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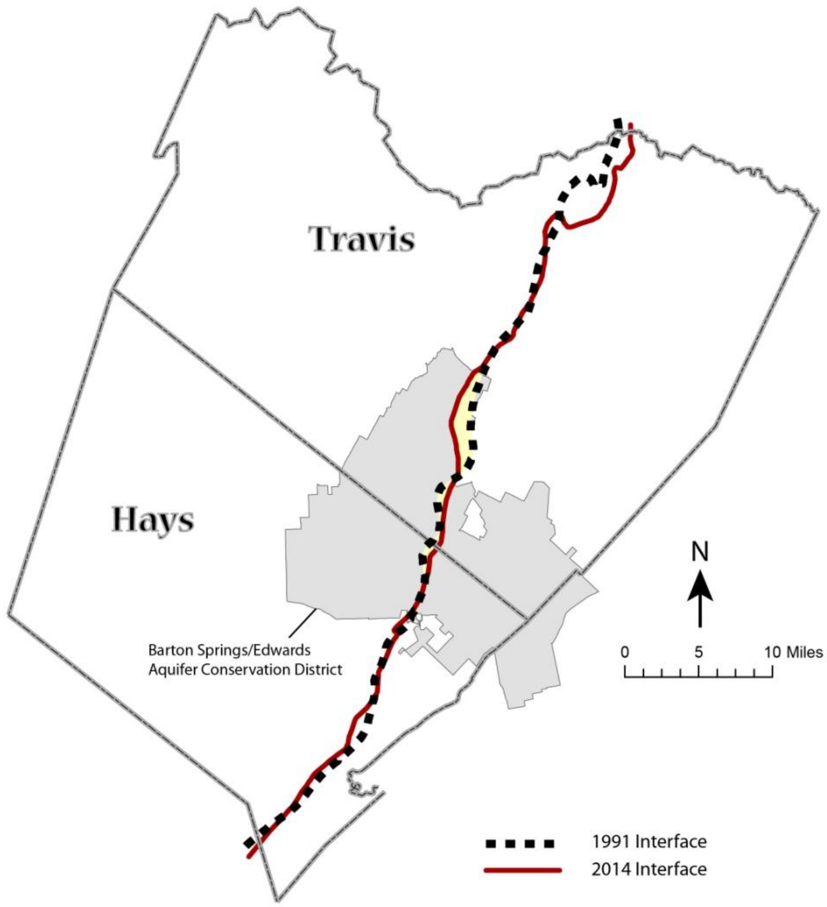
Refining the Freshwater/Saline-Water Interface, Edwards Aquifer, Hays and Travis Counties, Texas



BSEACD Report of Investigations 2014-1001

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Barton Springs/Edwards Aquifer Conservation District
1124 Regal Row
Austin, Texas

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Cover. Results of this study showing the revised freshwater/saline-water interface (red) compared to the 1991 interface (Ashworth and Flores, 1991). The change in boundaries is the result of new (additional) data points and interpretation of the location of the interface.

Refining the Freshwater/Saline-Water Interface, Edwards Aquifer, Hays and Travis Counties, Texas

Brian B. Hunt, P.G., Robin Gary, Brian A. Smith, Ph.D., P.G., and Alan A. Andrews, GIT

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ABSTRACT

This study refines the freshwater/saline-water interface in the Edwards Aquifer of Travis and Hays Counties based upon 855 data points compiled from measured or estimated total dissolved solids (TDS) in groundwater. Changes to the boundary include localized lateral shifts of up to 1.3 miles and an apparent net loss of 3.8 mi^2 of areal extent of freshwater aquifer. The freshwater/saline-water interface as mapped is a two-dimensional estimate of a very complex three-dimensional boundary. As with any mapped boundary, there is inherent uncertainty of the exact location and geometry of the interface. Studies suggest the interface appears to be relatively stable over time in the Barton Springs segment of the Edwards Aquifer. Variation in TDS values measured in wells along the interface could be due to localized flow within boreholes rather than true encroachment of the saline zone. Although saline encroachment does not appear to be a threat to freshwater supplies, changes in the springflow chemistry at Barton Springs suggests some leakage from the saline zone under drought conditions. This improved boundary map has relevance to future water availability (aquifer storage and recovery, desalination), karst speleogenesis (hypogene processes), groundwater flow, and groundwater management.

INTRODUCTION

The interface (boundary) between the freshwater/saline-water zones of the Edwards Aquifer were first mapped by Petitt and George (1956). As new data and studies of the boundary have become available, it has been periodically refined (Flores, 1990; Schultz, 1993). The purpose of this investigation is to provide an updated and detailed delineation of the freshwater/saline-water interface based on new information. This boundary has relevance to future water availability and groundwater management. If the interface shifts due to climatic or pumping influences, there may be significant impacts to the water quality of the freshwater aquifer, and therefore the water supplies of thousands of people. Furthermore, significant changes to the interface could also impact the chemistry of springflows at San Marcos or Barton Springs, home to numerous endangered species. Lastly, the location and mobility of the interface could have implications for of alternative water supply strategies such as desalination and aquifer storage and recovery.

Definition of "Saline Zone"

Total dissolved solids (TDS) is a measure of water salinity and reflects the amount of dissolved minerals in units of milligrams per liter (mg/L), or sometimes as parts per million (ppm). Terms used to describe the salinity of water are not consistent. **Table 1** provides a summary of definitions and terms for the area of interest. In this report the term "saline" is used synonymously with the term "Brackish". The term "saline zone" is used to describe the area east of the freshwater zone where groundwater can be produced that contains greater than 1,000 mg/L TDS. Water with less than 1,000 mg/L (or ppm) is considered fresh, generally does not need treatment, and is suitable for most uses. Brackish groundwater generally describes water with 1,000 to 10,000 mg/L TDS (George et al., 2011; NGWA, 2010). Water with greater than 1,500 mg/L TDS may be used for irrigation, depending on the concentrations of certain ions (chloride, sodium etc). Water with up to 3,000 mg/L TDS can be suitable for livestock (George et al., 2011).

Table 1. *Summary of definitions and terms*

Term	TDS (mg/L)	Source	Comment
Freshwater	< 1,000	George et al., 2011	This is also the threshold for secondary drinking water standards set by the TCEQ*.
Brackish water	1,000 to 10,000	NGWA, 2010	
Slightly saline	1,000 to 3,000	NGWA, 2010	
Moderately saline	3,000 to 10,000	NGWA, 2010	
Highly saline	10,000 to 35,000	NGWA, 2010	
Brine	>35,000		Salinity of seawater

*EPA and the WHO have a secondary standard of 500 mg/L

Study Area

The focus of the study is the eastern edge of the freshwater Edwards Aquifer in the Balcones Fault Zone of Hays and Travis Counties. This segment is known as the Barton Springs segment of the Edwards Aquifer (**Figure 1**). **Figure 2** shows a portion of the study area with the underlying geology and the existing freshwater/saline-water interface provided by the TWDB.

Hydrogeologic Setting

The Edwards Aquifer is a karst aquifer developed in faulted and fractured Cretaceous-age limestones and dolomites. The Edwards Aquifer system lies within the Miocene-age Balcones Fault Zone (BFZ) of south-central Texas and consists of an area of about 4,200 mi^2 (11,000 km^2) (Fig. 1). The aquifer extends about 250 miles (430 km) from Kinney County, west of San Antonio, to Bell County, north of Austin. Groundwater from the Edwards Aquifer is the primary source of water for about two million people plus numerous industrial, commercial, and irrigation users. The Edwards Aquifer system also supports 11 threatened or endangered species, aquatic habitats in rivers of the Gulf Coastal Plain, and coastal bays and estuaries. Hydrologic divides separate the Edwards Aquifer into three segments. North of the Colorado River is the Northern segment of the Edwards Aquifer, and south of the southern hydrologic divide near the City of Kyle is the San Antonio or southern segment. The Barton Springs segment is situated between the Northern and San Antonio segments (**Figure 1**).

Development of the Edwards Aquifer was influenced significantly by fracturing and faulting associated with Miocene-age tectonic activity and subsequent dissolution of limestone and dolomite units by infiltrating meteoric water (Sharp, 1990; Barker and Ardis, 1996; Hovorka et al., 1995; Hovorka et al., 1998; Small et al., 1996). In addition, development of the aquifer is also thought to have been influenced by deep dissolution processes along the fresh/saline-water interface, what is known as hypogene speleogenesis (Klimchouk, 2007; Schindel et al., 2008).

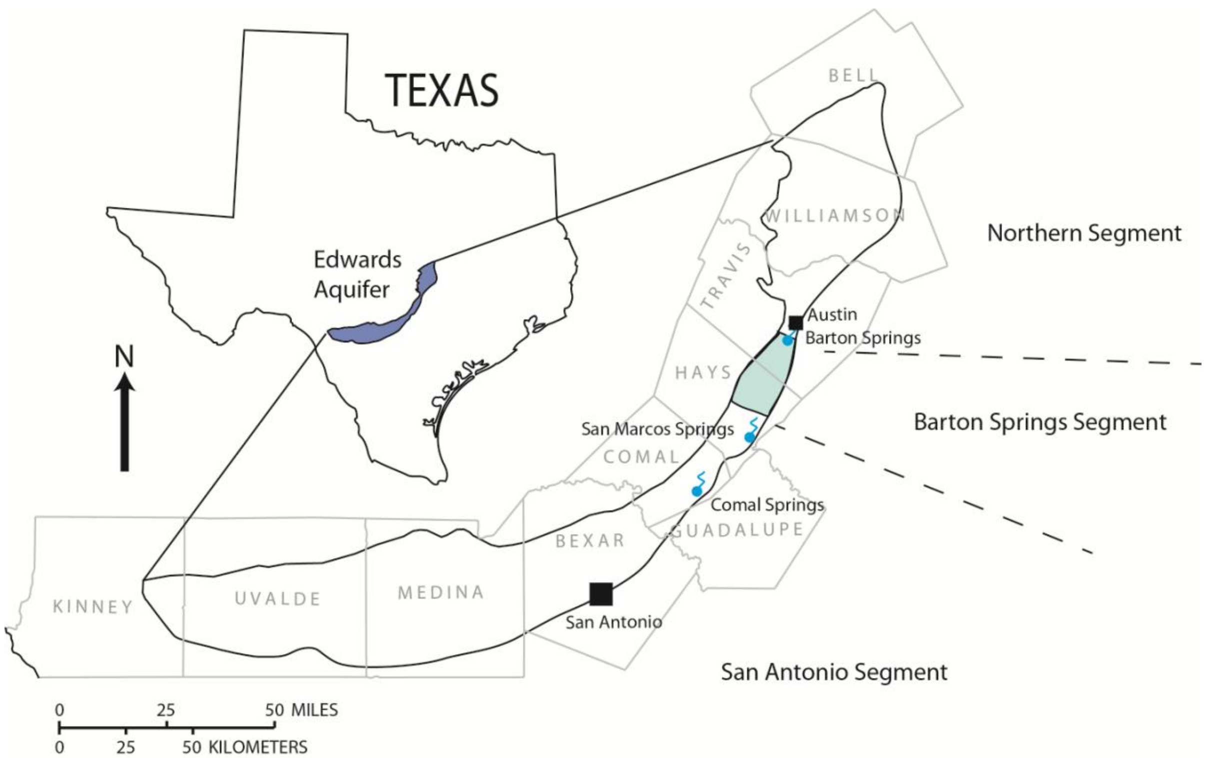

Figure 1. *Location map of the Edwards Aquifer and its segments. The focus of this study is on the Barton Springs segment of the Edwards Aquifer in Hays and Travis Counties. Figure modified from Ryder, 1996.*

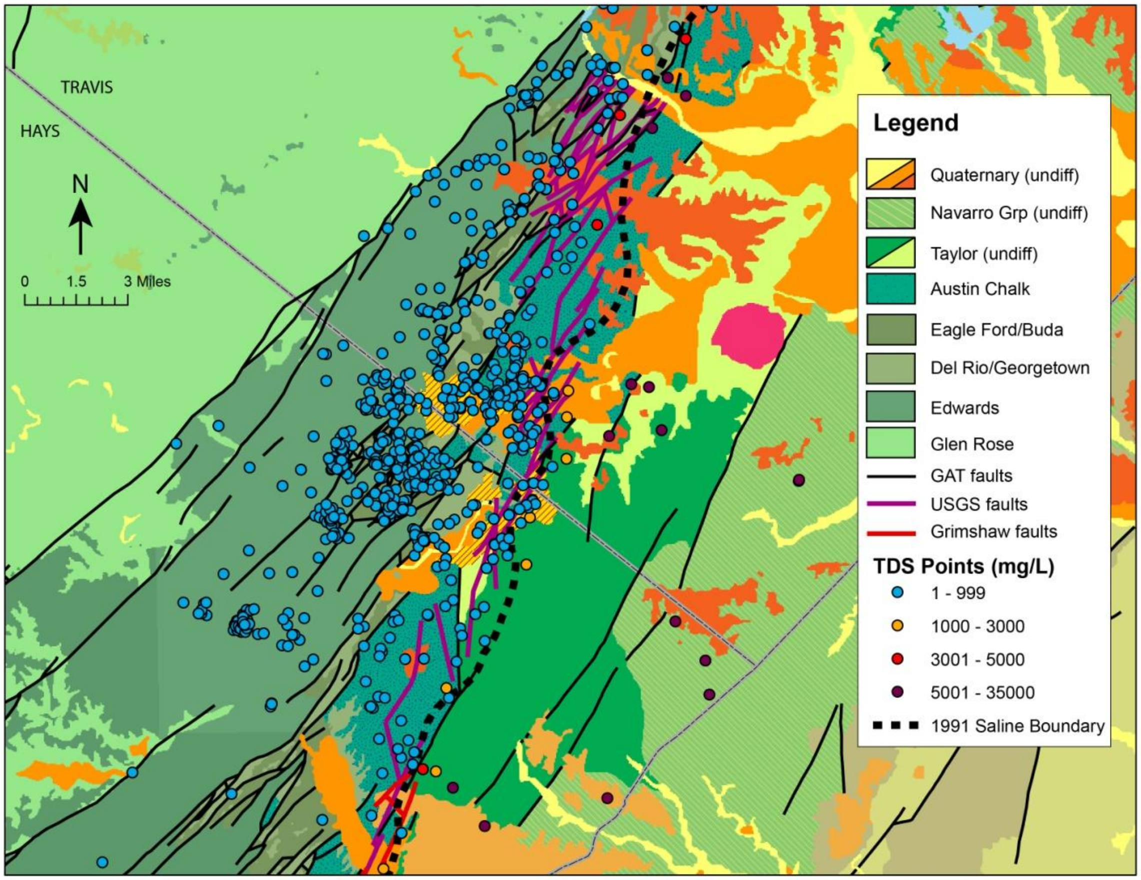

Figure 2. *Geologic map of a portion of the study area showing previous saline boundary and also faults mapped in the study area. TDS values from this study are plotted that show a need to revisit the boundary delineation. The geology is modified from the Geologic Atlas of Texas (GAT).*

PREVIOUS STUDIES

Numerous studies have focused on the freshwater/saline-water interface, and its evolution, in the Edwards Aquifer. Below is a brief summary of some of those studies and relevant conclusions presented in chronological order.

Petitt and George (1956) provide the first regional saline boundary in the Edwards Aquifer (San Antonio segment). The delineation extends from the Val Verde-Kinney boundary through the San Antonio area and to the Travis-Hays County line. The boundary in Hays County generally follows IH-35. Petitt and George (1956) note that faults appear to control the boundary in some locations, but not in others. They further note the spatial heterogeneity of the quality of the water east and south of the boundary with some high-yielding wells producing hydrogen sulfide water. Garza (1963) presents the boundary map of Petitt and George (1956) and further notes changes in water quality related to head, but only in wells proximal to this boundary.

DeCook (1960) presents a geologic and hydrogeologic study of Hays County. A detailed geologic map of Hays County is presented, but no delineations of the Edwards Aquifer boundaries (and saline zone) are described. However, in general he describes Edwards limestones southeast of the Kyle fault as being downfaulted to depths such that circulation of groundwater is slow and the water is highly mineralized (average of 2,990 mg/L TDS).

Abbott (1975) describes the evolution of the Edwards Aquifer in general and uses the term “bad-water” line to describe the boundary between freshwater and saline water in the Edwards Aquifer. Abbott describes the boundary as the early “bypass” or a boundary that defined the limit of circulating groundwater.

Puente (1978) presents a map that delineates the “bad-water” line, or the down dip limit of freshwater for the Edwards Aquifer. His map generally coincides with the one first defined by Petitt and George (1956) except that it does not extend all the way west to Val Verde County.

Brune and Duffin (1983) describe the Edwards Aquifer in Travis County and provide a delineation of a boundary that is the “down dip limit of fresh to slightly saline water.” Their boundary also generally follows IH-35; however, the boundary trends to the southeast of IH-35 approaching Hays County. They present cross sections through the aquifer indicating a general vertical boundary between the freshwater and saline-water that do not coincide with faulting shown as vertical normal faults.

Senger and Kreitler (1984) discuss the “bad-water” zone and describe a minor hydraulic gradient from the southeast to the northwest across the “bad-water” line. They furthermore describe water-level and chemistry fluctuations in a brackish well (58-50-301, Lovelady)and suggest an interconnection between the “bad-water” zone and the freshwater aquifer.

Baker et al. (1986) present a map that delineates the Edwards Aquifer TDS boundaries of <1,000 mg/L, 1,000 to 3,000 mg/L, and > 3,000 mg/L through Hays, Travis, Williamson, and into Bell Counties. Baker et al. (1986) note that the increase in TDS with distance from the recharge zone in Travis and Hays Counties appears to be due to the intense faulting in those two counties.

Slade et al. (1986) present the first comprehensive study of the Barton Springs segment of the Edwards Aquifer. They describe the eastern boundary of the aquifer as the divide between groundwater containing less than, and more than 1,000 mg/L of dissolved solids. They indicate this boundary is called the “bad-water” line, and the area east of this line is the “bad-water” zone. They describe this zone as having a greatly reduced circulation to Barton Springs. Slade et al. (1986) use the term “bad-water” encroachment to describe the potential movement of water from the “bad-water” zone toward the freshwater zone in the northern portion of the study area. Potentiometric gradients and increases in TDS at Barton Springs and wells located along the interface are the basis for that conclusion. They further discuss that “bad-water” encroachment may not occur in the southern portion of the study area (Kyle) because faults may act as barriers; however, they note that during extreme drought conditions the gradients could induce some flow from the “bad-water” zone into the freshwater zone.

Land and Prezbindowski (1981) reviewed chemical variation and water-rock diagenetic models about the source of the saline water in the Edwards. They conclude that major faults provide a pathway for brines from the deep Gulf of Mexico basin, driven north and westward by overpressure, to mix with and become progressively diluted by younger meteoric waters.

Flores (1990) presents a detailed delineation of the freshwater/saline-water interface in the study area (Williamson, Travis, and Hays Counties). The study included drilling new wells and significant hydrogeologic evaluations of those wells and provided important data for this study. TDS data from the Flores (1990) was not found within the TWDB database at the time of writing this report, but was incorporated into this geodatabase. The freshwater/saline-water boundary in Flores (1990) appears to be the boundary used by the TWDB for the eastern extent of the Edwards Aquifer in the major and minor aquifers of Texas (Ashworth and Flores, 1991; Ashworth and Hopkins, 1995; George et al., 2011).

Ashworth and Flores (1991) formally designated the boundaries of all the major and minor aquifers in Texas. The eastern boundary delineated for the Edwards (Balcones Fault Zone) is the same boundary used today in Hays and Travis Counties.

Schultz (1993) presents estimated total dissolved solids data using geophysical (resistivity) data. The report uses the estimated TDS data to draw contour lines in the area between San Antonio and Kyle. Data from the appendix of Schultz (1993) was incorporated into this report.

Groschen and Buszka (1997) present a detailed study of the hydrogeologic framework and the geochemistry of the saline-water zone. Using hydrogen and oxygen isotopes they identified two hydrological and geochemical regimes in the saline-water zone. The first one, a shallower updip regime of predominantly meteoric water recharged from the freshwater zone; and the second, a deeper downdip regime that is thermally altered, hydrologically stagant, and much older. They further describe the saline zone as hydrologically compartmentalized due (in part) to faults that impede updip and downdip flow. They conclude that substantial amounts of updip flow of saline-water toward the freshwater zone is unlikely.

Hovorka et al. (1998) studied the permeability structure of the Edwards Aquifer. They use the studies of Shultz (1993), which identify a complex three dimensional boundary, but whose two dimensional map boundary was used to infer the influence of structure on the geochemistry. Hovorka et al. (1998) conclude that faults, and the ramp-relay geometry described by Grimshaw (1976), strongly influence the boundary of the saline-water zone.

Payne et al. (2007) conducted a geophysical pilot study using time-domain electromagnetic (TDEM) sounding profiles to delineate the freshwater/saline-water interface in the Barton Springs segment of the Edwards Aquifer. The results indicate a relatively sharp transition from west to east. The northern-most profile shows some relatively conductive (interpreted to be saline) water extending below relatively resistant water (interpreted to be fresh).

The 2007 State Water Plan (TWDB, 2007; Appendix 7.1) discusses revisions to boundaries of aquifers, including the Edwards (Balcones Fault Zone) in the San Antonio Segment. Revisions to the saline interface were made based on the data in Schultz (1993, 1994) and Waugh (1993, 2005). The boundary changes put the official TWDB-defined aquifer boundary in agreement with the Edwards Aquifer Authority. Significant changes were made in Medina, Uvalde, and Frio Counties (TWDB, 2007).

Mahler (2008) presents statistical analyses of major ion and trace element geochemistry data from wells that transect the freshwater/saline-water interface in the San Antonio area. Data was collected for more than 21 years from these wells. Mahler (2008) concludes that the transition zone wells (wells 1,000 to 10,000 mg/L) have relatively constant geochemistry and are not as connected to the surface hydrological conditions as the freshwater wells. Despite being less influenced by surface hydrological conditions, these wells do show some geochemical response to varying hydrologic (drought versus non-drought) conditions, although more slowly than the freshwater wells. Cross sections through the study area indicate vertical stratification of the freshwater/saline-water interface with saline water extending west beneath the Person Formation of the Edwards Group.

Lambert et al. (2010) looked at physiochemical properties and the hydraulics of flow near the freshwater/saline-water boundary in four transects created by 15 wells. The transect most relevant to this study area is the Kyle area transect. The average lateral flow potential (based on heads) in the Kyle transect area (Hays County) is from the saline zone into the freshwater zone. However, they conclude that the data for all the wells (and especially the Kyle #2) suggest that the interface is likely to remain stable laterally and vertically over time.

Thomas et al. (2012) assessed the potential for lateral flow across the freshwater/saline-water interface. Some results of their study describe “the daily mean equivalent freshwater heads indicated that, although the lateral-head gradient at the Kyle transect varied between into and out of the freshwater zone, the lateral-head gradient was typically from the transition zone into the freshwater zone.”

A workshop was convened on August 22, 2008 by the Barton Springs/Edwards Aquifer Conservation District to discuss what is known about the saline zone and the freshwater/saline-interface. Many of the studies outlined above were discussed. In attendance at the workshop were 25 groundwater scientists and other groundwater professionals in addition to District staff. Some of the consensus conclusions include: 1) over the period of data collection (~25 years), movement of saline water into freshwater areas has been localized. 2) Under moderate drought conditions with current pumping, there is little threat to the freshwater zone. However, it is not understood how that might change with more extreme drought and more pumping. 3) Dissolution due to mixing of saline and fresh waters (hypogenetic porosity development) is probably taking place on the freshwater side of the interface. This would imply that this process is not taking place to any significant degree farther into the saline zone (Brian Smith, personal communication).

DATA SOURCES/METHODS

Appendix A provides the site and TDS data used in this evaluation (n=856). The primary sources of data for this evaluation were the Texas Water Development and the Barton Springs/Edwards Aquifer

Conservation District's well databases (TWDB, 2013; BSEACD, 2013). Well information and geochemical data for wells completed in the Edwards Aquifer in Travis and Hays counties were queried and combined into a single geodatabase of about 830 wells and springs using Microsoft© Access. The data were analyzed for count, minimum, maximum, and average of the TDS and conductivity data available at each site. The data consists of about 50% TDS and 50% specific conductivity information, with the majority of the specific conductivity data originating from the BSEACD database.

TDS was either directly measured or calculated from major ions as described in Rein and Hopkins (2008). Specific conductivity data were measured in the field with various instruments (Horiba, InSitu, etc). Those data were converted into TDS using an empirical relationship between TDS and specific conductivity. That relationship was derived from 377 data points (**Figure 2**). On average the correlation results in TDS values about 6% higher than measured TDS.

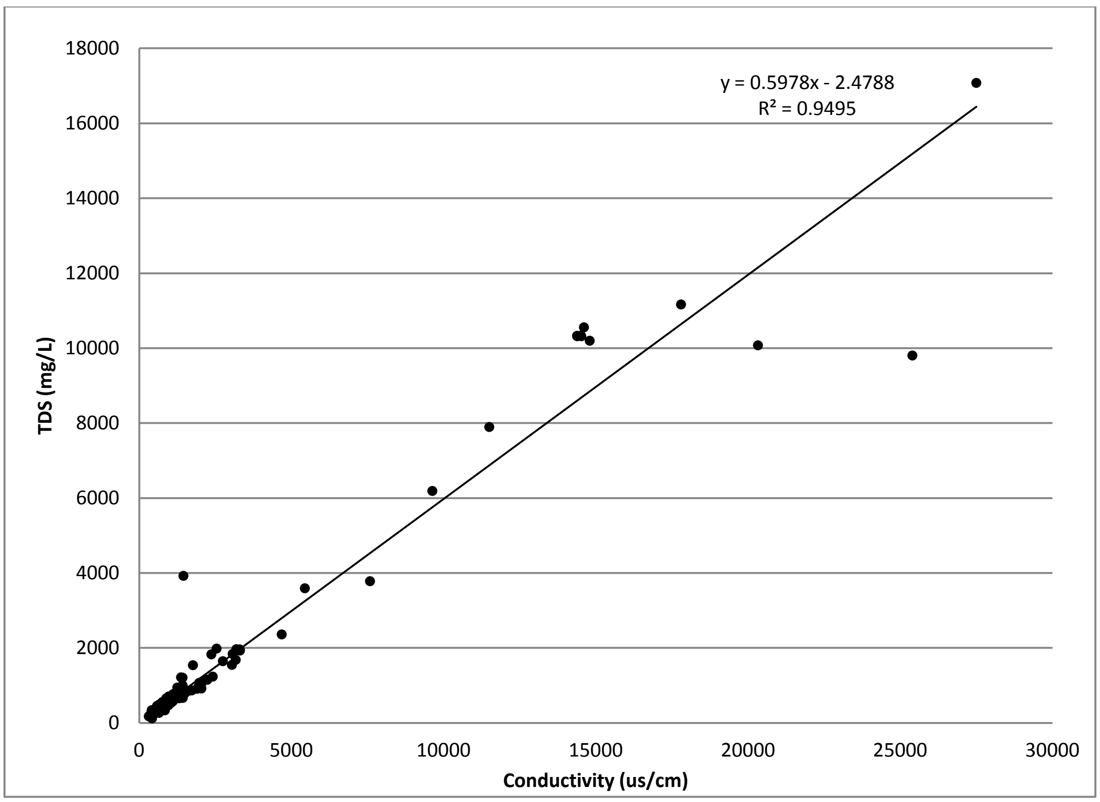

Figure 3. *Correlation between measured total dissolved solids and specific conductivity.*

TDS and conductivity data not within the BSEACD or TWDB databases were obtained from Flores (1990; n=3) and Schultz (1993; n=6). An additional 10 qualitative (not measured values) data points were obtained from the Texas Licensing and Regulation Driller's Database (TDLR, 2013) by reviewing all wells within a mile of the existing boundary and fields where drillers indicated the quality of the water. The authors also inserted three qualitative data points where depths and surface casing corrosion were consistent with high TDS waters.

The final dataset used in this evaluation is termed “composite” TDS data and consists of measured TDS (average value if more than one sample exists at a site) and the estimated TDS data from specific conductivity measurements as well as qualitative data (n=13).

The data set was then gridded (kriging method) in Goldenware Surfer©. The grid was blanked outside the convex hull of the data. Contours and point data were reviewed and errors were corrected or deleted. These contours were exported from Surfer© as a shapefile and imported into ArcGIS. Contours were then hand-modified by the author based upon the distribution of eastern-most freshwater data points and also geologic features such as faults that can influence the geometry of the boundary. Source maps for the faulting include Grimshaw (1976), Geologic Atlas of Texas (GAT, 2007), and the USGS (Blome et al., 2005).

RESULTS

The final datasets used to refine the freshwater/saline-water interface are presented in **Appendix A**. The final delineation of the freshwater/saline-water interface is shown in **Figure 3**. Changes in the 1,000 mg/L contour line result in a mapped lateral shift of the boundary of up to 1.3 miles within the District. In the northern portion of the District the mapped extent of the interface shifts to the west compared to the 1991 delineation, for an apparent net loss of 6.9 mi^2 of areal extent of freshwater aquifer. In the southern portion of the District the mapped extent of the interface shifts to the east compared to the 1991 delineation for apparent gain in freshwater area of about 3.1 mi^2. In total, the mapped extent of this study indicates a net loss of the freshwater aquifer of 3.8 mi^2 in the District compared to the 1991 delineation. **Figure 4** slows the wells that demonstrate some variability in TDS in relation to the interface.

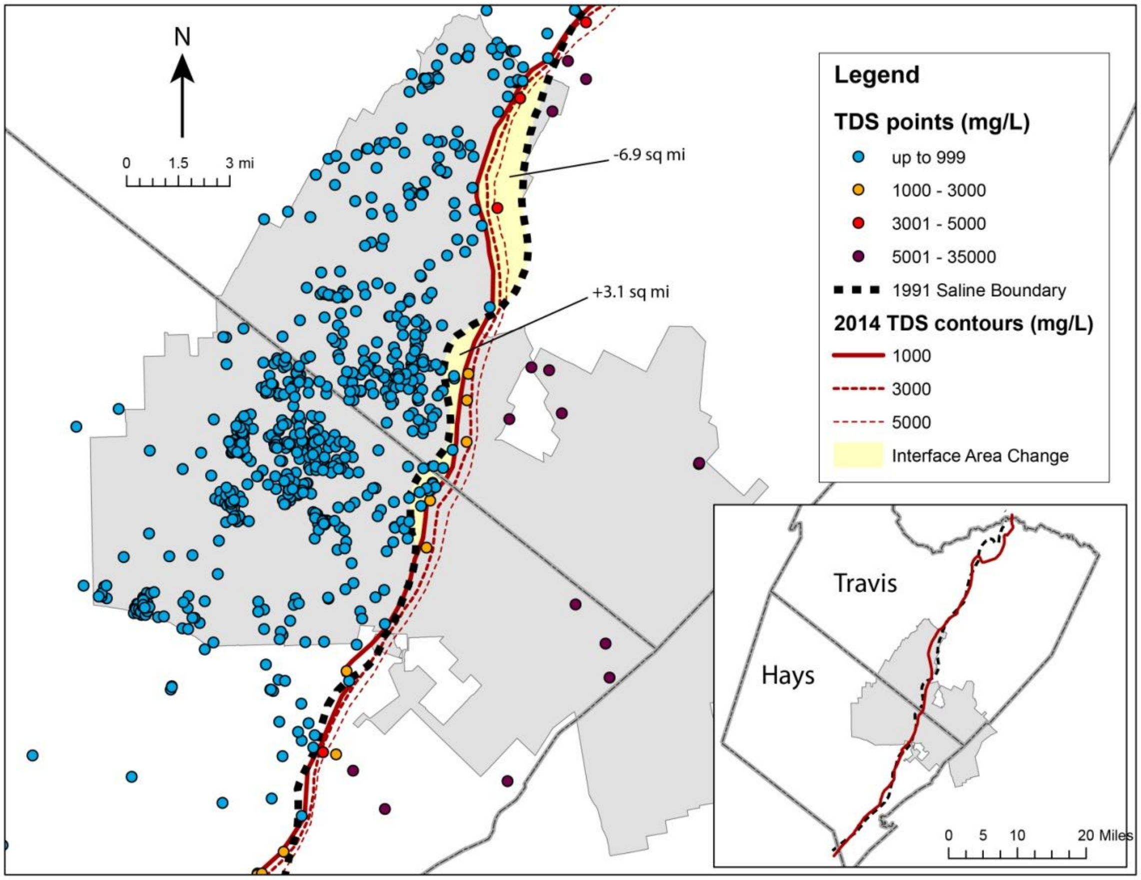

Figure 4. *Results of assimilated composite TDS data from wells completed in the Edwards Aquifer and the resulting delineation of the freshwater/saline-water interface. There is a mapped apparent net loss of 3.8 mi*^{2} *of freshwater aquifer when compared to the 1991 saline boundary delineation.*

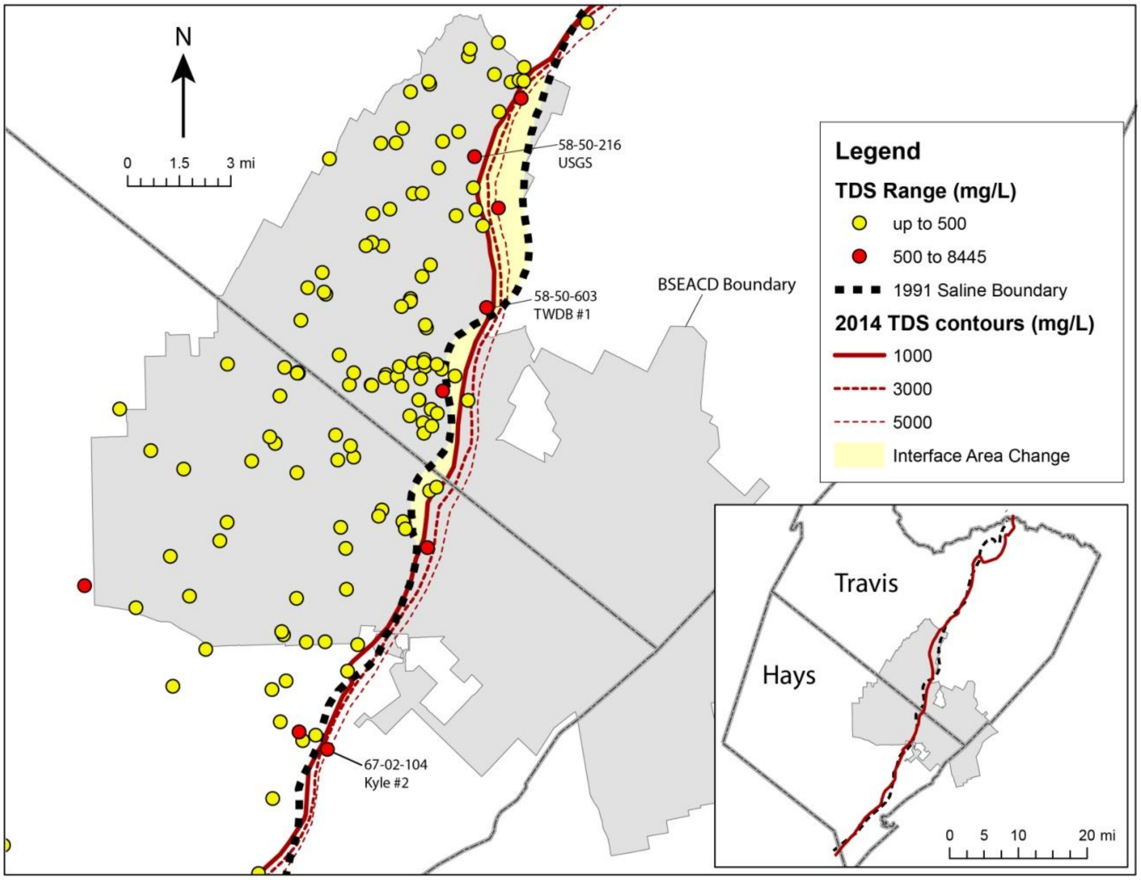

Figure 5. *Map of wells that show a range of measured and estimated TDS values. Wells noted in the text are labeled on the map. The well on the southwest portion of the study area is likely influenced by completion of the well in a portion of the Trinity Aquifer, often a source for elevated TDS.*

DISCUSSION

The freshwater/saline-water interface as presented in this study is a two-dimensional representation of a very complex boundary that has three (depth) and four (time) dimensional variability not represented by this simple boundary.

The vertical nature of this boundary is known to be influenced by structure, lithology, and hydrodynamics. In Hays and Travis Counties faulting does appear to have a strong influence on the position of the interface (Baker et al., 1986). However, the boundary is likely not a truly vertical interface, owing to the heterogeneity of the lithologic units in the Edwards overprinted by the structure. The vertical heterogeneity of TDS within the Edwards along the interface is well illustrated by the work done by Flores (1990). In that report they show the results of five Edwards zones isolated with packer tests for test well #1 (58-50-603). The zones vary in TDS from 4000 mg/L to 450 mg/L. The minimum TDS was measured in a zone completed in the middle of the Edwards Group. The composite TDS from the well was 704 mg/L and so the mapped position of the boundary is east of the well.

Lambert et al. (2010) shows a well drilled on the actual freshwater/saline-water interface (Kyle #2, 67-02-104). The data and conceptualized diagram for this well clearly indicate a wedge of saline water below the freshwater-bearing intervals extending about 1 mile southeast to northwest between two faults.

Studies have established a somewhat muted hydrologic connection between the freshwater and saline zones (Senger and Kreitler, 1984; Slade et al., 1986; Mahler, 2008; Lambert et al., 2010). Increases in salinity at Barton Springs and some wells during dry conditions, when gradients from the saline zone are toward the freshwater zone, support that hypothesis (Slade et al., 1986; Garner and Mahler, 2007). However, substantial increases in salinity have not occurred to date despite severe droughts and heavy pumping. This lack of increased salinity supports the ideas of Groschen and Buszka (1997) that substantial flows of saline water into the freshwater are unlikely due the compartmentalization (both vertical and horizontal) of the Edwards saline zone.

Figure 4 shows the wells that have a range of TDS values over time and could be interpreted as indicating saline-zone encroachment. However, most of these wells are open well bores that are likely drilled across a complex, non-vertical freshwater/saline-water interface. Accordingly, the boreholes themselves may be pathways for an apparent "encroachment" of salinity as hydrologic conditions vary. This is supported by Lambert et al. (2010) who document intra-aquifer flow within the borehole and flow reversals with changing hydrologic conditions. Competing heads within a borehole are likely the reason for the sudden conductivity changes within a monitor well near Barton Springs (**Figure 4**, 58-50-216). With increased recharge conditions, large and rapid changes in the conductivity of the water in the well are likely the result of head reversals between saline-water and freshwater sources stratified within the formation, but freely available to flow (**Appendix B**).

CONCLUSIONS

- This report documents a substantial refinement of the freshwater/saline-water interface. Mapped changes to the boundary include localized lateral shifts of up to 1.3 miles and an apparent net loss of 3.8 mi^2 of freshwater aquifer when compared to the previous 1991 delineation. This change is due to the new interpretation from more available data.
- The freshwater/saline-water interface as mapped is a two-dimensional estimate of a very complex three-dimensional boundary. As with any mapped boundary, there is inherent uncertainty as to the exact location and geometry of the interface.
- The interface appears to be relatively stable over time in the Barton Springs segment of the Edwards Aquifer. Variation in TDS values measured in wells along the interface could be due to localized flow within boreholes rather than true encroachment of the saline zone. Although encroachment does not appear to be a threat to freshwater supplies, changes in the springflow chemistry at Barton Springs suggest some leakage (flow) into the freshwater aquifer under drought conditions.

ACKNOWLEDGMENTS

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Appendix A: Geodatabase (separate file)

Appendix B: Austin Geological Society Poster Presentation

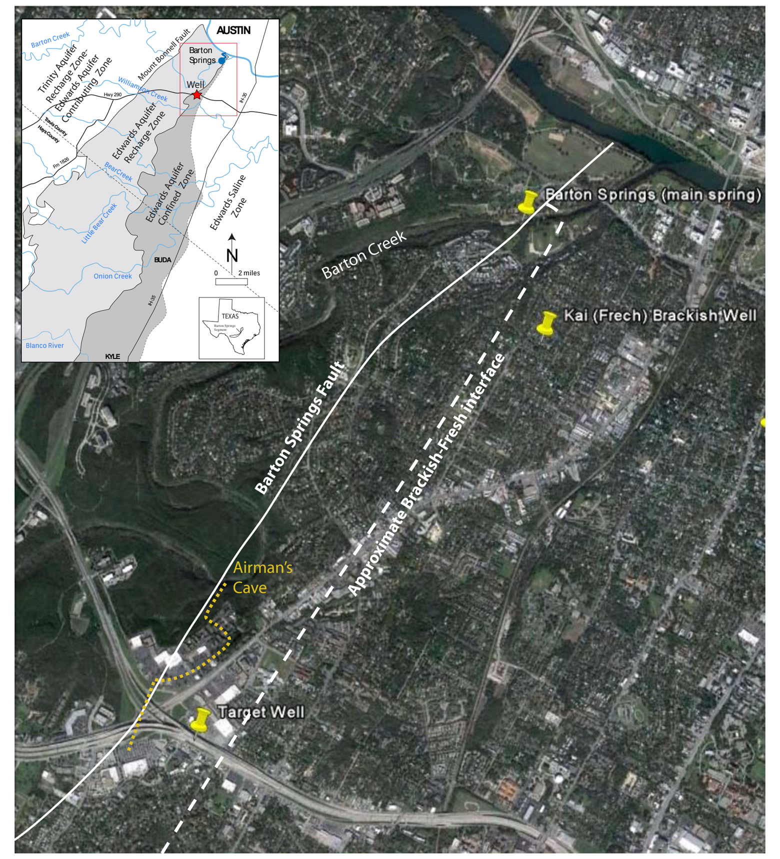
Unusual hydrophysical response in a Edwards Aquifer monitor well: What is going on?

Brian B. Hunt, P.G.

Barton Springs Edwards Aquifer Conservation District

ABSTRCT

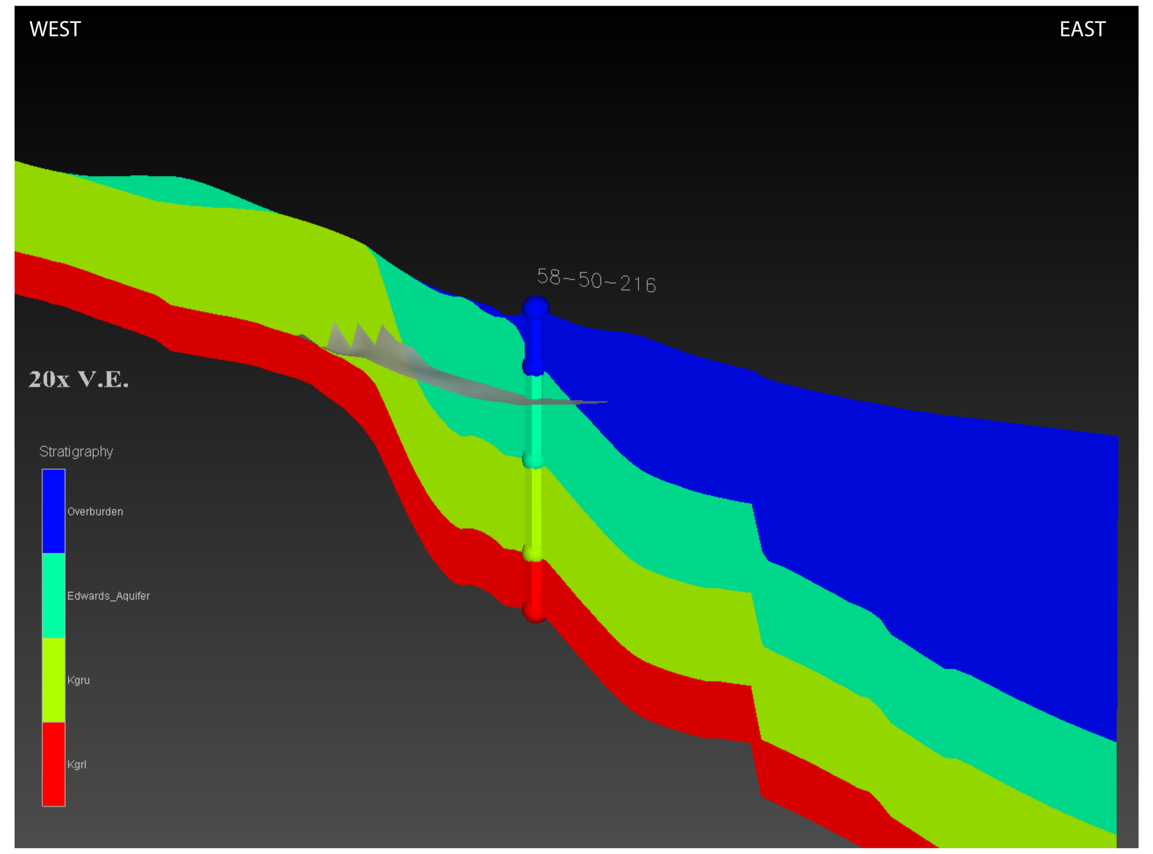
Water level, temperature, and specific conductivity data were collected in a monitor well completed in the Edwards Aquifer near the brackish- fresh-water interface. Data were collected over 2.5 years that spanned one of the wettest (2007) and driest (2009) periods on record. The data presented here appears somewhat unusual in response to long-term and short-term recharge when compared to Barton Springs. For example, conductivity in the Target Well generally has a negative correlation to Barton Springs throughout the periodof record, while temperature and level have a positive correlation to Barton Springs. Understanding the nature and character of the brackish- fresh-water interface is important for resource managment in terms of water-supply and endangered species habitat. The purpose of this poster is to present the data and illicit observations or comments from the wider geologic community. The ultimage goal is to come up with several working hypothesis.



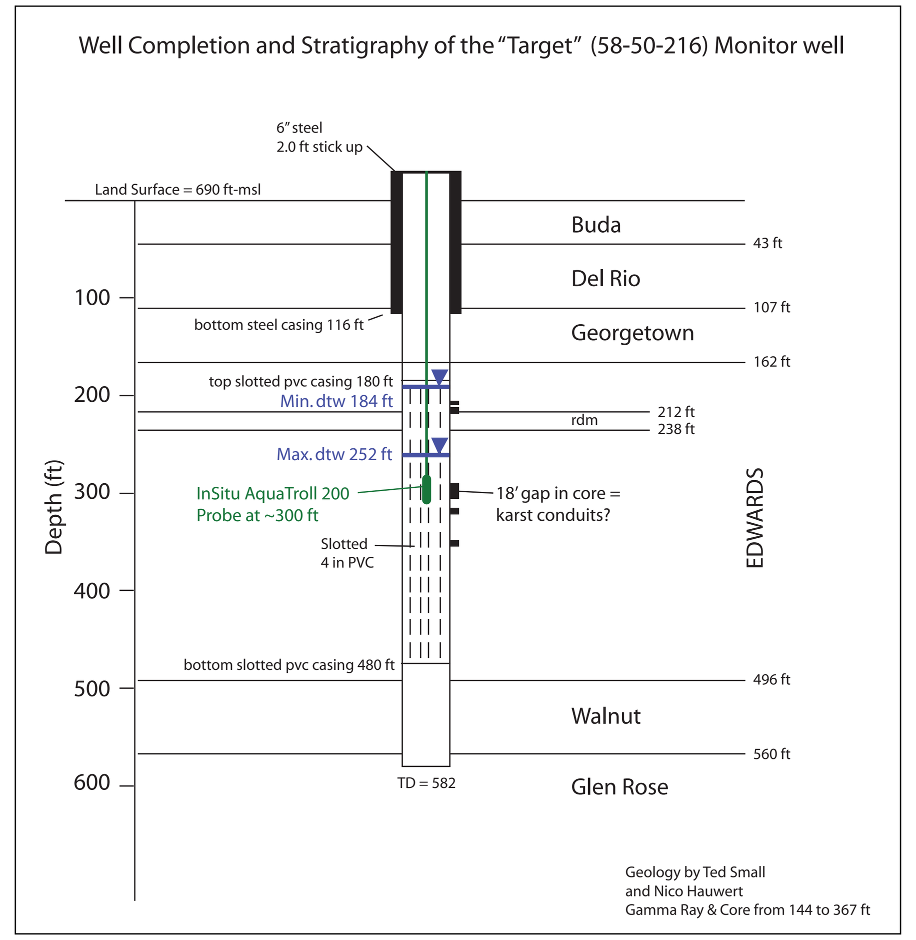
Location map of study area. The Target Well is ~2.5 miles from Barton Springs.

The Barton Springs Fault roughly delineates the eastern edge of the Edwards Aquifer recharge zone.

Airman's Cave, the longest cave in Travis County, is located in the vicinity.



Oblique view of the geologic cross section (west to east) through the Target Well. Cross section from regional model. March 2009 potentiometric surface is denoted as gray shading.



The well fully-penetrates the Edwards Aquifer. Core was taken from the well and gaps in the core could correspond to karst voids.

DATA

Hourly data was collected in the Target Well using an In-Situ, Inc. AquaTroll 200 which measures and rcords level/pressure, temperature, and conductivity data in groundwater. Daily mean springflow, temperature, and conductivity from Barton Springs was obtained from the U.S. Geological Survey. Streamflow data were also obtained from the USGS. Daily rainfall data is from the BSEACD weather station in Manchaca. The data is displayed in its entirety and then is broken up into shorter time periods based upon the Barton Springs hydrograph.