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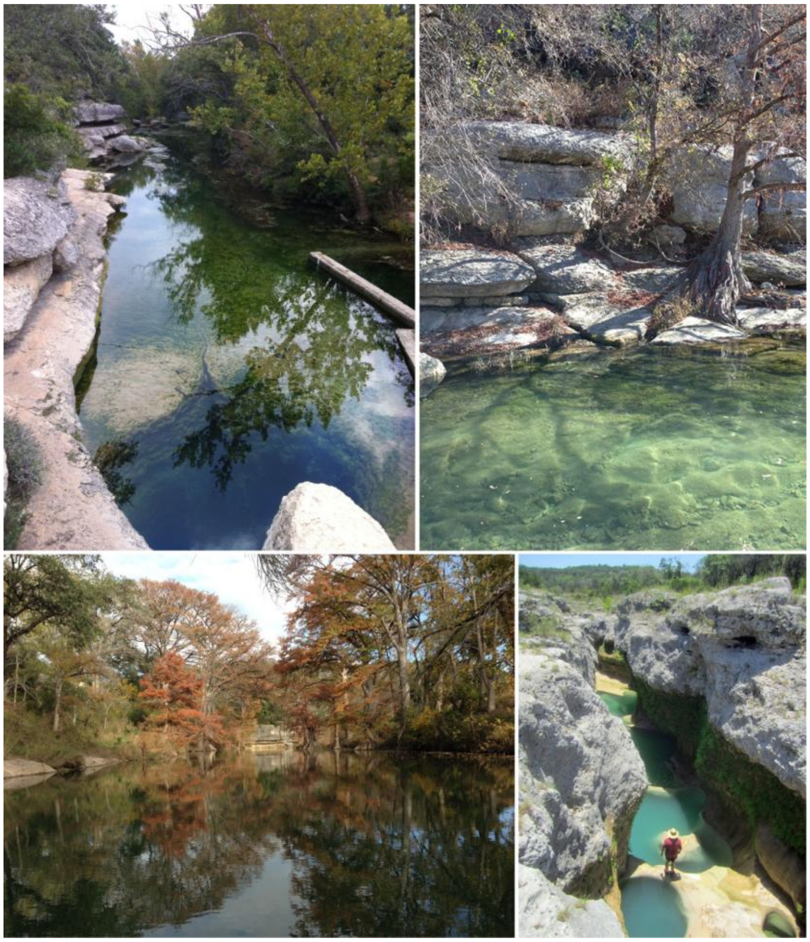
Potentiometric Surface Investigation of the Middle Trinity Aquifer in Western Hays County, Texas



BSEACD Report of Investigations 2014-1002

October 2014
Barton Springs/Edwards Aquifer Conservation District
1124 Regal Row
Austin, Texas

Disclaimer

All of the information provided in this report is believed to be accurate and reliable; however, the Bauthors or associated agencies assume no responsibility for any errors or for the use of the information provided.

Cover Photos: Top left: Jacob's Well Spring orifice in Cypress Creek; top right: Pleasant Valley Spring fracture spring orifice along Blanco River; bottom right: The Narrows, Blanco River, bottom left: Blanco River upstream of Pleasant Valley Spring.

Potentiometric Surface Investigation of the Middle Trinity Aquifer in Western Hays County, Texas

Jeffery A. Watson[1]; Brian B. Hunt[1], P.G.; Marcus. O, Gary, Ph.D.[2] , P.G.; Doug A. Wierman, P.G. [3]; Brian A. Smith[1], PhD., P.G.

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[2]Edwards Aquifer Authority; University of Texas at Austin, Jackson School of Geosciences
[3]Independent Geologist

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ABSTRACT

Pleasant Valley Spring (PVS) and Jacob's Well Spring (JWS) are large karst springs providing perennial baseflow to the Blanco River and Cypress Creek, respectively, which eventually recharges the Edwards Aquifer. JWS flow has become intermittent in recent years due to drought and increased pumping driven by nearby population growth within the Cypress Creek watershed. In order to better understand groundwater flow and sources of recharge to these springs (springsheds), we created a potentiometric map of the area surrounding the springs from water level measurements (n=59) taken in July 2013. Springflow measurements (n=9) were taken to document PVS springflow from Dec. 2012 to Aug. 2013. Results indicate that general groundwater flow is NW to SE in the study area, parallel to the direction of structural dip of Middle Trinity strata. Potentiometric gradients increase from 15ft/mi in recharge areas to 60ft/mi in the confined zone SE of the springs and major faults in the Balcones Fault Zone (BFZ). Potentiometric data suggest the Blanco River watershed, including and area of exposed Cow Creek Fm in the river, is a source of recharge for PVS. Potentiometric data suggest the source area for JWS could be limited to the Cypress Creek watershed, although contributions under differing hydrologic conditions could also include the Blanco River. We interpret a potentiometric trough, which represents a preferential flow path, surrounding the mapped JWS cave passage extending NW along Cypress Creek. A small potentiometric ridge is present between the Blanco River and Cypress Creek watersheds, suggesting a localized hydraulic separation between PVS and JWS. Additional evidence for hydrologic separation of the JWS and PVS springsheds was demonstrated by the differential springflow response to a large storm on May 25-26, 2013. PVS increased significantly in response to increased Blanco River flows, while JWS did not respond. These data help to define the source areas for PVS and JWS and suggest under drought conditions they may have independent springsheds. These data have implications for groundwater management and the preservation of springflows.

Note: An earlier version of this abstract was published in the South-Central Geological Society of America Abstracts with Program, April, 2014, Fayetteville, Arkansas.

INTRODUCTION

The Blanco River is an important recharge source for the Barton Springs segment of the Edwards Aquifer in central Texas. Hauwert (2011) estimated that during low flow conditions discharge to Barton Springs, the primary discharge point of the Barton Springs segment, is sustained in part by recharge from the Blanco River as it flows over the Edwards Aquifer recharge zone. A substantial portion of perennial base flow to the Blanco River is sustained by springs discharging from the Middle Trinity Aquifer, a regionally extensive carbonate aquifer underlying the central Texas Hill Country upgradient of the Edwards. Of particular interest are Jacob's Well Spring (JWS) and the recently documented Pleasant Valley Spring (PVS), large karst springs that have been shown to provide between 34 and 100% of flow to the Blanco River during times of low flow (Hunt et al. 2013; Watson 2013). If perennial flow to the Blanco River is being sustained by springs discharging from the Trinity, then the river is an important connection between the Trinity and Edwards Aquifers.

Potentiometric maps are useful tools for identifying subsurface flow paths and potential locations of aquifer recharge within karst systems. Previous investigations have provided potentiometric maps of the Trinity Aquifer in the region where JWS and PVS occur, but no detailed maps have previously been created to investigate the hydrologic connection of both springs directly. This report presents a potentiometric map created from data collected during a synoptic water-level measuring event conducted in early July, 2013. In presenting this data, we hope to provide valuable information on local groundwater flow paths in the Middle Trinity Aquifer within the study area, as well as aiding with the identification of potential sources of recharge to JWS and PVS. The potentiometric map provided in this report was also created to aid future hydrogeologic investigations on the Trinity Aquifer, which will hopefully increase scientific understanding of these important karst springs and the Trinity Aquifer system as a whole.

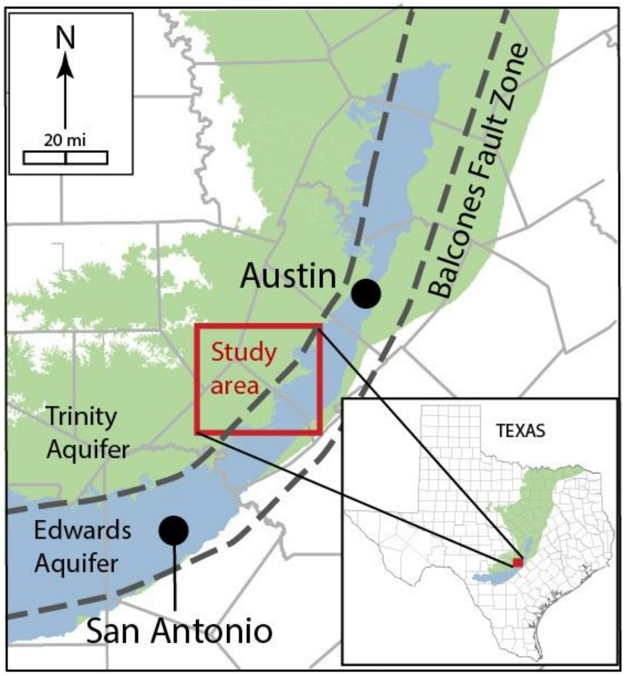


Figure 1. *Regional map of Central Texas showing study area and relevant geology.*

SETTING

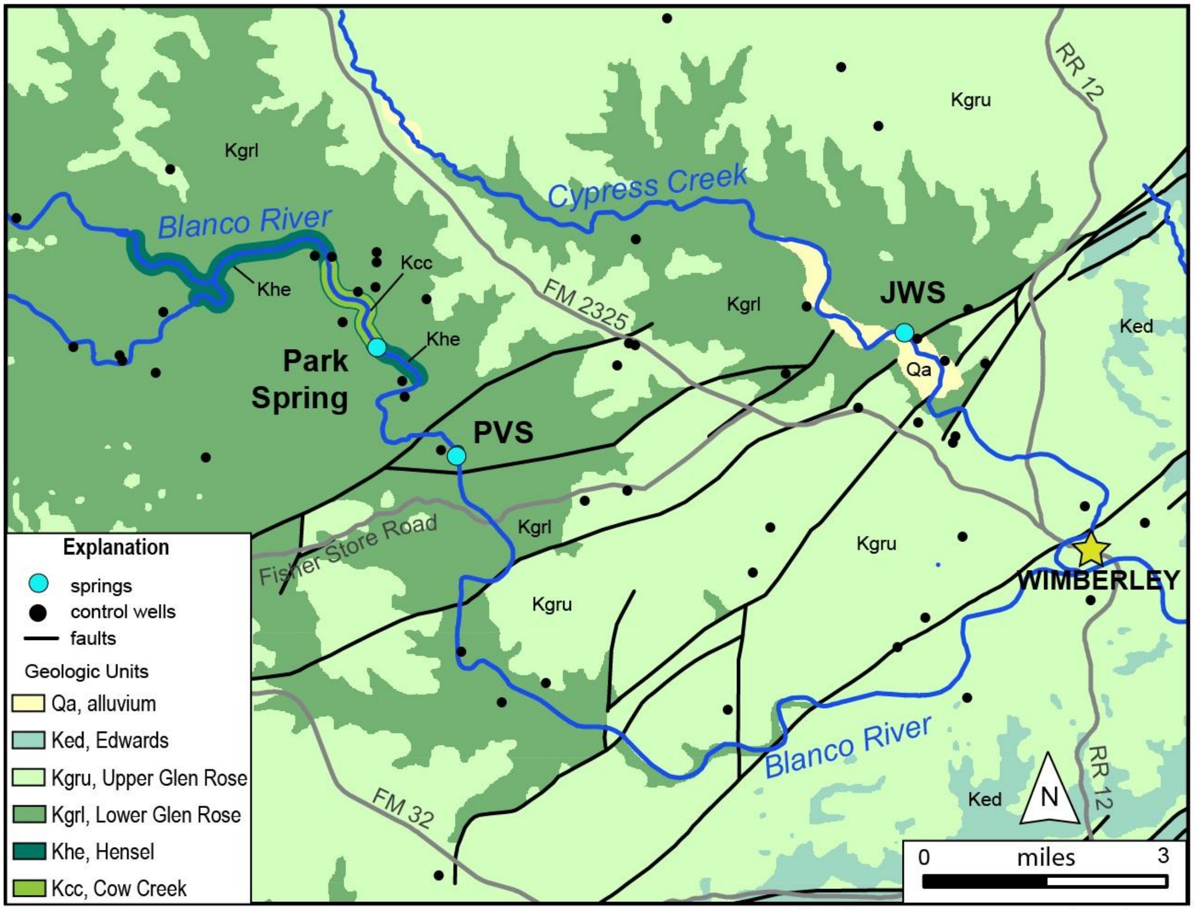
The synoptic study area is located in the central Texas Hill Country within western Hays and eastern Comal Counties (Figure 1). The Trinity Aquifer is the primary source of freshwater for commercial, public water supply, industrial, and domestic use within the study area. Rapid population growth in recent decades has increased regional water demand, spurring the drilling of many new domestic and public water-supply wells to meet demand.

The study area covers a portion of the Blanco River and Cypress Creek watersheds. Over time these major streams and their tributaries have downcut into surface limestones, creating a steep, hilly topography which is characteristic of the central Texas Hill Country. The stretch of the Blanco River downstream of PVS flows perennially due to sustained baseflow from the springs. Upstream of PVS the river is marked by gaining and losing reaches that flow intermittently depending upon hydrologic conditions. Downstream of Wimberley, the Blanco passes over the Edwards Aquifer recharge zone where it loses substantial flow as recharge to the Edwards Aquifer. Cypress Creek is a major tributary of the Blanco River, merging with the main river channel in Wimberley. Base flows within Cypress Creek are sustained primarily by JWS, which has changed from a perennial to an ephemeral spring in recent decades due to increased upgradient pumping and recent drought conditions.

Climate in the Wimberley area is semi-arid, with annual precipitation of approximately 35 inches (NCDC 2013). Precipitation patterns in the Texas Hill Country are marked by high levels of variability. Multi-year droughts are common and can strain water resources locally and regionally.

Timing of Synoptic

Most of the measurements used to construct the Middle Trinity potentiometric map presented in this report were made in late June to early July 2013. During this time period the area was classified as being in a severe drought on the Palmer Drought Severity Index (NOAA, 2013). Blanco River flow during the synoptic ranged from 10-20 cubic feet-per-second (cfs), well below the historical mean of 51 cfs (USGS 2013). Measured flow at JWS according to the USGS gage was less than 0.5 cfs during the course of the synoptic timeframe.



Basemap data from TWDB: Major Aquifers of Texas and Major Rivers; USGS: Geologic Atlas of Texas

Figure 2. *Geologic map of the 2013 potentiometric map investigation study area. Cow Creek and Hensel outcrops exaggerated for visibility. Control wells are the wells measured in this study (n=59).*

GEOLOGIC FRAMEWORK

The rocks on the surface and subsurface across the study area are made up almost entirely of Cretaceous carbonate units within the Trinity Group (**Figures 2 and 3**). Outcrops over the study area are dominated by the Upper and Lower Glen Rose formations, with the older Lower Glen Rose cropping out in the valleys and topographic lows incised from down cutting of Cypress Creek and the Blanco River (**Figure 2**). The Cow Creek and Hensel formations are present in outcrop only along a narrow strip of the Blanco River several miles north of PVS. The water-level measurements presented in this study focus on wells completed within the Middle Trinity Aquifer, which consists of the Cow Creek, Hensel, and Lower Glen Rose formations (from oldest to youngest). Figure 3 presents a stratigraphic column from Wierman et al. (2010) that summarize characteristic lithologies of the subunits within the Trinity Group in the study area.

The lower confining unit of the Middle Trinity is the Hammett Shale, which is composed of silty dolomite, siltstone, and a very low permeability claystone unit, and is approximately 40 ft thick

(Wierman et al. 2010). Owing to the low permeability of the Hammett within the study area, it is unlikely that a significant connection between the Lower and Middle Trinity Aquifers exists (Wierman et al. 2010). The Cow Creek within the study area is approximately 100 ft thick, consists of oyster-dolomite units at its base, and is overlain by a high-energy beach/shoreline skeletal grainstone unit (Wierman et al. 2010). It has high levels of primary and secondary porosity which make it an excellent water-bearing unit. It is thought that the Cow Creek is the primary source of water for PVS (Hunt et al. 2013). The primary horizontal conduit leading to the JWS opening occurs within the Cow Creek (Wierman et al., 2010). The Hensel is 25 to 40 ft thick across the study area and composed of clastic sedimentary rocks NW of the study area (Wierman et al. 2010). Within the study area, the Hensel changes facies to a less permeable dolomitic wackestone, where it acts as a semi-confining unit to the Cow Creek (Wierman et al. 2013). The Lower Glen Rose is 180 to 250 ft thick, increasing in thickness from NW to SE. It is composed of water bearing fossiliferous limestones with “mound/reef” facies variably present across the study area (Wierman et al. 2010).

The Upper Glen Rose formation is the sole formation comprising the Upper Trinity hydrostratigraphic sub-group and typically yields only small amounts of water. Ephemeral seeps and springs issuing from the Upper Glen Rose commonly feed tributaries to the Blanco River after rainfall events. It is composed mostly of micritic limestone beds separated by marls and clays which prevent the downward migration of water into the Middle Trinity Aquifer (Wierman 2010). The Edwards formation overlies the Upper Glen Rose and crops out in the eastern portion of the study area and on some hilltops.

Trinity group beds within the study area exhibit an approximately 1% SE dip (pers comm., Hunt 2013). A large portion of the study area is intersected by a zone of SE dipping, Miocene-aged, normal faults known collectively as the Balcones Fault Zone (BFZ). Displacement from the BFZ has dropped Cretaceous strata by up to 400 ft, juxtaposing younger Edwards limestone to the SE with Trinity strata to the NW (Wierman et al. 2008). Locally, secondary faults and fractures associated with BFZ are common across the study area, and are likely a major control on the spatial distribution of groundwater storage, flow direction, and permeability within the Trinity Aquifer (Wierman et al. 2010; Ferrill et al. 2005). Fault displacement associated with the BFZ has been shown to have varying effects on groundwater flow, with major faults acting as barriers to flow in some locations and having little effect in others (Ferrill et al. 2005; Ferrill et al. 2003; Maclay 1995).

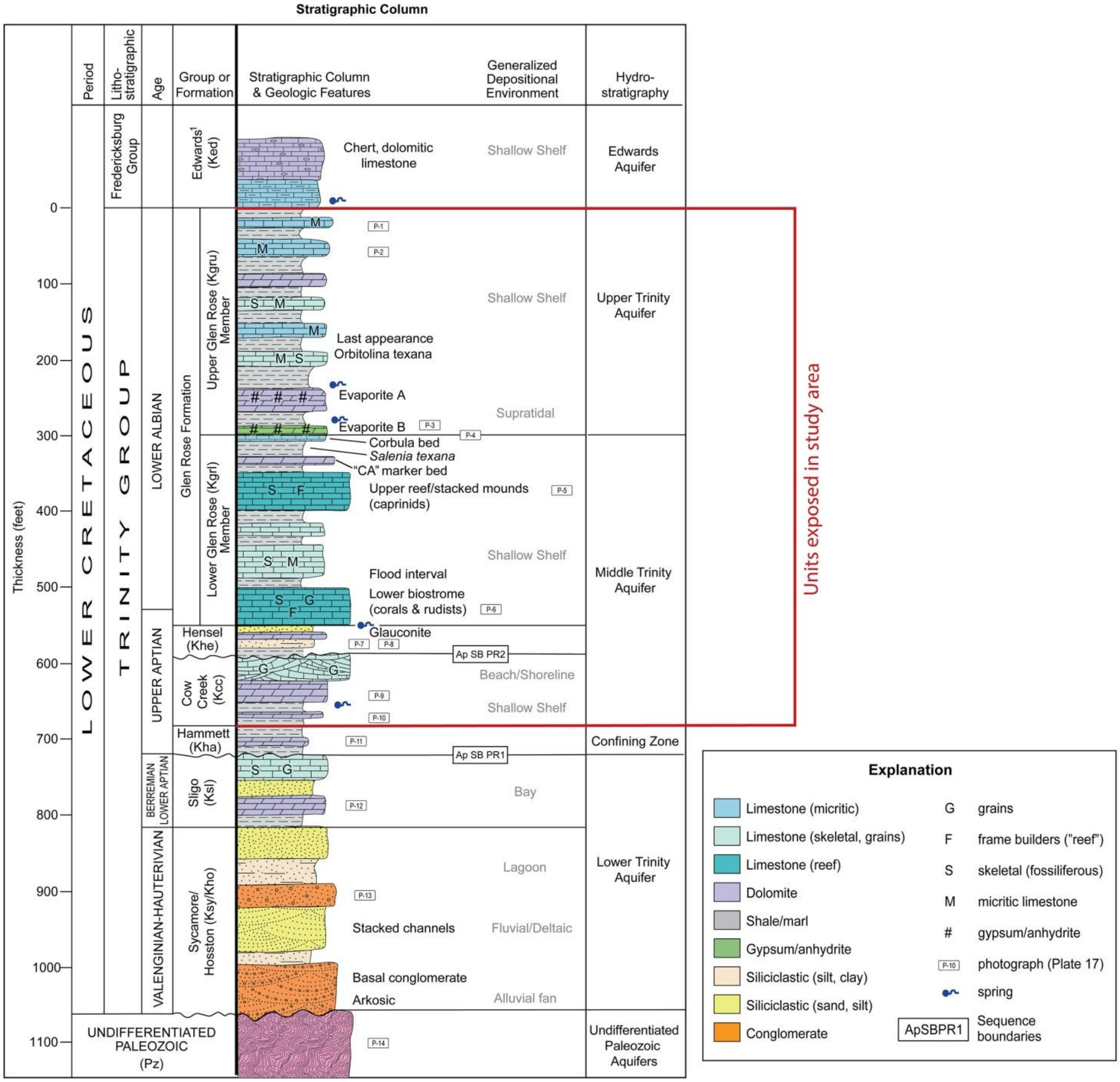


Figure 3. *Stratigraphic column of the Trinity Group from the Hydrogeologic Atlas of the Hill Country Trinity Aquifer (modified from Wierman et al. 2010). The synoptic study presented in this report focuses on wells competed in the Middle Trinity hydrostratigraphic group.*

PREVIOUS INVESTIGATIONS

There have been many investigations conducted on the Trinity Aquifer within the Texas Hill Country. Some of the more relevant studies to the western Hays area are described below.

Regional Maps

Mace et al. (2000) presents a regional scale groundwater availability model of the Texas Hill Country. Also provided in the report is a potentiometric map compiled from water level measurements during relatively average rainfall conditions in 1975. The map shows a general SE flow direction throughout the study area, but has few data points close to the study area in this report. Hunt et al. (2009) presents a potentiometric map of the Middle Trinity in the Texas Hill Country constructed from a synoptic event conducted in March of 2009 during drought conditions (**Figure 4**). Water-level data was collected with the collaboration of BSEACD and several other groundwater agencies over an area covering parts of eight counties. The map provides a coarse regional picture of groundwater flow, showing a general trend of NW-SE regional groundwater flow across the region.

Local Maps

Davidson (2008) presents a May 2008 potentiometric map of the JWS and Cypress Creek area. Contour patterns in some parts of the Davidson map closely resemble those of the map provided in this report. Wierman et al. (2008) provides a finer resolution May 2008 potentiometric map of the Middle Trinity that focuses around JWS and the Cypress Creek watershed (**Figure 5**). The map highlights several key features of local groundwater flow in western Hays County. Closely spaced potentiometric contours across the BFZ indicates that faults may be acting as partial barriers to flow. Water levels in the vicinity of JWS closely match the constant head discharge elevation of the spring itself, indicating that JWS is likely maintaining relatively constant water levels close by. The potentiometric maps presented in the Wierman et al. (2008) and Davidson (2008) maps represent drought conditions.

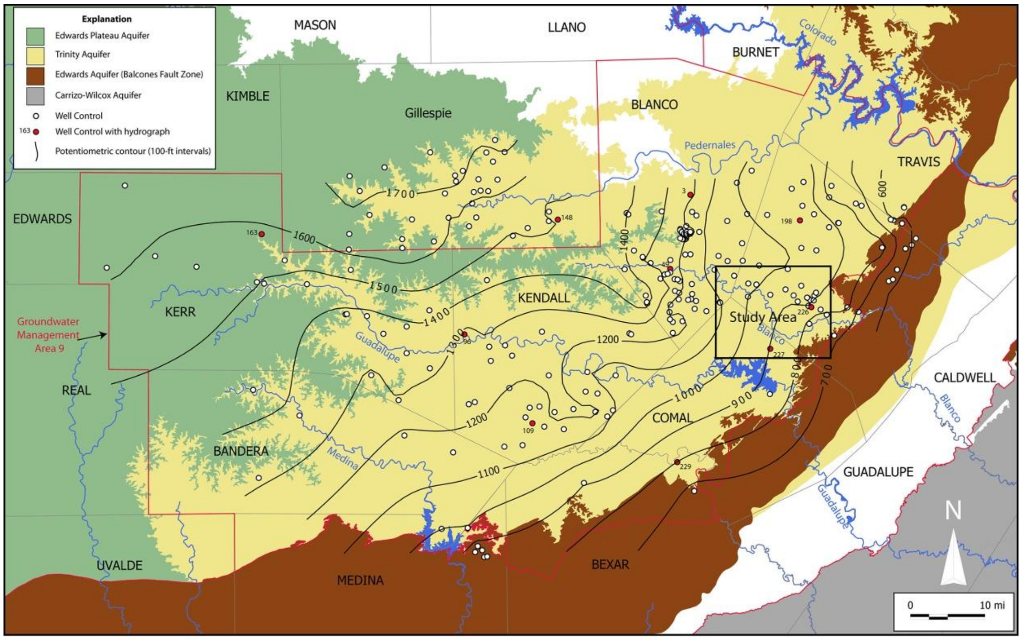


Figure 4. *Spring 2009: Potentiometric map of the Middle Trinity Aquifer in Groundwater Management Area 9 during low-flow conditions; 100 ft contour interval. Modified from Hunt et al. (2000; N=232)*

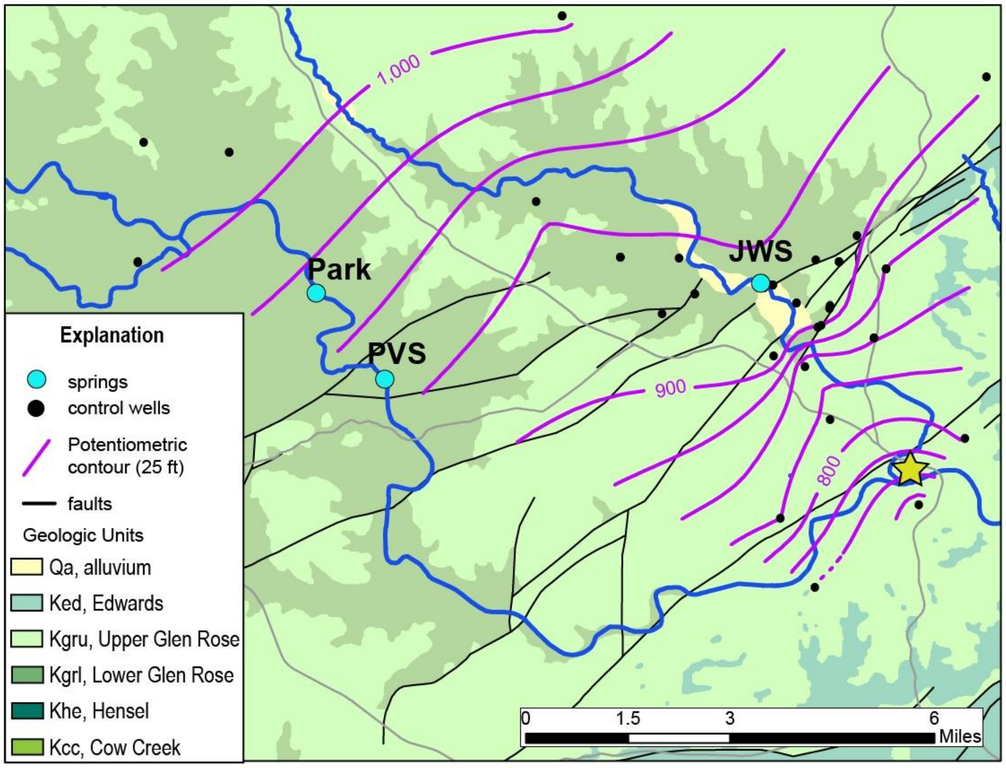


Figure 5. *Summer 2008: Potentiometric map of the Middle Trinity Aqufer in the study area; low-flow conditions. 25 ft contour interval. Data contoured from Wierman et al. (2008; N=26).*

METHODS

Water level measurements

Water level data are provided in **Table 1**. The synoptic water-level data used for the construction of the potentiometric map were primarily measured by BSEACD staff from privately owned wells in the study area. Additional data were collected by the Texas Water Development Board (TWDB), Hays Trinity Groundwater Conservation District (HTGCD), and Wimberley Water Supply Corporation (WWSC). An electric line (e-line) was used for all BSEACD measurements except for the Robins well, where a Ravensgate Model 200 sonic water-level meter was used due to an obstruction in the well preventing the use of the e-line. Manual measurements are generally accurate to within ± 0.01. The majority of uncertainty for each water-level measurement comes from elevation values, which add approximately ± 5 ft uncertainty to the measurements. Most of the water-level measurements made during the synoptic event were taken from wells completed in the Middle Trinity Aquifer. Depth measurements ranged from 41 to 417 ft and elevations ranged from 649 to 1024 ft-msl.

HTGCD, TWDB, and WWSC Data

The HTGCD water-level data used for the potentiometric map (11 measurements total) include manual water-level measurements as well as data from continuously monitored wells. Manual measurements are made on a monthly basis using an eline and sonic meter by HTGCD staff. Eight sites record continuous water-level data using pressure transducers with data loggers from which data are downloaded every three months. All HTGCD water-level data are published and available through their website (HTGCD 2013).

Data from two TWDB wells continuously monitored by pressure transducers were also included in this study. These data are available through the TWDB Texas Water Information Integration & Dissemination (WIID) website (TWDB 2013).

WWSC water levels were measured using an e-line by WWSC. Measurements from four WWSC wells were used in the potentiometric map presented in this report.

Well Completion Information

Varying amounts of well-completion information were available for each individual well measured in this study. Completion information such as total well depth, completion interval, and casing interval were mostly taken from submitted driller's reports or official state well reports published online through the TWDB WIID system (TWDB 2013). In cases where these reports were unavailable for a given well, completion information was either provided by well owners or inferred from nearby water-level measurements taken from wells where completion information was available. Wells suspected of questionable completion were omitted from the final potentiometric map. Aquifer unit completion was determined using geophysical data imported to KMZ format (BSEACD 2013).

Contouring

Goldenware ® Surfer 11 was used to grid the data and create the potentiometric contours of the map. The Kriging geostatistical method was used for gridding the data. Contours were slightly modified in

Adobe Illustrator to reflect additional hydrologic information not accounted for in the water-level data. These changes were made within the Cypress Creek watershed where conduit passages of JWS have been mapped and provide spatial information on flow within the Aquifer.

Datums, Spatial Coordinates, and Elevations

The water-level measurements used in this study were made relative to a measuring point (MP), or elevation above the land surface. For each water-level measurement, the MP (typically on top of the well casing) was measured relative to land surface and subtracted from the measured depth to water to obtain the depth to water from the land surface. GPS coordinates in decimal degrees for each well were initially obtained using an iPhone 5, and later refined using Google Earth, which provides more accurate elevation data. These spatial coordinates were then imported to ESRI ArcMap ® and overlaid onto a USGS NED Digital Elevation Model (DEM) to obtain elevations above mean sea level (AMSL). Depth to water from the land surface was subtracted from these elevations to obtain a water level (AMSL) for each well. Elevations are accurate to 5 ft. Horizontal datums are in North American Datum 1983 (NAD 83). PVS and JWS elevations were determined using LIDAR data.

PVS springflow measurements

Manual springflow measurements of PVS were taken from late 2012 until after the time of the water-level synoptic event (**Table 2**). Most flow measurements were taken using a Sontek Flowtracker Acoustic Doppler Velocimeter (ADV). The early June PVS flow measurement was taken using a Sontek Acoustic Doppler Current Profiler (ADCP). A minimum of 26 velocity station measurements were collected for each ADV cross-section. The 0.6 method was used where water depth was less than 1.5 ft and the 0.2, 0.8 method where depths were greater than 1.5 ft. A 40-second velocity measurement averaging time was used for most measurements, but a 20-second averaging time was used in some cases due to time constraints in the field. For the June 2013 ADCP measurement, an average of three flow measurements were taken as an upstream/downstream flow value. Flow upstream of PVS was subtracted from downstream flow as total calculated springflow. When no flow was present upstream of PVS only one downstream flow measurement was necessary. Table 2, included in the appendix of this report, provides a summary of the PVS flow measurements.

Spatial rainfall distribution analysis

In order to better understand PVS and JWS responses to a late May rainfall event, we conducted a spatial analysis of rainfall distribution for May 24 to 26, 2013. Nexrad precipitation datawere mapped to determine where rainfall was most prevalent (**Figure 8**). Observations made from this analysis were then compared with discreet point precipitation data taken from the Community Collaborative Rain and Hail Network (CoCoRaHS, 2013). These data are available in **Table 3**.

RESULTS

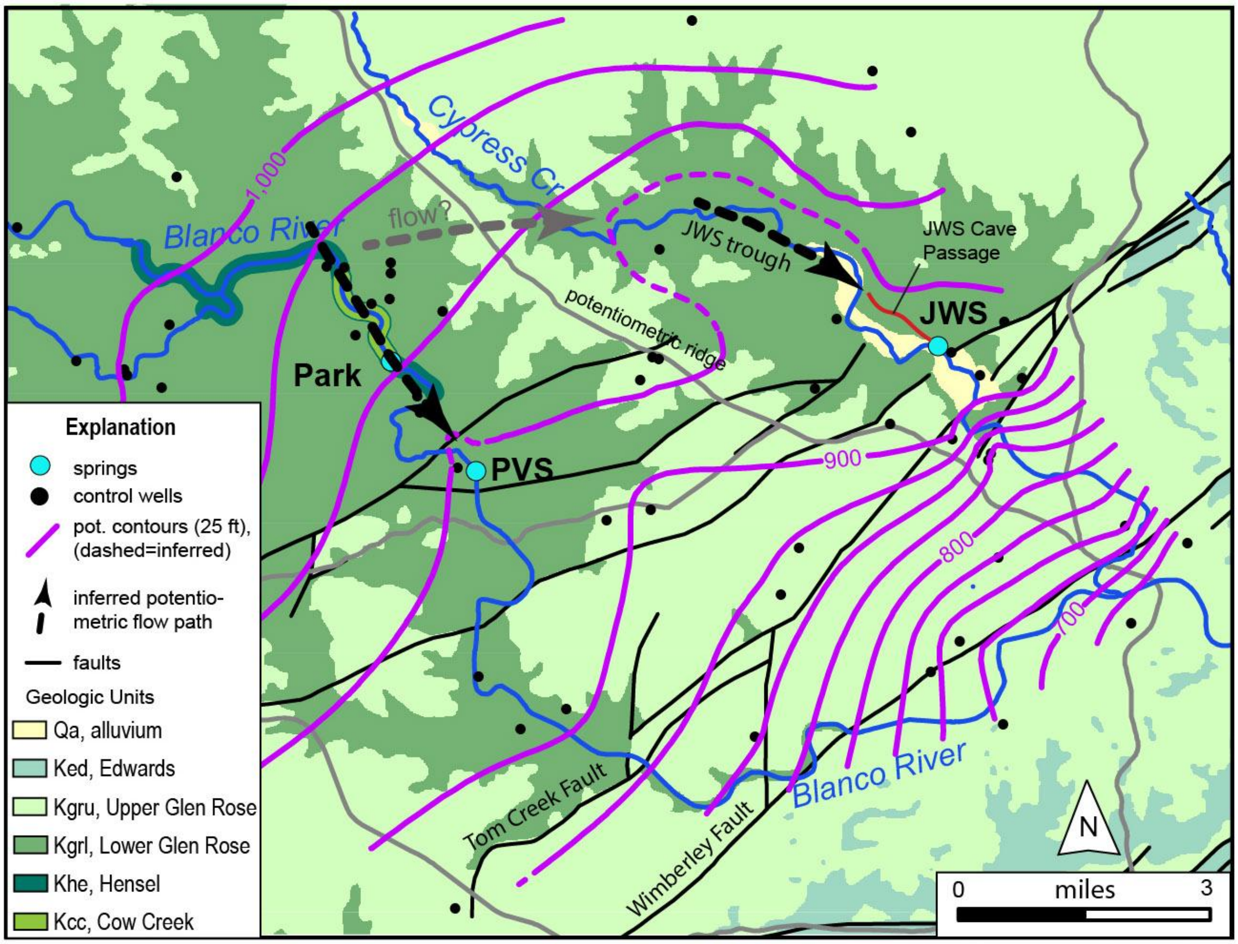
Figure 6 is a potentiometric map of the Middle Trinity Aquifer in western Hays County (next page). The well-control data used to construct this map are available in **Table 1**. **Figure 7** provides a summary of gage and manually measured spring discharge, river discharge, and precipitation for an 8-month timeframe leading up to the water-level synoptic event. **Figure 8** presents a Nexrad rainfall distribution map and **Table 3** point rainfall data, respectively, used for the May 24 to 26 rainfall distribution analysis.

Table 1. *Potentiometric data collected during water level investigation.*

Well ID	Well or spring name	DDlat	DDlong	Elevation (ft-msl)	Water Level Measurement (depth, ft)	Measurement date	MP	Pot. Elev	Agency	Aquifer
1	Goines	30.01340	-98.20906	973.77	51.65	5/31/2013	1.1	923.22	BSEACD	MT
2	Schoen	29.97827	-98.12734	920.63	163.5	7/6/2013	1.7	758.83	BSEACD	MT
3	Lovelass	30.00618	-98.17571	1123.84	237.93	7/6/2013	2.25	888.16	BSEACD	MT
4	Tartakov	29.96831	-98.19816	976.68	72.21	7/6/2013	0	904.47	BSEACD	MT
5	Lee	29.97181	-98.19024	1000.90	96.2	7/8/2013	1.5	906.20	BSEACD	MT
6	Amaon	29.97746	-98.20544	949.93	41.66	7/6/2013	1.4	909.67	BSEACD	MT
7	Elsey	30.00441	-98.18328	1110.80	199.5	7/6/2013	2.5	913.80	BSEACD	MT
8	Brown (shop)	30.03224	-98.17431	1161.55	234.54	7/5/2013	1.3	928.31	BSEACD	MT
9	Brown (house)	30.03258	-98.17538	1167.26	240.4	7/5/2013	1.55	928.41	BSEACD	MT
10	DiLeo (BR)	30.02300	-98.21547	1025.71	92.33	7/8/2013	1	934.38	BSEACD	MT
11	DiLeo (hum)	30.02583	-98.21601	1008.51	67.1	7/8/2013	0.8	942.21	BSEACD	MT
12	Zlatlkovic	29.97366	-98.26688	1191.27	245.43	7/9/2013	1.8	947.64	BSEACD	MT
13	Robins	29.99791	-98.11572	949.12	176.6	7/8/2013	1.5	774.02	BSEACD	MT
14	Braumbac	30.04039	-98.21163	1185.23	233.8	7/5/2013	0.42	951.85	BSEACD	MT
15	Pope	30.04181	-98.22384	1013.00	55.91	7/5/2013	0.79	957.88	BSEACD	MT
16	Tell	30.04885	-98.22050	1073.77	115.44	7/5/2013	2.22	960.55	BSEACD	MT
17	Frank	30.04801	-98.22853	1048.54	89.9	7/5/2013	0.5	959.14	BSEACD	MT
18	Soderst	30.04710	-98.22058	1064.84	105.8	7/5/2013	3.59	962.63	BSEACD	MT
19	Button	30.03634	-98.22662	1046.02	89.35	7/8/2013	1.1	957.77	BSEACD	MT
20	Christian	30.04256	-98.22075	1059.29	99.1	7/5/2013	1.38	961.57	BSEACD	MT
21	Threeton	30.02110	-98.13443	1053.44	139.5	6/6/2013	2.4	916.34	BSEACD	MT
22	Wade	29.96700	-98.15769	973.77	122.62	7/6/2013	2.3	853.45	BSEACD	MT
23	Leigh	29.99158	-98.15320	1033.00	166.37	7/8/2013	2.4	869.03	BSEACD	MT
24	Sklar	30.02860	-98.17755	1167.66	240.84	7/5/2013	2	928.82	BSEACD	MT
25	Steffien	29.99967	-98.15013	1116.33	247.75	7/8/2013	2.3	870.88	BSEACD	MT
26	Hargrave	30.05103	-98.17414	1159.21	239.41	7/5/2013	1.3	921.10	BSEACD	MT
27	Stude #2	30.03044	-98.26649	1077.43	80.35	6/20/2013	1.4	998.48	BSEACD	MT
28	Stude #3	30.02726	-98.26003	1121.03	124.64	6/20/2013	1.95	998.34	BSEACD	MT
29	Stude #4	30.02948	-98.26605	1071.25	74.08	6/20/2013	1.62	998.79	BSEACD	MT
30	Stude wind	30.03183	-98.27478	1091.07	81.65	6/20/2013	0	1009.4	BSEACD	MT
31	Dickason	30.01212	-98.25111	1262.73	273.22	7/9/2013	0.9	990.41	BSEACD	MT
32	Cole	30.07137	-98.13080	1272.83	305.88	7/6/2013	1.72	968.67	BSEACD	MT
33	Stuart	30.08194	-98.13744	1260.77	284.63	7/6/2013	0.85	976.99	BSEACD	MT
34	Roeling	30.04810	-98.23163	1037.49	69.49	7/8/2013	1.52	969.52	BSEACD	MT
35	HTStill1	30.03820	-98.25874	1074.52	83.34	7/12/2013	0.16	991.34	HTGCD	MT

Well ID	Well or spring name	DDlat	DDlong	Elevation (ft-msl)	Water Level Measurement (depth, ft)	Measurement date	MP	Pot. Elev	Agency	Aquifer
36	HTStill4	30.06368	-98.25752	1206.99	182.45	7/12/2013	0.25	1024.7	HTGCD	MT
37	HTStrmrn	30.09053	-98.16852	1292.80	308.1	7/12/2013	0.53	985.23	HTGCD	MT
38	HTGCD 23	30.03917	-98.14361	1046.56	129.33	7/12/2013	1.5	918.73	HTGCD	MT
39	HTGCD 25	30.02720	-98.14730	1036.79	116.88	7/18/2013	1.91	921.82	HTGCD	MT
40	HTGraha	30.03332	-98.12380	954.26	35.21	7/12/2013	0.4	919.45	HTGCD	MT
41	HTHCP	30.03870	-98.11468	1037.26	118.48	7/12/2013	2.25	921.03	HTGCD	MT
42	HTCamp	30.02950	-98.11885	956.58	39.9	7/12/2013	2	918.68	HTGCD	MT
43	HTMnt2	30.02889	-98.11161	965.77	47.21	7/12/2013	2	920.56	HTGCD	MT
44	LPSpring	30.03537	-98.22286	957.60				957.60		MT
45	Park Spring	30.03180	-98.22038	952.60				952.60		MT
46	JWS	30.03448	-98.12611	922*				922.00		MT
47	PVS	30.01319	-98.20597	922*				922.00		MT
48	WWSC 3	30.01468	-98.11743	931.13	101	7/1/2013		830.13	WWSC	MT
49	WWSC 5	29.98356	-98.12237	986.53	256	7/12/2013		730.53	WWSC	MT
50	WWSC 4	29.98667	-98.09278	890.42	235	7/1/2013		655.42	WWSC	MT
51	WWSC 7	30.00056	-98.08305	920.27	271	7/12/2013		649.27	WWSC	MT
52	WWSC 6	30.01833	-98.12361	1057.54	158	7/1/2013		899.54	WWSC	MT
53	Fischer	29.97606	-98.26436	1153.94	206.45	7/9/2013	1.4	948.89	BSEACD	MT
54	TWDBCL	29.93750	-98.20944	1196.74	317.38	7/9/2013	0	879.36	TWDB	MT
55	WWSBald	30.01583	-98.11694	929.12	122.09	7/9/2013	2	809.03	TWDB	MT
56	Narrows	30.05498	-98.28498	1094.86	95.58	6/27/2013	0	999.28	BSEACD	MT
57	HTGlenn	29.96918	-98.11490	1069.97		7/9/2013		722.19	HTGCD	MT
58	HTSabino	30.00344	-98.09384	882.50		7/9/2013		756.33	HTGCD	MT
59	Weeks	29.94972	-98.09261	1174.00	416.6	7/11/2013	1.9	759.30	BSEACD	MT
60	HTMcMean	30.00786	-98.1767	1103.519	213.15	7/9/2013	1.95	927.27	HTGCD	LT
61	HTStill6	30.04122	-98.2418	1103.77	178.45	6/1/2013	1.5	927.00	HTGCD	LT
62	HTThoma	30.17028	-98.0742	1165		7/9/2013		878.42	HTGCD	LT
63	HTSumm	29.92389	-98.0828	1020		7/9/2013		817.49	HTGCD	UT
64	HTStorm	30.10389	-98.12	1244		5/13/2013		845.50	HTGCD	UT
65	Flores	30.03124	-98.1771	1162.07	275.96	7/9/2013	1.7	887.83	BSEACD	LT
66	Sherrill	30.01761	-98.2145	1003.13	99.55	7/9/2013	1.7	905.26	BSEACD	LT
67	Don E	29.97712	-98.157	973	84.5	5/30/2013	1	887.50	BSEACD	UT
68	HTGum	30.01078	-98.0962	913		7/9/2013	0	836.00	HTGCD	UT

*****Indicates elevation measurements made with LIDAR. Only Middle Trinity (MT) wells and springs were used in the final potentiometric map.



Basemap data from TWDB: Major Aquifers of Texas and Major Rivers; USGS: Geologic Atlas of Texas

Figure 6. *2013 potentiometric map of the Middle Trinity Aquifer (N=59). Dashed arrows represent possible groundwater flow paths to each major spring. The grey dashed line represents potential contribution from the Blanco River. Potentiometric ridge could be a barrier to flow between PVS and JWS under drought conditions. A trough is inferred (dashed line) centered along Cypress Creek.*

Table 2. *Manual PVS discharge measurements. Spring discharge measurements with 2 measurements include one upstream and one downstream measurement. Measurements recorded by Jeffery Watson, (BSEACD), Marcus Gary (EAA), Chad Norris (TPWD), and students from the 2013 UT Karst Hydrogeology* Course.

Date	Discharge (ft3/s)	Method	Measurements
12/18/2012	16.1	ADV	2
1/11/2013	16.6	ADV	2
2/10/2013	14.4	ADV	1
3/10/2013	12.3	ADV	1
4/6/2013	13.6	ADV	1
4/21/2013	11.9	ADV	1
5/31/2013	20	ADCP	2
7/12/2013	16.6	ADV	2
8/9/2013	13.9	ADV	1

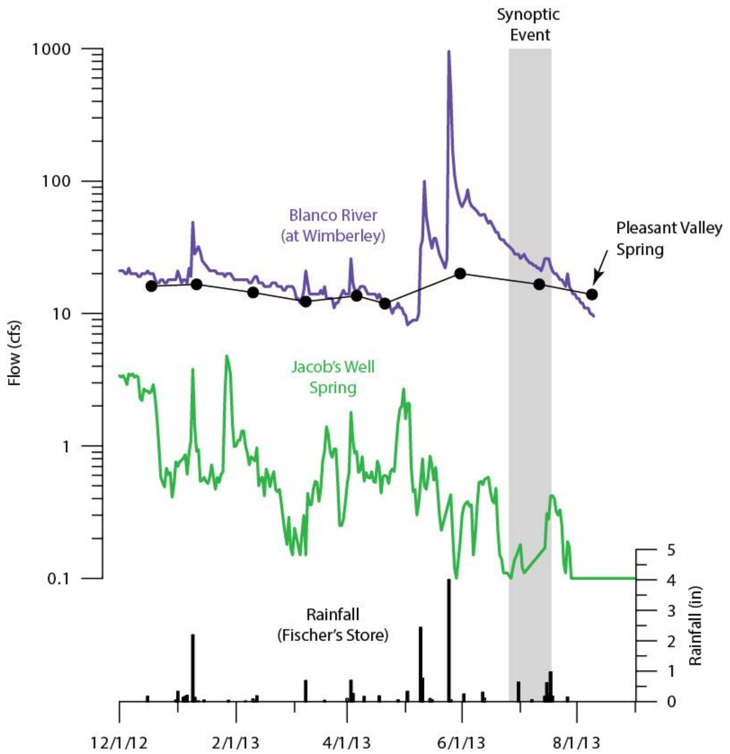


Figure 7. *Summary of spring discharge and precipitation conditions leading up to the water-level synoptic event. Blanco River and Cypress Creek discharge data from USGS (2013). Precipitation data from NCDC (2013). PVS showed increased flow in response to a rainfall event in late May 2013. JWS showed no response to the same rainfall event.*

Table 3. *Summary of point May 25-26 2013 rainfall data used for spatial rainfall analysis (CoCoRaHS 2013).*

Station	Lat	Long	2 day Rainfall total (in)
TX-HYS-17	30.166634	-98.2263	2.99
TX-HYS-93	30.029308	-98.1393	1.95
TX-HYS-53	30.130576	-98.1064	0.93
TX-CML-48	29.94537	-98.3706	4.41
TX-HYS-67	30.105934	-98.2626	2.22
TX-BLC-12	30.092092	-98.3927	4.73
TX-HYS-63	30.20483	-98.1093	1.67
TX-HYS-52	30.2105	-98.1076	1.51
TX-HYS-35	30.2256	-98.1063	0.88
TX-HYS-88	30.17649	-98.0268	1.56
TX-HYS-60	30.0506	-98.0187	2.07

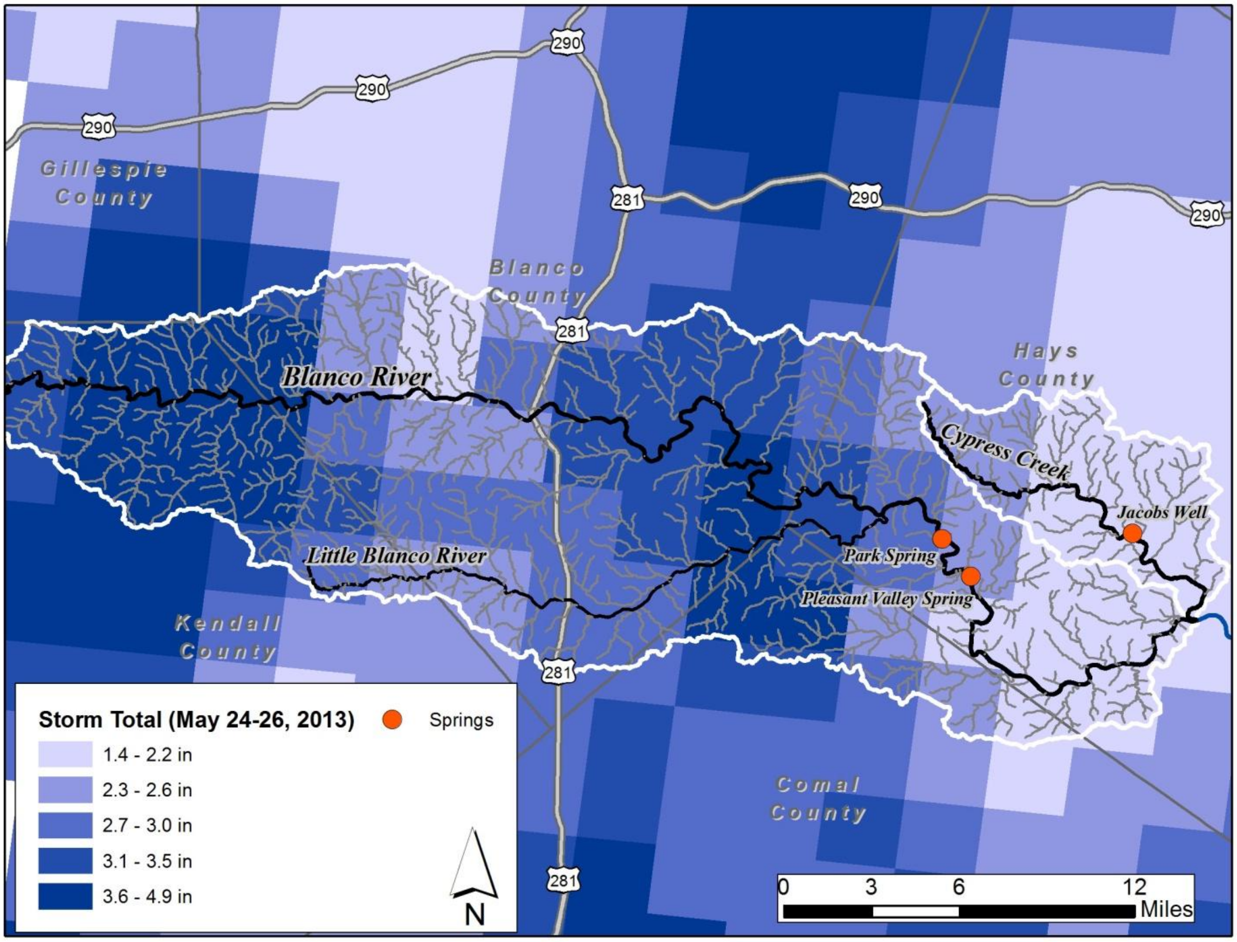


Figure 8. *Rainfall images showing rainfall distribution over a three-day period from a late May 2013 storm event. Nexrad data source: Edwards Aquifer Authority.*

DISCUSSION

The July 2013 potentiometric map shows that groundwater flow within the Middle Trinity Aquifer is generally from NW to SE in the study area (**Figure 6**). This is in agreement with the regional flow direction indicated by the 2009 and 1975 regional potentiometric maps presented by Mace et al. (2000) and Hunt et al. (2009) (**Figure 4**). In the NW portion of the study area potentiometric contours are relatively widely spaced, with a potentiometric gradient of approximately 15 ft/mi. Contours tighten (steepen) significantly to the SE in the confined region of Middle Trinity Aquifer and downgradient of the Tom Creek and Wimberley faults (Figure 6), which together have approximately 350-to-400 ft of displacement (Wierman *et al.* 2008). Gradients in this region increase to approximately 60 ft/mi. This is consistent with steeper gradients seen in the Wierman et al. (2008) map (**Figure 5**), and indicates that the large BFZ faults are likely acting as partial barriers to groundwater flow in the study area.

PVS and JWS are major discharge points for the Middle Trinity Aquifer. Thus, understanding the sources of recharge to these large karst springs is an important step toward developing a conceptual model of groundwater flow within the aquifer. PVS was not documented until 2013 (Hunt et al., 2013) and so previous studies were focused solely on JWS. Davidson (2008) presents two possible models for JWS recharge: (1) Recharge from flow losses in the Upper Blanco basin passes eastward to discharge at JWS; and, (2) A groundwater divide exists between the Blanco River and Cypress Creek basins, separating upper Blanco recharge from JWS. Model 2 implies that the Cypress Creek watershed is the recharge source for JWS. The 2013 potentiometric map (potentiometric ridge) and springflow response to the May storm presented in this report supports the second model, but does not rule out the possibility of the first model.

In the upper stretches of the Blanco River, where Cow Creek and Hensel occur in outcrop, potentiometric contours indicate flow to the SE parallel to the Blanco River to PVS (**Figure 6**). Groundwater flow between the upper Blanco and Cypress Creek watershed requires flow sub-parallel to potentiometric contours. Since flow within karst aquifers is often anisotropic, and given the sparse data defining the contours in that area, flow from the Blanco River two JWS flow cannot be ruled out.

Studying the relationship between springflow and the spatial distribution of rainfall can be a useful way to identify potential sources of recharge to karst springs. Budge (2008) studied the correlation between JWS springflow and modeled rainfall distribution from Next-Generation Radar (NEXRAD) to identify potential sources of recharge to the spring. The highest correlations were found within the surface-water catchment of Cypress Creek, suggesting that the Cypress Creek watershed may be the primary recharge area to JWS. Conducting this type of analysis for delineation of PVS and JWS recharge areas is beyond the scope of this report. However, we did observe the springflow response at JWS and PVS from a May 24-26, 2013 rainfall event and subsequent flow in the Blanco River. Nexrad rainfall (**Figure 8**) and point-precipitation data (**Table 3;** CoCoRaHS, 2013) showed that the largest amount of modeled and measured rainfall occurred within the upper Blanco River watershed, with significantly less in the Cypress Creek watershed. PVS springflow increased significantly in response to the rainfall event, while JWS showed no response (**Figure 7**). This suggests that PVS and JWS have distinct recharge areas (in the case of this specific event), and that the upper Blanco River catchment is likely a source of recharge to PVS and not to JWS.

A small potentiometric ridge is present between the Blanco River and Cypress Creek in the 925 ft-contour of the 2013 map (**Figure 6**). This provides some evidence that inter-basin flow may not occur downstream of the exposed Cow Creek in the Blanco River. A similar ridge is present in the Davidson (2008) potentiometric map, which suggests that this feature has been relatively stable (at least in times of low flow). The presence of the ridge is based on water-level measurements from three wells within a mile of one another. Although the higher water-level elevations could be the result of leakage from the overlying Upper Trinity Aquifer for some wells in the area, completion data from a driller's report indicate that at least one of these wells named "Brown shop" (**Table 1**) is completed only in the Middle Trinity. Because water levels from the other two nearby wells are in close agreement with the cased well, it is unlikely that Upper Trinity leakage is influencing the presence of the potentiometric ridge.

Other salient features of the potentiometric map include potentiometric troughs, which are interpreted to be preferential flow paths, that occur up gradient of PVS and JWS. The flow path toward JWS is centered along the mapped cave passage of JWS, and extends up Cypress Creek where the karstic Lower Glen Rose is exposed (**Figure 6**). In addition, aquifer testing has revealed hydraulic (karst) connections extending from Jacob's Well to the northwest and west to Aqua Water Supply Company Wells number 21 and 23 (Wierman et al., 2008). The trough could provide a mechanism to allow groundwater to quickly flow to JWS and thus help define and create the potentiometric ridge discussed above. A smaller flow path toward PVS is also inferred (**Figure 6**). These troughs illustrate that the Middle Trinity is indeed karstic and the potentiometric surface is responding to the presence of the spring. The troughs further illustrate the Middle Trinity Aquifer as the primary source of PVS and JWS.

Several Upper Trinity and Lower Trinity water-level measurements were collected during the course of this investigation (well ID 60-68, **Table 1**). When compared to the July 2013 potentiometric map water-level elevations from both the Upper and Lower Trinity Aquifers were markedly different than Middle Trinity elevations. Heads in the Lower Trinity ranged from 25 to 50 ft lower than the Middle Trinity (well ID 61, 65, and 66, **Table 1**). Heads in the Upper Trinity ranged from 32 to 81ft higher than the Middle Trinity (well ID 67 and 68, **Table 1**). These significant differences in head suggest a clear hydrologic separation of the Middle Trinity from overlying and underlying aquifers.

CONCLUSIONS

The July 2013 potentiometric map provides valuable information for quantifying groundwater flow paths, as well as sources of recharge to PVS and JWS. Some conclusions from this investigation include:

- Groundwater flow is generally from NW to SE from the upper Blanco River catchment across the extent of the study area.
- Potentiometric gradients tighten (steepen) downgradient of major faults associated with the BFZ, suggesting that faults are locally acting as partial barriers to groundwater flow.
- A small potentiometric ridge is present between PVS and JWS, indicating a localized groundwater divide between portions of the Blanco River and Cypress Creek watersheds.
- Potentiometric troughs are present for PVS and JWS indicating preferential flow paths feed those springs. The PVS trough is relatively subdued compared to the well-developed JWS trough centered on the cave passage and inferred along Dry Cypress Creek and other wells with known hydraulic connections to JWS.
- PVS response to a storm event in the upper Blanco watershed suggests a good hydrologic connection; however the lack of response at JWS suggests that hydrologic connection from the Blanco watershed to JWS is absent (under study conditions).
- Differences in head between the vertically adjacent Upper and Lower Trinity Aquifers suggest that the Middle Trinity Aquifer is not in good hydraulic connection with these aquifers over the extent of the study area.

PVS and JWS are major karst springs which sustain perennial baseflow to the Blanco River, which is an important recharge contributor to the Edwards Aquifer. Pumping appears to already influence flow at JWS and baseflows to Cypress Creek and the Blanco River, thus focused groundwater management in the Cypress Creek watershed could benefit JWS flow. PVS flows could also be threatened by increased pumping in the region

FUTURE WORK

Additional work needs to be done in order to better understand the Middle Trinity and PVS/JWS system. Additional potentiometric maps reflecting intermediate and high aquifer conditions are needed to fully understand spring sources. In addition to water-level, geophysical, geochemical investigations, and dye-trace studies are needed to provide a more complete understanding of the Middle Trinity system. Groundwater samples collected from many of the wells in this investigation for geochemical analysis could provide key information for understanding the Middle Trinity. The Lower Glen Rose and Cow Creek formations are assumed to be a part of the same aquifer, but this may not be a valid assumption, particularly where the Hensel changes facies and becomes more of a confining unit to the Cow Creek. A more detailed investigation comparing the water levels between the Lower Glen Rose and Cow Creek is necessary to test this assumption.

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