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Watershed Protection

Groundwater Characteristics and Age-Dating in the Jollyville Plateau

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Abstract

The Jollyville Transmission Main tunnel was proposed to run from the new Water Treatment Plant 4 site at RR620 and RR2222 to the Jollyville Reservoir at McNeil Dr. and US Hwy 183. Four shafts provided access during construction of the tunnel; at the plant, the Four Points area, along Spicewood Springs Rd, and the Jollyville Reservoir. The tunnel runs through portions of the Balcones Canyonlands Preserve system and below Bull Creek. These areas are close to a significant spring that provides habitat for the Jollyville Plateau Salamander. Shafts, particularly those in the Four Points area, at Spicewood Springs Road and at the Jollyville Reservoir, had the potential to damage the shallow groundwater system feeding the creek and springs. Based on available data from water levels, borehole packer tests, dye tracing, creek and spring flows, and field observations, a conceptual model of the groundwater system in the Jollyville Plateau area was developed. The model proposed a shallow groundwater system on the order of 10's of feet think closely connected to the surface through which recharging water migrated to springs and creeks and a deeper groundwater system which was isolated from the shallow system. Excavation of the tunnel was proposed in the deep system whereas the shafts were excavated through the shallow system into the deep system. Due to community concerns about environmental impacts of the project, a sampling plan was developed to verify the conceptual model of a shallow and deep groundwater system using geochemical analysis and tritium age-dating.

Introduction

The geology of the study area includes up to approximately 80 feet of the basal Edwards, approximately 100 feet of the Walnut formation. The Glen Rose is up to 500 feet thick but only the upper 150 feet of the upper Glen Rose is investigated for this study. Tributary terraces less than 10 feet thick are present in the valley floor.

Based on limited water level data and dye tracing (Johns 2011, 2013, 2014) the groundwater assessment for the Jollyville Transmission Main project developed a conceptual model of groundwater in the project area as being comprised of two systems: a shallow system in the Edwards and Walnut formations 10's of feet thick and a deeper system in the Glen Rose formation (Daniel B Stephens Associates 2010). The Stephens report further clarifies that the upper roughly 50 ft of the Glen Rose appears more permeable than deeper in the formation and is thus included in the shallow groundwater system. Discharges from the shallow system, including the upper Glen Rose, feed the springs and creeks. The proposed finished water transmission tunnel will be completed into the deeper Glen Rose groundwater system whereas the access shafts will be mined through the shallow system to the deeper system. Critical review of the project led to a suggestion to perform age-dating of groundwater as a method to verify the conceptual model as well as a tool to evaluate well water levels documented in background monitoring. Water chemistry from monitoring wells, springs and surface water was also evaluated and compared to age-dating results.

Age-dating groundwater using tritium isotopes provides semi-quantitative ages and is commonly used to date "young" groundwater, water in the ground on the order of 10's of years. Tritium is an isotope of hydrogen containing one proton and 2 neutrons and is unstable or radioactive with a half-life of 12.43 years (Appelo and Postma 2010, Kazemi et al 2006) or 12.3 years (Kresic and Stevanovic 2010, Freeze and Cherry 1979). Atmospheric thermonuclear testing beginning in 1951 caused a large increase in environmental tritium (Freeze and Cherry 1979, Kazemi et al 2006). Water recharged prior to approximately 1952 would contain little detectable tritium due to the natural decay of the isotope. Greater tritium values are expected in groundwater exposed to the atmosphere and recharged within the past 10 years. Water recharged since 1952 would contain detectable tritium but since natural decay of recharge water pulses or mixing of water of different ages can produce similar results, the difference between these waters cannot be distinguished (Musgrove, personal communication 2013). For this study, age-dating using carbon-14 was considered but rejected because of possible chemical modeling required to account for water-rock interactions with the carbon-bearing carbonate host rocks. Tritium age-dating should be sufficient to evaluate the relative age differences between the shallow and deep groundwater systems. General information on tritium in groundwater can be found in Freeze and Cherry, 1979; Kazemi, et al, 2006; Faure, 1977; and Clark and Fritz, 1997.

Age-dating has been conducted in the Edwards Aquifer in the San Antonio region (Musgrove, et al, 2010; Fahlquist and Ardis, 2004; Kuniansky et al, 2001) and to a lesser extent in the Barton Springs segment (Brain Hunt, personal communication 2011; Smith and Hunt, 2011). Fahlquist and Ardis (2004) also present results of age-dating in the Trinity Aquifer (which includes the Glen Rose formation). A limited amount of tritium data is in the City of Austin's field sample database.

Water samples were collected to determine geochemical characteristics and the relative age of water in each system testing the hypothesis that the shallow hydrologic system would have younger and less chemically evolved water than the deep hydrologic system.

Methods

Sampling

Water samples were collected from wells, selected springs, specific creek reaches, and from within Jollyville Transmission Main Four Points and Jollyville Reservoir shafts (Figure 1 – location of sites) and analyzed for tritium in addition to standard inorganics and field parameters. Surface water samples were collected in April and May 2012. Well samples were collected from

May through August 2012. Table 1 shows general well completion data. Sampling of water within the tunnel was proposed but due to the lack of significant discrete inflows this sampling was not conducted. Table 3 and Figure 1 show the surface water, springs, wells and shafts sampled.

Table 1. General completion data for monitoring wells used in this study.

Well ID	Monitoring Well Completion Depth	Sand Backfill Interval	Screened Interval	Approximate Preconstruction Water Level	Formation
	Feet Below Ground Surface	Feet Below Ground Surface	Feet Below Ground Surface	Feet Below Ground Surface	
JT101A	85	61-85	63-83	71	Edwards
JT112	96	75-96	75-95	80	Edwards
JT113	95	69-95	71-91	70	Edwards
JT114	85	61-85	63-83	67	Edwards
JT115	74	50-74	52-72	59	Edwards
JT124A	107	82-107	85-105	64	Edwards
JT127	150	126-150	128-148	66	Edwards
JT128	90	67-90	69-89	80	Edwards
JT104	125	101-125	103-123	96	Walnut
JT109	43	18-43	20-40	38	Walnut
JT107S-A	32	18-32	20-30	25	Glen Rose
JT107PZ-A	102	78-102	80-100	27	Glen Rose
JT107D-A	207	183-207	185-205	63	Glen Rose
JT108A	102	78-102	80-100	19	Glen Rose
JT118A	102	77-102	80-100	27	Glen Rose
JT120A	95	71-95	73-93	13	Glen Rose
JT125A	247	223-247	225-245	102	Glen Rose

Springs were sampled by collecting water as close to the spring orifice as possible in bottles provided by the contract laboratory.

Surface water was sampled in pools or creek runs where access was available. Samples were free of suspended sediment or other debris, and collected in bottles provided by the contract laboratory.

In the two shafts, water samples were collected as close to the rock face as possible from selected inflow points from the Glen Rose. In the 4 Points shaft, water was collected from a stream discharging from a rock bolt approximately 235 feet below ground and approximately 55 feet into the Glen Rose Formation. Access was provided by the contractor using a manbasket suspended from a crane. In the Jollyville Reservoir shaft, water was collected during excavation from a discrete discharge from a vug approximately 305 feet below ground approximately 35 feet into the Glen Rose Formation.

The boring logs and completion data for the monitoring wells are contained in the Geotechnical Data Report (Black&Veatch 2011). Monitoring wells (Table 1) completed in the Edwards formation on the west side of the project area typically have casing with a 20-ft screen across the Edwards/Walnut contact. Sand packs were installed surrounding the well screens and typically to a distance of 2 ft above and below the well screen. These wells typically have only a few feet of water above the formation contact which means that the screen and adjacent sand-pack are exposed to the atmosphere. These wells were purged to remove a minimum of 3 volumes of water from both the well pipe and adjacent sand-pack. E-line measurements determined water levels at the time of purging and combined with well completion data to determine the volume of water removed. The objective is to minimize dewatering and air entry into the sand pack and avoid introducing tritium into the water sample. Multiple samples were collected from selected wells to document tritium geochemical variation in water from purging which might indicate influence of the Lake Austin water used as a drilling fluid. Photo 1 shows a typical well sampling site.

Monitoring wells in the Glen Rose and Walnut (Table 1) are completed at horizons ranging from near the Edwards/Walnut contact to below tunnel horizon. Water levels in these wells are above the well screen with the exception of the water-table wells JT-109 and JT-107Sa. These wells were purged to remove a minimum of 3 volumes of water from both the wells pipe and adjacent sand-pack to remove introduced water or other contaminants. When purging, an e-line was used to keep the water level from dropping below the well screen to prevent air from the atmosphere from entering the sand pack and avoid introducing atmospheric tritium into the water sample. JT-109 and JT-107Sa were sampled similar to the Edwards wells.

Well purging duration varied from hours to days. Water levels in some wells recovered quickly, indicative of the relatively high permeability of the screened interval of the host rock formation. In other wells, water levels recovered very slow and required repeated visits over several days to completely purge the wells.

Samples were iced and delivered to the laboratory with appropriate chain-of-custody documentation.

Field parameters included temperature, pH, specific conductance, and dissolved oxygen. Field measurements were made as close to the spring outlet as possible in either a pool sufficient to immerse the probes or by using a flow-through cell. For wells, field parameters were measured using a bucket collecting water purged from the wells or a flow-through cell and recorded once parameters have stabilized. In surface water, field parameters were measured in pools or creek runs of sufficient depth to cover the probe sensors.

Sample Plan

Sampling was conducted in two phases (Attachment 1) although results are considered together.

Phase 1: During Phase 1 water samples were collected from springs that discharge from the Edwards, Walnut and Glen Rose formations (Photo 2 and 3) and surface water points including

Lake Austin downstream of Mansfield Dam and selected points along Bull Creek in the project area. Figure 1 shows spring and surface sample locations.

Phase 2: Phase 2 samples were collected from monitoring wells drilled as part of the geotechnical investigations for the JTM project (Photo 4) and include wells ranging from >30 ft to >200 ft deep completed in the Edwards, Walnut, shallow Glen Rose (defined as shallower than the tunnel horizon) and the deep Glen Rose (defined as the tunnel horizon or below). Figure 1 shows well sample locations.

These monitoring wells were drilled with air rotary methods or using drilling fluids that include water collected from Lake Austin at a low-water crossing about 2,200 ft downstream of Mansfield Dam. Most Edwards wells were drilled using air rotary methods only, whereas some Glen Rose wells were drilled using fluids. Entry of young Lake Austin water into the rock formation could potentially impact water samples for tritium analysis. To detect possible impacts by younger lake water, multiple samples were collected from selected wells and analyzed for tritium and inorganics. For three selected Glen Rose wells, a sample was collected of initial purge water, another sample collected approximately half way through purging and a final sample collected after 3 volumes have been purged from the well and adjacent sand-pack. Significant variation in tritium concentrations, particularly a trend toward older water in final well samples, may indicate impacts from drilling or other well construction activities. For five selected Edwards wells, a sample was collected of the initial purge water and a final sample collected after 3 volumes have been purged from the well and adjacent sand-pack.

Samples were also collected from Four Points and Jollyville Reservoir shafts, which were both open in the spring of 2012. The samples collected from these shafts targeted water discharging from the Glen Rose. No samples were collected from the Spicewood (excavation not started during sampling) and WTP shafts (not accessible due to excavation method used by the contractor).

Duplicate samples were collected from a single spring and from two wells. Multiple samples (either two or three) collected from eight wells during purging, either at the beginning and end of purging or beginning, middle and end of purging. These samples effectively served as duplicate tritium samples.

An additional phase of collecting samples from the tunnel was proposed but was not conducted due to a lack of significant discrete groundwater inflows into the tunnel.

Analytical Methods:

Tritium samples were collected following guidelines from the University of Miami Rosenstiel School of Marine Atmospheric Science Tritium Laboratory (www.rsmas.miami.edu/groups/tritium/). All water samples were delivered to the LCRA Environmental Laboratory for analysis of inorganic parameters and for shipment to the University of Miami for tritium analysis.

Physical parameters were measured in the field using a multi-probe water quality sonde from the City of Austin Watershed Protection Department and included temperature, pH, dissolved oxygen, and specific conductance. The LCRA analyzed inorganic parameters using standard methods and included alkalinity, calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride and strontium. Samples for tritium analysis were delivered to the LCRA lab for shipment to the University of Miami Rosenstiel School of Marine Atmospheric Science Tritium Laboratory.

Sources of Possible Contamination of Water Samples: The groundwater system in the Jollyville plateau has not previously been studied to the level of detail that it has for the JTM project. The Edwards is known to be karstic with numerous nearby caves and solution features. However, based on observations of the Edwards during excavation of the Four Points and Jollyville shafts, not all the Edwards displays karst properties and not all the groundwater is moving through karst features. This study tests a conceptual model that proposes young, tritium-bearing water in shallow formations and surface waters, and old non-tritium bearing water in deep formations. However, the following are some factors which we expected to complicate the results:

1) *Natural mixing of water:* Given that almost all the spring and creek sites were completely dry for several months in 2011 and began flowing again in late 2011 following several rain events, these sites are expected to be predominantly recent water. However, older water from the aquifer may be mixing with the recent rain water and complicate interpretation of the results.

2) *Introduction of river water to geologic formations during well drilling:* Water from the Colorado River was used for drilling fluid in most wells. River water is expected to have a recent age signature and mixing of river and formation waters in samples from the monitoring wells may generate problematic results that will require professional judgment and interpretation by considering other factors such as ion concentrations, recent rain events, a well's response to rain, or other stresses to the aquifer such as pumping. Duplicate samples and analysis of variance from samples collected during purging will help interpret tritium concentrations.

3) *Introduction of river water to shallow groundwater during tracing and permeable ring testing at Four Points:* Dye tracing at the Four Points shaft site has documented a connection between the shaft and several monitoring wells and at least one spring (Johns 2011, 2013, 2014) northeast of the shaft. There have been four dye injections at the Four Points site, three in which injected water and dye entered the formation; one in a monitoring well prior to shaft excavation and two in the permeable ring at the Edwards/Walnut contact and an unsuccessful injection into the permeable ring in which all injected dye and water appeared to drain onto the shaft floor and not enter the rock formation. Water from the Colorado River was used in the pre-excavation trace in March 2011 which introduced river recent/modern water into the formation. For the permeable ring traces (December 2011, January 2012 and July 2012), injection water was from and open air settling tank contained water pumped from the shaft and tunnel. This water was presumably old water, however the water was stored in open-air tanks on site which may

have introduced recent tritium via rainfall or atmospheric contact. Water collected from the shaft discharged from various geologic intervals in the shaft and tunnel including some tap water which was used to cool the tunnel boring machine. The portions of water from each of the potential sources is not known and so the resulting tritium signature of this water is not known as well. During the last permeable ring test in January 2012, water successfully entered the geological formation to reach at least one nearby monitoring well as indicated by a rapid rise in water level in the well. Tritium concentrations in downgradient wells with demonstrated connections to the shaft may certainly be influenced by this injected water.

4) *Possible direct introduction of surface water to the water table in JT-128:* Rapid water level rises in JT-128 (next to Four Points shaft) following at least four rain events suggests that surface water may be rapidly entering the well and adjacent geologic strata. At this time, it is unknown whether the water is directly entering the well or is recharging through a nearby karst feature and rapidly migrating to the water table. In either case, this may be a source of recent water entering the Edwards formation.

Analytical Results

Tritium concentrations are reported in tritium units with estimated errors. More detail can be found on the laboratory web site (www.rsmas.miami.edu/groups/tritium/). Inorganic results from the LCRA Environmental Laboratory are reported as mg/L or ug/L as appropriate. These results are electronically entered into the City's field sample database and verified using electronic copies of the results. These results can be compared to previous samples from the same site or samples from similar sites.

Groundwater age ranges based on tritium data from Clark and Fritz (1997) were converted to values expected in 2012 using the decay function of:

$$a_t{}^3\mathrm{H} = a_o{}^3\mathrm{H}e^{-\lambda t}$$

or

$$t = -17.93\ln(a_t{}^3\mathrm{H}/a_o{}^3\mathrm{H})$$

In these equations, $a_o{}^3\mathrm{H}$ is the initial tritium concentration in TU and $a_t{}^3\mathrm{H}$ is the residual concentration remaining after decay over time t. The decay term λ equals ln2 divided by the half-life $t_{1/2}$, which is 12.43 years. Results are shown in Table 2.

Table 2. Classification of relative age of groundwater based on tritium (Clark and Fritz, 1997) converted to expected 2012 values based on natural tritium decay.

Continental	1997		2012	
Range	Initial Low value	Initial High value	Present low value (TU)	Present high value (TU)
Submodern (recharged prior to 1952	<	0.8	<	0.3
Mix between submodern and recent recharge	0.8	4	0.3	1.7
Modern	5	15	2.2	6.5
Some "bomb" 3H present	15	30	6.5	13.0
Mostly recharge from 1960s	>	30	>	13.0
Dominantly 1960's recharge	>	50	>	21.7

Coastal	1997		2012	
Range	Initial Low value	Initial High value	Present low value (TU)	Present high value (TU)
Submodern (recharged prior to 1952	<	0.8	<	0.3
Mix between submodern and recent recharge	0.8	2	0.3	0.9
Modern	2	8	0.9	3.5
Some "bomb" 3H present	10	20	4.3	8.7
Mostly recharge from 1960s	>	30	>	13.0
Dominantly 1960's recharge	>	20	>	8.7

based on data from Clark and Fritz, 1997, Environmental Isotopes in Hydrogeology

Results and Discussion

A conceptual groundwater model was proposed for the Jollyville Plateau area comprised of (1) a shallow system tens of feet thick feeding springs and creeks documented by groundwater tracing and (2) a deeper system greater than 100 ft below the surface poorly connected to the shallow system. For the purpose of discussing these results the JT107S-A, JT104A and JT109 wells will be discussed in the context of the shallow aquifer system (grouped with the Edwards wells).

Forty nine water samples were collected at four surface sites, 11 different springs, 17 wells and two shafts. In addition, three duplicate samples were collected. Multiple samples were collected from eight wells. These include duplicates from two wells, and samples collected through the purging cycle in eight wells. Sample collection began in April 2012 and was completed in August 2012. Table 3 shows results.

Field Parameters

Initial water pumped from the wells was often gray and very turbid, probably due to fine drill cuttings from the rock formation settling in the bottom of the well (Photo 5A). Water generally cleared as purging in each well progressed (Photos 5B). Glen Rose water samples tended to have a distinctive sulfur smell.

On average, wells with greater depths to water had higher water temperatures whether they were completed in the Edwards or Glen Rose. In wells with multiple samples, temperature tended to be highest in the final sample even when the purging was conducted over a period of days or even weeks. It is not likely that seasonality was a factor as even deep wells, isolated from surface influences, sampled in May had higher water temperatures (such as JT104A and JT124A).

Table 3. Analytical results of water samples collected from surface, springs, wells and access shafts.

SITE	DATE	TEMP	SPECIFIC CONDUCTANCE	DISSOLVED OXYGEN	PH	CALCIUM	MAGNESIUM	POTASSIUM	SODIUM	STRONTIUM	CHLORIDE	FLUORIDE	SULFATE	ALKALINITY	TRITIUM
		C	uS/cm	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	TU
Surface Water															
LkA Low Water Crossing	4/17/2012 1350	16.12	484	13.62	8.24	42.8	22.1	3.92	25.2	0.37	42.2	0.24	26.9	164	2.94
Bull Ups Gaas	4/17/2012 1310	19.80	618	1.86	7.22	109	14.7	0.821	10.2	0.237	21.7	0.12	25.3	280	2.41
Bull Dwns WTP4	4/17/2012 1140	19.01	576	3.90	7.31	103	15.7	0.468	9.54	0.334	17.6	0.12	21.1	264	2.33
Bull at Trib 7	4/17/2012 0855	17.71	541	6.68	7.85	95.1	15.1	0.616	8.45	0.715	16.7	0.12	19.3	249	2.18
Springs															
Tanglewood Spr	4/17/2012 1440	20.79	1022	7.77	7.22	154	31.2	1.96	33.8	0.219	76.4	0.25	70.4	364	2.17
Spider Spr	5/1/2012 0955	22.48	1053	5.92	7.05	154	35	1.1	29.3	0.194	56.5	0.2	51.5	410	2.33
Powerline Spr	4/17/2012 1215	18.90	627	8.44	7.37	126	14.5	0.321	6.7	0.131	13	0.12	12.6	313	2.67
Gaas Spr	4/17/2012 1320	19.14	668	7.04	7.01	118	25	0.398	8.97	0.282	14.4	0.18	13.1	340	1.78
Cistern Spr	4/17/2012 0940	19.64	583	8.14	7.30	106	20	0.229	4.54	0.335	8.15	0.13	8.25	300	2.07
Pit Spr-bank	4/17/2012 0910	18.28	544	4.92	7.57	95	15.1	0.595	8.38	0.758	16.7	0.13	19.9	252	2.55
Pit Spr-channel	5/1/2012 0925	18.76	542	2.90	7.12	92.8	12	0.52	7.78	0.724	14.2	0.09	16.5	247	2.49
Lanier Spr	4/17/2012 1005	18.10	600	6.29	7.22	109	15.6	0.499	9.35	0.451	17.6	0.12	21.2	279	2.22
Ribelin Spr	4/17/2012 1045	17.95	586	8.72	7.30	104	17.7	0.706	9.23	0.259	18.7	0.15	17.3	272	2.46
Ribelin Spr dup	4/17/2012 1055					101	17.1	0.69	9	0.252	18.7	0.15	17.4	270	2.26
4 Points Spring 1	8/8/2012 1055	NT	568	NT	7.41	105	17.60	0.26	6.84	0.169	10.30	0.15	12.4	301	2.05
4 Points Spring 2	8/8/2012 0925	NT	675	NT	7.22	122	17.50	0.47	11.80	0.266	21.70	0.13	30.1	322	2.48
Wells and Shafts															
Glen Rose															
4 Pts - 235 ft	5/18/2012 0940	NT	NT	NT	NT	80.9	34.9	2.32	7.53	19.6	15.7	0.35	35.7	284	1.59
JR - 305 Ft	5/22/2012 1210	NT	NT	NT	NT	59.3	66.5	23.4	29	38.6	20.5	3.51	188	330	0.05
JT118A	5/24/2012 1215	21.59	1107	5.57	7.07	85	87.2	18.8	26.7	27.6	19.4	3.76	303	317	-0.08
JT120A	6/14/2012 1040	NT	NT	NT	NT	75.8	87.8	25.1	37.4	25.4	23.2	3.76	299	332	0.08
JT107S-A	7/19/2012 1140	21.51	571	7.71	7.14	127	29.1	1.49	8.71	1.81	12.3	0.19	24.4	324	2.28
JT107PZ-A	6/26/2012 1110	21.48	874	2.00	7.07	154	79.9	16	14.9	35.7	7.93	3.12	182	541	0.15
JT107PZ-A	7/3/2012 1055	21.68	876	3.57	7.05	84.2	70	14	15.2	34.1	8.29	2.92	177	130	0.04
JT107PZ-A	7/5/2012 1410	22.68	880	2.23	7.10	127	72.4	14.4	15.6	33.8	8.3	2.81	170	338	0.05
JT107D-A	8/8/2012 1305	26.26	801	3.75	7.23	65	65.1	13.6	18	37	8.49	2.96	164	320	0.17
JT107D-A	8/9/2012 0855	24.38	1061	1.62	7.03	71.9	76.1	15.9	22.6	34.3	11.1	3	234	308	0.29
JT107D-A	8/9/2012 1410	29.86	1164	4.56	7.18	82	85.3	17.5	26.1	31.1	13.5	3.23	296	306	0.32
JT107D-A (dup)	8/9/2012 1420					82.7	85.7	17.9	26.3	32.3	13.6	3.24	297	304	0.33
JT108A	7/5/2012 1025	20.61	864	1.67	7.12	174	71.8	14.6	21.2	29.4	10.5	2.53	162	670	0.17
JT108A	7/5/2012 1507	21.01	906	1.41	7.14	313	90.6	15.5	26.2	32.6	9.86	2.82	186	610	0.02
JT108A	7/19/2012 1315	23.31	905	3.02	7.24	81	67.3	10.9	23.5	32.7	9.72	2.84	181	325	-0.03
JT125A	8/10/2012 0930	23.50	921	3.07	7.10	68.3	61.2	18	19.3	38	14.8	2.85	128	344	0.5
JT125A	8/10/2012 1100	24.08	921	0.90	7.04	63.6	61.1	18.1	18.3	37.8	14.7	2.88	128	330	0.49
JT125A (dup)	8/10/2012 1110					63.6	30.9	18.1	18.2	38.2	14.7	2.86	126	330	0.56
Walnut															
JT104	5/29/2012 1305	26.93	852		7.50	88.3	28.1	6.62	123	16.1	16.2	3.72	87.7	459	0.16
JT109	5/1/2012 1005	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	0.69
Edwards															
JT124A	5/29/2012 1150	23.90	592	5.20	6.97	72.3	34.4	0.924	8.58	0.175	13.5	2.27	7.88	298	-0.04
JT127	8/2/2012 1230	26.50	788	NT	7.60	107	42.8	0.759	28.4	0.218	40.1	0.4	31.5	378	1.55
JT113	6/5/2012 1215	22.51	2010	2.98	11.82	183	0	8.37	12.1	1	16.2	0.44	14.5	367	1.53
JT113	7/26/2012 1210	23.34	1470	4.16	11.48	160	0.703	4.34	10.4	0.637	14.8	0.47	27.5	476	1.4
JT114	6/5/2012 0940	21.81	605	7.88	NT	99.9	40.3	1.24	14.7	2.81	10.4	0.23	20.1	312	0.04
JT114	6/5/2012 1005	21.81	594	6.99	5.21	79.9	36.8	0.876	8.41	1.93	10	0.24	13.8	322	0.02
JT115	6/1/2012 0935	NT	NT	NT	NT	145	2.73	3.95	25.9	3.2	11.9	0.44	206	164	0.14
JT115	8/2/2012 1438	26.50	781	NT	7.60	79.5	19.5	4.03	10.8	2.75	11.2	0.41	98	144	0.13
JT112	6/12/2012 1430	22.77	616	6.23	7.08	87.1	27.9	0.779	8.17	1.18	12.7	0.18	7.12	310	1.13
JT128	6/12/2012 1530	21.01	513	7.84	7.16	72.6	22	0.558	8.08	0.36	13	0.19	9.38	246	1.57
JT101A	6/19/2012 0905	21.93	474	6.37	7.47	139	165	4.88	6.97	2.18	0	0.31	0	2030	-0.03
JT101A	6/19/2012 1345	22.68	467	7.91	7.24	152	36.4	1.51	5.68	1.18	7.65	0.35	3.85	344	-0.03
JT101A	7/26/2012 1110	21.95	474	7.83	7.45	227	47.7	2.14	5.97	1.28	7.66	0.34	3.9	446	-0.01

However, more measurements of higher temperature were made in August so season may have been a factor in some wells. The temperature differences are unlikely due to the natural geothermal gradient of 0.4-0.6° C/100m (Luetscher and Jeannin 2004) or 1-2° F/100 ft (Woodruff 1982) since some wells show a difference up to three or four degrees C over a couple hundred feet. The difference is more likely due to the increased work that the small pump used to pull water from greater depths, resulting in heated water. Surface water temperatures are obviously seasonally influenced. Spring water temperatures are also influenced by season based on spring samples throughout Austin, although Tanglewood and Spider Springs had the highest temperatures even though they were sampled in relatively cool months of April and May respectively. Surface water temperature averaged 18.2 C and springs averaged 19.3 C.

Specific conductance (SC) in surface and spring water were mostly less than 670 uS/cm although Tanglewood and Spider Springs had SC over 1000 uS/cm. The Glen Rose wells of the deep aquifer system (excepting JT107S-A) had the highest SC, ranging from 801 to 1164 uS/cm. Edwards wells of the shallow system ranged from 467 to 788 uS/cm (excepting an anomalously high SC (and pH) at JT113.

It is not clear if the pump operation impacted levels of dissolved oxygen (DO) in the wells. The deep system wells mostly had low DO, averaging less than 3 mg/L while the shallow system wells averaged 6.5 mg/L. In the surface waters DO was highest on the Colorado River just downstream of Mansfield Dam (13.6 mg/L) and lowest in the main stem of Bull Creek upstream of Gaas Spring (1.9 mg/L). DO in springs were mostly above 6 mg/L, averaging 6.7 mg/L except at two outlets of Pit Spring. A bank outlet of the spring measured 4.9 mg/L while a bedrock outlet measured 2.9 mg/L. These values are unusually low compared to other sites and given recent tracing work that documents the water source for the bank outlets is from the creek about 1000 ft upstream and at least a partial water source for the bedrock outlets is water recharging in nearby tributary 7 (Hatch and Johns, 2015). However, there are additional data showing DO values less than 3.0 mg/L at this spring during periods of low discharge so these values may not be unusually for this site.

pH averaged 7.7 and 7.3 in surface and spring waters, respectively. pH averaged 7.11 in the deep system wells but 7.8 in the shallow system wells. The shallow system average was strongly influenced by two unusually high measurements from the JT113 well, 11.8 and 11.5. The cause of this high pH is not known.

It is unclear if purging impacted field measurements other than water clarity. As noted above, temperature may have been affected by the pump. SC changing during purging were relatively minor except in JT107D-A where it jumped from 801 uS/cm to 1164 uS/cm in the final sample. Most changes were on the order of a few percent of the original measurement. DO was generally higher in final samples than in initial samples (JT107D-A, JT108A, JT113) but was sometimes lower or not changed (JT107PZ-A, JT125A, JT114, JT101A).

Geochemistry

Geochemical signatures of surface and shallow groundwater are calcium-bicarbonate ($CaHCO^3$) evolving to greater enrichment in magnesium (Mg) and sulfate (SO_4) in deeper groundwater (Figure 2). Ion chemistry of the springs, creeks and shallow wells are largely identical with the exception of the Colorado River which has significantly higher magnesium (Mg), potassium (K), sodium (Na) and chloride (Cl) and lower calcium (Ca) ion concentrations.

Figure 3 plotting fluoride (F) vs strontium (Sr) shows clear distinction of deeper Glen Rose and Walnut wells with higher concentrations of F and Sr from shallower Edwards wells and springs and surface waters. Edwards well JT124A is anomalous with higher F concentrations than other Edwards wells. Chemistry of the shallow Glen Rose JT107S well is similar to surface water, springs and Edwards wells.

Figure 4 plotting Mg vs SO_4 also shows a clear distinction between deeper and shallower wells, springs and surface water. Sulfate has been used in previous studies to distinguish between shallow Edwards and deeper Trinity waters (Senger and Kreitler, 1984, Garner and Mahler, 2007, Wong et al, 2013).The initial sample (prior to purging) of JT101A (Edwards) is anomalously high for Mg and low for SO_4. Both samples from JT115 (Edwards) are anomalously high for SO_4. Samples from Tanglewood and Spider Springs tend to have greater ion concentrations possibly suggesting a mixed water source for these two springs of either Glen Rose water or deeper Edwards water with higher ion concentrations. Glen Rose well JT125 has lower concentrations of SO_4 than the other Glen Rose wells. Plotting Mg vs SO_4 illustrates chemical differences between formation waters for both parameters. Although SO_4 concentrations are similar between surface and shallow Edwards and Glen Rose wells, Mg concentrations are greater in wells than surface waters and much greater in Glen Rose wells than Edwards wells. Notably, JT115, Tanglewood and Spider Springs exhibit anomalously high SO_4 concentrations.

Figure 5 plotting Na vs Cl shows some distinction between surface and Edwards wells with lower Na concentrations and Glen Rose wells with higher Na concentrations. Chloride does not generally provide any distinction between the sites. However, Tanglewood and Spider Springs both, again, have anomalously high concentrations of Cl as does the Colorado River (EPA 2015) and JT127. As with some other parameters, JT113 and 115 have Na concentrations slightly out of range higher than other Edwards wells.

Figure 6 of SO_4 vs SO4/Cl uses geochemical fields defined by previous studies and compares those results with this study (Senger and Kreitler, 1984, Garner and Mahler, 2007, Wong et al, 2013). The current study has similar results where Glen Rose groundwater samples fall in the lowest portion of the Trinity groundwater field (lower SO_4 and SO_4/Cl ratio).

The ratio of Ca/Mg is generally considered to decrease (Mg concentrations increase) as water is in longer contact with carbonate host rocks (Musgrove and Banner 2004, Wong et al. 2011), and can be used to represent relative residence time of the water. Figure 7 (Ca/Mg vs Tr) shows greater tritium concentrations (generally young water) in surface and spring water along with higher Ca/Mg ratios and trends to lower tritium values and Ca/Mg ratios in some Edwards and most Glen Rose wells. Edwards wells JT113 and 115 have anomalously high Ca/Mg ratios. The data supports the relationship be Ca/Mg ratios and relative groundwater age.

In addition, Tanglewood and Spider Springs also have elevated ion concentrations, possibly due to impacts from urbanization (CoA, 1997) or a deeper water source with greater residence water times leading to higher ion concentrations (Table 3). Chemistry in deeper wells (Glen Rose) is characterized by greater ion concentrations, particularly strontium (Sr), fluoride (F), sulfate (SO4), and K and lower Ca/Mg ratios (i.e. shallow water has more calcium and deeper water has more magnesium) (Table 3, Figures 2-7). The high SO_4 concentration in the Glen Rose gives rise to a distinctive sulfur or rotten egg smell.

All wells were purged as part of the sampling process. It was not clear how much each well was purged during monitor well construction. Some samples were collected during purging to assess any changes in water chemistry (JT101A, JT107PZ-A, JT107D-A, JT108, JT125A, JT113, JT114, JT115). In general, purging did not significantly change water chemistry. However, there were some small changes and a few notable exceptions. The initial sample from JT101A had significantly greater Mg and K concentrations than the following two samples. All other Edwards wells had only minor changes over the purging process. Of the Glen Rose wells, JT108A and JT107D-A had notable increases in SO_4 concentrations whereas JT107PZ-A had a slight decrease in both SO_4 and Mg concentrations. JT125A had only minor chemical changes.

Tritium

Given its short half-life, the presence of tritium in a sample is indicative of recent groundwater recharge (Clark and Fritz 1997). Table 2 shows a classification of relative groundwater age presented in Clark and Frtiz (1997) and modified based on tritium decay to indicate relative groundwater age based on samples collected in 2012 for this study. Based on this data, the break between premodern and mixed water is 0.3 TU. The break between modern and mixed water is either 1.7 TU (based on continental rainfall) or 0.9 TU based on coastal rainfall. A range for modern or mixed water is shown in Figure 8 due to uncertainty of the project area being in a coastal or upland setting regarding rainfall.

Tritium results are shown in Table 3 and Figure 8. Tritium results indicate that the springs and creeks contain modern water (from precipitation since 1952) averaging 2.3 and 2.5 Tritium Units (TU) respectively. The deeper groundwater system (all Glen Rose wells) contains mostly pre-modern water (recharged before 1952) averaging 0.19 TU. A couple of Glen Rose wells, JT107D-A and JT125A, have values in the range of 0.3 and 0.5 TUs, respectively, which suggests there is mixing of pre-modern and modern water. However, there is no other data that suggests a connection to the shallow groundwater system or surface water such as water level response to rain events or water chemistry. Lack of significant change in tritium during purging indicates that the water chemistry was effected by drilling operations.

The shallow groundwater system (Edwards, Walnut and shallow Glen Rose), has a modern relative groundwater age based on tritium data (Figure 8/Table 3). Edwards wells JT127, JT113, JT112, and JT128 appear to have modern water based on coastal precipitation tritium values. Walnut well JT109 has a mixture of modern and submodern water. Edwards wells JT124, JT114, JT115, and JT101A are clearly characterized by submodern water as is the Walnut well JT104.

Six Edwards and Walnut wells, JT104, JT109, JT112, JT113, JT115, JT127 and JT128 appear to contain a mix of pre-modern and modern water, ranging from 0.13 to 1.57 TUs.

JT127 is adjacent to the Jollyville shaft and had a large drop in the local water table prior to sampling that may have influenced the tritium results.

Discussion

Several Edwards wells and springs in the Four Points area may have been impacted by waters used in the four tracer injections at the Four Points shaft (see Methods/Analytical Methods section of this report) including JT128, JT112, JT113, JT114, JT115, and Gass Spring. The tracer injection in March 2011 was detected downgradient and so water used in the injection also migrated downgradient. The December 2011 trace probably never significantly entered the formation. Although dye from the January 2012 injection was never positively identified downgradient the July injection was detected downgradient and so the water used also migrated. Results in JT112 and JT128 are likely altered due to introduction of water since they were strongly hit by the tracers and were close to the Four Points shaft. JT113 and JT115 may also be influenced by tracing water since tracers were detected in those wells. However, natural mixing of older and younger water may also be occurring. JT104 and JT109 may have natural mixing within the Walnut. JT112, JT114, JT128 and Gaas Spring were sampled prior to the July 2012 tracer injection. However, JT113 and JT115 were sampled after the July 2012 tracer injection.

Edwards wells JT101A and JT124A and all springs except Gaas Spring are not known to be impacted by any tracing injection water. Therefore, tritium age-dating should also not be impacted.

The following elements were useful to distinguish water from the different formations, springs and surface waters: K, Sr, F, Mg, SO_4, and Na (Figures 2-8). Ca, Alk and Cl were not useful.

Based on the geochemical results from this study, shallow/surface water (also JT107S) indicators include concentrations of:

- <0.5 mg/L F
- <5 mg/L Sr
- <50 mg/L Mg and SO_4 (wells)
- <20 mg/L Mg and <50 mg/L SO_4 (surface water)
- <20 mg/L Na
- Ca/Mg ratio >4.

Geochemical indicators of Glen Rose (Trinity) water include concentrations of:

- >2.5 mg/L F
- >25 mg/L Sr
- >60 mg/L Mg
- >150 mg/L SO_4
- >20 mg/L Na
- Ca/Mg ratio <4

The general boundaries of these geochemical indicators may be different in other areas of the Edwards and Glen Rose rock units.

The cause of the anomalous chemistry of JT113 and JT115 compared to other Edwards wells is unknown. There is a large research facility as well as an electrical substation southeast of these wells although it is not known if they are upgradient of the wells. At the time of sampling, there was little other development within several 1,000 ft of the wells.

Changes in water levels corresponding to rain events was a very clear indictor of a connection to surface events (Figure 9) that was supported by geochemical results. For example, JT107S-A is a Glen Rose well but it is clearly influenced by surface waters and rainfall as illustrated in the charts (Figures 3-8). In addition, the water levels and geochemical results generally supported the relative groundwater ages as determined by tritium concentrations.

Inspection of the Jollyville Tunnel during construction indicated almost no inflow of groundwater, and only a few drips of water were observed. This suggests very low formation permeability, which was supported by low packer test results (Black&Veatch, 2011). This supports the conceptual model of a deeper groundwater system poorly connected to the surface since a system with better connection to the surface would likely have higher permeability.

Other observations contribute to a conclusion that the hydro-dynamic portion of the Edwards in the study area is even shallower than conceptualized. Inspections of a shaft excavated in the Four Points area revealed open voids and solution-enlarged openings in the upper 30 feet of the Edwards. Below this depth, solution-enlarged voids were few and fossil molds were clay-filled. In addition, water levels in a number of wells completed at the base of the Edwards (up to 80-90 feet deep) changed very little (tenths of a foot) in response to rain events and during severe drought in 2011. At the same time, during the 2011 drought, most springs dried up and only two continued to flow - Tanglewood and Gaas Springs, and even Pit Spring was dry. Following significant rain, all springs began flowing again even though water levels in the basal Edwards wells remained steady. These observations combined with age-dating and geochemical results suggest that water movement from the surface (recharge) into the vadose zone and to springs was confined to the uppermost portion of the Edwards formation and did not involve the water table at the base of the formation. Figure 9 clearly demonstrates the connection of the upper portion of the Glen Rose formation (generally less than 32 ft deep) with the surface whereas the formation below approximately 100 ft has poor connection to the surface.

Conclusions

Results of this study confirms the conceptual groundwater model of the Jollyville Plateau composed of a shallow groundwater system closely associated with surface waters and springs that is poorly connected to a deeper groundwater system. Results of this study included young relative ages based on tritium concentrations in surface, spring water and shallow wells in the Edwards and Glen Rose. These wells also exhibited water level changes in response to rain events as well as geochemical signatures indicative of less rock/water interactions resulting in lower ion concentrations. Relatively older groundwater, either submodern (pre-1952) or mixed modern and submodern, is indicated by lower tritium concentrations in deeper Glen Rose wells and some Edwards wells. Water from these wells typically contained higher concentration of ions and water levels did not respond to rain events. Purging wells did not appreciably change age or geochemical results for most wells.

Geochemical data shows noticeable differences between shallow waters (surface, springs and shallow wells) and deeper water. The deeper wells tended to contain higher concentrations of Sr, F, Mg, SO_4, Na and a greater Ca/Mg ratio. Neither Cl nor Ca showed significant differences between the shallow and deeper groundwater system.

The shallow dynamic groundwater system, however, is much shallower than hypothesized. Based on tritium data, water chemistry and observations of the Edwards formation during excavation of the Four Points shaft the shallow groundwater system in this area appears to include only the upper 30 feet or so of the Edwards. It is in this zone that recharging rainwater enters the vadose zone and migrates to nearby springs and appears to largely bypass the water table at the base of the formation. Shallow wells (less than 30 ft deep) in the Glen Rose indicated connection to surface conditions as shown by geochemistry and water levels changes in response to rain events.

Recommendations

Given the unexpected old age (pre-1952) of some water in the Jollyville Plateau, samples could be collected from other springs and wells to start refining the distribution of old versus young water. This is especially true in areas with little or no groundwater tracing to help identify groundwater flow paths and document rapid connections to the surface. A focus could be at significant JPS springs or larger springs which supply significant water feeding Bull Creek and its tributaries. Understanding the relative age of the groundwater would benefit investigations of pollutant concentrations. For example, documenting that a specific spring has water recharged prior to 1952 would suggest that testing for modern pollutants like atrazine would be unlikely but detecting older legacy pollutants like DDT or chlordane might be likely.

Additional samples collected from sites in this study could help verify relative groundwater age especially under a range of flow conditions. This would further understanding of the importance of shallow recent surface recharge in vadose zone conduits versus deeper water.

Expand tritium testing to other JPS sites to help understand source water and contaminant potential at JPS springs. For example, is there a pollutant slug recharged years ago potentially moving through the groundwater system that may discharge from a JPS spring?

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PHOTOS

Photo 1. A typical well sampling setup (for JT108A in this case) with running vehicle supplying power to a downhole pump, an eline to monitor water levels, discharge water collecting in 5 gallon bucket to measure volume and multiprobe measuring field parameters. Car batteries were quickly drained by the pumps. Note the turbid water during the initial purging of this well.

Photo 2. Collecting water and measuring field parameters is sometimes challenging in springs discharging low volumes of water such as Spider Spring near Spicewood Springs Road.

Photo 3. Groundwater from Pit Spring discharges from outlets in the alluvial bank as seen on the upper left as well as solutional openings in the channel bedrock where the multiprobe water quality sensors measure field parameters that include temperature, pH, specific conductance, dissolved oxygen, and turbidity.

Photo 4. Field technician Matt Westbrook collects water samples from the JT125A well. Note the clear water after the well was purged.

Photo 5A. Initial water pumped from JT107PZ-A shows a dull gray color indicative of the host Glen Rose limestone and marl and due to fine cuttings left over from well drilling.

Photo 5B. After lengthy well purging water in JT107PZ-A is clear and largely free of fine suspended sediment and represents natural formation groundwater.

FIGURES

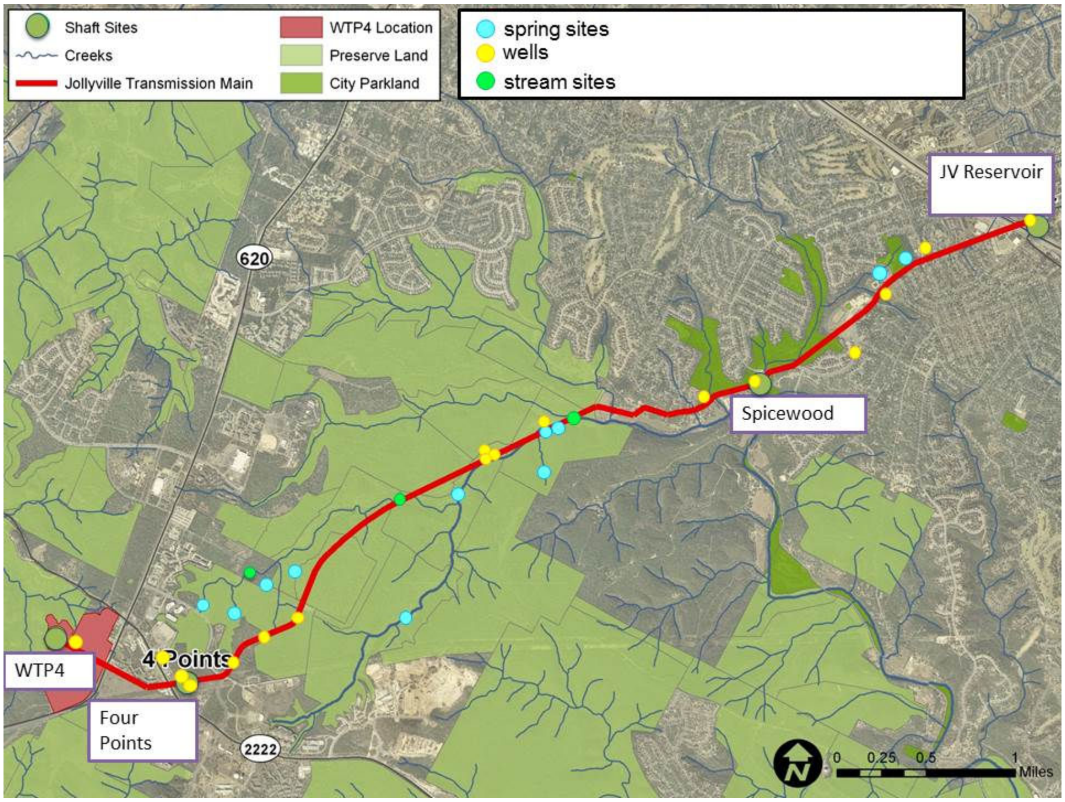

Figure 1. Location of sampling sites for wells, springs and surface water. Samples were also collected from the Four Points and Jollyville Reservoir Shafts and on the Colorado River downstream of Mansfield Dam (not shown).

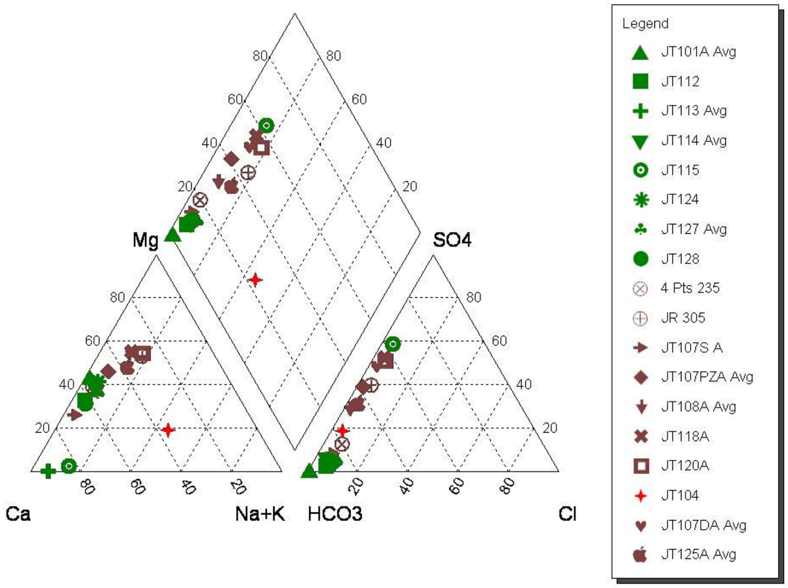

Figure 2. Piper diagram showing the ion relationship in the monitoring wells completed in the Edwards, Walnut, and Glen Rose Formations. Note that water from the Glen Rose (reddish-brown) is generally more enriched in sulfate than the Edwards (green) or Walnut (red).

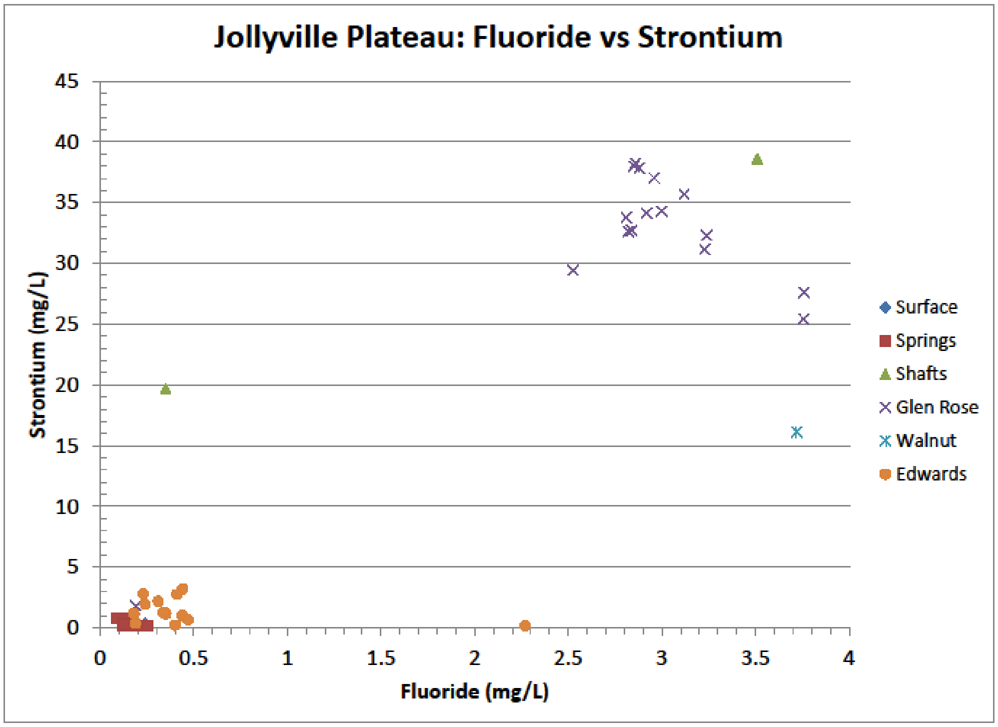

Figure 3. Glen Rose wells in the deep hydrologic system have significantly higher concentrations of fluoride and strontium than wells and springs of the shallow groundwater system.

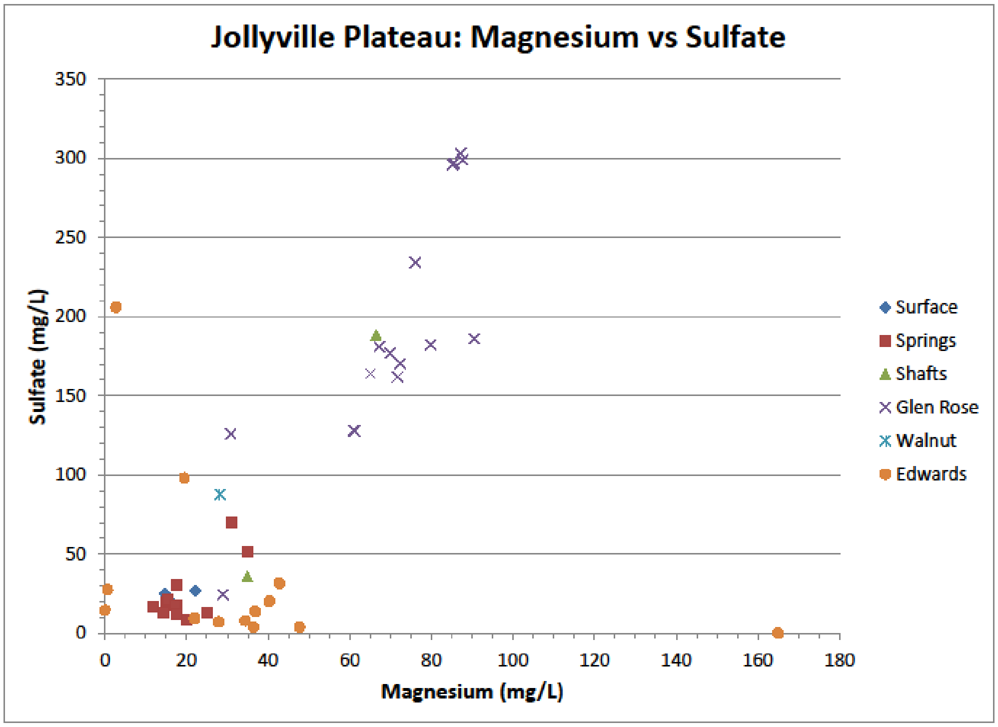

Figure 4. Glen Rose wells in the deep groundwater system have higher concentrations of magnesium and sulfate than wells, springs, and surface waters.

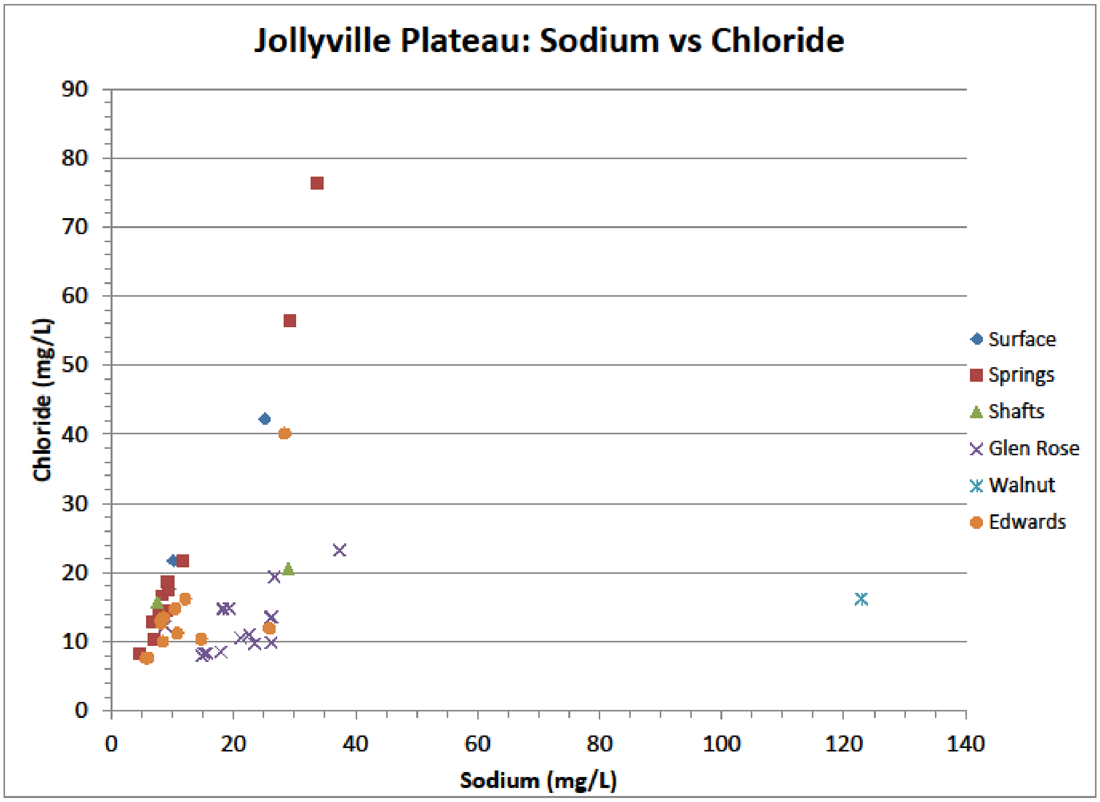

Figure 5. Concentrations of sodium are slightly higher in deeper Glen Rose wells than in shallow wells, springs and surface waters although chloride concentrations are not different.

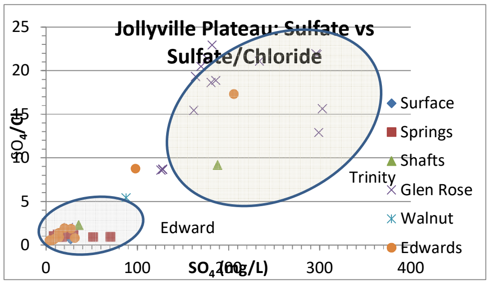

Figure 6. The relationship between sulfate and sulfate/chloride has been used to distinguish between Edwards and Trinity waters (Senger and Kreitler, 1984, Wong et all 2013). Results from the Jollyville Plateau study show similar results with surface, springs, and Edwards water samples clustering in the "Edwards" groundwater field of SO_4 below 100 mg/L and the SO_4/CL ratio below 5 and the Glen Rose samples falling in the lower portion of the "Trinity" groundwater field characterized by higher SO_4 concentrations and a higher SO_4/Cl ratio.

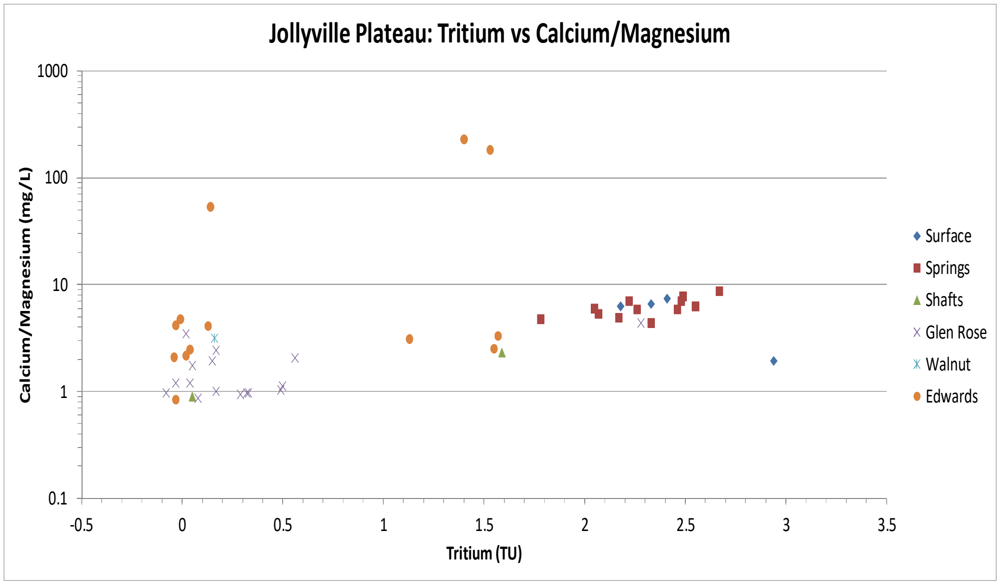

Figure 7. There is a slight positive relationship between tritium and the calcium/magnesium ratio showing younger waters as indicated by higher tritium concentration, with a higher Ca/Mg ratio.

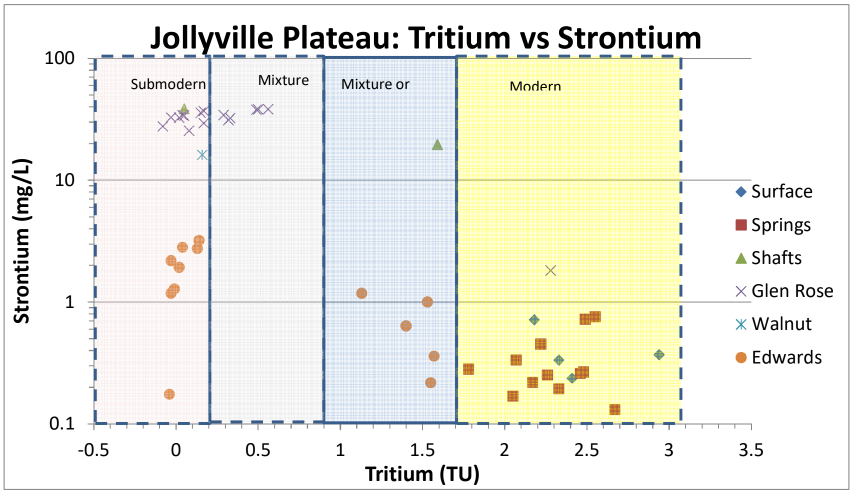

Figure 8. Relative age of water in the Jollyville Plateau is indicated by tritium as interpreted from Fritz and Clark (1997). Surprisingly, some wells completed in the Edwards have submodern rather than modern water.

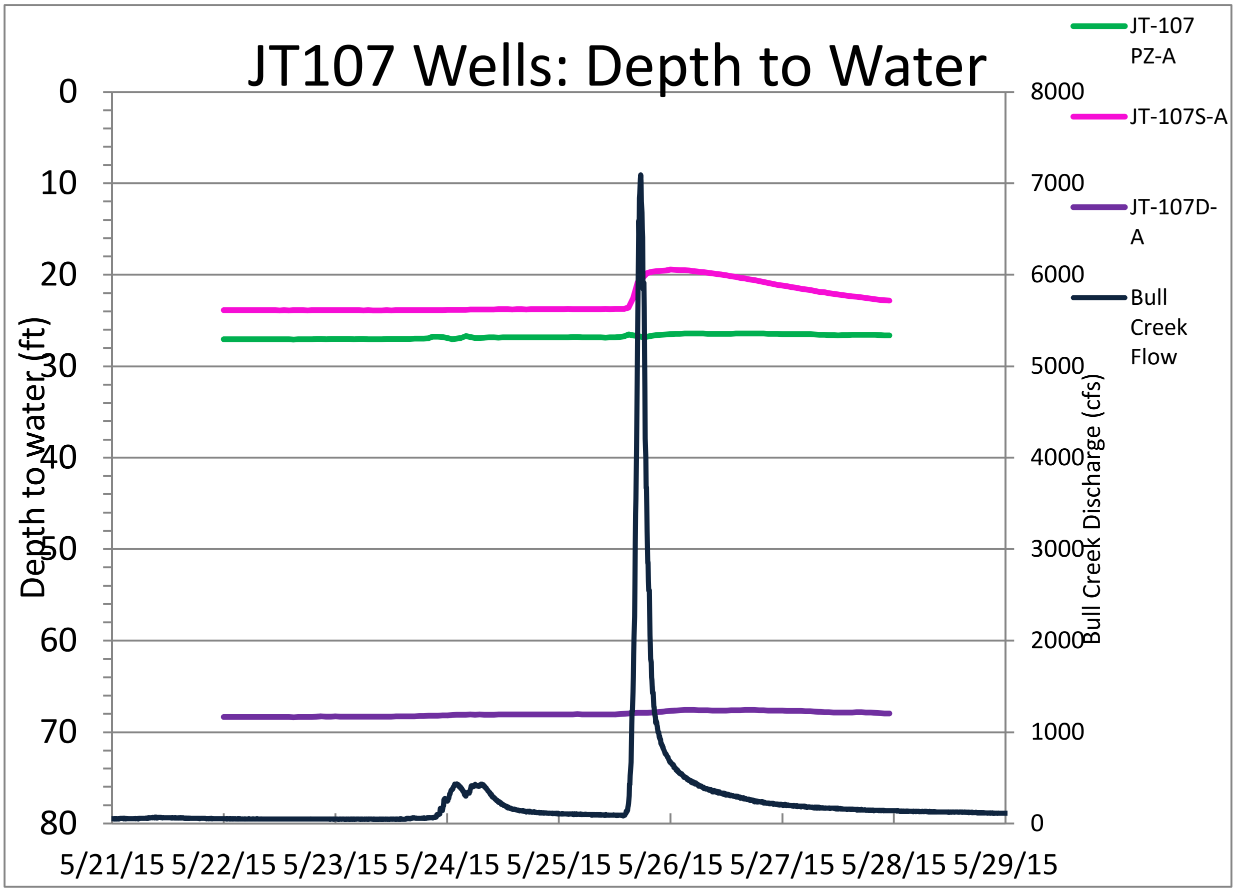

Figure 9. Heavy rain in late May 2015 is indicated by a large increase in discharge in Bull Creek. This event clearly affected the shallow JT107S-A well whereas the deeper two wells were not affected, supporting the geochemical interpretation of a TJ107S-A being part of the shallow groundwater system and the others wells as a part of the deep groundwater system.