Barton Springs Edwards Aquifer CONSERVATION DISTRICT

Groundwater Flow as Evidenced from a Historic Petroleum Contamination Site, Barton Springs Segment of the Edwards Aquifer, Austin, Texas

BSEACD Report of Investigations 2014-1201

December 2014

Barton Springs/Edwards Aquifer Conservation District

1124 Regal Row

Austin, Texas

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Cover. *Photograph of the spill site beneath the removed AST. Photo taken October 2, 1992. Photo from TCEQ archives. Note the lack of containment walls and floor and the exposed soil and fill.*

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ABSTRACT

Leaking petroleum storage tanks from gas stations are one of the most common sources of contamination of groundwater in the U.S. and Texas. In 1992 a 2,900 gallon gasoline and diesel release occurred at the Big Wheel Truck Stop located on the highly sensitive Edwards Aquifer in Austin, Texas. The fate and transport of the contaminants in the aquifer was never fully realized in the subsequent site studies required by the State of Texas. We hypothesize that by applying an accurate conceptual aquifer model to the historic site investigation data, combined with recent hydrogeologic data, one can realistically constrain the fate and transport of the released contaminants. Key aspects of that conceptual model should include the karstic nature of the Edwards Aquifer and the proximity of the site to a major fault zone.

Results of our evaluation suggest that the petroleum hydrocarbons likely behaved similar to groundwater tracing studies performed in the region, with approximate minimum flow velocities of 400-500 ft/d. The spill was therefore one of the first (unintended) groundwater tracer tests in the region. Contaminants at wells down-gradient and off-site from the spill quickly decreased in concentration in a matter of days as the detached plume moved rapidly past the wells, or became diluted. Soil and epikarst horizons were likely a source for remobilization of contaminants with subsequent recharge events. After remediation of the soil in 1996, it took more than five years for groundwater contaminant concentrations at the spill site to reach target levels. By using an accurate conceptual model at this site, limited historic site contamination data provides insight into how future petroleum contaminants could behave in the karstic Edwards Aquifer recharge zone. A secondary finding of the evaluation was that the Mount Bonnell fault, running through the site, appears to behave as a barrier to inter-aquifer flow in the study area. This has implications for water resource management of the Edwards and Trinity Aquifers.

An earlier version of this abstract was presented at the Geological Society of America, South-Central Section, in Fayetteville Arkansas, March 17, 2014.

INTRODUCTION

Leaking petroleum storage tanks from gas stations are one of the most common sources of contamination of groundwater in the U.S. and Texas. In 1992 a 2,900 gasoline and diesel release occurred at the Big Wheel Truck Stop located on the highly sensitive Edwards Aquifer in Austin, Texas. The Edwards Aquifer is an important groundwater resource and known to have rapid groundwater flow to wells and springs due to its fractured and karstic nature (e.g. bedrock characterized by sinkholes and caves). After the petroleum release, contaminants were detected in three water wells nearby to the truck stop—demonstrating impact to the Edwards Aquifer and public groundwater supplies.

The Texas Commission for Environmental Quality (State's regulatory agency over contamination cases) required remediation of the soils and site characterization. Data collection and activities at the site included: numerous soil borings and sampling, installation of four groundwater monitor wells, and near-quarterly groundwater sampling from 1996-2003. Never the less, the fate and transport of the contaminants in the groundwater from the site was never fully described in the consulting reports to the TCEQ.

In this case study we hypothesize that by applying an accurate conceptual aquifer model to the historic data, hydrogeologists can realistically constrain the fate and transport of the contaminants. Key aspects of that conceptual model should include the karstic nature of the Edwards Aquifer and the proximity of the site to a major fault zone. The approach of this evaluation was to revisit historic data collected from the site combined with new hydrogeologic information from the area. This study represents one of the few well-documented petroleum contamination cases in the Barton Springs segment of the Edwards Aquifer and provides an opportunity to better understand: 1) groundwater flow within the karstic aquifer, 2) the influence of the fault zone on groundwater flow and contaminants in the study area, and 3) better understand the fate and transport from future petroleum spills in the karstic aquifer.

SETTING

The site is located southeast of the intersection of U.S. Hwy. 290 West and William Cannon Drive (**Figures 1 and 2**). The site was formerly the Big Wheel Truck Stop that operated as a gas station since the 1970s and contained up to 11 above-ground petroleum storage tank (ASTs). The site contained underground distribution pipes and dispenser islands for gasoline, diesel, and kerosene (**Figure 2**; IT Corp, 1999). Presently, the site is owned and operated by Texas Department of Transportation and is within the right of way improvements of Hwy 290. None of the original infrastructure exist at the site presently.

Site Geology

The site is located along the western boundary of the recharge zone of the Edwards Aquifer and over the Mount Bonnell Fault Zone (Small et al., 1996; **Figures 1 and 3**). The geology beneath the site east of the fault is the lower-most units of the Edwards Group limestones. West of the fault the site consists of the Upper Glen Rose formation (Small et al., 1996, **Appendix B**). At the time of the spill the site was covered with asphalt and concrete from 6 to 12 inches thick, except beneath the leaking AST, which had exposed soil and fill material (see front cover). Borings and four monitor wells drilled on the site provide subsurface geologic information (**Appendix C**). Beneath the concrete from 3-5 ft below ground is a intermixed stiff dark gray and tan clay with fractured limestone (IT Corp, 1999). One well (MW-1) has a geophysical log and indicates the total thickness of the Edwards is about 125 ft thick under the site (about 50 ft saturated thickness) (**Appendix C**). The western monitor well MW-3 is only 40 ft deep and is interpreted to be completed in the Upper Glen Rose or fault gouge based on the perched water encountered. Accordingly, the Mount Bonnell Fault is interpreted to occur between MW-3 and the other wells (**Figures 1-3**).

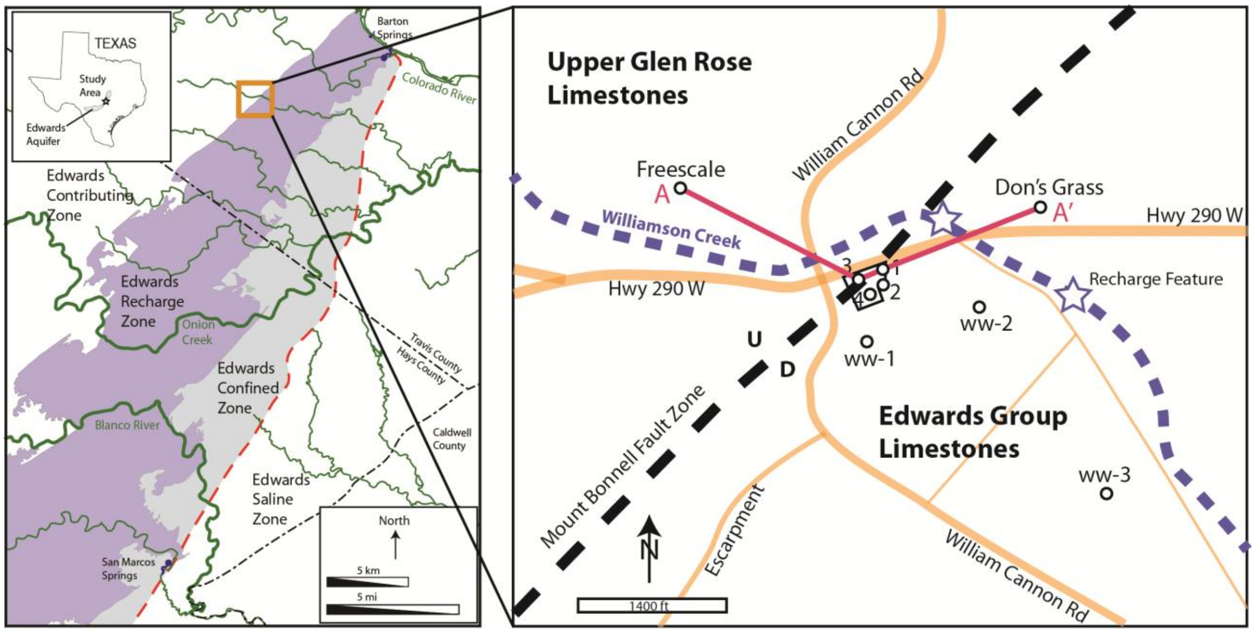

Figure 1. *Location and site map. The site is along the western margin of the Edwards Aquifer. The Balcones fault is inferred to occur along the NE corner of the property (Small et al., 1996). Water wells are indicated by white circles. Geologic cross section indicated by red lines and shown in Figure 3.*

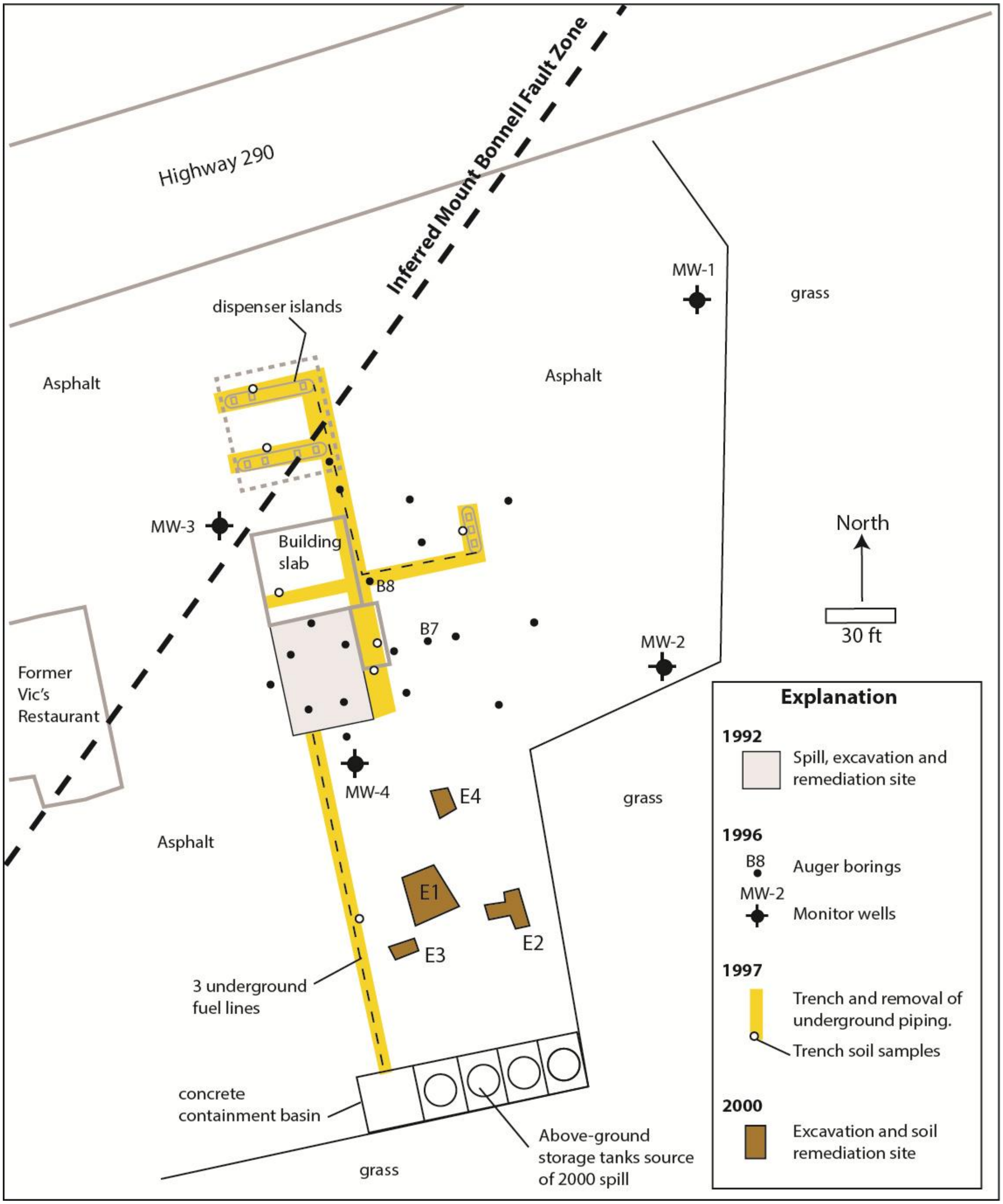

Figure 2. *Map of the Big Wheel site showing location and types of borings and remediation activities through time. Mapped fault inferred from perched water levels in wells, and rock outcrops in Williamson Creek. Figure modified from Raba-Kistner, 1996.*

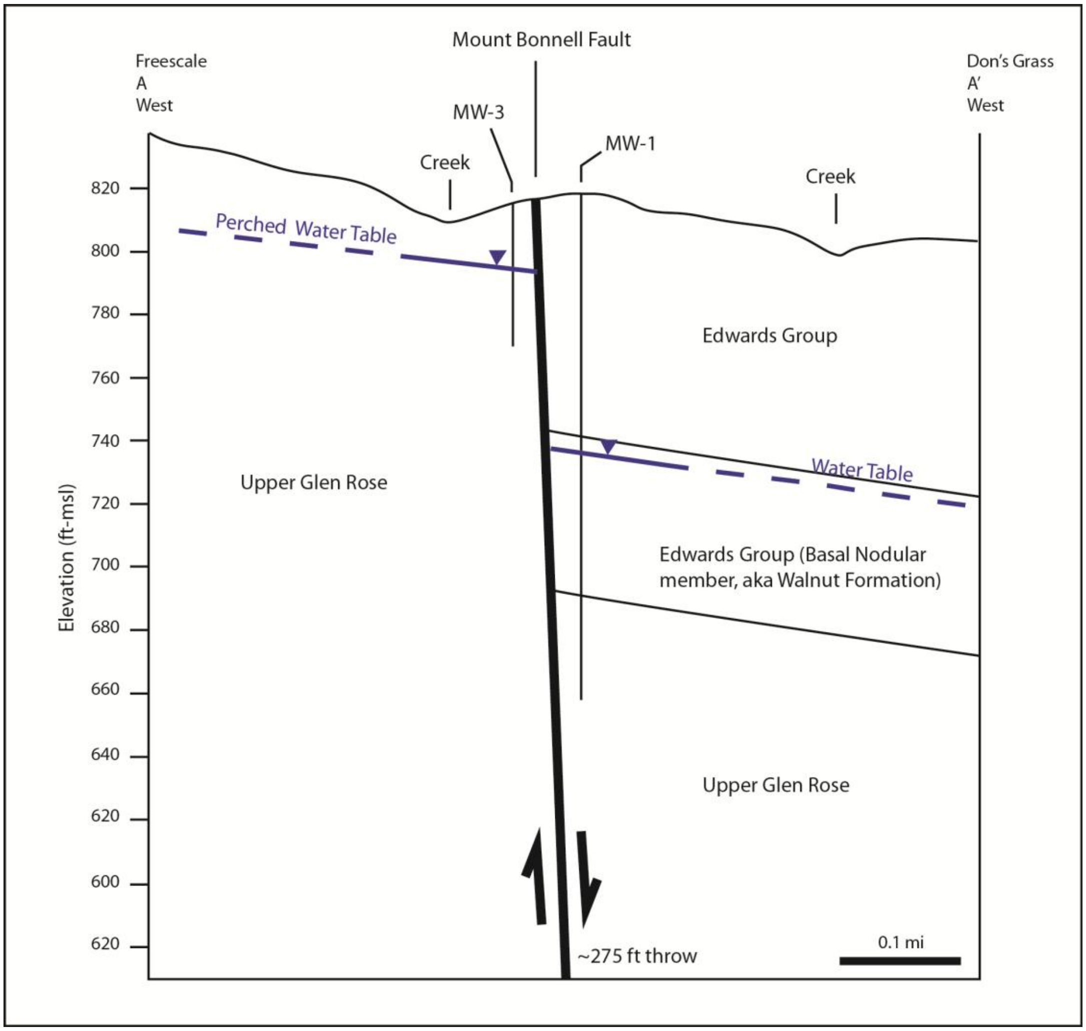

Figure 3. *Geologic cross section showing about 275 feet of throw across the Mount Bonnell Fault Zone. The fault appears to influence water levels in wells on either side of the fault, acting as a barrier to flow resulting in a large groundwater head gradient.*

Williamson Creek is located about 300 ft north of the spill site. Outcrops of the Edwards Limestone are well-exposed in Williamson Creek north of the site and east of the fault zone. Those exposures contain recrystallized limestone with toucasid fossils characteristic of the Edwards Group. At least two discrete karst features are present within Williamson Creek (**Figure 1, Appendix B**). About 750 ft west of the site units of the Upper Glen Rose are exposed in "Oak Hill." Fossiliferous and nodular limestone exposures of the Upper Glen Rose are located within the creek west of the fault zone. Fossil fauna confirm the unit is the upper-most (Units 6 or 7) of the Upper Glen Rose and include: echinoids (Loriolia rosana; coenholectypus planatus), pectins, gastropods, flattened disc-shaped ammonite Engonoceras/Metengonoceras, oysters, and various steinkerns, (Bill Rader, personal communication, **Appendix B**).

The Balcones Fault Zone is a Miocene-age, normal, down to the east fault zone forming the Balcones Escarpment. The Balcones Escarpment is a major geographic feature and eco-region of Texas. One of the largest faults is named the Mount Bonnell Fault Zone and is interpreted to cross through the site. The Mount Bonnell Fault is the major fault that defines the western extent of the Edwards Aquifer in the study area. The fault has about 275 ft of throw down to the east estimated from the correlation of the Lower Glen Rose in geophysical logs of the Freescale and Don's Grass wells (**Figures 1 and 3**).

Edwards Aquifer Flow Characteristics

Karst aquifers, such as the Barton Springs aquifer, are commonly described as triple porosity (and permeability) systems consisting of matrix, fracture, and conduit porosity (Ford and Williams, 1992; Quinlan et al., 1996; Palmer et al., 1999). Halihan et al., (1999) describe permeability in the Edwards Aquifer that varies with the direction and scale of measurement and values ranging over nine orders of magnitude. Accordingly, the system is often characterized as having a slow flow system (diffuse or matrix flow) and a fast flow system (fracture/conduit flow). The matrix permeability is relatively low for rocks in the outcrop (Hovorka et al., 1998). Groundwater dye-tracing and other studies demonstrate that a significant component of groundwater flow is discrete, occurring in a well integrated network of conduits, caves, and smaller dissolution features (Hauwert et al., 2004). Interpreted flow paths from tracer testing generally follow the potentiometric surface.

DATA SOURCES

The Texas Commission for Environmental Quality (TCEQ)--and its predecessor the Texas Natural Resource Conservation Commission (TNRCC)--has a Remediation Division that develops regulatory guidance documents for cases of leaking petroleum storage tanks. The Remediation Division investigates and requires reporting of releases, assessments, monitoring, and remediation from leaking petroleum storage tank sites. Reports and data for the Big Wheel Truck Stop (LPST ID# 104820) site were obtained from the TCEQ library (Raba-Kistner, 1996; IT Corp, 1999; IT Corp. 2000; GeoStrata, 2003; **Tables 1-4**). In addition, the Barton Springs/Edwards Aquifer Conservation District has additional hydrogeologic data from wells in the area (BSEACD, unpublished data). Regional and local potentiometric data supplemented the site data and was derived from Hunt et al., 2006.

Table 1. *Table of Well Data and Parameters*

Well ID	MW1	MW2	MW3	MW4	WW1	WW2	WW3
State Well Number	**58501C1**	**58501C2**	**58501C3**	**58501C4**	**5850123**	**58501NF**	**58501DH**
Name	Vic's #1	Vic's #2	Vic's #3	Vic's #4	Cook-Walden #1	Cook-Walden #2	Haney
Classificaiton	Monitor	Monitor	Monitor	Monitor	Irrigation	Irrigation	Domestic
Date Drilled	7/18/96	7/19/96	7/22/96	7/24/96	1/1/60	unknown	unknown
TD (ft)	159.00	143.00	43.00	142.00	214.99	unknown	unknown
Casing Depth (ft)	54.60	55.00	14.50	51.00	147.00	unknown	unknown
Borehole dia. (in)	9 7/8	9 7/8	9 7/8	9 7/8	10.00	unknown	unknown
Casing borehole completion	cement	cement	cement	cement		unknown	unknown
Screen	Open Hole	Open Hole	Gravel Pack	Open Hole		unknown	unknown
Pump depth (ft)	n/a	n/a	n/a	n/a	197.00	unknown	unknown
Pumping rate (gpm)	n/a	n/a	n/a	n/a	25.00	unknown	unknown
Casing Inner Diameter (in)	5.50	5.50	5.63	5.50	8.00	7.00	unknown
Open-hole Diameter (in)	4.00	4.00	5.63	4.00	unknown	unknown	unknown
Latitude	30.234354	30.233972	30.234100	30.233854	30.232521	30.233581	30.228506
Longitude	-97.862828	-97.862860	-97.863424	-97.863227	-97.863449	-97.859750	-97.855586
Elevation (ft-msl)	813.26	814.47	815.00	815.88	836.00	815.00	793
Aquifer	Edwards	Edwards	Upper Trinity	Edwards	Edwards	Edwards	Edwards
Hydraulic conductivity (K)-1 ft/d	*0.30*	*70.00*	*4.00*	*1.00*			
Hydraulic conductivity (K)-2 ft/d	*0.11*	*30.49*	*3.75*	*0.07*			

1-Solution: Bouwer-Rice (spreadsheet)
2-Solution: Bouwer-Rice (Aqtesolv)

RESULTS

The results of this evaluation are to attempt to put historic data collected from the site, combined with some new hydrogeologic information from the area, into its proper geologic context.

Table 2 provides a summary of the nearly 20 years of petroleum contamination activities and events at the Big Wheel Truck Stop. **Figure 4** shows the concentration of BTEX in groundwater showing initial high concentrations that diminished over time. Peak concentrations appear to be related to flow events (and recharge) in the streams. Remediation of the soils below the ASTs and the trenches where the piping was located reduced the soil contaminants below target levels (**Figure 3**; IT Corp, 1999). Groundwater samples also contained elevated contaminants that decreased over time, but persisted above target levels for six years after soil remediation (**Figure 4**).

Water levels in wells are presented in **Table 4** and as a hydrograph in **Figure 5**. There is a high degree of variability in water level flux ranging from 2 ft to 28 feet for the monitor wells on the Big Wheel Truck Stop, reflecting (karst) aquifer heterogeneity (**Table 4**).

Table 2. Summary of events and contamination

Date	Event/Activity	Samples/Detections	Comments
8/14/1984	Petroleum odors reported from two wells. Three RPs identified including Big Wheel and Circle K.	Groundwater samples inconclusive	Hydrocarbon odors reported in WW1 (Cook-Walden) and Mrs. A.R. Enoch reported hydrocarbon odor in Patton Ranch well.
10/1984	Groundwater sampling	Gasoline confirmed	
6/1985	Hydrocarbon seep found in Williamson Creek adjacent to manhole, traced to sewer line adjacent to Circle K gas station. LPST # 91010 assigned.	Gasoline in seep along manholes in Williamson Creek.	Review of records reveal loss of 10,000 gallons from Circle K storage tanks (USTs) in from Jan-Ju 1984. Supply lines tested 7/12/1984 and replaced.
9/24/1992	Spill consisting of 900 gallons of diesel and 1,100 gallons of gasoline occurred from two ASTs. LPST ID # 104820 assigned.	Soil: TPH and BTEX; Groundwater: BTEX	Soil and groundwater above target levels.
9/25/1992	Remediation: remove 7 ASTs, excavation up to 6 ft deep 290 yd^3 soil. Pit lined and filled and capped with concrete.	Soil: BTEX and TPH	Max Benzene 0.868 mg/kg (Target level 0.13 mg/Kg)
10/2/1992	Groundwater sampling	Groundwater: BTEX and TPH	BSEACD staff sample WW 1-3
11/2/1992	Groundwater sampling	Non-detect	WW 1-3; (Hauwert & Vickers, 1994)
3/9/1994	Groundwater sampling	TPH	WW1, hydrocarbon odors noted. (Hauwert & Vickers, 1994)
12/19/1994	Headspace analysis	Gasoline	
3/12/1996	Transferred to State-Lead Remediation Section		
5/22/1996	Groundwater sampling	Groundwater: BTEX, TPH, MTBE	BTEX and TPH WW 1-3 below target levels; MTBE WW1.
7/1996 to 8/1996	Site characterization: 18 shallow soil borings (2-14 ft deep) and four monitor wells (MW1-4)	Soil and Groundwater: BTEX, TPH, PAH	Benzene primary contaminant of concern above MCL and target concentrations in both soil and groundwater
10/1996	Ten additional soil borings from depths of 1-9 feet installed adjacent to the pump islands and piping		
11/11/1997 to 12/30/1997	Remediation: approximately 288 $yrds^3$ of contaminated soil excavated; site was backfilled and covered with a concrete slab.		
	Samples (T1-7) were collected from the piping trenches.	Maximum concentration of benzene was 0.349 mg/Kg	
1997-1999	Quarterly groundwater sampling of MW 1-4.		MW1-2 consistently exceeded the Benzene target levels and MW3-4 exceeded them intermittently. MTBE was consistently detected above MDLs in MW1, 2, and 4 and was intermittently detect in WW1-3
2/7/2000	Small hydrocarbon spill reported of diesel from the remaining 4 unused above-ground storage tanks		
3/13/2000	Removal 4 remaining ASTs and containments were cleaned and evacuated.		
4/25/ 2000	Excavation and removal of contaminated asphalt and fill materials--total of 7 yd^3. Areas were backfilled and covered with concrete.		
7/16/2001	BSEACD staff sampling of WW1	No BTEX, TPH, MTBE or PAH	Part of a regional water quality study.
2000 and 2003	Additional groundwater samples taken MW1-4	Groundwater: BTEX and THP detected	2003 below target levels
1/29/2003	Slug testing by BSEACD		Hydrocarbon odors noted in monitor wells.
2/25/2003	Groundwater sampling	BTEX 0.005	MW1 and MW4
3/11/2003	The case was closed with a final concurrence letter issued on		
5/2003	MW1-4 plugged		

Table 3. *Summary groundwater contamination results*

Date	BTEX (mg/L)-MW1	TPH (mg/L)-MW1	BTEX (mg/L)-MW2	TPH (mg/L)-MW2	BTEX (mg/L)-MW3	TPH (mg/L)-MW3	BTEX (mg/L)-MW4	TPH (mg/L)-MW4	BTEX (mg/L)-WW1	TPH (mg/L)-WW1	BTEX (mg/L)-WW2	TPH (mg/L)-WW2	Comment
1984									*	*			*Petroleum Odors reported
9/24/92									>0.005				Spill occurred
10/2/ 92									NR**		NR**	12.0	**Reported in IT Corp, 1999 narrative; BTEX detected in WW1-3
11/2/92										ND		ND	Hauwert and Vikcers, 1994
3/9/94									11				Hauwert and Vikcers, 1994
5/22/96									<0.005	<1	<0.005	<1	MTBE detected in WW1
7/26/96	ND	ND	0.004		0.050	1.30	0.390***	4.60	0.003		ND		***highest value
10/30/96	0.175	1.40	0.228	1.00	0.029	NS	0.012	ND	ND		ND		
3/13/97	0.166	6.80	0.061	1.40	0.009	NS	0.005	1.50	ND	0.80	ND		4.6 gpd/ft measured in MW1
6/5/97	0.340	2.00	0.008		ND		ND	ND	ND		ND		
9/16/97	0.007	5.10	0.121	1.70	0.132	1.30	ND	2.00			ND		
11/19/97	0.148	0.90	0.058		0.005	NS	0.002	ND			ND		
5/20/98	0.023	ND	0.022		0.003	ND	0.002	ND			<.002	ND	
5/5/99	0.038		0.022	ND	<0.002	ND	<0.002		0.002		<.002	ND	
8/24/99	BRL		0.023		BRL		0.036		BRL		BRL		
12/28/99	0.012		0.003		0.005		0.003		BRL		BRL		
3/13/00	0.002		0.045		BRL		0.003		BRL		BRL		
6/8/00	0.035		0.009		BRL		0.068		BRL		BRL		
7/16/01	NS								ND	ND			BSEACD sample
2/21/2003	0.005	5.35	BRL	BRL	BRL	BRL	0.005	BRL					

Blank=not sampled
ND= non-detect
BRL= below reporting limits
NR= not (quantitatively) reported

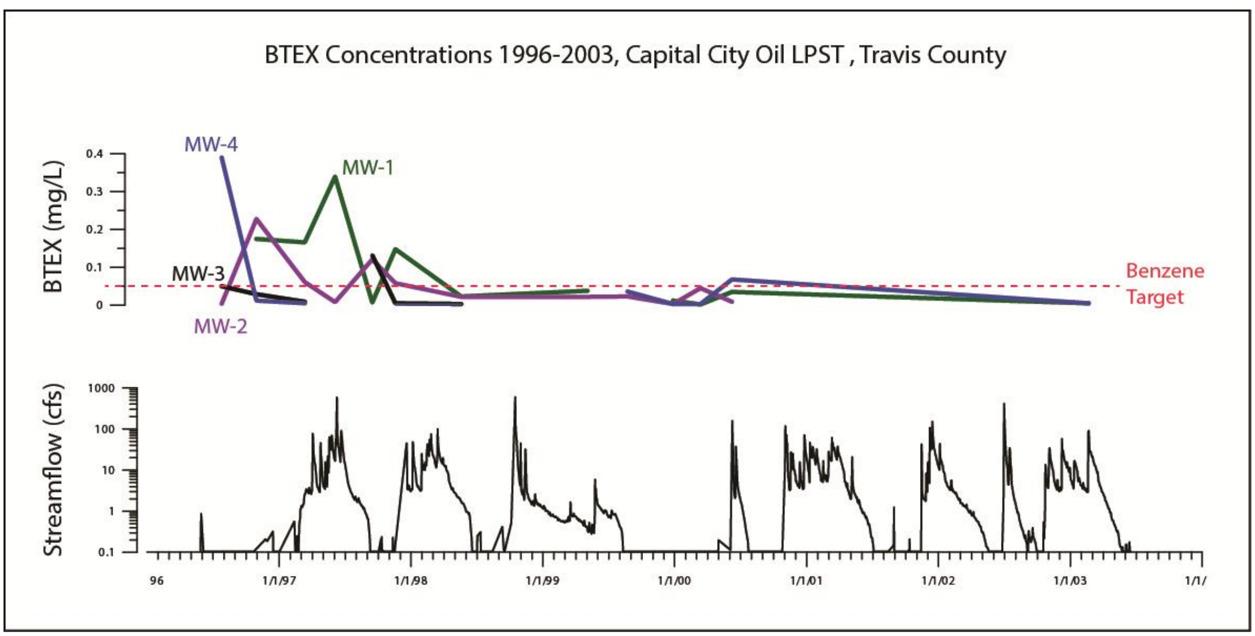

Figure 4. *Chemograph of BTEX concentrations from the 4 monitor wells over time. Streamflow is from Slaughter Creek at FM 1826.*

__Table 4.__ Table of groundwater levels

Date	DTW-MW1	WL-MW1	DTW-MW2	WL-MW2	DTW-MW3	WL-MW3	DTW-MW4	WL-MW4	DTW-WW1	WL-WW1	DTW-WW2	WL-WW2	Comment
3/9/1994											207.10	607.90	
7/22/1996									127.27	707.73			
7/26/1996	100.97	712.29	80.39	735.08	20.66	794.34	93.86	722.02					
10/30/1996	93.80	719.46	80.03	735.44	18.75	796.25	88.02	727.86					
3/13/1997	74.42	738.84	79.35	736.12	17.65	797.35	89.32	726.56					4.6 gpd/ft measured in MW1
6/5/1997	74.61	738.65	79.55	735.92	15.37	799.63	89.73	726.15					
9/16/1997			79.98	735.49	19.24	795.76							
11/19/1997	82.15	731.11	79.58	735.89	18.20	796.80	99.00	716.88					
5/20/1998	87.69	725.57	79.76	735.71	18.41	796.59	95.84	720.04					
8/27/1998									132.10	702.90			
3/16/1999	92.90	720.36											downhole camera
5/5/1999	81.66	731.60	79.70	735.77	18.05	796.95	91.89	723.99					
7/29/1999									130.36	704.64			
8/16/1999	103.15	710.11											
8/24/1999			80.72	734.75									
9/18/1999	75.52	737.74											
12/28/1999			81.40	734.07	21.92	793.08	95.50	720.38					
3/13/2000	93.45	719.81	80.31	735.16	19.40	795.60	95.03	720.85					
6/8/2000	99.40	713.86	80.17	734.30	20.30	794.70	99.60	716.28					
6/20/2000									148.68	686.32			
7/19/2000									165.75	669.25			
8/18/2000									121.37	713.63			
4/26/2001											210.00	605.00	
4/26/2001									121.30	713.70			
6/25/2001									125.68	709.32			
7/6/2001									140.50	694.50			
2/6/2002	94.60	718.66					96.42	719.46					
5/17/2002									125.01	709.99			
1/29/2003	94.09	719.17	79.98	734.49	19.30	795.70	96.02	719.86					BSEACD staff slug tests on MW1-4
2/21/2003	92.40	720.86	80.01	735.46	19.43	795.57	96.04	719.84					
3/24/2003					19.30	795.70							
5/19/2003									157.30	677.70			
11/1/2005											121.40	693.60	
2/20/2009									121.40	713.60			
max	103.15	738.84	81.40	736.12	21.92	799.63	99.60	727.86	165.75	713.70	210.00	693.60	
min	74.42	710.11	79.35	734.07	15.37	793.08	88.02	716.28	121.30	669.25	121.40	605.00	
mean	89.39	723.87	80.07	735.26	19.00	796.00	94.33	721.55	134.73	700.27	179.50	635.50	
range	28.73	28.73	2.05	2.05	6.55	6.55	11.58	11.58	44.45	44.45	88.60	88.60	
count	15	15	14	14	14	14	13	13	12	12	3	3	

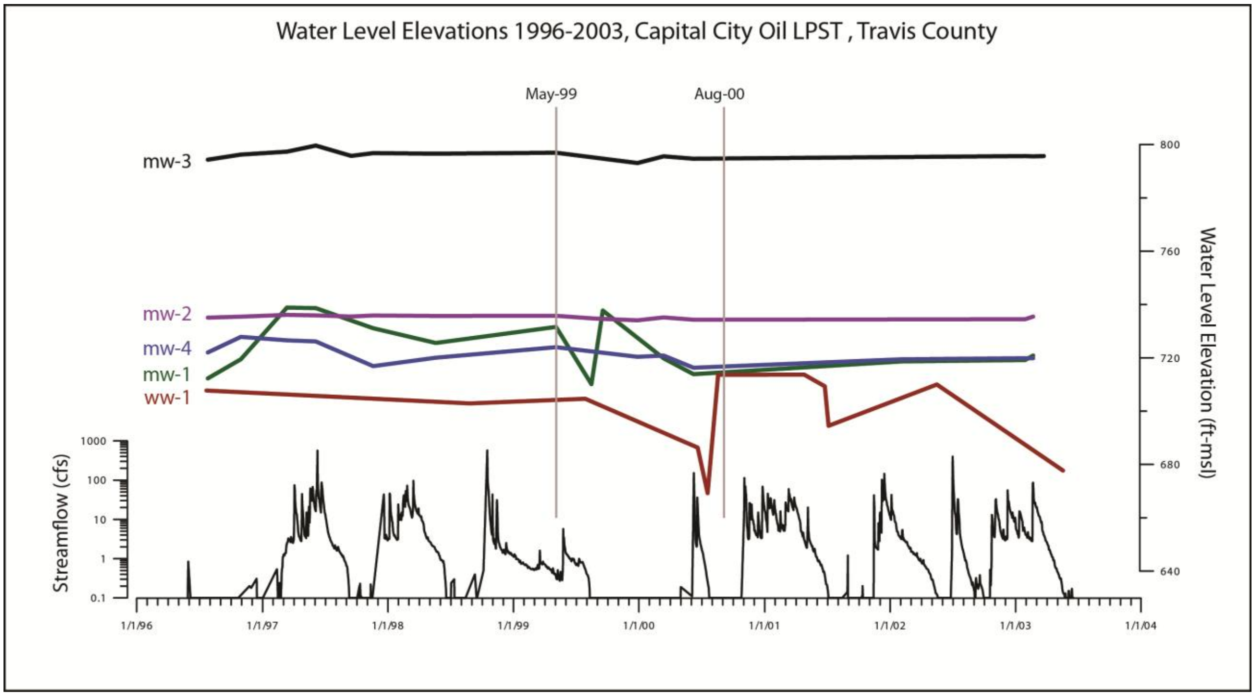

Figure 5. *Hydrograph of water levels for the site. Lines indicate the time period of potentiometric maps (Figure 6). Streamflow is for Slaughter Creek at FM 1826.*

Review of Petroleum Hydrocarbon Contaminants in relation to the Big Wheel Truck Stop

Leaking petroleum storage tanks are the most widespread point-source of contamination to groundwater in developed countries (Kresic, 2007). O'Rourke (2011) reports that over half of the active groundwater contamination cases in Texas are from leaking petroleum storage tanks. Accordingly, the contamination at the Big Wheel Truck stop, which had up to 11 above-ground petroleum storage tanks, is not unusual or unexpected. In fact, the gasoline station (Circle K) across Hwy 290 also had a significant hydrocarbon release in 1984 (LPST # 91010; **Table 2**).

Light Non-Aqueous Phase Liquids (LNAPLs)

The spills at the Big Wheel Truck Stop consisted of gasoline and diesel fuels, also called Light Non-Aqueous Phase Liquids (LNAPLs). These are a class of contaminants that are less dense than water and can enter the soil and groundwater as immiscible (hydrophobic) liquids. Kresic (2007) describes LNAPLs as multi-component organic mixtures composed of chemicals with varying degrees of solubility. In refined petroleum (gasoline and diesel) the most water soluble constituents are aromatic compounds and oxygenation additives, such as Methyl-tertiary butyl ether (MTBE), a common oxygenation agent added to certain gasoline blends since the early 1980s. Benzene, toluene, ethylbenzene, and total xylenses (BTEX) are slightly soluble contaminants. These five chemicals are the primary contaminants of concern at the Big Wheel Truck stop. **Table 5** lists the drinking water standards for these five contaminants of concern. Total Petroleum Hydrocarbons (TPH) is defined as any mixture of hydrocarbons found in crude oil such as BTEX and other contaminants. TPH is often used as a screening test for the presence of the more toxic contaminants, but can also be a contaminant of concern and trigger corrective actions.

Table 5. *US EPA Drinking Water Standards*

Contaminant	Max. Cont. Level (mg/L)
Benzene	0.005
Ethylbenzene	0.7
Toluene	1.0
Xylenes (total)	10
MTBE	0.013*
TPH	5**

*No US EPA MCL; California EPA
**TCEQ target level

Fate and Transport

As contaminants travel in the vadose (unsaturated) or phreatic (saturated) zones, they are subject to various physical and bio-geochemical processes called "fate and transport." Fate refers to the bio-geochemical factors that influence the contaminants, and transport refers to the movement of the contaminant in water (Kresic, 2007). The liquid can migrate through the vadose zone toward the water table in its original state (free-phase product), or dissolve with vadose zone waters. Adsorption onto soils and volatilization into the atmosphere (soil gas) can inhibit migration of contaminants (Kresic, 2007). Volatile fuel components are commonly metabolized into carbon dioxide and water by naturally occurring bacteria in the soil—a process called natural attenuation (O'Rourke, 2011). Because of the natural attenuation effect, petroleum contaminant plumes tend to reach a maximum length and stabilize before decreasing in concentration—accordingly, this results in few cases that impact public water supplies in Texas (O'Rourke, 2011). This is typically true for porous media aquifers, and is not likely true for karst systems, as we shall discuss.

Contaminants from the 1992 spill moved through the relatively thin (~2-6 ft) clay-rich soil horizon relatively unimpeded. The contaminants then migrated to the water table flowing through 75-100 feet of the unsaturated weathered bedrock (epikarst zone) and fractured/karstic limestone bedrock in the vicinity of MW1, 2, and 4. Due to faulting and the change in aquifer units, the contaminants only had to migrate through 15-20 feet of unsaturated limestone bedrock in the vicinity of MW3.

Pools of hydrocarbons from a release can become trapped within the karst, epikarst, and soil horizons to become sources of contamination by slowly dissolving into the groundwater (Fels, 1999). At the Big Wheel Truck Stop it is also likely that the contaminated epikarst and soil/fill horizon provided a reservoir and source of remobilized contaminants.

Transport of petroleum contaminants in a karst aquifer (saturated zone) is different from what occurs in porous aquifer systems, in that contaminants are concentrated along the rapid karstic flow routes. The rapid conduit nature of flow diminishes the microbial effects observed in other porous media settings.

Instead, concentrations of contaminants likely get diluted farther down the flow path. In the case of the Big Wheel Truck stop, the high groundwater velocities (rapid advection) and likely minor dispersion of the contaminants likely transported the contaminants as pulses during recharge events from the source area to wells and springs (Barton and perhaps Cold Springs).

Groundwater Flow Direction

It is common practice to use potentiometric data to determine the direction of regional groundwater flow, even in karst areas (Quinlan, 1989; Kresic, 2007; Hunt et al., 2007). However, in karst terrains it is important to also conduct tracing to confirm the validity of potentiometric maps (Quinlan, 1989; Fels, 1999; Kresic, 2007).

At the truck stop, shallow groundwater (15-21 ft below ground surface, bgs) occurs within MW-3 and is interpreted to be either associated with the fault zone or the Upper Trinity Aquifer. This well has about 60-80 feet of higher head than the other remaining Edwards monitor wells on the site. Edwards Aquifer water depths in the area are generally between 80-100 ft bgs (**Table 4**; **Figure 3**). The steep gradients separating MW-3 from the remaining monitor wells are interpreted to be the result of the presence of the Mount Bonnell fault. The persistence of this gradient suggests the fault is a barrier (perhaps leaky) to groundwater flow.

Initial investigations (AES, 1999 and 2000) show flow gradients in the Edwards Aquifer on the site inferred to the northwest or the southeast, depending on the time of year and the consultant map selected **(Figure 6**). However, when the data are put into a larger Edwards Aquifer potentiometric surface context, the map in **Figure 6A** matches the regional potentiometric map (**Figure 7**) that shows a general flow direction to the east. **Figure 8** is a close-up of the 1999 potentiometric map with some of features with dye-trace data indicated. Water levels in surrounding wells completed in the Upper, Middle, and Lower Trinity aquifers to the west of the Mount Bonnell Fault have very steep gradients compared to the Edwards Aquifer levels. This suggests that the fault provides a barrier to flow between the Trinity and the Edwards aquifers.

Figure 9 is a composite potentiometric map including all the site data and some regional data. Recharge along Williamson Creek is interpreted to create a mound in the potentiometric surface and force groundwater flow to the south and east in the vicinity of the Big Wheel Truck Stop—this has been observed in other portions of the Barton Springs Aquifer (Hunt et al., 2007).

Groundwater Velocity

In porous media aquifers, the linear groundwater velocity (advection) value can be used to answer how long would it take the contaminant to reach a potential receptor? The average linear groundwater velocity (v_L) given by **Eq. 1** equation:

Eq.1 $\mathbf{v_L = (K \times \mathit{i})/\mathit{n}_{ef}}$

K = hydraulic conductivity (ft/d)
i = hydraulic gradient
n_{ef} = effective porosity (similar to specific yield)

Eq. 2 $\mathbf{v_L = (1.9\ ft/d \times 0.012)/0.017 = \underline{1.34\ ft/d}}$

K = value for the basal nodular from Andrews, in review; *i* = gradient between MW1 and WW3 from July 1999 potentiometric map (3,200 ft distance and 38 ft head change); n_{ef} = specific yield from Slade et al., 1985

Using the linear groundwater velocity formula ignores all the fate processes, and makes the assumption that the variables are constant. Most critically, it makes the assumption of a porous media, and does not incorporate flow along fractures or karstic pathways. For example **Eq. 2** suggests the arrival of the contaminants would be 6.5 years to WW3 from the truck stop. However, we know in a karst system flow generally does not follow Darcy's Law used in this equation, but is much more rapid. Equations governing flow in fractured medium (cubic law) and pipe (Bernoulli's) or channel systems are more appropriate for determining the fast flow component. However, direct measures of groundwater flow through dye tracing have occurred in area. Rates of groundwater flow were measured as fast as 4 to 7 mi/day under high-flow conditions or about 1 mi/day under low-flow conditions (Hauwert et al., 2004). A dye trace in a feature along Barton Creek and near the Mount Bonnell Fault was traced to Cold Springs with a velocity of about 0.5 mi/d. **Figure 8** shows two features east of the site with dye tracing results--each had very rapid velocities of about 1 mi/d.

Given the area dye tracing results, the first arrival of contaminants from the truck stop to WW1-3 would be measured in days rather than months or years. In fact, BTEX was detected in WW1 (500 feet to the south) the same day as the large release. Assuming the contaminants can be attributed to the release, that is a minimum velocity of 500 ft/day. In addition, WW2-3 also had detections of contaminants eight days after the release for a minimum velocity of 400 ft/day (**Figure 9**). The actual arrival and velocity was likely much quicker. **Figure 10** is a conceptualized hydrogeologic model of the area in **Figure 9**. The figure illustrates the complex and dual nature of rapid (karstic) and diffuse groundwater flow and potential contaminant pathways to wells.

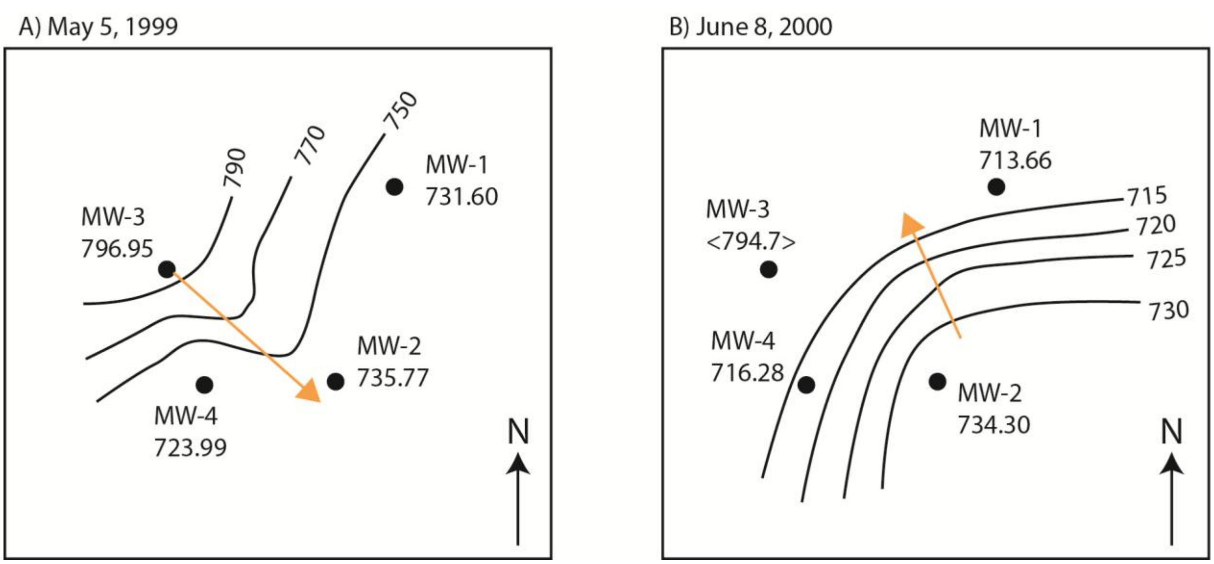

Figure 6. *Two potentiometric maps generated by project consultants showing the inferred groundwater flow path (and presumably contaminants) based solely upon the monitor wells on the site. A) Potentiometric map for May 1999 conditions showing groundwater flow to the southeast. B) Potentiometric map for June 2000 showing groundwater flow to the northwest. Data from MW-3 is not used in the June 2000 map. Both maps created by Applied Earth Sciences Inc. 1999 and 2000.*

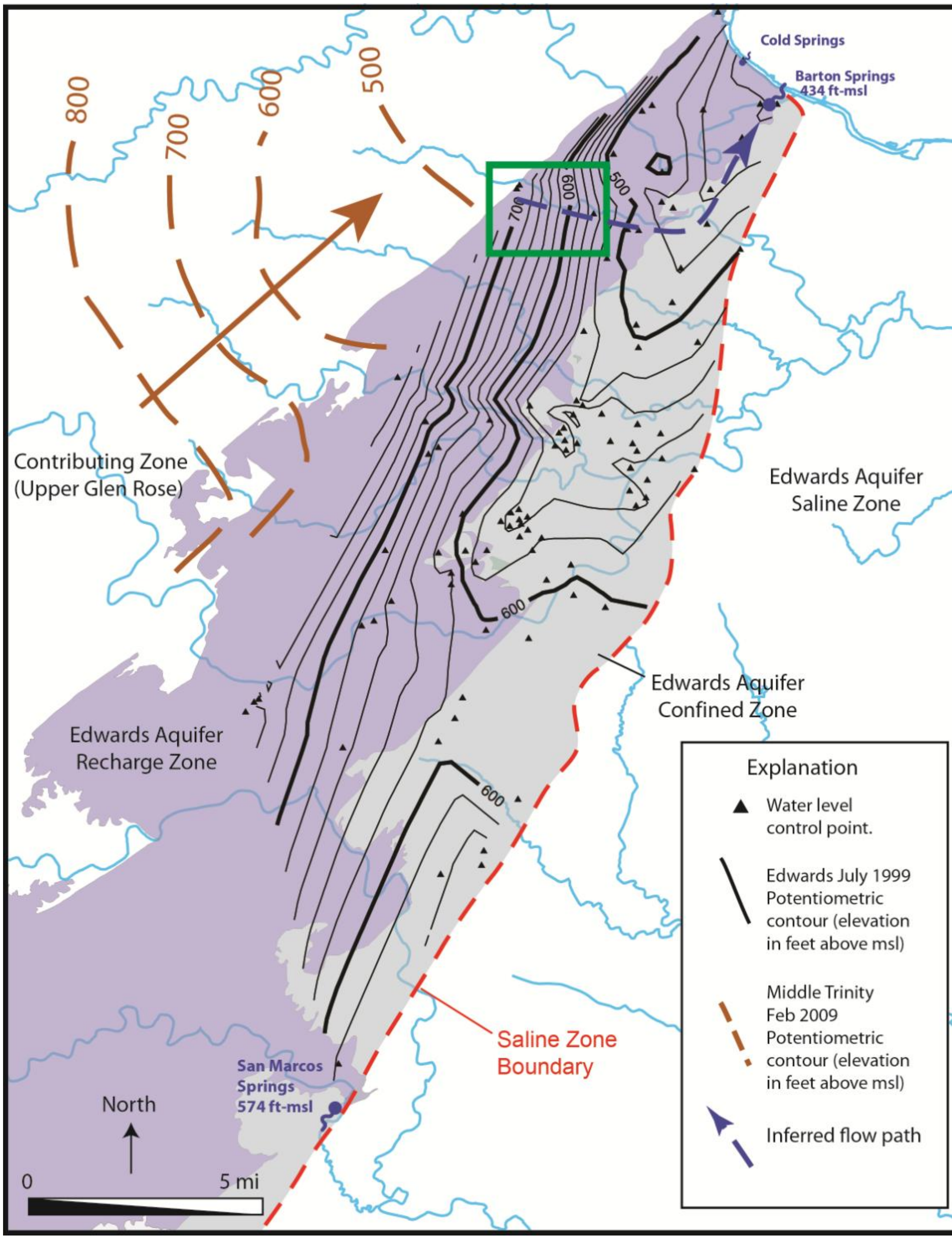

Figure 7. *Potentiometric map from May 1999 (average conditions) for the Barton Springs segment of the Edwards Aquifer. Also shown are Middle Trinity Potentiometric lines from February 2009 (drought conditions). General groundwater flow in the Edwards in the study area is to the east. The groundwater divide between the Sunset Valley groundwater basin to the south, and the Cold Springs basin to the north, generally follows Williamson Creek. Groundwater flow in the Middle Trinity is to the north-northeast. Map modified from Hunt et al., 2006.*

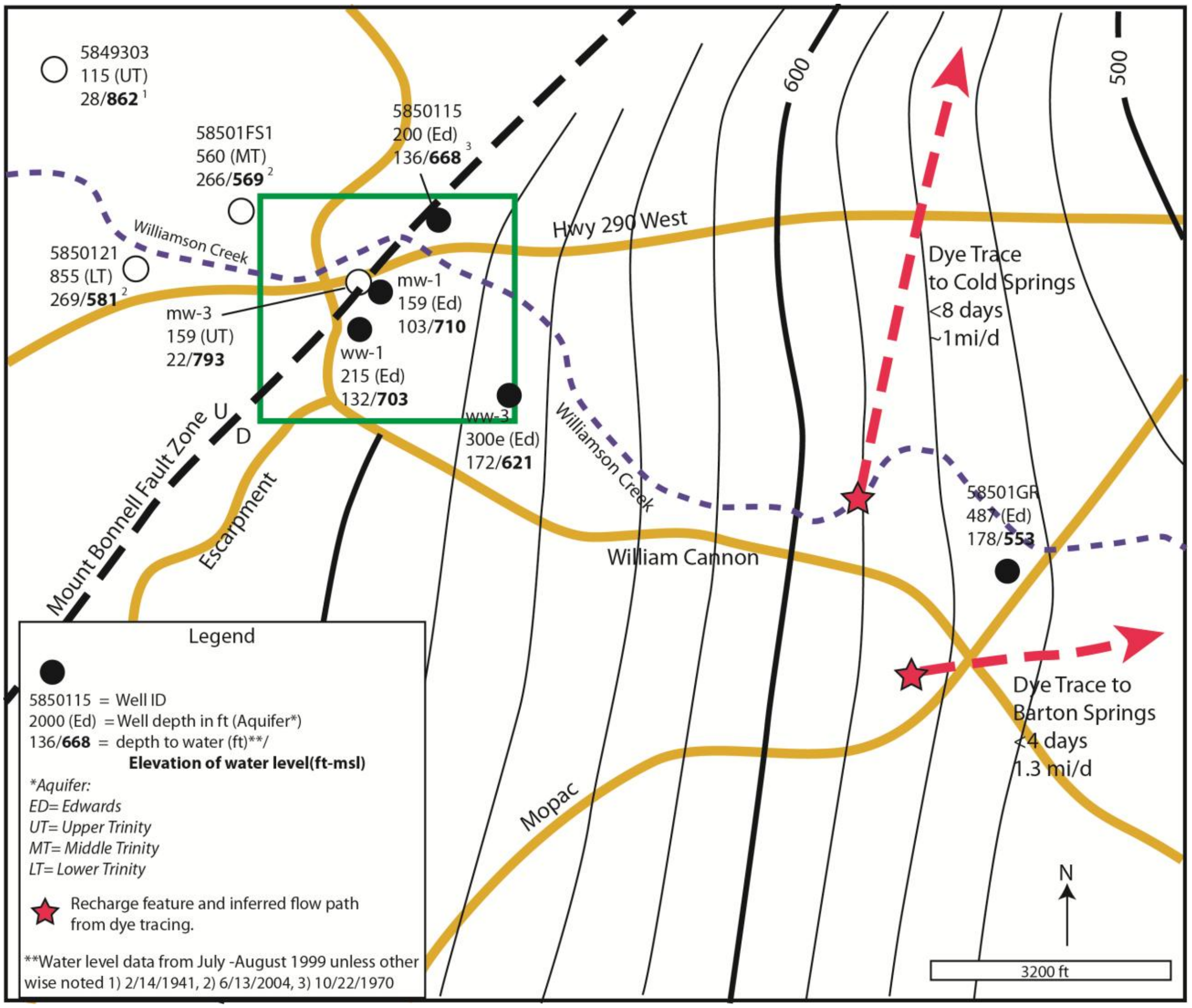

Figure 8. *Regional potentiometric map of the Barton Springs segment of the Edwards Aquifer. Two wells (MW-1 and WW-1 and WW3) from the study area are included in this regional contour map. Additional water level elevations from wells completed in other aquifers west of the fault are indicated. Karst features dye traced in the area are also shown with their destinations indicated.*

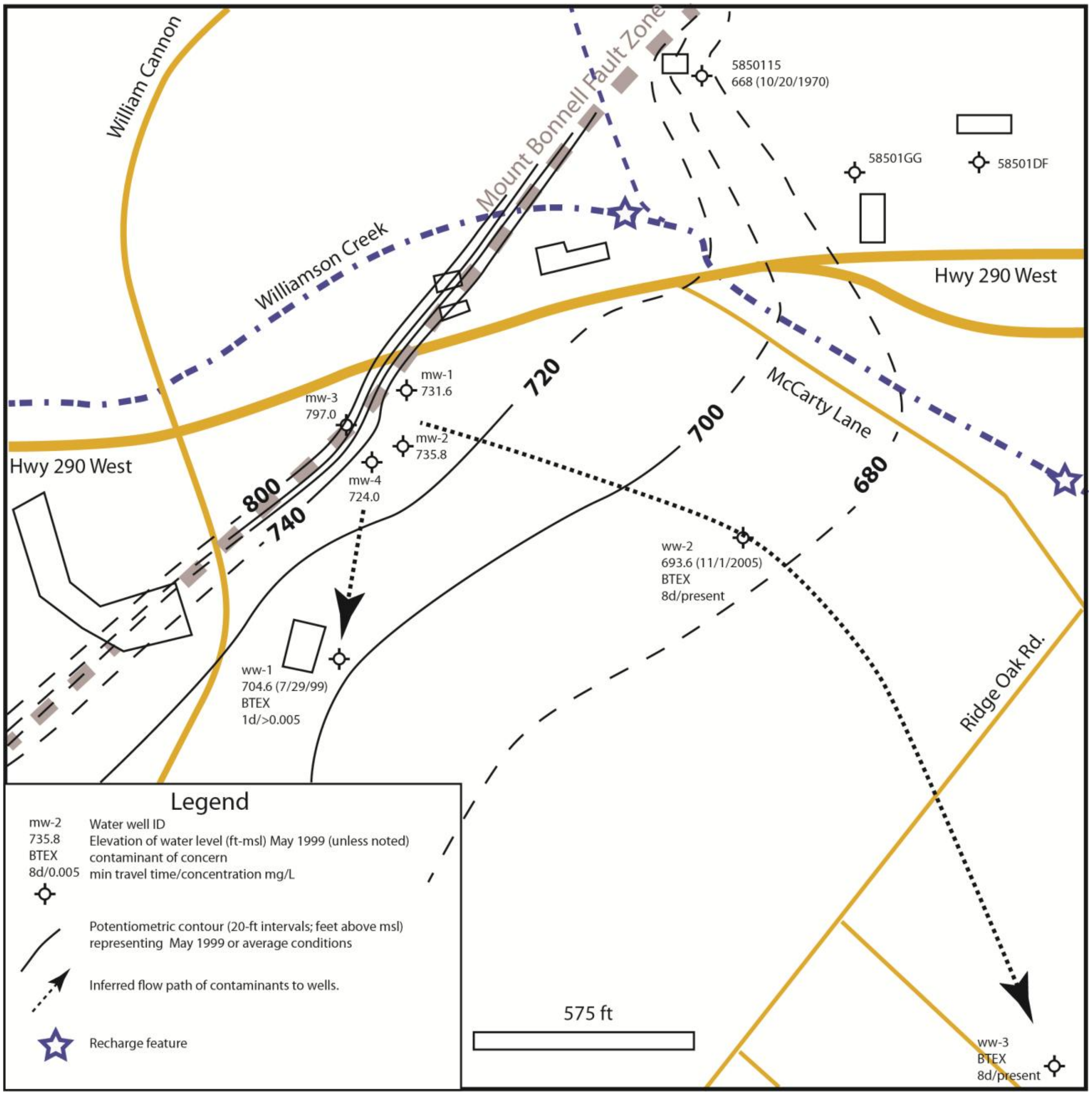

Figure 9. *Local May 1999 potentiometric map of the study area. A groundwater mound is inferred to be present along Williamson Creek due to the nature of recharge in the Edwards and the confirmed presence of recharge features. Groundwater flow is inferred to the southeast and within the Sunset Valley Groundwater Basin, which ultimately flows to Barton Springs. The steep gradient (740-800 ft-msl) likely represents the location of the Mount Bonnell Fault Zone, behaving as a barrier to flow between portions of the Upper Glen Rose (Upper Trinity Aquifer) and the Edwards Aquifer.*

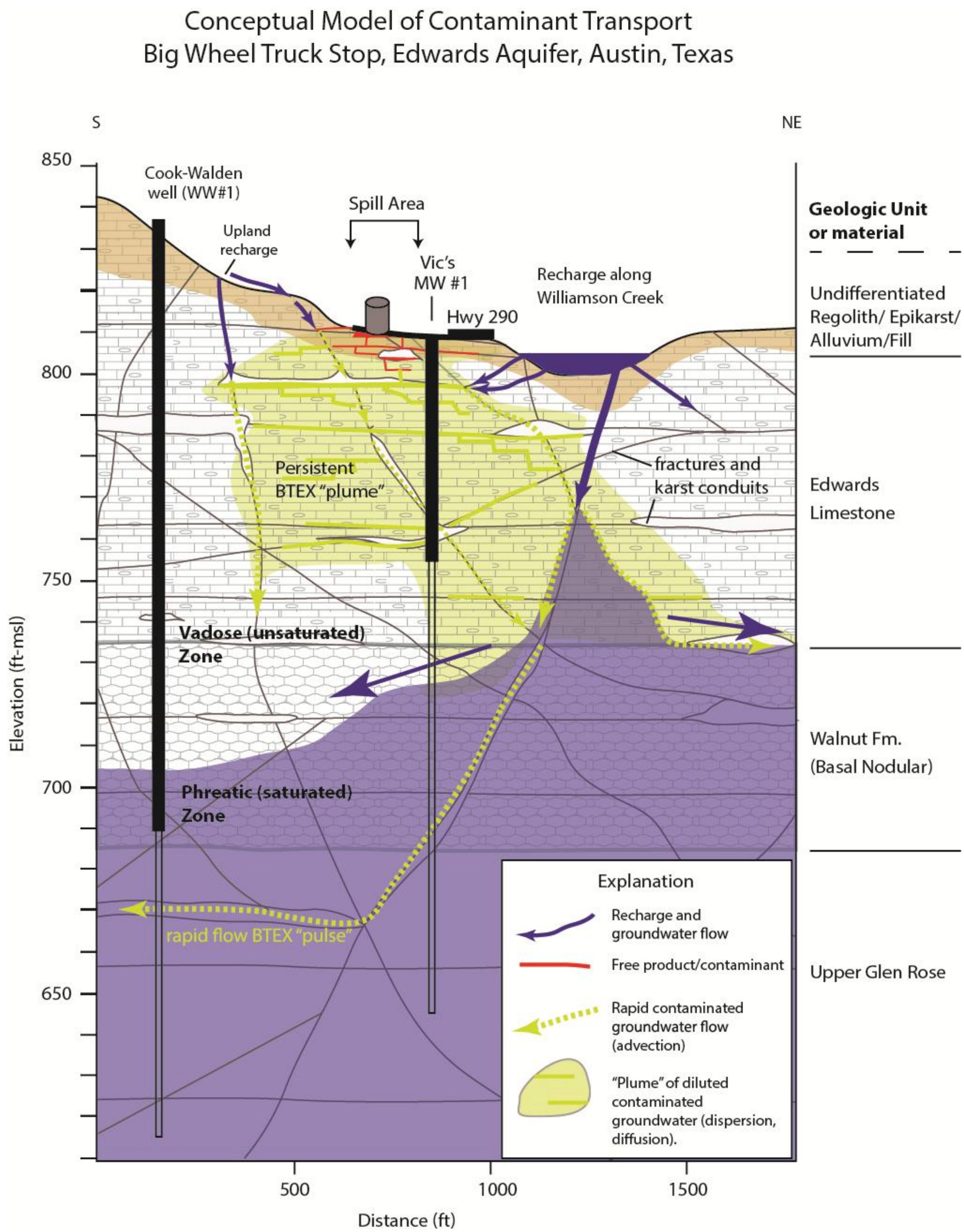

Figure 10. *Conceptual model of contaminant transport for the Big Wheel Truck Stop.*

DISCUSSION

Figure 10 summarizes some important aspects of the hydrogeologic conceptual model of the area and helps us address the potential fate and transport of contaminants released at the Big Wheel Truck Stop. In this context we can attempt to answer the key questions posed by Kresic (2007) for the fate and transport of contaminants in groundwater:

- Is there a pathway to a receptor (well)? Yes, the detections in nearby water wells (WW1-3) and monitor wells (MW1-4) prove the connection to the groundwater system and receptors. Karst conduits provide a rapid and direct pathway.
- How long would it take the contaminant to reach the potential receptor? Contaminants likely reached water wells (WW1-3) within one day flowing along karstic pathways.
- What would the concentration of the contaminant be when it reaches the receptor? BTEX concentrations for water well 1 (WW1), located about 500 feet south, were reported as >0.005 mg/L (above MCL) the same day as the petroleum release.

Contaminant concentrations at WW 1-3 diminished quickly after initial 1992 detection. It is possible that the contaminants were rapidly transported as a detached plume to the off site wells after the spill. Additional pulses of contaminants from the soil and epikarst reservoirs could have been released after recharge events. This is reasonable considering the BTEX persistence in the soils and groundwater at the site and is analogous to what we observe with dye tracing--where dyes are bound up in the epikarst zone get remobilized and can persist for years. Contaminant concentrations in groundwater at the site diminished after removal/remediation of the piping and soil--four years after the 1992 release. However, it took an additional six years for Benzene to decrease below target levels in groundwater at the spill site after soil removal.

Head data suggest the Mount Bonnell Fault Zone is a barrier to flow between the shallow (perched?) Upper Glen Rose and the Edwards Aquifer. Middle and Lower Trinity wells completed west of the Fault also have steep gradients between the Edwards and suggest little potential for flow between those units.

A limitation to this evaluation is the sparse quantitative groundwater samples and measured water levels in the vicinity of the truck stop between the release in 1992 until the site characterization studies in 1996. Concentrations and extent of groundwater contamination could have been much greater than the sparse data suggests.

Leaking petroleum storage tanks make up nearly half of the Texas' active groundwater contamination cases, but most do not impact groundwater supplies (O'Rourke, 2011). This site represents a case where there was impact to groundwater supplies. While the author is not aware of other petroleum releases in the last 15 years for the Barton Springs segment of the Edwards Aquifer, other BTEX contaminants have been noted to occur in the Edwards Aquifer (O'Rourke, 2011). This evaluation provides some insight into the fate and transport of future spills in the karstic aquifers of Texas.

CONCLUSIONS

- Characterizing the transport and fate of contaminants in the Edwards Aquifer must have an accurate conceptual model and include regional data extending beyond the contamination site scale.
- Petroleum hydrocarbon contaminants such as BTEX can flow rapidly, and relatively long distances to wells and springs. The contaminants appear to behave similar to groundwater tracing studies with minimum velocities of 400-500 ft/d. This spill could constitute one of the first (unintended) groundwater traces in the region.
- Contaminants at wells down-gradient from the spill quickly decreased in concentration as the detached plume moved rapidly past the wells, or became diluted.
- Contamination of karstic groundwater can (locally) persist for many years after surface remediation. The soils and epikarst appear to behave as a reservoir of contaminants, allowing contaminants to remobilize with recharge events. Despite soil removal groundwater target levels were not reached for another six years.
- The Mount Bonnell Fault appears to behave as a barrier to inter-aquifer flow in the study area.

Acknowledgments

Nico Hauwert at the City of Austin Watershed Protection Department collected or facilitated the collection of important information from the contamination site, such as the geophysical log (Appendix C) and water chemistry and level data from surrounding wells. Additionally, dye trace studies he conducted were also very important to our understanding of flow in the area. Robin Shaver (TCEQ) provided additional data and her dedication to oversee the monitoring and clean up of the site is noteworthy. Alan Andrews and Robin Gary (BSEACD) provided editorial review of this report.

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Appendix A: Contamination Narrative and photos

The area has experienced a couple major fuel spills from gasonline stations. In 1984 hydrocarbon odors were first reported from a water well about 300 feet south of the site at the Cook-Walden Cemetery (WW1; **Figure 1**) and also from a nearby Patton Ranch well (north of Williamson Creek). An investigation found a hydrocarbon seep (gasoline) in Williamson Creek adjacent to a manhole, and was traced to sewer line adjacent to the Circle K gas station. Review of records from the Circle K station reveal loss of 10,000 gallons from USTs from Jan-July 1984. Supply lines were tested 7/12/1984 and later replaced. LPST # 91010 was assigned to that case. No sampling or testing is documented; however, the adjacent Capital City Oil Company (Big Wheel Truck Stop) was also identified as one potential source by the Travis County Health Department (Raba-Kistner, 1996).

On 9/24/1992 a spill consisting of 900 gallons of diesel and 1,100 gallons of gasoline occurred from two ASTs in the middle of the Big Wheel Truck Stop site (**Figure 3**). The ASTs were within concrete wall perimeters, but without liners on the bottom and so the petroleum infiltrated the ground (**see cover photo**). Soil and groundwater samples detected Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) and Total Petroleum Hydrocarbons (TPH). Due to the impacts on the groundwater, the case was given an official Leaking Petroleum Storage Tank case number by the State (LPST ID # 104820; Raba-Kistner, 1996). Remedial action began on 9/25/92 with removal of 7 of the ASTs and excavation of soils up to 6 ft depth (290 yrd^3). No petroleum liquids (free product, NAPL) were found in the soils or groundwater during excavation. The pit was lined, filled with clean soil, and covered with a concrete slab. Further sampling on 10/2/1992 of groundwater resulted in TPH and BTEX above targets (IT Corp, 1999); although details of these groundwater samples are unreported, it is assumed results were from WW1-3.

PHOTOGRAPH NO. 3
VIEW OF CANOPY AND VIC'S RESTAURANT FROM NORTHEAST CORNER OF PROPERTY.
VIEW LOOKING WEST. PHOTOGRAPH TAKEN BY R-KCI ON 7-02-96.

PHOTOGRAPH NO. 1
CONCRETE SLAB OF FORMER BIG WHEEL TRUCK STOP BUILDING. EXCAVATION AREA (GRASS) WAS LOCATION OF LEAKING ASTs. VIEW LOOKING SOUTH.
PHOTOGRAPH TAKEN BY R-KCI ON 7-02-96.

In September 1992 Capital City Oil Company requested the case be transferred to the State-Lead Remediation Section, which was completed in March 1996. The program authorizes State-funded remediation of sites where releases from petroleum storage tanks have occurred. Sites eligible for the program generally involve responsible parties who are either financially unable, or unwilling, to take corrective action at an LPST site.

On July and August 1996 Raba-Kistner Inc. began an assessment of the contaminants on the site that included 18 shallow soil borings (2-14 ft deep) and four monitor wells (MW1-4) (**Figure 3**). Contaminants of concern (BTEX, TPH) were found in many of the soil borings and in all 4 monitor wells. Maximum level of contamination in native soil and groundwater are listed in **Tables 1 and 2**, respectively. Benzene was the primary contaminant of concern that was above MCL and target concentrations in both soil and groundwater (**Figure 4**).

Continued detection of contaminants in groundwater triggered further site characterization studies. Ten additional soil borings from depths of 1-9 feet were installed October 1996 adjacent to the pump islands and the piping, and revealed further soil remediation was needed. Remediation was performed Nov 11-Dec 30, 1997 and approximately 288 $yrds^3$ of contaminated soil was excavated. Samples (T1-7) were collected from the piping trenches--maximum concentration of benzene was 0.349 mg/Kg. The excavation site was backfilled and covered with a concrete slab (**Figure 3**; IT Corp., 1999).

After the soil remediation, quarterly groundwater sampling by Applied Earth Sciences Inc (AES) occurred from 1997-1999 (**Figure 4**). Three offsite water wells (WW1-3) were sampled intermittently, but were discontinued after repeated non-detects. MW1-2 consistently exceeded the Benzene target levels and MW3-4 exceeded them intermittently. MTBE was consistently detected above MDLs in MW1, 2, and 4 and was intermittently detect in WW1-3 (IT Corp., 1999)

On February 7, 2000 a small hydrocarbon spill was reported. A suspected release of diesel (on the order of tens of gallons) occurred from the remaining 4 unused above-ground storage tanks (**Figure 3**). The contaminants appeared to have migrated across the pavement and infiltration through cracks in the asphalt cover. By March 13, 2000 the 4 remaining ASTs and containments were cleaned and evacuated. On April 25, 2000 an excavation and removal of contaminated asphalt and fill materials occurred in three areas (total of 7 yd^3; **Figure 3**). Areas were backfilled and covered with concrete. As a result of the release, additional groundwater samples were taken for the contaminants of concern in 2000 and 2003 (GeoStrata, 2003).

The case was closed in March 2003 after sampling in 2003 revealed BTEX reduced to target levels. The four monitor wells were plugged in May 2003.

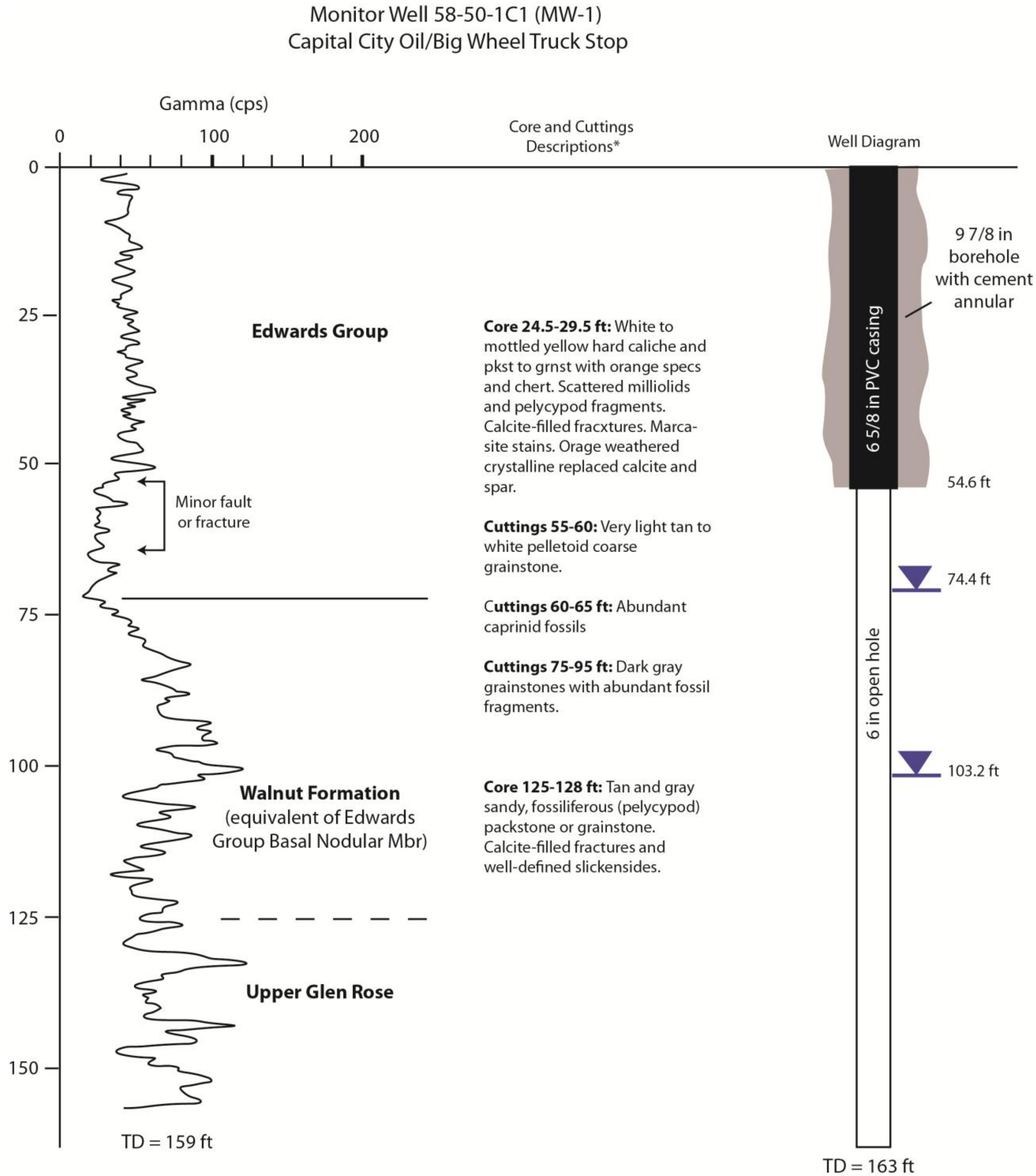
Appendix B: Geologic Map of the Mount Bonnell Fault Area, Williamson Creek, Austin, Texas

Geology by Brian B. Hunt

Photograph of the Upper Glen Rose Formation exposed in Williamson Creek west of the Mount Bonnell Fault. Note nodular, grey limestone overlain by a nodular, fossiliferous marly limestone.

Photograph of the Edwards Group limestone exposed in Williamson Creek east of the Mount Bonnell Fault. The limestone consists of fractured crystalline mudstones with local rudistid fossils.

Appendix C: Geophysical log



* From Nico Hauwert, BSEACD files