Summary of Groundwater Dye Tracing Studies (1996-2002), Barton Springs Segment of the Edwards Aquifer, Texas

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Introduction

The Barton Springs/Edwards Aquifer Conservation District (BSEACD), in cooperation with the City of Austin (COA), injected non-toxic organic dyes into caves, sinkholes, and wells within the Barton Springs segment of the Edwards Aquifer to trace groundwater flow routes and determine groundwater flow rates. This document summarizes groundwater dye tracing studies conducted between 1996 and 2001 with funding from an Environmental Protection Agency 319(h) grant and presents new groundwater dye tracing results conducted during 2002. These studies have provided new insight into groundwater flow for this karst aquifer by defining three primary groundwater basins with related groundwater flow routes. Groundwater flow rates from major recharge locations to the springs are very rapid and variable under different aquifer conditions.

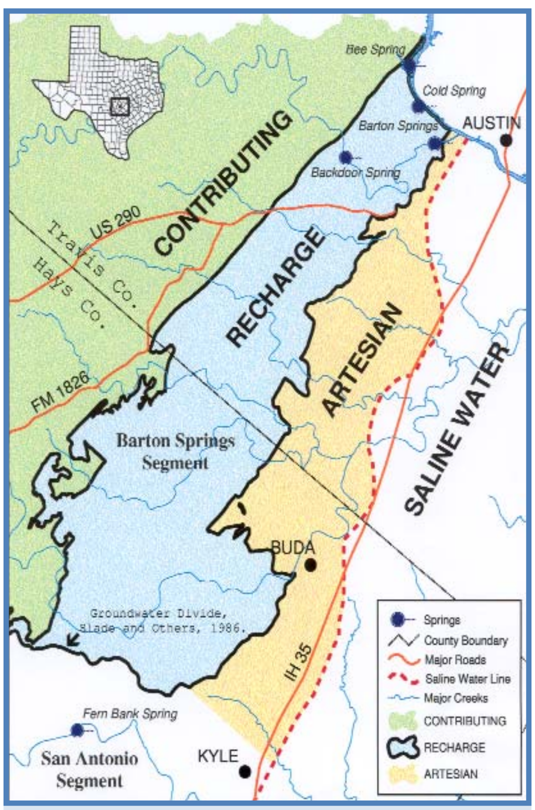


Figure 1: Location map of the study area with hydrologic zones of the Barton Springs segment of the Edwards Aquifer.

Overview

The Barton Springs segment of the Edwards Aquifer is located south of the Colorado River at Austin and extends south to the Buda and Kyle areas, east to Interstate 35, and west to FM 1826 (Figure 1). The portion of the aquifer segment south of the Williamson Creek watershed is a federally designated sole source aquifer. The Barton Springs segment provides water for municipal, commercial, industrial, agricultural, recreational, and domestic uses in the Austin, Sunset Valley, Manchaca, San Leanna, Buda, Hays, Creedmoor, Niederwald, Kyle, and Mountain City areas. In 1995 the aquifer was a sole source of water for an estimated 44,000 people.

The primary discharge for the Barton Springs segment occurs at Barton Springs, located in Zilker Park near the center of Austin. Barton Springs consists of Main (Parthenia) Springs, Eliza (Concession) Springs, Old Mill (Sunken Gardens, Xenobia, or Walsh) Springs, and Upper Barton Springs. The Main Springs discharge directly into Barton Springs pool, a major recreational attraction for the city which received about 350,000 paid visits in 1996. Discharge from Barton Springs sustains flow in the lower portion of Barton Creek and contributes to Town Lake, which serves as a source of drinking water for the City of Austin and other municipalities located downstream on the Colorado River. Barton Springs are the only known habitat for two rare aquatic salamanders: the endangered Barton Springs salamander, *Eurycea sosorum*, and the Austin blind salamander, *Eurycea waterlooensis*, a candidate for endangered listing.

The Barton Springs segment is composed of Cretaceous-age (65-145 million years old) limestone units that have been fractured (associated with the Balcones Fault Zone) and partially dissolved by infiltrating rainwater. The fracturing and dissolution of the Edwards Group limestone units have resulted in the development of a prolific karst aquifer containing abundant caves, sinkholes, and springs. The Barton Springs segment is recharged with water by infiltration via caves, sinkholes, fractures, and solution cavities located primarily along creeks within a 98-square mile area of exposed Edwards Group limestone units. This area is referred to as the recharge zone (Figure 1). A smaller portion of the water that recharges the aquifer infiltrates through the soil that covers the limestone bedrock. The major creeks that recharge the Barton Springs segment include Barton, Williamson, Slaughter, Bear, Little Bear, and Onion Creeks. Previous studies have estimated the location of the southern groundwater divide, which is a boundary delineating where groundwater either flows north to Barton Springs or south to San Marcos Springs, to be located somewhere between the cities of Kyle and Buda in Hays County (Figure 1). Delineation of the groundwater divide is based primarily on potentiometric surface (water level) maps. The location of the groundwater divide is believed to change under varying aquifer conditions.

Figure 2: Ron Fieseler pours a fluorescein dye and water mixture into Dry Fork Sink (site C) on June 17, 1997. The sinkhole is located on Kitcheon Branch, a tributary of Williamson Creek, in Sunset Valley. The dye traveled 4.5 miles to Barton Springs in less than 30 hours after injection. Photograph taken by Nico Hauwert.

Methodology

Groundwater tracing techniques are recognized as the only direct method to measure groundwater flow routes and travel times in karst aquifers. Groundwater dye tracing involves the introduction of non-toxic organic dyes into the subsurface via injection points, such as caves and sinkholes, and analysis of charcoal receptors and water samples taken from discharge points such as wells and springs (Figures 2, 3). Five traditional, well-documented, and distinct organic dyes used in this study include: fluorescein (Fl), rhodamine WT (RWT), eosine (Eos), sulforhodamine B (SRB), and pyranine (Pyr). These dyes have been evaluated to be suitable for this study due to their physical characteristics, safety for drinking water supplies and aquatic habitats, and low background concentrations.

A total of 22 injections were conducted in all the major contributing watersheds supplying water to Barton Springs. The dyes were injected into 19 different natural recharge features, such as caves and sinkholes, and one well within the Barton Springs segment. Injections were conducted twice at site A and three times at site M. All dyes were generally flushed into the aquifer with approximately 10,000 gallons of water to carry the dye to the water table. To monitor the movement of the dyes, charcoal receptors were placed in springs, creeks, river sites, and many accessible wells. Receptor sites were monitored using a combination of charcoal receptors, which contain adsorbent activated charcoal in mesh packets, and water samples. Charcoal receptors absorb dye from the water and allow detection of dyes over extended periods of time. Water samples, known as grab samples, were collected in plastic bottles at the time the receptors were replaced. Grab samples provide information on the instantaneous dye concentrations in the water. Receptor sites were monitored for 2 weeks prior to dye injection to detect any background presence of dyes. After injection of the dye, receptors were collected at intervals ranging from several hours to 3 weeks. Prior to September 2001, all receptors and corresponding water samples were sent to Ozark Underground Laboratories (OUL) in Missouri for laboratory analyses. After September 2001, laboratory analysis was conducted at both the Edwards Aquifer Authority in San Antonio (well samples) and at OUL (spring samples). Breakthrough curves, which are graphs displaying dye concentrations over time, were evaluated to characterize the dye response at the springs.

Results

Groundwater dye tracing results are summarized and presented in Table 1. Estimated and inferred groundwater flow routes between dye injection and recovery sites were created using potentiometric surface, geological, and cave maps (Figure 4). This groundwater dye tracing study has defined three groundwater basins known as the Cold Springs, Sunset Valley, and Manchaca basins, each with its own major groundwater flow route.

Five dye injections from four different locations within Barton and Williamson Creeks were traced to Cold Springs, located along the south bank of the Colorado River (Table 1, Figure 4). These traces define the Cold Springs groundwater basin, which is estimated to cover approximately 11.8 square miles. Groundwater in the Cold Springs basin discharges primarily to Cold Springs along the inferred Cold Springs flow route, which corresponds to a trough (area of lower water levels) on the potentiometric map. Groundwater within this basin may also discharge at Bee Springs and other unidentified springs along the Colorado River.

Two dye injections within Williamson Creek were traced to the Main outlet of Barton Springs and Upper Barton Springs (Table 1, Figure 4). These traces support the existence of a Sunset Valley groundwater basin estimated to cover approximately 11.7 square miles. Water recharging in this groundwater basin converges to the inferred Sunset Valley flow route, represented by a trough in the potentiometric map, during high and moderate groundwater flow conditions. However, the boundaries of this groundwater basin may change with varying aquifer levels. During low flow conditions potentiometric data suggest that the trough defining the Sunset Valley flow route becomes less distinct and may therefore allow flow from this basin to contribute to all Barton Springs outlets. For this study low flow conditions are defined as springflow below 40 cubic feet per second (cfs) at Barton Springs and no flow at Upper Barton Springs. Average springflow at Barton Springs is reported to be about 53 cfs. Additionally, there is evidence suggesting that during major flood events groundwater may overflow from the Manchaca groundwater basin into the Sunset Valley groundwater basin.

Ten dye injections from 12 different locations within the Barton, Slaughter, Bear, Little Bear, and Onion Creek watersheds were traced directly to Barton Springs, or to wells previously linked to Barton Springs through other traces such as site K. These traces, along with potentiometric data, define the roughly 113-square mile Manchaca groundwater basin, which discharges from the Main, Eliza, and Old Mill outlets of Barton Springs. Groundwater generally flows across the recharge zone east towards a wide potentiometric surface trough located along the eastern edge of the recharge zone. Groundwater follows this potentiometric surface trough to the northeast and parallel to regional faulting

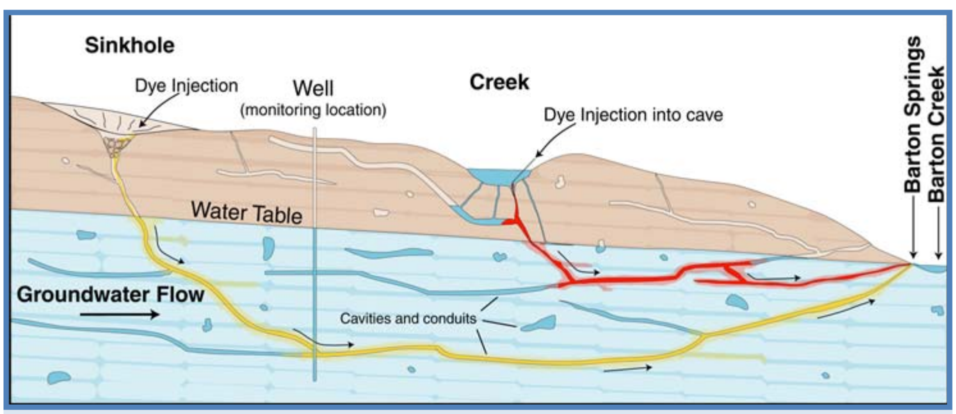
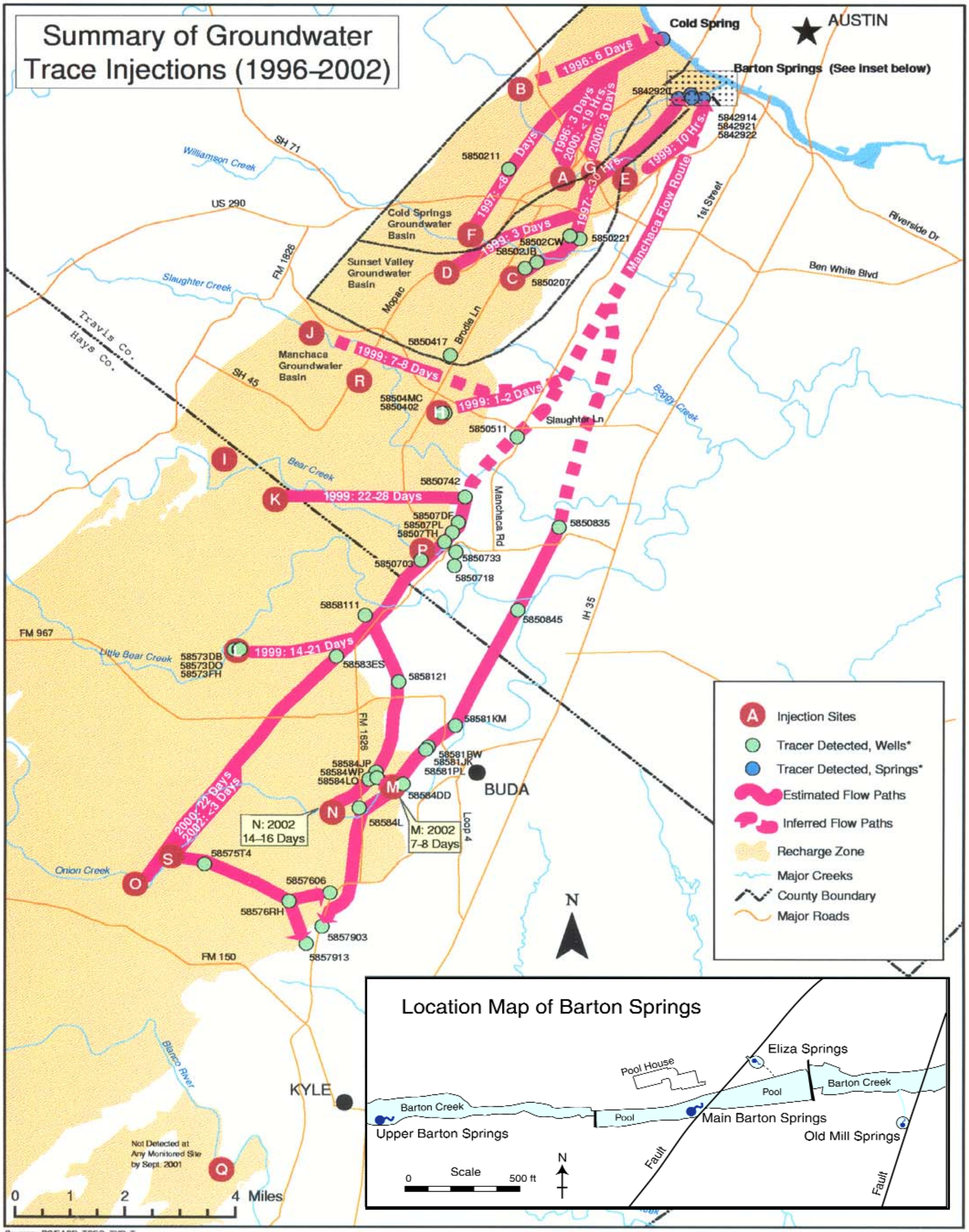


Figure 3: This schematic cross section illustrates the key concepts of groundwater dye tracing in the Edwards Aquifer. Dyes (shown in yellow and red) were injected into recharge features, such as sinkholes and caves. Wells and springs were monitored for the arrival of the dyes to measure groundwater flow rates and flow routes.



Sources: BS/EACD, TCEQ, TXDoT
Created by Jason West (BS/EACD)

* Monitored wells and springs with no detections are not shown.
** All travel times are to the Springs (Cold Spring and Barton Springs).

Figure 4: Summary Map of Groundwater Dye Tracing Injections (1996 to 2002)

Table 1: Summary of Dye Trace Data

Site	Injection Site Name	Watershed	Injection Date	Dyes	Amount (lbs)	Discharge and Dye Recovery Site	Spring flow at Barton Springs (cfs)	Min est. flow path to discharge point (miles)	*First Arrival Time (days)
A	Mopac Bridge	Barton Cr.	8/13/96	RWT	10 lbs	Cold Spr.	18	3.4	5
A'	Mopac Bridge	Barton Cr.	8/5/97	Eos	5 lbs	Cold Spr.	107	3.4	0.79
B	Mnt. Bonnell Fault	Barton Cr.	8/13/96	Fl	10 lbs	Colorado River	18	2.7	6
C	Dry Fork Sink	Williamson Cr.	6/17/97	Fl	3 lbs	Upper Barton Spr. Main Barton Spr.	101	4.8	1.25 1.25
D	Whirlpool Cave	Williamson Cr.	6/16/99	Eos	5 lbs	Upper Barton Spr. Main Barton Spr.	68	5.7	** 3 to 4
E	Westhill Drive	Barton Cr.	6/16/99	SRB	2 lbs	Main Barton Spr. Old Mill Spr.	68	2.0	0.38 to 0.41 1 to 2
F	Brush Country	Williamson Cr.	6/24/97	RWT	10 lbs	Cold Spr.	110	5.3	< 8
G	Loop 360	Barton Cr.	6/23/00	Pyr	5 lbs	Cold Spr.	61	3.3	< 2
H	Brodie Sink	Slaughter Cr.	4/27/99	Eos	7 lbs	Main Barton Spr. Eliza Spr. Old Mill Spr.	83	8.6	1 to 2 1 to 2 1 to 2
I	Hobbit Hole	Bear Cr.	9/28/99	Fl	5 lbs	unrecovered	37	-	-
J	Midnight Cave	Slaughter Cr.	4/27/99	RWT	5 lbs	Main Barton Spr. Eliza Spr. Old Mill Spr.	83	11.0	7 to 8 7 to 8 7 to 8
K	Spillar Ranch Sink	Bear Cr.	9/28/99	RWT	10 lbs	nearby well only	37	-	-
L	Dahlstrom Cave	Little Bear Cr.	9/28/99	Eos	10 lbs	Main Barton Spr. Eliza Spr. Old Mill Spr.	37	14.9	14 to 21 21 21 to 29
M	Antioch Cave	Onion Cr.	3/28/00	RWT	20 lbs	nearby wells only	26	-	-
M'	Antioch Cave	Onion Cr.	11/21/00	RWT	24 lbs	nearby wells only	81	-	-
M"	Antioch Cave	Onion Cr.	8/2/02	Fl	25 lbs	Main Barton Spr. Eliza Spr. Old Mill Spr.	99	17.5	7 to 8 7 to 8 7 to 8
N	Barber Falls	Onion Cr.	3/29/00	Fl	10 lbs	Main Barton Spr. Eliza Spr.	26	15.7 15.7	14 to 16 16 to 18
O	Crooked Oak Cave	Onion Cr.	8/12/00	Eos	25 lbs	Main Barton Spr. Eliza Spr. Old Mill Spr.	28	18.6	23 < 24 30 to 32
P	Marbridge Sink	Bear Cr.	3/28/00	Eos	20 lbs	Main Barton Spr.	26	11.0	36 to 43
Q	Tarbutton Cave	Blanco River	8/3/00	Fl	15 lbs	unrecovered	24	-	-
R	Recharge Sink	Slaughter Cr.	10/6/00	SRB	12 lbs	unrecovered	24	-	-
S	Cripple Crawfish Cave	Onion Cr.	8/6/02	Eos	35 lbs	Main Barton Spr. Eliza Spr. Old Mill Spr.	98	17.5	< 3 < 3 < 3

* First arrival times are presented as a range in some cases due to sampling frequency ** Arrival inferred, but obscured by background data

and discharges at Barton Springs. The potentiometric trough is interpreted to be a preferential groundwater flow route. This flow route is parallel to Manchaca Road and is referred to as the Manchaca flow route. Dye injections into Bear, Little Bear, and upper Onion Creeks (sites K, L, O, and P) were all recovered in well 58-50-742 (subsequently plugged before the 2002 injections) representing the convergence of groundwater flow routes along the western branches of the Manchaca flow route. Three dye injections (sites J, K, and L) appear to flow across northeast-trending faults from west to east to join the northeast-trending Manchaca flow route. Dyes injected into two recharge features (sites M and N) within the creek bed of Onion Creek were both recovered in well 58-58-121, which is located within a broad potentiometric surface trough. Injections at only two features (sites I and R) during low groundwater flow conditions were not detected at any well or spring.

Southern Groundwater Divide

Dyes were injected at four locations (sites M, N, O, and S) on Onion Creek to help delineate the location of the southern groundwater divide. Dye from all four locations was detected at Barton Springs. Two of the injections (sites N and O) occurred under low springflow conditions of 26 and 28 cfs, respectively. Under these springflow conditions, dye was detected only at wells north of Onion Creek before arriving at Barton Springs. The remaining two injections (M" and S) occurred during high springflow conditions of 98 and 99 cfs, respectively. In addition to positive detections at wells north of Onion Creek and Barton Springs, dye was detected at several wells south of Onion Creek. During these high springflow conditions significant recharge is occurring creating a groundwater mound (an area of high water levels) along Onion Creek. Therefore, dye injected during these conditions flows north of Onion Creek towards Barton Springs, and south of the creek in the direction of San Marcos Springs. Another example of this occurred during a previous injection into site M on March 2000 during low springflow conditions (26 cfs). Initially dye was detected only in wells north of Onion Creek. However, during early June 2000 springflow increased to 65 cfs due to significant rainfall and subsequent recharge to the aquifer. Dye was detected in July 2000 at a well (58-57-903) south of Onion Creek that was attributed to the injection at site M. It is unclear if the flow south of Onion Creek continues to San Marcos Springs, or temporarily moves south and then flows back toward Barton Springs when the recharge and associated groundwater mound declines. As of January 2003, dye attributed to these injections has not been detected at San Marcos Springs. Dye injected into a sinkhole on the Blanco River (site Q) during low groundwater flow conditions in 2000 has not been detected at either Barton or San Marcos Springs. A previous trace, conducted in 1986 at the same site, reported that the dye required a full year to arrive at San Marcos Springs. Results of the dye trace conducted on Onion Creek do not contradict the hypothesized divide located somewhere between the cities of Buda and the Kyle, although the data suggest that the boundary may shift under varying aquifer or recharge conditions.

Groundwater Flow Rates

Groundwater flow rates were calculated for 16 of the traces for which sufficient samples were collected. The rates are described here by the first arrival of the dye (Table 1). The time of peak dye arrival was more difficult to define in some cases and generally occurred shortly after the first arrival. The results illustrate a correlation between springflow and groundwater flow rates. The difference in flow rates between high and low groundwater flow conditions was measured at Site A. Groundwater flow rates of 0.6 miles per day were measured under drought conditions in 1996 while rates of 5 miles per day were measured under higher groundwater flow conditions from the same site in 1997. Cripple Crawfish Cave (site S) is located very close to Crooked Oak Cave (site O). Both injections were directly traced to Barton Springs; however, the first arrival time for each trace was significantly different. The dye injected at site O arrived at Barton Springs in about 23 days when springflow was 28 cfs. The dye injected at site S arrived at Barton Springs in less than 3 days when springflow was 98 cfs. Generally, dyes injected during low flow conditions (sites A, B, L, N, O, and P) moved at a rate of 0.6 to about 1 mile per day. During moderate and high groundwater flow conditions, above 40 cfs at Barton Springs, groundwater flow rates exceeded 1 mile per day ranging up to approximately 6 miles per day. Groundwater flow rates also appear to vary with the proximity and connection to major preferential groundwater flow routes. Under moderate and high groundwater flow conditions, groundwater generally travels approximately 4 to 7 miles per day parallel to the major groundwater flow routes oriented to the northeast. However, groundwater travels at a rate of approximately 1 mile per day from the western side of the recharge zone to the eastern side of the aquifer (Figure 4).

Figure 5: Whirlpool at Cripple Crawfish Cave (site S). This recharge feature is located within Onion Creek and was injected with Eosine dye on August 6, 2002. The dye arrived at Barton Springs, 17.5 miles away, in less than 3 days. Photograph taken by David Johns.

Dye Recovery

In most cases, the peak dye concentration reached the discharge spring within hours after the initial arrival of the dye. This suggests an aquifer system strongly influenced by conduit (rapid, pipe-like) flow relative to diffuse (slow) flow. The amount of recovery of dye injected into recharge features that subsequently discharged from springs and wells is calculated to range from 0% to about 77%. The amount of dye recovery did not vary directly with the distance from the injection point to the discharge springs. The dye travel times and recoveries may underestimate the actual groundwater flow rates and character of groundwater flow due to absorption of the dye, the complexity of the actual flow routes, the frequency of sampling, and the amount of dye used.

Conclusions

Groundwater dye tracing indicates that Cold Springs is hydraulically linked to surface water recharging from the upper portions of Williamson and Barton Creeks on the recharge zone. Barton Springs is hydraulically linked to water recharging from Slaughter, Bear, Little Bear, and Onion Creek watersheds and lower portions of Williamson and Barton Creek watersheds on the recharge zone.

The Barton Springs segment of the Edwards Aquifer is composed of three primary groundwater basins: the Cold Springs, Sunset Valley, and Manchaca groundwater basins. Each groundwater basin has preferential groundwater flow routes that generally trend to the northeast, parallel to regional faults, and converge towards the springs. Although the groundwater basin divides are generally defined in this study, additional tracing is necessary to more accurately delineate the divides under varying aquifer conditions.

Groundwater flow rates appear to vary with (1) the proximity and connection to major preferential groundwater flow routes and with (2) varying groundwater flow conditions. Under moderate and high groundwater flow conditions at Barton Springs, groundwater generally travels approximately 4 to 7 miles per day along the major groundwater flow routes, but only about 1 mile per day from the western side of the recharge zone to the eastern side. During low flow conditions at Barton Springs, groundwater moves at rates of about 0.6 miles per day to 1 mile per day across the aquifer.

This groundwater tracing study provides valuable information necessary to improve wellhead protection, to anticipate the fate of a hazardous material spill on the recharge zone, to assist in developing effective monitoring strategies, to prioritize purchases of water quality/quantity protection lands, and to evaluate sites for potential recharge enhancement.

Acknowledgements

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Figure 6: BSEACD staff Hydrogeologist Brian Hunt changes charcoal packets (receptors) at San Marcos Springs. San Marcos Springs are a collection of springs beneath Spring Lake, with depths up to 25 feet requiring scuba equipment to retrieve samples. Photograph taken by Brian Smith.

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