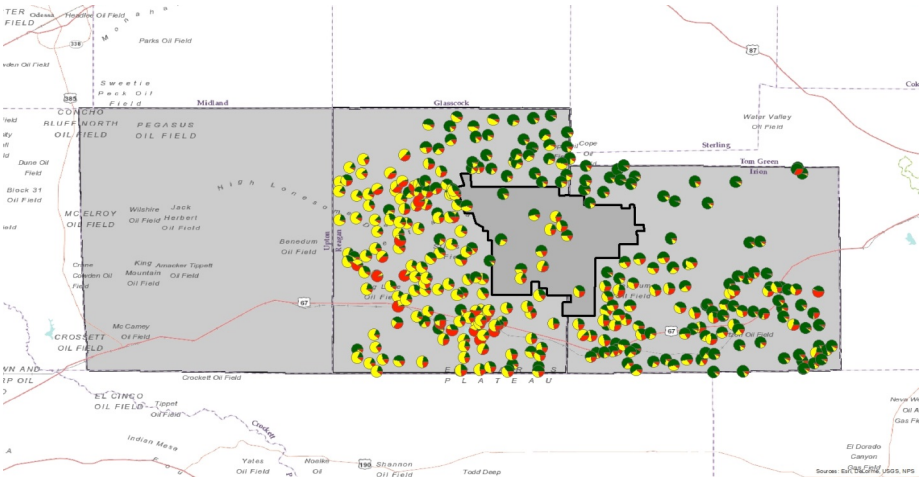

Figure 6 shows the geochemical models of the Edwards-Trinity; yellow depicts sulfate, red depicts chloride and green depicts bicarbonate.

After modeling the geochemistries of these aquifers on ArcGIS to give a visual representation of the aquifers, piper plots are used to demonstrate a representation of every parameter given at each aquifer.

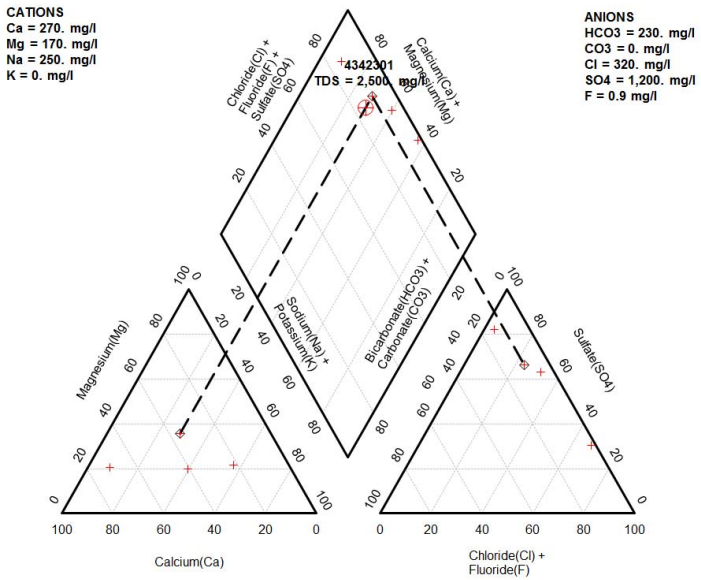

Figure 7 models the chemistries of the White Horse (Permian).

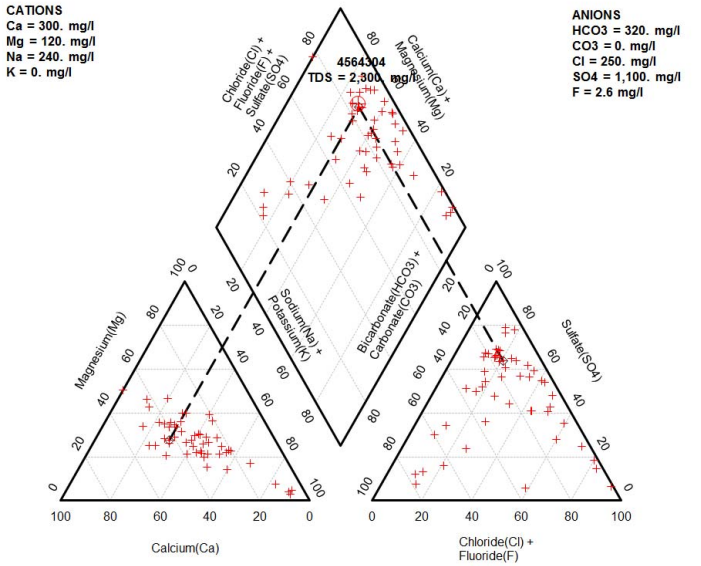

Figure 8 models the chemistries of the Dockum.

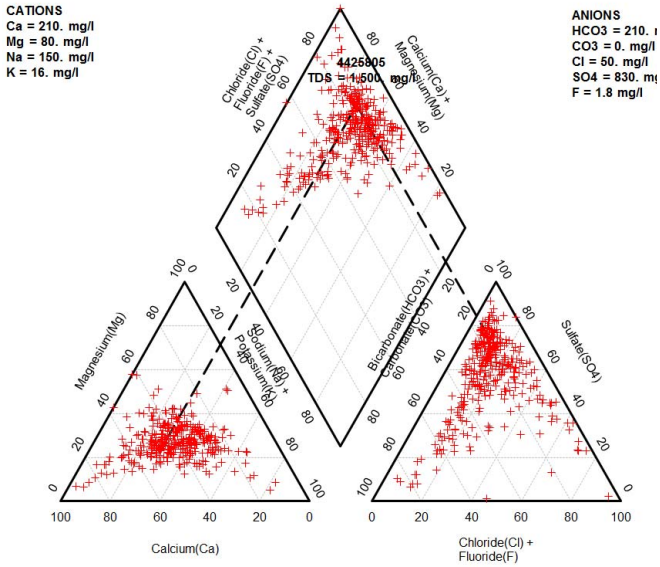

Figure 9 models the chemistries of the Antler Sands.

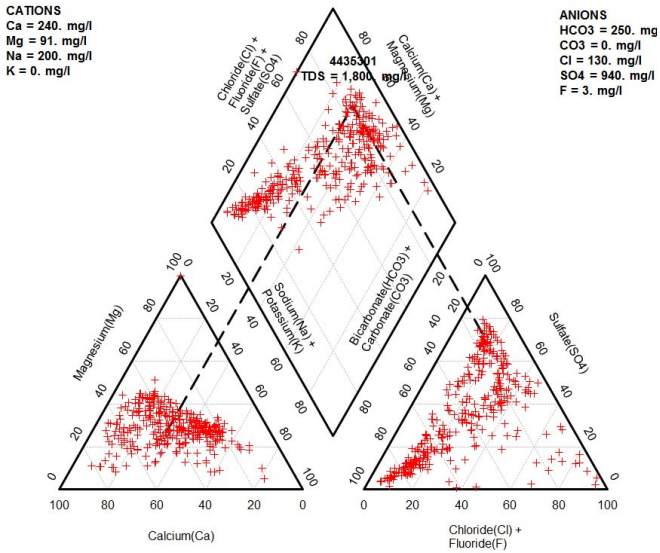

Figure 10 models the chemistries of the Edwards-Trinity.

After viewing the chemistries of these aquifers, 3D models were constructed using ArcGIS and ArcScene. This 3D model depicts the depth of each aquifer in the region and shows the predominant aquifer at each county (Fig 11). Since the Permian aged aquifer has only 4 data points measured from the site, it has been thrown out of the 3D model.

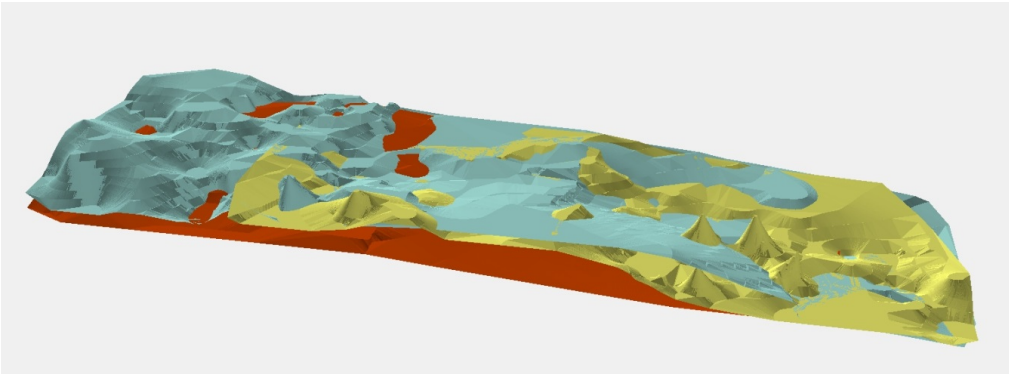

Figure 11. A three Dimensional representation of the Edwards-Trinity, Antler Sands, and Dockum aquifers. Yellow depicts the Edwards-Trinity water table, blue depicts the Antler Sands water table and red depicts the Dockum aquifer.

Results and Discussion

After viewing the two dimensional chemical models in each aquifer, the western side of the Edwards-Trinity aquifer is driven more so by bicarbonate while on the eastern side, sulfate is the dominant anion. The trend that occurs in the Edwards-Trinity's piper plot shows that; bicarbonate is equal to about 250 mg/l, chloride is equal to 130 mg/l and sulfate equals 940 mg/l. roughly 70% of the Edwards-Trinity's anions are sulfate. The same trends can be said for the Antler Sands aquifer, and even the Dockum. A possible reason for the separation can be due upwelling caused by over use of fresh cretaceous groundwater in the eastern portion could be causing sulfate activity to move up vertically through compromised areas of impermeable strata and increasing the TDS values of sulfate (Bumgarner, 2012). The reason bicarbonate is still predominant in the west is because the Edwards-Trinity is the main aquifer in this area, as noted in the three dimensional conceptual model. The Edwards-Trinity is composed of limestone and dolomite and has a much larger influence on water chemistry than the sandstones of the Antler Sands making bicarbonate the dominant ion in the aquifer.

Conclusion

Though an exact cause for as to why upwelling is occurring from brackish Permian waters into the fresh cretaceous waters is not known, similar studies have shown faulting to be the major culprit in Pecos County for this event. It is possible that faulting is at play in this area as well or there may be a link to high secondary recovery tactics in the petroleum industry. Regardless to the cause of how the separate aquifer's waters are interacting with each other, upwelling is caused when an artesian aquifer has been relieved of its pressure and acts as suction to nearby aquifers. The data from the Texas Water Development Board was gathered over several years spanning from the early 1960s to the present day, this means the models were created using all data. This does affect the outcome of multiple representations due to a limited data pull time was not factored into the conceptual models. To fully grasp the complete interactions of aqueous chemistry in this area, further studies can be done with the help of geophysical tactics and more data from the area.

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