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Potential Hydraulic Connections Between the Edwards and Trinity Aquifers in the Balcones Fault Zone of Central Texas

By: Brian A. Smith and Brian B. Hunt

ON THE COVER

Drilling operations on Edwards/Trinity multiport monitoring well, discussed in this month's featured article. Upper right: Pressure testing and installation of one of 13 packers. Lower right: Close-up of measurement/sampling tool in cut-away of sampling port. Upper left: Sampling and pressure measurements of completed well.

October Meeting Notice

Date: Wednesday, October 14, 2009

Location: Petroleum Club of San Antonio
8620 N. New Braunfels
San Antonio, TX

Speaker: Kevin P. Corbett
Wrangler Resources, LLC
Denver, CO

Topic: Eagleford Shale Exploration Models: Depositional Controls on Reservoir Properties

See Meeting Notice for detailed information.

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SOUTH TEXAS GEOLOGICAL SOCIETY BULLETIN

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Potential Hydraulic Connections Between the Edwards and Trinity Aquifers in the Balcones Fault Zone of Central Texas

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Abstract

As demand for groundwater has increased significantly in recent years in central Texas, limitations have been placed on the amount of water that can be pumped from the Edwards and Trinity Aquifers. Proper management of these aquifers requires an understanding of factors affecting the hydraulic relationship between the two aquifers. Until recently, there has been insufficient head data and water-quality data to assess the hydrologic connection and potential for flow between the Edwards and the Trinity Aquifers.

Potentiometric data were collected from three Edwards/Trinity well pairs and a deep multiport well, plus water-quality data from 13 zones in the multiport well. Potentiometric data from all four sites show that head values are considerably higher in the Edwards than in the Middle Trinity. Head differences between the Edwards and Middle Trinity are as much as 160 ft at the northern well pair and about 50 ft at the southern well pair.

Water-quality data show that groundwater from the 13 sampling zones of the multiport well can be divided into three distinct hydrochemical facies: calcium bicarbonate, calcium sulfate, and an intermediate facies. The calcium sulfate facies has the highest levels of sulfate, magnesium, calcium, and total dissolved solids (TDS) and is associated with zones in the upper member of the Glen Rose Limestone. The lowest TDS zones are in the Edwards, the Cow Creek Limestone, and a rudist reef unit in the lower member of the Glen Rose Limestone.

Significant head differences between zones and the distribution of hydrochemical facies suggest that there is very little, if any, vertical flow between zones. Faults in the area do not appear to create pathways for vertical flow nor do they create barriers to lateral flow. Relay-ramp structures, that are common in the Balcones Fault Zone, provide for some lateral continuity of lithologic units and therefore lateral flow.

Introduction

The Edwards and Trinity Aquifers are important sources of water for domestic, industrial, and agricultural use and for ecological habitats in central Texas, and are the sole-sources of water for many people in the area. In the Barton Springs/Edwards Aquifer Conservation District (District), demand for groundwater has increased considerably in recent years, to the point that usage has either reached or nearly reached the sustainable yield of the Edwards Aquifer (Smith and Hunt, 2004). The Trinity Aquifer has increasingly become an alternative source of water as limits have been placed on the Edwards Aquifer. Stratigraphically, the Trinity Aquifer underlies the Edwards Aquifer. However, along the Balcones Fault Zone (BFZ), normal faulting has juxtaposed the two aquifers laterally, with Trinity units exposed west of the Edwards outcrop in the study area (Figure 1). Previous hydrologic studies of groundwater resources acknowledge a hydraulic connection between the Trinity and Edwards Aquifers (Slade et al., 1986; Mace et al., 2000). However, the extent of that hydraulic connection and the flow of water between aquifers are poorly understood. Current numerical modeling for the Barton Springs segment of the Edwards Aquifer does not account directly for flow between the Edwards and Trinity Aquifers (Scanlon et al., 2001). Characterizing the hydraulic connection is important for predictions of groundwater availability in both aquifers and for spring flow at Barton Springs. Additionally, significant inflow from some units of the Trinity Aquifer could have impacts on the water quality of the Edwards Aquifer and Barton Springs.

Until recently, there have been insufficient head data and water-quality data to assess the hydrologic connection and potential for flow between the Edwards and the Trinity Aquifers. The purpose of this study was to collect data from discrete intervals of the Edwards and Trinity Aquifers that could provide insight to the amount and characteristics of potential flow within and between the Edwards and Trinity Aquifers so that groundwater availability and quality issues for these aquifers may be better addressed. Studies by Smith and Hunt (2004) have shown that during periods of severe drought with high rates of pumping, water quality may be degraded, low water levels could lead to wells going dry, and flow at Barton Springs could be reduced to such low rates that the endangered salamanders in the springs would be jeopardized.

Geology, Structure, and Hydrogeology

The geologic framework of the Edwards and Trinity Aquifers in central Texas has been well described in various papers in recent decades (Maclay and Small, 1986; Small et al., 1996; and Barker and Ardis, 1996). Within the study area, the Edwards Aquifer is composed of the Cretaceous-age Edwards Group (Kainer and Person Formations) which is overlain by the Georgetown Formation. Sediments making up the Edwards Group accumulated on the Comanche Shelf as shallow marine, intertidal, and supratidal deposits. The Georgetown Formation, disconformably overlying the Edwards Group, was deposited in a more openly circulated shallow-marine environment (Rose, 1972).

Mapping of the Barton Springs segment of the Edwards Aquifer has delineated geologic faults and several informal stratigraphic members of the Kainer and Person Formations of the Edwards Group (Rose, 1972), each having distinctive hydrogeologic characteristics (Small et al., 1996). The limestone units generally step down to the east, primarily because of faulting. Most faults trend to the northeast and are downthrown to the southeast, with total offset of about 1,100 ft across the study area. As a result of faulting and erosion, the aquifer ranges from about 450 ft at its thickest along the east side, to 0 ft along the west side of the recharge zone (Slade et al., 1986). Studies of structures along the BFZ (Collins and Hovorka, 1997; Ferrill and Morris, 2008) indicate that much of this area consists of southeast dipping, *en echelon*, normal faults with throws from less than 1 ft to as much as 850 ft. Some of these faults are continuous over many miles, while others extend only a few miles or less. Fault blocks between the points where fault displacement decreases to zero are called relay ramps. The relay ramps transfer displacement from one fault to an adjacent fault (Collins, 1995).

The Edwards Aquifer, located in south-central Texas, is one of the most prolific karst aquifers in the United States and provides water to nearly 2,000,000 people, in addition to agriculture, industry, and commerce. Between 50,000 to 60,000 people depend on the Edwards

Aquifer within the District. The Edwards Aquifer is a karst aquifer developed in faulted and fractured Cretaceous-age limestones and dolomites and lies within the BFZ. It is characterized at the land surface by numerous solution features such as caves, sinkholes, and enlarged fractures. In the subsurface, conduits have developed along faults, fractures, and bedding planes. Tracer studies have shown that groundwater flows rapidly through these conduits at rates up to 39,000 ft/day (Hunt et. al, 2006). Hydrologic divides separate the Edwards Aquifer into three major segments. The smallest segment, the Barton Springs segment of the Edwards Aquifer, is the subject of this paper. North of the Colorado River is the Northern segment of the Edwards Aquifer. It extends from the Colorado River into Bell County near Salado. Separating the Barton Springs segment from the San Antonio (or Southern) segment is a groundwater divide near Kyle that varies depending on water levels in the aquifer and recharge contributions from the Blanco River and Onion Creek.

The Trinity Aquifer is composed of Cretaceous-age limestones, shales, marls, and sandstones that are divided into the Upper, Middle, and Lower Trinity Aquifers. The Trinity Aquifer is the primary source of water in the Texas Hill Country. In the BFZ, the Edwards Aquifer both overlies and is adjacent to the Trinity Aquifer system. Groundwater quality of the Trinity Aquifer is generally poorer and more variable than the Edwards Aquifer, containing higher total dissolved solids (TDS) and less desirable constituents such as sulfates. The boundary between fresh and slightly saline (1,000-3,000 mg/l) water is poorly defined for the Trinity Aquifer. Along the western part of the District, where the Edwards Aquifer is thin, water-supply wells commonly penetrate the lower Edwards units and are completed in the Upper and Middle Trinity Aquifers. Many Trinity wells have open-hole, or multiple-zone, completions and produce water from both the Upper Trinity and part of the Middle Trinity Aquifers, with exact water-bearing units difficult to determine.

The Upper Trinity Aquifer consists solely of the upper member of the Glen Rose Limestone which is composed of thick beds of alternating limestone, dolomite, marl, and shale; gypsum and anhydrite are common (Brune and Duffin, 1983; Ashworth, 1983)). The Middle Trinity Aquifer is composed of (from stratigraphically lowest to highest) the Cow Creek Limestone, Hensel Sand, and the lower member of the Glen Rose Limestone. The Cow Creek Limestone represents a beach facies and is a massive, sandy dolomitic limestone that yields moderate amounts of good quality water to wells (Broun et al. 2007; Brune and Duffin, 1983; Ashworth, 1983)). The Hensel Sand is composed of alternating gravel, sand, silt, and shale. The lower member of the Glen Rose Limestone is composed of massive fossiliferous limestone and dolomite that grade upward into thin beds of limestone, shale, and marl. In the upper section of the lower member of the Glen Rose Limestone are thick rudist mound facies that can yield considerable amounts of water to wells (Broun et al. 2007). Underlying the Middle Trinity Aquifer is the Hammett Shale that acts as a confining layer between the Middle and Lower Trinity Aquifers.

Previous Studies

The hydraulic connection between the Trinity and Edwards Aquifers is poorly understood. The amount of cross-formational flow is unknown, although it is thought to be relatively small on the basis of water-budget analysis for surface recharge and discharge in the Edwards Aquifer (Slade et al., 1985; Scanlon et al., 2001). Yet hydrochemical evidence near Barton Springs suggests that older, more saline water from the Trinity and lower Edwards

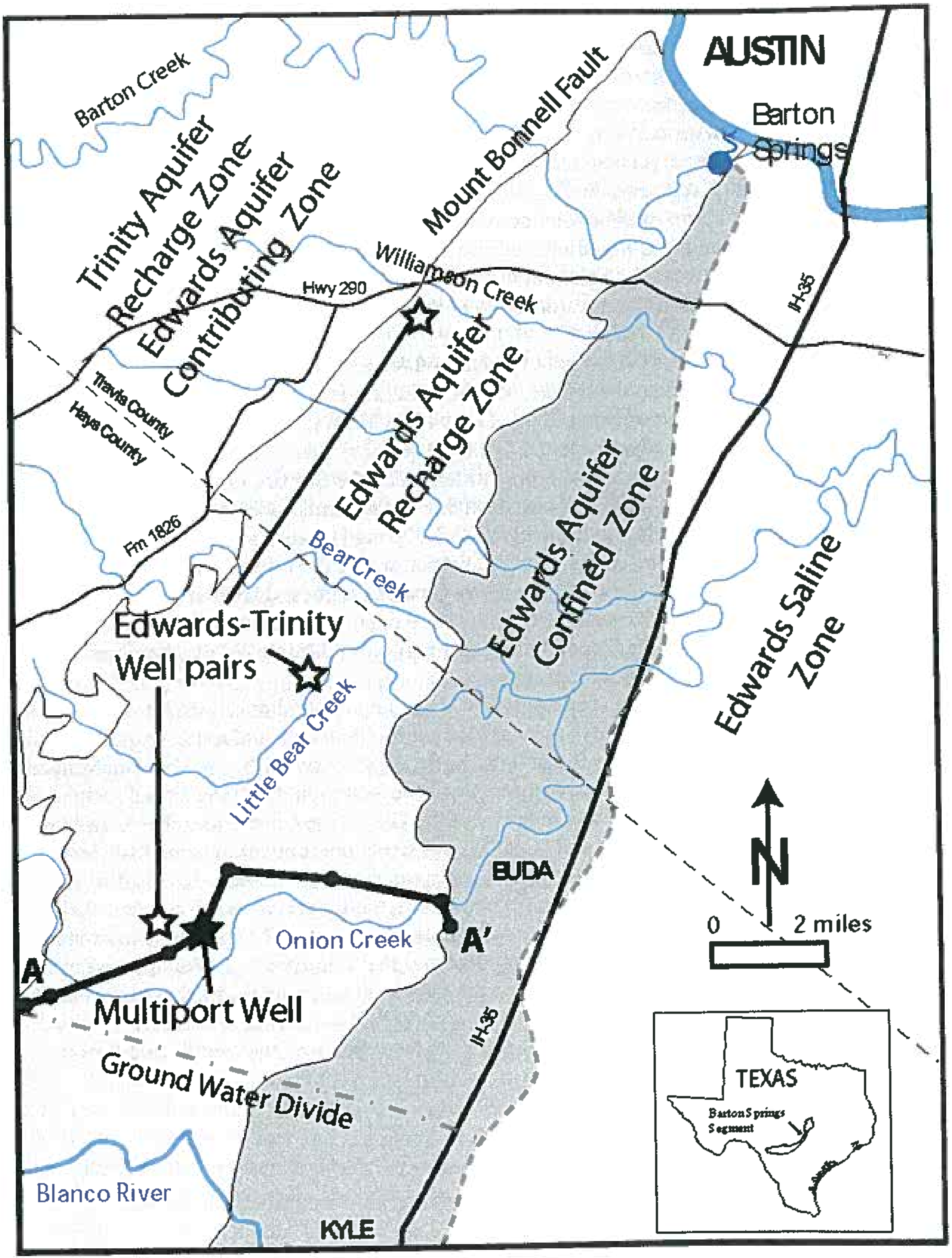


Figure 1. Location map of the Barton Springs segment of the Edwards aquifer and monitor wells used for this study.

formations flows upwards, generally along faults, into the upper Edwards. Leakage may locally affect water quality and influence water levels (Senger and Kreitler, 1984; Slade et al., 1985; Slade et al., 1986).

A regional groundwater model of the Trinity Aquifer in the Hill Country includes lateral groundwater leakage into the Edwards Aquifer in the San Antonio area in order for the model to simulate observed hydrogeologic conditions (Mace et al., 2000). However, where the Trinity Aquifer is in contact with the Barton Springs segment, the regional Trinity model indicates little or no lateral flow into the Edwards Aquifer in the study area. Potentiometric maps along the western boundary of the Edwards Aquifer show similar elevations for the Edwards and Upper Trinity Aquifers, suggesting some hydrologic connection where the aquifers are laterally juxtaposed (Hunt et al., 2007).

Flow from the Upper Trinity Aquifer into the Edwards Aquifer has been documented by tracer studies conducted in northern Bexar County (San Antonio) by the Edwards Aquifer Authority (Smith et al., 2007). Groundwater flow was traced for a distance of about 5 miles from the injection point in a cave in the uppermost units of the upper member of the Glen Rose Limestone to the reception point in a monitor well completed in the Edwards. Flow crossed over seven faults; several of which have throws of greater than 200 ft. Travel time based on arrival time of the initial tracer detection in the well was 1.8 days or about 13,300 ft/day. Obviously, the presence of conduits is indicated by these results.

Methodology

Because demand for groundwater in Central Texas is rapidly increasing, groundwater scientists are now studying its aquifers in far greater detail. Most aquifer parameters are determined from wells that penetrate the entire Edwards section or wells that are completed over considerable thicknesses of the Trinity. Monitoring of more discrete intervals is needed to provide data that reflect the true complexity of these aquifers. To address these issues, the District collects data from three well pairs and has installed a multiport well with 14 monitoring zones (Figure 2).

Monitor Well Pairs

To complete the well pairs, shallow Edwards wells were installed next to abandoned wells that are completed in the upper or Middle Trinity units. The District installed a monitor well next to a well that supplied water to a quarry from the Upper and Middle Trinity Aquifers (Figure 3). The saturated portion of the monitor well was in the dolomitic and basal nodular (Walnut Formation equivalent) informal members of the Kainer Formation (Edwards Group). Two other well pairs were completed when the U. S. Geological Survey (USGS) installed shallow Edwards wells next to abandoned Upper and Middle Trinity wells. These two wells were installed as part of a National Water Quality Assessment (NAWQA) program in the Austin area.

Multiport Monitor Well

To better understand the complexities within a single aquifer and between aquifers, a Westbay® (Schlumberger) multiport monitor well was installed in the study area (Figure 2).

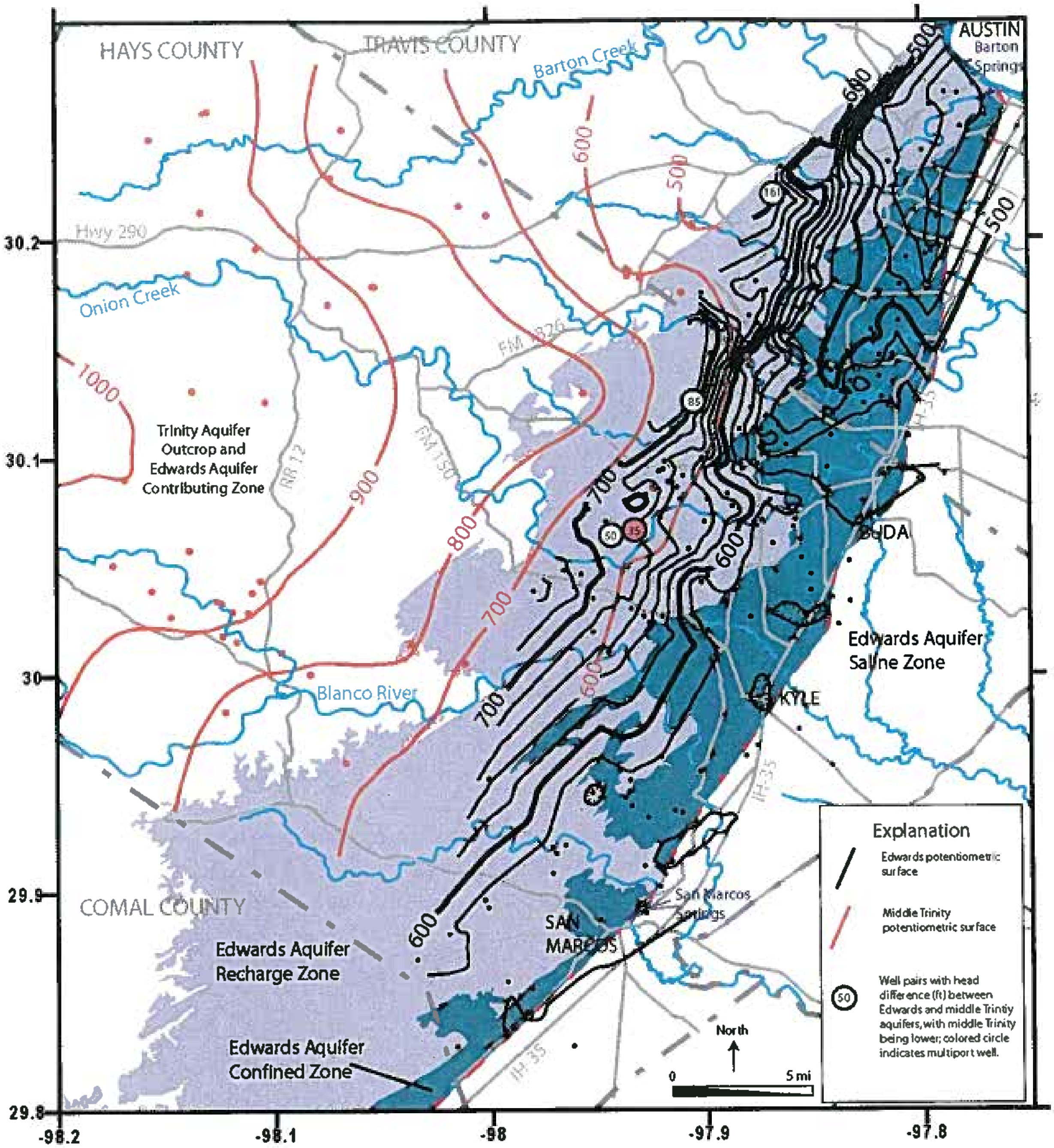


Figure 2. Potentiometric map of the Edwards and Middle Trinity Aquifers (February 2009) and locations of well pairs and multiport monitoring well.

The well was designed to monitor heads and water quality in pre-selected, discrete zones in the Edwards, Upper Trinity, and Middle Trinity Aquifers (Figure 4). A Westbay® well consists of 1.9-inch OD Schedule 80 PVC casing with PVC couplings connecting each section of casing. A borehole with a diameter between 3 to 5 inches is required. Where a monitor zone is to be established, permanent inflatable packers are placed in the string of casing at the top and bottom of the zone (Figure 4). Between the packers, a special coupling with a spring-loaded valve

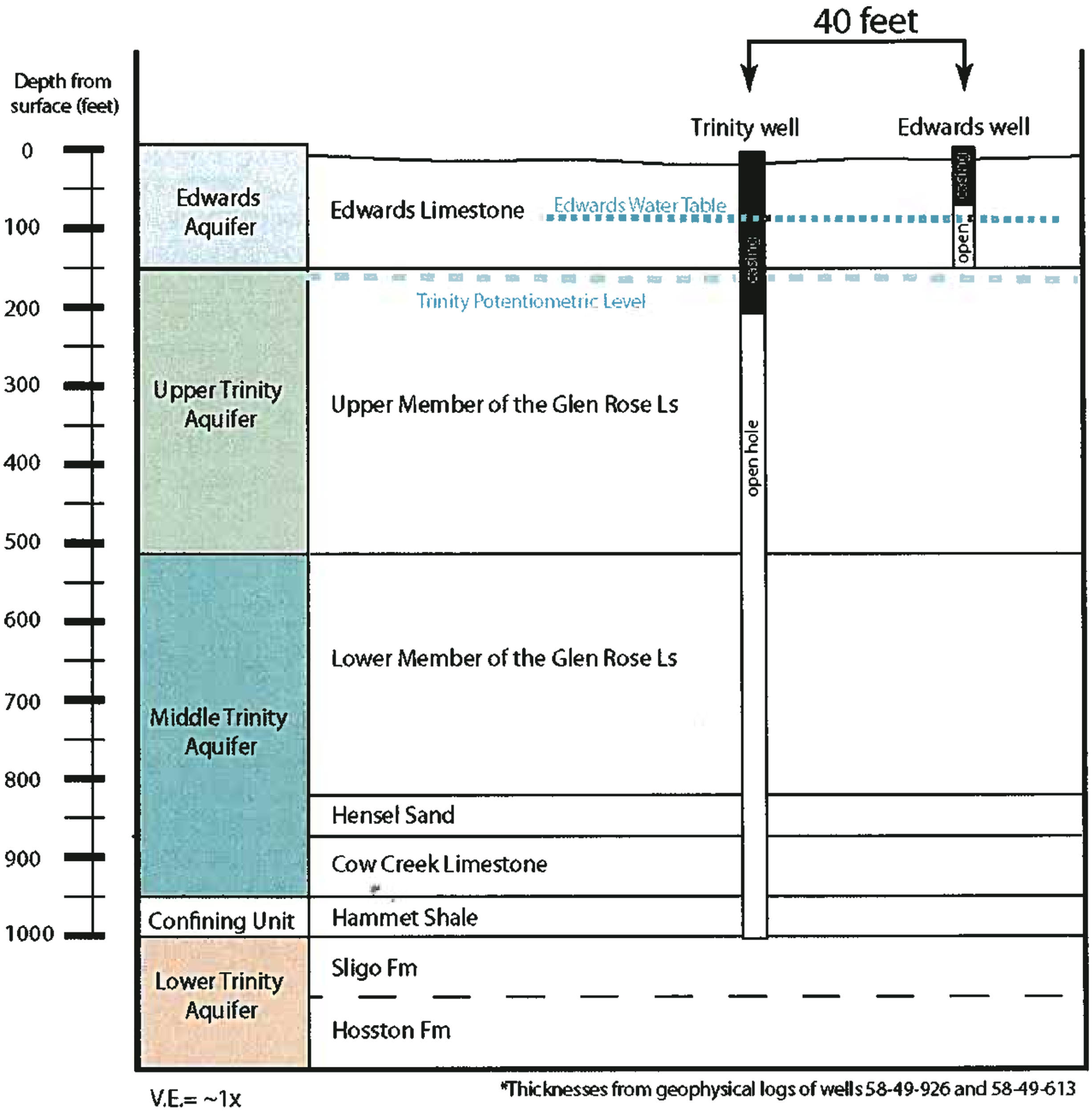


Figure 3. Stratigraphy, well completion diagrams, and potentiometric levels (February 2009) at Borheim Quarry.

(sampling port) is used rather than a standard coupling. Pumping ports may also be installed in each zone through which the annular space may be purged of drilling fluids and slug tests may be conducted. After the entire string of casing, couplings, and ports have been installed, the packers are inflated with water, thereby sealing the annular space between the PVC casing and the borehole walls. Water samples collected through the sampling ports are representative of water in the formation between the two packers. Any number of zones may be installed in a single borehole. To measure heads in a zone or to collect a water sample, a special instrument is

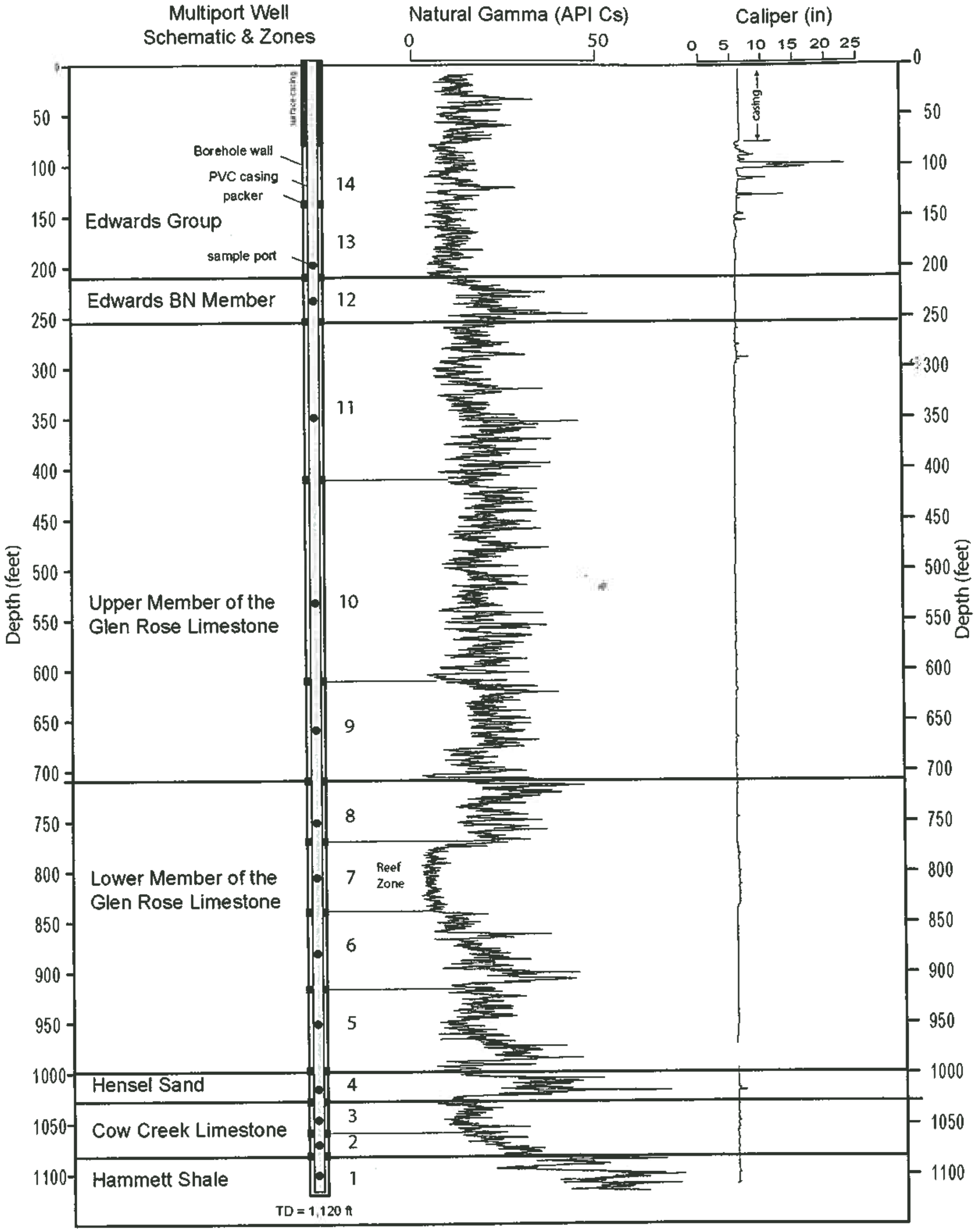


Figure 4. Schematic diagram showing multiport well construction, sampling zones, and natural gamma and caliper geophysical logs of the borehole.

lowered into the casing. This instrument has a built-in pressure transducer and a valve though which water samples can be collected when the valve in the instrument is aligned with the valve in the coupling. The instrument is controlled by an operator at the surface and pressure data are sent from the instrument to a read-out device. Up to a liter of sample may be collected from a zone for each trip of the instrument into the well.

Geophysical logging of the borehole, using natural gamma and caliper tools, was conducted (Figure 4). These data are critical to the design of the well, such as the placement of packers, sample ports, and pumping ports. HX steel casing was inserted in the borehole as a guide to facilitate placement of the Westbay® system and logging of unstable portions of the borehole. District and Westbay® staff assembled and installed the system through the HX casing. Each joint was pressure tested during the installation. After installation, the HX casing was removed and the packers were inflated.

The cross section shown in Figure 5 shows how the multiport well was completed across various Edwards and Trinity units. The deepest monitoring zone was completed in the Hammett Shale. The location of the cross section is shown in Figure 1. Other wells shown on the cross section are open to thick sections of the Edwards and Trinity Aquifers. Because of this, water-level and water-quality data collected from these wells are of limited use.

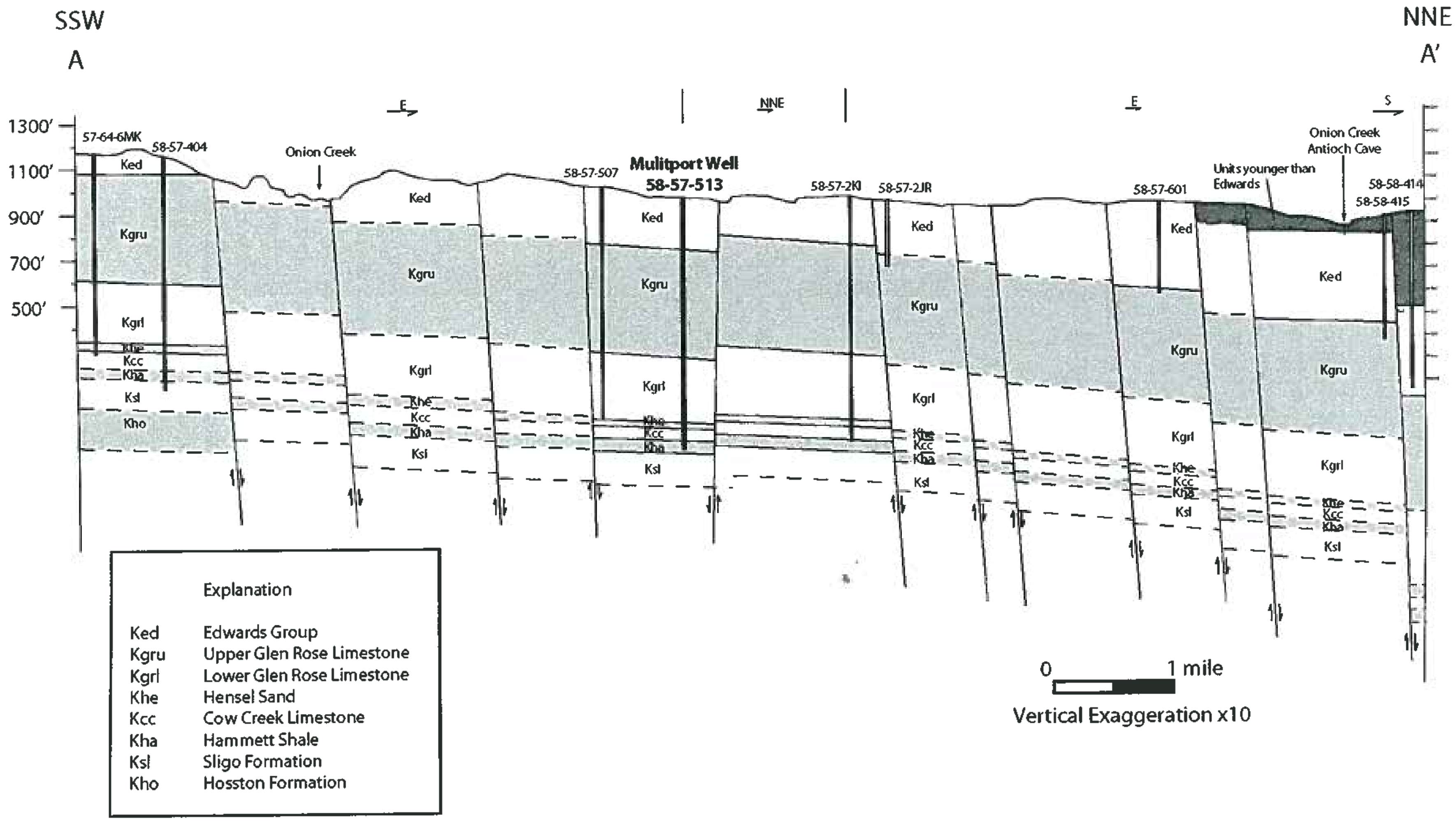
Results

Monitor Well Pairs

Water-level data from the three monitor well pairs show significant potentiometric differences between the Edwards and the underlying Middle Trinity, with downward head gradients from the Edwards to the Middle Trinity. Head differences range from 30 ft in the southwestern part of the study area to as much as 160 ft in the north (Figure 2). Substantial temporal changes are seen in water-level fluctuations of both aquifers, with peak Middle Trinity water levels lagging behind peak Edwards levels by about one to two months (Figure 6). Trinity water levels are slower to rise than Edwards water levels. Head differences seen in the quarry well pair vary from 71 ft to 107 ft with a mean difference of 85 ft over a 5-yr period of data collection.

Synoptic Potentiometric Levels

The Edwards and Middle Trinity potentiometric surfaces shown in Figure 2 were collected over a 3-week period in February 2009. A comparison of the two surfaces show that the differences in potentiometric elevations vary considerably, but the Middle Trinity levels are mostly less than those of the Edwards. Within Hays County, potentiometric elevations are mostly lower to the southeast and east for both aquifers. At the southern boundary of Travis County, the Middle Trinity gradients change to a northeasterly direction, perhaps due to discharge to the Colorado River, west of the Mount Bonnell Fault that delineates the western boundary of the Edwards Aquifer. Edwards gradients also change to the northeast where groundwater flow follows preferred pathways that direct that water to Barton Springs. Distinct troughs in the potentiometric surface highlight these pathways.



Explanation

Ked	Edwards Group
Kgru	Upper Glen Rose Limestone
Kgrl	Lower Glen Rose Limestone
Khe	Hensel Sand
Kcc	Cow Creek Limestone
Kha	Hammett Shale
Ksl	Sligo Formation
Kho	Hosston Formation

Figure 5. Cross section showing Edwards and Trinity stratigraphy, structures, and location of multiport monitor well. Location of cross section shown on Figure 1.

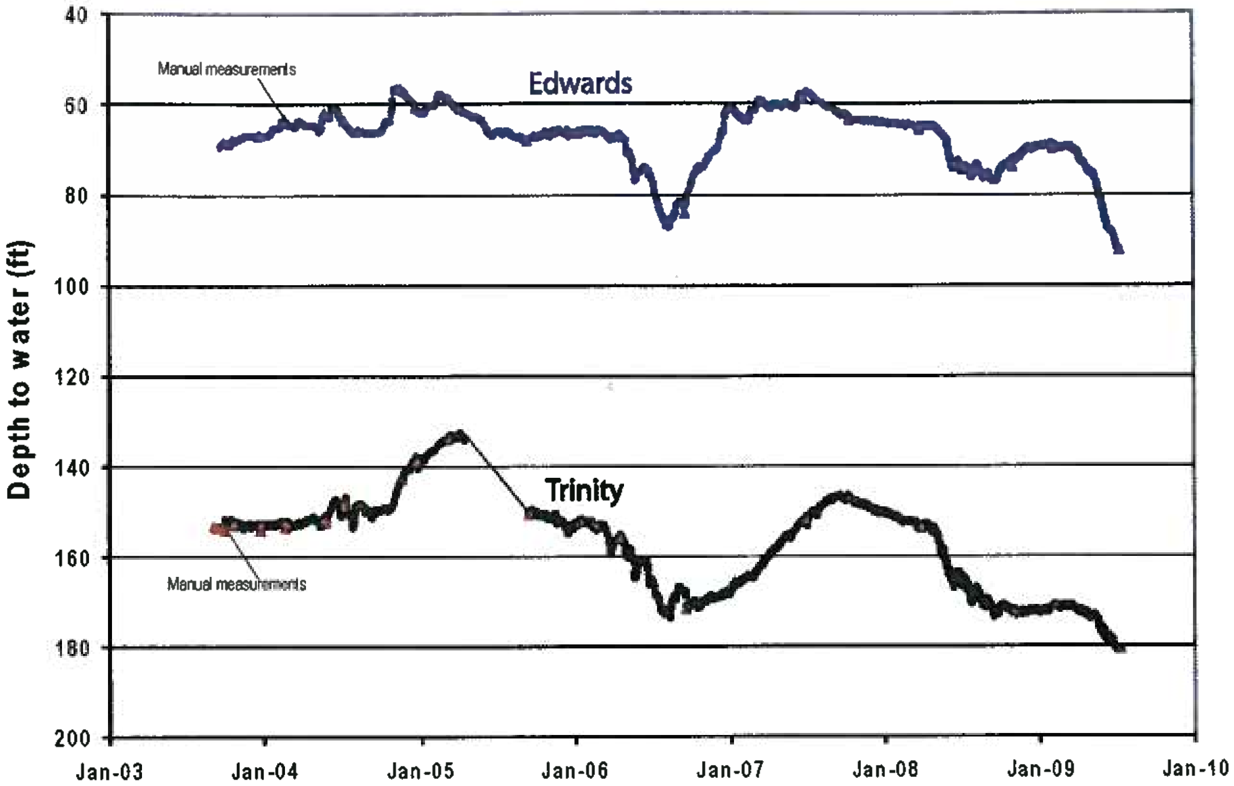


Figure 6. Hydrographs from Edwards-Trinity well pair at Borheim Quarry. Location of well pair is shown on Figure 2.

Multiport Monitor Well

The Westbay® multiport system used in this study allows pressure measurements and sample collection at 14 discrete zones within a single borehole. A 5-in diameter borehole was drilled to a total depth of 1,120 ft and equipped with permanent packers to isolate the 14 zones into separate hydrostratigraphic units of the Edwards and Trinity Aquifers that may be studied individually (Figure 4). Packers were placed as close as possible to stratigraphic boundaries determined from an interpretation of the natural gamma log. Three zones were installed in the Edwards section of the well; two of which were standard multiport completions. The uppermost zone (14) of the Edwards was completed as an open-hole standpipe without a measurement port or upper packer. The upper member of the Glen Rose Limestone was divided into three zones and the lower member of the Glen Rose Limestone was divided into four zones. The Hensel Sand was completed as one zone. The Cow Creek was divided into two zones and the 30 ft of Hammett Shale that was penetrated was completed as one zone. The average thickness of the multiport zones in the well is 73 ft with the thickest zone at 197 ft and the thinnest zone at 27 ft (Figure 4).

Head Data

Head measurements and water samples are taken using a specially designed tool, which is lowered by wireline into the casing system. Measured head differences between adjacent zones in the multiport well range from less than one foot to as much as 30 feet between the lowermost zone of the Upper Trinity (zone 9) and the uppermost zone of the Middle Trinity (zone 8) (Figure 7). Head values generally decrease with depth in the well, although the heads are slightly higher in elevation within some Upper Trinity zones than the Edwards. Heads in the upper five zones of the well differ by only about 3 feet over the 16 months that head measurements were made. Heads went up in some zones during this period while heads went down in other zones. Head differences between adjacent zones within the upper five zones are also about 3 ft or less. The most significant head differences between adjacent zones are between zone 10 and 9, and between zone 9 and 8 with head differences of about 12 ft and 30 ft, respectively (Figure 7). Heads in the lower eight zones of the multiport well have shown a steady decrease of about 20 ft over this same 16-month period. Head differences between the lower eight zones are mostly less that 2 ft and are generally decreasing with depth. It is notable that Central Texas was experiencing a severe drought during the time that these measurements were made, and water levels in the recharge areas of the Trinity and Edwards Aquifers were substantially lower than normal and also declining during this time.

Water Samples

Groundwater samples were collected from 13 of the 14 monitoring zones in the multiport well on April 10 and July 23 and 24, 2008. The uppermost zone of the well was not sampled owing to low water levels brought about by drought conditions in central Texas. Samples from the April 10 event were analyzed for total dissolved solids (TDS). Samples from the July 23 and 24 event were analyzed for major anions and cations and certain metals. Concentrations for select analyses are shown in the table below.

Multiport Zone	**Zone Thickness (ft)**	**Alkalinity (mg/L)**	**HCO_3 (mg/L)**	**Calcium (mg/L)**	**Chloride (mg/L)**	**Magnesium (mg/L)**	**Potassium (mg/L)**	**Sodium (mg/L)**	**Sulfate (mg/L)**	**TDS (mg/L)**	**Hydrochemical Facies**
13	72	331	403	90	10.1	36.1	1.08	6.57	11.4	357	$Ca\text{-}HCO_3$
12	34	250	304	58.1	9.58	34.6	1.8	7.16	23.7	292	
11	159	261	318	283	13.9	175	10.3	22.2	1080	1320	$Ca\text{-}SO_4$
10	197	237	288	506	20.2	287	20.2	33	2240	1890	
9	97	228	277	670	20.4	296	23.4	34.3	2480	3550	
8	57	262	319	521	16.8	243	17	29.9	2040	2690	
7	67	265	322	89.4	8.69	40	1.93	6.58	85.3	465	$Ca\text{-}HCO_3$
6	72	271	330	118	10.1	66	3.96	4.3	264	653	Intermediate
5	77	274	333	128	10.1	61.2	3.14	2.43	258	661	
4	31	254	309	122	11.3	71.8	6.56	6.76	325	720	
3	27	252	307	91.4	9.1	44.7	2.61	1.12	136	433	$Ca\text{-}HCO_3$
2	20	258	314	113	10.6	66.5	7.2	5.35	288	674	Intermediate
1	41	261	318	123	13.1	76.8	10.8	13.2	340	589	
	# of Samples										
Edwards Aquifer Wells	60	252	307	73.5	17.84	27.6	1.8	13.2	51	365	$Ca\text{-}HCO_3$
Trinity Aquifer Wells	9	276	335	179.5	33.3	97.1	11.2	53	638	1210	$Ca\text{-}SO_4$
Edwards Saline Wells	8	249	305	156.6	502	63.9	16.3	383	558	1912	Saline
Edwards Springs	18	269	327	90.6	34.6	23.3	1.31	18.9	35	386	$Ca\text{-}HCO_3$

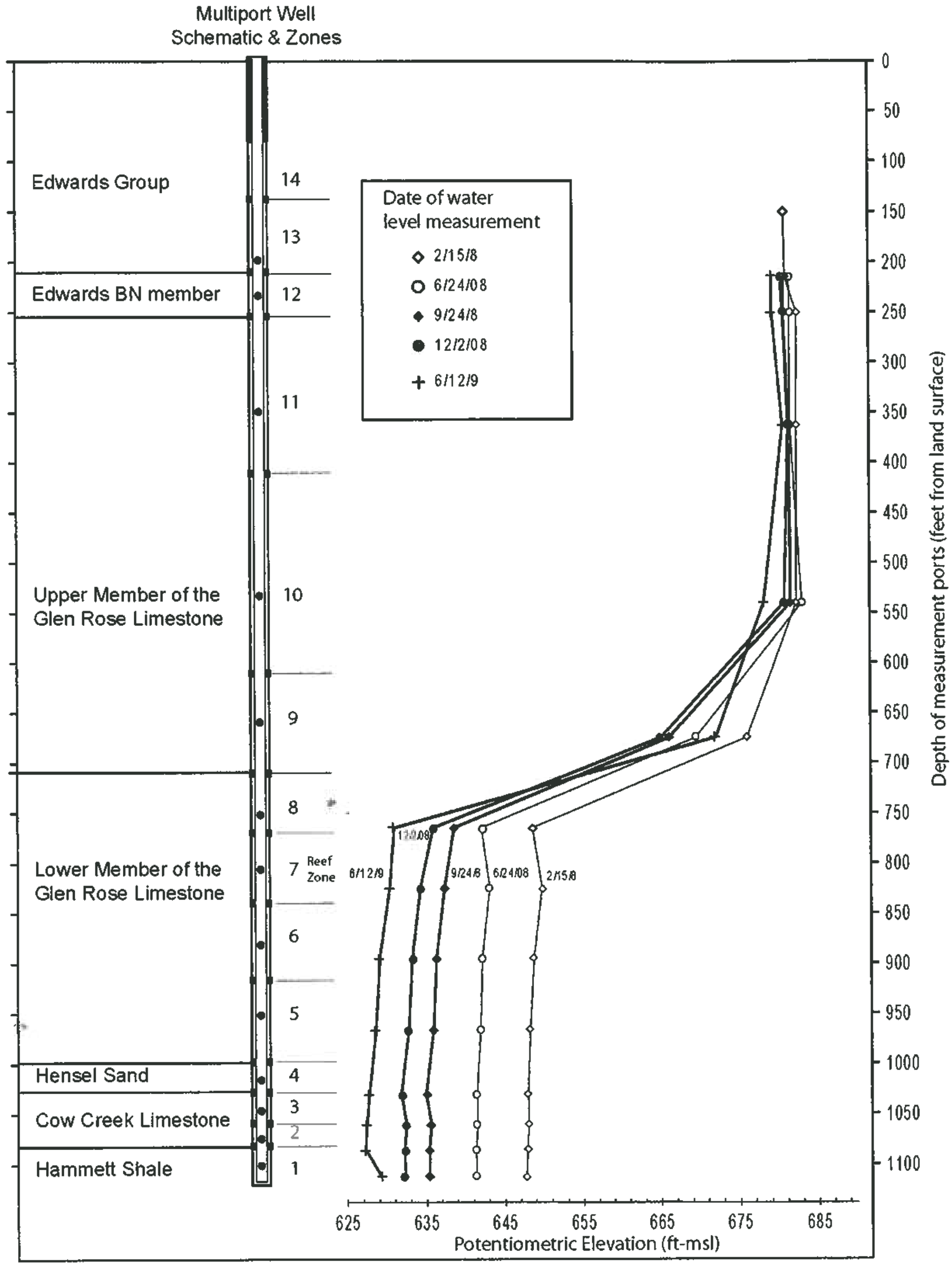


Figure 7. Potentiometric levels of each monitoring zone in the multiport well for five measuring events.

Total dissolved solids (TDS) range from 292 milligrams per liter (mg/L) in an Edwards zone to 3,550 mg/L in the lowermost zone of the Upper Trinity (Figure 8). High TDS values (>1,000 mg/L) occur in the three monitoring zones of the upper member of the Glen Rose Limestone and the uppermost zone of the lower member of the Glen Rose Limestone. Two monitoring zones that were installed in the Cow Creek Limestone, near the bottom of the well, have TDS values of 433 and 674 mg/L (Figure 8).

A review of select cation and anion concentrations shows that the 13 samples can be divided into three distinct groupings (hydrochemical facies). The distinctions between each facies can be seen in the Stiff and Piper diagrams shown in Figures 8 and 9, respectively. The Ca-HCO_3 facies is associated with the two zones in the Edwards Aquifer (zones 12 and 13), zone 3 in the upper zone of the Cow Creek Limestone, and zone 7 in the lower member of the Glen Rose Limestone which is completed in a thick unit of rudist reefs. The Ca-SO_4 facies occurs in zones 8 through 11 in the lower and upper members of the Glen Rose. Another hydrochemical facies occurs in five zones in the lower member of the Glen Rose and is considered an intermediate facies. This facies is characterized by TDS and SO_4 values significantly lower than those of the Ca-SO_4 facies, but notably higher than the Ca-HCO_3 facies (Figures 8 and 9).

One explanation for the similarity in geochemistry between the Edwards samples and those from the upper zone of the Cow Creek Limestone and zone 7 (rudist reefs) of the lower member of the Glen Rose is that the water in these zones is travelling though similar limestones that either never had significant amounts of evaporates or the evaporates have been removed earlier by flux of meteoric water.

Another explanation is that the residence time for the water is too short for the water to dissolve sufficient constituents to elevate the levels in the water. However, this seems less likely since the water flowing through the Cow Creek Limestone and the rudist-reef zone of the Glen Rose at these depths is not likely to have caused the development of pathways (conduits) to the extent that they are developed in the shallow, freshwater Edwards. Therefore, residence times would be considerably greater than for water flowing through the Edwards.

Results of chemical analyses of samples collected from the multiport well were compared to results from wells and springs from the study area (Table 1 and Figure 9). Samples from Edwards wells and from springs that discharge from the freshwater Edwards fall into the same Ca-HCO_3 hydrochemical facies as were noted in the multiport well. Nine samples from water-supply wells completed in thick sections of the Upper and Middle Trinity Aquifers fall about halfway between the two hydrochemical facies seen in the Trinity zones in the multiport well. Eight samples from saline Edwards wells have high levels of sodium, potassium, and chloride and are distinct from any samples from the Trinity and freshwater Edwards wells and the multiport zones. Samples from all zones in the multiport well are characterized by low concentrations of sodium, potassium, and chloride.

Interpretation

Head Values

Differences in head values show that there is a potential for flow between the various aquifer units, but pathways are needed for flow to actually take place. Considering that there are many low permeability beds in the upper and lower members of the Glen Rose Limestone

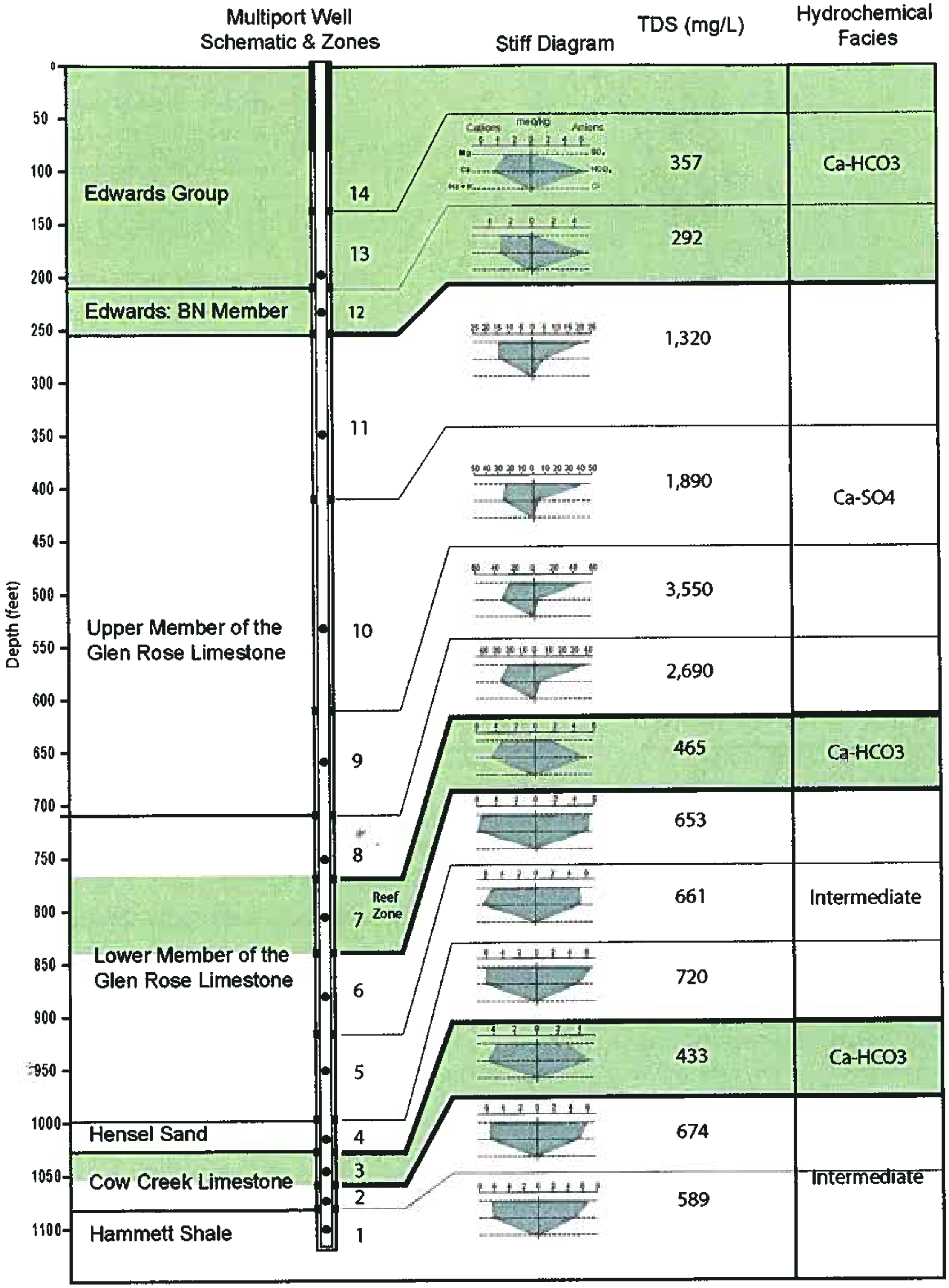


Figure 8. Geochemistry of sampling zones in multiport well and an interpretation of hydrochemical zones.

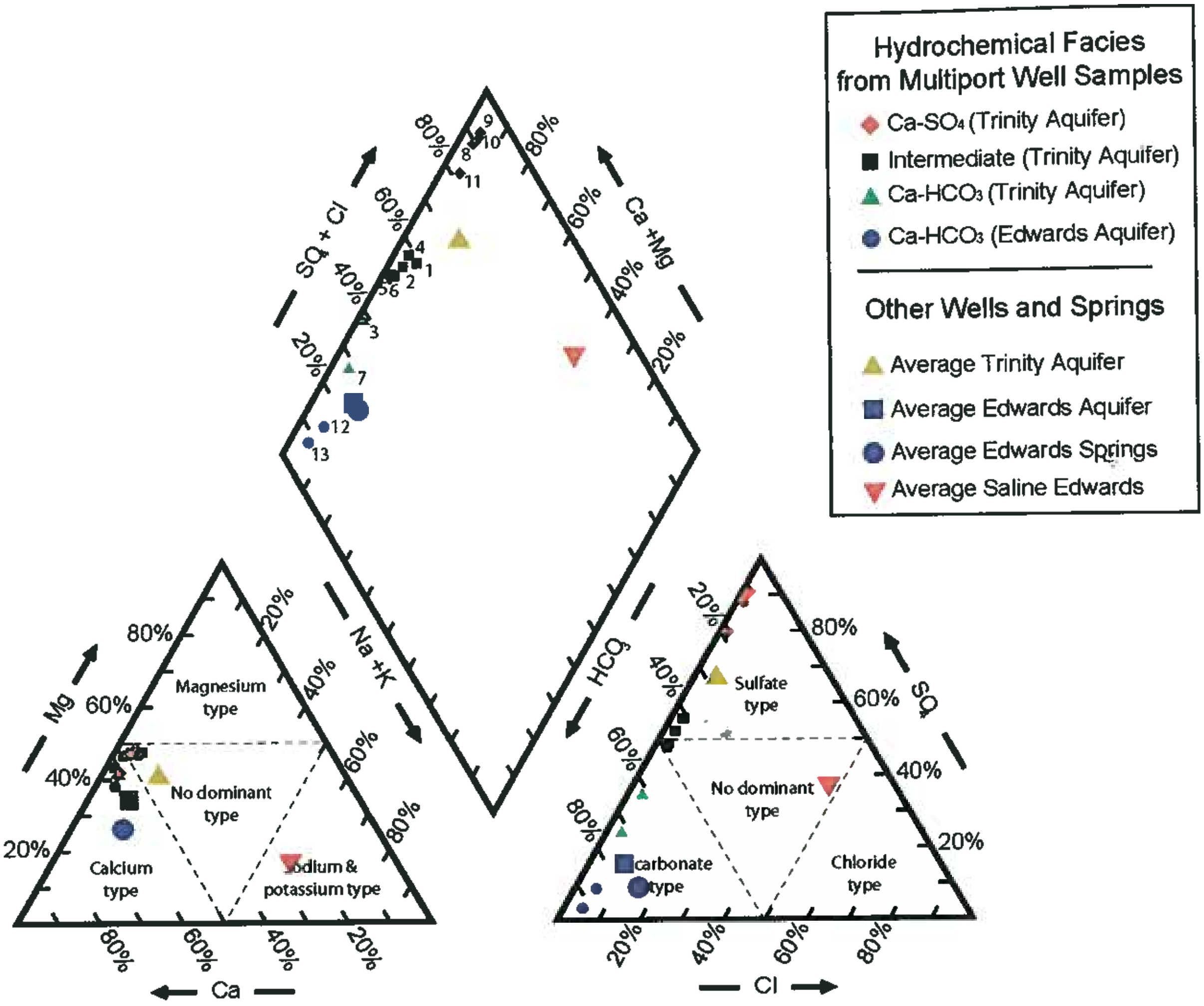


Figure 9. Piper diagram showing differentiation of samples from multiport well and other wells and springs into distinct hydrochemical facies.

(Brune and Duffin, 1983; Ashworth, 1983), vertical flow would likely occur only through faults and fractures.

Declining heads in the lowermost zones during the study period, which took place during an increasingly severe regional drought, is consistent with meteorological droughts affecting even deep groundwater; this suggests a hydrologic regime that is well connected to a source area.

Geochemistry

Significant geochemical differences between monitoring zones provides additional evidence that there is virtually no vertical flow through the formations. There is a possibility for vertical flow along faults, but head values and geochemistry suggest that any flow along faults in this area is very limited. The nearest mapped faults to the multiport well are about 1,300 ft to the northwest and about 2,000 ft to the southeast (Small et al., 1996).

Groundwater samples with the highest values of TDS and sulfate are associated with low permeability units of limestone, dolomite, marl, and shale with evaporites. Groundwater samples characterized by high calcium and bicarbonate are associated with high permeability units of limestone, dolomite with few evaporites, if any. Samples with intermediate values of calcium and sulfate are associated with units with varied permeabilities that are predominantly limestone, dolomite, sand, silt, and shale.

Structural and Stratigraphic Influences

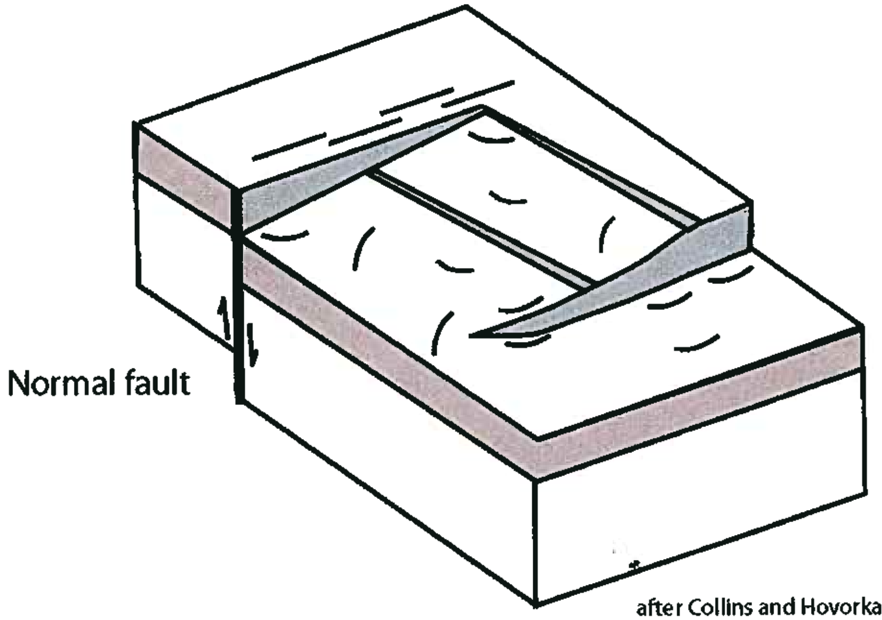
The dominant structures in the study area are *en echelon* normal faults associated with the BFZ (Collins and Hovorka, 1997; Ferrill and Morris, 2008). Where displacement is greater than the thickness of high permeability units, flow through the units can be cut off if low permeability units are juxtaposed against these high permeability units. However, many of these faults are considered relay-ramp structures which start at a point with no displacement then increase in displacement over the strike of the fault (Figure 10). Therefore, there is considerable lateral continuity of permeable units, even though some portions of the permeable units may be entirely offset by faults.

Conclusions

Significant differences in head and geochemical values suggest that there is little vertical flow between zones in the vicinity of the multiport well. Where nearby faults cut across the Edwards and Trinity units, there is greater potential for flow between zones. However, the large differences in geochemical values between zones and the presence of distinct hydrochemical facies suggest that flow along faults in this area is small compared to horizontal flow in each zone. Whereas extensive faulting associated with the BFZ might suggest that lateral flow would be fairly limited due to offsetting of permeable beds, the presence of relay ramps between faults indicates that there is considerable lateral continuity of permeable beds.

Potentiometric, structural, and geochemical data support the interpretation that the groundwater encountered in the various zones sampled from the multiport well are influenced more by lateral flow though distinct lithologies rather than flow along faults. Groundwater flowing through more permeable units consisting mostly of limestone and dolomite and lacking evaporites falls into the Ca-HCO_3 hydrochemical facies. Groundwater flowing through less permeable units consisting of limestone, dolomite, marl, shale, and evaporites falls into the Ca-SO_4 hydrochemical facies. Groundwater of the intermediate facies is associated with low permeability lithologies consisting of limestone, dolomite, marl, and shale. A greater amount of mixing would take place if there was significant flow along faults and there would be less hydrochemical distinction between the various zones.

This study has shown that multiport well monitoring is critical to understanding the hydrologic relationships within and among the Trinity and Edwards Aquifer units. Additional multiport wells should be installed on or near faults to evaluate the potential for flow along these faults, and where geochemical data suggest upward flow from the Trinity into the artesian portion of the Edwards. Data from multiport wells will help to increase our understanding of these aquifers that will lead to better management of all the groundwater resources of the Trinity and Edwards Aquifers.



after Collins and Hovorka, 1997

Figure 10. Schematic diagram showing relationship of faults and fault blocks typical of faulting along Balcones Fault Zone.

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