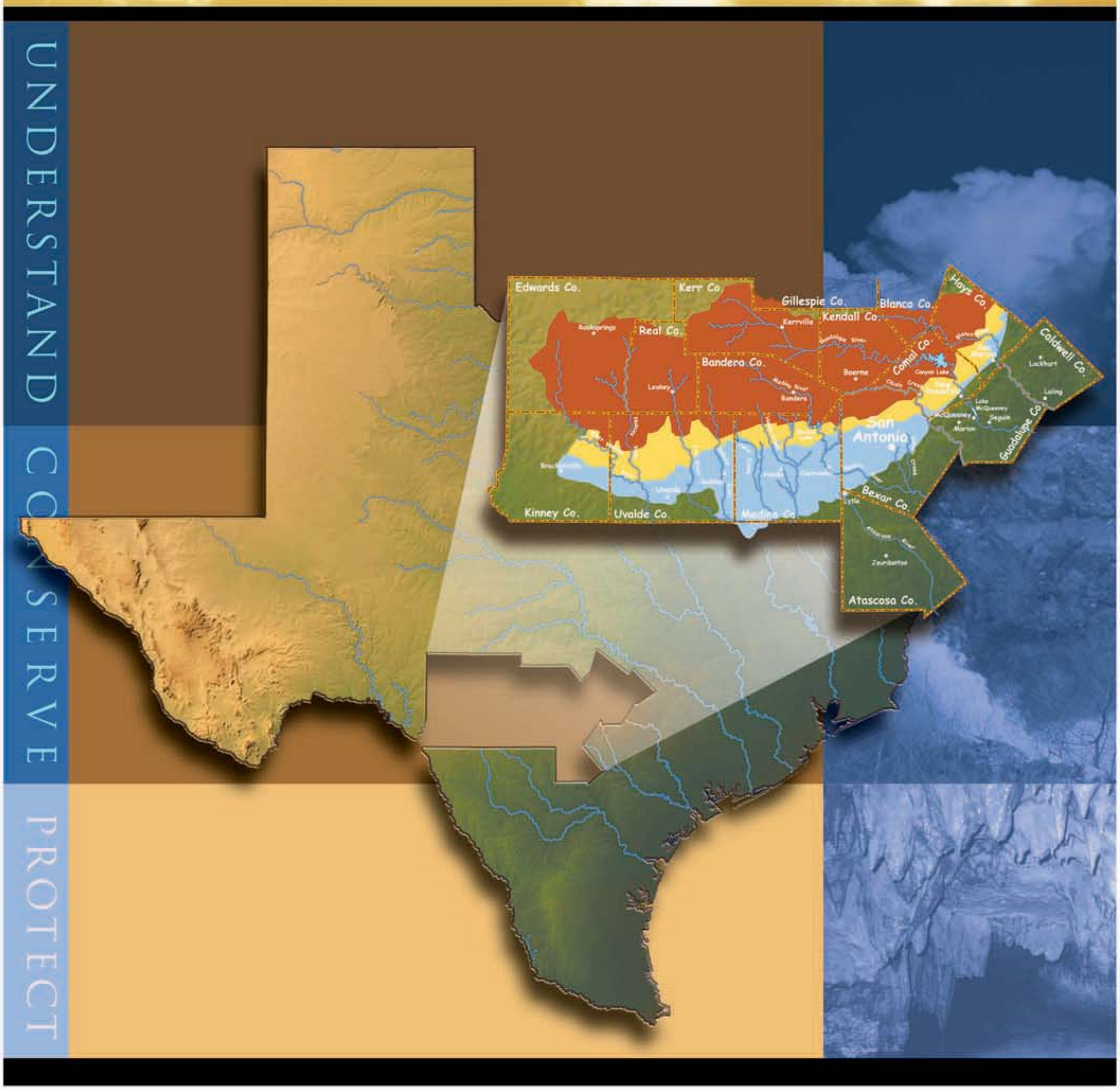
Tracing Groundwater Flowpaths in the Vicinity of San Marcos Springs, Texas



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TRACING GROUNDWATER FLOWPATHS IN THE VICINITY OF SAN MARCOS SPRINGS, TEXAS

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CONTENTS

Figures

Tables

Executive Summary

This report presents the findings of investigations between 2002 and 2010 by the Edwards Aquifer Authority (EAA) regarding groundwater flowpaths in the San Marcos Springs springshed. In addition, it describes a collaborative investigation with the Barton Springs Edwards Aquifer Conservation District (BSEACD) and the City of Austin Watershed Protection and Development Review Department (COA) to define and understand the groundwater boundary between San Marcos Springs in the southern segment of the Edwards Aquifer and Barton Springs in the Barton Springs segment of the Edwards Aquifer.

Purpose

The purpose of this study was to characterize the nature of groundwater flow to San Marcos Springs, Texas, in the Edwards Aquifer recharge zone in Hays County in south-central Texas.

Scope of Investigation

The scope of this investigation consists of 31 tracer tests (dye injections) completed between 2002 and 2010 at various locations in the vicinity of San Marcos Springs using one or more injection points and tracers. Most of the tests were conducted by the EAA, and the tests that involved Barton Springs (in Travis County) were a collaboration with BSEACD and COA. The tests consisted of injections of nontoxic organic dyes into the Edwards Aquifer to trace groundwater flowpaths and measure groundwater flow velocities to San Marcos Springs or Barton Springs. Groundwater samples were collected from public and private wells completed in either the Edwards or the Trinity aquifer, along with samples from surface water sites.

Findings of Investigations

Results of the tracer tests revealed discrete groundwater flowpaths and rapid groundwater velocities connecting the recharge zone to San Marcos Springs and Barton Springs, which is consistent with the karstic nature of the Edwards Aquifer. Apparent (injection point to detection point) velocities ranged from less than one to 11,800 ft/d (3,600 m/d). These are straight-line distances between dye injection and recovery points divided by travel time. The actual groundwater flowpaths are certainly longer than straight lines. Dyes were recovered from every injection test, and many were recovered from San Marcos Springs and Barton Springs, indicating that both spring complexes are important discharge points for the regional Edwards Aquifer flow system. These results also mean that both spring complexes are vulnerable to solid or liquid wastes released in their springsheds. Given the fastest groundwater velocities, San Marcos Springs receives most of its recharge from the southwest along the San Marcos Springs Fault and smaller amounts from west and north of the springs. Some dye injection points indicated bidirectional flow of groundwater to both San Marcos and Barton springs and other recovery points both parallel and perpendicular to the Balcones Fault Zone. Tracer tests reveal the three-dimensional groundwater flow system in the Edwards Aquifer. The boundary between San Marcos Springs and Barton Springs springsheds lies near the confluence of the Blanco River and Halifax Creek under drought conditions when Onion Creek is dry. The divide moves north along Onion Creek in the recharge zone during wetter conditions when Onion creek is flowing and recharging groundwater. Consequently, the Blanco River can recharge both spring complexes, depending on hydrologic conditions. The tests also highlighted the heterogeneity that exists in karst aquifers that is often underrated or even ignored when groundwater systems are characterized.

Introduction

Purpose and Scope

The Edwards Aquifer Authority (EAA) conducts a variety of studies so that the characteristics of the Edwards Aquifer can be better understood, thus providing the technical basis for effective management and protection of the aquifer. This report presents the results of tracer-test investigations of groundwater flowpaths in the Edwards Aquifer in the vicinity of San Marcos, Texas. Tracer tests consist of injecting nontoxic fluorescent dyes into the ground-water system and then tracking their movements through samples collected from wells and springs. Groundwater velocities and flowpaths are calculated from rates and directions of dye movement.

This report presents details of tracer tests that have been conducted by the Edwards Aquifer Authority (EAA) in the vicinity of San Marcos Springs since 2002. In addition, it describes results of a 2008–2010 collaborative tracer test by the EAA, the City of Austin (COA), and the Barton Springs/Edwards Aquifer Conservation District (BSEACD) in the vicinity of the Blanco River in Hays County. Tracer tests in this report are organized by their geographic direction relative to San Marcos Springs: southwest, west, Blanco River vicinity, north, and northeast.

San Marcos Springs is one of the principal discharge points for the southern segment of the Balcones Fault Zone (BFZ) Edwards Aquifer and is located within the City of San Marcos, Texas. Barton Springs is the principal discharge point for the Barton Springs (BS) segment of the BFZ and is located south of the Colorado River within the City of Austin, Texas. One of the objectives of these tracer tests was to investigate the hydraulic connections between these two segments of the BFZ Edwards Aquifer.

Geologic Setting of the Edwards Aquifer

The BFZ Edwards Aquifer consists of the Cretaceous-age Georgetown Formation and Edwards Group (Kainer and Person formations in descending order), which are composed primarily of limestone and dolostone about 500 ft (150 m) in thickness (Rose, 1972; Small, 1986). In south central Texas, it consists of three segments: the southern, the BS, and the northern segment, which is northeast of the Colorado River. It is a dissolution-modified and faulted karst aquifer, making it one of the most permeable and productive aquifers in the United States.

Rose (1972) divided the Kainer and Person formations of the Edwards Group into seven informal members on the basis of lithology. Maclay and Small (1976) described the hydrogeologic characteristics of the members, combined the Cyclic and Marine members and Leached and Collapsed members, and added the Georgetown Formation to form eight informal hydrogeologic subdivisions. The eight subdivisions are listed in Table 1 in descending order.

The Upper Cretaceous Navarro and Taylor Groups (undivided), Austin Group, Eagle Ford Group, Buda Limestone, and Del Rio Clay overlie the Georgetown Formation. One or more of these units may be absent at any particular location, depending on the degree of faulting and erosion.

In the BS segment, the Edwards Aquifer has general lithological characteristics that are the same as those in the east part of the southern segment (Bexar, Comal, and southwestern Hays counties). However, the Cyclic and Marine members (undivided) of the Person Formation, which is about 70 ft (21 m) thick in Hays County, are missing in Travis County (Small et al., 1996).

The Edwards Aquifer has been displaced by faults related to the Balcones Fault system with bimodal trends of N40E (dominant) and N45W (secondary) (Alexander, 1990). Both aquifer segments are characterized by long, northeast-trending fault blocks offset by normal, high-angle faults downthrown to the southeast. The Tom Creek Fault in Hays County, which becomes the Mount Bonnell Fault in Travis County, marks the western boundary of the Balcones Fault Zone. Displacement on the Mount Bonnell Fault is more than 650 ft (200 m) near the Colorado River (Small et al., 1996), and Barton Springs Fault is also a major fault in the BS segment. Major faults in the southern segment in the vicinity of San Marcos Springs include San Marcos Springs, Comal Springs, Bat Cave, Kyle, Mustang Branch, Hidden Valley,

Table 1. Edwards Aquifer Lithology in the San Marcos Area

Formation/Member Name		Lithology	Thickness
Upper confining units	Eagle Ford Group	Brown, flaggy shale and argillaceous limestone	30–50 ft (9–15 m)
	Buda Limestone	Buff, light gray, dense mudstone	40–50 ft (12–15 m)
	Del Rio Clay	Blue-green to yellow-brown clay	40–50 ft (12–15 m)
	Georgetown Formation	Gray to light-tan marly limestone	40–60 ft (12–18 m)
Person Formation	Cyclic and marine members, undivided	Mudstone to packstone; *miliolid* grainstone; chert	0–70 ft (0–21 m)
	Leached and collapsed members, undivided	Crystalline limestone; mudstone to grainstone; chert; collapsed breccia	30–80 ft (9–24 m)
	Regional dense member	Dense, argillaceous mudstone	20–30 ft (6–9 m)
Kainer Formation	Grainstone member	*Miliolid* grainstone; mudstone to wackestone; chert	45–60 ft (14–18 m)
	Kirschberg member	Crystalline limestone; chalky limestone; chert	65–75 ft (20–23 m)
	Dolomitic member	Mudstone to grainstone; crystalline limestone; chert	110–150 ft (34–46 m)
	Basal nodular member	Shaly, nodular limestone; mudstone and *miliolid* grainstone	45–60 ft (14–18 m)
Lower confining unit	Upper member of the Glen Rose Limestone	Yellowish tan, thinly bedded limestone and marl	35–-500 ft (110–150 m)

Source: Small et al. (1996)

Wimberley, and Tom Creek faults. The Hueco Springs Fault is also known as the San Marcos Springs Fault in Hays County. The displacement of San Marcos Springs and Mustang Branch faults nearly juxtapose the entire thickness of the Edwards Aquifer against overlying units (Hanson and Small, 1995).

The Edwards Aquifer recharge zone is defined largely by the Balcones Fault Zone (Figure 1). The Tom Creek/Mount Bonnell faults in the northwest and the Comal Springs/Mustang Branch faults to the southeast generally form the upgradient and downgradient limits of the Edwards Group outcrop, respectively. The Glen Rose Limestone is in fault contact or stratigraphic contact with the Edwards Aquifer to the northwest and is exposed at the ground surface west of the Tom Creek/Mount Bonnell Fault. The overlying confining units (Del Rio Clay and younger) are in fault contact with the Edwards Aquifer to the southeast.

In the vicinity of San Marcos Springs, the Edwards Aquifer is divided into four main fault blocks from northwest to southeast: Bat Cave, Hueco Springs, and Comal Springs fault blocks in the recharge zone and the Artesian fault block, which comprises the part of the Edwards Aquifer under confined conditions (Figure 2). Each fault block has geologic characteristics that influence the hydrologic system. Within the Bat Cave fault block, the lower formation and members of the Edwards Group (Kainer Formation) crop out, including the Dolomitic member, the Basal Nodular member, and small outcrops of the Kirschberg member. Most wells within the Bat Cave fault block are completed in the underlying Glen Rose Formation of the Trinity Group because the Edwards Aquifer is thin, and the water table is often beneath the Edwards Group members.

Within the Hueco Springs fault block, members of the Person and Kainer formations of the Edwards Group crop out, including the Leached and Collapsed, the Regional Dense, and the Grainstone, with the Kirschberg and underlying members exposed along the Guadalupe River and other streams. The Edwards Aquifer yields an adequate quantity of water to wells from the Hueco Springs fault block.

Within the Comal Springs fault block, the Person Formation and the upper members of the Edwards Group crop out, including the Cyclic and Marine members. The Georgetown Formation, Del Rio Clay, Buda Limestone,

Figure 1. Regional Geology Map of Balcones Fault Zone Edwards Aquifer.

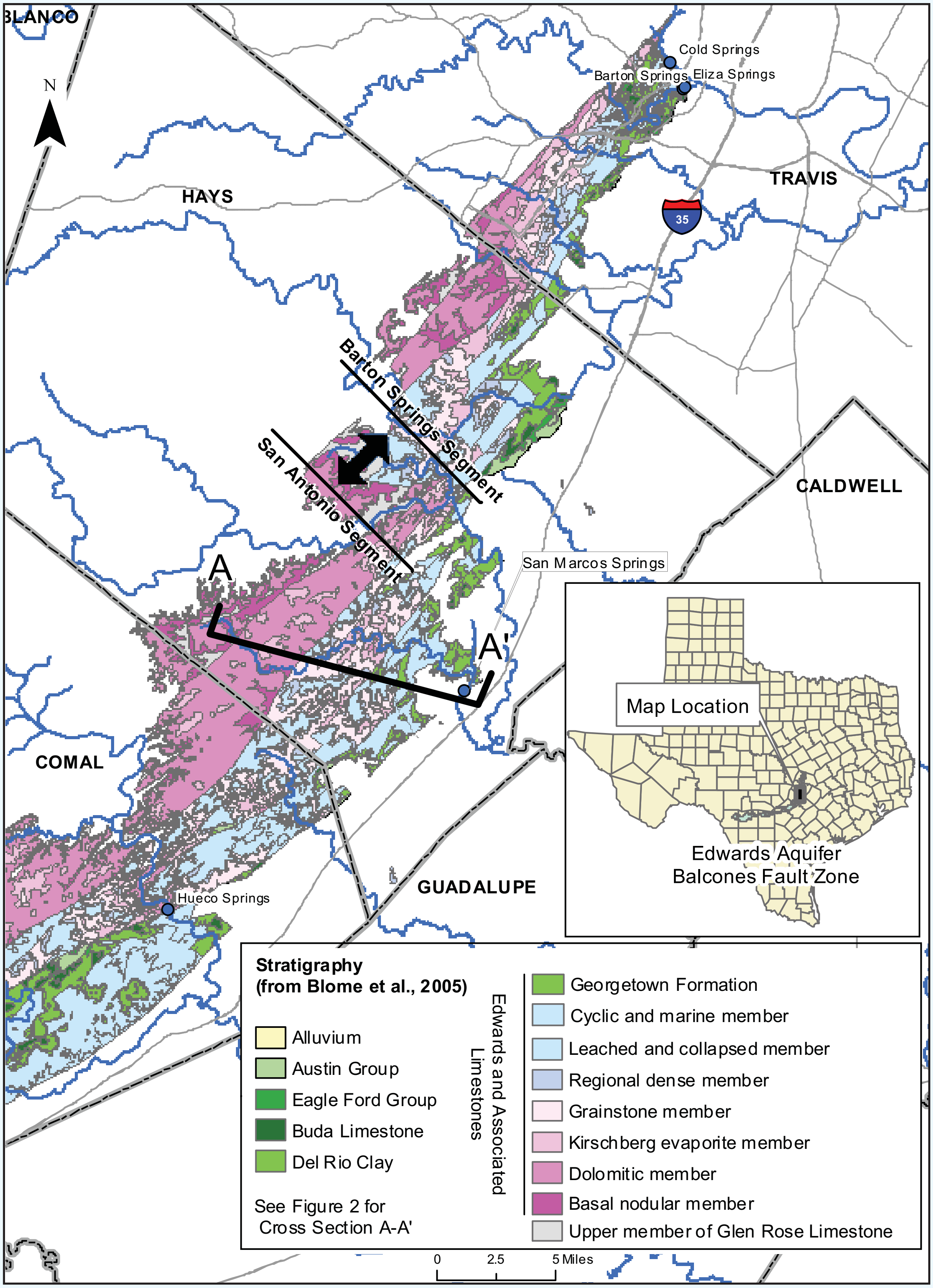


Figure 2. Edwards Aquifer Cross Section near San Marcos Springs

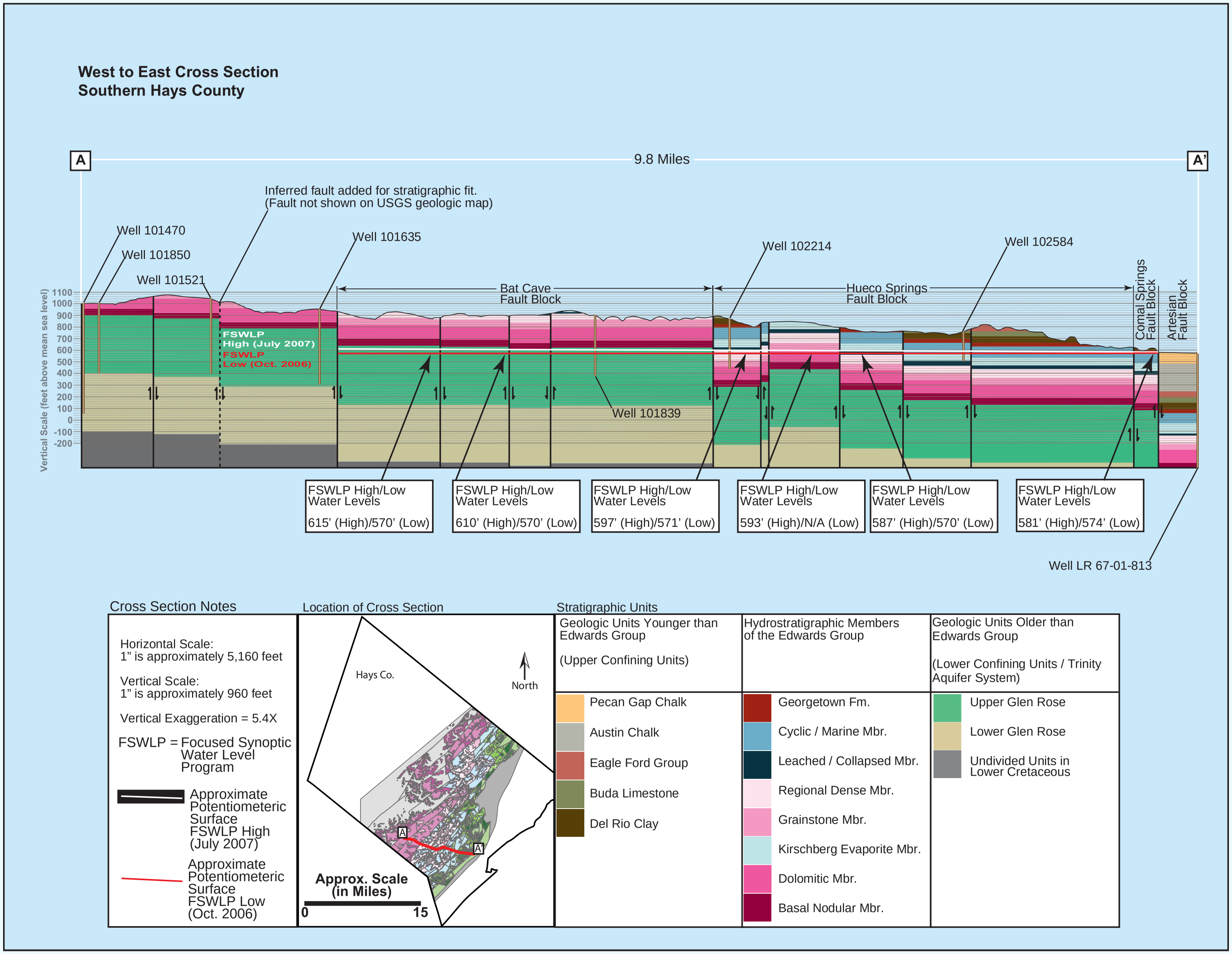


Table 2. Relative Discharges from Individual Springs and Sand Boils at San Marcos Springs

Individual Orifice	Approximate Discharge (cfs; m³/s)	Sand Boil Area	Approximate Discharge (cfs; m³/s)
Crater	5.1 (0.14)	Cabomba	1.0 (0.028)
Deep	11 (0.31)	Catfish	11 (0.31)
Diversion	6.0 (0.17)	Cream of Wheat	22 (0.62)
Hotel	0.59 (0.017)	Deep	12 (0.34)
Weissmuller	15 (0.42)	Diversion	4.0 (0.11)
		Kettleman's	42 (1.2)
		Ossified Forest	14 (0.40)
		River Bed	38 (1.1)
		Salt & Pepper 1	2.0 (0.057)
		Salt & Pepper 2	5.0 (0.14)
Totals	38 (1.1)		151 (4.3)

Source: LBG-Guyton Associates (2004).

Eagle Ford Group, and Austin Group, which overlie the Edwards Group, also crop out within the Comal Springs fault block. The fault has displaced the Edwards Group approximately 490 ft (150 m) (George et al., 1952) in the San Marcos Springs area. The Edwards Aquifer also yields an adequate amount of water to wells from the Comal Springs fault block.

Within the Artesian fault block, the Edwards Aquifer is completely saturated and buried beneath the Del Rio Clay and younger formations. At well 6701813, located adjacent to the east side of Spring Lake, the top of the Edwards Aquifer is approximately 400 ft (122 m) below ground. It contains saline water in which total dissolved solids (TDS) exceed 1,000 mg /L. According to a City of San Marcos well immediately west of Spring Lake, the potentiometric head on the Artesian fault block ranges from 580 to 590 ft (177 to 180 m) msl, which is slightly above the Spring Lake elevation of 573 ft (175 m) msl.

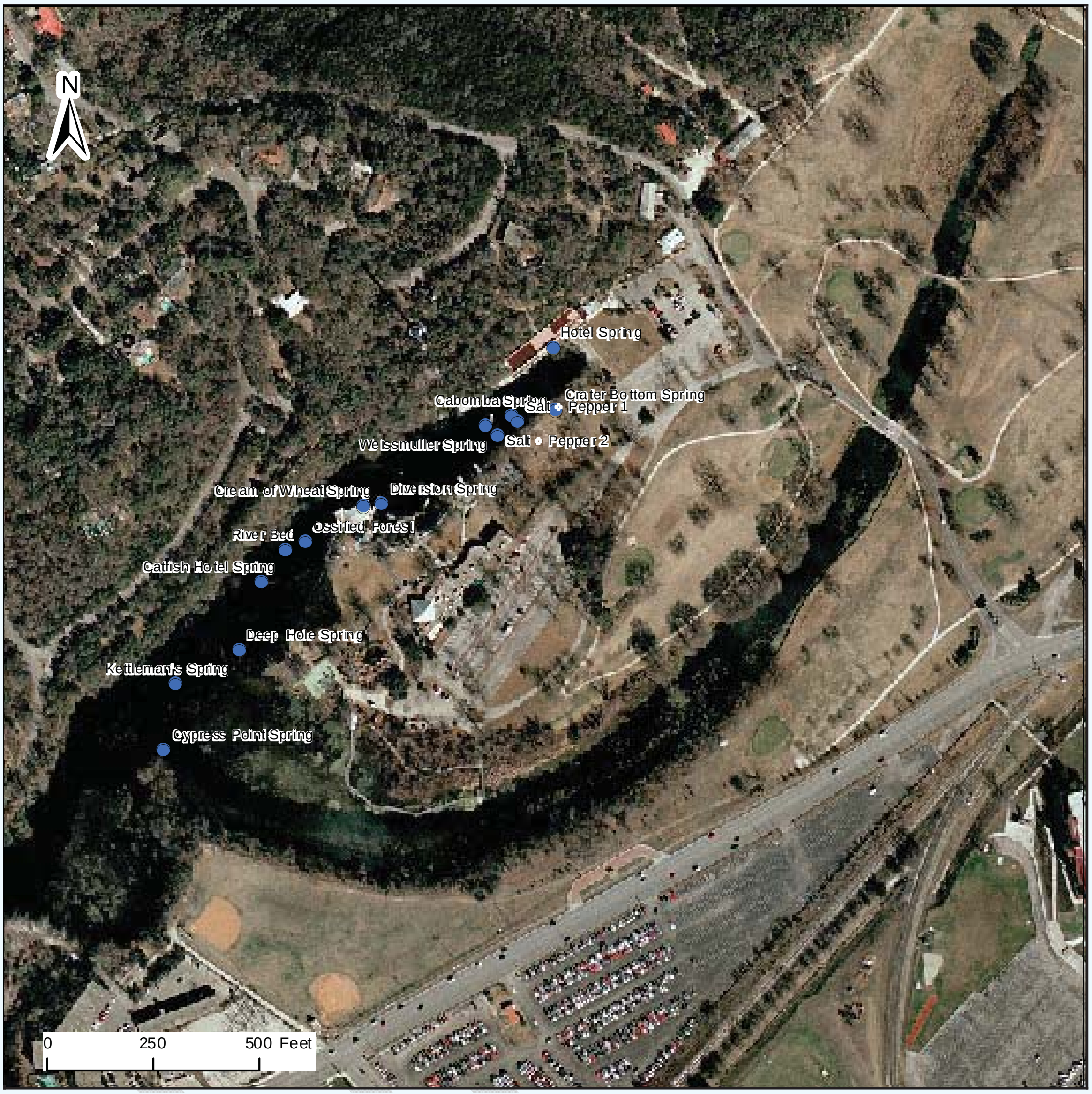
Hydrogeology

The San Marcos Springs Complex has the second-largest average discharge of all Texas springs; only Comal Springs discharge is larger. Long-term average discharge is 173 cfs (4.9 m^3/s), ranging from 43 cfs (1.3 m^3/s) to 630 cfs (18 m^3/s). Most individual springs are submerged beneath Spring Lake, which was created by a dam constructed in the 1800s to provide water power for a nearby mill system. Individual springs discharge water through sediments (sand boils) or orifices in bedrock on the lake bottom. Discharging water is clear and colorless, with a TDS of 300 to 400 mg/L, although some orifices produce turbid water after precipitation events. Spring Lake forms the headwaters of the San Marcos River. San Marcos Springs discharge has been measured by the U.S. Geological Survey (USGS) since 1956 at the Aquarena Springs Drive Bridge near Sessom Drive on the Texas State University (TSU) campus.

Groundwater discharges into Spring Lake primarily from sand boils throughout the bottom of the lake, with smaller amounts from discrete orifices (LBG-Guyton Associates, 2004). Sand boils, which are also referred to as *springs* in this report, are areas of lake bottom that consist of sand-sized limestone and possible silica particles that are fluidized to some degree by upwelling groundwater. Discharge measurements by LBG-Guyton Associates (2004) showed that only 38 cfs (1.1 m^3/s) flowed from discrete spring orifices, as compared with a total discharge of 180 cfs (5.1 m^3/s) (Table 2). The most prolific sand boils are Kettleman's, River Bed, and Cream of Wheat. Figure 3 shows locations of discrete spring orifices and sand boils in Spring Lake. Water samples were collected from many of these locations during the tracer tests described in this report.

The Barton Springs complex, the fourth-largest in Texas, has four main spring outlets: Upper Barton Springs, Eliza Springs, Old Mill Springs (also known as Sunken

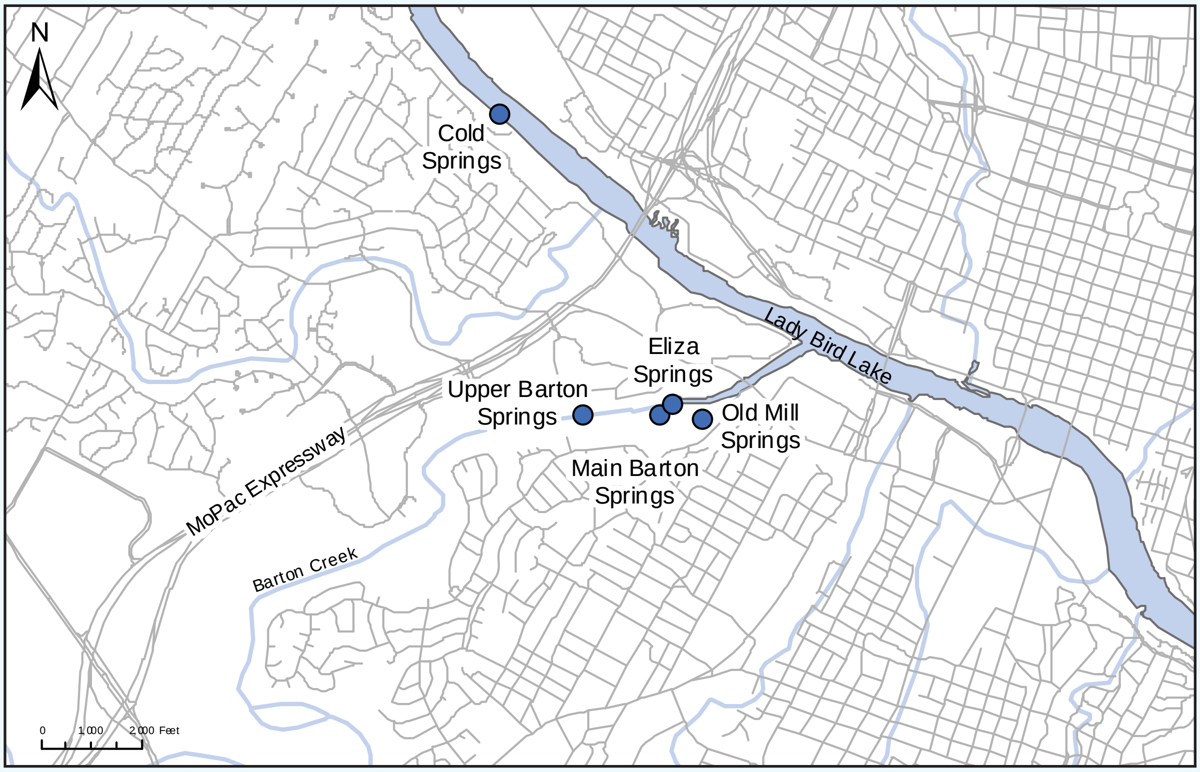
Figure 3. Locations of Spring Orifices and Sand Boils in Spring Lake



Garden), and Main Barton Springs (originally named Parthenia) (Figure 4). Main Barton Springs is retained by a dam, forming the 980-ft (300-m)-long Barton Springs Pool, a major recreational pool at Zilker Park in central Austin. Main Barton Springs discharges from a series of orifices in the pool bottom along the trend of the Barton Springs Fault. The volume of water discharged by Main Barton Springs is by far the greatest of the four springs in the complex. Upper Barton Springs discharges directly into Barton Creek upstream of Main Spring and pool and ceases to flow during dry conditions. Eliza Springs is located along the Barton Springs Fault and discharges into a culvert and pool bypass. Old Mill Springs is located downstream of the pool and discharges directly into Barton Creek/Lady Bird Lake.

Average discharge for the Barton Springs Complex (not including Upper Barton Springs) is about 53 cfs (1.5 m^3/s), ranging from 10 cfs (0.3 m^3/s) to 166 cfs (4.7 m^3/s). The segment of Barton Creek upstream of Barton Springs Pool flows only after rain or during high groundwater levels. It does not flow into Barton Springs Pool but instead is routed around the pool through a bypass. In times of flood, however, creek flow overtops the dam,

Figure 4. Locations of Spring Orifices at Barton Springs



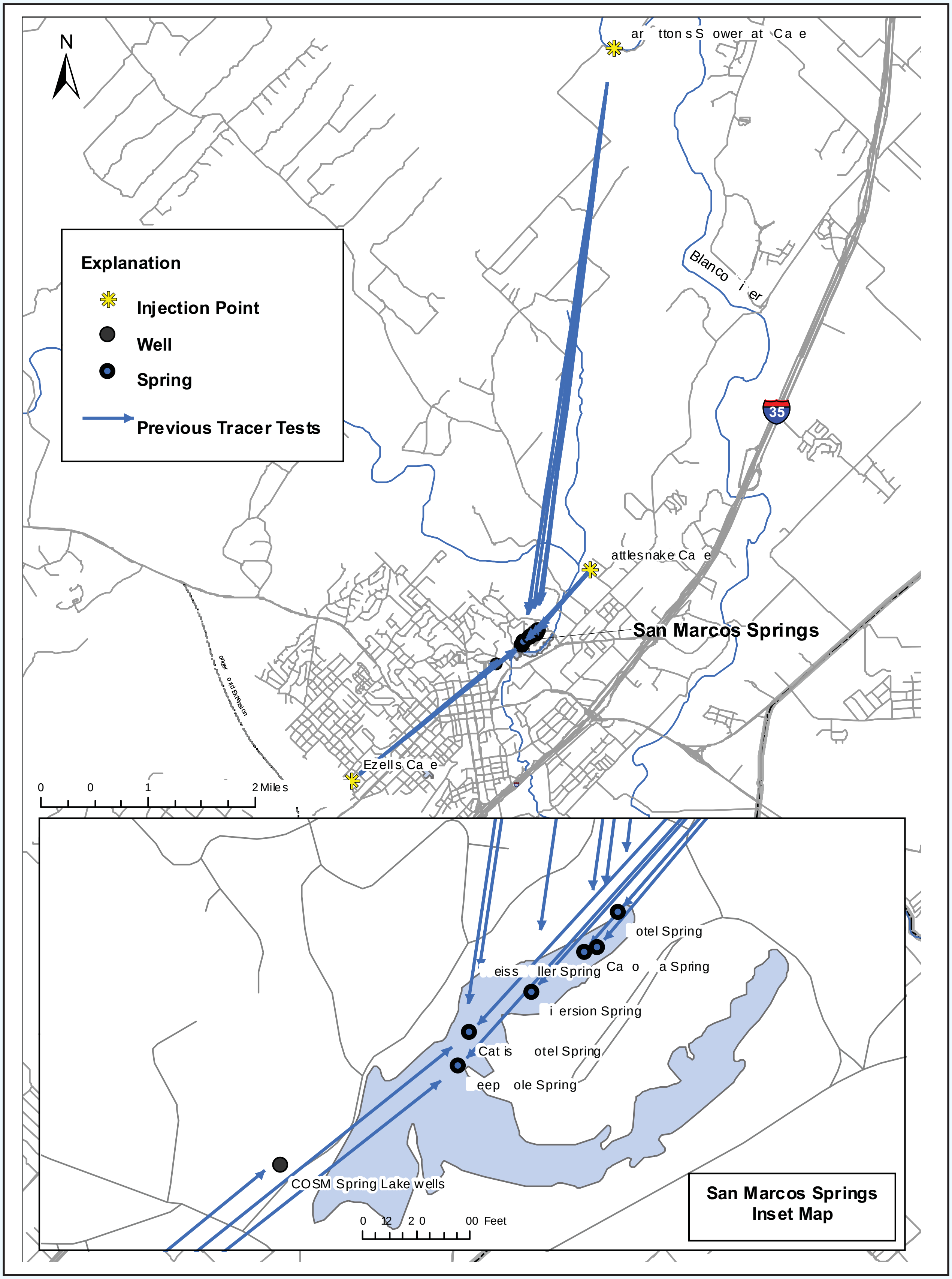
separating it from the pool and Main Barton Springs, delivering water and sediment from the creek into the pool. Most of the recharge to the aquifer feeding the Barton Springs system was thought to infiltrate through fractures and fissures in the beds of five creeks as they crossed the recharge zone (Slade and others, 1986). Recent studies also indicate a significant portion of water coming from uplands in the recharge zone (Hauwert, 2009). Recharge from these creeks can take as little as several hours to many days to arrive at the springs (Hauwert, 2009). Water discharging from the four spring outlets is generally clear and colorless with TDS of 300 to 400 mg/L and suspended sediment concentrations of a few milligrams per liter or less. After a rain of one inch or more, however, spring discharge often becomes turbid, and suspended sediment concentrations can exceed 100 mg/L.

Cold Springs discharges approximately four cfs (0.1 m^3/s) or less (Hauwert and Vickers, 1994) directly into the Colorado River at a point 1.5 mi (2.4 km) upstream of the confluence with Barton Creek along the south bank of Lady Bird Lake. Flow is from a relatively small groundwater basin that apparently is not connected to the larger part of the aquifer or Barton Springs under normal hydrologic conditions (Hauwert et al., 2004).

Previous Studies

Tracer tests were conducted in the San Marcos Springs area by Ogden et al. (1986) and Hauwert et al. (2004). Ogden et al. (1986) completed tracer tests from Ezell's Cave, Rattlesnake Cave, and Tarbutton's Showerbath Cave to San Marcos Springs (Figure 5). The Ezell's Cave tracer test involved a pound of Fluorescein (Uranine) injected into the pool in the bottom of the cave. Ogden et al. (1986) measured groundwater velocity between Ezell's Cave and Deep Hole and Catfish Hotel springs, which are part of the San Marcos Springs complex, at approximately 1,000 ft/d (300 m/d). No dye was detected at the four other spring orifices that were monitored: Diversion, Weissmuller, Hotel, and Cabomba. Dye was also detected at the Artesian Well next to the

Figure 5. Previous Tracer Tests at San Marcos Springs



Edwards Aquifer Research and Data Center at TSU and at a City of San Marcos (COSM) municipal well next to Spring Lake.

From Rattlesnake Cave, approximately one mi (1.2 km) northeast of San Marcos Springs, the tracer traveled to all six of the monitored orifices in less than 40 days, which is slower than what was measured in the Ezell's Cave tracer test. Ogden et al. (1986) attributed the slower velocity to drought conditions that caused the water table to be relatively flat near the springs and reduced San Marcos Springs discharge to approximately 70 cfs (2.0 m^3/s). Dye was also detected in Sink Spring and Rattlesnake Well, approximately 500 ft (150 m) from the cave. Tarbutton's Showerbath Cave is approximately seven mi (11 km) northeast of San Marcos Springs on the Blanco River. Dye injected in the cave reportedly appeared in all six orifices 359 days later and persisted for one and one-half months.

Hauwert et al. (2004) described a second tracer test involving Tarbutton's Showerbath Cave in August 2000. Approximately 13 lb (six kg) of fluorescent dye was injected into the cave, and various individual springs were monitored at San Marcos Springs. No dye was detected before monitoring ended in August 2003. San Marcos Springs discharge was higher during this tracer test, ranging from approximately 110 to 320 cfs (3.1 to 9.1 m^3/s), compared with approximately 70 cfs (2.0 m^3/s) during the Ogden et al. (1986) tests. Other tracer tests completed in Onion Creek resulted in positive recoveries of dye in San Marcos and Barton springs and are reported in Hunt et al. (2006). San Marcos Springs discharge was 277 cfs (7.6 m^3/s), which is well above average, during their tracer tests.

Methodology

Groundwater tracing techniques (tracer tests) are recognized as the only direct method of determining apparent or point-to-point groundwater travel times and flow directions in karst aquifers. The tracer tests described in this report involve introducing nontoxic, fluorescent, organic dyes into the subsurface via injection points, such as caves, sinkholes, and wells. Charcoal receptors and water samples are collected from wells and springs and analyzed for the presence of dyes. Alexander and Quinlan (1996) discussed the methodology of groundwater tracing using fluorescent dyes in karst terrains.

Between 2002 and 2009, 27 tracer tests were completed in the vicinity of San Marcos Springs. Most of the tests were conducted by the EAA and its contractors (George Veni and Associates and Zara Environmental LLC). In 2008, the EAA collaborated with the BSEACD and the COA to investigate potential flowpaths originating from the Blanco River north of San Marcos Springs. This section describes methodologies for injections, sample collection, and sample analysis for all tracer tests.

Groundwater Tracers (Dyes)

Dyes used in this study were selected because they are nontoxic, inexpensive, widely tested and used, and easily detected. All dyes used in these tests are fluorescent and are also used as colorants for medicine, foods, cosmetics, and industrial applications. These dyes have been evaluated to be suitable for this and other studies because of their physical characteristics, safety for drinking water supplies and aquatic habitats, and low background concentrations (Smart, 1984; Field et al., 1995). Table 3 lists the names, molecular weights, and emission wavelengths of the dyes used in this series of tracer tests. Uranine, Eosin, and Sulforhodamine B (SRB) are liquid dyes, and Phloxine B is a powder that was mixed with water before injection.

One objective of tracer testing is to use a quantity of dye sufficient for detection at monitoring points but not enough to produce visible color at well and spring monitoring sites. Consequently, the target peak recovery concentration was set below visible concentrations at 0.05 g/m^3 (50 µg/L or parts per billion). Volumes were

Table 3. Chemical Characteristics of Dyes

Common Name	Color Index Generic Name	Molecular Weight	CAS Number	D&C No.	Peak Emission Wavelength (nm)
Uranine (sodium Fluorescein)	Acid Yellow 73	376.27	518-47-8	Yellow No. 8	493
Eosin (Eosin)	Acid Red 87	691.85	17372-87-1	Red No. 22	512
Phloxine B	Acid Red 92	829.63	18472-87-2	Red No. 28	541
Sulforhodamine B (SRB)	Acid Red 52	580.65	3520-42-1	None	566

calculated using an equation developed by Worthington and Smart (2003) on the basis of empirical data from 185 tracer tests between sinkholes and springs over distances between 50 ft (15 m) and 20 mi (31 km) and with tracer recovery times varying from two minutes to two months. The following formula from Worthington and Smart (2003) was used:

$$m = 19\,(LQc)^{0.95},$$

where

m = mass of dye injected in grams,

Q = output discharge in m^3/s,

c = peak recovery dye concentration in g/m^3, and

L = distance in meters between injection and recovery points.

Distance (L) used in the calculation is the distance to the closest monitoring wells or water supply wells. The equation was found to work well for Uranine but was slightly less effective for other, less-fluorescent dyes. Consequently, where Eosin or Phloxine B was used, the target peak dye concentration was generally doubled to 0.10 g/m^3. Generally dye concentrations above 50 µg/L (0.050 g/m^3) are visible.

With one exception, caves and sinkholes were selected for injection points because they are integrated into the regional groundwater flow system. Although the exact pathway is not known, infiltrating water sufficient to form a cave or sinkhole is also presumed to recharge the aquifer. In contrast, dyes placed directly in a stream channel or other nonkarstic surface injection point may travel some unknown distance on the surface or through soil or alluvium before finding a potential route to the water table. Depending on the properties of the dye (resistance to photodegradation and adsorption) and soil, the soil system could retain all or most of the dye and prevent it from reaching the aquifer. Therefore, tracer tests originating in discrete karst features, such as caves, sinkholes, or sinking streams (perennial), are expected to be more successful than other injection points. One well was used as an injection point, although wells are not typically preferred as injection points because they may not be as integrated into the regional groundwater flow system as caves or other dynamic karst features. In addition, measurable concentrations of dye can remain in the well for many months. As described later, the well at Watershed Dam #3 on Sink Creek was used in the absence of other, more suitable karst features.

The procedure of dye injection consisted of prewetting injection points with at least 264 gal (1,000 L) of water, injecting the dye, and then flushing the dye with additional water to carry it into the aquifer. Prewetting reduces adsorption of the dye on rock and soil as it flows through the epikarst and vadose zone. Dyes were injected into the deepest accessible locations to minimize travel and storage in the vadose zone. Finally, tens to hundreds of thousands of liters of water was used to flush dyes into the aquifer and push them into active flowpaths. Water used to inject dyes was obtained from private wells, the City of San Marcos, or the Blanco River. Injection water was considered fresh, with a pH near 7.0.

Sample Collection

Samples were collected by a variety of agencies and contractors during the course of this study. Most of the samples described in this report were collected according to EAA protocols and by EAA staff and contractors. However, both EAA and BSEACD/COA protocols were followed for samples collected during tracer tests north of the Blanco River (2008–2009). The methods are generally similar, and details are noted where the BSEACD/COA protocols differ significantly from the EAA protocols described later. BSEACD/COA sampling protocols are detailed in Hauwert et al. (2004). During the course of the Blanco River study (2008–2009), samples were analyzed at the EAA tracer test laboratory, and duplicate water and charcoal samples were collected for analyses at Ozark Underground Laboratory (OUL) in Protem, Missouri.

Water samples (grab sample, autosampler)

Water samples provided information on instantaneous dye concentrations in the water at the time of sampling. They were collected manually (grab) or by automatic water samplers (autosamplers). Autosamplers were deployed at selected private wells, public water supply wells, or springs and were programmed to collect 24 samples at six- or eight-hour intervals. Autosamplers at Barton Springs were programmed to collect samples at higher frequencies (hourly) after an injection or a recharge event, and sample frequencies decreased with time. Water sampling was started before dye injection so that samples could be collected for analysis for possible background fluorescence. At the end of each automatic cycle, each bottle was decanted into a 13-mm glass screw-top vial and marked with an identification number written in nonfluorescent permanent ink. Vials were placed in a rack and labeled with the date, time, and location of the sample set. A grab water sample from the well and duplicate samples were taken for each batch of samples.

The EAA collected grab samples in 13-mm glass screw-top vials and marked them with identification numbers written in nonfluorescent permanent ink. Samples collected by the BSEACD/COA were bagged (Whirl-Pak®), labeled, and stored in a refrigerator before being sent to OUL.

All samples were stored in a light-proof box to avoid photodecomposition of dye. Vials were handled using standard chain-of-custody protocols as outlined in the EAA's QC/QA Manual for Tracer Testing (see Appendix A of this report) or, for the Blanco River traces, as outlined in Hauwert et al. (2004). Residual water was disposed of away from the sampling location so that it would not be accidentally resampled or cause cross contamination. Empty autosampler bottles were rinsed three times with deionized water. The deionized water and rinsate from one of the autosampler bottles were sampled and analyzed with each batch of samples. Samples from all sites north of the Blanco River were collected in duplicate and sent to both OUL and the EAA's laboratory for analyses.

Charcoal receptors

Charcoal receptors (detectors), also known as *bugs*, were used to determine whether dye traveled to sites not monitored by autosamplers. They were also used as backup for all autosampling sites if an autosampler failed or dye arrived at low concentrations over time. Charcoal adsorbs dye from the water that passes through the receptor. It yields a time-integrated sample that, barring interference from other organic compounds, is a product of continuous sorption of dye whenever dye is present in water. Thus, charcoal receptors can effectively have a much lower detection limit when exposed to very low concentrations of dye over time. However, dye concentrations extracted from charcoal packets can be used only qualitatively. Charcoal receptors consist of small nylon-screen-mesh packets about the size of a tea bag containing activated coconut charcoal. Where employed, these packets were placed in wells or in the discharge line of a pump. The EAA used engravable aluminum tags and BSEACD/COA used labeled Whirl-Pak® bags to identify charcoal receptors with a site identification number, site name, date, time, and initials of persons collecting the receptors. The receptors were then submitted for laboratory analysis. At some sites, two dye receptors were set at each site as a duplicate or were replaced on eight-day intervals, staggered four days apart, to give a four-day resolution to the data. During initial placement of the charcoal packets and during each replacement, a grab sample of water was collected for confirmation, as described in the previous section. All well sites north of the Blanco River during the 2008–2009 tracer tests were collected in duplicate and sent to OUL and the EAA's laboratory.

Collecting samples from individual spring orifices in Spring Lake required protocols to prevent dye discharging from one orifice to flow though the lake and cross-contaminate samples from other orifices, producing false positive results. The appearance of tracers at multiple springs from previous studies was expected, but the potential for false positive results had to be minimized. So that the risk of false positives by flow through the lake could be eliminated, discharge from each spring was isolated for sampling. For each spring discharge not already isolated by a preexisting structure, such as Hotel Spring, the charcoal receptor was attached to a six-inch-diameter (15-centimeter) PVC tube inserted into the orifice and held in place by ballast. The purpose of the tubes was not to capture all flow from a given orifice, but to immerse the charcoal receptor in water discharging solely from that orifice. Charcoal detectors and hoses for automatic water samplers were attached at the bottoms of the tubes, close to the orifices. During installation, nonfluorescent food coloring was released into the lake no more than 1.6 ft (0.5 m) upstream from each tube so that whether any lake water entered them could be visually determined. The name of the sampled spring was written on each tube to verify each location. Divers periodically collected the charcoal receptors and replaced them with minimal-exposure to ambient lake water. Divers also filled a 13-mm glass vial in the discharge from the orifice with each charcoal receptor exchange.

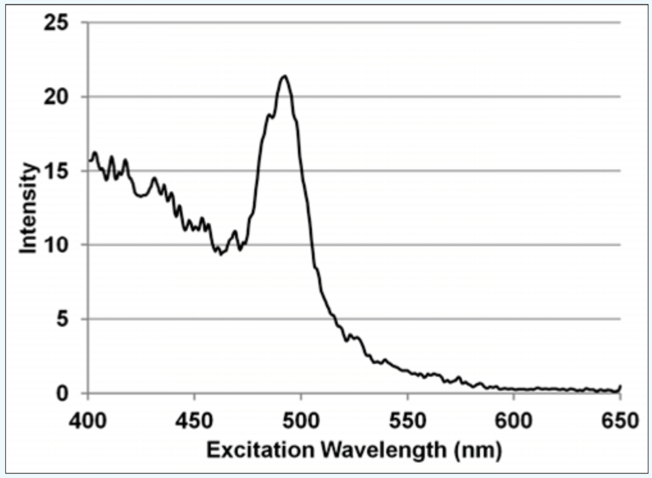
Preparation and Analyses of Samples

Two methods were followed for analyzing the water and charcoal samples: the EAA used its Perkin Elmer LS-50B Luminescence Spectrometer, whereas the BSEACD and COA sent duplicate sets of samples (2008–2009) to the EAA's laboratory and OUL. EAA methods are described next, and OUL methods are described in Aley (2008).

EAA Analyses

Although vials from autosamplers and grab samples required no preparation before analysis, dye must be removed from charcoal receptors prior to analysis. Dye was extracted from the charcoal receptors by eluting the charcoal (desorbing the dye) for one hour in a solution containing 95% of a 70% solution of 2-propanol in water and 5% sodium hydroxide. The eluent was then decanted into a labeled glass vial and stored in darkness until analyzed.

Figure 6. Typical Spectrograph of Uranine Dye from the LS-50B



Uranine, Phloxine B, Eosin, and SRB in vials and eluents from charcoal were analyzed in the laboratory using a Perkin Elmer LS-50B Luminescence Spectrometer. Samples were analyzed using a synchronous scan and right-angle sampling geometry. The scan spanned 401 to 650 nm at 0.5-nm intervals, with a difference between excitation and emission wavelengths (delta lambda) of 15 nm and emission and excitation slits set at 6 nm. Figure 6 shows a typical spectrograph with an Uranine peak of 492 nm. Note that the LS-50B reports the excitation wavelength for the sample, whereas some instruments report emission wavelength. Results of the analysis are recorded in intensity units and converted to concentrations by comparison with known standards.

OUL Analyses

OUL elutes charcoal in a mixture of 5% aqua ammonia and 95% isopropyl alcohol solution and sufficient potassium hydroxide flakes to saturate the solution. The isopropyl alcohol solution is 70% alcohol and 30% water. The aqua ammonia solution is 29% ammonia. Potassium hydroxide is added until a super-saturated layer is visible in the bottom of the container. The solution is used to elute Uranine, Eosin, Rhodamine WT, Sulforhodamine B, and Pyranine dyes. Fifteen mL of the eluting solution is poured over washed charcoal in a disposable sample beaker, which is capped and allowed to stand for

Table 4. Excitation and Emission-Slit-Width Settings Routinely Used for OUL Dye Analyses

Parameter	RF5000U	RF5301
Excitation slit for Eosin, Uranine, Rhodamine WT, and Sulforhodamine B in eluent	5 nm	3 nm
Emission slit for Eosin, Uranine, Rhodamine WT, and Sulforhodamine B in eluent	3 nm	1.5 nm
Excitation slit for Eosin, Uranine, Rhodamine WT, and Sulforhodamine B in water	5 nm	5 nm
Emission slit for Eosin, Uranine, Rhodamine WT, and Sulforhodamine B in water	10 nm	3 nm

60 minutes. Then the liquid is carefully poured off the charcoal into a new disposable beaker, which has been appropriately labeled with the laboratory identification number (Aley, 2008).

OUL analyzes water and eluent samples on one of two Shimadzu spectrofluorophotometers, model RF- 5000U or RF-5301. The RF-5301 is the primary instrument used; the RF-5000U is used primarily as a back-up instrument except in tracing studies, which were begun using this instrument. Approximately three mL of the eluent is withdrawn from the sample container using a disposable polyethylene pipette, placed in a transparent, disposable, rectangular polystyrene cuvette designed for fluorometric analysis and then inserted into the RF-5000U or the RF-5301. For Uranine, Eosin, Rhodamine WT, or Sulforhodamine B analyses, the instruments are set up for synchronous scanning of excitation spectra from 443 to 613 nm and emission spectra from 460 to 630 nm, with a 17-nm separation between excitation and emission wavelengths. The typical scan speed setting is "very fast" on the RF-5000U; it is "fast" on the RF-5301. The typical sensitivity setting used on both instruments is "high" (Aley, 2008). Excitation and emission-slit-width settings vary between the two instruments. Widths vary with the dyes that are being analyzed and for the matrix in which the dyes may be present. Excitation and emission-slit-width settings for OUL dye analyses are summarized in Table 4.

Quality Control

Approximately one in ten samples analyzed was a quality control sample, including dye standards, duplicate and replicate samples, distilled water blanks, and rinsate samples. Dye standards were analyzed at the beginning and end of each analytical session, and a partial set was analyzed after every 20 samples. Duplicate and rinsate samples were included into the routine sampling and analysis program.

Figure 7. Example of Regression Curves for Dye Standards

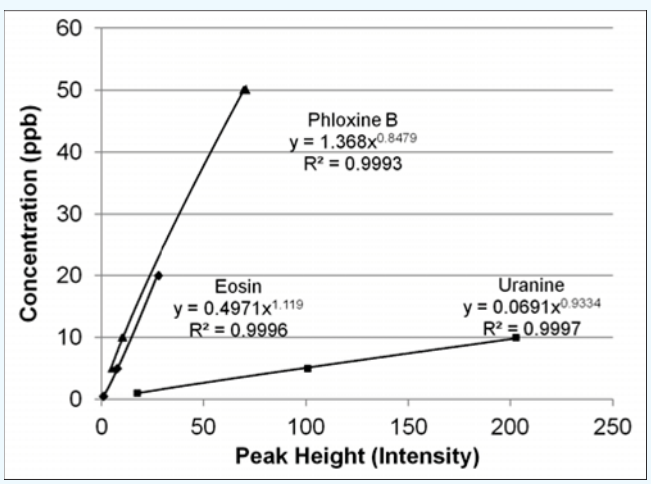


Table 5. Limits of Detection and Quantitation for the Dyes for the EAA Laboratory

Dye	Sample	Fit Standard Error	Limit of Detection (µg/L)	Limit of Quantitation (µg/L)
Uranine	Artesian well 8/28/2005 3:40 AM	0.22	0.047	0.064
Eosin	Artesian well 1/15/2004 4:44 AM	0.16	0.22	0.84
Phloxine B	AY-68-28-608 1/20/2005 2:46 AM	0.27	1.14	3.18
SRB	NA	NA	NA	NA

Table 6. Limits of Detection for OUL

Dye	Detection Limit (µg/L) in eluent	Detection Limit (µg/L) in water
Uranine (Fluorescein)	0.010	0.0005
Eosin	0.035	0.005
Sulforhodamine B	0.15	0.08

Dye Standards, Duplicate and Replicate Samples, and Rinsate Samples for the EAA Laboratory

Three standards were prepared for each of the three dyes used in the tracer tests. Dye solutions were prepared on the basis of mass and diluted with deionized water to produce dye concentrations in the range that were expected in the water samples. Figure 7 shows an example of a power regression of dye concentration versus peak height for each dye. Beginning in 2009, dye standards were prepared by the San Antonio River Authority laboratory from EAA dye stocks.

Duplicate Samples

Duplicate samples were analyzed to measure precision of the Perkin-Elmer LS-50B Luminescence Spectrometer. The duplicate samples were prepared by filling two vials from the same autosampler container. Precision is calculated using relative percent difference (RPD), which is the absolute difference between the two intensities of the samples divided by the mean of the two intensities ×100. An RPD of zero indicates that the two concentrations are equal. Of 47 duplicate water samples, 62 percent had an RPD less than 20.

Detection Limits

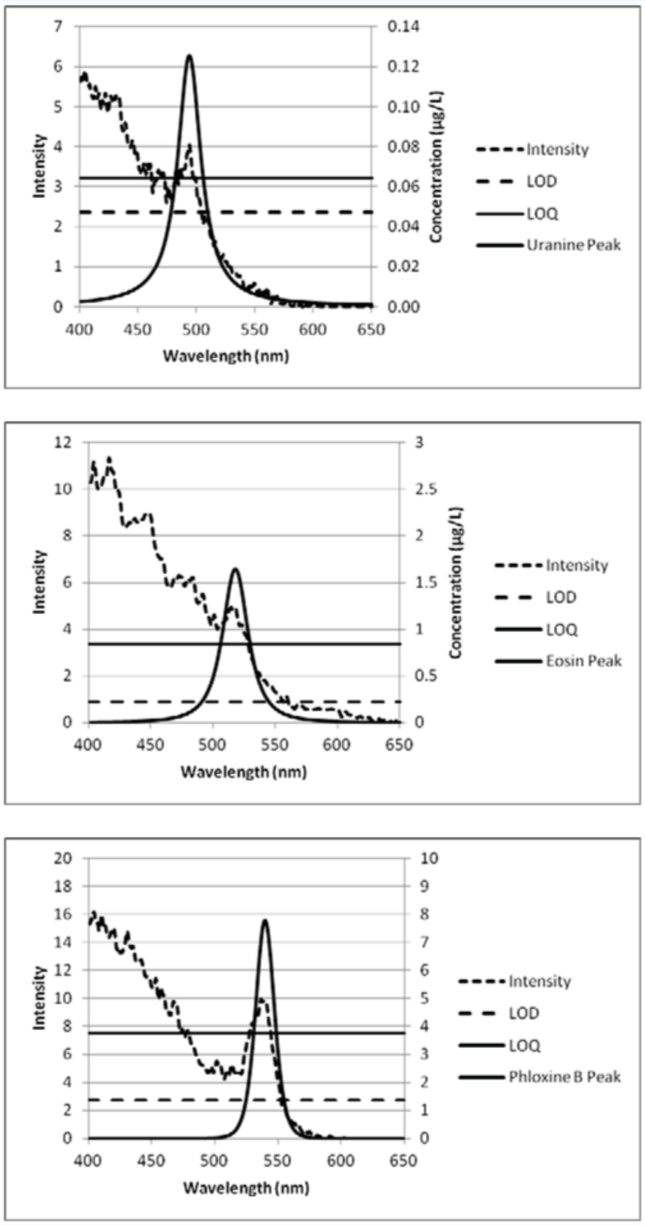
Positive Dye-Recovery Interpretation

The LS-50B measures fluorescence in intensity units, which is directly proportional to the concentration of dye. However, the maximum intensity of each sample is the sum of any dye present + background fluorescence. Dye peaks were separated from background fluorescence by fitting the curves to the Pearson VII statistical function using Systat PeakFit® or fityk software. The difference between sample and background fluorescence is the net intensity. Net intensity measurements were converted to a concentration, with the calibration curve determined from analyses of standards, as described in the previous sections.

EAA Laboratory

Detection and quantitation limits for each dye were calculated from background fluorescence of naturally occurring fluorophores and instrument noise, following the method of Alexander (2005). The method defines limits of detection (LOD) and quantitation (LOQ) as three and 10 times the fit standard error of background fluorescence, respectively. Water samples were selected that contained dyes at concentrations just above background fluorescence to calculate LOD and LOQ, and fit standard error was calculated using PeakFit® or fityk

Figure 8. Calculation of LOD and LOQ for Uranine, Eosin, and Phloxine B



software. Figure 8 shows original intensities, separated dye peaks, and calculated LODs and LOQs for each dye. Using regression equations in Figure 7 yields the limits of detection and quantitation for each dye in Table 5. Because SRB was detected only in charcoal eluent and not water samples, limits of detection and quantitation were not determined.

OUL

OUL detection limits were determined by using spiked samples with each dye in water and eluent. Spike concentrations are automatically and accurately calculated daily from standard dye solutions. With successive dilutions, the quantity of spike in each iteration was decreased, until the signal:noise ratio of the dye intensity on the spectrograph was three times higher than background. The concentration of dye at this signal:noise ratio was then used as the detection limit.

Quantitation limits were based on the levels of background noise in water and eluent samples from the field. Positive dye detections were defined as samples in which the height of the fluorescence peak near the wavelength range of the dye was at least three times the height of background noise on the spectrograph.

Table 6 lists the detection limits for OUL in this study.

Breakthrough Curves

Breakthrough curves are graphs displaying dye concentrations over time that were prepared for both spring and well sites. Calculations of initial travel time, duration, and peak concentrations were based on breakthrough curves. The time of first arrival from breakthrough curves is used to calculate apparent velocity of the dye. The rate of dye movement is "apparent velocity" because the true length of the flowpath is unknown; therefore, it is calculated from the straight-line or point-to-point distance between the injection point and the monitoring point. Duration of travel is measured from time of injection until first arrival of the dye at the monitoring site, which corresponds to the date and time of a water sample or the placement date of a charcoal receptor. For charcoal receptors, this calculated apparent velocity represents the highest possible velocity. If dye arrived after the placement date, apparent velocity would be slower. Actual velocity is probably faster than apparent velocity because the actual distance is certainly a longer, irregular route through saturated and unsaturated parts of the aquifer.

Breakthrough curves for some of the traces (e.g., Blanco River trace in 2008–2009) were also constructed using charcoal receptors, sometimes with concentrations normalized to the number of days deployed. Although concentrations cannot be quantified directly, they do provide a relative and qualitative assessment of the dye breakthrough at both spring and well sites and complement water results.

Tracer Tests

Testing Phases

For this study, 31 tracer tests (dye injections) were completed between 2002 and 2010 at various locations in the vicinity of San Marcos Springs using one or more injection points and tracers. For the purposes of this report, they are organized by locations of the injections relative to San Marcos Springs: southwest, west, Blanco River vicinity, north, and northeast. Table 7 lists the location, date, dye, and quantity of dye for each injection.

Most of the tracer tests were completed during periods of declining spring discharge at both San Marcos Springs and Barton Springs (Figure 9). Tests in 2008 were largely completed just before extensive rainfall occurred throughout the San Marcos and Barton springsheds.

Southwest of San Marcos Springs Traces: Ezell's Cave and Primer's Fissure (2002, 2004, 2005)

Southwestern traces consist of injection points southwest (hydraulically upgradient) of San Marcos Springs, generally parallel to the regional strike of the Balcones Fault Zone (Alexander, 1990).

Purpose

The purpose of the southwestern tracer tests was to measure groundwater velocities along the southwestern groundwater flowpaths to various spring orifices. Two injection points were used, Primer's Well and Ezell's Cave, and monitoring sites consisted of several orifices at San Marcos Springs and wells between injection points and San Marcos Springs.

Figure 9. Tracer-Test Durations Compared with Discharge at San Marcos and Barton Springs

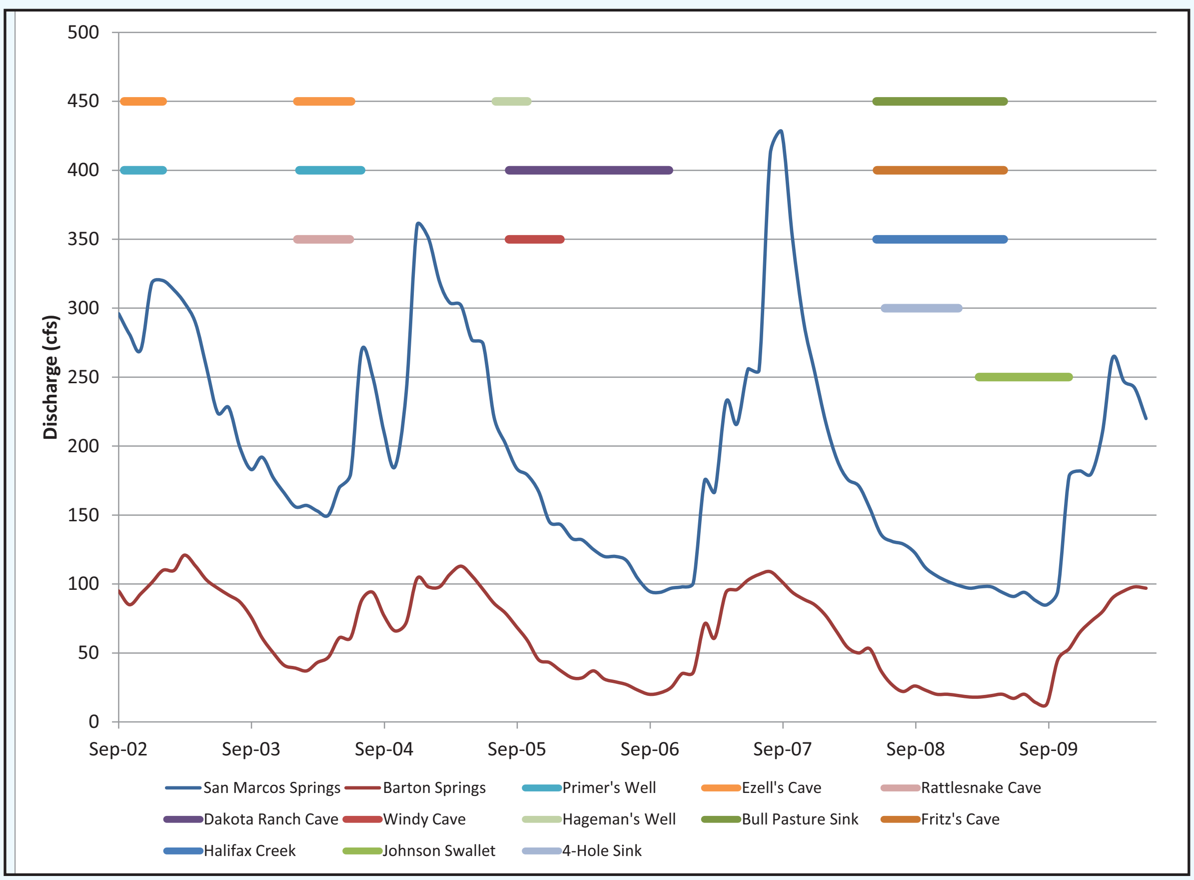
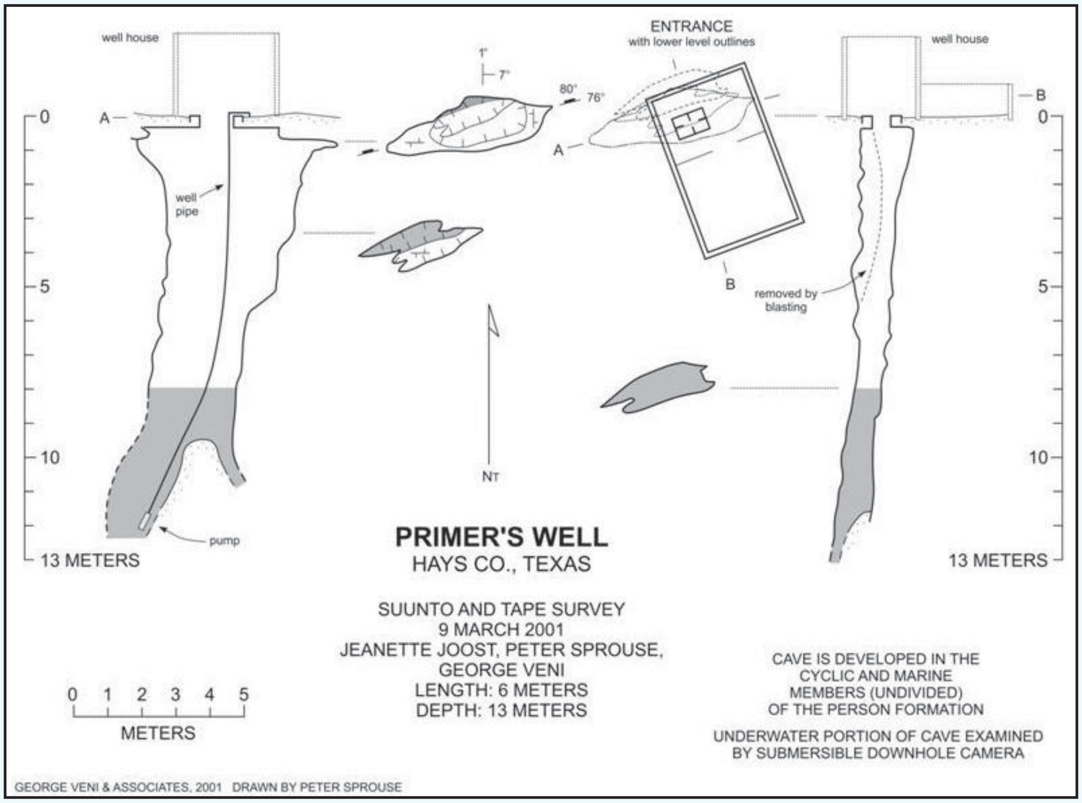


Table 7. Injection Points, Dates, and Dyes

Location	Injection Date	Dye	Quantity[1]	Latitude	Longitude
Southwest of San Marcos Springs					
Ezell's Cave	9/16/2002	Uranine	1.5 L (3.3 lb)	29.873738	-97.959090
Ezell's Cave	1/6/2004	Eosin	1,000 g (2.2 lb)	29.873738	-97.959090
Ezell's Cave	7/2/2004	Uranine	1,000 g (2.2 lb)	29.873738	-97.959090
Ezell's Cave	7/5/2005	Uranine	2,500 g (5.5 lb)	29.873738	-97.959090
Primer's Well	9/16/2002	Eosin	50 g (0.16 lb)	29.867746	-97.966037
Primer's Well	1/12/2004	Uranine	150 g (0.33 lb)	29.867746	-97.966037
West of San Marcos Springs					
Dakota Ranch Cave	8/12/2005	Phloxine B	300 g (0.66 lb)	29.898017	-97.967965
Dakota Ranch Cave	8/19/2005	Phloxine B	3,307 g (7.3 lb)	29.898017	-97.967965
Dakota Ranch Cave	9/7/2005	Phloxine B	4.6 kg (10 lb)	29.898017	-97.967965
Dakota Ranch Cave	10/26/2005	Phloxine B	30,000 g (66 lb)	29.898017	-97.967965
Windy Cave	8/11/2005	Eosin	200 g (0.44 lb)	29.885287	-97.968260
Windy Cave	8/20/2005	Eosin	2,976 g (6.6 lb)	29.885287	-97.968260
Windy Cave	9/6/2005	Eosin	2,500 g (5.5 lb)	29.885287	-97.968260
Windy Cave	10/25/2005	Eosin	25,400 g (56 lb)	29.885287	-97.968260
Blanco River Vicinity					
Bull Pasture Sink	5/20/2008	Uranine	107 g (0.24 lb)	30.029851	-97.939359
Bull Pasture Sink	6/10/2008	Uranine	13.6 kg (30 lb)	30.029851	-97.939359
Halifax Creek	5/20/2008	Eosin	100 g (0.22 lb)	30.012805	-97.940526
Halifax Creek	5/21/2008	Eosin	104 g (0.23 lb)	30.012805	-97.940526
Halifax Creek	6/10/2008	Eosin	13.6 kg (30 lb)	30.012805	-97.940526
Halifax Creek	9/12/2008	Eosin	6.35 kg (14. lb)	30.012805	-97.940526
Johnson Swallet	2/26/2009	Eosin	22.7 kg (50 lb)	30.010646	-97.941644
North of San Marcos Springs					
Fritz's Cave	5/21/2008	Phloxine B	107 g (0.24 lb)	29.962028	-97.956255
Fritz's Cave	6/11/2008	Phloxine B	1.42 kg (3.1 lb)	29.962028	-97.956255
Fritz's Cave	9/10/2008	Phloxine B	6.8 kg (15.4 lb)	29.962028	-97.956255
Sink Creek at Dam #3	12/2/2009	Uranine	1 kg (2.2 lb)	29.906465	-97.945529
Sink Creek at Dam #3	1/26/2010	Uranine	3.15 kg (6.9 lb)	29.906465	-97.945529
TSU Cooling Tower	12/2/2009	Uranine	3.8 L (8.3 lb)	29.890936	-97.944526
Northeast of San Marcos Springs					
Hageman's Well	7/6/2005	Eosin	61 g (0.13 lb)	29.900496	-97.918747
Rattlesnake Cave	1/6/2004	Phloxine B	70 g (0.15 lb)	29.902148	-97.921554
Rattlesnake Cave	12/3/2009	Phloxine B	620 g (1.4 lb)	29.902148	-97.921554
Fern Bank Spring					
4 Hole Sink (to Fern Bank Spring)	6/12/2008	SRB	255 g (0.56 lb)	29.976614	-98.012095

[1]Weight reported as neat dye (i.e., no solvent).

Figure 10. Map of Primer's Well



Setting

Primer's Well (or Primer's Fissure) was an injection point for tracer tests in 2002 and 2004. It is a naturally occurring joint that early settlers enlarged so that they could withdraw water. Located approximately 13,800 ft (4,200 m) southwest of the San Marcos Springs and 3,100 ft (950 m) southwest of Ezell's Cave, it is within the same fault block as Ezell's Cave. This cave is a pit formed along a fault that strikes 76º and dips 80ºN. It is a known locality of the federally listed endangered species *Eurycea rathbuni*, the Texas blind salamander. Groundwater is approximately 25 ft (8 m) below ground (Figure 10) under water table conditions. The cave is a 30-ft-deep (10-m) pit developed in thick beds of the Cyclic and Marine members (undivided) of the Person Formation. It is a vadose cave formed by recharge to the Edwards Aquifer from Purgatory Creek (G. Veni, 2010, personal communication).

Ezell's Cave (see Figure 11), located approximately 11,500 ft (3,500 m) southwest (upgradient) of San Marcos Springs on the outskirts of the City of San Marcos, is currently secured and owned by the Texas Cave Management Association (TCMA). The EAA injected dyes in Ezell's Cave four times between 2002 and 2005. The cave penetrates the Georgetown Formation approximately 13 ft (four m) to a large room formed as a phreatic chamber probably in the top of the Person Formation. Small passages descend approximately another 13 ft (four m) to a flooded chamber. Water level fluctuations in the cave closely correlate with discharge from San Marcos Springs (Figure 12). Spring discharge and cave water levels declined throughout 2008 and 2009, although the rate of descent slowed as they approached the minimum, which was only several centimeters higher than the elevation of Spring Lake at 573 ft (174.6 m) msl. Consequently, the hydraulic gradient from southwest of the springs appears to influence discharge from the springs. As shown in Figure 9, San Marcos Springs discharge (and the corresponding hydraulic gradient) was relatively high during the injections in 2002 and 2004. Groundwater

Figure 11. Map of Ezell's Cave

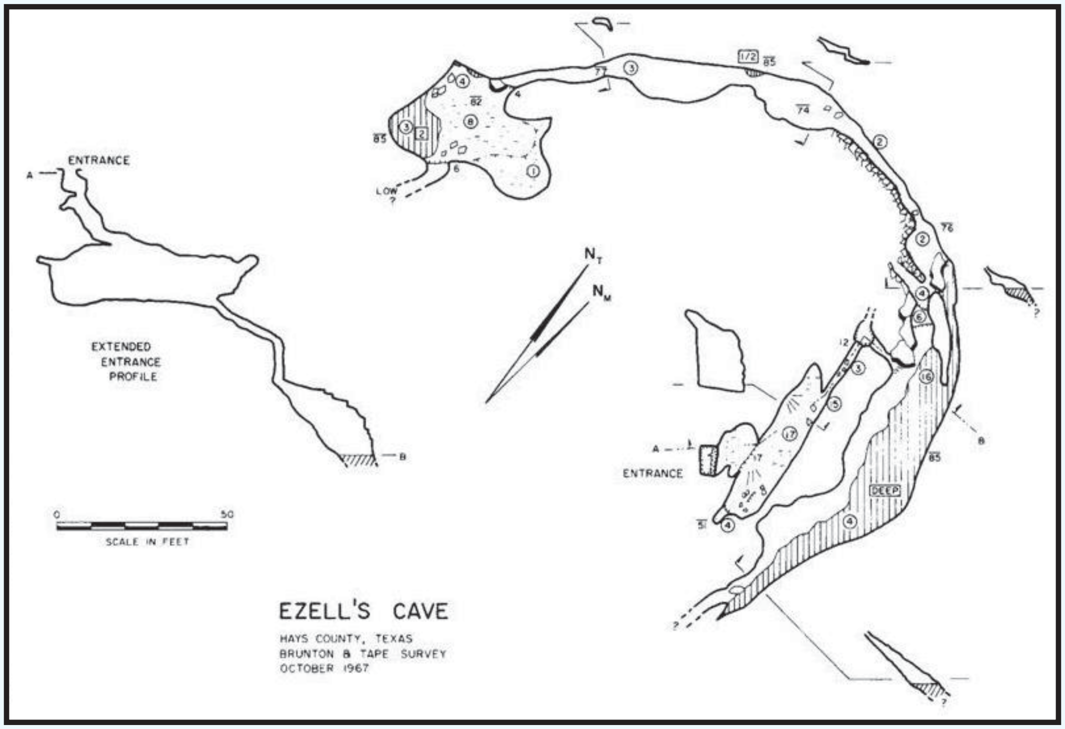
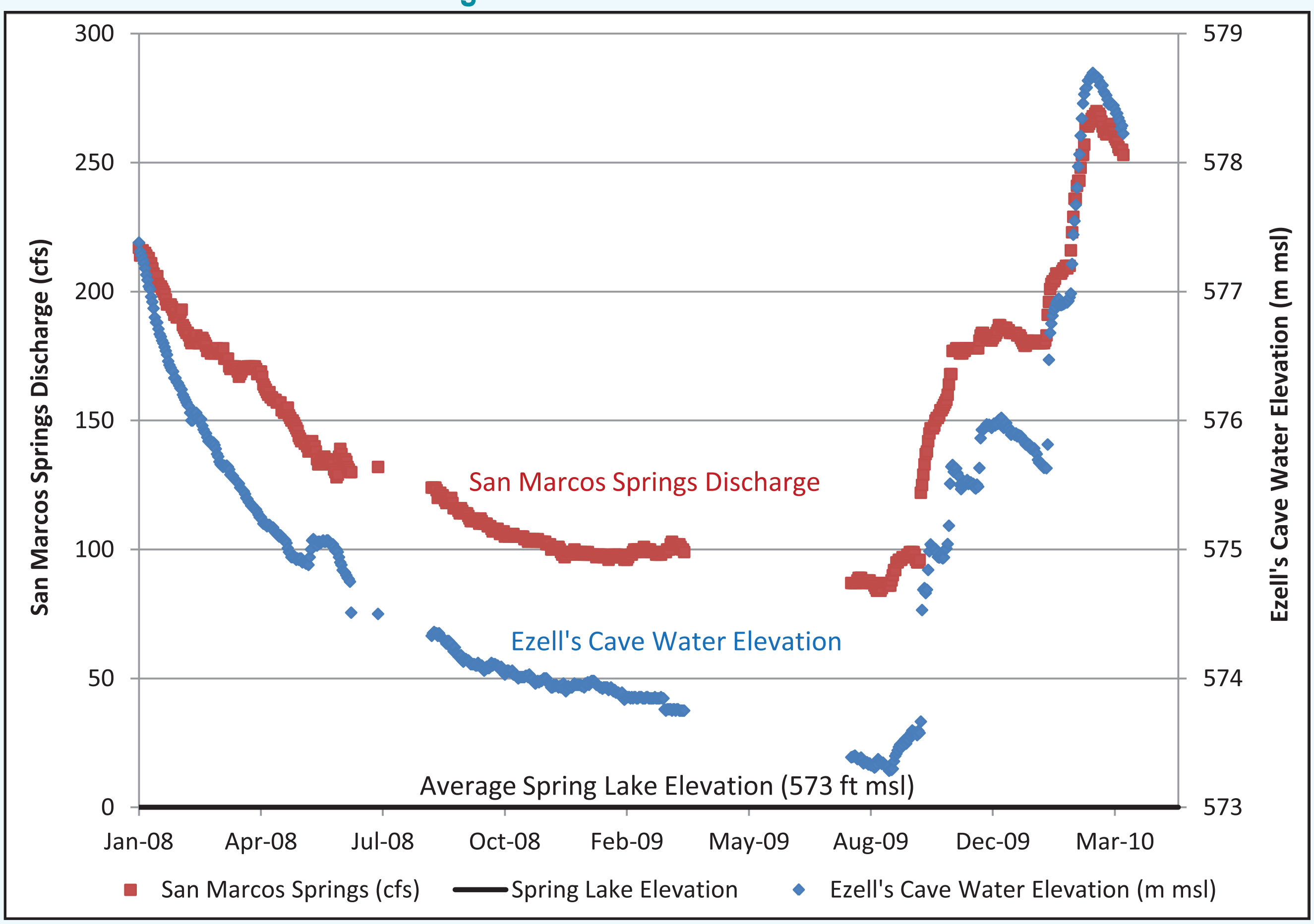


Figure 12. Comparison of San Marcos Springs Discharge with Water Levels in Ezell's Cave



velocities, which are typically proportional to hydraulic gradient, would be expected to be faster during periods of higher discharge.

The hydraulic gradient for southwestern traces is probably controlled by the level of Spring Lake. Water levels in Ezell's Cave and Primer's Well are slightly above Spring Lake's level (Figure 12). This elevation is more than 100 ft (30 m) below the top of the Georgetown Formation, which is the uppermost unit of the Edwards Aquifer. Consequently, the flowpath connecting Primer's Well and Ezell's Cave with San Marcos Springs appears to be in the Edwards Aquifer recharge zone, parallel to the artesian zone boundary.

Injections

In September 2002, the EAA conducted simultaneous injections in Primer's Well and Ezell's Cave. Both the cave and the well allow ready access to the water table. Dye was injected into Primer's Well through a flexible hose inserted below the groundwater surface to avoid staining the rock walls of the well. Flush water was poured directly into the well. Dye was poured directly into the lake in the bottom of Ezell's Cave, coloring the water bright green, and no flush water was necessary (see Figure 13). Although dye eventually becomes invisible through dilution in the cave, cave divers reported residual visible dye in underwater parts of the cave for some time after an injection. Volumes of dye ranged to 5.5 lb (2,500 g) (Table 7).

The EAA repeated these tracer tests in January 2004, with injections at Primer's Well and Ezell's Cave. A larger volume of dye (0.33 lb; 150 g) was injected into Primer's Well in 2004 than in 2002 so that groundwater flowpaths might be traced beyond Ezell's Cave.

Two focused tracer tests were conducted using Ezell's Cave as an injection point during the EAA's annual water conferences for educators in July 2004 and 2005. Monitoring sites consisted of Artesian Well at TSU and selected individual springs at San Marcos Springs.

Figure 13. Dye Injection at Ezell's Cave on July 5, 2005

September 2002 Results

As shown in Figure 14, uranine injected in Ezell's Cave on September 16, 2002, was detected at several monitoring locations: Artesian Well on the TSU campus, COSM Spring Lake Well, TSU Jackson Wells, Wonder World Cave, and two springs that were monitored at Spring Lake: Diversion and Deep Hole springs. The dye was first detected at Wonder World Cave after it had traveled 1,600 ft (480 m) in approximately two days at an apparent velocity of 790 ft/d (240 m/d) (see Table 8). Figure 15 shows the breakthrough curve for Uranine at Wonder World Cave. After three days, it appeared at Artesian Well (Figure 16), moving at an apparent velocity of 3,050 ft/d (930 m/d). It arrived at Deep Hole Spring in four days at 2,700 ft/d (825 m/d) and at the COSM Spring Lake Well 2 after seven days at 1,300 ft/d (400 m/d). The TSU Jackson Wells are not directly downgradient from Ezell's Cave, which might be reflected by the slower apparent velocity of 660 ft/d (200 m/d) and longer travel times. Dye arrived at Diversion Spring sometime before October 4, 2002, because that was the date of the first sample. Uranine was detected at the chute (water released from the Spring Lake Dam) and spillway (unimproved channel near the dam) starting on October 1, 2002, and September 20, 2002, respectively. The closest well to Ezell's Cave, Well 157, intercepted Uranine approximately 25 days after the injection. Monitoring was discontinued on October 28, 2002, although Uranine was still present at most sites.

Table 8 also lists the sites at which no dye was detected. Eosin from Primer's Well was not detected at any of the monitoring points, probably because the volume of dye was minimized to avoid coloring nearby private wells. Ezell's Cave could not be used as a monitoring point because the Uranine would mask the presence of Eosin dye. Sites that did not intercept any Uranine from Ezell's Cave include COSM Comanche Street Well, COSM Spring Lake Well 1, Crater Bottom Spring, Salt and Pepper Spring, Weissmuller Spring, a TSU hand-dug well (163), Wells 155 and 156 near the cave, and saline zone transect wells. Because only a small number of samples were collected from springs other than Deep Hole and Diversion, future tests would investigate those springs in detail.

The tracer tests revealed a highly transmissive groundwater flowpath parallel to the Hueco Springs Fault, which was traced from Primer's Well to Ezell's Cave to Wonder World Cave to the Spring Lake well field and to San Marcos Springs. Apparent groundwater velocities along the flowpath were calculated at approximately 700 to 3,050 ft/d (200 to 930 m/d).

January 2004 Tracer-Test Results

On January 6, 2004, Eosin was injected into Ezell's Cave, and Uranine was injected into Primer's Well on January 12, 2004. Both dyes were detected at monitoring locations northeast (downgradient) of the injection points (Figure 17; Table 9). More monitoring locations were employed for this test than for the 2002 test. Test results generally corroborated 2002 tracer tests described previously.

Eosin Results. After Eosin was injected at Ezell's Cave on January 6, 2004, it was detected in water samples from Wonder World Cave on January 9, 2004, through January 13, 2004. The distance between Ezell's Cave and Wonder World Cave is about 1,570 ft (480 m), so the apparent velocity was approximately 525 ft/d (160 m/d). Because maximum concentration was below the LOQ, results were not suitable for preparing a breakthrough curve.

Eosin from Ezell's Cave was also detected in water samples from Artesian Well on January 12, 2004, through January 21, 2004. The dye traveled at an apparent velocity of approximately 1,530 ft/d (470 m/d) over a distance of 9,180 ft (2,800 m). Eosin was detected in Sessom Creek beginning January 12, 2004, possibly fed by water from Artesian Well because the creek emerges from under a building on TSU campus near Artesian Well. Sessom Creek samples contained Eosin until January 18, 2004.

Samples from COSM Spring Lake wells contained Eosin from about January 13, 2004, until monitoring ended in March 2004 in Well #1 and through early February in Well #2. Sampling results were inconsistent during that time because the wells were pumped intermittently. These results represent an apparent velocity of approximately 1,400 ft/d (430 m/d).

Table 8. Summary of Southwestern Tracer-Test Results—September 2002

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Primer's Well	9/16/2002	Eosin 50 g	None	None			
Ezell's Cave	9/16/2002	Uranine 150 g	Well 157	10/9/2002	180 ft (55 m)	23	7.2 ft/d (2.2 m/d)
			Wonder World Cave (141)	9/18/2002	1,600 ft (480 m)	2	790 ft/d (240 m/d)
			TSU Jackson Well (46)	9/27/2002	7,400 ft (2,250 m)	11	660 ft/d (200 m/d)
			Artesian Well (77)	9/19/2002	9,180 ft (2,800 m)	3	3,050 ft/d (930 m/d)
			COSM Spring Lake wells (137)	9/23/2002	9,840 ft (3,000 m)	7	1,300 ft/d (400 m/d)
			Deep Hole Spring (29)	9/20/2002	10,800 ft (3,300 m)	4	2,700 ft/d (825 m/d)
			Diversion Spring (30)	Before 10/4/2002	11,200 ft (3,400 m)	<18	620 ft/d (189 m/d)
			Well 148	10/28/2002	1,500 ft (470 m)	42	36 ft/d (11 m/d)
			Spring Lake Chute (108)	10/1/2002	unknown	14	unknown
			Spring Lake Spillway (110)	9/20/2002	unknown	4	unknown
			COSM Comanche Street Well (149)	ND			
			Crater Bottom Spring (118)	ND			
			TSU hand-dug well (145)	ND			
			Well 155	ND			
			Well 156	ND			
			Salt & Pepper 1 Spring (128)	ND			
			West Campus Well (133)	ND			
			Transect well A (160)	ND			
			Weissmuller Spring (31)	ND			
			Transect well B (160)	ND			

ND = not detected

Figure 14. Southwestern Tracer Tests—September 16, 2002, Results

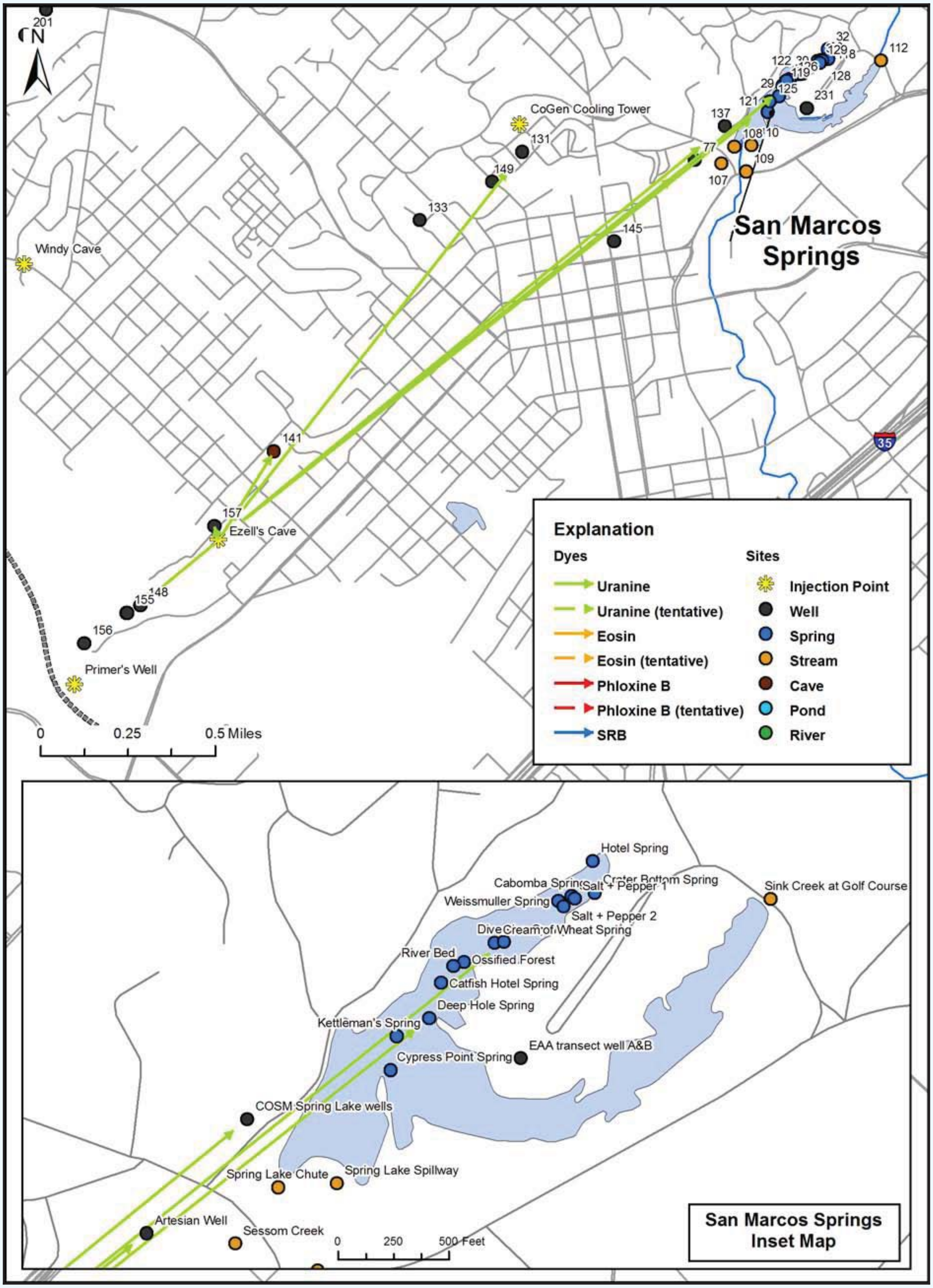


Figure 15. Breakthrough Curve for Wonder World Cave for September 16, 2002 Tracer Test

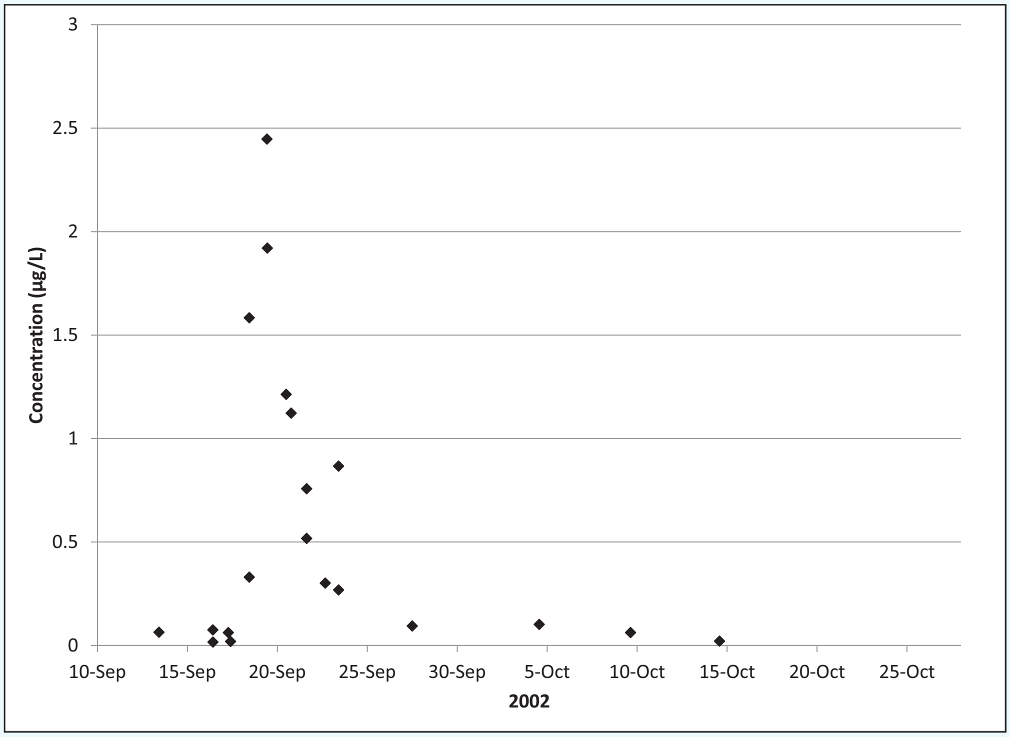


Figure 16. Breakthrough Curve for Artesian Well for September 16, 2002 Tracer Test

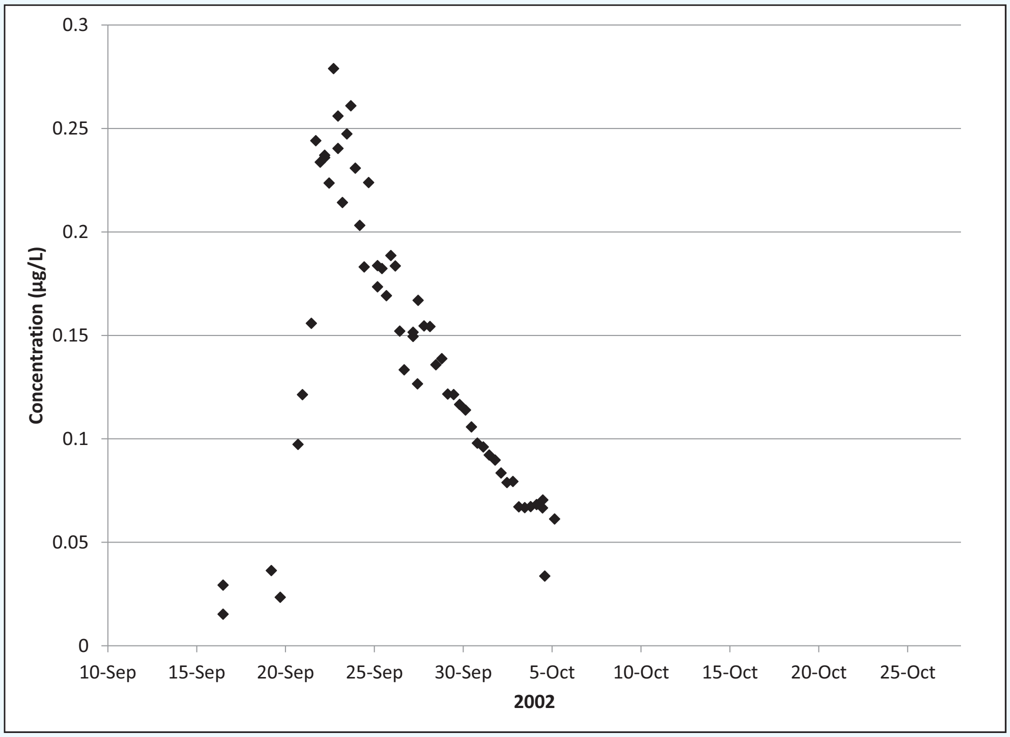


Figure 17. Southwestern Tracer Tests—January 2004

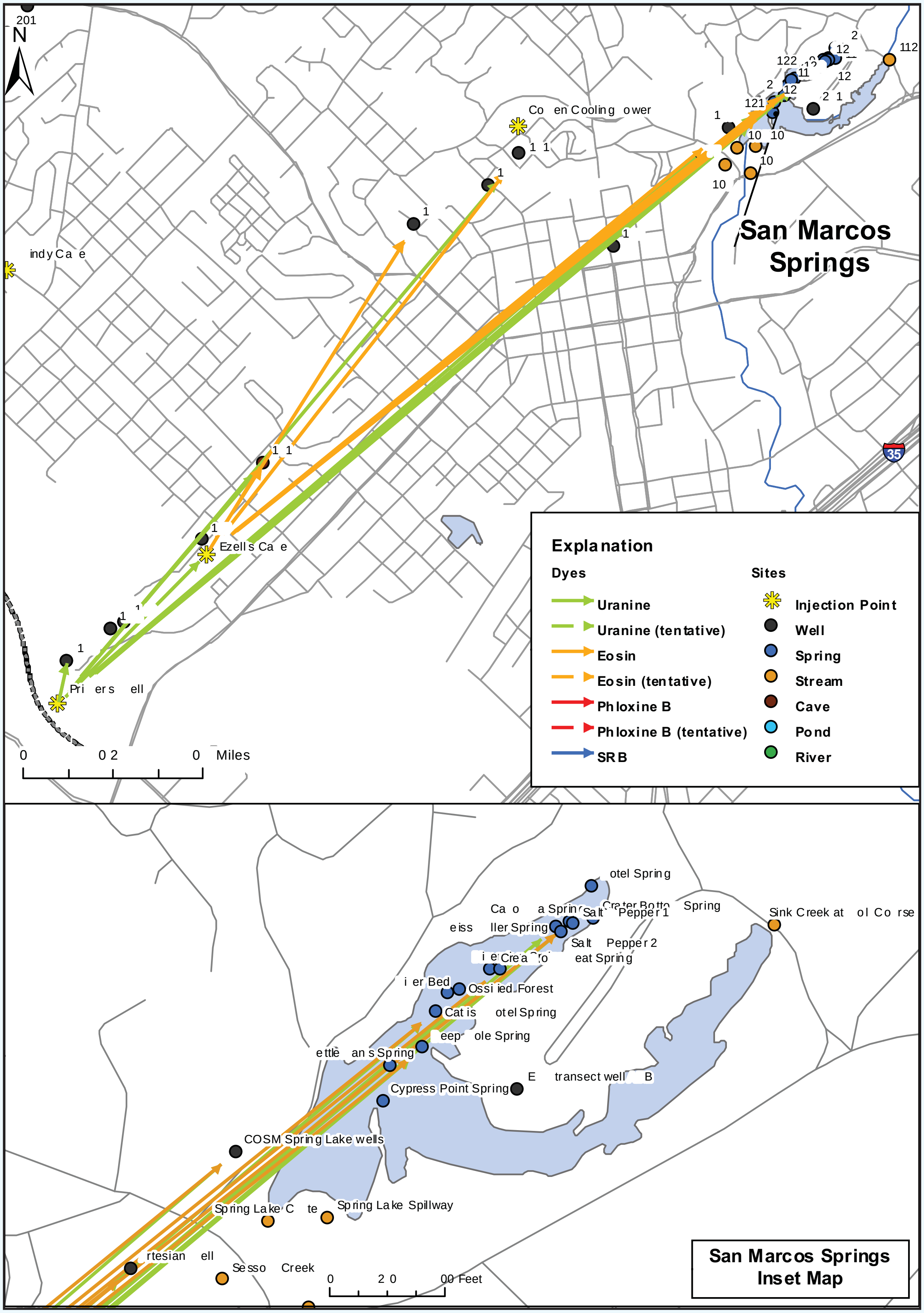
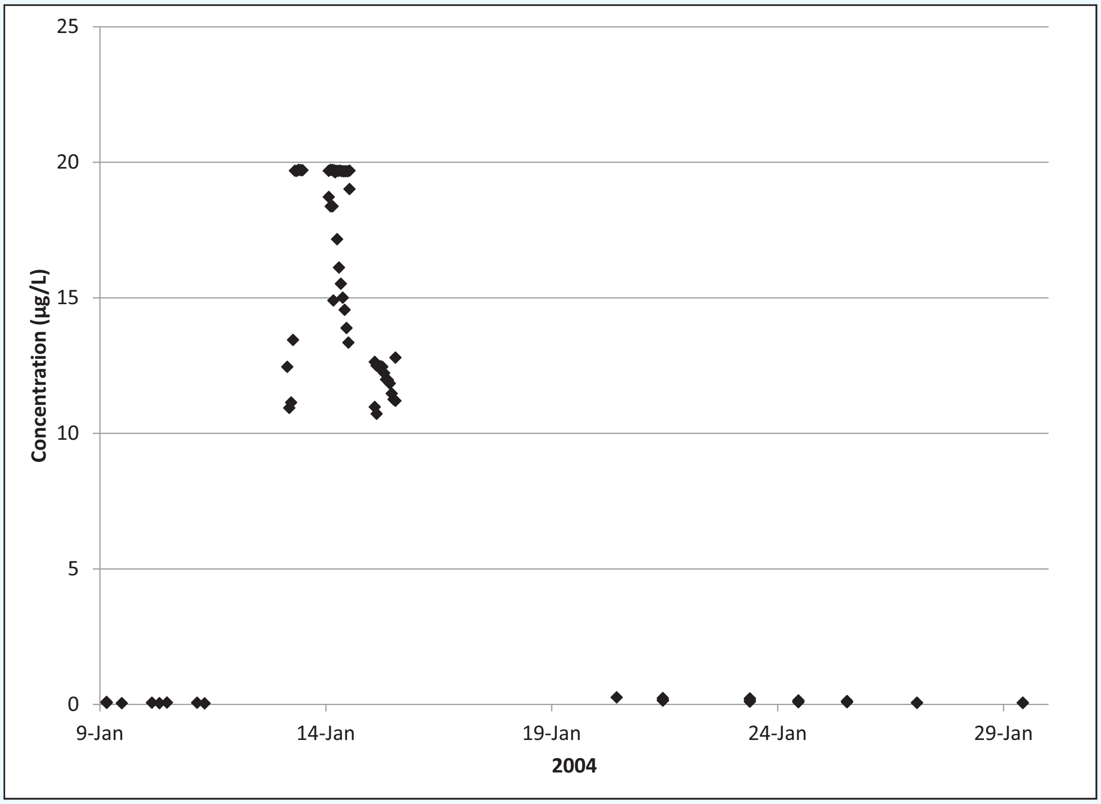


Figure 18. Uranine Concentration in Ezell's Cave, January 13–25, 2004, in water samples



Eosin was detected in water from the TSU Jackson Wells starting between January 15 and 26, 2004, and persisted until monitoring ended in March 2004. These results represent an apparent velocity of approximately 820 ft/d (250 m/d).

No Eosin was detected in West Campus Well or Comanche Street Well before monitoring ended in March 2004.

At Spring Lake, Eosin from Ezell's Cave was detected in water samples from Deep Hole Spring beginning between January 12 and 13, 2004, and quickly increased in concentration. It persisted until monitoring ended in March 2004. The arrival represented an apparent velocity of approximately 1,800 ft/d (550 m/d). Eosin appeared at both Catfish Hotel and Diversion springs about a week after appearing at Deep Hole Spring, between January 22 and 25, 2004, for an apparent velocity of approximately 660 ft/d (200 m/d). It persisted at Catfish Hotel Spring until monitoring ended in March 2004 and at Diversion Spring through February 2004. At Cabomba Spring, Eosin arrived between February 7 and 10, 2004, for an apparent velocity of approximately 330 ft/d (100 m/d) and persisted until the end of February 2004.

Samples were collected from three locations that intercept water from multiple springs beneath Spring Lake. In the Spring Lake Chute, Eosin was detectable from between January 14 and 18, 2004, until monitoring ended in March 2004. Eosin was detectable at Spring Lake Spillway from between January 13 and 14, 2004, through the middle of February 2004. Eosin was detectable at Spring Lake Outflow from between January 13 and 14, 2004, until monitoring ended in March 2004. These results suggest that no Eosin arrived at springs beneath the lake earlier than when it arrived at Deep Hole Spring on January 12, 2004, and dye was carried to the lake by flowpaths to springs that were not monitored.

Uranine Results. Uranine was injected into Primer's Well on January 12, 2004, and was detected in water samples from Ezell's Cave beginning January 13, 2004, and continuing until it was last detected between February 11 and 15, 2004. Figure 18 shows the breakthrough curve. A pump failure prevented sampling of the arrival of the dye, although it quickly increased in concentration to approximately 20 µg/L at 11:30 p.m. on January 13, 2004. Results represent an apparent velocity of approximately 6,230 ft/d (1,900 m/d) over the short distance between Primer's Well and Ezell's Cave (3,100 ft; 950 m).

Wells 155 and 156 were monitored, although only Well 156 intercepted Uranine from Primer's Well. The well is approximately 660 ft (200 m) from Primer's Well, and Uranine arrived between January 10 and 19, 2004, for an approximate apparent velocity of more than 98 ft/d (30 m/d). No Uranine was detected in other private wells (Well 148 or Well 164) 1,300 to 1,640 ft (400 to 500 m) northeast of Primer's Well.

Uranine from Primer's Well was detected in water samples from Wonder World Cave beginning on January 17, 2004, and ending on January 22, 2004, representing an approximate apparent velocity of 920 ft/d (280 m/d). Uranine was also detected at Artesian Well on January 18, 2004, COSM Spring Lake wells on March 3, 2004, and Jackson Wells, along with Ezell's Cave. Apparent velocities ranged from 78 to 6,230 ft/d (30 to 1,900 m/d).

Uranine was detected in samples from Artesian Well starting between January 18 and 20, 2004, for an apparent velocity of approximately 1,970 ft/d (600 m/d). It persisted through the end of monitoring in March 2004. Samples from Sessom Creek showed the same behavior as that of Artesian Well samples, with Uranine arriving between January 19 and 24, 2004, and persisting until monitoring ended in March 2004.

Uranine was present in COSM Spring Lake Well #1 samples starting between January 21 and 24, 2004, until monitoring ended in March 2004, whereas it was detected in Well #2 samples from approximately January 26 through February 6, 2004. However, concentrations were inconsistent because the wells were pumped intermittently. These results represent an approximate apparent velocity of 1,080 ft/d (330 m/d) for Well #1 and 590 ft/d (180 m/d) for Well #2. The apparent velocities are higher because the exact date of arrival is not known.

TSU Jackson Wells samples contained Uranine starting between January 27, 2004, and February 2, 2004, and persisted until the period of February 17 through 23, 2004. These results suggest an apparent velocity of 490 to 660 ft/d (150 to 200 m/d), depending on the actual arrival date.

Uranine was detected in the West Campus Well in background samples beginning January 9, 2004, and it persisted until February 15, 2004.

No dye was detected in the Comanche Street Well. However, sample coverage was incomplete because the well was operated only about once a month, and many charcoal receptors were dry. This well was monitored from the beginning of the traces through February 24, 2004.

At Spring Lake, Uranine appeared in all individual springs that were monitored. Concentrations were too low to be detectable in water, but high enough to be adsorbed by charcoal receptors. Uranine appeared at Deep Hole Spring between January 17 and 21, 2004, and persisted through the end of monitoring on March 2, 2004. Uranine appeared at Diversion Spring between January 21 and 25, 2004, and continued from February 2 through 6, 2004. At Catfish Hotel Spring, Uranine was detectable starting between January 29 and February 2, 2004, through the end of February 2004. At Weissmuller Spring, Uranine was detected on January 17, 2004, representing an approximate apparent velocity of more than 1,640 ft/d (500 m/d). It persisted until monitoring ended in March 2004. At Cabomba Spring, Uranine was detectable starting between February 5 and 14, 2004. At Crater Bottom and Cream of Wheat springs, Uranine was detected in background samples before the Primer's Well injection, so its arrival time is unknown, and it persisted until monitoring ended in March 2004. Uranine apparently had remained in the system since the 2002 Ezell's Cave injection. Similarly, at Hotel Spring, Uranine was detected in a sample collected on January 13, 2004, which was unreasonably soon after injection. It was also a remnant of previous injections, although the detections were intermittent, as demonstrated by a charcoal receptor on January 9, 2004, that contained no detectable Uranine. The last sample in which Uranine was detected was on February 14, 2004. Conditions were similar at Salt and Pepper Springs 1 and 2, where background charcoal receptors early in January 2004 contained no detectable Uranine, but it appeared in samples collected within a day after injection. It was also detectable in samples collected from both springs in February 2004.

Uranine was detected at all Spring Lake discharge sites. Uranine was detectable in the Spring Lake Chute between January 18 and 24, 2004, until monitoring ended in March 2004. Uranine was detectable in the Spring Lake Spillway starting between January 13 and 14, 2004, through January 24 through 30, 2004. Uranine was detectable in the Spring Lake Outflow charcoal receptor starting from January 18, 2004, until monitoring ended in March 2004. The Uranine detection between January 13 and 14, 2004, preceded its appearance at Deep Hole Spring, which was the first individual spring to indicate dye. None of the preceding background samples contained Uranine. Consequently Uranine apparently had arrived at Spring Lake via an unmonitored spring sometime before January 14, 2004.

Table 9. Summary of Southwestern Tracer-Test Results–January 2004

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Primer's Well	1/12/2004	Uranine 150 g	Well (156)	1/19/2004	660 ft (200 m)	7	98 ft/d (30 m/d)
			Ezell's Cave (146)	1/13/2004	3,100ft (950 m)	1	6,230 ft/d (1,900 m/d)
			Wonder World Cave (141)	1/17/2004	4,600 ft (1,400 m)	5	920 ft/d (280 m/d)
			TSU Jackson Well (131)	2/2/2004	10,500 ft (3,200 m)	21	490 ft/d (150 m/d)
			Artesian Well (77)	1/18/2004	12,100 ft (3,700 m)	6	1,970 ft/d (600 m/d)
			COSM Spring Lake Well 1 (137)	3/3/2004	13,100 ft (4,000 m)	51	260 ft/d (78 m/d)
			COSM Spring Lake Well 2 (137)	3/3/2004	13,100 ft (4,000 m)	51	260 ft/d (78 m/d)
			Deep Hole Spring (29)	21/2004	13,800 ft (4,200 m)	9	1,540 ft/d (470 m/d)
			Catfish Hotel Spring (119)	2/2/2004	14,10 ft (4,300 m)	21	660 ft/d (200 m/d)
			Diversion Spring (30)	1/25/2004	14,400 ft (4,400 m)	13	1,100 ft/d (340 m/d)
			Cabomba Spring (33)	2/14/2004	14,800 ft (4,500 m)	33	460 ft/d (140 m/d)
			Weissmuller Spring (31)	1/17/2004	14,800 ft (4,500 m)	5	>2,950 ft/d (>900 m/d)
			Crater Bottom Spring (118)	Interference			
			Hotel Spring (32)	Interference			
			Cream of Wheat Spring (122)	Interference			
			Salt & Pepper 1 Spring (128)	Interference			

(Table 9. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Salt & Pepper 2 Spring (129)	Interference			
			West Campus Well (133)	Interference			
			Spring Lake Chute (108)	1/18/2004	Unknown	6	Unknown
			Spring Lake Spillway (110)	1/13/2004	Unknown	1	Unknown
			Spring Lake Total Outflow (109)	1/18/2004	Unknown	6	Unknown
			Well 148	ND (1 sample)	1,300 ft (400 m)		
			Well 155	ND	1,300 ft (400 m)		
			Well 164	ND	1,640 ft (500m)		
			COSM Comanche Street Well (149)	ND	9,800 ft (3,000 m)		
Ezell's Cave	1/6/2004	Eosin 1,000 g	Wonder World Cave (141)	1/9/2004	1,570 ft (480 m)	3	525 ft/d (160 m/d)
			Artesian Well (77)	1/12/2004	9,180 ft (2,800 m)	6	1,530 ft/d (470 m/d)
			West Campus Well (133)	2/15/2004	5,740 ft (1,750 m)	40	140 ft/d (44 m/d)
			TSU Jackson Well (131)	1/15/2004	7,400 ft (2,250 m)	9	820 ft/d (250 m/d)
			COSM Spring Lake Well 1 (137)	1/13/2004	9,800 ft (3,000 m)	7	1,400 ft/d (430 m/d)
			COSM Spring Lake Well 2 (137)	1/13/2004	9,800 ft (3,000 m)	7	1,400 ft/d (430 m/d)
			Catfish Hotel Spring (119)	1/25/2004	10,800 ft (3,300 m)	19	560 ft/d (170 m/d)
			Deep Hole Spring (29)	1/12/2004	10,800 ft (3,300 m)	6	1,800 ft/d (550 m/d)
			Diversion Spring (30)	1/25/2004	11,200 ft (3,400 m)	19	590 ft/d (180 m/d)
			Cabomba Spring (33)	2/7-10/2004	11,500 ft (3,500 m)	35	330 ft/d (100 m/d)
			Sessom Creek (107)	1/12/2004	Unknown	6	Unknown
			Spring Lake Chute (108)	1/18/2004	Unknown	12	Unknown
			Spring Lake Spillway (110)	1/14/2004	Unknown	8	Unknown

(Table 9. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Spring Lake Total Outflow (109)	1/14/2004	unknown	8	unknown
			Well 148	ND		(1 sample)	
			Crater Bottom Spring (118)	ND			
			Cream of Wheat Spring (122)	ND			
			Hotel Spring (119)	ND			
			Well 155	ND			
			Well 156	ND			
			Salt & Pepper 1 Spring (128)	ND			
			Salt & Pepper 2 Spring (129)	ND			
			Weissmuller Spring (31)	ND			
			West Campus Well (133)	ND			
			Well 164	ND			

ND = not detected

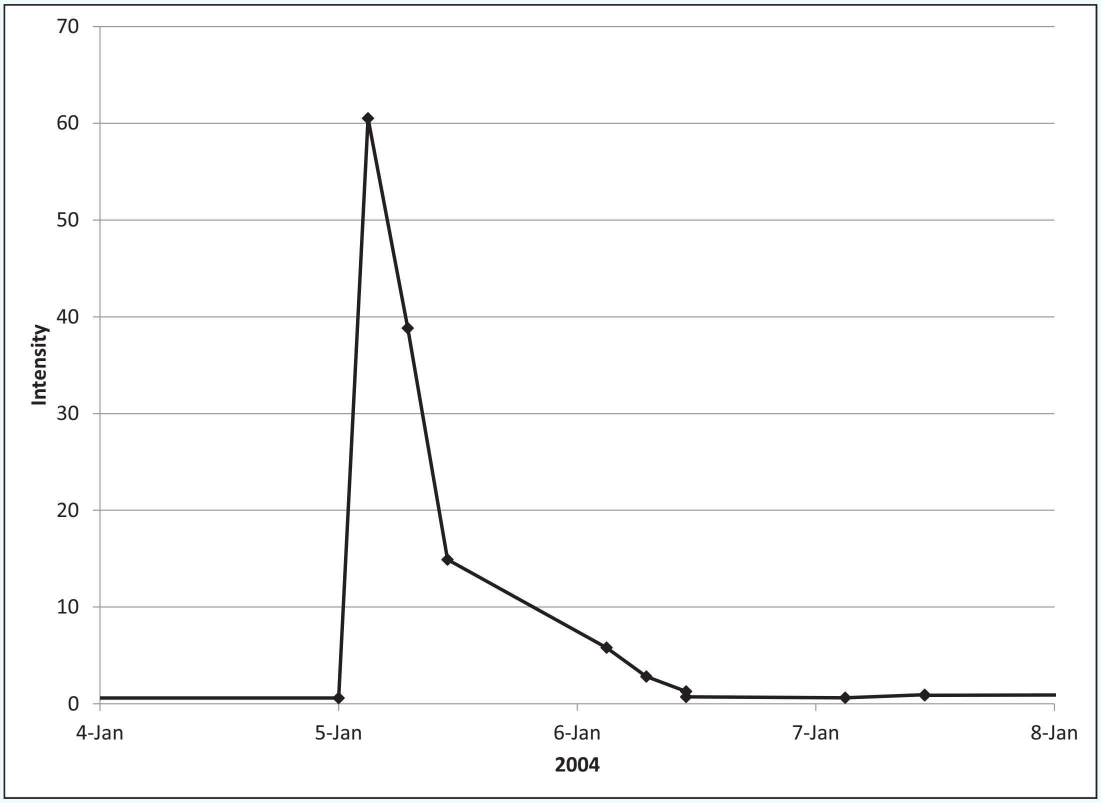
During the January 2004 tracer test, a fluorescent substance appeared in samples from Deep Hole Spring in Spring Lake, while background conditions were being monitored. It appeared on January 5, 2004, and persisted for about two days (Figure 19). It had a wavelength of 561 nm, slightly higher than that of the dyes used in these tracer tests. Because the material was unknown, the concentration could not be determined, and it is not known whether the material was naturally occurring or anthropogenic. However, it must have resulted from a single release because the breakthrough curve showed only one peak. The steeply increasing leg of the breakthrough curve indicated that the source was relatively close to Spring Lake.

July 2004 and July 2005 Tracer-Test Results

Two focused tracer tests were conducted during the EAA's annual water conferences for educators in July 2004 and July 2005. In 2004, Uranine was poured into the lake at the bottom of Ezell's Cave, and autosamplers were located at Artesian Well, TSU Jackson Wells, and Deep Hole Spring. Charcoal receptors were placed at Diversion Spring and Wonder World Cave. Uranine arrived at Artesian Well on July 6, 2004, for an apparent velocity of approximately 2,300 ft/d (700 m/d) (Figure 20; Table 10). It was also detected at Wonder World Cave, although the arrival time could not be determined. It was not detected at Diversion Spring, although only four water samples were collected because of equipment malfunctions, nor was it detected at TSU Jackson Wells before sampling ended on July 23, 2004.

In 2005, Uranine was injected at Ezell's Cave, and autosamplers were located at Deep, Diversion, and Weissmuller springs in Spring Lake and at Artesian Well at TSU. Each autosampler was programmed to collect 24 water samples at six-hour intervals. Uranine from

Figure 19. Breakthrough Curve for Unknown Substance at Deep Hole Spring in January 2004



Ezell's Cave was detected in Artesian Well on the TSU campus, Deep Hole Spring, and Weissmuller Spring. No dye was detected in Diversion Spring. Groundwater velocities calculated from the tracer tests ranged to as much as 8,860 ft/d (2,700 m/d), given the first detection of dye at the monitoring sites. Dye persisted in the groundwater system until late October 2005. Apparent velocities to Artesian Well were 1,530 ft/d (470 m/d) and 2,200 ft/d (670 m/d) for 2004 and 2005, respectively. For Deep Hole Spring, apparent velocities were 2,200 ft/d (670 m/d) and 1,840 ft/d (560 m/d) for 2004 and 2005, respectively. Table 10 lists other monitoring sites and dye detections.

Artesian Well. Figure 21 shows the breakthrough curve for Artesian Well. The high-frequency sampling created an extremely detailed curve starting before the injection on July 5, 2005, and continuing until the dye was no longer detectable. The first sample that contained dye was collected at 7:40 p.m. on July 9, 2005, approximately 101 hours after injection. The concentration quickly increased to a peak recorded by the 6:30 a.m. sample on July 15, 2005, approximately 131 hours after injection. The concentration then gradually decreased until it passed the detection limit (0.08 µg/L) on September 5, 2005. Artesian Well is approximately 9,180 ft (2,800 m) from Ezell's Cave, where the dye (Uranine) was injected. Calculated from the first arrival time (101 hours), the apparent groundwater velocity was approximately 2,200 ft/d (670 m/d).

Uranine was last detected in water samples collected on September 11, 2005, although the charcoal detectors indicated that dye was still discharging from Artesian Well. However, the concentration of dye extracted from the charcoal was useful mainly to indicate that dye was present at the site. Dye persisted in charcoal samples for approximately six weeks at Artesian Well after it was not detectable in water samples.

Figure 20. Southwestern Tracer Tests—July 2004 and July 2005

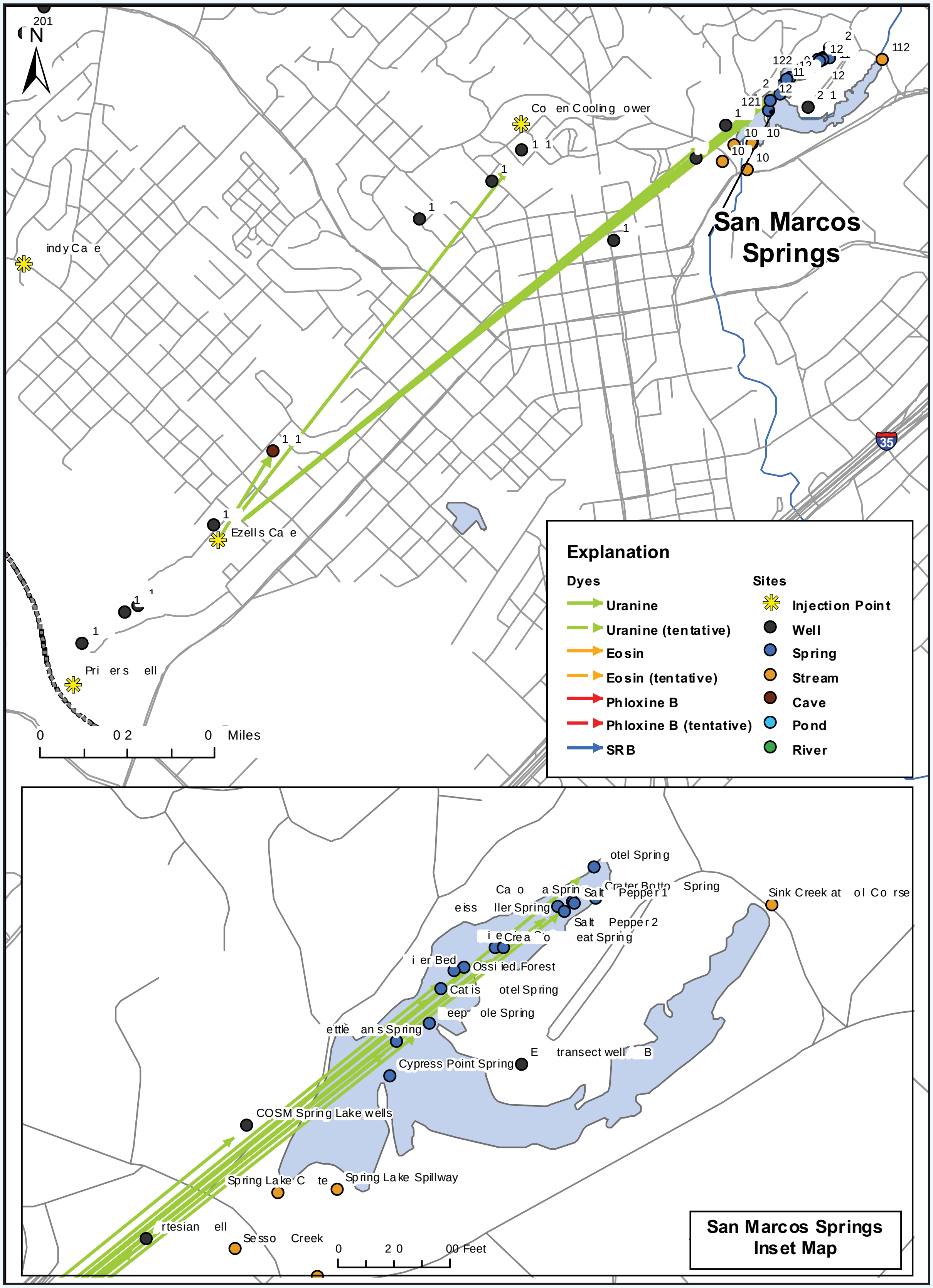


Table 10. Summary of Southwestern Tracer-Test Results—July 2004 and 2005

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Ezell's Cave	7/2/2004	1,000 g Uranine	Wonder World Cave (141)	<7/5/2004	1,570 ft (480 m)	<3	>520 ft/d (>160 m/d)
			Artesian Well (77)	7/6/2004	9,180 ft (2,800 m)	4	2,300 ft/d (700 m/d)
			Deep Hole Spring (29)	7/7/2004	10,758 ft (3,280 m)	5	2,260 ft/d (670 m/d)
			Diversion Spring (30)	ND	11,000 ft (3,400 m)	4 samples	
			TSU Jackson Well (131)	ND	7,400 ft (2,250 m)		
Ezell's Cave	7/5/2005 14:45	Uranine 2.5 kg	Wonder World Cave (141)	<8/11/2005	1,600 ft (480 m)	<37	>43 ft/d (>13 m/d)
			TSU Jackson Well (131)	8/22/2005	7,400 ft (2,250 m)	28	260 ft/d (80 m/d)
			COSM Spring Lake Well (137)	<8/12/2005	9,800 ft (3,000 m)	<38	>260 ft/d (>80 m/d)
			Kettleman's Spring (125)	<8/23/2005	10,600 ft (3,250 m)	<49	>220 ft/d (>66 m/d)
			Artesian Well (77)	7/10/2005	9,180 ft (2,800 m)	4	2,200 ft/d (670 m/d)
			Deep Hole Spring (29)	7/11/2005	10,800 ft (3,300 m)	6	1,840 ft/d (560 m/d)
			Catfish Hotel Spring (119)	<8/17/2005	10,800 ft (3,300 m)	<43	>250 ft/d (>77 m/d)
			Diversion Spring (30)	8/17/2005	11,000 ft (3,400 m)	43	260 ft/d (79 m/d)
			Cream of Wheat Spring (122)	<8/17/2005	11,000 ft (3,400 m)	<43	>260 ft/d (>79 m/d)
			River Bed Spring (127)	<8/23/2005	11,000 ft (3,400 m)	<49	>720 ft/d (>220 m/d)
			Weissmuller Spring (31)	7/6/2005	11,800 ft (3,600 m)	1.3	8,850 ft/d (2,700 m/d)
			Hotel Spring (119)	<8/23/2005	12,000 ft (3,600 m)	<49	>240 ft/d (>73 m/d)
			Cabomba Spring (33)	<8/23/2005	12,000 ft (3,600 m)	<49	>240 ft/d (>73 m/d)
			Spring Lake Chute (108)	<8/15/2005	Unknown	Unknown	Unknown
			Spring Lake Total Outflow (109)	<8/15/2005	Unknown	Unknown	Unknown
			Spring Lake Spillway (110)	<8/15/2005	Unknown	Unknown	Unknown
			Ossified Forest Spring (126)	ND	10,200 ft (3,100 m)		
			Crater Bottom Spring (118)	ND	11,800 ft (3,600 m)		
			Nancy Moore (202)	ND	9,500 ft (2,900 m)		
			COSM Comanche Street Well (149)	ND	6,900 ft (2,100 m)		

< = arrival prior to date shown.

ND = not detected

Figure 21. Breakthrough Curve for Artesian Well Showing Percent of Dye Mass for July 5, 2005, Tracer Test

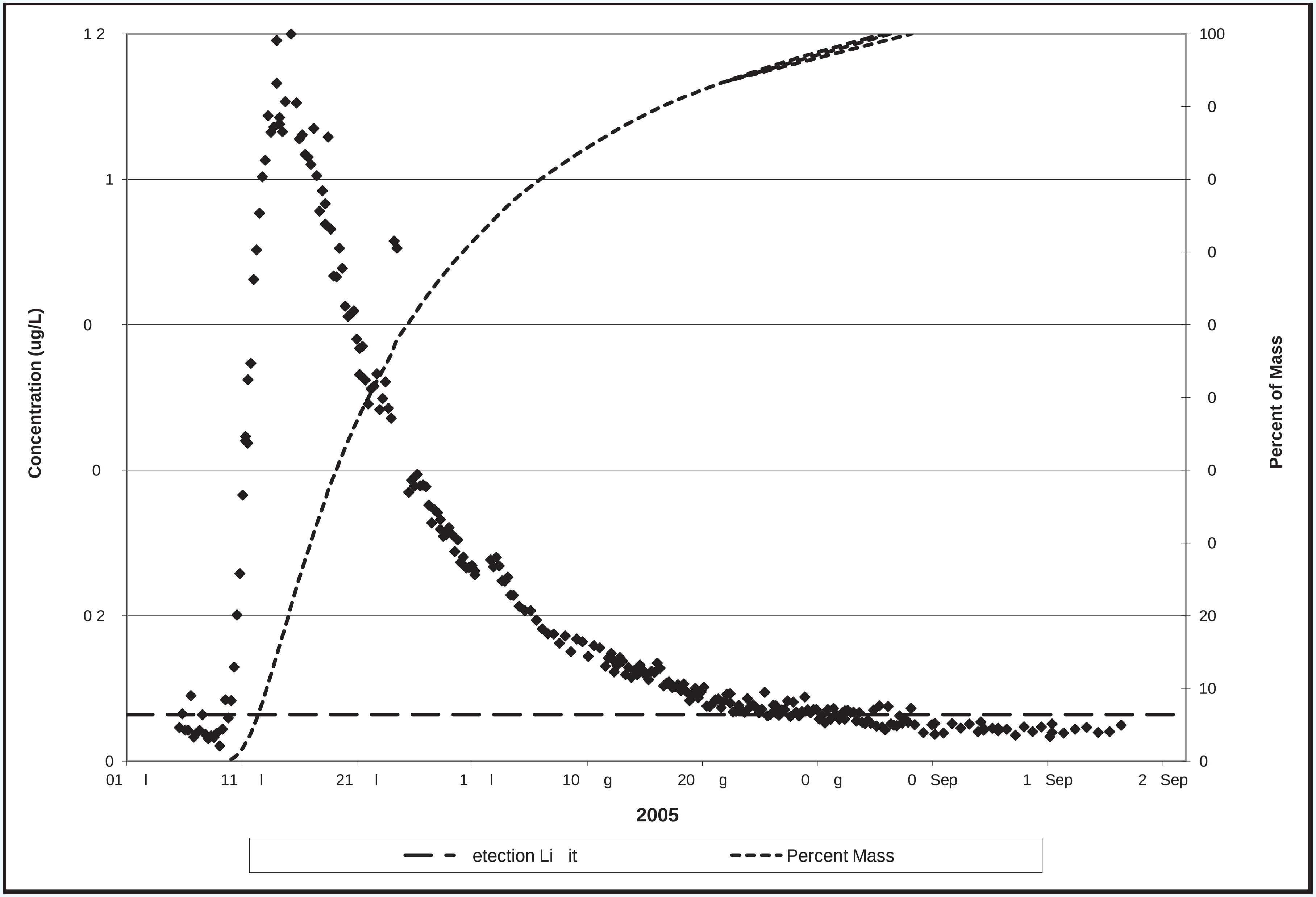
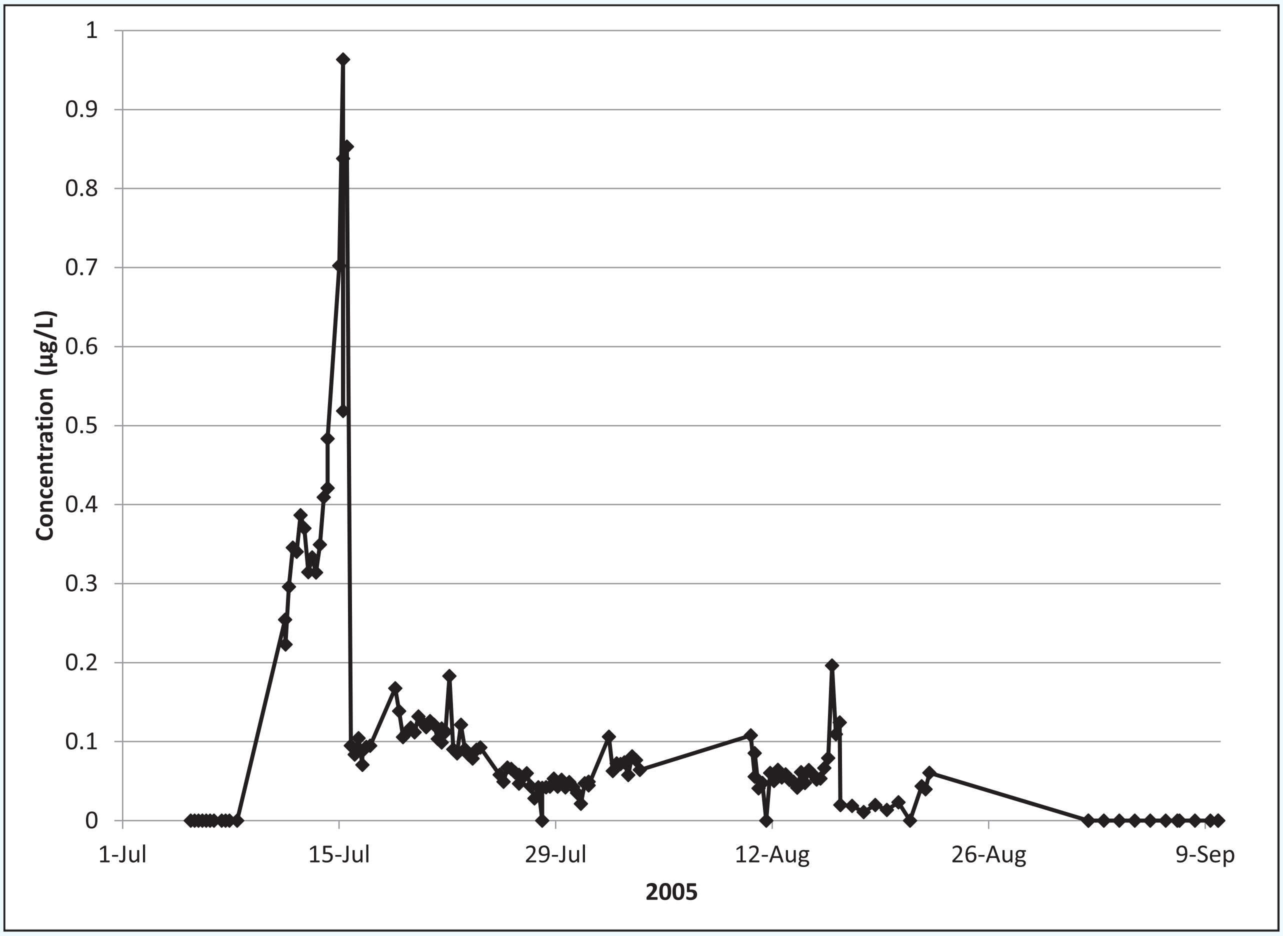


Figure 22. Breakthrough Curve for Deep Hole Spring for July 5, 2005, Tracer Test



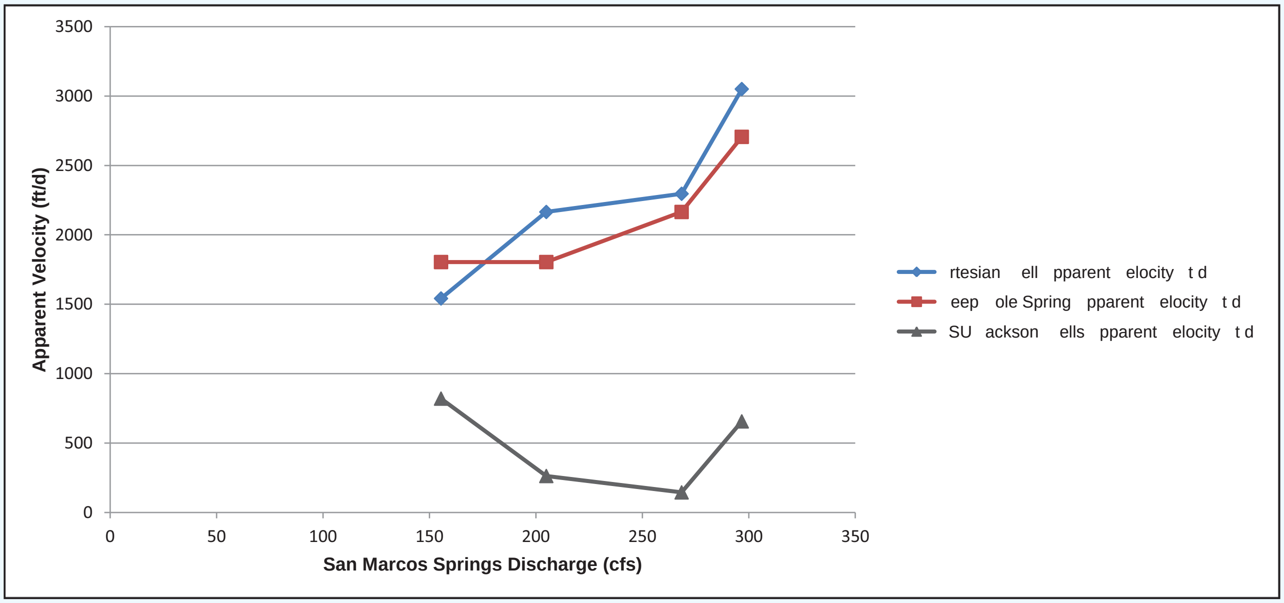
Artesian Well discharged at approximately 100 gpm (6.3 L/sec), so it was possible to calculate the mass of Uranine recovered during the tracer test (Figure 21). The mass of dye in each sample was calculated by multiplying the concentration by the sampling interval (usually six hours) and the discharge rate. The total mass of dye that passed by Artesian Well was 0.012 g, or 0.046 percent of the dye that was injected at Ezell's Cave.

Deep Hole Spring. Uranine from Ezell's Cave was detected at Deep Hole Spring, which is 10,800 ft (3,280 m) from Ezell's Cave. Dye first arrived at Deep Hole Spring at 12:55 p.m. on July 11, 2005, approximately 141 hours after injection, for a groundwater velocity of approximately 1,840 ft/d (560 m/d). The highest concentration was detected on July 15, 2005, at 6:12 a.m. at 0.96 µg/L (Figure 22).

Like at Artesian Well, dye concentrations increased quickly after arrival, although they abruptly decreased on July 17, 2005, because of natural variation, or the sampling tube may have dislodged from the spring orifice, causing dilution of the samples. Dye was detected in individual water samples from Deep Hole Spring until September 9, 2005. Charcoal detectors indicated that the dye persisted in Deep Hole Spring until sometime between October 4 and October 18, 2005.

Weissmuller Spring. Uranine injected in Ezell's Cave on July 5, 2005, was also detected in Weissmuller Spring, which is approximately 11,800 ft (3,600 m) from Ezell's Cave. Dye was first detected at Weissmuller Spring at 11:05 p.m. on July 6, 2005, only 32 hours after injection, which represents an apparent groundwater velocity of approximately 8,850 ft/d (2,700 m/d). Maximum concentration was detected on July 13, 2005, at 2:57 a.m., 180 hours after injection. Dye was detected only sporadically in water samples from Weissmuller Spring, and no charcoal detectors were installed at that site. The last sample with detectable dye was on July 14, 2005.

Figure 23. Comparison of Apparent Velocities from Southwestern Tracer Tests



Eosin was detected in charcoal receptors in September, October, and November from the January 2004 injection at Ezell's Cave.

Comparison of the Southwestern Tracer Tests

Southwestern tracer tests in 2002, 2004, and 2005 provided an opportunity to evaluate the relationship between apparent velocities and San Marcos Springs discharge. All tracer tests included injections at Ezell's Cave and detections in water samples from autosamplers at Artesian Well, TSU Jackson Wells, and Deep Hole Spring at San Marcos Springs. Water samples provided an accurate measurement of arrival times, whereas charcoal samples only bracketed arrival time between placement and pickup times. During the 2002 tests, San Marcos Springs discharge was approximately 297 cfs (8.4 m^3/s), as compared with 157 cfs (4.4 m^3/s) in January 2004, 268 cfs (7.6 m^3/s) in July 2004, and 207 cfs (5.8 m^3/s) in 2005. Apparent velocities from Ezell's Cave to Artesian Well were 3,050 ft/d (930 m/d) in 2002, as compared with 1,540 ft/d (470 m/d) in January 2004, 2,200 ft/d (670 m/d) in July 2004, and 2,200 ft/d (670 m/d) in 2005. These results indicate that groundwater velocities were directly proportional to San Marcos Springs discharge (Figure 23). Deep Hole Spring showed similar results. Apparent velocities were higher in 2002 than 2004 and 2005, when San Marcos Springs discharge was higher. Results from TSU Jackson Wells were not consistent because the wells are not on the main southwest-northeast flowpath that connects Ezell's Cave, Artesian Well, and San Marcos Springs, and arrival times were probably affected by intermittent pumping.

West of San Marcos Springs Traces: Windy Cave and Dakota Ranch Cave (2005)

Western traces consisted of injections at Windy Cave and Dakota Ranch Cave, which are located west-southwest and west of San Marcos Springs, respectively (Figure 24).

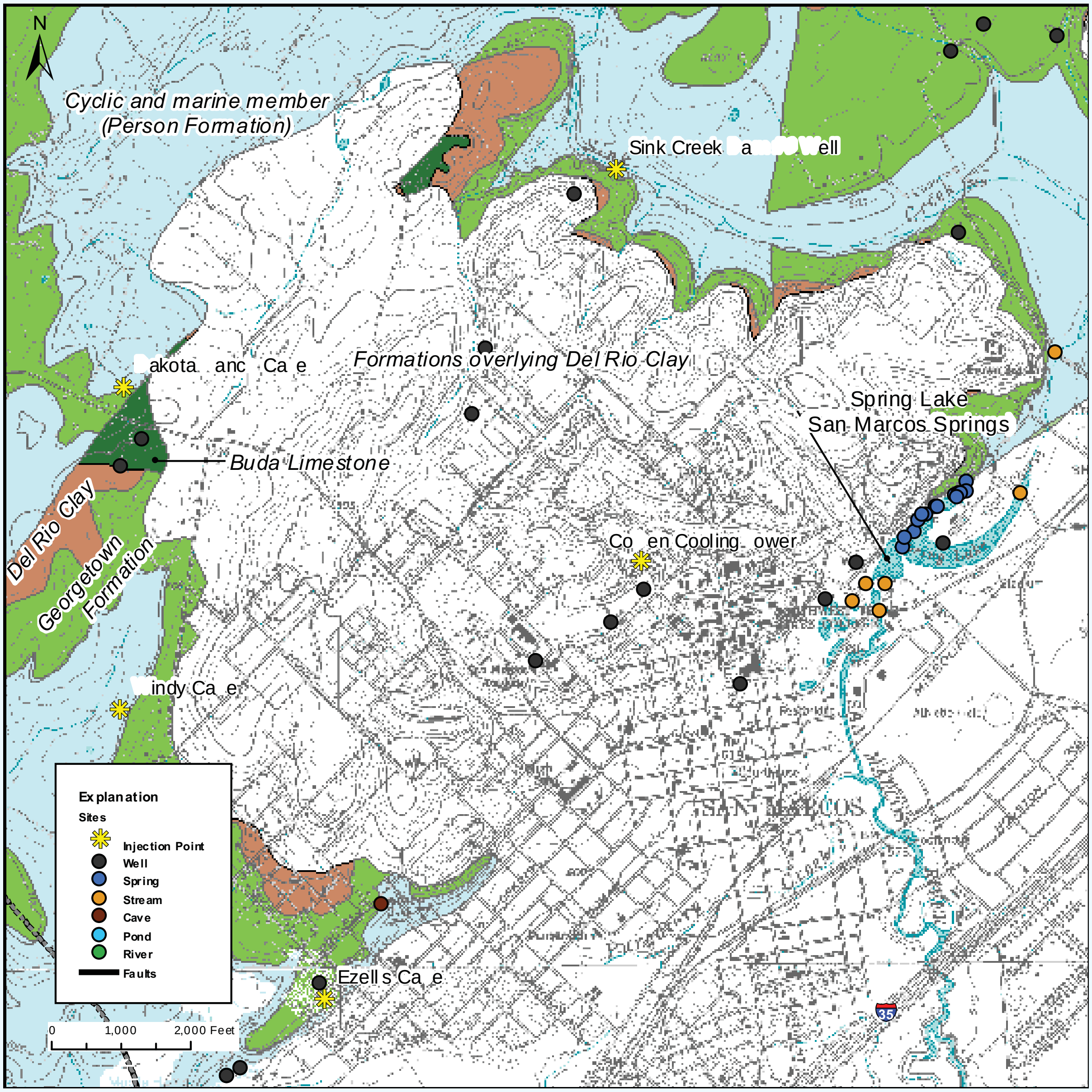
Purpose

The purpose of these tests was to investigate groundwater flowpaths west of San Marcos Springs. As shown in Figure 2, fault displacements range up to 160 ft (50 m) and may act as barriers to groundwater, potentially forcing flow parallel to the faults. If groundwater flowed across the faults, tests would yield apparent velocities from directions oblique to the strike of the Balcones Fault Zone.

Setting

Windy Cave is located on Bishop Street just north of Craddock Avenue in the City of San Marcos. The entrance is in the Cyclic and Marine member (undivided), which is the uppermost unit of the Person

Figure 24. Geologic Setting of Tracer Tests West of San Marcos Springs



Formation, at an elevation of approximately 690 ft (210 m), or about 120 ft (35 m) above the elevation of Spring Lake. It is on the hillside adjacent to a small creek that is a tributary to Purgatory Creek, approximately 11,150 ft (3,400 m) from San Marcos Springs. None of the original solutionally formed void was accessible as a result of extensive infilling that created the sinkhole and entrance. Sheetwash from a roughly 10-m × 30-ft × 13-ft (four-m-wide) area drains to the cave's entrance, although a larger area certainly contributes drainage that enters the cave through fractures and other avenues, such as the rock-choked fissure above and near the cave. This cave was modified by collapse after it was formed, and measures 36 ft (11 m) × 10 ft (three m). Significant airflow indicates that most of the cave's extent is not yet known.

Dakota Ranch Cave is located near Ranch Road 12 just north of Craddock Avenue, approximately 11,800 ft (3,600 m) from San Marcos Springs. Its entrance is also in the Cyclic and Marine member at an elevation of approximately 750 ft (230 m). The rubble-filled sinkhole is about seven m × 23 × 16 × 1.6 ft (five m × 0.5 m). The underlying cave was described as a single room, a few meters in diameter, and a few meters deep. Groundwater is 100 to 130 ft (30 to 40 m) below ground near the caves.

The two caves are separated from San Marcos Springs by several faults that are part of the Balcones Fault Zone (Figure 24). The San Marcos Springs Fault "completely, or almost completely" offsets the Edwards Aquifer, leaving the Edwards Limestone against upper confining units that are nearly impermeable (Hanson and Small, 1995), such as the Del Rio Clay and other overlying formations. Other nearby faults have displaced the Georgetown Formation, which ranges from 10 to 43 ft (3 to 13 m) in thickness. One of the objectives of this tracer test is to test the hypothesis that faults in this area are barriers to groundwater flow to San Marcos Springs. Because of the faulting, Buda, Eagle Ford, and Austin formations crop out between the caves and San Marcos Springs; therefore, possible, although unlikely, pathways for the dye penetrate formations other than the Edwards.

Injections

Tracer tests were conducted by a series of four injections, dye volume being increased each time as a precaution against coloring nearby wells. Between August and October 2005, Eosin was injected into Windy Cave, and Phloxine B was injected into Dakota Ranch Cave. As shown in Figure 25 and Table 11, each injection was followed by several days or weeks of monitoring to determine whether the dyes were visible in any wells. Monitoring continued until October 2006.

Results

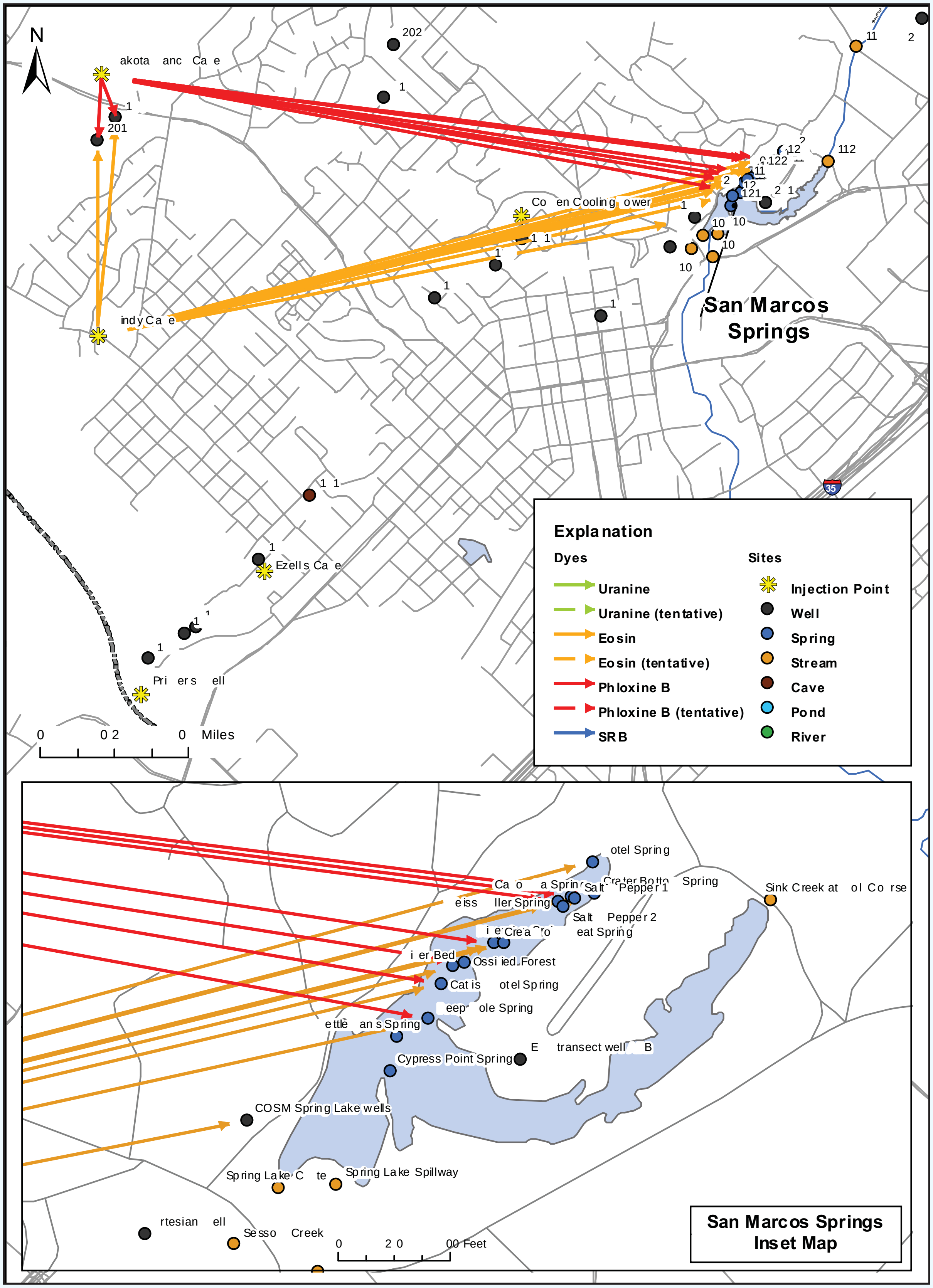
Prior to the injections, background monitoring began in August 2005 and revealed that Uranine from the Ezell's Cave injection in July 2005 was detected at Hotel, Weissmuller, Cabomba, Diversion, Catfish Hotel, Cream of Wheat, and Kettleman's springs. Consequently, it was also detected in samples of Spring Lake discharge at Chute, Spillway, and Total Outflow. In addition, it was detected in samples from TSU Jackson Wells and COSM Spring Lake Wells. However, Uranine in the samples did not interfere with detections of Eosin or Phloxine B from the western injection points.

With multiple injections, arrival times may be ambiguous because dyes injected on different dates at the same location are not chemically discernable at monitoring sites. Different injections can be recognized only by higher concentrations at arrival because each injection involves more dye than the previous one. Injections are timed to allow dyes to travel to nearby monitoring sites so that initial apparent velocities can be calculated. However, groundwater velocities are difficult to predict as a result of the heterogeneous, karstic nature of the Edwards Aquifer. In addition, charcoal receptors, which were placed at most of the monitoring sites, provide only approximate arrival times and concentrations. Consequently, all travel durations were calculated on the basis of the injection date immediately preceding the detection, which yielded maximum apparent velocities. This approach was based on the assumption that dye from preceding injections was diluted below detectable levels before reaching the monitoring sites, and the larger volume of dye in subsequent injections was necessary to raise the concentration to detectable levels. On that basis, no Eosin was detected from the first or second injection at Windy Cave, and no Phloxine B was detected at any distant site until after the fourth injection at Dakota Ranch Cave. However, Phloxine B from Dakota Ranch Cave was detected after the third injection at two nearby unmonitored sites as discussed later. In spite of the ambiguity regarding arrival times, tests were successful because they revealed one or more groundwater flowpaths.

Windy Cave. Eosin from Windy Cave was first detected eight to 15 days after the third injection on September 6, 2005, at Diversion, Weissmuller, Cabomba, Catfish Hotel, and Deep Hole springs. The detections represented an apparent velocity of approximately 820 ft/d (250 m/d). Eosin persisted at Diversion, Weissmuller, Cabomba, and Deep Hole springs through February 21, 2006. It disappeared from Catfish Hotel Spring on January 6, 2006.

Other detections followed in November 2005. Eosin was detected at Cream of Wheat Spring between November 4 and 14, 2005, for an approximate apparent velocity of 610 ft/d (185 m/d) and only persisted until December 5, 2005. Eosin was detected at Crater Bottom Spring between November 14 and 22, 2005, for an apparent velocity of approximately 450 ft/d (136 m/d) and then was not detected again. It was detected at River Bed Spring between November 4 and 14, 2005, for an approximate apparent velocity of 590 ft/d (180 m/d) and persisted in trace amounts until February 21, 2006.

Figure 25. Western Tracer Tests in September and October 2005



However, the fastest apparent velocity was recorded at Hotel Spring, where Eosin was detected between two and 10 days after the final injection on October 25, 2005, for a minimum apparent velocity of approximately 1,200 ft/d (370 m/d). If Eosin had originated from the third injection, its apparent velocity would be approximately 210 ft/d (64 m/d), significantly slower than that of other springs. Although Hotel Spring is the most distant monitoring site from Windy Cave, it is certainly possible in a karst setting to have the fastest apparent velocity. Eosin persisted at Hotel Spring until December 12, 2005, which is also evidence of the faster apparent velocity. The relatively short period of detection suggests that the flowpath to Hotel Spring is more direct than other flowpaths and is characterized by more advection and less diffusion than flowpaths to other springs.

Of the sites that did not intercept dye, only two were springs: Kettleman's and Ossified Forest springs. Eosin was never detected at Spring Lake discharge sites Chute, Spillway, or Total Outflow before monitoring ended in October 2006. It was never detected at monitoring sites southwest of San Marcos Springs such as TSU Jackson Wells, Artesian Well, COSM Comanche Street Well, COSM Spring Lake Wells, or Wonder World Cave. Well 114 and Sink Creek at the Golf Course were monitored, although they had not been expected to intercept dye from Windy Cave, and they did not.

Dakota Ranch Cave. Phloxine B was visible after the third injection in samples from two wells approximately 1,150 ft (350 m) south and southeast of Dakota Ranch Cave, although they were not monitored by the EAA until after the last injection. Well owners did not report the appearance immediately, so the actual arrival time is not known. Phloxine B persisted in these wells at invisible concentrations for several years after injection.

At Spring Lake, Phloxine B from Dakota Ranch Cave arrived at Deep Hole Spring first between February 21 and March 21, 2006, for an apparent velocity of at least 82 ft/d (25 m/d). It was detectable in Deep Hole Spring when monitoring ended in October 2006. Similarly, it was detected at Weissmuller and Cabomba springs between 146 and 167 days after the final injection on October 25, 2005, for an apparent velocity of 72 to 82 ft/d (22 to 25 m/d). It traveled 200 or more days to Crater Bottom, Cream of Wheat, Ossified Forest, and Catfish Hotel springs for apparent velocities ranging from 52 to 59 ft/d (16 to 18 m/d). It was detectable at Hotel, Deep Hole, Diversion, Weissmuller, Cabomba, Crater Bottom, Ossified Forest, and Cream of Wheat springs when monitoring ended in October 2006.

Of the sites that did not intercept dye, three were springs: Hotel, River Bed, and Kettleman's springs. Phloxine B was not detected at Artesian Well, TSU Jackson Wells, or Well 114. In addition, it was not detectable at Spring Lake discharge sites Chute, Spillway, or Total Outflow.

Table 11. Summary of Western Tracer-Test Results—Windy Cave and Dakota Ranch Caves

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Windy Cave	8/11/2005	Eosin 200 g	None	None			
Dakota Ranch Cave	8/12/2005	Phloxine B 300 g	None	None			
Windy Cave	8/20/2005	Eosin 2,976 g	None	None			
Dakota Ranch Cave	8/19/2005	Phloxine B 3,307 g	None	None			
Windy Cave	9/6/2005	Eosin 2,500 g	Catfish Hotel Spring (119)	9/21/2005	11,800 ft (3,600 m)	15	792 ft/d (240 m/d)
			Deep Hole Spring (29)	9/21/2005	11,800 ft (3,600 m)	15	792 ft/d (240 m/d)
			Diversion Spring (30)	9/21/2005	12,100 ft (3,700 m)	15	820 ft/d (250 m/d)
			Weissmuller Spring (31)	9/21/2005	12,500 ft (3,800 m)	15	820 ft/d (250 m/d)
			Cabomba Spring (33)	9/21/2005	12,500 ft (3,800 m)	15	820 ft/d (250 m/d)
Dakota Ranch Cave	9/7/2005	Phloxine B 4,630 g	None	None			
Windy Cave	10/25/2005	Eosin 25,400 g	Well 201	<12/3/2005	3,480 ft (1,060 m)	<39	>89 ft/d >(27 m/d)
			Well 134	<11/30/2005	3,900 ft (1,190 m)	<36	>108 ft/d (>33 m/d)
			COSM Spring Lake Well (137)	11/21/2005	11,000 ft (3,300 m)	27	400 ft/d (122 m/d)
			Hotel Spring (119)	11/4/2005	12,100 ft (3,700 m)	10	1,200 ft/d (370 m/d)
			Cream of Wheat Spring (122)	11/14/2005	12,100 ft (3,700 m)	20	610 ft/d (185 m/d)
			Crater Bottom Spring (118)	11/22/2005	12,500 ft (3,800 m)	28	450 ft/d (136 m/d)
			River Bed Spring (127)	11/14/2005	11,800 ft (3,600 m)	20	590 ft/d (180 m/d)
			Artesian Well (77)	ND			
			Wonder World Cave (141)	ND			
			Kettleman's Spring (125)	ND			
			Ossified Forest Spring (126)	ND			

(Table 11. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			TSU Jackson Well (131)	ND			
			COSM Comanche Street Well (149)	ND			
			Spring Lake Total Outflow (109)	ND			
			Sink Creek at Golf Course (112)	ND			
			Spring Lake Chute (108)	ND			
			Spring Lake Spillway (110)	ND			
			Blanco River at I-35 (203)	ND			
			Well 114	ND			
			Well 202	ND			
Dakota Ranch Cave	10/26/2005	Phloxine B 30,000 g	Well 134	<11/30/2005	790 ft (240 m)	Unknown	Unknown
			Well 201	<12/3/2005	1,150 ft (350 m)	Unknown	Unknown
			Catfish Hotel Spring (119)	5/14/2006	11,5000 ft (3,500 m)	200	59 ft/d (18 m/d)
			Cream of Wheat Spring (122)	5/14/2006	11,800 ft (3,600 m)	200	59 ft/d (18 m/d)
			Ossified Forest Spring (126)	6/12/2006	11,800 ft (3,600 m)	229	52 ft/d (16 m/d)
			Crater Bottom Spring (118)	6/12/2006	12,100 ft (3,700 m)	229	52 ft/d (16 m/d)
			Deep Hole Spring (29)	3/21/2006	12,100 ft (3,700 m)	146	82 ft/d (25 m/d)
			Weissmuller Spring (31)	3/21/2006	12,100 ft (3,700 m)	146	82 ft/d (25 m/d)
			Cabomba Spring (33)	4/11/2006	12,100 ft (3,700 m)	167	72 ft/d (22 m/d)
			Hotel Spring (32)	ND			
			Diversion Spring (30)	ND			
			Artesian Well (77)	ND			
			Wonder World Cave (141)	ND			
			River Bed Spring (127)	ND			

(Table 11. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Kettleman's Spring (125)	ND			
			COSM Spring Lake Well (137)	ND			
			TSU Jackson Well (131)	ND			
			COSM Comanche Street Well (149)	ND			
			Sink Creek at Golf Course (112)	ND			
			Spring Lake Chute (108)	ND			
			Spring Lake Spillway (110)	ND			
			Spring Lake Total Outflow (109)	ND			
			Blanco River at I-35 (203)	ND			
			Well 114	ND			
			Well 91	ND			
			Well 202	ND			

< = arrival prior to the date shown.

ND = not detected

Blanco River Tracer Tests: Bull Pasture Sink, Halifax Creek, and Johnson Swallet

Blanco River traces consisted of three injection points near Blanco River 5 to 9 mi (8 to 15 km) north of San Marcos Springs. The injection points, Bull Pasture Sink, Johnson Swallet, and Halifax Creek, were selected because dyes could potentially travel to either or both San Marcos Springs and Barton Springs. These tracer tests were conducted as a collaborative project between the EAA, BSEACD, and the COA, with assistance from EAA contractor Zara Environmental.

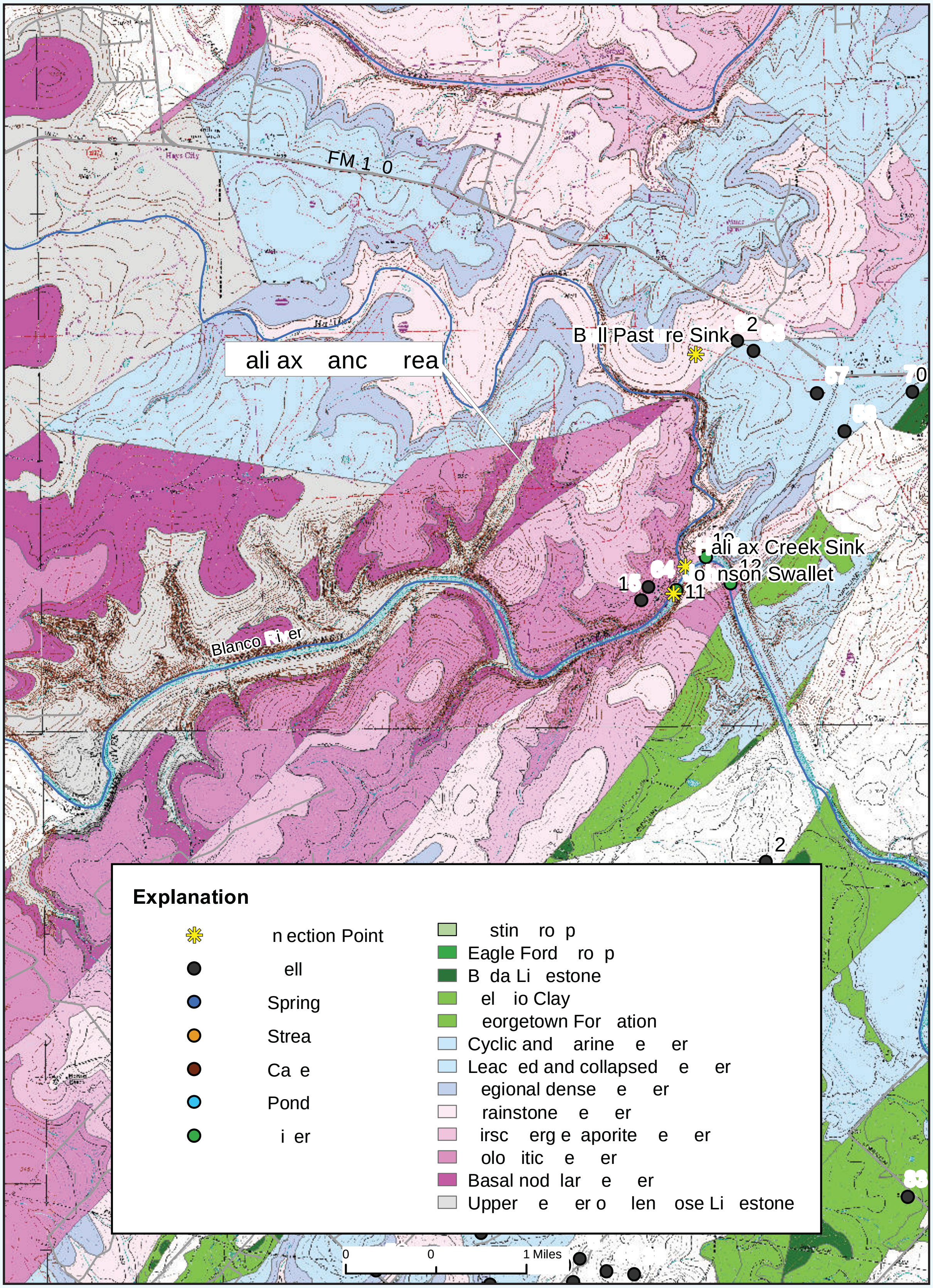
Purpose

The purpose of the Blanco River tracer tests was to investigate groundwater flowpaths near the Blanco River, which has long been postulated as a source of recharge for San Marcos and/or Barton springs. Tracer-test results also would reveal information about the nature of the hydrologic divide separating the SA and BS segments. The tracer tests were designed to measure travel times and determine the destination of water infiltrating the Blanco River watershed.

Setting of the Blanco River Tracer Tests

The Blanco River tracer-test area is located in Hays County, Texas, west of the City of Kyle (Figure 26). The terrain consists of rolling to nearly level karst uplands and valleys that drain surface water to the southeast. The Blanco River incised the Edwards Group limestones and created high bluffs along the river upstream of Kyle. The cities of Kyle and San Marcos are highly urbanized,

Figure 26. Map of Halifax Ranch Showing Geology and Injection Points



whereas surrounding areas are developed to lesser degrees by cultivation, roads, occasional buildings, dams, and other construction. Land use is characterized by several large ranches, as well as rapidly expanding housing developments.

The tracer-test area is in the Edwards Aquifer recharge zone (Figure 26), where groundwater occurs in the Edwards and the Trinity aquifers. Although the Edwards Aquifer is the principal source of water in the area, it is partly saturated or unsaturated in some areas, and shallow wells also extract water from the underlying Upper Glen Rose Formation. Groundwater is typically 100 to 250 ft (30 to 75 m) below ground surface. The regional groundwater hydraulic gradient slopes eastward and southeastward, generally reflecting the surface topography and structural dip of the Edwards Group. Groundwater gradients and flowpaths to San Marcos Springs are generally perpendicular to the strike of the Balcones Fault Zone, crossing several faults. Surface water drainages display a similar orientation. In contrast, groundwater flowpaths to Barton Springs are generally parallel to the strike of the Balcones Fault Zone (Hunt et al., 2006).

Injection Site Selection for the Blanco River Tracer Test

This area was selected for injections because it has long been suspected as a groundwater divide separating the springsheds of San Marcos Springs and Barton Springs and because the Blanco River is a potential source of recharge for either or both spring complexes. DeCook (1963) placed the groundwater divide near Buda, whereas LBG-Guyton Associates (1995) refined it to the area between Onion Creek and the Blanco River on the basis of potentiometric-surface elevations.

Specific injection sites, Bull Pasture Sink, Johnson Swallet, and Halifax Creek, were chosen after karst surveys north and south of the river and within the channel of the river. Halifax Ranch occupies much of the study area north of the Blanco River and contains most of the Halifax Creek watershed.

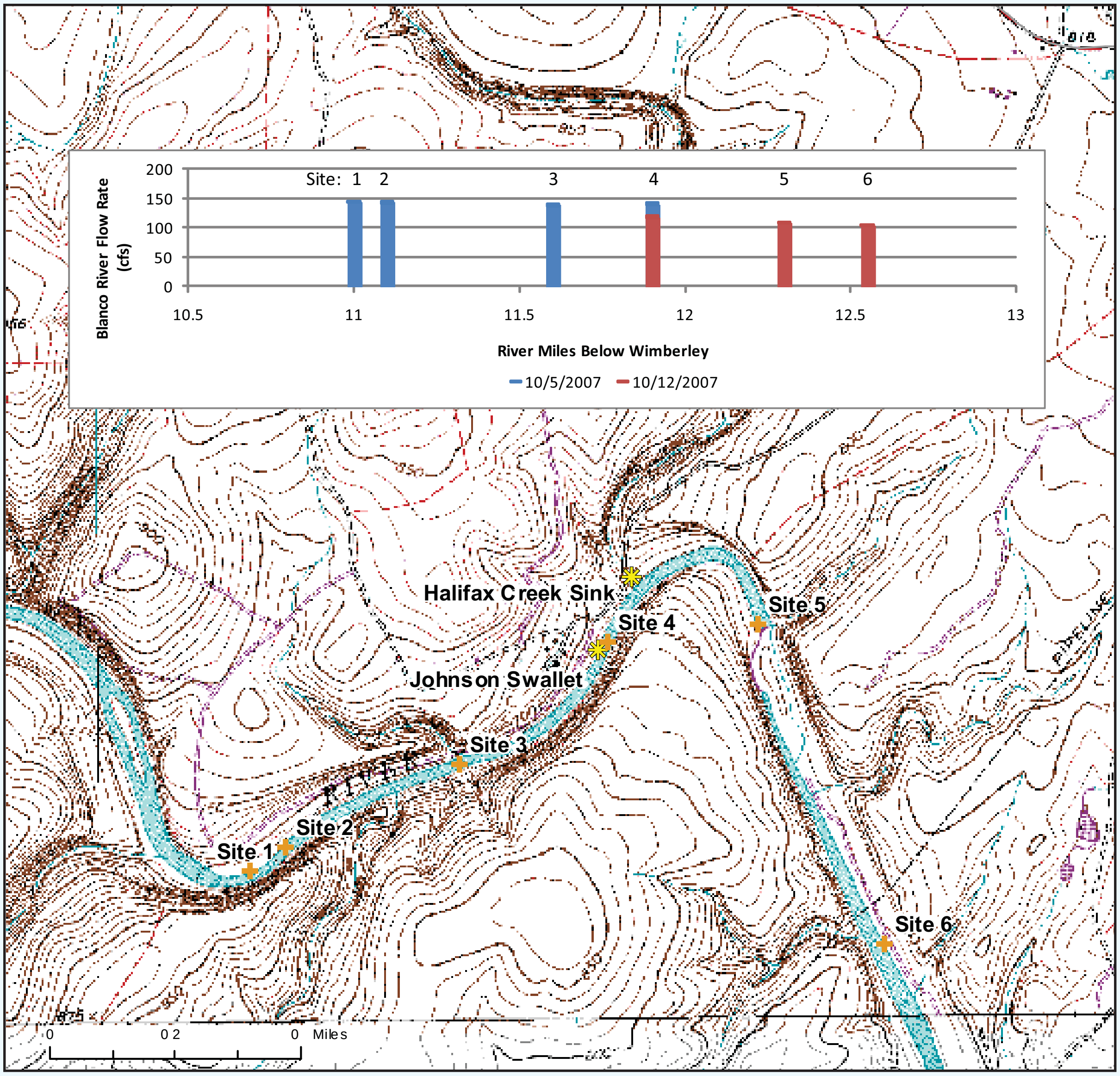
Bull Pasture Sink, the northernmost injection site for this tracer test, is located south of FM 150, approximately 5 mi (8 km) west of Kyle at an elevation of approximately 840 ft (256 m) msl. Bull Pasture Sink was selected for the tracer test because of its location near the topographic divide between the Blanco and Onion Creek watersheds. Dye injected there had a high probability of flowing to Barton Springs, according to previous tracer tests (Hauwert, 2009). Because Bull Pasture is located along the margins of a large and well-known cave system, it was thought that the feature would have a good hydrologic connection to the aquifer. The sinkhole receives surface water recharge from a large drainage area, estimated at 10 to 30 acres (4 to 12 hectares). It catches water north of the Halifax Creek drainage basin and south of the Onion Creek drainage basin. The sinkhole reportedly accepts all water flowing from this drainage basin except during exceptional precipitation events, when surface runoff overflows the sinkhole and continues north to another larger karst feature (Sinkhole and Cave). The opening of Bull Pasture Sink is roughly two × three ft (0.5 m × one m) and is filled with woody debris and soil. The feature is too small for access by humans, and it was not excavated during this study.

The confluence of Halifax Creek with the Blanco River was a potential injection point because the river loses eight to 12 percent of flow in the reach, as measured by the study team in October 2007 and previous studies by the USGS (Slade et al., 2002).

The confluence of Halifax Creek with the Blanco River was also explored as a potential injection point because of documented channel losses in the vicinity and reports of a historical sinkhole. Channel losses from the Blanco River were measured by the USGS (Slade et al., 2002). The reach of the Blanco River about a mile above and below Halifax Creek recorded approximately 10 cfs (2.8 m^3/s) of flow loss in January and March 1955. In October 2007, as a part of this study, river flow was measured to identify the losing reach more precisely. The flow loss between Sites 4 and 5 (Figure 27) was about 10 cfs (2.8 m^3/s), which is similar to 1955 measurements for this reach of the river and corresponds to the approximate location of Halifax Sinkhole.

In addition to channel losses, there was anecdotal evidence of a large sinkhole existing at this location about 100 years ago. According to stories told to Mr. Johnson

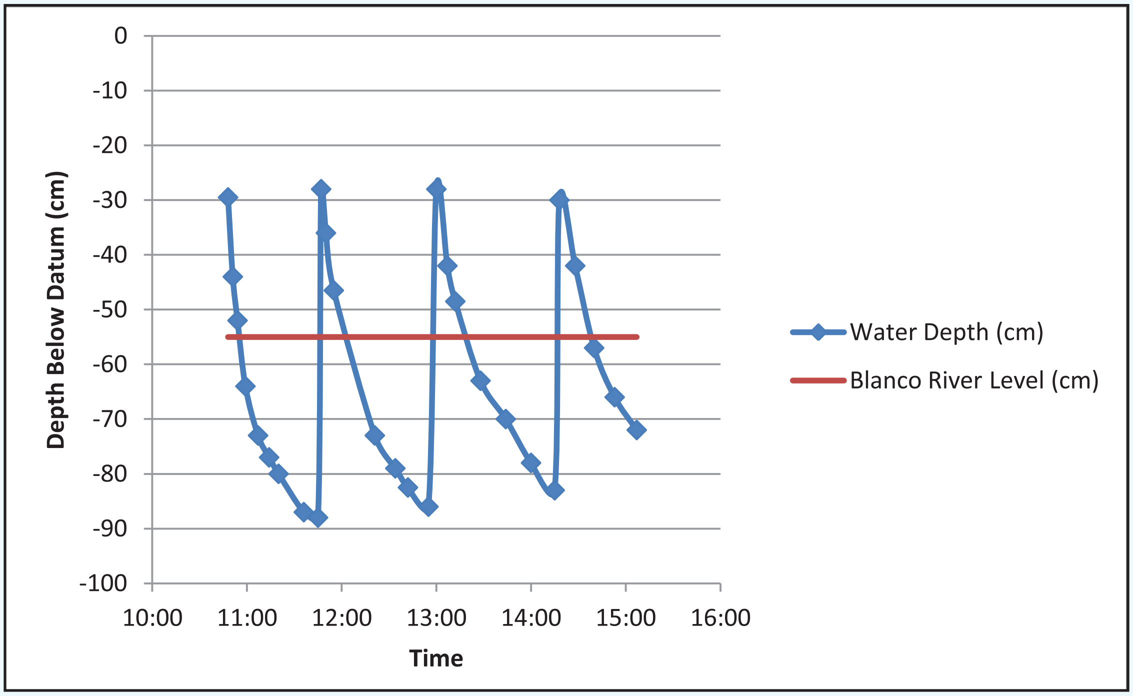
Figure 27. Flow Survey of the Blanco River along Halifax Ranch, October 2007. Flow Measured by Marcus Gary, Nico Hauwert (COA), and Joseph Beery (BSEACD)



and other local residents, a large sinkhole reportedly opened at the confluence of Halifax Creek and the Blanco River around the year 1899 that diverted all flow from the Blanco River, leaving no water for powering a grist mill downstream. Consequently, residents at that time filled the sinkhole with rocks, trees, soil, and other debris to sustain river flow to the grist mill. A memorandum from the Texas Department of Water Resources (Watson, 1985) provided additional, corroborating information about the historical sinkhole at the mouth of Halifax Creek. However, no obvious surface expression of a sinkhole currently exists at this location, although the channel loss in this general location suggests the presence of a large recharge feature.

To locate the sinkhole, the study team excavated several pits at the mouth of Halifax Creek. Although the original sinkhole was not found, the team excavated a shallow pit within 10 ft (three m) of the river to use as an injection point. The team conducted percolation tests to determine whether the excavation was suitable for an injection point. The tests showed consistent loss rates of water

Figure 28. Percolation Test of the Pit Dug in the Approximate Location of the Halifax Sinkhole. Data and Chart from Marcus Gary.



(Figure 28). This hole is 10 ft (three m) from the north bank of the river, and a static water level was found to be approximately 3.3 ft (one m) below the river level, resulting in a steep hydraulic gradient of 0.33 ft/ft (0.06 m/m) and flow potentially away from the river. Substrate material between the river bank and the test hole was sandy loam with large cobbles and boulders. So that a high gradient with relatively permeable soils could be maintained, significant amounts of subsurface water probably flowed from the river at this site, making it a suitable injection point. The ground surface elevation is approximately 675 ft msl (206 m msl), which is approximately 102 ft (31 m) above San Marcos Springs and approximately 213 ft (65 m) above Barton Springs.

In December 2008, flow in the Blanco River was 13 cfs (0.37 m^3/s) at Wimberley. These low flows allowed for a careful inspection for other recharge features normally below the river's water level. Johnson Swallet (named for the family that owns Halifax Ranch) was subsequently discovered in December 2008 on the south bank of the Blanco River by Nico Hauwert of the COA. It is located approximately 1,000 ft (320 m) upstream of Halifax Creek at an elevation of approximately 670 ft msl (204 m msl). Upon discovery, the feature was actively recharging approximately 0.2 cfs (0.006 m^3/s) of water to the aquifer, so it was an obvious choice for an injection point.

Pre-Injection Preparation and Monitoring

Background water samples were collected at monitoring sites before the initial dye injection. No naturally occurring fluorescent materials in the ranges of the dyes used for the tests were detected in background samples from wells. Barton Springs samples contained relatively low levels of residual Eosin and Uranine. However, they were low enough that the additional dye injected for these tracer tests would be expected to exceed background concentrations, as discussed in the Results section later. Background samples were collected from individual springs at San Marcos Springs to determine whether Eosin and Phloxine B were still present from the western tracer tests in 2006. Although Phloxine B from Dakota Ranch Cave was still detectable at several individual springs at San Marcos Springs, Eosin from Windy Cave had disappeared from all sites when monitoring ended in October 2006. Consequently, only Eosin was used for Blanco River tracer tests.

Figure 29. Julie Jenkins (BSEACD) and Justin Camp (COA) Injecting Uranine into Bull Pasture Sink

Figure 30. From left, Bill Russell (TCMA), Julie Jenkins (BSEACD), and Justin Camp (COA) Injecting Eosin into Halifax Sink

Study team members divided the sites to monitor for the presence of dye. Monitoring sites included public and private water wells and some periodic monitoring of the Blanco River. The EAA (and its contractor, Zara Environmental) monitored all wells south of the Blanco River (27 wells), San Marcos River (five sites), and San Marcos Springs (five sites in Spring Lake). The BSEACD monitored all wells north of the Blanco River (40 wells), and the COA monitored Barton Springs (four sites).

Injections

The Blanco River tracer tests were completed during drought conditions, which enhanced the probability for flow to be directed toward San Marcos Springs and Barton Springs. Dye tracing is challenging during drought conditions because travel times slow considerably, or even cease. Consequently, recovery of dyes has consistently been poor during drought conditions (Hauwert et al., 2004; Hauwert, 2009). Therefore, relatively large volumes of dye were necessary so that they could be detected during drought conditions, and especially for long distances to the springs in this study. In addition, dyes were injected in two stages; an initial stage involved a small amount of dye to determine whether dye would be visible at nearby water-supply wells. Subsequent injections involved much larger quantities of dye that would be necessary to reach both spring complexes.

Bull Pasture Sink. A small amount of Uranine dye (0.11 kg; 0.24 lb) was injected into Bull Pasture Sinkhole on May 20, 2008, and was flushed with approximately 10,000 gal (38,000 L) of Blanco River water. Two nearby wells (Wells 62 and 70) had low-level positive detections in a water sample and receptor, respectively. No visible dye was detected or reported after this initial injection. A follow-up quantity of 13.6 kg (30 lb) of Uranine was injected on June 10, 2008, and was similarly flushed with approximately 10,000 gal (38,000 L) of Blanco River water (Figure 29).

Halifax Creek Sink. A small amount of Eosin (0.2 kg; 0.45 lb) was injected with a peristaltic pump through piezometers hammered into the excavation at Halifax Creek on May 20 and 21, 2008, and was flushed with Blanco River water (Figure 30). Up to a week after the initial injection, low levels of Eosin were detected on a charcoal receptor in one public water supply well (Well 75), located approximately 3 mi (5.3 km) north-northeast of the injection point. Because no visible dye was detected or reported in nearby wells after this initial injection, larger quantities of dye (6 kg; 13 lb) were subsequently injected on June 10, 2008, and September 12, 2008 (Table 12).

Johnson Swallet. Eosin, which was injected at Halifax Creek sinkhole, was also injected into Johnson Swallet because it was presumed that both features received

Figure 31. Johnson Swallet with Injection Pipe Inserted into Feature

infiltration from the Blanco River and could be treated hydrologically as a single location. In addition, other dyes capable of tracing long distances had already been injected at other points. A single mass of 23.7 kg (52.5 lb) of Eosin was injected into Johnson Swallet on February 26, 2009. The injection was staged on a gravel bar, and dye was injected into the swallet through plastic tubing (Figure 31). The natural flow of the Blanco River, estimated at 0.2 cfs (0.006 m^3/s), carried the dye into the feature.

Results

Dyes from the Blanco River injection points were detected at monitoring sites north and south of the Blanco River and at San Marcos and Barton springs. Monitoring sites at which one or more dyes were detected are summarized in Table 12.

Bull Pasture Sink (Uranine Dye) Wells. A relatively large volume of Uranine (13.6 kg; 30.8 lb) was injected into Bull Pasture Sink to produce detectable concentrations after traveling up to 20 mi (32 km) to Barton Springs. As a precaution, a small volume (107 g; 0.24 lb) of Uranine was initially injected into Bull Pasture Sink on May 20, 2008, to evaluate effects on nearby wells. Although dye was visible in nearby wells, it did not disrupt any water supplies, so a larger volume of dye was subsequently injected at Bull Pasture Sink on June 10, 2008.

Within eight days after the first injection, Uranine was detected at Well 70, which is 6,400 ft (1,960 m) east of Bull Pasture Sink, for an apparent velocity of approximately 800 ft/d (260 m/d) (Figure 32). Uranine from the second injection at Bull Pasture Sink was also detected, and it persisted at low levels until sampling ended in May 2009.

Dye was detected at non-visible levels in Well 62 within 10 days after initial injection on May 20, 2008. However, Uranine was visible in Well 62 the day after the subsequent June 10, 2008, Uranine injection. The well is 1,300 ft (400 m) east of the injection point, and it persisted at visible concentrations for three days. In addition, dye was detected in Well 63, a private domestic well located approximately 1,700 ft (520 m) east-northeast of Bull Pasture Sink and adjacent to Well 62. Owners of Wells 62 and 63 reported that water from Well 62 turns turbid after significant rainstorms, which is consistent with being completed in a conduit connected to nearby karst features. Uranine was still present at low levels when sampling ended in September 2008.

Uranine was detected in a water sample from Well 48 on June 17, 2008, approximately 28,500 ft (8,700 m) south of Bull Pasture Sink (Figure 33), for an apparent velocity of approximately 3,900 ft/d (1,200 m/d). It was detected again in a water sample on June 27, 2008. This was the only location south of the Blanco River that showed a positive detection of Uranine.

Figure 32. Tracer-Test Results North of the Blanco River

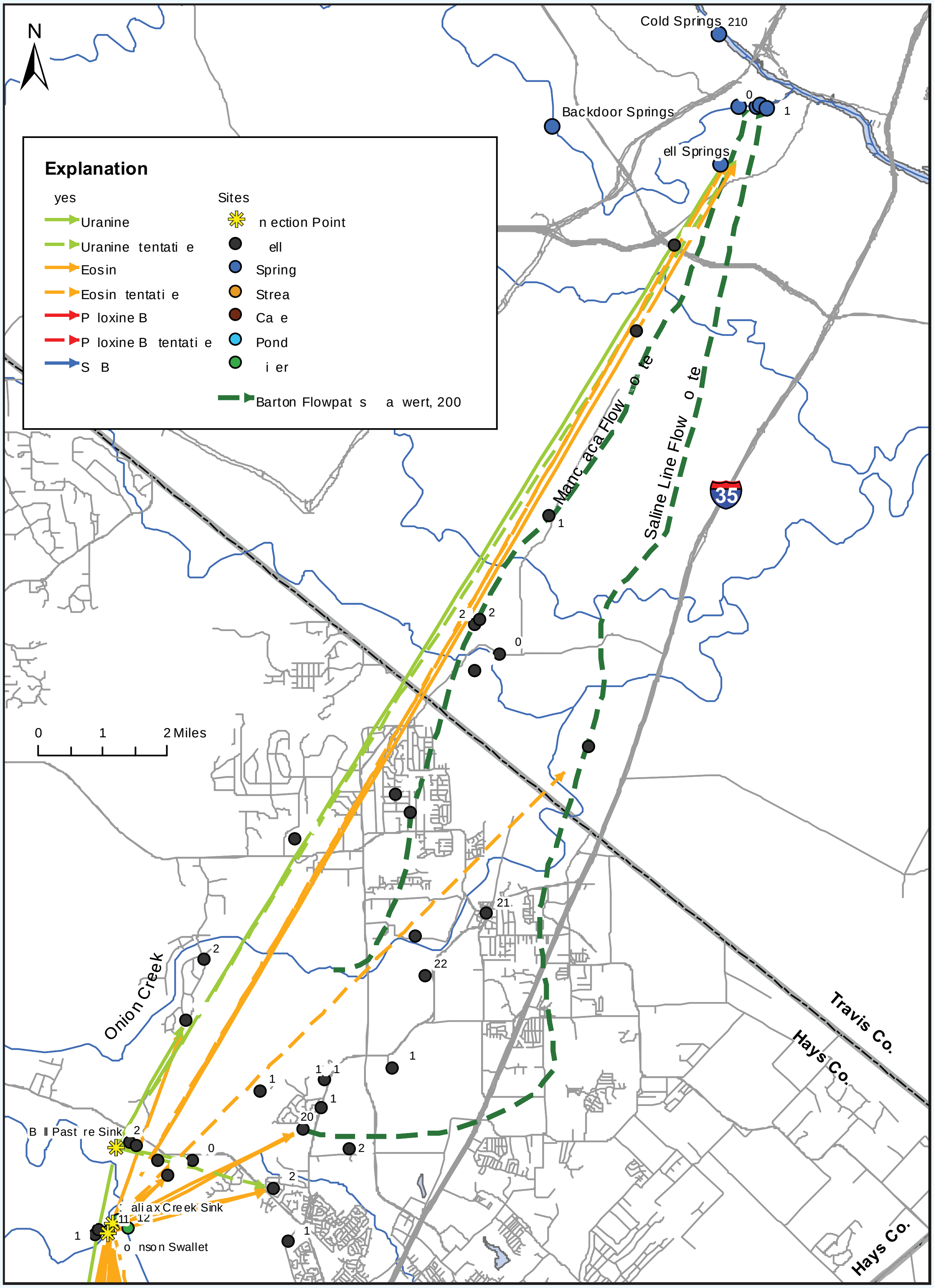


Figure 33. Tracer-Test Results South of the Blanco River from Blanco River Injection Points

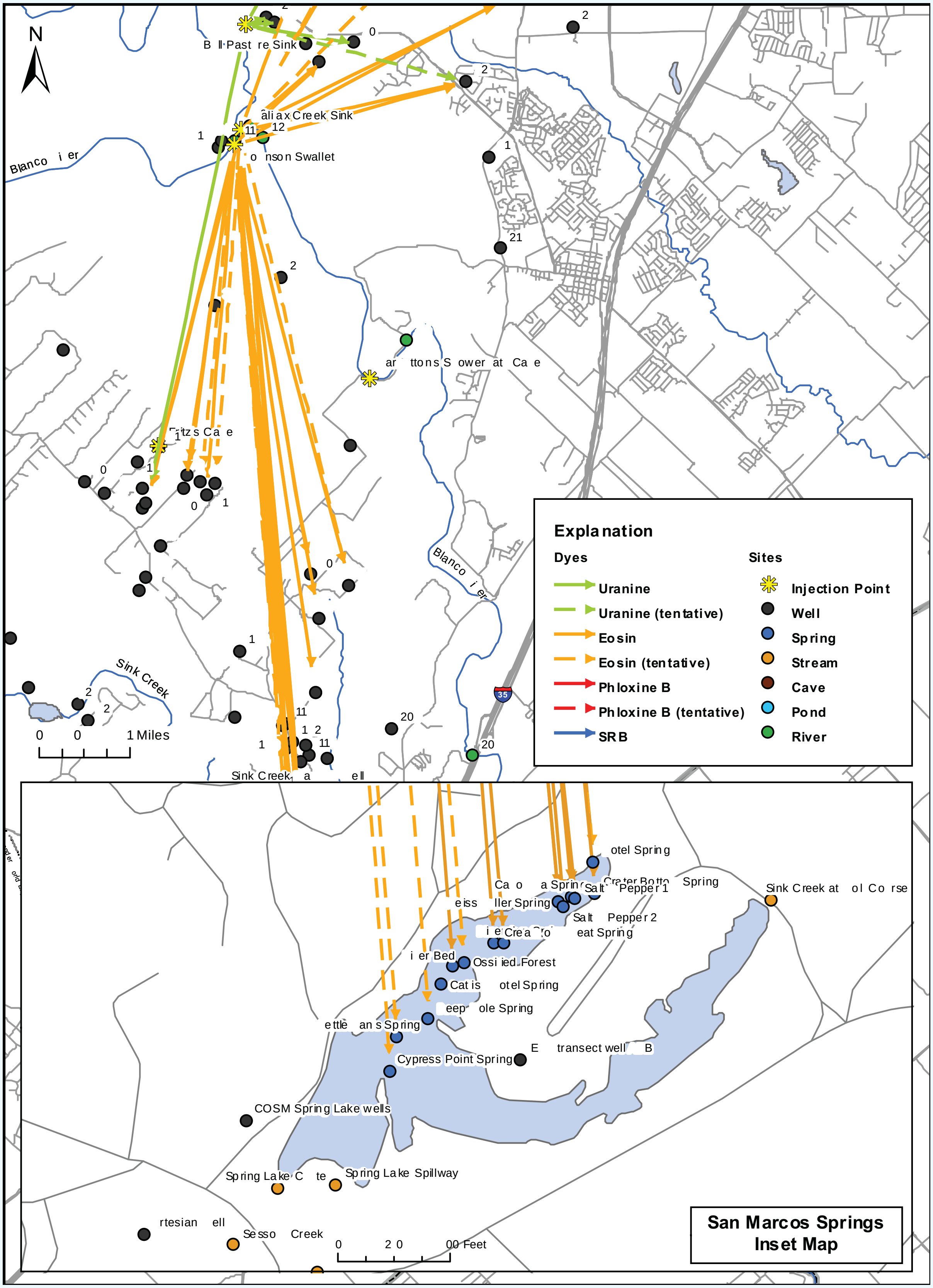
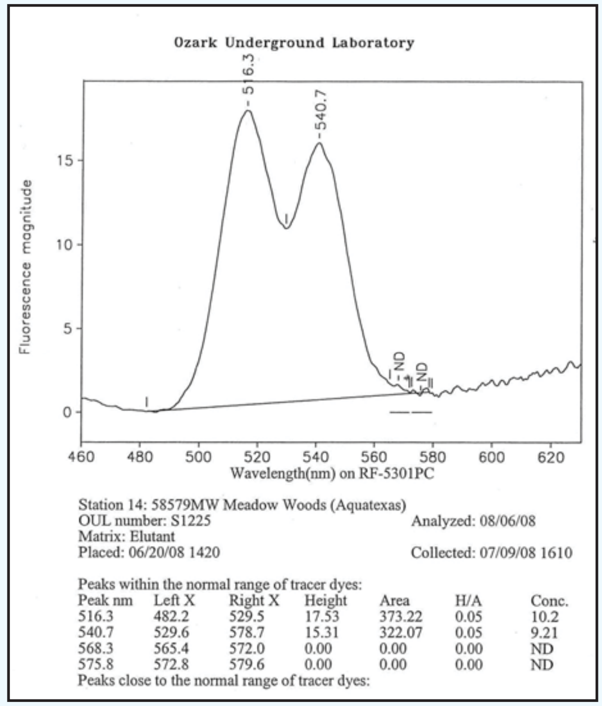


Figure 34. Monitoring Site 58579MW (Meadow Woods) and PVC Canisters that Hold Charcoal Receptors

Figure 35. Fluorescence Results from a Charcoal Sample from Meadow Woods Well with Uranine and Eosin Peaks



Uranine was detected in a single sample from Well 72, which is 13,500 ft (4,100 m) southeast of Bull Pasture Sink, for an apparent velocity of approximately 460 ft/d (140 m/d). It is considered tentative because no other samples contained detectable Uranine. Figure 34 shows a charcoal receptor in Well 72, and Figure 35 shows the analysis from OUL for this sample in which both Uranine and Eosin were detected.

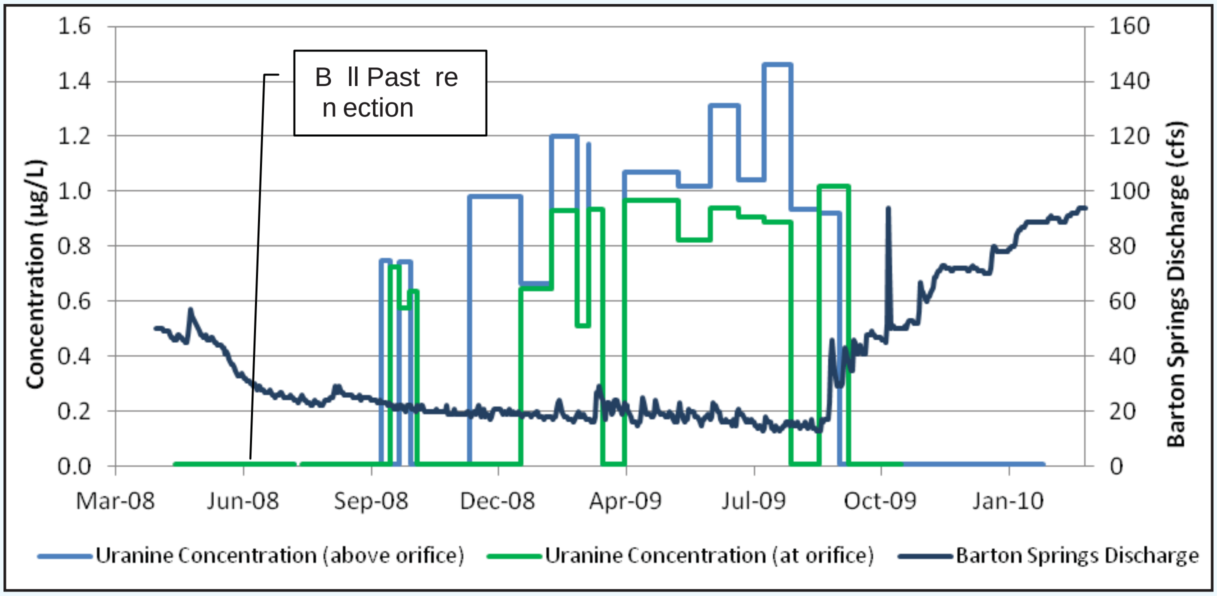
San Marcos Springs. No Uranine from Bull Pasture Sink was detected at San Marcos Springs.

Barton Springs. Because Uranine had not been detected at Barton Springs in charcoal receptors since May 30, 2007, Uranine injected at Bull Pasture Sink would be recognized unequivocally. Uranine injected on May 20, 2008, at Bull Pasture Sink was detected at nearby wells, but the amount (107 g; 0.24 lb) was assumed to be too small to be detected at Barton Springs. On June 10, 2008, 13.6 kg (30 lb) of Uranine was injected into Bull Pasture Sink, and it arrived at Main Barton Springs 106 days later on September 24, 2008, for an apparent velocity of approximately 950 ft/d (290 m/d). It persisted at Barton Springs until November 6, 2009. Because one sample from Old Mill Spring, collected on October 16, 2008, contained Uranine, it is considered a tentative detection. Uranine concentrations also appeared to increase after precipitation events flushed dye stored in the vadose zone below the Bull Pasture Sink injection site and into the groundwater system (Figure 36).

Previous tracer tests revealed two principal routes through the EABS segment to Barton Springs: Manchaca and Saline-Line flow routes (Figure 32). The Manchaca Flow Route discharges at Eliza, Main Barton, and, to a lesser extent, at Old Mill Springs, and contributes the most flow to Main Barton Springs. Saline-Line flow route discharges primarily at Old Mill and Main Barton springs (Hauwert, 2009). Uranine detected at 58579MW Well (78) may have become entrained in the Saline-Line Flow route, although it was not detected in any wells known to be on the Saline-Line flow route to Barton Springs. Although Uranine was detected at Main Barton Springs, the exact flowpath is not known.

Abrupt increases in flow at both the Blanco River and Barton Springs from September 5 through 11, 2009, appeared to flush dyes to Barton Springs. Assuming that

Figure 36. Breakthrough Curves for Uranine in Barton Springs



residual Uranine was trapped near Bull Pasture Sink and then flushed by infiltrating precipitation, conditions were similar to those of new injections. Uranine was detected at Old Mill Springs on October 16, 2009, 493 days after the Blanco River discharge increased, for an apparent velocity of approximately 2,800 ft/d (840 m/d).

Halifax Creek Sinkhole (Eosin Dye) Wells. Eosin from Halifax Creek traveled northeast to four wells north of the Blanco River (Figure 37). The initial injection (completed over two days) showed up within seven days on May 28, 2008, only at Well 75, a public supply well located 17,400 ft (5,300 m) north-northeast of the injection site, for an apparent velocity of approximately 2,500 ft/d (760 m/d). Eosin was also detected at the same well five days after the third Eosin injection on September 12, 2008. Dye concentrations quickly declined to near detection limit concentrations. However, charcoal receptors from this site were frequently dry because the well was periodically turned off. Because this well also yielded Eosin detections from a tracer test in Onion Creek conducted by the COA and the BSEACD in May 2005 (Hunt et al., 2006), there was some uncertainty regarding the origin of the Eosin. Although no background samples were collected before the Eosin injections for this study, the large increase in Eosin concentrations from subsequent injections in September 2008 confirmed that it is hydrologically connected to Halifax Creek.

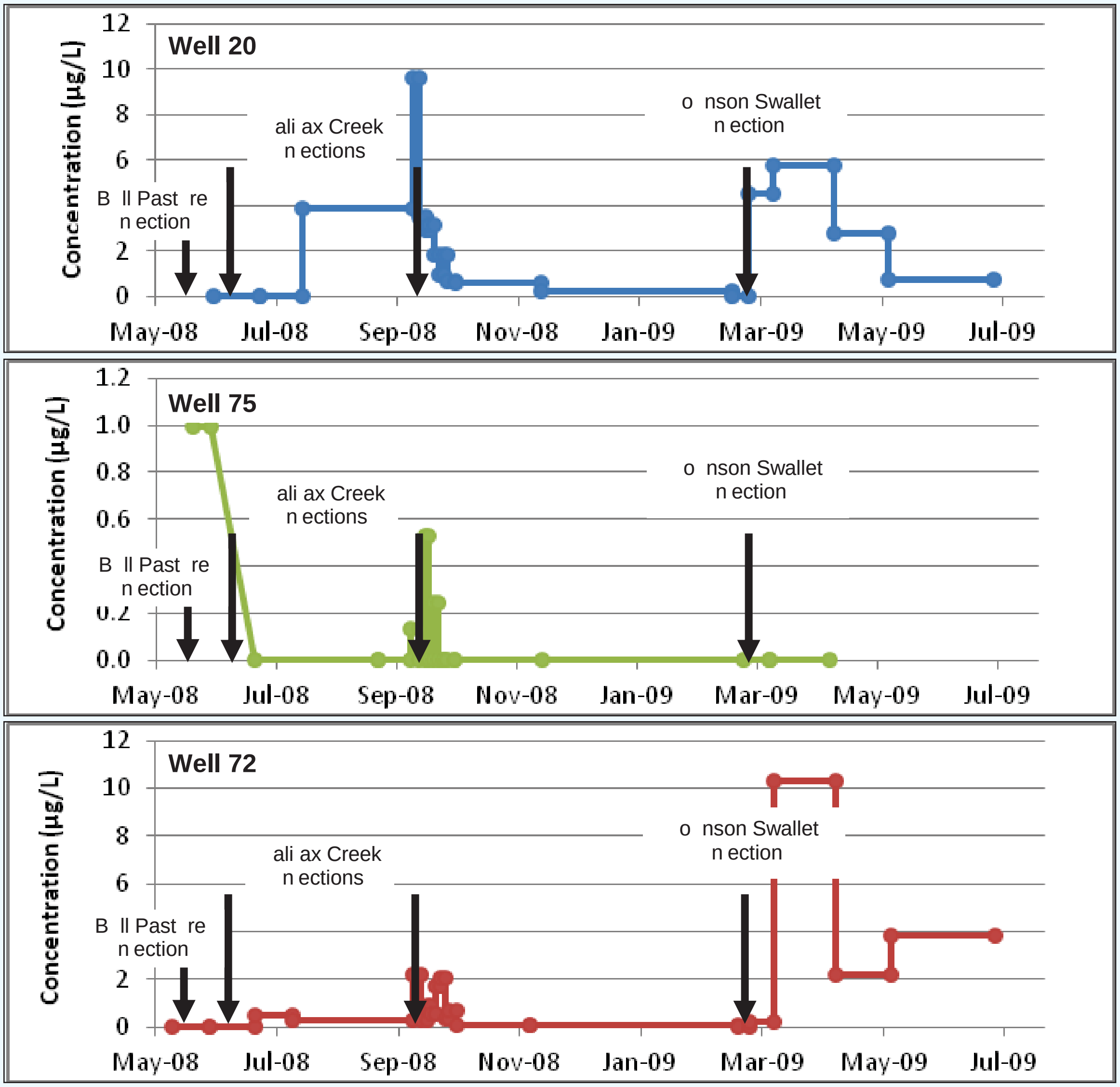
Eosin was detected in Well 58, which is 6,230 ft (1,900 m) northeast of Halifax Creek, after the third injection at Halifax Creek, for an approximate apparent velocity of 39 ft/d (12 m/d). Eosin was detectable there until the Johnson Swallet injection in February 2009.

Well 72, 13,450 ft (4,100 m) northeast of Halifax Creek, also intercepted Eosin 29 days after the second injection on July 9, 2008, for an apparent velocity of approximately 460 ft/d (140 m/d). Eosin concentrations declined until the Johnson Swallet injection in February 2009 (Figure 37).

Well 20 intercepted Eosin following the second and third injections. Eosin arrived within three days after the third injection, for an apparent velocity of approximately 1,300 ft/d (400 m/d). This well also yielded Eosin detections from a tracer test in Onion Creek conducted by the COA and the BSEACD in May 2005 (Hunt et al., 2006). No background fluorescence was detected in the well prior to injection for this study, so the Eosin was clearly from Halifax Creek Sinkhole. Concentrations peaked in September 2008 following the third Eosin injection at Halifax Creek and then declined until the Johnson Swallet injection in February 2009 (Figure 37).

Eosin was detected at Well 48, which is 22,300 ft (6,800 m) south of Halifax Creek Sinkhole, starting on July 25, 2008, for an apparent velocity of approximately

Figure 37. Breakthrough Curves for Wells 20 (5857913), 75 (5857512), and 72 (58579MW) in Charcoal Receptors



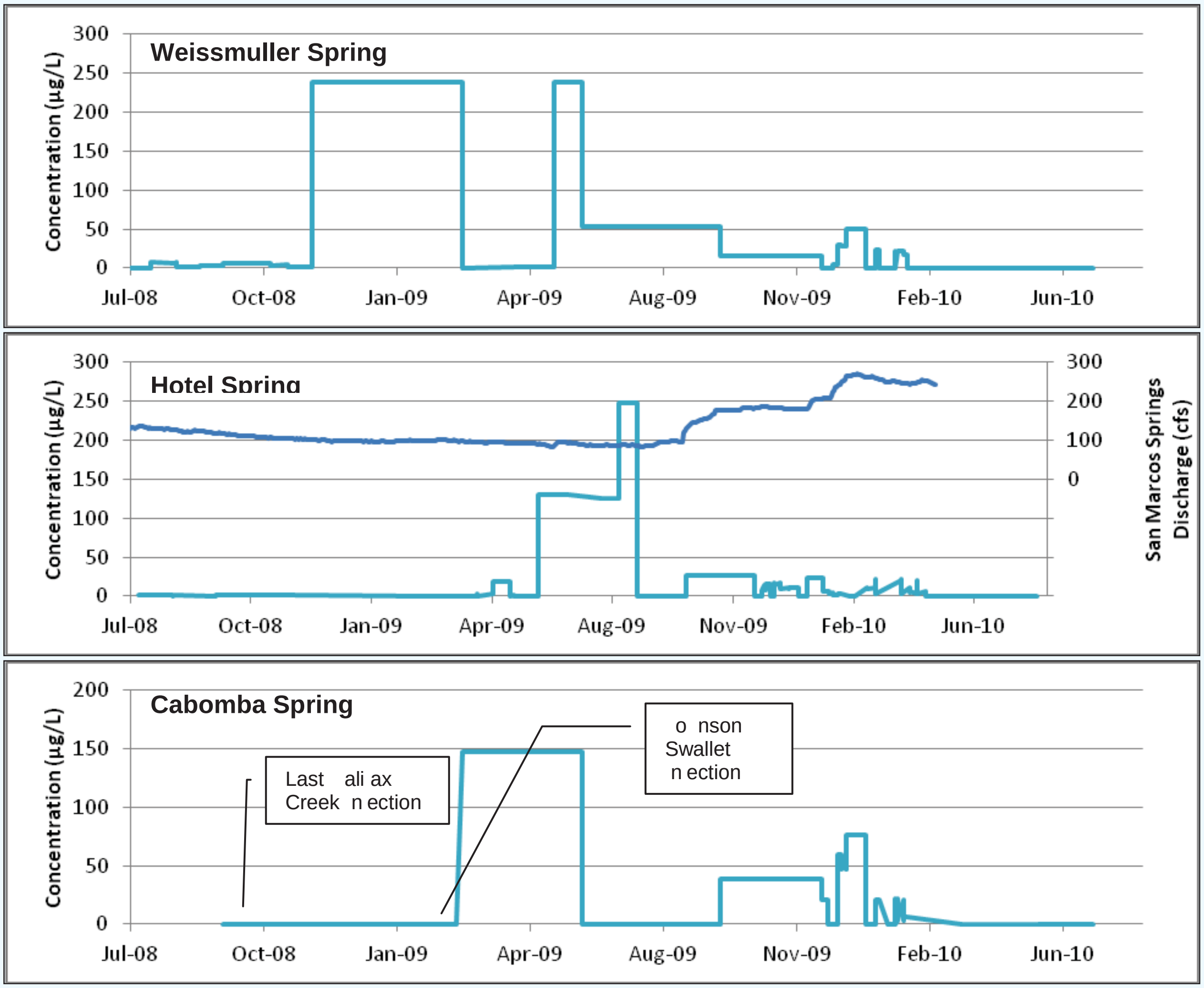
490 ft/d (150 m/d). It was detected in several subsequent samples until November 2008. Uranine from Bull Pasture Sink was also detected at Well 48.

Three tentative Eosin detections were reported: Wells 38, 49, and 66. Although analyses were reliable, a single detection was considered tentative. Well 66, which is located about 10.6 mi (17,000 m) northeast of Halifax Creek along the Edwards Aquifer Saline Water interface, had one detection on July 9, 2008. Eosin was detected once at Well 38, which is 21,300 ft (6,500 m) south of Halifax Creek Sinkhole, on August 4, 2008. It was detected at Well 49, which is the same distance from Halifax Creek, on September 9, 2008. Apparent velocities ranged from 240 to 1,900 ft/d (72 to 590 m/d). The hydrologic connections with Halifax Creek Sinkhole will have to be confirmed by future tracer tests.

Eosin from Halifax Creek Sinkhole was not detected in several wells south of the Blanco River, including Wells 2, 3, 6, 35, 37, 41, and 91.

San Marcos Springs. Individual springs at San Marcos Springs responded to injections at Halifax Creek Sinkhole. The most complete sample set was from Hotel Spring (Figure 38), which is 8.3 mi (13,300 m) from Halifax Creek Sinkhole. After the Halifax Creek Sinkhole injection on June 10, 2008, Eosin was detected

Figure 38. Eosin Concentrations at Weissmuller, Hotel, and Cabomba Springs in Charcoal Receptors



at Hotel Spring beginning between July 8, 2008, and August 5, 2008, which represented an apparent velocity of approximately 790 ft/d (240 m/d). It persisted at Hotel Spring until November 2008. At Weissmuller Spring, Eosin from Halifax Creek Sinkhole was initially detected in a charcoal receptor on August 4, 2008, which represents an apparent velocity of approximately 790 ft/d (240 m/d).

Barton Springs. Prior to the Blanco River tracer tests, background Eosin concentrations at Barton Springs ranged from 0.7 to 0.3 µ/L per day, which originated from an injection of 13.6 kg (30 lb) of Eosin west of Highway 45 and MoPac Expressway on April 10, 2007 (Hauwert et al., 2011). Because the residual Eosin was relatively low and below detection limits in water samples, it was expected that dye from injections near the Blanco River would be distinguishable from background concentrations.

For Eosin injections, interpretation of dye arrival times at Barton Springs was more complex than that of Uranine because of residual Eosin in background samples prior to first injection and because the dye moved relatively slowly during the tests. Eosin injections into Halifax Creek Sinkhole on May 20 and 21, 2008 (204 g; 0.45 lb), and June 10, 2008 (13.6 kg; 30 lb), did not create clear breakthroughs at Barton Springs that were distinguishable from background. Following October 1, 2008, Eosin concentrations in charcoal declined below quantitation limits, and Eosin was injected two more times in an attempt to produce a breakthrough at Barton Springs. On September 12, 2008, 6.35 kg (13 lb) of Eosin was injected at the Halifax Creek Sinkhole. Low concentrations of Eosin were measured in Main Barton Springs in a charcoal receptor in place between December 3, 2008, and January 12, 2009. However, it was a tentative detection because (1) Eosin concentrations were low, (2) it was measured only in one sample, and (3) it was not distinguishable at Eliza Springs.

Eosin from Halifax Creek Sinkhole was intercepted by Wells 20 and 75 and may have followed the Saline-Line Flow route to Old Mill Springs. Previous tracer tests linked the Ruby Ranch wells (Well 75) to Barton Springs after an injection at Crippled Crawfish Cave in Onion Creek, particularly during low-flow conditions (Hauwert et al., 2004, 2009). Similarly, Eosin detected at Well 58579MW (Well 72) may have become entrained in the Saline-Line Flow route, although it was not detected in any wells known to be on the route closer to Barton Springs. Eosin was tentatively detected at Well 5858209 (Well 66), which is located approximately 11 mi (17 km) northeast of Halifax Sink along the Edwards Aquifer saline water interface and perhaps close to the Saline-Line Flow Route.

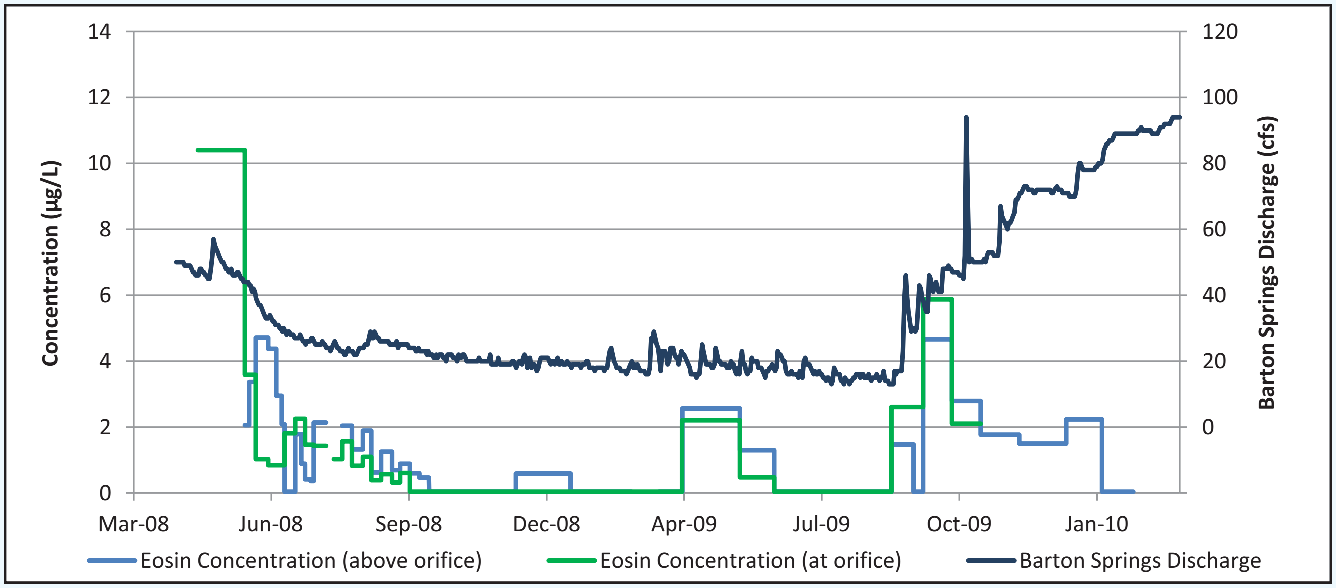
Eosin in background samples from Cold Springs interfered with any additional Eosin from current tracer tests. However, it is currently thought to be unlikely that dyes from Blanco River injection points would travel to Cold Springs because previous tracer tests have shown that it has its own springshed (Hauwert, 2009).

Johnson Swallet (Eosin Dye) Wells. Eosin injected into Johnson Swallet on February 26, 2009, was detected at three monitoring sites (Wells 20 and 72) north of the Blanco River (Figure 32). Although Eosin was already present at Well 20, its concentration significantly increased within 12 days after the Johnson Swallet injection for an apparent velocity of approximately 1,500 ft/d (460 m/d). Similarly, Eosin concentrations abruptly increased at Well 72 after injection. Although it responded to Halifax Creek injections, no Eosin was detected at Well 75 after the Johnson Swallet injection, which is probably the result of problems with the charcoal receptors taken offline at the pump as described earlier.

Eosin was detected at 11 wells south of the Blanco River after the Johnson Swallet injection (Table 12). Eosin was visible at two wells: Well 90, starting March 9, 2009, and Well 48, starting March 2, 2009, for apparent velocities of approximately 2,300 and 5,200 ft/d (710 and 1,600 m/d), respectively. Several samples from Well 89 contained Eosin beginning in March 2009 and disappearing in December 2009. Eosin was detected in a single sample from Well 202 on April 15, 2009. It was subsequently detected at Well 40 on March 6, 2009, for an apparent velocity of more than 2,600 ft/d (780 m/d), and it persisted until May 2009. Eosin was detected at Well 5 starting June 30, 2009, for an apparent velocity of approximately 210 ft/d (64 m/d) and persisted at relatively high concentrations until May 2010. It appeared at Well 7 in March 2009 at low concentrations and at relatively high concentrations in August 2009, before disappearing by October 2009. Eosin was detected at Well 41 between June and October 2009, although it did not intercept any dye from the Halifax Creek injection. Wells 99 and 100 contained Eosin from October 2009 until May 2010. Similarly, Well 92 yielded Eosin from December 2009 until May 2010.

In some wells, the origin of Eosin was ambiguous because it could have been either Halifax Creek Sinkhole or Johnson Swallet injections, given only the dates of detection. However, evidence supports Johnson Swallet as the origin for most distant wells south of the Blanco River. For example, Eosin was detected at Well 89 (6.2 mi; 9,900 m) south of Halifax Creek Sinkhole) in the first sample collected there on March 13, 2009. Because this well was added to the monitoring network after the Johnson Swallet injection, the origin of the Eosin could be either Halifax Creek Sinkhole or Johnson Swallet. If it originated from Halifax Creek Sinkhole, the apparent velocity would be greater than 180 ft/d (55 m/d), compared with less than 2,300 ft/d (710 m/d) if it originated from Johnson Swallet. Either scenario is plausible, although the relatively strong response and higher apparent velocity suggest that the origin was Johnson Swallet. With the higher velocity, there is less dilution, so dye would arrive at the well at a higher concentration. Eosin concentrations at Well 90 (4.8 mi; 7,800 m) south of Johnson Swallet) were also relatively high, which suggests that a slug of groundwater with less diluted Eosin from Johnson Swallet was moving in the same direction as Well 89. In addition, Eosin concentrations at Wells 5 and 48 indicated that Eosin from Halifax Creek Sinkhole had passed by in late 2008 or early 2009, before it had exhibited a strong response

Figure 39. Breakthrough Curves for Eosin at Main Barton Springs in Charcoal Receptors



to the Johnson Swallet injection in March 2009. No Eosin was detected at Wells 5, 47, or 48 until March 2009 or later, which could be evidence that Eosin from Halifax Creek Sinkhole had been diluted beyond detection before the Johnson Swallet dye arrived.

San Marcos Springs. Most of the individual springs at San Marcos Springs that were monitored intercepted Eosin from the Johnson Swallet injection, including Cabomba, Cream of Wheat, Cypress Point, Deep Hole, Diversion, Kettleman's, Ossified Forest, River Bed, Salt and Pepper 1 and 2, and Weissmuller. The most complete sampling results were recorded at Weissmuller, Hotel, and Cabomba springs (Figure 38). In the figure, the width of the rectangle spans the period of time that the charcoal receptor was in each spring, and the height represents the concentration of dye in the sample. Eosin from Johnson Swallet was detected in a charcoal receptor from Hotel Spring collected on April 28, 2009, for an apparent velocity of approximately 720 ft/d (220 m/d). It was subsequently detected at Diversion and Weissmuller springs on May 15, 2009, for an apparent velocity of approximately 560 ft/d (170 m/d). Eosin concentrations peaked between June and September 2009 and again between November 2009 and February 2010, before disappearing by May 2010. Velocities could not be calculated for other springs because Eosin was detectable in the first sample, indicating that it had arrived prior to the sample date. Eosin detected in 2008 had originated from Johnson Swallet because Eosin from Windy Cave (2005) was no longer detectable in the groundwater system. In addition, although Eosin was detectable in many samples from individual springs, it was rarely detectable at the USGS gauge that represented the total outflow of Spring Lake. During the period, San Marcos Springs discharge ranged from 83 to 270 cfs (2.4 to 7.2 m^3/s).

Catfish Hotel was the only individual spring monitored that had no Eosin detections. Some of the wells near San Marcos Springs had no detections, including Wells 86, 101, and 115.

Barton Springs. The final Eosin injection was 24 kg (52.5 lb) at Johnson Swallet on February 26, 2009. Eosin was measured in multiple charcoal receptors collected on May 15, 2009, at both Eliza and Main Barton springs, 78 days after injection, for an apparent velocity of approximately 1,400 ft/d (420 m/d). The breakthrough of Eosin following the 24-kg (52.5-lb) injection was significantly higher than after the 6.35-kg (13-lb) injection at Halifax Creek Sinkhole (Figure 39).

As mentioned earlier, increased flow in the Blanco River beginning September 9, 2009, appeared to flush Eosin to Barton Springs. Assuming that residual Eosin trapped near Johnson Swallet was flushed by infiltrating river water, it was detected at Old Mill Springs 86 days later on December 4, 2009, for an apparent velocity of approximately 1,200 ft/d (370 m/d).

Table 12. Summary of Blanco River Tracer-Test Results (2009)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Halifax Creek Sinkhole	5/20/2008	Eosin 100 g	None				
Halifax Creek Sinkhole	5/21/2008	Eosin 104 g	Well 75	5/28/2008	17,400 ft (5,300 m)	7	2,500 ft/d (760 m/d)
Halifax Creek Sinkhole	6/10/2008	Eosin 13.6 kg	Well 72	7/9/2008	13,450 ft (4,100 m)	29	460 ft/d (140 m/d)
			Well 20	6/23/2008	17,400 ft (5,300 m)	13	1,300 ft/d (410 m/d)
			Well 38[T]	8/4/2008	21,300 ft (6,500 m)	55	390 ft/d (120 m/d)
			Well 49[T]	9/9/2008	21,300 ft (6,500 m)	90	240 ft/d (72 m/d)
			Well 48	7/25/2008	22,300 ft (6,800 m)	45	490 ft/d (150 m/d)
			Weissmuller Spring (31)	8/4/2008	43,300 ft (13,200 m)	55	790 ft/d (240 m/d)
			Hotel Spring (32)	8/5/2008	43,600 ft (13,300 m)	56	790 ft/d (240 m/d)
			Well 66[T]	7/9/2008	10.6 mi (17,000 m)	29	1,900 ft/d (590 m/d)
Halifax Creek Sinkhole	9/12/2008	Eosin 6.35 kg	Well 58	2/20/2009	6,230 ft (1,900 m)	160	39 ft/d (12 m/d)
			Well 75	9/17/2008	17,400ft (5,300 m)	5	3,600 ft/d (1,100 m/d)
			Well 5	10/29/2008	27,200 ft (8,300 m)	47	590 ft/d (180 m/d)
			Hotel Spring (32)	10/1/2008	43,600 ft (13,300 m)	19	2,300 ft/d (700 m/d)
			Main Barton Springs (80)[T]	1/12/2009	20 mi (32,100 m)	122	850 ft/d (260 m/d)
			Cold Springs (210)	Interference	21 mi (33,500 m)		unknown
Bull Pasture Sink	5/20/2008	Uranine 107 g	Well 70	5/28/2008	6,400 ft (1,960 m)	8	800 ft/d (250 m/d)
Bull Pasture Sink	6/10/2008	Uranine 13.6 kg	Well 62	6/11/2008	1,300 ft (400 m)	1	1,300 ft/d (400 m/d)
			Well 63	6/20/2008	1,700 ft (520 m)	10	170 ft/d (52 m/d)
			Well 72	7/9/2008	13,500 ft (4,100 m)	29	460 ft/d (140 m/d)
			Well 48	6/17/2008	28,500 ft (8,700 m)	7	3,900 ft/d (1,200 m/d)
			Main Barton Springs (80)	9/24/2008	19 mi (30,800 m)	106	950 ft/d (290 m/d)
			Old Mill Springs (81)[T]	10/16/2009	19 mi (31,100 m)	493	210 ft/d (63 m/d)
Johnson Swallet	2/26/2009	Eosin 24 kg	Well 58	3/10/2009	14,100 ft (4,300 m)	12	1,200 ft/d (360 m/d)
			Well 20	3/10/2009	18,000 ft (5,500 m)	12	1,500 ft/d (460 m/d)
			Well 6	4/28/2009	19,700 ft (6,000 m)	61	320 ft/d (98 m/d)

(Table 12. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Well 40	<3/6/2009	20,300 ft (6,200 m)	8	>2,600ft/d (>780 m/d)
			Well 41	7/2/2009	20,700 ft (6,300 m)	126	160 ft/d (50 m/d)
			Well 48	3/2/2009	21,600 ft (6,600 m)	4	5,200 ft/d (1,600 m/d)
			Well 90	3/9/2009	25,600 ft (7,800 m)	11	2,300 ft/d (710 m/d)
			Well 5	3/18/2009	26,900 ft (8,200 m)	20	1,300 ft/d (410 m/d)
			Well 7	8/10/2009	28,200 ft (8,600 m)	165	170 ft/d (52 m/d)
			Well 89	<3/12/2009	32,500 ft (9,900 m)	<14	>2,300 ft/d (>710 m/d)
			Well 87	4/15/2009	6.5 mi (10,400 m)	48	720 ft/d (220 m/d)
			Weissmuller Spring (31)	5/15/2009	8.1 mi (13,000 m)	78	560 ft/d (170 m/d)
			Hotel Spring (32)	4/29/2009	8.1 mi (13,000 m)	62	690 ft/d (210 m/d)
			Cabomba Spring (33)	6/5/2009	8.1 mi (13,000 m)	99	430 ft/d (130 m/d)
			Deep Hole Spring (29)[T]	12/2/2009	8.1 mi (13,100 m)	279	150 ft/d (47 m/d)
			Diversion Spring (30)	5/15/2009	8.1 mi (13,100 m)	78	560 ft/d (170 m/d)
			Salt & Pepper 1 Spring (128)	<12/2/2009	8.1 mi (13,100 m)	<78	>560 ft/d (>170 m/d)
			Salt & Pepper 2 Spring (129)	<12/2/2009	8.1 mi (13,100 m)	<78	>560 ft/d (>170 m/d)
			Crater Bottom Spring (118)	<12/2/2009	8.1 mi (13,100 m)	<78	>560 ft/d (>170 m/d)
			Ossified Forest Spring (126)[T]	<1/4/2010	8.1 mi (13,100 m)	<114	>360 ft/d (>110)m/d
			Cream of Wheat Spring (122)	<12/2/2009	8.1 mi (13,100 m)	<78	>560 ft/d (>170 m/d)
			Cypress Point Spring (121)[T]	<12/2/2009	8.1 mi (13,100 m)	<78	>560 ft/d (>170 m/d)
			Kettleman's Spring (125)[T]	<12/2/2009	8.1 mi (13,100 m)	<78	>560 ft/d (>170 m/d)
			River Bed Spring (127)	<12/2/2009	8.1 mi (13,100 m)	<78	>560 ft/d (>170 m/d)
			Old Mill Springs (81)	12/4/2009	20 mi (32,600 m)	281	360 ft/d (120 m/d)
			Main Barton Springs (80)[T]	5/5/2009	20 mi (32,600 m)	78	1,400 ft/d (420 m/d)
			Catfish Hotel Spring (119)	ND	8.1 mi (13,000 m)		
			Well 75	ND	3.5 mi (5,600 m)		

(Table 12. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Well 4	ND	4.5 mi (7,300 m)		
			Well 86	ND	6.9 mi (11,100 m)		
			Well 101	ND	7.6 mi (12,300 m)		
			Well 115	ND	6.5 mi (10,400 m)		
Four-Hole Sink	6/12/2008	SRB 255 g	Fern Bank Spring (45)	8/26/2008	2,500 ft (770 m)	75	33 ft/d (10 m/d)

T = tentative detection
< = arrival prior to the date shown
ND = not detected

No dye was detected at the following sample locations north of the Blanco River injection points:

Blanco River (four sites)	Well 209
6701310 Kyle (97)	5857606 Barton Property (18)
5858427 David Dement (65)	5850731 Shady Hollow (Aqua Texas)
5858417 Hays Co Youth Complex (71)	5850718 Bear Creek Estates (Aqua Texas) (69)
5858416 Lehigh Well (22)	5857808 Halifax House (64)
5858403 Buda #1 (21)	5857802 Halifax Office (57)
5858121 Leisurewoods (Aqua Texas) #6B (67)	58576RH Ray Holt (19)
58579N1 Kyle #4 (23)	5857307 Buda #4 (74)
5857903 Negley (17)	5850707 McCoys (60)
5857902 Gregg (61)	5850511 Johnson (13)
5857809 Halifax Horse Pen (15)	58502xx Castletop_HOA (73)
5857807 Halifax Windmill on Hill (158)	5850216 Target (59)
Well 58	Well 92

Northern Tracer Tests: Fritz's Cave (2008), Sink Creek (2009), and TSU Cooling Tower Leak Test (2009)

Purpose

Northern tracer tests consisted of two injection points, Fritz's Cave (five mi; eight km) and Sink Creek (1.2 mi; two km), north of San Marcos Springs. The purpose of the tests was to investigate potential flowpaths from north of the springs and to determine whether Sink Creek is a potential source of recharge for San Marcos Springs. The monitoring system consisted of wells that were involved in the Blanco River tracer tests. The TSU cooling tower leak test was included because the injection occurred on December 2, 2009, the same day as the injection at the well at Dam #3 on Sink Creek.

Injections

Northern tracer tests consisted of three injections of Phloxine B at Fritz's Cave in 2008 and two injections of Uranine at a private well adjacent to Sink Creek at Flood Control Dam #3 in 2009 and 2010 (Table 13 and Table 14, respectively). Three successively increasing volumes of Phloxine B were injected at Fritz's Cave to avoid coloring nearby private wells. Similarly, the first injection at Sink Creek Dam #3 was small to determine whether the dye would appear in a private well less than 330 ft (100 m) away. Both dyes were flushed into the groundwater system with large volumes of water. Dyes injected at Fritz's Cave and Sink Creek Dam would be expected to travel south or southwest toward San Marcos Springs rather than Barton Springs. On December 2, 2009, TSU injected liquid Fluorescein, which is a synonym for Uranine, into a cooling tower at the Co-Gen plant. Sufficient dye (one gal) was added so that it was visible to locate leaks in the cooling tower reservoir, which holds 100,000 gal (380,000 L) of water. Although it was from a different manufacturer, Fluorescein in cooling tower reservoir water was chemically and spectrographically identical to the Uranine that the EAA had injected into the well at Dam #3. Consequently, arrival times, distances, and relative concentrations would have to be used to discern the origins of the Fluorescein and Uranine because detections alone would not be sufficient. The EAA injected Uranine into Sink Creek at Flood Control Dam #3 a second time on January 26, 2010, to help eliminate any ambiguities.

Setting of Sink Creek

Sink Creek drains an area northwest of San Marcos Springs and flows into Spring Lake northeast of the springs. It is an ephemeral stream that carries large volumes of runoff during flood events. Three flood control dams have been built on Sink Creek to mitigate the impact of flooding on the City of San Marcos.

Dam #3 is located on Sink Creek in the Edwards Aquifer recharge zone approximately 6,560 ft (2,000 m) upstream of San Marcos Springs. The ground surface elevation is approximately 590 ft (180 m) above msl, compared with 573 ft (175 m) at Spring Lake. The dam was constructed in the top of the Person Formation, just below the Georgetown Formation contact. It forms a pool in a channel eroded approximately 49 ft (15 m) into the Leached and Collapsed members.

Several wells were installed during construction of Dam #3 for water supplies or geotechnical tests. One well on the floodplain of Sink Creek is still accessible, immediately upstream of the dam. It penetrates the Del Rio Clay and is completed in the Cyclic and Marine members, although its depth is not known because the casing is partly filled with rocks. It is approximately 100 ft (30 m) deep, and the ground surface elevation is approximately 590 ft (180 m), a few meters above San Marcos Springs. It is constructed with 6-in-diameter (15-cm) steel casing that sticks up approximately three ft (one m). To evaluate the well as a potential injection site, EAA staff pumped 10 gpm (0.6 l/s) into the well and concluded that it was suitably connected with the groundwater system for a tracer test.

Uranine was injected into the well at Dam #3 on December 2, 2009, and January 26, 2010. The initial injection consisted of one kg of Uranine to determine whether it would be visible in a private well less than 100 m from the injection well. No dye was detected in the private well, so 3.15 kg (7 lb) of Uranine was injected to attempt to produce detections at San Marcos Springs. Both injections were flushed with several thousand liters of water.

Setting of Fritz's Cave

Fritz's Cave is located in a subdivision on the north side of Hilliard Road. The entrance is on the side of a hill in a bare bedrock-solution sinkhole in the Person Formation at an elevation of approximately 820 ft (250 m) msl. It drops six ft (two m) to a crawlway that has low bedding-plane openings extending to the east (Figure 40). The crawlway goes north for 21 ft (seven m) until it drops down three ft (one m) and then cuts back beneath the previous crawlway. The crawlway was too low to explore, although it had strong airflow, indicating that more cave could be accessed by excavation.

Setting of the TSU Cooling Tower

The cooling tower was associated with the Co-Generation plant located on Buckner Street just south of W. Sessom Road, approximately one mi (1.4 km) west

Figure 40. Map of Fritz's Cave

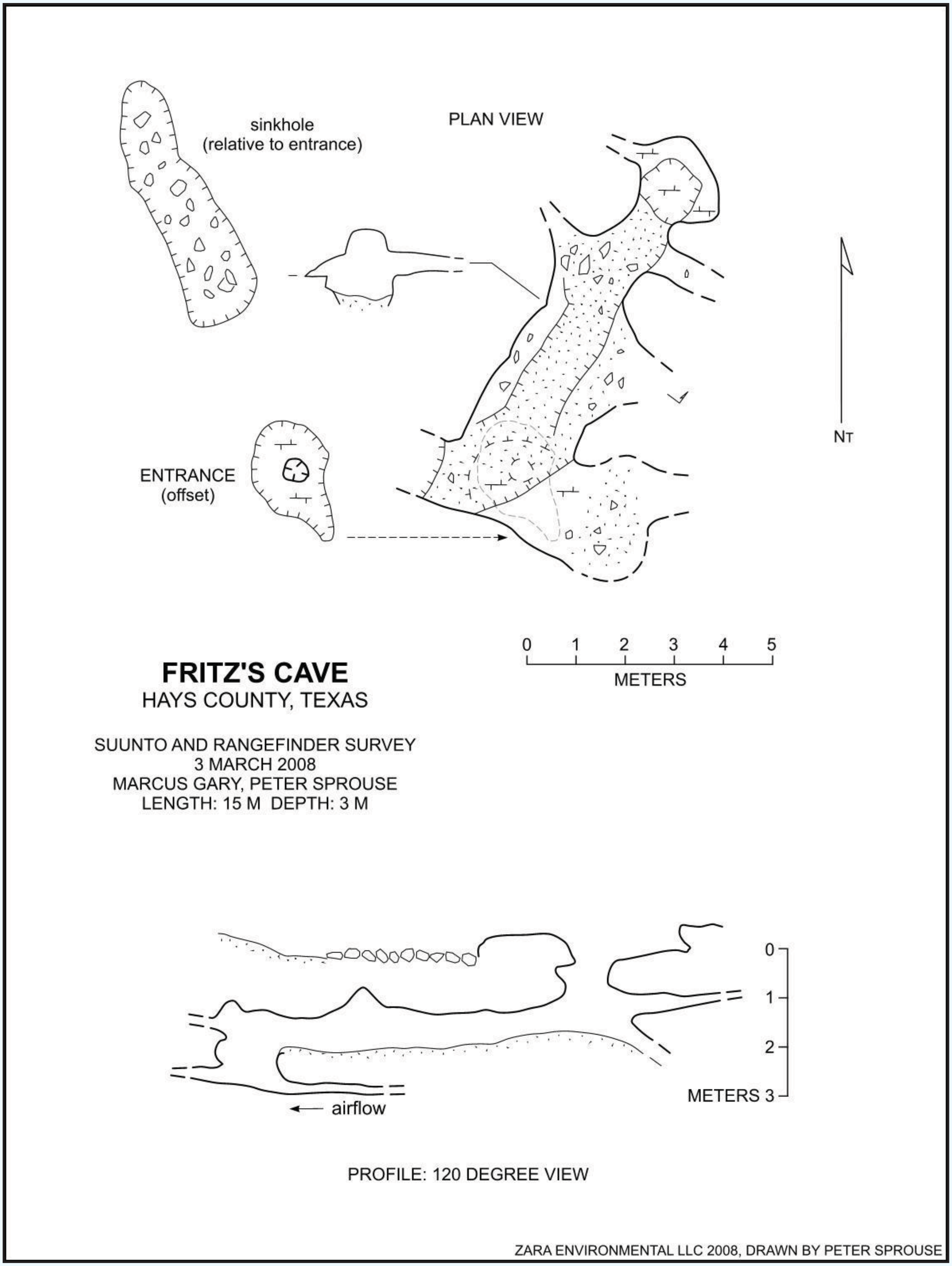
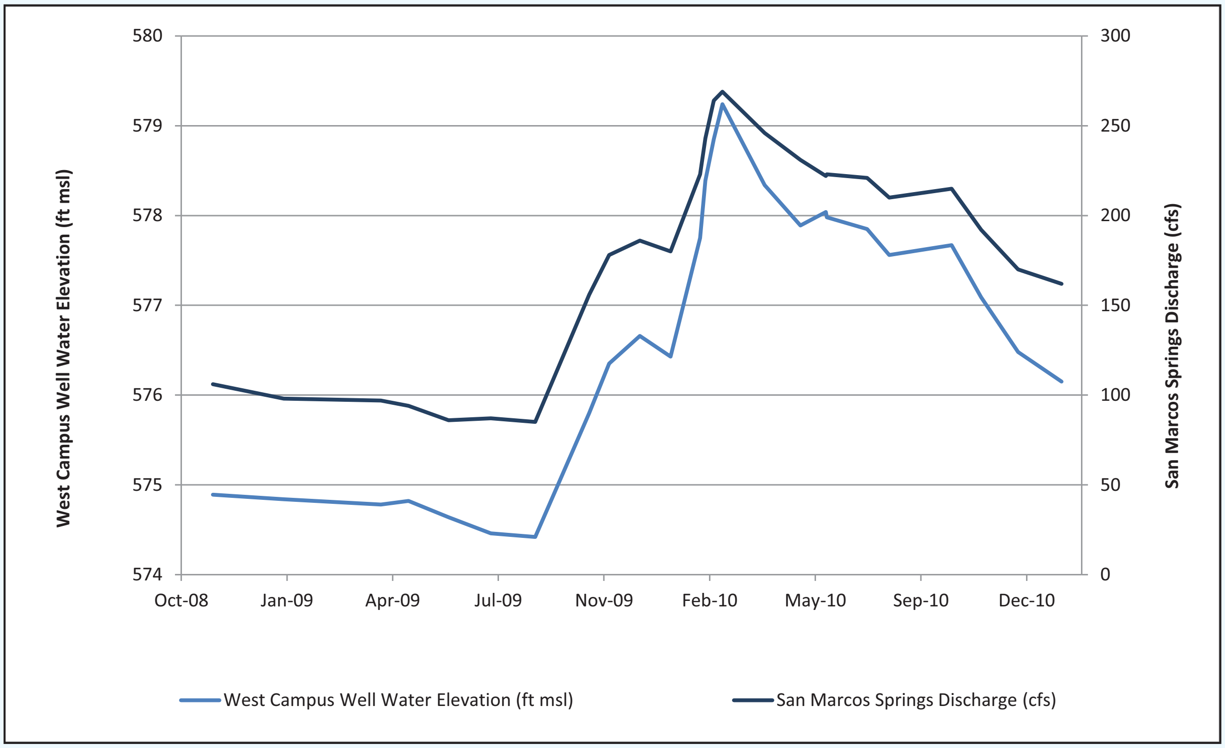


Figure 41. Comparison of San Marcos Springs Discharge and Shallow Groundwater Elevations



of San Marcos Springs. It is at an elevation of 715 ft (218 m) msl, compared with the Spring Lake elevation of approximately 573 ft (175 m) msl. Geologically the plant is located on an upthrown fault block consisting of the Eagle Ford Group and Buda Limestone, which are underlain by Del Rio Clay and the Georgetown Formation. A private well drilled 3,200 ft (976 m) north-west of the cooling tower penetrated the base of the Del Rio Clay at 118 ft (36 m) below ground, or approximately 672 ft (205 m) msl.

Groundwater may be perched above the Del Rio Clay, whereas regional groundwater is unconfined in the Edwards Aquifer in the vicinity of the TSU cooling tower. When the private well described earlier was drilled in 2006, the depth to water was 215 ft (65.5 m), or approximately 575 ft (175 m) msl, which was approximately 97 ft (30 m) below the top of the Georgetown Formation. Similarly, at the West Campus well (133; state well number 6701826), which is approximately 2,100 ft (640 m) southwest of the cooling tower, water levels collected by the USGS between 2008 and 2011 (see Figure 41) were within six ft (two m) higher than Spring Lake. Also shown in Figure 41, San Marcos Springs discharge is directly proportional to water levels in this area, according to measurements from the West Campus well. Although the USGS reported discharge measurements from gauge 08170000 as spring flow, the measurements represent discharge from Spring Lake, which is a combination of spring flow and other groundwater that has recharged the lake.

In 2009, dye was still visible in the cooling tower on December 7, 2009, five days after injection. No dye was observed by TSU personnel in Sessom Creek (Elizabeth S. Arceneaux, TSU, December 2009, personal communication).

Results of Fritz's Cave Injections

Phloxine B was injected into Fritz's Cave on May 20 and May 21, 2008, and it was detected only at Well 49 on September 9, 2008, for an apparent velocity of approximately 36 ft/d (11 m/d). After a third injection on September 10, 2008, it appeared intermittently in other nearby wells at non-visible concentrations. In general, apparent velocities were slower than in other tracer tests. Because concentrations were relatively low, near detection limits, and intermittent, some of the detections were considered tentative. The Phloxine B appeared at Wells 13 and 41 in February 2009. In March and April 2009, it appeared at several wells that are south and southeast of the cave (Figure 42) at apparent velocities of generally less than 330 ft/d (100 m/d). The longest distances traveled by Phloxine B from Fritz's Cave were 13,780 ft (4,200 m) southeast to Well 7 and 16,400 ft (5,000 m) south to Well 88. However, a single sample from Well 106 on April 29, 2010, contained a peak in the Phloxine B range. It may be Phloxine B, but it is considered a tentative detection at best. Phloxine B detected near the City of San Marcos and San Marcos Springs, like at Well 91, may have originated from Dakota Ranch Cave during the western tracer tests. It was detected in TSU Jackson Well (131) on April 1, 2010, and in subsequent samples. However, several background samples from this well contained no detectable Phloxine B, so it is thought to have originated from Fritz's Cave.

At San Marcos Springs, Phloxine B from the 2005 Dakota Ranch Cave tracer test was detected in background samples from individual springs. It was thought that the arrival of Phloxine B from Fritz's Cave would be recognizable by increased concentrations. In fact, Phloxine B concentrations in charcoal receptors from Hotel Spring increased somewhat beginning in June 2009, although they were not high enough to resolve the ambiguity of the origin. If Phloxine B had been detectable in water samples, Fritz's Cave as its origin would have been a reasonable conclusion. Consequently, the arrival of Phloxine B, if any, was masked by preexisting concentrations. Similarly, Phloxine B concentrations at Weissmuller Spring increased slightly beginning October 14, 2008, which may represent the arrival of dye from Fritz's Cave. However, it will be considered tentative because of the ambiguity of the origin and the relatively high apparent velocity necessary to make the connection.

Table 13. Summary of Northern Tracer-Test Results—Fritz's Cave (2008)

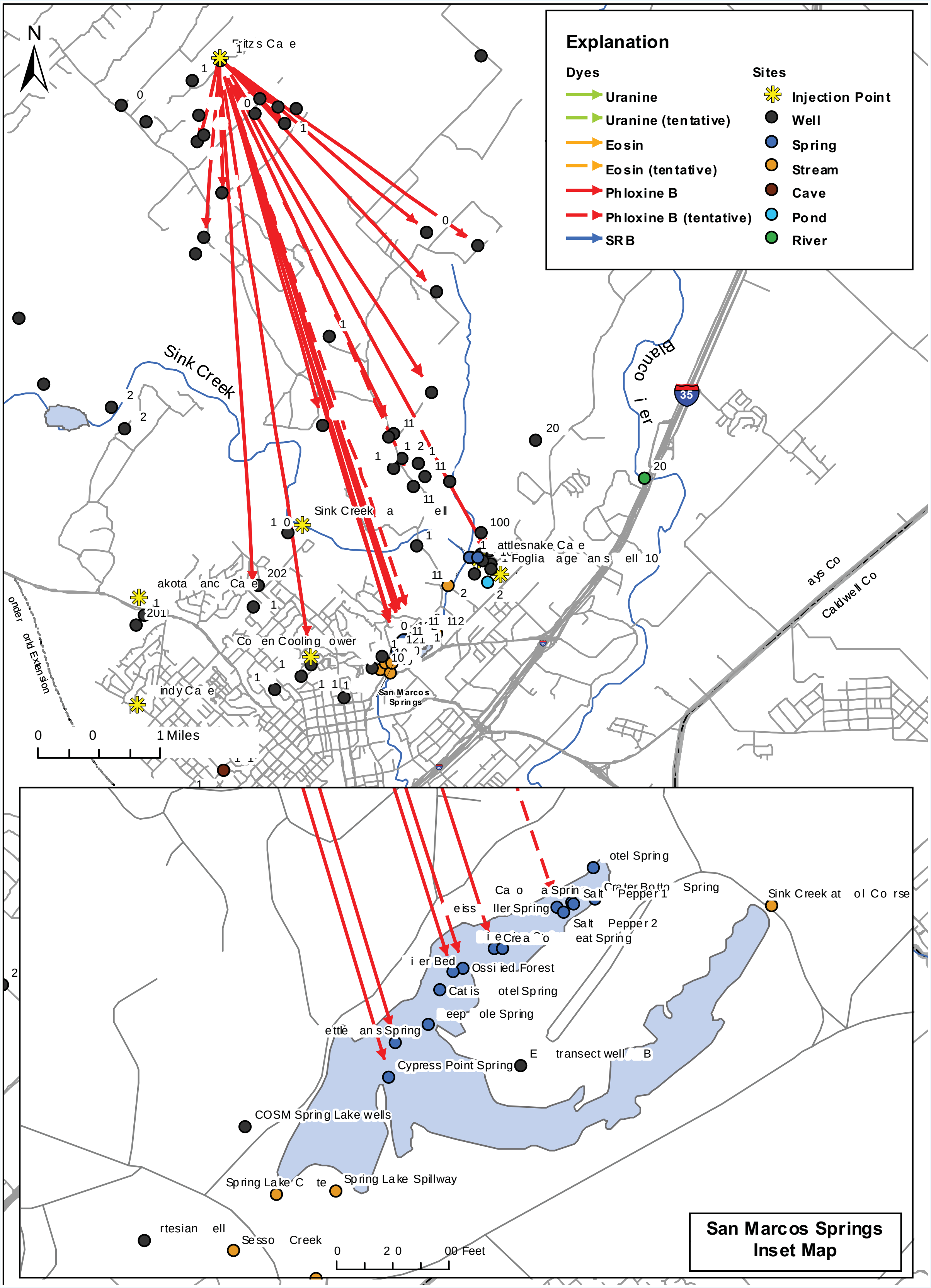
Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Fritz's Cave	5/20/2008	Phloxine B 107 g	None				
Fritz's Cave	5/21/2008	Phloxine B 1.42 kg	Well 49	9/9/2008	3,150 ft (960 m)	89	36 ft/d (11 m/d)
Fritz's Cave	9/10/2008	Phloxine B 6.8 kg	Well 6	3/18/2009	2,460 ft (750 m)	596	43 ft/d (13 m/d)
			Well 49	3/25/2009	3,150 ft (960 m)	196	16 ft/d (4.9 m/d)
			Well 47	2/20/2009	3,610 ft (1,100 m)	163	23 ft/d (7 m/d)
			Well 41	2/20/2009	3,940 ft (1,200 m)	163	23 ft/d (7 m/d)
			Well 4	3/18/2009	5,900 ft (1,800 m)	188	33 ft/d (10 m/d)
			Well 35	4/1/2009	7,872 ft (2,400 m)	203	39 ft/d (12 m/d)
			Well 90	3/6/2009	11,810 ft (3,600 m)	177	66 ft/d (20 m/d)
			Well 7	3/18/2009	13,780 ft (4,200 m)	188	72 ft/d (22 m/d)

(Table 13. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Well 5	4/15/2009	13,780 ft (4,200 m)	189	72 ft/d (22 m/d)
			Well 88	4/28/2009	16,400 ft (5,000 m)	230	72 ft/d (22 m/d)
			Well 115	12/17/2009	18,040 ft (5,500 m)	463	39 ft/d (12 m/d)
			Well 91	4/15/2009	23,800 ft (7,260 m)	217	110 ft/d (34 m/d)
			Well 106[T]	4/29/2010	25,260 ft (7,700 m)	189	130 ft/d (41 m/d)
			TSU Jackson Well (131)	4/1/2010	26,500 ft (8,100 m)	568	47 ft/d (14 m/d)
			Weissmuller Spring (31)[T]	10/14/2008	26,240 ft (8,000 m)	34	787 ft/d (240 m/d)
			Well 117	4/15/2010	36,410 ft (11,100 m)	582	39 ft/d (12 m/d)
			Kettleman's Spring (125)	Unknown			
			Ossified Forest Spring (126)	Unknown			
			River Bed Spring (127)	Unknown			
			Well 89	Unknown			
			Cypress Point Spring (121)	Unknown			
			Cream of Wheat Spring (122)	Unknown			
			Cabomba Spring (33)	Interference			
			Hotel Spring (32)	Interference			
			Diversion Spring (30)	Interference			
			Deep Hole Spring (29)	Interference			
			Well 1	ND	1,510 ft (460 m)		
			Well 48	ND	3,280 ft (1,000 m)		
			Well 38	ND	3,940 ft (1,200 m)		
			Well 36	ND	4,260 ft (1,300 m)		
			Well 50	ND	4,590 ft (1,400 m)		
			Well 39	None (2 samples)	8,530 ft (2,600 m)		

T = tentative detection

Figure 42. Northern Tracer-Test Results from Fritz's Cave Injections



Results of Sink Creek Dam #3 and TSU Cooling Tower Injections

After the first injection of 1 kg (2.2 lb) of Uranine into Sink Creek Dam #3 Well on December 2, 2009, which coincided with an injection of Fluorescein in a TSU cooling tower tank, Uranine was detected at several orifices at San Marcos Springs beginning on December 7, 2009. After the second injection of 3.15 kg [6.6 lb]) had been injected into Sink Creek Dam #3 Well on January 26, 2010, it appeared at several monitoring wells and spring orifices where none had appeared in December 2009 (Figure 43). Some of the detections are tentative because Uranine from Sink Creek cannot be discerned using Fluorescein from the TSU cooling tower, although the two names will be used in this report to differentiate between the two injection points. Table 14 lists results of the Sink Creek Dam #3 tracer test, and Table 15 lists results of the TSU cooling tower leak test. However, arrival times, distances, and hydraulic gradients were used to identify the origin of the dyes.

Uranine was initially detected in charcoal receptors that were in place between December 2 and 7, 2009, at Catfish Hotel, Cypress Point, Deep Hole, and Salt and Pepper 2 springs. It was subsequently detected at West Campus Well on December 9, 2009, Kettleman's Spring on December 14, 2009, Weissmuller Spring on December 15, 2009, and Sink Creek at Lime Kiln Road on December 17, 2009. Uranine was detectable in water samples from Weissmuller Spring, which was unusual because almost all other water samples contained no detectable dye. However, Uranine did not reappear in any of these locations, with the exception of Hotel, Weissmuller, and Salt and Pepper 2 springs after the second injection at Dam #3 Well, so detections at the other locations in December 2009 were probably from the TSU cooling tower leak test (Table 16). Uranine was detected in Hotel Spring starting on March 11, 2010, and continued through April 2010. It was detected in Weissmuller Spring on March 17, 2010.

On January 14, 2010, peaks in the Uranine range were observed in charcoal receptor samples from Wells 6, 40, and 41, some of which had been in place since October 2009. However, these wells are approximately 4.4 mi (seven km) upgradient of both Uranine injection points, so they represent either an interfering compound or, less likely, Uranine from the Bull Pasture injection on June 10, 2008.

After the second injection on January 26, 2010, Uranine was detected at Cabomba Spring and Sink Creek at Lime Kiln Road on February 2, 2010, and then at Sink Creek on the Golf Course on February 8, 2010. This could be Uranine from Sink Creek or Fluorescein from the cooling tower.

Because subsequent Uranine detections occurred at private wells near Lime Kiln Road that are upgradient and far from the TSU cooling tower, they almost certainly originated at the Sink Creek Dam #3 injection point. Well 101 yielded Uranine on February 11, 2010, for an apparent velocity of approximately 520 ft/d (160 m/d). On February 22, 2010, it was detected in Sink Creek at the Golf Course and Sessom Creek and was tentatively detected at Well 98. A sample from Well 89 showed a peak in the Uranine range on April 15, 2010, but it was probably an interfering compound because that well is upgradient of Sink Creek. Uranine was detected at Well 100 on May 6, 2010, Wells 99 and 106 on May 13, 2010, and Sink Spring on May 13, 2010. These are the monitoring sites farthest from Sink Creek Dam #3, approximately 2 mi (2.5 km) southeast of the injection point. Uranine persisted in the groundwater system through May 2010.

Figure 43. Northern Tracer-Test Results from Sink Creek Dam #3 Injections

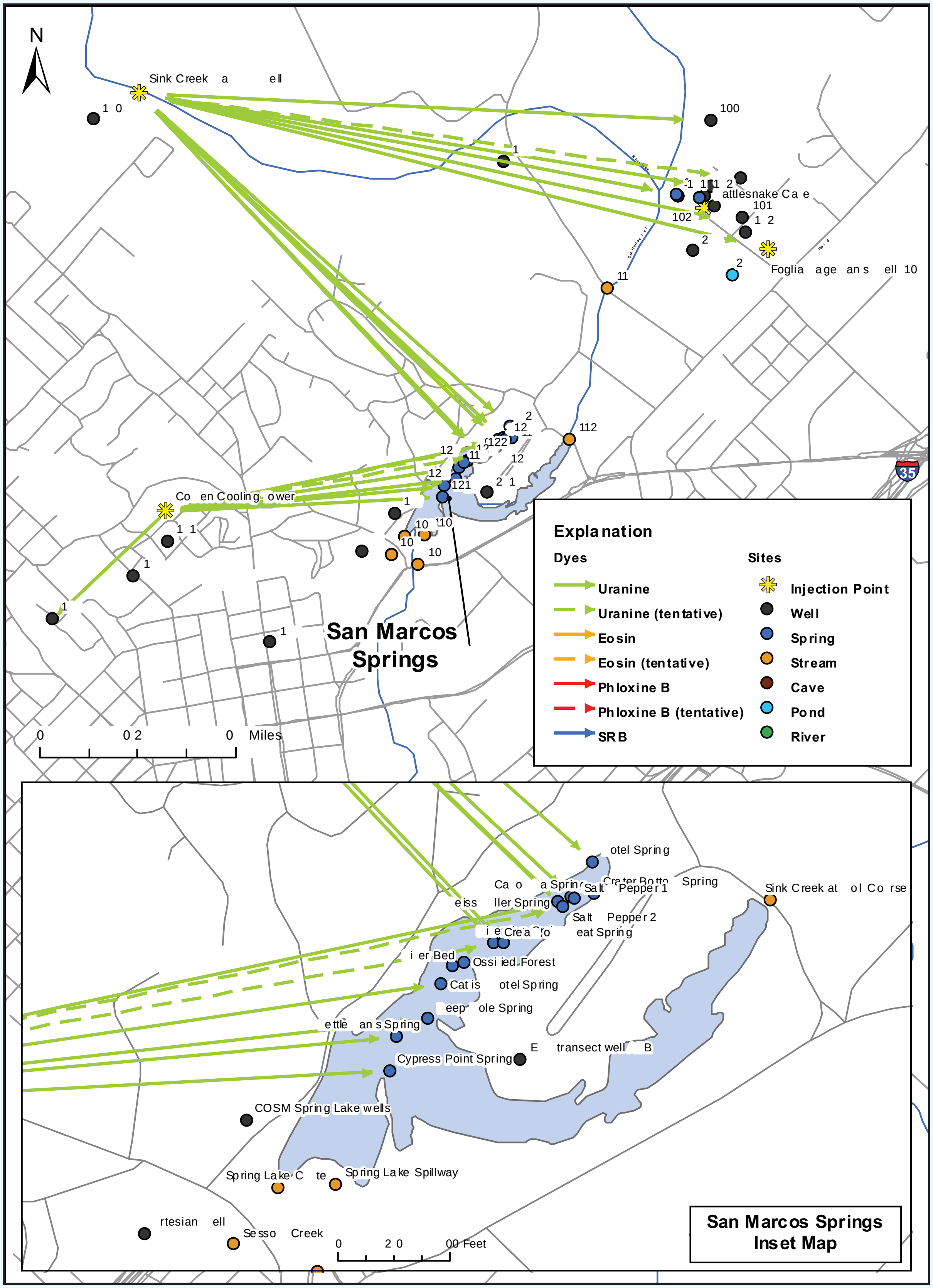


Table 14. Summary of Northern Tracer-Test Results—Sink Creek Dam #3 (2009)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Dam #3 Well	12/2/2009	Uranine 1 kg	Weissmuller Spring (31)	12/15/2009	6,900 ft (2,100 m)	13	525 ft/d (160 m/d)
Dam #3 Well	1/26/2010	Uranine 3.15 kg	Cabomba Spring (33)	3/17/2010	6,900 ft (2,100 m)	50	140 ft/d (42 m/d)
			Cream of Wheat Spring (122)	3/17/2010	6,900 ft (2,100 m)	50	140 ft/d (42 m/d)
			Diversion Spring (30)	3/17/2010	6,900 ft (2,100 m)	50	140 ft/d (42 m/d)
			Hotel Spring (32)	3/17/2010	6,900 ft (2,100 m)	50	140 ft/d (42 m/d)
			Salt and Pepper 1 Spring (128)	3/17/2010	6,900 ft (2,100 m)	50	140 ft/d (42 m/d)
			Salt and Pepper 2 Spring (129)	3/17/2010	6,900 ft (2,100 m)	50	140 ft/d (42 m/d)
			Weissmuller Spring (31)	3/17/2010	6,900 ft (2,100 m)	50	140 ft/d (42 m/d)
			Sink Spring (104)	5/13/2010	7,200 ft (2,200 m)	107	66 ft/d (20 m/d)
			TSU Jackson Well (131)[T]	4/22/2010	6,100 ft (1,850 m)	86	72 ft/d (22 m/d)
			Well 100	5/6/2010	7,900 ft (2,400 m)	100	79 ft/d (24 m/d)
			Well 99	5/13/2010	7,900 ft (2,400 m)	107	72 ft/d (22 m/d)
			Well 101	2/11/2010	8,200 ft (2,500 m)	16	520 ft/d (160 m/d)
			Well 98[T]	2/22/2010	8,200 ft (2,500 m)	27	300 ft/d (92 m/d)
			Well 106	5/13/2010	8,860 ft (2,700 m)	107	82 ft/d (25 m/d)
			Sessom Creek (107)	2/22/2010	Unknown		
			Sink Creek at Golf Course (112)	2/22/2010	Unknown		
			Spring Lake Chute (108)	3/11/2010	Unknown		
			Spring Lake Spillway (110)	3/11/2010	Unknown		
			Deep Hole Spring (29)	ND	6,890 ft (2,100 m)		
			Well 140	ND	690 ft (210 m)		
			Well 171	ND	7,400 ft (2,260 m)		

(Table 14. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Well 138	ND	5,000 ft (1,500 m)		
			COSM Comanche Street Well (149)	ND	6,500 ft (1,990 m)		
			Well 98	ND	8,200 ft (2,500 m)		

T = tentative detection

At Spring Lake, Chute and Spillway samples collected on February 22, 2010, contained Uranine, and it persisted until April 2010 at both locations.

Table 15. Summary of Northern Tracer-Test Results—TSU Cooling Tower (2009)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
TSU Cooling Tower Leak Test	12/2/2009 13:30	Uranine 3.8 l	West Campus Well (133)	12/9/2009	2,100 ft (640 m)	7	300 ft/d (91 m/d)
			Cypress Point Spring (121)	12/7/2009	3,600 ft (1,100 m)	5	720 ft/d (220 m/d)
			Kettleman's Spring (125)	12/14/2009	3,900 ft (1,200 m)	12	330ft/d (100 m/d)
			Catfish Hotel Spring (119)	12/7/2009	3,900 ft (1,200 m)	5	790 ft/d (240 m/d)
			Deep Hole Spring (29)	12/7/2009	3,900 ft (1,200 m)	5	790 ft/d (240 m/d)
			Cream of Wheat (122)[T]	12/17/2009	4,300 ft (1,300 m)	15	280 ft/d (87 m/d)
			Salt & Pepper 2 Spring (129)[T]	12/7/2009	4,600 ft (1,400 m)	5	920 ft/d (280 m/d)
			Weissmuller Spring (31)	12/15/2009	4,600 ft (1,400 m)	13	360 ft/d (110 m/d)
			Sink Creek at Lime Kiln Road (113)	12/17/2009	Unknown		
			Spring Lake Chute (108)	12/10/2009	Unknown		

T = tentative detection

Identification of origins of dye at several monitoring sites was ambiguous because the same dye was injected simultaneously on December 2, 2009, at the TSU cooling tower and Sink Creek Dam #3 well. Uranine was injected a second time at Sink Creek Dam #3 well on January 26, 2010. Dye that was detected after the December injection but not after the January injection was presumed to originate from the TSU cooling tower. Conversely, dye detected only after the January injection but not after the December injection was presumed to originate from Sink Creek Dam #3 well. Dye detected after both injections could have originated from either location. Results indicated that three of the northern springs (Hotel, Cabomba, and Salt and Pepper 1) received recharge from Sink Creek, whereas three of the southern springs (Deep Hole, Kettleman's, and Cypress Point) received recharge from the TSU cooling tower area. Table 16 lists these different combinations. However, there are other variables that affect dye movement that could render these conclusions incorrect, such as dilution in the flowpath or lake, cross contamination between lake water and spring water, and inconsistent groundwater transport.

Groundwater conditions are not well enough known to describe how the dyes migrated to the springs. Previous studies have demonstrated discrete spring orifices beneath Spring Lake, so there are many potential flowpaths for dyes to follow. Dissolution pathways from the vicinity of the TSU cooling tower or Sink Creek Dam #3 may be hydraulically connected to Spring Lake or one or more spring orifices. Potential hydraulic head seems to be sufficient to overcome the Spring Lake pressure. An underground collapse feature could act as a mixing chamber for one or more pathways. Future tracer tests will have to be designed to match injection points with individual springs.

Table 16. Evaluation of Potential Sources of Recharge for Individual Springs

Spring	Spring Lake Location	December 2009 Detection	January 2010 Detection	Potential Recharge Source
Ossified Forest	Center	No	No	Neither
Cream of Wheat	Center	Yes	Yes	Either/Both
Diversion	Center	No	Yes	Sink Creek
River Bed	Center	No	Yes	Sink Creek
Catfish Hotel	Center	Yes	No	TSU
Crater Bottom	North	No	No	Neither
Salt & Pepper 2	North	Yes	Yes	Either/Both
Weissmuller	North	Yes	Yes	Either/Both
Cabomba	North	No	Yes	Sink Creek
Hotel	North	No	Yes	Sink Creek
Salt & Pepper 1	North	No	Yes	Sink Creek
Cypress Point	South	Yes	No	TSU
Kettleman's	South	Yes	No	TSU
Deep Hole	South	Yes	No	TSU

Northeastern Traces: Rattlesnake Cave (2004, 2009), Hageman's Well (2005)

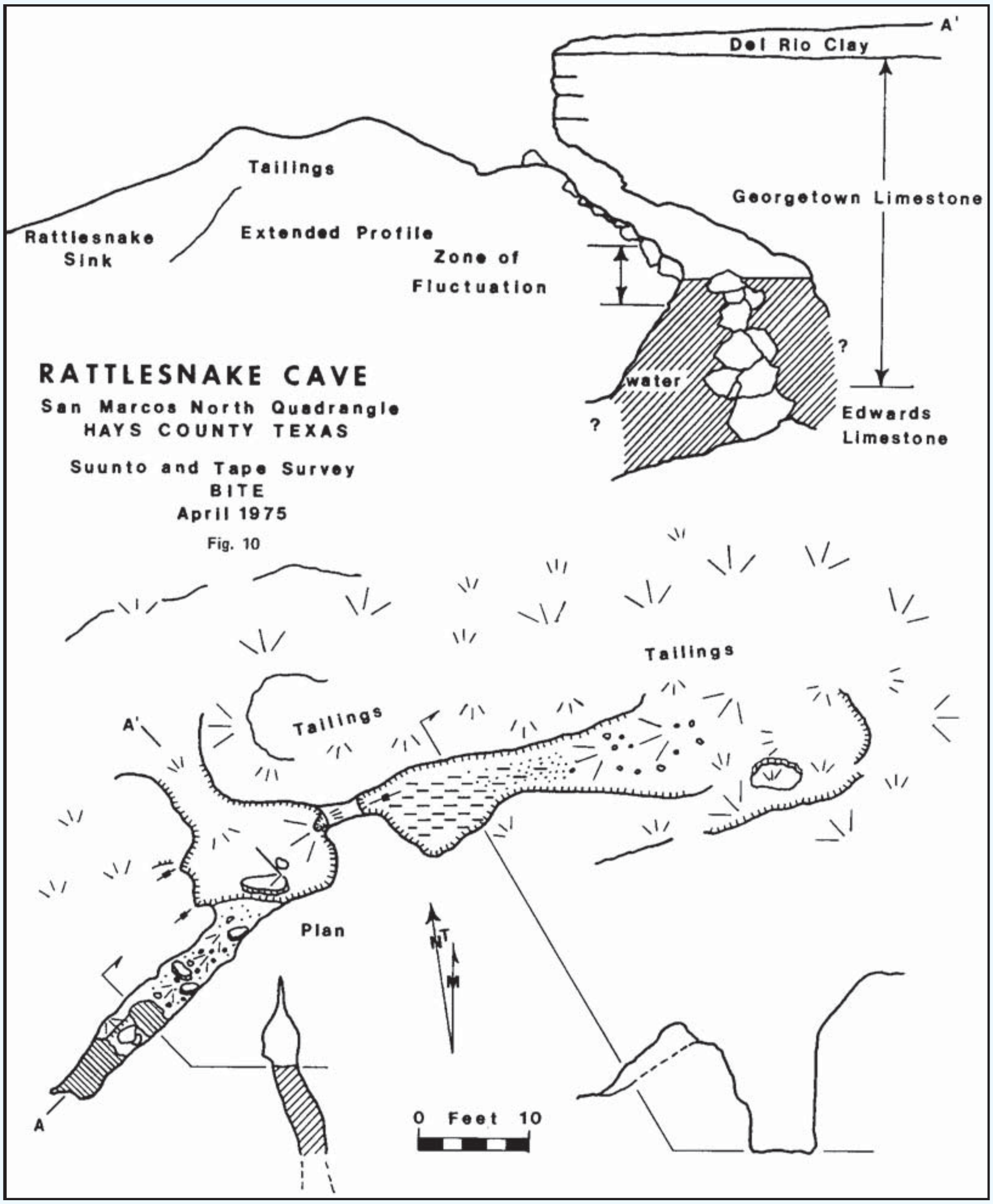
Purpose

Northeastern traces consisted of injections at sites northeast of San Marcos Springs generally parallel to the strike of the Balcones Fault Zone. The purpose of the traces was to expand Ogden's (1986) traces to the northern spring orifices (Diversion, Cabomba, Weissmuller, and Hotel springs) and to investigate groundwater conditions near Rattlesnake Cave.

Setting

Northeastern traces included injections at Rattlesnake Cave and Hageman's Well, which are located approximately 1 mi (1.2 km) northeast of the springs along the strike of the Balcones Fault Zone. The Rattlesnake Cave entrance is located in Edwards Limestone at an elevation of approximately 600 ft (183 m) msl, slightly higher than San Marcos Springs (573 ft; 174.6 m) msl. As shown in Figure 44, it is shallow, although the water table may be accessed through it. The cave is on the margin of a large sinkhole in which water ponds

Figure 44. Map of Rattlesnake Cave



during wet weather. Nearby monitoring sites included Rattlesnake Well, private wells, and Sink Spring.

Rattlesnake Cave is probably not along a high-velocity flowpath, which was suggested by the Ogden et al. (1986) tracer test in 1984. After approximately 85 g (0.19 lb) of Uranine dye and 2.27 kg (5 lb) of Tinopal CBS-X optical brightener were injected into the cave, an unspecified tracer appeared at Sink Spring in 11 days and then at six monitored springs at Spring Lake (Deep Hole, Catfish Hotel, Diversion, Weissmuller, Hotel, and Cabomba) 30 days later. The velocity to Sink Spring was about 36 ft/d (11 m/d), and the overall velocity from the cave to the springs was 95 ft/d (29 m/d). The difference may result from injecting the dye into the cave's pool, which rises up into a shaft and has no noticeable flow at the surface. The dye could have been held up in this area until slowly reaching conduits with active and greater groundwater flow. If the time between the appearance of the dye at Sink Spring until its appearance at San Marcos Springs is generally representative of velocities along that flowpath, then the mean velocity was approximately 130 ft/d (39 m/d). This tracer test took place under extremely low flow conditions (mean spring discharge = 74 cfs; 2.1 m^3/s), which were probably indicative of low groundwater gradients and relatively slow groundwater flow rates.

Well 106 is a 30-ft-deep (10-m) sinkhole that penetrates the Edwards Aquifer approximately one mi (1.6 km) north of San Marcos Springs at an elevation of 614 ft (187.2 m) msl. It is a private well created by enlargement of a fracture in the Georgetown Formation. Depth to water was approximately 10 ft (three m) below ground during the tracer tests.

Injections

Phloxine B was injected at Rattlesnake Cave on January 6, 2004 (70 g; 0.15 lb) and December 3, 2009 (620 g; 1.4 lb). Additional dye was injected in 2009 to increase concentrations at San Marcos Springs so that it would be distinguishable from the Phloxine B that originated from Dakota Ranch Cave. Both injections were flushed with several thousand liters of water.

Eosin (61 g; 0.13 lb) was injected directly into the water at Hageman's Well (106) on July 6, 2005. A small volume was used to avoid coloring nearby private wells.

Results of 2004 Injection

Eosin from Well 106 was probably not detected at any monitoring locations because the volume was too small.

Phloxine B from Rattlesnake Cave in 2004 was not detected in any of the six locations that were monitored near the cave: Sink Spring; Wells 101, 152, and 167; Rattlesnake Sink; and Rattlesnake Well. Dye persisted in Rattlesnake Cave until sometime between January 14 and January 25, 2004. These results were largely corroborated with 2009 results because Phloxine B was not detected in Sink Spring until 126 days after injection, and it was not detected in any nearby wells except Well 106 approximately 147 days after injection.

Dye traveled from Rattlesnake Cave to the springs (Figure 45) for three to five days and then mixed with Spring Lake water for another day until it flowed down the Spillway and Chute into the San Marcos River. Phloxine B was detected at Spring Lake in Crater Bottom, Cream of Wheat, Diversion, Salt and Pepper 1 and 2, and Weissmuller springs between January 9 and 10, 2004, at apparent velocities of approximately 1,100 ft/d (340 m/d) (Table 17). It appeared in Cabomba and Hotel springs between January 11 and 12, 2004, when it also appeared in the Spillway and Chute charcoal receptors. It was detected at the downstream Total Outflow site between January 9 and 13, 2004.

Phloxine B disappeared from Cream of Wheat Spring between January 30, 2004, and February 2, 2004. Phloxine B continued to be detectable in the Crater Bottom and Salt and Pepper 1 and 2 springs through the end of sampling on March 3, 2004. Phloxine B was no longer detectable at Cabomba Spring between January 30, 2004, and February 2, 2004. Diversion Spring yielded low levels of Phloxine B through at least February 26, 2004.

Figure 45. Northeastern Tracer Tests

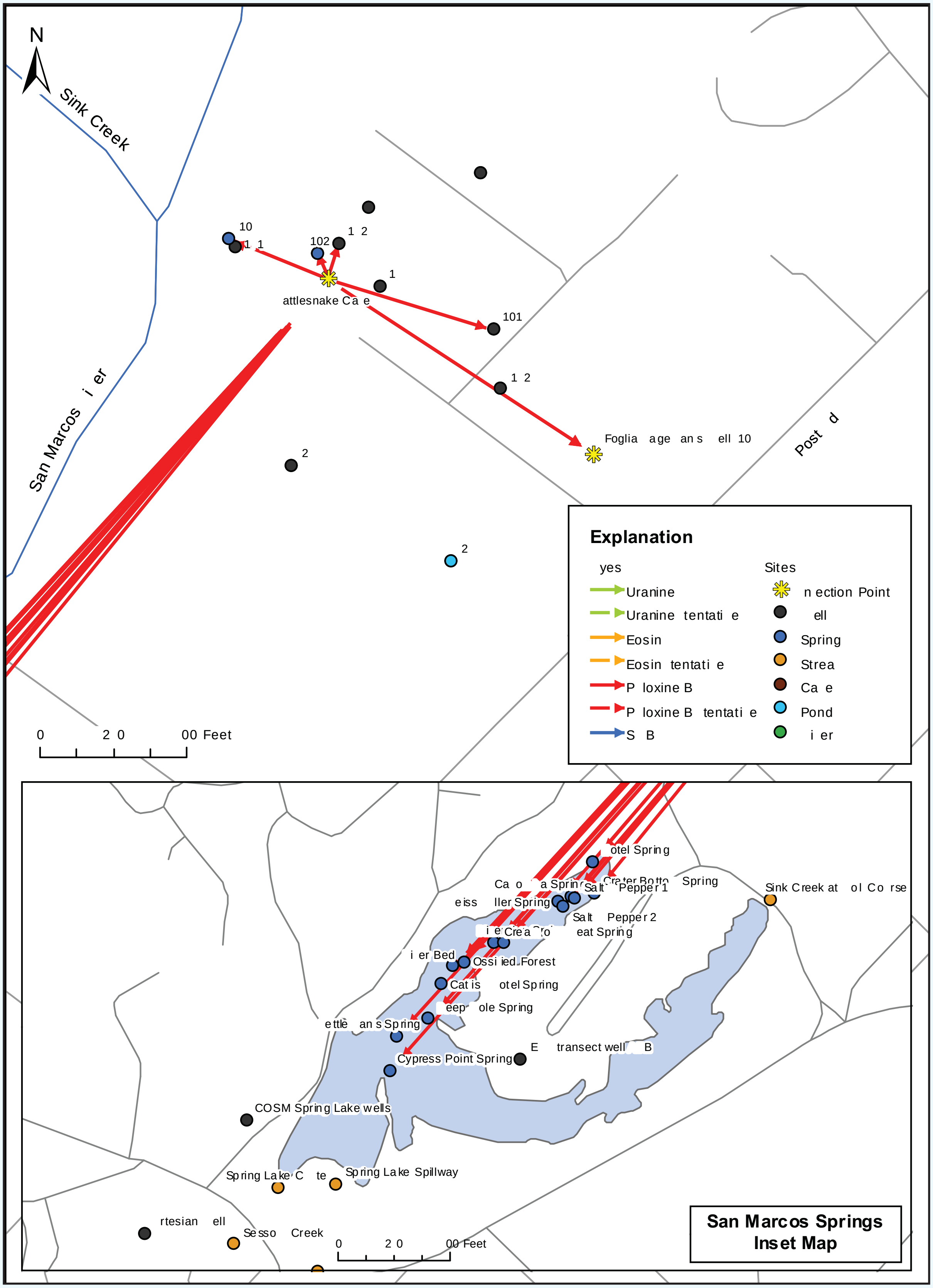


Table 17. Summary of Northeastern Tracer-Test Results—Rattlesnake Cave and Hagemen's Well

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Rattlesnake Cave	1/6/2004	Phloxine B 70 g	Crater Bottom Spring (118)	1/10/2004	3,900 ft (1,200 m)	4	980 ft/d (300 m/d)
			Salt and Pepper Spring 1 (128)	1/10/2004	3,900 ft (1,200 m)	4	980 ft/d (300 m/d)
			Salt and Pepper 2 Spring (129)	1/10/2004	4,200 ft (1,300 m)		
			Hotel Spring (32)	1/12/2004	3,900 ft (1,200 m)	6	660 ft/d (200 m/d)
			Cabomba Spring (33)	1/12/2004	3,900 ft (1,200 m)	6	660 ft/d (200 m/d)
			Weissmuller Spring (31)	1/10/2004	4,300 ft (1,300 m)	4	1,100 ft/d (320 m/d)
			Cream of Wheat Spring (122)	1/10/2004	4,300 ft (1,400 m)	4	1,100 ft/d (350 m/d)
			Diversion Spring (30)	1/10/2004	4,300 ft (1,400 m)	4	1,100 ft/d (350 m/d)
			Spring Lake Chute (108)	1/12/2004	Unknown		
			Spring Lake Spillway (110)	1/12/2004	Unknown		
			Spring Lake Total Outflow (109)	1/13/2004	Unknown		
			Catfish Hotel Spring (119)	ND	4,800 ft (1,470 m)		
			COSM Spring Lake Well (137)	ND	5,871 ft (1,790 m)		
			COSM Comanche Well (149)	ND	9,100 ft (2,800 m)		
			Well 101	ND	600 ft (180 m)		
			Well 152	ND	660 ft (200 m)		
			Sink Spring (104)	ND	100 ft (30 m)		
			Well 105	ND	246 ft (75 m)		
			Well 167	ND	134 ft (41 m)		
Rattlesnake Cave	12/3/2009	Phloxine B 620 g	Rattlesnake Well (172)	4/29/2010	130 ft (40 m)	147	0.89 ft/d (0.27 m/d)
			Rattlesnake Sink (102)	4/8/2010	150 ft (45 m)	126	1.2 ft/d (0.36 m/d)

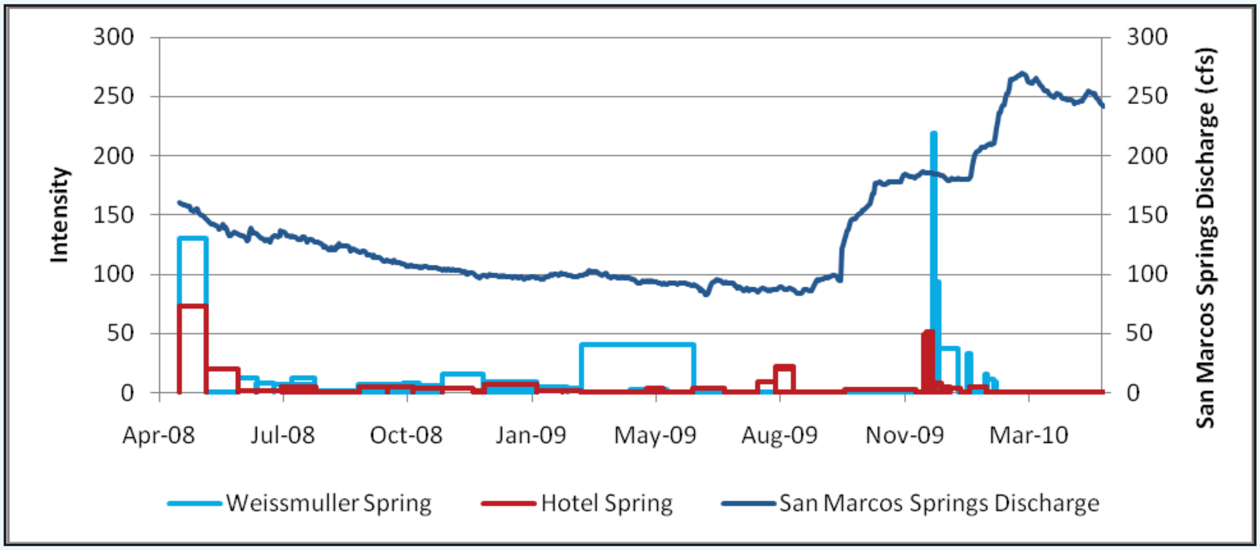
(Table 17. continued)

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
			Well 101	2/11/2010	590 ft (180 m)	70	8.5 ft/d (2.6 m/d)
			Sink Spring (104)	4/8/2010	820 ft (250 m)	126	6.6 ft/d (2.0 m/d)
			Well 106	4/29/2010	1,100 ft (330 m)	147	7.2 ft/d (2.2 m/d)
			Crater Bottom Spring (118)	12/7/2009	3,900 ft (1,200 m)	4	980 ft/d (300 m/d)
			Hotel Spring (32)	12/10/2009	3,900 ft (1,200 m)	7	560 ft/d (170 m/d)
			Cabomba Spring (33)	12/7/2009	4,300 ft (1,300 m)	4	1,100 ft/d (340 m/d)
			Salt & Pepper 1 Spring (128)	12/17/2009	4,300 ft (1,300 m)	14	300 ft/d (93 m/d)
			Salt & Pepper 2 Spring (129)	12/17/2009	4,300 ft (1,300 m)	14	300 ft/d (93 m/d)
			Weissmuller Spring (31)	12/17/2009	4,300 ft (1,300 m)	14	300 ft/d (93 m/d)
			Cream of Wheat Spring (122)	12/7/2009	4,600 ft (1,400 m)	4	1,500 ft/d (470 m/d)
			Diversion Spring (30)	12/7/2009	4,600 ft (1,400 m)	4	1,500 ft/d (470 m/d)
			Catfish Hotel Spring (119)	12/7/2009	4,900 ft (1,500 m)	4	1,200 ft/d (380 m/d)
			Deep Hole Spring (29)	12/17/2009	4,900 ft (1,500 m)	14	360 ft/d (110 m/d)
			Kettleman's Spring (125)	12/20/2009	5,200 ft (1,600 m)	17	310 ft/d (94 m/d)
			Cypress Point Spring (121)	Interference	5,200 ft (1,600 m)		
			Ossified Forest Spring (126)	Interference	4,600 ft (1,400 m)		
			River Bed Spring (127)	Interference	4,700 ft (1,400 m)		
			Sessom Creek (107)	10/10/2009	Unknown		
			Sink Creek at Lime Kiln Road (113)[T]	12/10/2009	Unknown		
			Spring Lake Spillway (110)	12/14/2009	Unknown		
Hageman's Well (106)	7/6/2005 9:55	Eosin 61 g	None				

T = tentative detection

ND = not detected.

Figure 46. Phloxine B Concentrations in Charcoal Receptors at Hotel and Weissmuller Springs after 2009 Rattlesnake Cave Injection



Results of 2009 Injection

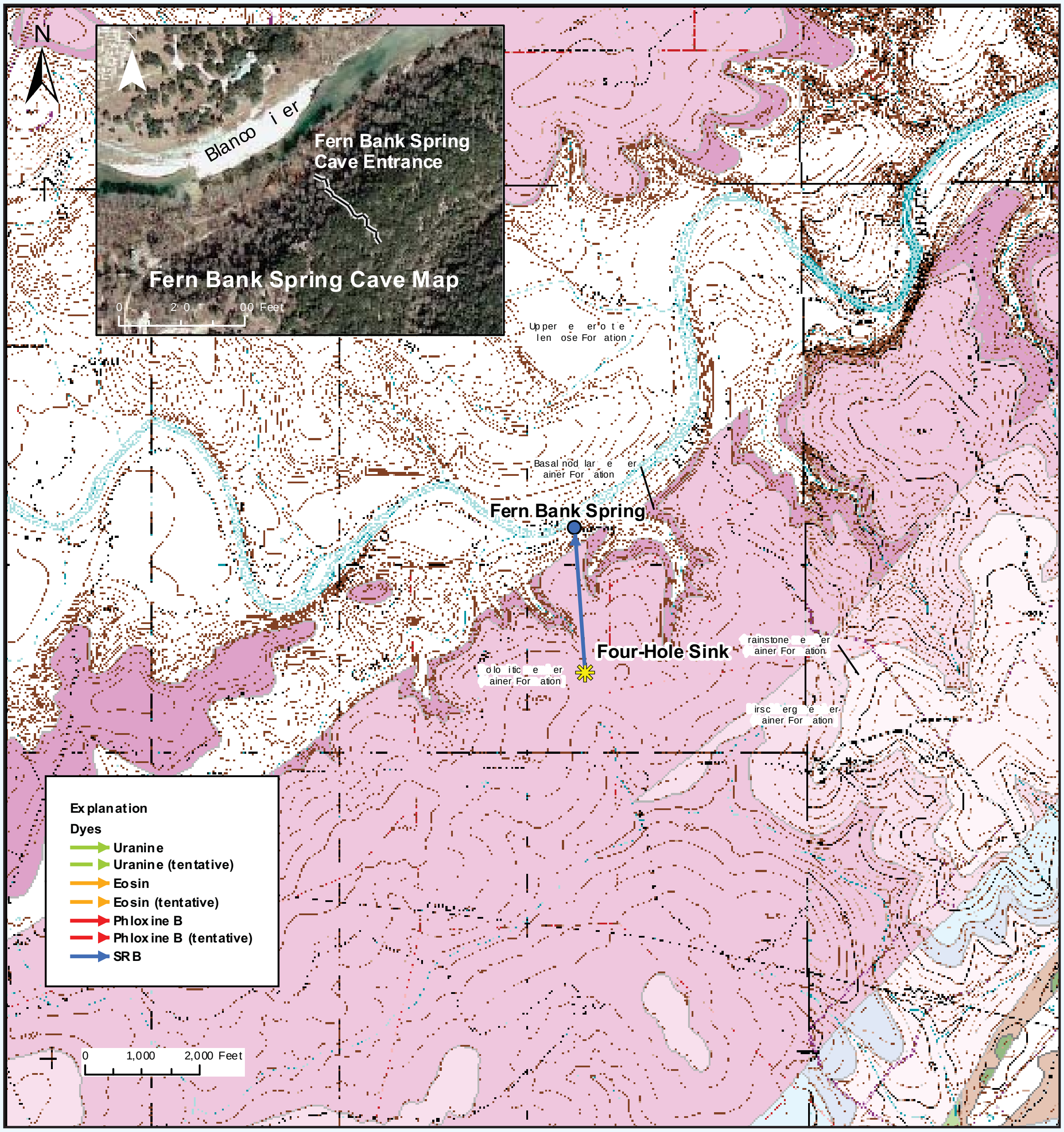
As described in previous sections, Phloxine B was continuously detected at individual springs at San Marcos Springs since the 2005 injection at Dakota Ranch Cave for the western tracer tests (see Results, p. 39). Results of the 2009 injection at Rattlesnake Cave may be distinguished from background Phloxine B concentrations by higher concentrations and timing. That is, Phloxine B concentrations from the 2009 injection should be significantly higher than background concentrations and should arrive after a reasonable travel time following injection. If not, then Dakota Ranch Cave would be considered the source of any Phloxine B detections.

Fortunately, results of the 2009 injection are readily recognizable at many monitoring sites compared with background concentrations (Figure 46). Prior to injection on December 3, 2009, background Phloxine B concentrations at Cabomba, Deep Hole, Diversion, Weissmuller, and Hotel springs ranged from nondetectable to less than 2 µg/L. Following injection, Phloxine B concentrations increased abruptly at Diversion (December 7, 2009) and Hotel (December 10, 2009) springs, followed by Cabomba, Deep Hole, and Weissmuller (December 17, 2009) springs. Consequently, results were sufficient to distinguish Phloxine B from the 2009 injection compared with previous injections. Apparent velocities ranged from approximately 160 ft/d (50 m/d) for Diversion Spring to approximately 1,500 ft/d (470 m/d) for Diversion Spring. Phloxine B was also detected at Kettleman's, Catfish Hotel, Cream of Wheat, Crater Bottom, and Salt and Pepper 1 and 2 springs. Background interference at River Bed and Ossified Forest springs prevented distinguishing any Phloxine B from that of Rattlesnake Cave. Only Cypress Point Spring did not have a detection of Phloxine B. Phloxine B persisted in various springs until February 2010, although the last sample of Spring Lake outflow that contained Phloxine B was on May 27, 2010, before monitoring ended in June 2010.

These apparent velocities are significantly higher than velocities measured by Ogden et al. (1986). Like the southwestern tracer tests (Figure 23), apparent velocities are directly proportional to San Marcos Springs discharge. On August 30, 1984, discharge during the injection was 74 cfs (2.1 m^3/s), as compared with 183 cfs (5.2 m^3/s) on December 3, 2009.

Like the injection in 2004, few monitoring points near Rattlesnake Cave yielded detections from the December 3, 2009, Phloxine B trace. Dye was detected in Sink Creek at Lime Kiln Road on December 10, 2009 (tentative), Well 101 on February 22, 2010, and Well 106

Figure 47. Fern Bank Spring Tracer Test



on April 29, 2010. It was detected in Rattlesnake Sink and Rattlesnake Well, which are within 160 ft (50 m) of Rattlesnake Cave, on April 8, 2010, and May 6, 2010, respectively.

Detections of Phloxine B at West Campus Well in December 2009 and April 2010 and Sessom Creek in December 2009 are probably not from Rattlesnake Cave. They either are from the Dakota Ranch Cave trace or are an interfering compound.

Fern Bank Spring Tracer Test: Four-Hole Sink (2008)

Fern Bank Spring, also known as Little Arkansas Spring, issues from the south bank of the Blanco River approximately 9 mi (14 km) downstream of Wimberley in Hays County (Figure 47).

Purpose

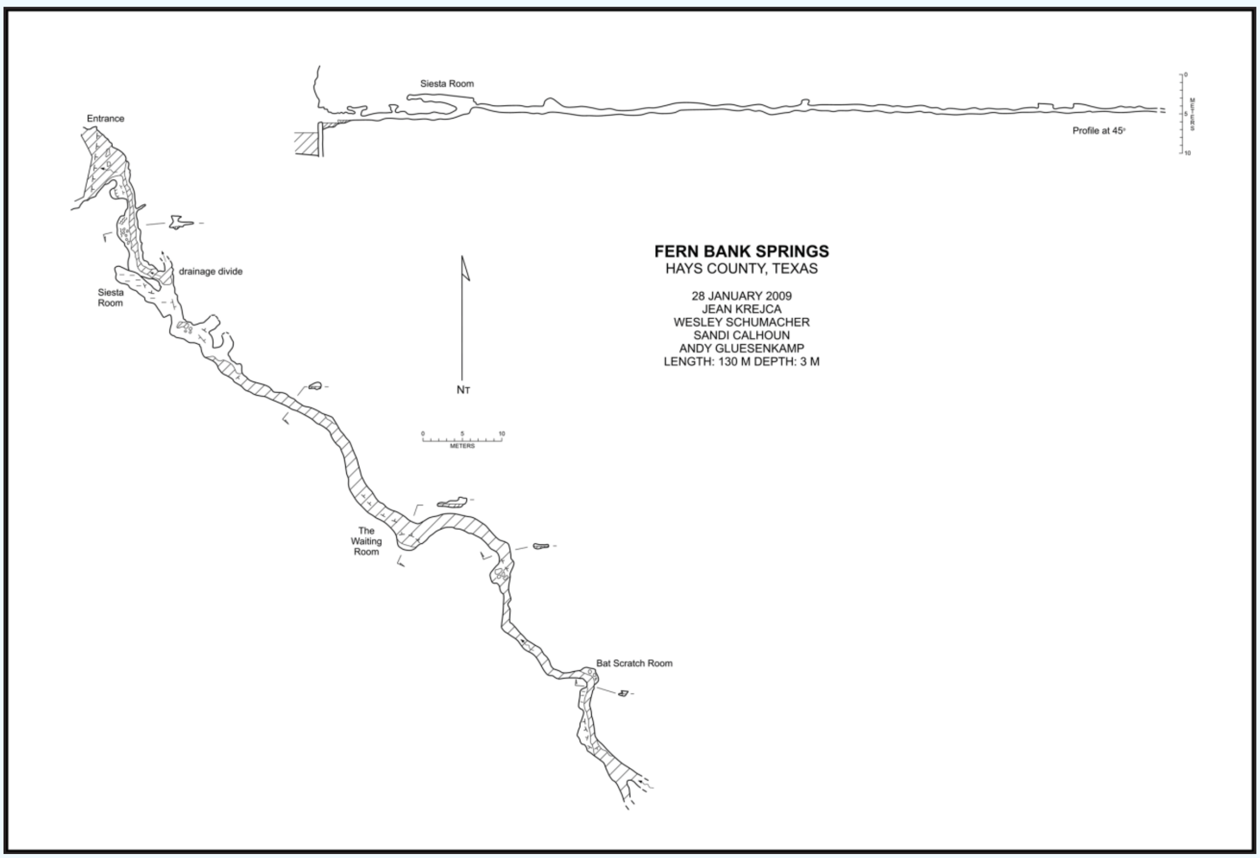
The purpose of the tracer test at Fern Bank Spring was to investigate its recharge area, which was hypothesized to be either the Blanco River or areas of higher elevation south of the springs. The geologic setting suggests that a groundwater divide exists between Fern Bank and San Marcos springs.

Setting

Fern Bank Spring discharges from a cave in the base of a steep bluff that forms the south bank of the Blanco River. Spring flow collects in a pool at an elevation of approximately 760 ft (232 m) msl that overflows into the river. The cave entrance is in the Upper Glen Rose Formation, which underlies the Edwards Limestone. Figure 48 shows a map of the cave from which the spring issues. The Dolomitic member of the Kainer Formation of the Edwards Limestone outcrops at an elevation of almost 1,000 ft (305 m) msl above the bluff. The bluff is the escarpment of the Hidden Valley Fault (Hansen and Small, 1995), which is one of several major faults in Hays County.

Four-Hole Sink is a set of solution sinkholes linearly oriented along a N20°E trend approximately 2,500 ft (760 m) south of Fern Bank Spring at an elevation of approximately 984 ft (300 m) msl. The feature is located in the Edwards Limestone (Dolomitic member of the Kainer Formation) in the uplands south of the Blanco River valley. Each of the individual solution sinkholes are up to three ft (one m) in diameter at the land surface and become gradually smaller with depth. All openings are too small to allow for human exploration without excavation. Observable depths of individual sinkholes range up to 10 ft (three m). Significant airflow was noticed from two openings.

Figure 48. Cave Map of Fern Bank Spring



Injection

A 255-g (0.56-lb) mass of Sulforhodamine B (SRB) was injected in Four-Hole Sink on June 12, 2008, and flushed with 10,000 gal (37,800 L) of water in increments of 2,000 gal (7,600 L). No water backed up in the sink, indicating rapid infiltration into the subsurface. The small mass was selected to avoid possible impacts to aquatic life in Fern Bank Spring, and that amount was suitable for a relatively short flowpath to the Blanco River. If there were a connection with Fern Bank Spring, some of the SRB would flow into the Blanco River and follow the groundwater flowpaths of previous injections in or near the mouth of Halifax Creek. However, owing to photodegradation of the dye by sunlight in the Blanco River and sorption within the aquifer, that SRB would be detected at San Marcos or Barton springs would be unlikely.

Results

Relatively low concentrations of SRB were detected in charcoal receptors placed in Fern Bank Spring beginning in August 2009, two months after injection, which represents an apparent velocity of approximately 33 ft/d (10 m/d) (Table 18). SRB was still detectable when monitoring ended in December 2008. The relatively slow apparent velocity suggests that drought conditions, prevalent at the time of injection, inhibited movement of dye.

SRB was initially detected at Barton Springs in a charcoal receptor collected on February 25, 2008, prior to the Four-Hole Sink injection. Consequently, subsequent detections of SRB at Barton and Eliza springs between March and October 2009 are ambiguous. The Halifax Creek Sinkhole and Johnson Swallet injections demonstrated that Fern Bank Spring could be connected to Barton Springs if dye entered the Blanco River and then infiltrated into the aquifer. However, that SRB detected at Barton Springs originated from Four-Hole Sink is unlikely because of the ambiguous detections, small amount of dye, and long duration of travel. In addition, no SRB was detected in any monitoring wells between Four-Hole Sink and Barton Springs, including those where Eosin was recovered.

Table 18. Summary of Tracer-Test Results at Northern Injection Locations

Injection Point	Injection Date	Dye Amount	Recovery Site Name or Number (Map Number)	Arrival Date	Distance	Travel Time (days)	Apparent Velocity
Four-Hole Sink	6/12/2008	SRB 255 g	Fern Bank Spring (181)	8/26/2008	2,525 ft (770 m)	75	33 ft/d (10 m/d)

Discussion

This section describes findings of the tracer tests with respect to Barton and San Marcos springs.

Vulnerability of the Springs

Tracer tests were successful from every injection point in the vicinity of San Marcos and Barton springs, indicating that both spring complexes are important discharge points for the greater Edwards Aquifer system. Consequently, these tests also demonstrated that the groundwater system and springs are vulnerable to virtually all activities in their springsheds, which may degrade water quality. Because dyes are surrogates for potential pollutants, releases of hazardous materials or other pollutants in the recharge zone will reach the groundwater and may impact water quality of the springs. Potential pollutants, similar to dyes, may enter the aquifer through karst features, such as caves or sinkholes, and descend unfiltered to the water table. Groundwater velocities would determine how quickly the pollutants would migrate toward wells or springs. An example is the unknown substance that was detected in Deep Hole Spring prior to dye injections in 2004 (Figure 19). Elsewhere, USGS studies have demonstrated the vulnerability of Barton Springs with detailed water quality studies (e.g., Mahler et al., 2011). Endangered species and other aquatic wildlife that rely on San Marcos or Barton springs may be affected by potential pollutants. In addition, water supply wells in the aquifer are vulnerable to water quality impacts in the recharge zone.

Springshed Boundary between Barton Springs and San Marcos Springs

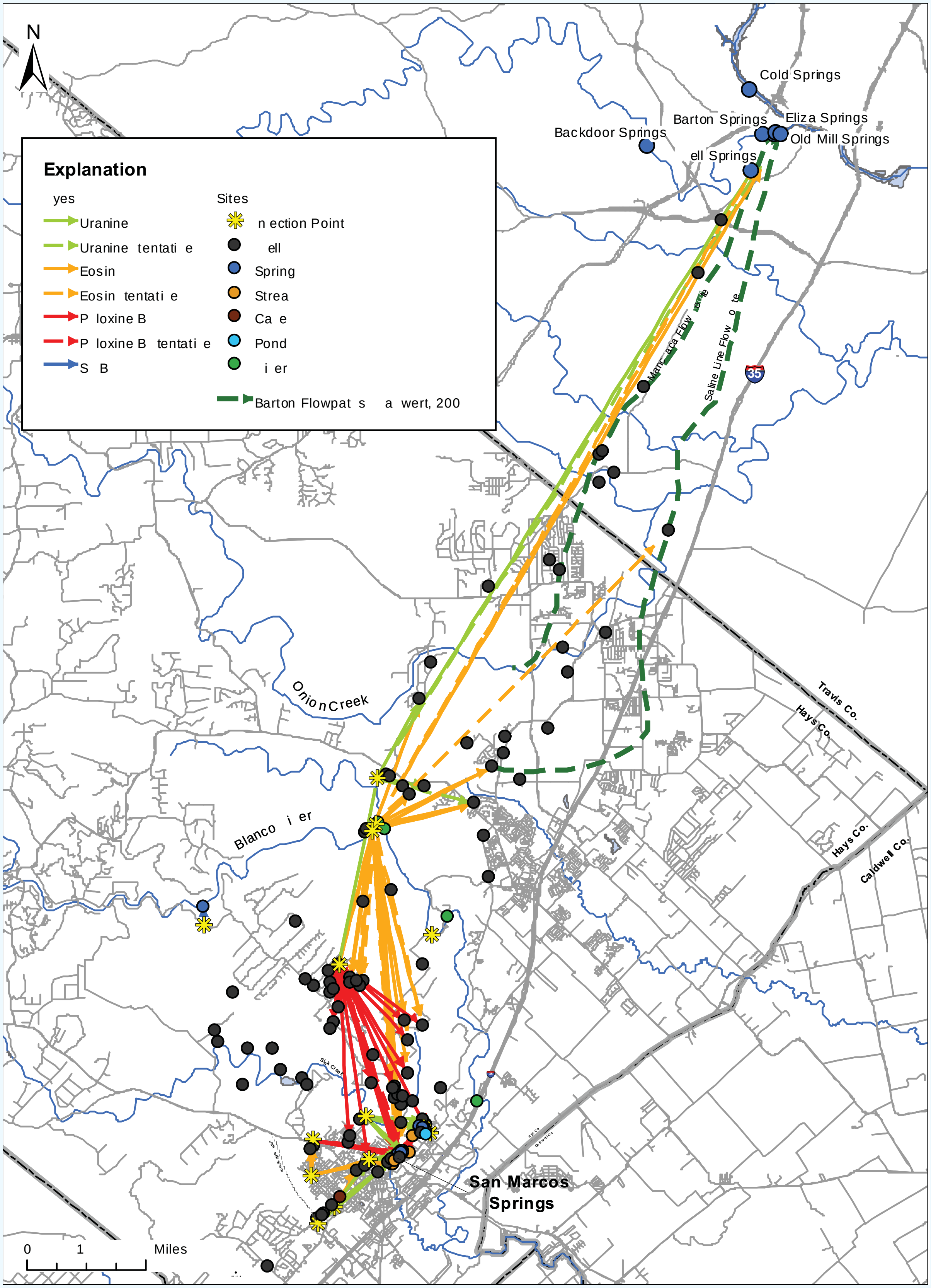
Tracer tests near and within the Blanco River helped improve understanding of the springshed boundary between San Marcos and Barton springs during moderate to low flow conditions. During this study, discharges at San Marcos Springs (Figure 9) ranged from less than 100 cfs to approximately 430 cfs (2.8 m^3/s to approximately 12 m^3/s), and at Barton Springs, discharges ranged from less than 20 cfs to more than 125 cfs (less than 0.6 m^3/s to more than three m^3/s). Tracer-test data indicated that there was bidirectional flow occurring from the Blanco River area to both San Marcos and Barton springs. Tracer tests by Hauwert et al. (2004) and Hunt et al. (2006) indicate that Onion Creek was a flow boundary between the Barton Springs (EABS) segment and the southern segment of the Edwards Aquifer under moderate to high flow conditions. The tracer-test data from this study indicate that the groundwater boundary (divide) migrates from Onion Creek during moderate to high flow conditions to Blanco River during moderate to low flow conditions in the vicinity of the tracer tests. Moderate to low flow conditions prevailed during most tracer testing performed for this study. These tracer tests indicate that in the absence of a hydraulic mound, which forms beneath Onion Creek during moderate to high flow conditions, the boundary between San Marcos and Barton springs springsheds moved to encompass the Halifax Creek Sinkhole and Johnson Swallet area. Because the divide requires seepage losses from Onion Creek, these findings may not apply to areas where there is no seepage from Onion Creek.

Flowpaths toward Barton Springs

The tracer-test study indicates that under dry conditions, Barton Springs receives some recharge from the Blanco River (Figure 49). The direct tracing between the Blanco River and Barton Springs described in this report supports the conclusions of the correlation of flow loss in the Wimberley to Kyle part of the Blanco River with Barton Springs. These correlations suggest that during low-flow conditions, the Blanco River contributes to Barton Springs (COA report in preparation).

The breakthrough of dyes injected in the Blanco River watershed at Old Mill Springs has revealed potentially new hydrologic information on flowpaths of the EABS segment. Early in the study in 2008, background Eosin discharged from Old Mill Springs, but concentrations declined below detection limits on charcoal after June 26, 2008. During this time, Barton Springs flow declined below 27 cfs (0.76 m^3/s). Beginning December 4, 2009, over 10 months after the February 26, 2009, Eosin injection on the Blanco River at Johnson Swallet, Eosin was detectable at Old Mill Springs, as Barton Springs flow increased to above 50 cfs (1.4 m^3/s) at the end of a long drought. During low-flow conditions, contributions from the Manchaca Flow Route (Figure 49) to Old Mill Springs probably cease or measurably diminish.

Figure 49. Tracer Tests between San Marcos Springs and Barton Springs



Using results of these tracer tests, we compared travel times from the Blanco River to Barton Springs with Blanco River flow and Barton Springs discharge. Higher river flows or spring discharges may reflect flooding of upper levels of the vadose zone or steeper hydraulic gradients that would increase tracer velocities. In addition, dye trapped in the vadose zone may be flushed out by higher flow in the Blanco River and greater upland runoff. Travel times for Eosin arrivals at Barton Springs after second and third injections at Halifax Creek, Uranine from Bull Pasture Sink, and late responses of both Eosin and Uranine to Old Mill Springs were plotted against maximum daily average Blanco River flow during travel time (Figure 50). Given these five injection responses, travel time from the Blanco River watershed to Barton Springs ranged from seven to 42 days, whereas Blanco River flow varied from 18 to 618 cfs (0.5 to 17.5 m^3/s). Similarly, travel times for the same responses were plotted, along with Barton Springs discharge, on the day of injection (Figure 51). Neither comparison indicates that Blanco River flow (assumed a surrogate for vadose flushing and phreatic flow pulses through the aquifer) or Barton Springs discharge (assumed a surrogate for aquifer flow conditions and potentiometric gradient) is a predictor of travel time. Groundwater flowpaths and travel times are dynamic and change in relation to aquifer stage, as well as other hydraulic properties of the aquifer. Additional tracers and more tightly constrained arrival times than can be obtained with charcoal receptors would be necessary to further investigate the relationship between water levels in the aquifer and tracer velocities.

Figure 50. Evaluation of Travel Time and Blanco River Flow

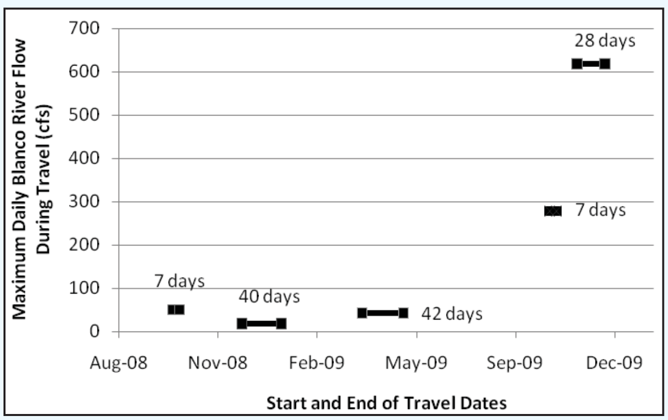
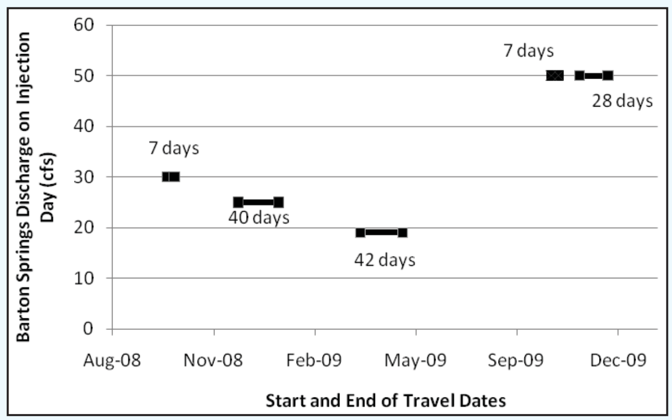


Figure 51. Evaluation of Travel Time and Barton Springs Discharge



Flowpaths toward San Marcos Springs

Results of tracer tests from this study indicate that groundwater flowed to San Marcos Springs from all injection locations. The results confirmed the prevailing conceptual model, in which San Marcos Springs receives local recharge, as well as regional contributions from the Edwards Aquifer artesian zone (Ogden et al., 1986 and Johnson and Schindel, 2008). This study confirms the contribution of the Blanco River to San Marcos Springs, which has long been suspected as a source of recharge. Previous studies have expanded the springshed to also include Onion Creek (Hunt et al., 2006). As described previously, these tracer tests also helped to provide a better understanding of the hydrologic divide between the southern and Barton Springs segments of the Edwards Aquifer.

Accordingly to groundwater velocities, most San Marcos Springs discharge originates southwest of the springs. Apparent groundwater velocities from the southwest exceeded 2,620 ft/d (800 m/d), whereas velocities from most other injection points were less than 1,640 ft/d (500 m/d). These findings corroborate studies by Johnson and Schindel (2008), who concluded that regional groundwater flow from the artesian zone southwest of San Marcos Springs was the principal source of recharge for the springs. Groundwater from local sources west, northeast, and north of San Marcos Springs contribute smaller amounts of recharge.

Further, apparent velocities measured from the Johnson Swallet injection indicate that groundwater flowpaths from the north vary in transmissivity from fast to slow with distance from the Blanco River. Groundwater traveled southward from Johnson Swallet at apparent velocities greater than 2,620 ft/d (800 m/d) for approximately seven kilometers to Wells 48 and 90. Apparent velocities to Well 89, which is almost six mi (10 km) from Johnson Swallet, exceeded 2,300 ft/d (710 m/d). However, Eosin injected at Johnson Swallet and arriving at San Marcos Springs (e.g., Weissmuller, Hotel, and Diversion springs), required 50 to 60 more days than dye injected at Well 89 required to arrive at the same springs. This fact indicates that apparent velocities slowed from 2,000 ft/d (610 m/d) from Johnson Swallet to Well 89 to 200 to 260 ft/d (60 to 80 m/d) from Well 89 to San Marcos Springs. Groundwater gradients are relatively steep north of Well 90 and then become shallower closer to San Marcos Springs. The groundwater gradient between the Blanco River at Johnson Swallet and groundwater at Well 89 is as much as 100 ft (30 m). However, the groundwater gradient drops between Well 89 and Spring Lake to less than 10 ft (three m) between Well 89 and Spring Lake, according to potentiometric surface maps developed by DeCook (1963) and Ogden et al. (1986). Discontinuity in the groundwater surface is caused by Balcones faulting, which strikes normal to the flowpaths. Groundwater carried the dyes through the faults; however, it could not be determined whether the faults and juxtaposition of Edwards Group and overlying units significantly reduce the permeability of the aquifer.

On a larger scale, the Halifax Creek Sinkhole and Johnson Swallet injections revealed evidence regarding groundwater flow from the Blanco River to San Marcos Springs. Dye from Halifax Creek Sinkhole traveled southward but was detected only in a high-transmissivity flowpath in which Well 48 was located. Groundwater velocities were high enough to offset dilution and maintain relatively high concentrations. Dye was not detected in other wells in the area, probably because of slower flowpaths and dilution or the dye traveled in preferential flowpaths not intersected by other wells. The flowpath is suspected to be relatively deep because Well 48 did not intercept Phloxine B from Fritz's Cave, which is 3,280 ft (1,000 m) north of Well 48. In addition, the flowpath connected to San Marcos Springs, where Phloxine B was detected in Hotel, Weissmuller, and Diversion springs. This conceptual model is hydraulically consistent because the flowpath probably passes beneath the geologic units that overlie the Edwards Aquifer near San Marcos Springs. Unfortunately, Phloxine B from Dakota Ranch Cave interfered with or masked any dye from Fritz's Cave at San Marcos Springs.

Dye from Johnson Swallet followed the same flowpath a few months later because it was detected at Well 48 and San Marcos Springs. Because Johnson Swallet was an efficient injection point, it delivered more dye to the groundwater system than did Halifax Creek Sinkhole. Consequently, the dye traveled farther before dilution rendered it undetectable. It traveled farther south-southeast to wells in which dye from Halifax Creek was not detected, such as Wells 40, 41, and 89. In addition, dye was detected in wells northeast of San Marcos Springs near Rattlesnake Cave. Whether these flowpaths eventually connected to San Marcos Springs or were captured by groundwater potentially flowing northeast toward Barton Springs is unknown. The location of the groundwater divide is not established in the area northeast of San Marcos Springs.

Although Sink Creek appeared to be a source of recharge, test results were ambiguous because of interference from the TSU cooling tower leak test. Unfortunately the timing of detections was not definitive, and dye concentrations at monitoring sites were not proportional to injections. Two conclusions are possible, and both may be true. First, results provided evidence that releases to groundwater on or near campus may eventually migrate to San Marcos Springs. Second, Sink Creek is a local source of recharge for San Marcos Springs. If Sink Creek contributes recharge to San Marcos Springs, it appears to be a relatively minor source because Uranine was detected intermittently and at relatively low concentrations at individual springs. Direct connections would be expected to show higher concentrations of Uranine at San Marcos Springs. Additional tracer tests are needed for a better understanding of the hydrologic relationships between Sink Creek and San Marcos Springs.

Previous studies using high-frequency sampling have revealed geochemical differences among water samples from individual springs in Spring Lake, indicating multiple sources of recharge. Ogden et al. (1986) concluded that two flow regimes separated by the San Marcos Fault supplied the springs. The first regime consists of groundwater flowing northeast from Comal County and discharging from southern springs (Deep Hole and Catfish Hotel), and the second regime consists of local recharge originating from the Blanco River. Their conclusions were based partly on tracer tests showing that Ezell's Cave was hydraulically connected only to the two southern springs, Deep Hole and Catfish Hotel springs, although tracers from Rattlesnake Cave and Tarbutton's Showerbath Cave appeared at all six of the monitored springs (Deep Hole, Catfish Hotel, Diversion, Cabomba, Weissmuller, and Hotel). The EAA's tracer tests generally corroborated previous tracer tests, although dyes from Ezell's Cave were detected in Cabomba and Diversion springs, as well as Deep Hole and Catfish Hotel springs, indicating that the San Marcos fault may not be a flow barrier. Highly detailed tracer tests, similar to the Artesian Well data collection program in 2005 and additional high-frequency sampling would be required to characterize the hydrologic differences among all of the individual springs that compose the San Marcos Springs complex.

CONCLUSIONS

- Tracer tests were successful from every injection point in the vicinity of San Marcos Springs and Barton Springs, which indicated that both spring complexes are important discharge points for the greater Edwards Aquifer system. Results indicated that groundwater in the Edwards Aquifer virtually anywhere in Hays County may discharge at San Marcos Springs or Barton Springs. The tests indicated that both springs are vulnerable to virtually all activities in their springsheds that may degrade water quality. Endangered species and other aquatic wildlife are potentially vulnerable to water quality impacts in the recharge zones for the springs.
- San Marcos Springs is recharged by regional and local sources of groundwater. Groundwater from the artesian zone, which flows northeastward along the strike of the Balcones Fault Zone, probably supplies the largest part of San Marcos Springs discharge. This conclusion is based on the fastest apparent velocities measured in this study

and previous studies (Johnson and Schindel, 2008). Apparent velocities from the southwest flowpaths were significantly faster than from other directions. Results of this study indicate that the Blanco River should be included as a regional source, especially during dry periods, when it drains a large watershed and helps sustain the springs. Local sources include Sink Creek, direct precipitation, and other areas.

- Solution features associated with groundwater flowpaths are connected to the ground surface. Injection points consisted of several caves (Ezell's, Windy, Dakota Ranch, and Fritz's) and sinkholes (Halifax Creek, Bull Pasture, and Four-Hole), all of which demonstrated a connection to groundwater offering little, if any, attenuation. Although some caves transmitted dye to groundwater more quickly than others, all had a direct and unfiltered connection. For example, Ezell's Cave quickly recharges groundwater, whereas Dakota Ranch Cave recharges more slowly.
- Groundwater carried dyes both parallel to and perpendicular to the Balcones Fault Zone from injection points to both San Marcos and Barton springs complexes and other detection points, indicating that faults do not act as barriers in the test area. However, the faults and juxtaposition of the Edwards Group members reduce the permeability of the aquifer, which shapes hydraulic gradients and apparent velocities. Consequently, during the 8.1-mi (13-km) trip from the Blanco River injection points to San Marcos Springs, apparent velocities were faster in the initial 4.3 mi (seven km)south of the Blanco River and then slowed considerably within the area approximately 3.7 mi (six km) north of San Marcos Springs.
- To reach San Marcos Springs from the Blanco River injection points, groundwater had to flow through multiple members of the Edwards Aquifer under both unconfined and confined conditions. These findings revealed the three-dimensional groundwater flow system in the Edwards Aquifer.
- During low-flow conditions, the groundwater boundary between the San Marcos Springs and Barton Springs springsheds is located near the confluence of the Blanco River and Halifax Creek. Blanco River apparently recharges both spring complexes, at least under low-flow conditions that existed during this study. This boundary moves toward Barton Springs during wet conditions when infiltration from Onion Creek forms a potentiometric mound. During dry conditions, the Blanco River provides more persistent base flow for both springs.

Acknowledgments

The Edwards Aquifer Authority would like to thank all those who allowed access to their wells: private well owners in Hays County who participated in these tracer tests, Barton Springs Edwards Aquifer Conservation District, City of Austin Watershed Protection and Development Review Department, Texas State University at San Marcos, and the City of San Marcos. Aquarena Center has always promoted research at San Marcos Springs and helped the EAA collect samples that are the basis for these tests. Data that we collected from their wells and springs enabled us to better protect and manage the Edwards Aquifer.

Regarding the Blanco River traces, we would like to specifically acknowledge the cooperation and support provided by Halifax Ranch owners and staff, specifically Mr. Bill Johnson (Owner) and Mr. Mike North (Manager). Without their help and support, that part of the study would not have been possible.

We also acknowledge the assistance of Joe Beery, Guy Rials, Julie Jenkins (BSEACD), Justin Camp (COA), and Bill Russell (TCMA) in many aspects of the study for the Blanco River.

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APPENDIX A. Edwards Aquifer Authority Quality Control/ Quality Assurance Manual For Tracer Testing

February 2012

These Quality Control/Quality Assurance (QC/QA) protocols were prepared to define field and laboratory operations and methods for the performance of tracer testing of groundwater in karst terranes using fluorescent dyes. The operations and procedures contained in this manual define a very high standard of data collection. However, depending on the data quality objectives of the project, the user may determine that some of the QC/QA methods are not necessary.

A 1.0 SAMPLING PROCEDURES

The initial field investigation for tracer test studies will be conducted by an Edwards Aquifer Authority (EAA) hydrogeologist experienced in the identification of karst features. Work will be supervised by EAA's Chief Technical Officer. The hydrogeologist doing the initial field investigation will also place the background charcoal detectors and oversee other personnel in the collection and replacement of charcoal detectors.

A 1.1 PROCEDURES FOR SAMPLING GROUNDWATER AND SURFACE WATER FOR DYE

Water samples may be collected for direct analysis of dye or in support of data from passive charcoal detectors. Water samples from springs and surface streams will be collected by submerging a laboratory-supplied container directly into the water. The clean sample bottle will be rinsed with sample water before being used to collect a sample for analysis. When a sample is collected from a spring or stream, the container will be held upstream of the sampler and oriented in an upstream direction during sample collection.

Samples from groundwater monitoring wells will be collected with precleaned, dedicated PVC or Teflon bailers or a dedicated submersible pump. Prior to sampling, the water level in the well will be determined with an electronic water level meter, fiberglass tape, or steel tape and recorded in a field book. Date, time, location, tracing project name, and other relevant field data will be recorded in a field book. Groundwater will not be purged from the well before the sample is collected.

Table A-1 lists the sample containers, preservatives, holding times, and conditions for groundwater and eluent samples. Only new sample containers will be used for sample collection. For each shipment of containers received, blanks will be taken from the lot and analyzed for the presence of dye. Results will be reviewed before any containers from the lot are used.

All sample containers will be stored in an area isolated from the extraction laboratory. Trip blanks for dye will also be prepared in this area.

TABLE A-1

REQUIRED CONTAINERS, SAMPLE STORAGE TECHNIQUES, AND RECOMMENDED HOLDING TIMES

Parameter	Sample Container	Sample Storage/Preservation	Recommended Maximum Holding Times
Uranine (Sodium Fluorescein) (Acid Yellow 73)	13-mm glass bottle with screw top lid or 50-mL plastic culture tube with screw top lid	Store in dark at four° C	six months
Rhodamine WT (Acid Red 388)	13-mm glass bottle with screw top lid or 50-mL plastic culture tube with screw top lid	Store in dark at four° C	six months
Sulforhodamine B (Acid Red 52)	13-mm glass bottle with screw top lid or 50-mL plastic culture tube with screw top lid	Store in dark at four° C	six months
Eosin (Acid Red 87)	13-mm glass bottle with screw top lid or 50-mL plastic culture tube with screw top lid	Store in dark at four° C	6 months
Phloxine B (Acid Red 92)	13-mm glass bottle with screw top lid or 50-mL plastic culture tube with screw top lid	Store in dark at four° C	six months
Optical Brightener Solophenyl (Direct yellow 96) Blankophor (F.B.A. 28) Tinopal CBSX (F.B.A. 35)	13-mm glass bottle with screw top lid or 50-mL plastic culture tube with screw top lid	Store in dark at four° C	six months

A 1.2 PROCEDURES FOR USE OF CHARCOAL DETECTORS

Dye receptors (detectors) consisting of granular-activated coconut carbon (charcoal) will be used to adsorb dye present in surface or groundwater. Approximately 20 grams of charcoal will be placed in a packet constructed from nylon screen mesh or a milk filter sock and placed in springs, cave streams, surface streams, and monitoring wells. Charcoal is used to adsorb Uranine, Rhodamine WT, Sulforhodamine B, Phloxine B, and Eosin.

Charcoal detectors will be suspended in a surface stream, spring, or cave stream using a wire, string, pins, and/or weight. The detectors will be placed so that they are exposed to any flow that may be present. A rock, brick, or concrete weight (gum drop) will be used to help maximize the volume of water flowing through the packet and secured with dark-colored nylon string to a nearby tree, tree root, rock, or pin. The dark-colored string is used to blend with the surroundings and help to minimize tampering.

The placement of charcoal detectors in monitor wells will also utilize the packet but will be weighted using new glass marbles to submerge the charcoal detectors below the surface water.

For sampling water wells, a PVC pipe will be fitted with a hose for attaching to a faucet. The PVC pipe will be constructed such that it will allow placement of a nylon screen packet within the pipe that will channel flow through the packet.

A 1.3 PROCEDURES FOR USE OF UNBRIGHTENED COTTON

Charcoal detectors consisting of unbrightened cotton, polyethersulfone (PES) film, or other absorbent media will be used to absorb dyes and brightening agents—specifically, Direct Yellow 96 and F.B.A. 28 and F.B.A. 351. A piece of cotton or filter media will be placed in a nylon screen mesh packet and suspended in water as described in Section A1.2.

A 2.0 SAMPLE CUSTODY

A 2.1 FIELD COLLECTION AND SHIPMENT

When samples are transferred/shipped from the field, they will be accompanied by chain-of-custody records. The records will include signatures of the relinquisher and the receiver, date and time of the exchange, and any pertinent remarks. Sample chain-of-custody forms are shown in Figures A-1 and A-2 at the end of this QA/QC document.

During sample collection, the following procedures will be observed:

- To maintain validity of the sample, on-site procedures will be reviewed prior to arrival in the field.
- Sample handling will be minimized in order to reduce the chance of error, confusion, and damage.
- Sample bags will be marked in the field with waterproof ink to prevent misidentification due to illegible labels.
- The shipping container will be either padlocked or secured with a tamperproof seal.

Samples will be shipped in one of the following ways so that safeguards in chain of custody can be observed:

- Hand carried and delivered.
- Registered mail, so that a return receipt can be requested and available for documentation.
- Common carrier, so that a bill of lading can serve this purpose.
- Air freight collect, for complete documentation.

Samples collected in the field under supervision of EAA's staff for field analysis will contain a sample identification form but will not require a chain-of-custody form. All samples determined to be hazardous, according to the U.S. Department of Transportation (U.S. DOT) (49 CFR Section 172.1 or 49 CFR 173.3), will be shipped in strict accordance with U.S. DOT regulations.

A 2.2 DOCUMENT AND SAMPLE CONTROL

A field log book will be maintained by the sampler as a permanent record of all activities relating to the collection of a sample. Information included in the log book will include a list of those responsible for a sample, the date collected, a description of the location, a sample number, and the testing objective. The log book will also include data on the weather at the sampling time and location and other related field conditions. If the field book is lost or damaged, its loss will promptly be reported to the EAA's Chief Technical Officer. This procedure will also be used for field-data and in-house records. Table A-2 presents a list of specific information that will be recorded at the time a sample is collected.

A sample log book will also be maintained by the sample custodian as a permanent record of all activities relating to receipt and disposition of the sample. Information in the log book will include initials of sampler, sample number and location, date collected, date received, project, and testing parameters.

Identification of samples will be serialized in an alpha-numeric system consistent with the procedures of the study. If a sample is contaminated, it is to be disposed of properly and noted in the log book. Similarly, if a sample is lost, the sampler will document the loss and promptly notify the EAA's Chief Technical Officer. Tags or labels affixed to the sample will include all of the information listed above and the sample number.

A 2.3 PACKAGING

Sample packaging for shipment is done such that, under normal handling, there is no release or damage of charcoal detectors, effectiveness of the packing is not reduced, and there is no internal mixing of substances. The procedures followed to achieve these objectives are:

- The volume of the sample will be limited to the quantity needed for analysis.
- Plastic containers will be used whenever possible. The plastic container will be protected from puncture. If glass containers are used, the glass will be well cushioned.
- Screw lids will be used whenever possible.
- Charcoal and cotton detectors will be placed in sealed plastic bags with a minimal volume of air.

TABLE A-2

SAMPLE INFORMATION

IN SITU SAMPLES, if collected (e.g., temperature, conductivity)	
DATA in LOG BOOK	**project name or code**
	identification number
	location name
	date
	time
	sampler(s) initials
	field observations—weather, problems, etc.
	remarks
	value of parameters measured
TRANSPORTED SAMPLES	
DATA on TAGS or LABELS	**all above information**
	split sample/duplicate
	sample/blank

A 2.4 SAMPLE RECEIPT

Upon receipt, the sample custodian will follow these procedures:

- If samples have been damaged during shipment, the remaining samples will be carefully examined to determine whether they were affected. Any affected samples will also be considered damaged. It will be noted on the chain-of-custody record that specific samples were damaged and that the samples will be removed from the analytical schedule.
- Samples received will be compared against those listed on the chain-of-custody form.
- The chain-of-custody form will be signed and dated and attached to the waybill.
- Samples will be entered in the sample log book, containing the following information:
  - Project identification
  - Sample numbers
  - Sample location name
  - Type of samples
  - Date and time sampled
  - Date and time received
- The samples will be placed in adequate storage.
- The appropriate project manager will be notified of sample arrival.
- The completed chain-of-custody records will be placed in the project file.

If samples arrive either without a chain-of-custody record or with an incorrect chain-of-custody record, the following procedure will be undertaken by the sample custodian:

- If the chain-of-custody form is incorrect or incomplete, a memorandum to the project manager and field personnel will be prepared, stating the inaccuracy and necessary correction. The memorandum must be signed and dated by the person originating the chain-of-custody form. The memorandum serves as an amendment to the chain-of-custody form. If the information on the chain-of-custody form cannot be corrected by the project manager or field personnel, the affected samples will be removed from the analytical schedule.
- If the chain-of-custody record is not shipped with the samples, field personnel will be contacted and a memorandum prepared, listing the persons involved in collection, shipment, and receipt, as well as the times, dates, and events of such. Each person involved must sign and date this memorandum. The completed memorandum will be maintained in lieu of the chain-of-custody record.

A 2.5 SAMPLE STORAGE

Water samples will be stored in a secure area in the dark unless signed out for analysis by analytical personnel.

A 2.6 CUSTODY DURING TESTING PROGRAM

When chain-of-custody samples are being analyzed or processed, they will be signed out by the appropriate analyst. The individual performing the tests becomes responsible for the samples at that point. The samples will be maintained within sight or in the secure possession of the individual performing the test. When the work is complete, the samples will be returned and logged in to secure them in the proper storage location. During processing, the sample may be split into several fractions, depending on the analysis required. The chain-of-custody record remains intact, however, for all sample fractions with the corresponding sample number.

After the analytical results have been reported, the chain-of-custody samples remain secured in storage. Restricted access to these samples is maintained.

A 3.0 CALIBRATION PROCEDURES

A 3.1 LABORATORY INSTRUMENTS

The following procedures will be followed for calibration of laboratory instruments:

A 3.1.1 Filter Fluorometer

The filter fluorometer is standardized for the parameter of interest by the analysis of calibration standards prepared by diluting a stock solution of known concentration. Five working standards are prepared from the stock solution with concentrations that cover the working range of the instrument. Subsequently, all measurements are made within this range. After the working standards are prepared, instrument response is calibrated to provide a direct readout. The calibration curve is completed by plotting instrument response versus concentration (in µg/L) of the parameter being analyzed. The calibration curve is verified by analyzing a midpoint standard. For the filter fluorometer, the accuracy checks must conform to within 20%.

Once the filter fluorometer has been initially calibrated, check standards are analyzed every twentieth sample to confirm the initial calibration curve. A typical analysis sequence is as follows:

- Working standards are prepared by dilution of a stock standard solution of the parameter of interest.
- A calibration curve is established within the working range of the instrument by analysis of five calibration standards.
- Samples are analyzed for the parameter of interest.
- During sample analysis, a calibration check standard is analyzed every twentieth sample to monitor instrument stability. If analysis indicates that instrument calibration is not within 20%, the instrument is recalibrated, and analysis is repeated.

- Following completion of the sample analysis, the calibration check standard is reanalyzed to confirm instrument calibration.

If calibration is confirmed (within 20%), the analysis is complete. However, if calibration is not confirmed, the instrument may be recalibrated, and the analysis should be repeated.

A 3.1.2 Luminescence Spectrometer (Perkin Elmer LS-50B)

The luminescence spectrometer is standardized for the parameter of interest by an analysis of calibration standards prepared by diluting a stock solution of known concentration. Four or five working standards are prepared from the stock solution with concentrations that cover the working range of the instrument. Subsequently, all measurements are made within this range. After the working standards are prepared, instrument response is calibrated to provide a direct readout. The calibration curve is completed by plotting instrument response versus concentration (in µg/L) of the parameter being analyzed. The calibration curve is verified by analyzing a midpoint standard. For the luminescence spectrometer, accuracy checks must conform to within 20%.

Once the luminescence spectrometer has been initially calibrated, check standards are analyzed approximately every twentieth sample to confirm the initial calibration curve. A typical analysis sequence is as follows:

- Working standards are prepared by dilution of a stock standard solution of the parameter of interest.
- A calibration curve is established within the working range of the instrument by the analysis of five calibration standards.
- Samples are analyzed for the parameter of interest.
- During sample analysis, a calibration check standard is analyzed every twentieth sample to monitor instrument stability. If the analysis indicates that instrument calibration is not within 20%, the instrument is recalibrated, and the analysis is repeated.

- Following completion of the sample analysis, the calibration check standard is reanalyzed to confirm instrument calibration.

If calibration is confirmed (within 20%), the analysis is complete. However, if calibration is not confirmed, the instrument may be recalibrated, and the analysis should be repeated.

A 4.0 QUALITY CONTROL SAMPLES

A 4.1 TRIP BLANKS

A trip blank for water samples will consist of dye-free distilled water that is placed in a sample bottle before fieldwork. Trip blank water will have been tested and shown to be negative for the presence of fluorescent dyes. The purpose of the trip blank is to test for the inadvertent presence of contamination by dye. A trip blank will accompany field personnel during all charcoal detector collection activities. A trip blank will not be used for activated carbon (charcoal) or unbleached cotton detectors.

All water samples will be collected in plastic or glass containers. A prepared trip blank will utilize the same type of container as is used for water sampling.

A 4.2 FIELD BLANKS

A field blank for water will be obtained by pouring dye-free distilled water into a sample bottle in the field at the first site sampled. One field blank will be collected for each sampling event. The field blank will be used to test for the presence of airborne dye particles as tracer injection artifacts.

A 4.3 CONTROL BLANKS

A control blank for activated charcoal will consist of an activated-charcoal detector that has been placed in a spring or well located in an area out of the influence of the tracer test. The control blank will have been placed during the previous sampling round and will be collected at the start of the current sampling round. Doing so assures that the control blank will be handled and treated like other charcoal detectors. This protocol better replicates field conditions, thus achieving one of the purposes of using blanks and enhancing the QC/QA program. The term *control blank* is used because, strictly speaking, it is neither a trip blank nor a field blank. A control blank will be utilized during the entire tracer test and will be collected during each charcoal detector collection event.

A 4.4 FIELD REPLICATES

A field replicate is a second water or charcoal sample collected from a location that is monitored as part of a tracer testing program. The field replicate must be placed, collected, and analyzed exactly like the original sample from the site. Replicate samples should be collected from one site in 20 that will be analyzed for the tracer test.

A 4.5 PREPARATION BLANKS

Eluent is used in the extraction of dye from charcoal. Preparation blanks consist of eluent solution that is analyzed before the elution is performed, ensuring that dye in the eluent is not an artifact from the eluent and making it possible to prevent contamination before it occurs. A preparation blank will be prepared for each batch of eluent solution used.

A 4.6 METHOD BLANK

Distilled water is analyzed so that it can be shown that the dye signal indicated is not a property of water itself. It will be analyzed once for every 20 samples.

A 4.7 LAB CONTROL STANDARDS

Lab control standards consist of serial dilutions by mass of a known concentration of dye. Five working standards are prepared from a stock solution. Concentrations of the calibration standards are chosen to cover the working range of the instrument. Subsequently, all measurements are made within this range. After the working standards are prepared, instrument response is calibrated to provide a direct readout. The calibration curve is verified by plotting instrument response versus concentration (in µg/L) of the parameter being analyzed. The calibration curve is verified by analyzing a midpoint standard. Lab control standards indicate that the instrument is capable of detection of at least the lowest standard concentration of dye if it were present.

Method blanks (distilled water) and lab control standards for each dye expected to possibly be in the samples are analyzed before and after a set of samples. A lab control standard for each expected dye is also analyzed after every 20 samples.

A 4.8 TEMPERATURE CONTROL

Air temperature will be recorded at the beginning and end of each dye analysis session because some dyes have a thermal coefficient of fluorescence of three %. Standard calibration for this particular dye can be adversely affected by ambient temperature.

A 4.9 DYE ABSORPTION/ELUTION VERIFICATION

A protocol will be followed for one sample of activated charcoal from each batch used in this investigation. The protocol has been developed to verify that the activated charcoal is capable of absorbing and eluting dye. The proposed procedure for testing the adsorption capacity for each lot of activated charcoal consists of the following steps:

- Tap water will be used to prewash approximately 40 grams of charcoal for three hours at about 0.25 gallon per minute (gpm) using a charcoal-holding device that forces all water to flow through charcoal.
- The charcoal will be split into halves.
- Half of the charcoal will be eluted using the standard procedure and the eluent analyzed for Uranine. The eluent will be analyzed to establish that there is no dye-like fluorescence compound in the charcoal.
- The remaining 10 grams of charcoal will be placed in a nylon mesh bag and suspended in a 1,000-mL beaker containing 250 mL of a 100-ppb solution of Uranine in water. The beaker will be fitted with a magnetic stirring device and stirred for one hour on a low setting.
- The remaining charcoal will be eluted using the standard procedure and analyzed for Uranine.
- Concentration of Uranine, if present, will be reported.

A 4.10 MATRIX SPIKES FOR CHARCOAL

The following protocol will be followed for one sample of activated charcoal for each sampling event using charcoal. The protocol has been developed to verify that the activated charcoal is capable of adsorbing and eluting dye after placement and recovery from the field. The procedure is proposed for testing the adsorption capacity after sample collection. If, after elution and analysis, no dye is detected, then the sampling event has the possibility of creating a false-negative result. Testing of charcoal using the matrix spike method is as follows:

- One charcoal packet that had been placed in the field for dye monitoring will be selected for a matrix spike and matrix spike duplicate. The packet will be rinsed with tap water for 30 to 60 seconds using a charcoal-holding device that forces water to flow through the charcoal to remove sediment.
- The charcoal will be split into halves.
- Half of the charcoal will be eluted using the standard procedure and analyzed for Uranine.
- If analysis indicates that there are no dye-like fluorescent compounds in the charcoal, the other half of the charcoal may be used for MS/MSD testing. If Uranine compounds are detected, another charcoal packet will be chosen.
- The remaining charcoal will be placed in a nylon mesh bag and suspended in a 1,000-mL beaker containing 250 mL of a 100-ppb solution of Uranine in water. The beaker will be placed on a magnetic stirring device and stirred for one hour on a low setting.
- The charcoal will then be eluted using the standard procedure and analyzed for Uranine.
- The concentration of Uranine will be reported, if present.

A 4.11 MATRIX SPIKES AND MATRIX SPIKE DUPLICATES FOR WATER

The following protocol will be followed for each sampling event in which water is collected and analyzed for the detection of fluorescent dyes. The protocol has been developed to determine whether the matrix interferes with the ability to detect fluorescent dyes in water. If the matrix interferes with the ability to detect fluorescent dyes, then the sampling event has the possibility of creating a false-negative result. The procedure for testing for matrix interference of water is as follows:

- Two additional water samples will be collected from a spring or well during each sampling event for matrix spike and matrix spike duplicate analyses.
- Each sample will be analyzed for the presence of fluorescent dyes.
- If the analysis indicates that there are dye-like fluorescent compounds in the water samples, the concentration will be recorded.
- A known volume of each sample will be measured and placed in a separate clean glass container with an equal volume of a known standard. The known standard will be a dye that is being considered or used in the tracer test. Each sample will then be analyzed for the presence of fluorescent dyes and the concentrations recorded. If fluorescent dyes were present in the original samples, a volume-adjusted concentration will be added to the calculated concentration.
- Each sample will be analyzed for the presence of fluorescent compounds.
- The first sample will be designated the matrix spike. The matrix spike should be between 30 and 170% of the calculated concentration of the sample.
- The second sample will be designated the matrix spike duplicate. Results of the analysis of the matrix spike duplicate will be recorded. The relative percent difference (RPD) of the matrix and matrix spike duplicate will be calculated using the following formula: $C_1 – C_2$/Average (C_1, C_2). The RPD should be less than 50%.

Figure A-1: Automatic Water Sampler Tracking Form

Tracking # EAA-WS-0051

EAA Tracer Project, 2006: Water Samples

Segment:		
Crew:		
Collection Date(MM/DD/YY)		
Location Name: ISCO Sampler ID #:		
Start time/date:		End Time/Date:
Water Level		Other comments:
Grab Sample?	Datum Type: ĺ Top of Well ĺ Staff Gauge	

Bottle #	Sample date (MM/DD/YY)	Sample Time	Other Comments
1	/ /		
2	/ /		
3	/ /		
4	/ /		
5	/ /		
6	/ /		
7	/ /		
8	/ /		
9	/ /		
10	/ /		
11	/ /		
12	/ /		
13	/ /		
14	/ /		
15	/ /		
16	/ /		
17	/ /		
18	/ /		
19	/ /		
20	/ /		
21	/ /		
22	/ /		
23	/ /		
24	/ /		
25	/ /		duplicate from bottle #:
26	/ /		rinsate with DI water
27	/ /		stock (tap water used for rinsing)
28	/ /		Trip blank (stock DI water poured up on site)

*Chain-of-Custody information should have signature, date and time

relinquished by:	received by:
relinquished by:	received by:
relinquished by:	received by:
relinquished by:	received by:
relinquished by:	received by:

Figure A-2: Charcoal Detector Sampler Tracking Form

GVA December, 2003

Tracking # EAA-CD-0005

EAA Tracer Project, 2003: Charcoal Detectors

Segment: ☐ San Marcos ☐ Comal ☐ Hueco ☐ Other	
Crew:	
Collection Date(MM/DD/YY)	
Start time/date:	End Time/Date:
Datum Type Options (for below) **Top of Well** or **Staff Gauge**	

Location	**Grab Sample**	**In date (MM/DD/YY)**	**Out Time/ Date (MM/DD/YY)**	**Water Level**	**Datum Type**	**Other Comments**
Blank						blank detector

*Chain-of-Custody information should have signature and date

relinquished by:	received by:
relinquished by:	received by:
relinquished by:	received by:
relinquished by:	received by:

Appendix B. Samples with Detectable Dye

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
10327	100	10/2/2009 to 11/18/2009	Charcoal	Eosin	18
12110	100	12/11/2009 to 12/14/2009	Charcoal	Eosin	12
12199	100	12/17/2009 to 12/22/2009	Charcoal	Eosin	10
12468	100	12/17/2009 to 12/22/2009	Charcoal	Eosin	7.1
12221	100	12/17/2009 to 12/22/2009	Charcoal	Eosin	10
12224	100	12/22/2009 to 12/29/2009	Charcoal	Eosin	11
12248	100	12/29/2009 to 1/6/2010	Charcoal	Eosin	9.3
12636	100	1/13/2010 to 1/27/2010	Charcoal	Eosin	1.7
11505	100	1/27/2010 to 2/1/2010	Charcoal	Eosin	15
11451	100	2/4/2010 to 2/8/2010	Charcoal	Eosin	5.8
11835	100	2/8/2010 to 2/11/2010	Charcoal	Eosin	13
12007	100	3/4/2010 to 3/11/2010	Charcoal	Eosin	19
12021	100	3/4/2010 to 3/11/2010	Charcoal	Eosin	19
12803	100	4/8/2010	Charcoal	Eosin	3
12834	100	4/15/2010	Charcoal	Eosin	5.4
13157	100	5/6/2010	Charcoal	Uranine	2.6
13157	100	5/6/2010	Charcoal	Uranine	1.9
11836	101	2/8/2010 to 2/11/2010	Charcoal	Uranine	0.5
11836	101	2/8/2010 to 2/11/2010	Charcoal	Uranine	0.7
11877	101	2/18/2010 to 2/22/2010	Charcoal	Uranine	6.2
11896	101	2/18/2010 to 2/22/2010	Charcoal	Uranine	1
11896	101	2/18/2010 to 2/22/2010	Charcoal	Uranine	9.3
11896	101	2/18/2010 to 2/22/2010	Charcoal	Phloxine B	0.5
11877	101	2/18/2010 to 2/22/2010	Charcoal	Uranine	0.8
12804	101	4/8/2010	Charcoal	Uranine	55
13156	101	5/6/2010	Charcoal	Uranine	1.4
13156	101	5/6/2010	Charcoal	Uranine	6.7
12338	102	1/6/2010 to 1/13/2010	Charcoal	Uranine	5.9
12805	102	4/8/2010	Charcoal	Phloxine B	28
13155	102	5/6/2010	Charcoal	Uranine	6.2
13155	102	5/6/2010	Charcoal	Phloxine B	2.5
13223	102	5/13/2010	Charcoal	Phloxine B	2
13223	102	5/13/2010	Charcoal	Uranine	8.6
13029	106	4/29/2010	Charcoal	Uranine	7.2
13019	106	4/29/2010	Charcoal	Phloxine B	4
13019	106	4/29/2010	Charcoal	Uranine	7.6

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
13029	106	4/29/2010	Charcoal	Phloxine B	3.8
10430	107	12/3/2009 to 12/8/2009	Charcoal	Eosin	0.6
12077	107	12/8/2009 to 12/10/2009	Charcoal	Phloxine B	1.2
12091	107	12/8/2009 to 12/10/2009	Charcoal	Phloxine B	1
11893	107	2/18/2010 to 2/22/2010	Charcoal	Uranine	19
13094	107	4/22/2010	Charcoal	Uranine	3.2
5350	108	12:00:00 PM to 9/9/2002	Charcoal	Uranine	0.5
5504	108	9/9/2002 to 10/1/2002	Charcoal	Uranine	0.3
5540	108	10/1/2002 to 10/4/2002	Charcoal	Uranine	0.3
5554	108	10/4/2002 to 10/9/2002	Charcoal	Uranine	0.2
5553	108	10/9/2002 to 10/14/2002	Charcoal	Uranine	0.2
1662	108	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	0.5
10429	108	12/3/2009 to 12/8/2009	Charcoal	Eosin	11
12078	108	12/8/2009 to 12/10/2009	Charcoal	Uranine	0.4
12078	108	12/8/2009 to 12/10/2009	Charcoal	Eosin	0.08
12078	108	12/8/2009 to 12/10/2009	Charcoal	Phloxine B	12
12102	108	12/10/2009 to 12/14/2009	Charcoal	Uranine	1.1
12102	108	12/10/2009 to 12/14/2009	Charcoal	Eosin	0.5
12102	108	12/10/2009 to 12/14/2009	Charcoal	Phloxine B	6
12652	108	1/13/2010 to 1/27/2010	Charcoal	Eosin	2
12652	108	1/13/2010 to 1/27/2010	Charcoal	Phloxine B	3.4
11523	108	1/27/2010 to 2/1/2010	Charcoal	Phloxine B	1.6
11523	108	1/27/2010 to 2/1/2010	Charcoal	Eosin	6.2
1282	109	1/13/2004 to 1/14/2004	Charcoal	Uranine	0.3
1282	109	1/13/2004 to 1/14/2004	Charcoal	Eosin	0.9
1282	109	1/13/2004 to 1/14/2004	Charcoal	Phloxine B	3.8
1283	109	1/14/2004 to 1/18/2004	Charcoal	Phloxine B	9.9
1283	109	1/14/2004 to 1/18/2004	Charcoal	Eosin	6.6
1283	109	1/14/2004 to 1/18/2004	Charcoal	Uranine	0.1
2316	109	2/23/2004 to 3/3/2004	Charcoal	Eosin	1.9
2316	109	2/23/2004 to 3/3/2004	Charcoal	Uranine	0.06
10396	109	11/23/2009 to 12/3/2009	Charcoal	Eosin	0.8
10428	109	12/3/2009 to 12/8/2009	Charcoal	Eosin	1
10428	109	12/3/2009 to 12/8/2009	Charcoal	Phloxine B	1.2
12103	109	12/10/2009 to 12/14/2009	Charcoal	Phloxine B	1.9
12320	109	1/6/2010 to 1/13/2010	Charcoal	Uranine	3.6
11522	109	1/27/2010 to 2/1/2010	Charcoal	Phloxine B	31
11461	109	2/4/2010 to 2/8/2010	Charcoal	Phloxine B	15
11853	109	2/8/2010 to 2/11/2010	Charcoal	Phloxine B	33

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
12026	109	3/4/2010 to 3/11/2010	Charcoal	Phloxine B	4.9
12026	109	3/4/2010 to 3/11/2010	Charcoal	Uranine	11
12879	109	4/1/2010	Charcoal	Uranine	25
12879	109	4/1/2010	Charcoal	Phloxine B	12
12849	109	4/15/2010	Charcoal	Phloxine B	11
13092	109	4/22/2010	Charcoal	Phloxine B	9.7
13033	109	4/29/2010	Charcoal	Phloxine B	7.1
13167	109	5/6/2010	Charcoal	Phloxine B	3.3
13292	109	5/27/2010	Charcoal	Phloxine B	125
13492	109	7/22/2010	Charcoal	Phloxine B	1.8
5208	110	9/16/2002 to 9/20/2002	Charcoal	Uranine	0.01
5505	110	9/20/2002 to 10/1/2002	Charcoal	Uranine	0.7
5424	110	10/1/2002 to 10/4/2002	Charcoal	Uranine	0.5
5425	110	10/4/2002 to 10/14/2002	Charcoal	Uranine	0.4
5426	110	10/14/2002 to 10/28/2002	Charcoal	Uranine	0.4
1659	110	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	0.2
10646	110	12/2/2009 to 12/7/2009	Charcoal	Eosin	22
10646	110	12/2/2009 to 12/7/2009	Charcoal	Uranine	1.1
12107	110	12/10/2009 to 12/14/2009	Charcoal	Phloxine B	1.2
11456	110	2/4/2010 to 2/8/2010	Charcoal	Phloxine B	1.2
11890	110	2/18/2010 to 2/22/2010	Charcoal	Uranine	0.8
11890	110	2/18/2010 to 2/22/2010	Charcoal	Uranine	8.8
11890	110	2/18/2010 to 2/22/2010	Charcoal	Phloxine B	0.6
12025	110	3/4/2010 to 3/11/2010	Charcoal	Uranine	33
12025	110	3/4/2010 to 3/11/2010	Charcoal	Phloxine B	7.5
12880	110	4/1/2010	Charcoal	Uranine	13
12880	110	4/1/2010	Charcoal	Phloxine B	31
13091	110	4/22/2010	Charcoal	Uranine	3.3
13091	110	4/22/2010	Charcoal	Uranine	19
13091	110	4/22/2010	Charcoal	Phloxine B	3.7
13052	110	4/29/2010	Charcoal	Phloxine B	3.3
13052	110	4/29/2010	Charcoal	Uranine	3.3
13052	110	4/29/2010	Charcoal	Uranine	28
13168	110	5/6/2010	Charcoal	Phloxine B	4.2
13291	110	5/27/2010	Charcoal	Phloxine B	4.6
10446	112	12/1/2009 to 12/8/2009	Charcoal	Eosin	3.5
12069	112	12/8/2009 to 12/10/2009	Charcoal	Phloxine B	2.3
12100	112	12/10/2009 to 12/14/2009	Charcoal	Phloxine B	1.4
11454	112	2/4/2010 to 2/8/2010	Charcoal	Uranine	0.08

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
11888	112	2/18/2010 to 2/22/2010	Charcoal	Phloxine B	0.2
11888	112	2/18/2010 to 2/22/2010	Charcoal	Uranine	5.9
11888	112	2/18/2010 to 2/22/2010	Charcoal	Uranine	0.8
13030	112	4/29/2010	Charcoal	Uranine	1.4
13030	112	4/29/2010	Charcoal	Uranine	6.4
13030	112	4/29/2010	Charcoal	Phloxine B	3.2
10448	113	12/1/2009 to 12/8/2009	Charcoal	Eosin	1.7
11061	113	12/14/2009 to 12/17/2009	Charcoal	Uranine	0.6
11061	113	12/14/2009 to 12/17/2009	Charcoal	Uranine	9.1
12642	113	1/13/2010 to 1/27/2010	Charcoal	Eosin	0.3
11423	113	2/1/2010 to 2/4/2010	Charcoal	Uranine	6.7
11448	113	2/4/2010 to 2/8/2010	Charcoal	Uranine	7.9
12809	113	4/8/2010	Charcoal	Phloxine B	1.9
12809	113	4/8/2010	Charcoal	Uranine	5.4
13164	113	5/6/2010	Charcoal	Phloxine B	0.2
6542	114	7/27/2009 to 8/10/2009	Charcoal	Phloxine B	31
6614	114	8/10/2009 to 8/25/2009	Charcoal	Uranine	9.3
6673	114	8/25/2009 to 9/14/2009	Charcoal	Uranine	13
6673	114	8/25/2009 to 9/14/2009	Charcoal	Phloxine B	2.6
6673	114	8/25/2009 to 9/14/2009	Charcoal	Uranine	1.8
6744	114	9/14/2009 to 10/5/2009	Charcoal	Uranine	0.9
10400	114	10/5/2009 to 12/1/2009	Charcoal	Uranine	7.6
10400	114	10/5/2009 to 12/1/2009	Charcoal	Uranine	0.3
12328	114	1/6/2010 to 1/13/2010	Charcoal	Uranine	5.8
12315	114	1/6/2010 to 1/13/2010	Charcoal	Uranine	5.8
12841	114	4/15/2010	Charcoal	Uranine	4.3
13230	114	5/13/2010	Charcoal	Uranine	6.9
11055	115	12/14/2009 to 12/17/2009	Charcoal	Uranine	0.9
11055	115	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	1.4
11055	115	12/14/2009 to 12/17/2009	Charcoal	Uranine	7
11515	115	1/27/2010 to 2/1/2010	Charcoal	Phloxine B	0.3
13162	115	5/6/2010	Charcoal	Uranine	5.2
13162	115	5/6/2010	Charcoal	Phloxine B	41
13229	115	5/13/2010	Charcoal	Phloxine B	1.1
13229	115	5/13/2010	Charcoal	Uranine	7.5
10323	117	10/20/2009 to 10/29/2009	Charcoal	Phloxine B	0.7
10406	117	10/29/2009 to 12/8/2009	Charcoal	Eosin	1.2
11887	117	2/18/2010 to 2/22/2010	Charcoal	Uranine	0.6
12844	117	4/15/2010	Charcoal	Phloxine B	43

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
13026	117	4/29/2010	Charcoal	Phloxine B	3.7
13171	117	5/6/2010	Charcoal	Phloxine B	2.1
5517	131	9/23/2002 to 9/27/2002	Charcoal	Uranine	0.2
5548	131	9/23/2002 to 9/27/2002	Charcoal	Uranine	0.1
5546	131	10/3/2002 to 10/4/2002	Charcoal	Uranine	0.2
5534	131	10/4/2002 to 10/7/2002	Charcoal	Uranine	0.3
5525	131	10/7/2002 to 10/9/2002	Charcoal	Uranine	0.7
5524	131	10/9/2002 to 10/14/2002	Charcoal	Uranine	0.3
5542	131	10/9/2002 to 10/14/2002	Charcoal	Uranine	0.1
5523	131	10/14/2002 to 10/28/2002	Charcoal	Uranine	0.1
11060	131	12/8/2009 to 12/17/2009	Charcoal	Eosin	40
11048	131	12/8/2009 to 12/17/2009	Charcoal	Eosin	3.3
12031	131	3/4/2010 to 3/11/2010	Charcoal	Phloxine B	13
12891	131	3/18/2010 to 4/1/2010	Charcoal	Phloxine B	18
12883	131	4/1/2010	Charcoal	Phloxine B	17
12853	131	4/15/2010	Charcoal	Phloxine B	5.4
13105	131	4/22/2010	Charcoal	Uranine	2
13105	131	4/22/2010	Charcoal	Phloxine B	82
13100	131	4/22/2010	Charcoal	Uranine	3.2
13341	131	6/10/2010	Charcoal	Phloxine B	1.6
13341	131	6/10/2010	Charcoal	Uranine	1.9
2159	133	2/2/2004 to 2/15/2004	Charcoal	Eosin	4.8
2159	133	2/2/2004 to 2/15/2004	Charcoal	Uranine	0.3
12064	133	12/3/2009 to 12/9/2009	Charcoal	Phloxine B	1.2
12064	133	12/3/2009 to 12/9/2009	Charcoal	Uranine	7.6
12064	133	12/3/2009 to 12/9/2009	Charcoal	Uranine	0.9
13102	133	4/22/2010	Charcoal	Phloxine B	1.7
13102	133	4/22/2010	Charcoal	Uranine	1.2
13102	133	4/22/2010	Charcoal	Uranine	4.1
13039	133	4/29/2010	Charcoal	Phloxine B	5.6
9858	134	11/16/2009 to 11/24/2009	Charcoal	Phloxine B	17
10351	134	12/8/2009 12:24:00 PM	Water	Phloxine B	11
12314	134	12/17/2009 to 1/13/2010	Charcoal	Phloxine B	23
12314	134	12/17/2009 to 1/13/2010	Charcoal	Eosin	93
12623	134	1/6/2010 to 1/13/2010	Charcoal	Eosin	0.7
12619	134	1/6/2010 to 1/13/2010	Charcoal	Eosin	0.7
10409	138	11/24/2009 to 12/8/2009	Charcoal	Eosin	1.5
12603	139	1/6/2010 to 1/13/2010	Charcoal	Phloxine B	0.2
11438	139	2/4/2010 to 2/8/2010	Charcoal	Eosin	5.8

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
11848	139	2/8/2010 to 2/11/2010	Charcoal	Uranine	7.9
11848	139	2/8/2010 to 2/11/2010	Charcoal	Uranine	0.5
11848	139	2/8/2010 to 2/11/2010	Charcoal	Phloxine B	1.2
11886	139	2/18/2010 to 2/22/2010	Charcoal	Uranine	5.4
11886	139	2/18/2010 to 2/22/2010	Charcoal	Uranine	0.5
11886	139	2/18/2010 to 2/22/2010	Charcoal	Phloxine B	0.9
12813	139	4/8/2010	Charcoal	Phloxine B	2.2
13024	139	4/29/2010	Charcoal	Uranine	7.7
13024	139	4/29/2010	Charcoal	Phloxine B	3.9
13024	139	4/29/2010	Charcoal	Uranine	1.6
13160	139	5/6/2010	Charcoal	Phloxine B	0.6
12882	140	4/1/2010	Charcoal	Uranine	17
12821	140	4/8/2010	Charcoal	Uranine	2.3
13179	140	5/6/2010	Charcoal	Phloxine B	3.3
5354	141	9/17/2002 to 9/18/2002	Charcoal	Uranine	1.6
5204	141	9/17/2002 to 9/18/2002	Charcoal	Uranine	1.4
5346	141	9/17/2002 to 9/18/2002	Charcoal	Uranine	0.4
5205	141	9/18/2002 to 9/19/2002	Charcoal	Uranine	2
5362	141	9/18/2002 to 9/19/2002	Charcoal	Uranine	1.9
5347	141	9/18/2002 to 9/19/2002	Charcoal	Uranine	2.4
5357	141	9/19/2002 to 9/20/2002	Charcoal	Uranine	1.2
5206	141	9/19/2002 to 9/20/2002	Charcoal	Uranine	1.3
5348	141	9/19/2002 to 9/20/2002	Charcoal	Uranine	1.9
5564	141	9/21/2002 3:05:00 PM	Water	Uranine	0.5
5508	141	9/20/2002 to 9/21/2002	Charcoal	Uranine	0.8
5565	141	9/22/2002 3:55:00 PM	Water	Uranine	0.3
5507	141	9/21/2002 to 9/22/2002	Charcoal	Uranine	0.3
5349	141	9/22/2002 to 9/23/2002	Charcoal	Uranine	0.9
5367	141	9/22/2002 to 9/23/2002	Charcoal	Uranine	0.3
5510	141	9/23/2002 to 9/27/2002	Charcoal	Uranine	0.2
5563	141	9/27/2002 12:00:00 PM	Water	Uranine	0.1
5433	141	9/27/2002 to 10/4/2002	Charcoal	Uranine	0.1
5434	141	10/4/2002 to 10/9/2002	Charcoal	Uranine	1.4
221	146	1/9/2004 3:30:00 AM	Water	Eosin	0.6
791	146	1/13/2004 4:34:00 AM	Water	Uranine	9.8
680	146	1/13/2004 3:30:00 AM	Water	Uranine	9.9
795	146	1/13/2004 8:34:00 AM	Water	Uranine	19
794	146	1/13/2004 7:34:00 AM	Water	Uranine	18
792	146	1/13/2004 5:34:00 AM	Water	Uranine	10

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
797	146	1/13/2004 10:34:00 AM	Water	Uranine	22
798	146	1/13/2004 11:34:00 AM	Water	Uranine	39
796	146	1/13/2004 9:34:00 AM	Water	Uranine	19
793	146	1/13/2004 6:34:00 AM	Water	Uranine	12
802	146	1/14/2004 3:34:00 AM	Water	Uranine	23
841	146	1/14/2004 4:59:00 AM	Water	Uranine	17
812	146	1/14/2004 1:34:00 AM	Water	Uranine	16
800	146	1/14/2004 1:34:00 AM	Water	Uranine	26
801	146	1/14/2004 2:34:00 AM	Water	Uranine	19
814	146	1/14/2004 3:34:00 AM	Water	Uranine	16
799	146	1/14/2004 12:34:00 PM	Water	Uranine	2
848	146	1/14/2004 11:59:00 AM	Water	Uranine	12
737	146	1/14/2004 4:00:00 AM	Water	Uranine	13
808	146	1/14/2004 9:34:00 AM	Water	Uranine	2.1
813	146	1/14/2004 2:34:00 AM	Water	Uranine	16
840	146	1/14/2004 3:59:00 AM	Water	Uranine	17
803	146	1/14/2004 4:34:00 AM	Water	Uranine	5.8
842	146	1/14/2004 5:59:00 AM	Water	Uranine	15
804	146	1/14/2004 5:34:00 AM	Water	Uranine	5.8
809	146	1/14/2004 10:34:00 AM	Water	Uranine	18
805	146	1/14/2004 6:34:00 AM	Water	Uranine	3.3
847	146	1/14/2004 10:59:00 AM	Water	Uranine	12
806	146	1/14/2004 7:34:00 AM	Water	Uranine	4.5
844	146	1/14/2004 7:59:00 AM	Water	Uranine	14
807	146	1/14/2004 8:34:00 AM	Water	Uranine	2.6
845	146	1/14/2004 8:59:00 AM	Water	Uranine	13
846	146	1/14/2004 9:59:00 AM	Water	Uranine	13
843	146	1/14/2004 6:59:00 AM	Water	Uranine	14
5463	148	12:00:00 PM to 10/28/2002	Charcoal	Uranine	6.6
10411	149	11/24/2009 to 12/8/2009	Charcoal	Eosin	0.6
5533	157	10/14/2002 to 10/28/2002	Charcoal	Uranine	0.4
12887	176	4/1/2010	Charcoal	Uranine	13
7865	20	6/23/2008 10:00:00 AM	Water	Uranine	0.6
7866	20	5/30/2008 1:40:00 PM to 6/23/2008	Charcoal	Eosin	4.1
7883	20	6/23/2008 10:00:00 AM to 7/14/2008	Charcoal	Eosin	13
7912	20	9/8/2008 1:15:00 PM to 9/12/2008	Charcoal	Eosin	3.2
7776	20	2/26/2009 10:25:00 AM to 3/10/2009	Charcoal	Eosin	17
9590	20	3/10/2009 to 4/10/2009	Charcoal	Eosin	8.6
10035	20	4/10/2009 to 5/8/2009	Charcoal	Eosin	7.5

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
10011	20	5/8/2009 9:52:00 AM	Water	Eosin	1.5
10176	20	5/8/2009 to 6/30/2009	Charcoal	Eosin	9.4
4685	201	3/21/2006 4:15:00 PM	Water	Phloxine B	93
9390	35	3/18/2009 to 4/1/2009	Charcoal	Phloxine B	10
9629	35	4/1/2009 to 4/15/2009	Charcoal	Phloxine B	1.1
6649	35	9/14/2009 1:18:00 PM	Water	Uranine	1.9
6677	35	8/25/2009 to 9/14/2009	Charcoal	Uranine	2.3
6649	35	9/14/2009 1:18:00 PM	Water	Eosin	1.9
6938	36	4/30/2008 12:00:00 PM to 5/28/2008	Charcoal	Eosin	19
7250	38	7/14/2008 4:35:00 PM to 8/4/2008	Charcoal	Eosin	7.3
7126	4	5/28/2008 10:00:00 AM to 6/30/2008	Charcoal	Eosin	31
7126	4	5/28/2008 10:00:00 AM to 6/30/2008	Charcoal	Eosin	31
7126	4	5/28/2008 10:00:00 AM to 6/30/2008	Charcoal	Eosin	4
7098	4	6/30/2008 12:40:00 PM	Water	Uranine	1.6
7098	4	6/30/2008 12:40:00 PM	Water	Eosin	1.4
7098	4	6/30/2008 12:40:00 PM	Water	Eosin	1.4
7098	4	6/30/2008 12:40:00 PM	Water	Uranine	1.6
7126	4	5/28/2008 10:00:00 AM to 6/30/2008	Charcoal	Eosin	4
7233	4	6/30/2008 12:40:00 PM to 8/4/2008	Charcoal	Eosin	0.7
7233	4	6/30/2008 12:40:00 PM to 8/4/2008	Charcoal	Uranine	0.1
7211	4	8/4/2008 3:30:00 PM	Water	Eosin	0.8
7211	4	8/4/2008 3:30:00 PM	Water	Uranine	0.2
7233	4	6/30/2008 12:40:00 PM to 8/4/2008	Charcoal	Eosin	0.7
7233	4	6/30/2008 12:40:00 PM to 8/4/2008	Charcoal	Uranine	0.1
7211	4	8/4/2008 3:30:00 PM	Water	Uranine	0.2
7211	4	8/4/2008 3:30:00 PM	Water	Eosin	0.8
7273	4	8/19/2008 12:40:00 PM	Water	Uranine	0.1
7297	4	8/4/2008 3:30:00 AM to 8/19/2008	Charcoal	Eosin	1.4
7297	4	8/4/2008 3:30:00 AM to 8/19/2008	Charcoal	Uranine	1.6
7273	4	8/19/2008 12:40:00 PM	Water	Uranine	0.1
7273	4	8/19/2008 12:40:00 PM	Water	Eosin	0.6
7273	4	8/19/2008 12:40:00 PM	Water	Eosin	0.6
7297	4	8/4/2008 3:30:00 AM to 8/19/2008	Charcoal	Uranine	1.6
7297	4	8/4/2008 3:30:00 AM to 8/19/2008	Charcoal	Eosin	1.4
7417	4	10/9/2008 1:50:00 PM	Water	Uranine	3.4
7417	4	10/9/2008 1:50:00 PM	Water	Eosin	16
7417	4	10/9/2008 1:50:00 PM	Water	Uranine	3.4
7417	4	10/9/2008 1:50:00 PM	Water	Eosin	16
7486	4	10/9/2008 1:50:00 PM to 10/29/2008	Charcoal	Uranine	0.1

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
7486	4	10/9/2008 1:50:00 PM to 10/29/2008	Charcoal	Eosin	0.7
7486	4	10/9/2008 1:50:00 PM to 10/29/2008	Charcoal	Eosin	0.7
7486	4	10/9/2008 1:50:00 PM to 10/29/2008	Charcoal	Uranine	0.1
9160	4	3/6/2009 to 3/18/2009	Charcoal	Phloxine B	9.8
9160	4	3/6/2009 to 3/18/2009	Charcoal	Phloxine B	9.8
9951	4	4/15/2009 to 4/28/2009	Charcoal	Phloxine B	0.7
9951	4	4/15/2009 to 4/28/2009	Charcoal	Phloxine B	0.7
6551	4	7/27/2009 to 8/10/2009	Charcoal	Phloxine B	0.2
6551	4	7/27/2009 to 8/10/2009	Charcoal	Phloxine B	0.2
6551	4	7/27/2009 to 8/10/2009	Charcoal	Uranine	0.1
6551	4	7/27/2009 to 8/10/2009	Charcoal	Uranine	0.1
6551	4	7/27/2009 to 8/10/2009	Charcoal	Eosin	0.6
6551	4	7/27/2009 to 8/10/2009	Charcoal	Eosin	0.6
6679	4	8/25/2009 to 9/14/2009	Charcoal	Eosin	2.1
6679	4	8/25/2009 to 9/14/2009	Charcoal	Uranine	2.3
6679	4	8/25/2009 to 9/14/2009	Charcoal	Phloxine B	3
6679	4	8/25/2009 to 9/14/2009	Charcoal	Phloxine B	3
6679	4	8/25/2009 to 9/14/2009	Charcoal	Uranine	2.3
6679	4	8/25/2009 to 9/14/2009	Charcoal	Eosin	2.1
6707	4	10/5/2009 12:36:00 PM	Water	Phloxine B	2.3
6728	4	9/14/2009 to 10/5/2009	Charcoal	Phloxine B	32
6707	4	10/5/2009 12:36:00 PM	Water	Eosin	8
6728	4	9/14/2009 to 10/5/2009	Charcoal	Uranine	2.4
6707	4	10/5/2009 12:36:00 PM	Water	Eosin	8
6707	4	10/5/2009 12:36:00 PM	Water	Uranine	1.9
6707	4	10/5/2009 12:36:00 PM	Water	Eosin	5.1
6728	4	9/14/2009 to 10/5/2009	Charcoal	Phloxine B	32
6728	4	9/14/2009 to 10/5/2009	Charcoal	Uranine	2.4
6707	4	10/5/2009 12:36:00 PM	Water	Phloxine B	2.3
6707	4	10/5/2009 12:36:00 PM	Water	Eosin	5.1
6707	4	10/5/2009 12:36:00 PM	Water	Uranine	1.9
7246	40	7/14/2008 3:50:00 PM to 8/4/2008	Charcoal	Eosin	1.3
7246	40	7/14/2008 3:50:00 PM to 8/4/2008	Charcoal	Uranine	0.2
8946	40	3/6/2009 12:20:00 PM	Water	Eosin	20
9079	40	3/18/2009 12:55:00 PM	Water	Uranine	1.4
9169	40	3/6/2009 to 3/18/2009	Charcoal	Eosin	11
9079	40	3/18/2009 12:55:00 PM	Water	Eosin	2.7
9366	40	4/1/2009 11:15:00 AM	Water	Eosin	2.3
9366	40	4/1/2009 11:15:00 AM	Water	Uranine	1.4

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
9952	40	4/15/2009 to 4/28/2009	Charcoal	Eosin	65
9997	40	4/28/2009 to 5/12/2009	Charcoal	Eosin	35
6684	40	8/25/2009 to 9/14/2009	Charcoal	Uranine	6.2
6733	40	9/14/2009 to 10/5/2009	Charcoal	Eosin	65
12377	40	10/5/2009 to 1/14/2010	Charcoal	Eosin	46
12377	40	10/5/2009 to 1/14/2010	Charcoal	Uranine	2
12377	40	10/5/2009 to 1/14/2010	Charcoal	Uranine	1.7
8992	41	1/30/2009 to 2/20/2009	Charcoal	Phloxine B	0.9
9047	41	2/20/2009 to 3/6/2009	Charcoal	Phloxine B	0.9
9084	41	3/18/2009 12:25:00 PM	Water	Phloxine B	0.3
9623	41	4/1/2009 to 4/15/2009	Charcoal	Phloxine B	2.6
10185	41	6/4/2009 to 7/2/2009	Charcoal	Eosin	19
6550	41	7/27/2009 to 8/10/2009	Charcoal	Eosin	5.1
6521	41	8/10/2009 10:58:00 AM	Water	Eosin	2.8
6603	41	8/10/2009 to 8/25/2009	Charcoal	Eosin	30
6590	41	8/25/2009 12:45:00 PM	Water	Uranine	0.2
6590	41	8/25/2009 12:45:00 PM	Water	Eosin	2.7
6708	41	10/5/2009 12:44:00 PM	Water	Eosin	0.2
6708	41	10/5/2009 12:44:00 PM	Water	Eosin	0.4
6734	41	9/14/2009 to 10/5/2009	Charcoal	Eosin	4.2
12379	41	10/5/2009 to 1/14/2010	Charcoal	Eosin	0.7
12379	41	10/5/2009 to 1/14/2010	Charcoal	Uranine	0.3
12379	41	10/5/2009 to 1/14/2010	Charcoal	Uranine	0.7
13233	41	5/13/2010	Charcoal	Phloxine B	1.4
8942	46	3/6/2009 12:45:00 PM	Water	Phloxine B	1
9917	46	4/28/2009 11:30:00 AM	Water	Phloxine B	0.9
9917	46	4/28/2009 11:30:00 AM	Water	Uranine	0.1
9917	46	4/28/2009 11:30:00 AM	Water	Eosin	0.5
9996	46	4/28/2009 to 5/12/2009	Charcoal	Uranine	0.2
9996	46	4/28/2009 to 5/12/2009	Charcoal	Phloxine B	1.6
9996	46	4/28/2009 to 5/12/2009	Charcoal	Eosin	0.8
10287	46	5/12/2009 to 6/4/2009	Charcoal	Uranine	0.2
10287	46	5/12/2009 to 6/4/2009	Charcoal	Eosin	1.2
10270	46	6/4/2009 12:00:00 PM	Water	Uranine	1.9
10270	46	6/4/2009 12:00:00 PM	Water	Eosin	1.8
9729	46	7/2/2009 2:37:00 PM	Water	Uranine	1.6
10184	46	6/4/2009 to 7/2/2009	Charcoal	Eosin	25
9729	46	7/2/2009 2:37:00 PM	Water	Eosin	1.9
10184	46	6/4/2009 to 7/2/2009	Charcoal	Uranine	4.8

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
6549	46	7/27/2009 to 8/10/2009	Charcoal	Eosin	1.2
6549	46	7/27/2009 to 8/10/2009	Charcoal	Phloxine B	3.2
6681	46	8/25/2009 to 9/14/2009	Charcoal	Uranine	1.3
6711	46	10/5/2009 1:12:00 PM	Water	Eosin	0.4
6711	46	10/5/2009 1:12:00 PM	Water	Uranine	1.5
8994	47	1/30/2009 to 2/20/2009	Charcoal	Phloxine B	1.1
9013	47	2/20/2009 to 3/6/2009	Charcoal	Phloxine B	14
9021	47	3/6/2009 to 3/10/2009	Charcoal	Phloxine B	1.7
9164	47	3/6/2009 to 3/18/2009	Charcoal	Phloxine B	2.7
9600	47	4/1/2009 to 4/15/2009	Charcoal	Phloxine B	1
9943	47	4/15/2009 to 4/28/2009	Charcoal	Phloxine B	0.9
7042	48	6/17/2008 1:45:00 PM	Water	Uranine	3.2
7042	48	6/17/2008 1:45:00 PM	Water	Eosin	2.5
7101	48	6/27/2008 4:25:00 PM	Water	Uranine	0.3
7101	48	6/27/2008 4:25:00 PM	Water	Eosin	3.3
7116	48	6/17/2008 1:45:00 PM to 6/27/2008	Charcoal	Uranine	0.3
7116	48	6/17/2008 1:45:00 PM to 6/27/2008	Charcoal	Eosin	3.7
7146	48	7/11/2008 4:55:00 PM	Water	Uranine	2.4
7146	48	7/11/2008 4:55:00 PM	Water	Eosin	1.5
7232	48	7/11/2008 10:30:00 AM to 7/25/2008	Charcoal	Eosin	2.2
7333	48	8/26/2008 9:55:00 AM	Water	Eosin	6
7336	48	8/26/2008 9:50:00 AM	Water	Eosin	2.8
7359	48	8/26/2008 9:50:00 AM to 9/22/2008	Charcoal	Eosin	3.2
7354	48	8/26/2008 9:55:00 AM to 9/22/2008	Charcoal	Uranine	0.2
7344	48	9/22/2008 11:15:00 AM	Water	Eosin	1
7354	48	8/26/2008 9:55:00 AM to 9/22/2008	Charcoal	Eosin	1.4
7350	48	9/22/2008 11:15:00 AM	Water	Uranine	0.2
7344	48	9/22/2008 11:15:00 AM	Water	Uranine	0.2
7350	48	9/22/2008 11:15:00 AM	Water	Eosin	1.1
7451	48	10/22/2008 1:10:00 PM	Water	Uranine	0.2
7451	48	10/22/2008 1:10:00 PM	Water	Eosin	1.7
7439	48	10/22/2008 1:05:00 PM	Water	Eosin	1.8
7439	48	10/22/2008 1:05:00 PM	Water	Uranine	0.2
7523	48	11/14/2008 11:40:00 AM	Water	Uranine	0.2
7523	48	11/14/2008 11:40:00 AM	Water	Eosin	1.4
7554	48	12/9/2008 12:25:00 PM	Water	Uranine	0.2
7556	48	12/9/2008 12:30:00 PM	Water	Eosin	1.3
7556	48	12/9/2008 12:30:00 PM	Water	Uranine	0.2
7555	48	11/14/2008 11:40:00 AM to 12/9/2008	Charcoal	Eosin	2

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
7554	48	12/9/2008 12:25:00 PM	Water	Eosin	1
7555	48	11/14/2008 11:40:00 AM to 12/9/2008	Charcoal	Uranine	0.09
7631	48	12/18/2008 2:35:00 PM	Water	Eosin	1.5
7631	48	12/18/2008 2:35:00 PM	Water	Uranine	0.2
7633	48	12/18/2008 2:45:00 PM	Water	Eosin	1.2
7633	48	12/18/2008 2:45:00 PM	Water	Uranine	0.1
8854	48	3/2/2009 9:50:00 AM	Water	Eosin	15
8853	48	3/2/2009 10:15:00 AM	Water	Eosin	15
9030	48	2/20/2009 to 3/3/2009	Charcoal	Eosin	8.1
8950	48	3/3/2009 9:50:00 AM	Water	Eosin	15
8949	48	3/6/2009 10:15:00 AM	Water	Eosin	14
9023	48	3/3/2009 to 3/9/2009	Charcoal	Eosin	14
9032	48	3/9/2009 2:00:00 PM	Water	Eosin	4.7
9043	48	3/9/2009 2:00:00 PM	Water	Eosin	4.6
7058	49	6/3/2008 10:40:00 AM to 6/18/2008	Charcoal	Phloxine B	7.3
7328	49	8/19/2008 1:20:00 PM to 9/9/2008	Charcoal	Eosin	2.7
7328	49	8/19/2008 1:20:00 PM to 9/9/2008	Charcoal	Phloxine B	2.4
9225	49	3/10/2009 to 3/25/2009	Charcoal	Phloxine B	1.7
9968	49	5/12/2009 12:35:00 PM	Water	Phloxine B	17
7402	5	9/17/2008 12:40:00 PM to 10/8/2008	Charcoal	Eosin	1.8
7482	5	10/8/2008 10:50:00 AM to 10/29/2008	Charcoal	Eosin	1.3
8211	5	12/18/2008 12:50:00 PM to 1/30/2009	Charcoal	Eosin	1.4
9003	5	2/20/2009 to 3/6/2009	Charcoal	Eosin	4.9
9163	5	3/6/2009 to 3/18/2009	Charcoal	Eosin	3
9380	5	3/18/2009 to 4/1/2009	Charcoal	Eosin	3
9612	5	4/1/2009 to 4/15/2009	Charcoal	Phloxine B	1.9
9612	5	4/1/2009 to 4/15/2009	Charcoal	Eosin	1.7
9939	5	4/15/2009 to 4/28/2009	Charcoal	Eosin	2.7
10002	5	4/28/2009 to 5/12/2009	Charcoal	Eosin	7.3
9732	5	6/30/2009 2:00:00 PM	Water	Eosin	2.7
6768	5	6/4/2009 to 6/30/2009	Charcoal	Eosin	6.1
6532	5	8/10/2009 10:18:00 AM	Water	Eosin	2.2
6537	5	7/27/2009 to 8/10/2009	Charcoal	Eosin	169
6596	5	8/25/2009 12:12:00 PM	Water	Eosin	2.6
6599	5	8/10/2009 to 8/25/2009	Charcoal	Eosin	102
6745	5	9/14/2009 to 10/5/2009	Charcoal	Eosin	13
6745	5	9/14/2009 to 10/5/2009	Charcoal	Uranine	0.9
6745	5	9/14/2009 to 10/5/2009	Charcoal	Uranine	0.5
12375	5	10/5/2009 to 1/14/2010	Charcoal	Eosin	62

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
12401	5	1/14/2010 11:18:00 AM	Water	Eosin	1.5
13308	5	4/15/2010	Charcoal	Eosin	26
13302	5	5/27/2010	Charcoal	Eosin	9.6
9613	52	4/7/2009 to 4/20/2009	Charcoal	Eosin	3.4
10004	52	4/28/2009 to 5/11/2009	Charcoal	Phloxine B	2.2
7322	6	8/19/2008 1:25:00 PM to 9/9/2008	Charcoal	Uranine	1.3
6671	6	8/25/2009 to 9/14/2009	Charcoal	Uranine	1.2
6730	6	9/14/2009 to 10/5/2009	Charcoal	Phloxine B	0.3
6730	6	9/14/2009 to 10/5/2009	Charcoal	Uranine	4.2
6730	6	9/14/2009 to 10/5/2009	Charcoal	Uranine	0.6
12378	6	10/5/2009 to 1/14/2010	Charcoal	Uranine	3.3
12388	6	10/5/2009 to 1/14/2010	Charcoal	Uranine	3.4
7698	62	6/20/2008 10:40:00 AM	Water	Uranine	1.9
7695	63	6/20/2008 10:50:00 AM	Water	Uranine	6.4
7710	63	5/30/2008 10:21:00 AM to 6/20/2008	Charcoal	Uranine	1.5
7710	63	5/30/2008 10:21:00 AM to 6/20/2008	Charcoal	Eosin	4.8
9156	7	3/6/2009 to 3/18/2009	Charcoal	Phloxine B	11
9948	7	4/15/2009 to 4/28/2009	Charcoal	Eosin	3.1
10003	7	4/28/2009 to 5/12/2009	Charcoal	Phloxine B	9.6
6538	7	7/27/2009 to 8/10/2009	Charcoal	Eosin	28
6600	7	8/10/2009 to 8/25/2009	Charcoal	Eosin	24
6674	7	8/25/2009 to 9/14/2009	Charcoal	Uranine	0.8
6674	7	8/25/2009 to 9/14/2009	Charcoal	Phloxine B	1.3
6674	7	8/25/2009 to 9/14/2009	Charcoal	Uranine	3
6704	7	10/5/2009 11:55:00 AM	Water	Uranine	4.1
6704	7	10/5/2009 11:55:00 AM	Water	Eosin	0.2
6731	7	9/14/2009 to 10/5/2009	Charcoal	Uranine	1.1
6731	7	9/14/2009 to 10/5/2009	Charcoal	Phloxine B	0.3
13307	7	4/15/2010	Charcoal	Eosin	17
13185	7	5/6/2010	Charcoal	Phloxine B	15
13227	7	5/13/2010	Charcoal	Phloxine B	1
13227	7	5/13/2010	Charcoal	Uranine	1.1
5366	77	12:00:00 PM to 9/7/2002	Charcoal	Uranine	0.2
5228	77	9/19/2002 4:46:00 AM	Water	Uranine	0.09
5227	77	9/18/2002 to 9/19/2002	Charcoal	Uranine	0.1
5230	77	9/20/2002 10:49:00 PM	Water	Uranine	0.2
5229	77	9/20/2002 4:49:00 PM	Water	Uranine	0.1
5226	77	9/19/2002 to 9/20/2002	Charcoal	Uranine	0.07
5233	77	9/21/2002 10:49:00 PM	Water	Uranine	0.3

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
5232	77	9/21/2002 4:49:00 PM	Water	Uranine	0.1
5231	77	9/21/2002 10:49:00 AM	Water	Uranine	0.2
5509	77	9/20/2002 to 9/21/2002	Charcoal	Uranine	3.7
5238	77	9/22/2002 10:49:00 PM	Water	Uranine	0.3
5239	77	9/22/2002 10:49:00 PM	Water	Uranine	0.3
5237	77	9/22/2002 4:49:00 PM	Water	Uranine	0.3
5234	77	9/22/2002 4:49:00 AM	Water	Uranine	0.2
5236	77	9/22/2002 10:49:00 AM	Water	Uranine	0.2
5235	77	9/22/2002 4:49:00 AM	Water	Uranine	0.3
5241	77	9/23/2002 10:49:00 AM	Water	Uranine	0.3
5240	77	9/23/2002 4:49:00 AM	Water	Uranine	0.3
5338	77	9/21/2002 to 9/23/2002	Charcoal	Uranine	74
5266	77	9/23/2002 4:11:00 PM	Water	Uranine	0.3
5267	77	9/23/2002 10:11:00 PM	Water	Uranine	0.2
5270	77	9/24/2002 4:11:00 PM	Water	Uranine	0.2
5268	77	9/24/2002 4:11:00 AM	Water	Uranine	0.09
5269	77	9/24/2002 10:11:00 AM	Water	Uranine	0.09
5275	77	9/25/2002 10:11:00 PM	Water	Uranine	0.2
5274	77	9/25/2002 4:11:00 PM	Water	Uranine	0.2
5273	77	9/25/2002 10:11:00 AM	Water	Uranine	0.2
5272	77	9/25/2002 4:11:00 AM	Water	Uranine	0.3
5271	77	9/25/2002 4:11:00 AM	Water	Uranine	0.2
5278	77	9/26/2002 4:11:00 PM	Water	Uranine	0.2
5276	77	9/26/2002 4:11:00 AM	Water	Uranine	0.2
5277	77	9/26/2002 10:11:00 AM	Water	Uranine	0.2
5279	77	9/26/2002 4:27:00 PM	Water	Uranine	0.2
5282	77	9/27/2002 10:11:00 AM	Water	Uranine	0.2
5280	77	9/27/2002 4:11:00 AM	Water	Uranine	0.3
5281	77	9/27/2002 4:11:00 AM	Water	Uranine	0.2
5289	77	9/27/2002 11:00:00 AM	Water	Uranine	0.1
5290	77	9/27/2002 7:00:00 PM	Water	Uranine	0.2
5334	77	9/23/2002 to 9/27/2002	Charcoal	Uranine	156
5292	77	9/28/2002 11:00:00 AM	Water	Uranine	0.2
5291	77	9/28/2002 3:00:00 AM	Water	Uranine	0.2
5293	77	9/28/2002 7:00:00 PM	Water	Uranine	0.2
5295	77	9/29/2002 11:00:00 AM	Water	Uranine	0.1
5296	77	9/29/2002 7:00:00 PM	Water	Uranine	0.1
5294	77	9/29/2002 3:00:00 AM	Water	Uranine	0.2
5298	77	9/30/2002 11:00:00 AM	Water	Uranine	0.1

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
5299	77	9/30/2002 7:00:00 PM	Water	Uranine	0.1
5297	77	9/30/2002 3:00:00 AM	Water	Uranine	0.1
5302	77	10/1/2002 7:00:00 PM	Water	Uranine	0.1
5301	77	10/1/2002 11:00:00 AM	Water	Uranine	0.1
5300	77	10/1/2002 3:00:00 AM	Water	Uranine	0.1
5304	77	10/2/2002 11:00:00 AM	Water	Uranine	0.1
5303	77	10/2/2002 3:00:00 AM	Water	Uranine	0.1
5305	77	10/2/2002 7:00:00 PM	Water	Uranine	0.1
5306	77	10/3/2002 3:00:00 AM	Water	Uranine	0.09
5307	77	10/3/2002 11:00:00 AM	Water	Uranine	0.08
5308	77	10/3/2002 7:00:00 PM	Water	Uranine	0.06
5324	77	10/4/2002 7:18:00 PM	Water	Uranine	0.07
5580	77	10/4/2002 11:23:00 AM	Water	Uranine	0.1
5468	77	9/27/2002 to 10/4/2002	Charcoal	Uranine	81
5312	77	10/4/2002 3:00:00 AM	Water	Uranine	0.07
5313	77	10/4/2002 11:00:00 AM	Water	Uranine	0.08
5325	77	10/5/2002 3:18:00 AM	Water	Uranine	0.08
5467	77	10/4/2002 to 10/14/2002	Charcoal	Uranine	15
5465	77	10/14/2002 to 10/17/2002	Charcoal	Uranine	14
1286	77	1/11/2004 to 1/12/2004	Charcoal	Eosin	7.6
1284	77	1/12/2004 to 1/13/2004	Charcoal	Eosin	28
2072	77	1/12/2004 to 1/13/2004	Charcoal	Uranine	0.4
2072	77	1/12/2004 to 1/13/2004	Charcoal	Eosin	11
1045	77	1/14/2004 12:44:00 PM	Water	Eosin	0.4
1048	77	1/14/2004 6:44:00 AM	Water	Eosin	0.4
763	77	1/14/2004 12:13:00 PM	Water	Eosin	0.3
1290	77	1/13/2004 to 1/14/2004	Charcoal	Eosin	51
1044	77	1/14/2004 10:44:00 AM	Water	Eosin	1
750	77	1/14/2004 10:13:00 AM	Water	Eosin	0.4
1049	77	1/14/2004 8:44:00 AM	Water	Eosin	0.4
766	77	1/14/2004 8:13:00 AM	Water	Eosin	0.3
1046	77	1/14/2004 2:44:00 AM	Water	Eosin	0.5
1060	77	1/15/2004 6:44:00 AM	Water	Eosin	0.9
1062	77	1/15/2004 10:44:00 AM	Water	Eosin	0.5
1053	77	1/15/2004 4:44:00 AM	Water	Eosin	3.8
1057	77	1/15/2004 12:44:00 PM	Water	Eosin	0.7
1056	77	1/15/2004 10:44:00 AM	Water	Eosin	0.4
1055	77	1/15/2004 8:44:00 AM	Water	Eosin	0.5
1061	77	1/15/2004 8:44:00 AM	Water	Eosin	0.5

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
1054	77	1/15/2004 6:44:00 AM	Water	Eosin	0.5
1059	77	1/15/2004 4:44:00 AM	Water	Eosin	0.5
1058	77	1/15/2004 2:44:00 AM	Water	Eosin	0.5
1052	77	1/15/2004 2:44:00 AM	Water	Eosin	0.4
1051	77	1/15/2004 12:44:00 PM	Water	Eosin	0.5
1064	77	1/16/2004 2:44:00 AM	Water	Eosin	0.5
1065	77	1/16/2004 4:44:00 AM	Water	Eosin	0.5
1066	77	1/16/2004 6:44:00 AM	Water	Eosin	0.6
1067	77	1/16/2004 8:44:00 AM	Water	Eosin	0.5
1063	77	1/16/2004 12:44:00 PM	Water	Eosin	0.4
1185	77	1/14/2004 to 1/18/2004	Charcoal	Eosin	199
1185	77	1/14/2004 to 1/18/2004	Charcoal	Uranine	2.8
1985	77	1/14/2004 to 1/18/2004	Charcoal	Eosin	370
1344	77	1/20/2004 12:08:00 PM	Water	Uranine	0.07
1184	77	1/18/2004 to 1/20/2004	Charcoal	Eosin	386
1986	77	1/18/2004 to 1/20/2004	Charcoal	Uranine	0.9
1986	77	1/18/2004 to 1/20/2004	Charcoal	Eosin	94
1068	77	1/20/2004 11:00:00 AM	Water	Uranine	0.07
1345	77	1/20/2004 6:08:00 AM	Water	Uranine	0.2
1347	77	1/21/2004 6:08:00 AM	Water	Uranine	0.2
1346	77	1/21/2004 12:08:00 PM	Water	Uranine	0.07
1351	77	1/22/2004 6:08:00 AM	Water	Uranine	0.3
1352	77	1/22/2004 12:08:00 PM	Water	Uranine	0.09
1352	77	1/22/2004 12:08:00 PM	Water	Eosin	0.4
1350	77	1/22/2004 12:08:00 PM	Water	Eosin	4.4
1353	77	1/22/2004 6:08:00 AM	Water	Uranine	0.07
1356	77	1/23/2004 12:08:00 PM	Water	Uranine	0.1
1355	77	1/23/2004 6:08:00 AM	Water	Uranine	0.09
1355	77	1/23/2004 6:08:00 AM	Water	Eosin	0.3
1357	77	1/23/2004 6:08:00 AM	Water	Uranine	0.6
1354	77	1/23/2004 12:08:00 PM	Water	Eosin	0.4
1356	77	1/23/2004 12:08:00 PM	Water	Eosin	0.4
1354	77	1/23/2004 12:08:00 PM	Water	Uranine	0.09
1929	77	1/24/2004 1:45:00 AM	Water	Eosin	0.1
1929	77	1/24/2004 1:45:00 AM	Water	Uranine	0.08
1359	77	1/24/2004 6:08:00 AM	Water	Uranine	0.08
1930	77	1/24/2004 7:45:00 AM	Water	Eosin	0.2
1930	77	1/24/2004 7:45:00 AM	Water	Uranine	0.08
1382	77	1/20/2004 to 1/24/2004	Charcoal	Eosin	1205

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
1358	77	1/24/2004 12:08:00 PM	Water	Eosin	0.4
1360	77	1/24/2004 12:08:00 PM	Water	Uranine	0.07
1931	77	1/25/2004 1:45:00 AM	Water	Eosin	0.5
1932	77	1/25/2004 7:45:00 AM	Water	Eosin	0.2
1933	77	1/25/2004 1:45:00 AM	Water	Eosin	0.2
1934	77	1/25/2004 7:45:00 AM	Water	Eosin	0.09
1932	77	1/25/2004 7:45:00 AM	Water	Uranine	0.002
1938	77	1/26/2004 7:45:00 AM	Water	Eosin	0.3
1936	77	1/26/2004 7:45:00 AM	Water	Eosin	0.4
1937	77	1/26/2004 1:45:00 AM	Water	Uranine	0.06
1937	77	1/26/2004 1:45:00 AM	Water	Eosin	0.08
1935	77	1/26/2004 1:45:00 AM	Water	Eosin	0.2
5974	77	7/17/2005 11:49:00 PM	Water	Uranine	1.1
9226	77	3/10/2009 to 3/25/2009	Charcoal	Phloxine B	0.9
6539	77	7/27/2009 to 8/10/2009	Charcoal	Eosin	28
6678	77	8/25/2009 to 9/14/2009	Charcoal	Uranine	1.6
6740	77	9/1/2009 to 10/5/2009	Charcoal	Uranine	1.2
6740	77	9/1/2009 to 10/5/2009	Charcoal	Phloxine B	2.4
9862	77	10/5/2009 to 12/1/2009	Charcoal	Eosin	1.2
12662	77	1/13/2010 to 1/27/2010	Charcoal	Eosin	1.2
11528	77	1/27/2010 to 2/1/2010	Charcoal	Eosin	1
13101	77	4/22/2010	Charcoal	Phloxine B	14
13038	77	4/29/2010	Charcoal	Phloxine B	27
13177	77	5/6/2010	Charcoal	Phloxine B	5.9
9628	87	4/1/2009 to 4/15/2009	Charcoal	Eosin	40
9617	87	3/23/2009 to 4/15/2009	Charcoal	Eosin	4.1
9947	88	4/15/2009 to 4/28/2009	Charcoal	Phloxine B	2.9
9333	89	3/12/2009 to 3/12/2009	Charcoal	Eosin	2.6
9325	89	3/23/2009 11:40:00 AM	Water	Eosin	2.2
9557	89	4/15/2009 12:05:00 PM	Water	Eosin	2.9
9630	89	3/23/2009 to 4/15/2009	Charcoal	Eosin	10
9509	89	4/15/2009 12:00:00 PM	Water	Eosin	2.5
9918	89	4/28/2009 8:55:00 AM	Water	Eosin	1.9
9944	89	4/15/2009 to 4/28/2009	Charcoal	Eosin	7.1
9986	89	4/28/2009 to 5/12/2009	Charcoal	Eosin	4.1
6773	89	6/4/2009 to 6/30/2009	Charcoal	Eosin	28
6541	89	7/27/2009 to 8/10/2009	Charcoal	Eosin	49
6598	89	8/10/2009 to 8/25/2009	Charcoal	Eosin	12
6682	89	8/25/2009 to 9/14/2009	Charcoal	Uranine	0.7

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
6742	89	9/14/2009 to 10/5/2009	Charcoal	Uranine	0.6
6742	89	9/14/2009 to 10/5/2009	Charcoal	Uranine	5.4
10447	89	12/1/2009 to 12/8/2009	Charcoal	Eosin	4.8
12874	89	4/1/2010	Charcoal	Phloxine B	2
12843	89	4/15/2010	Charcoal	Uranine	10
13023	89	4/29/2010	Charcoal	Phloxine B	3.8
13228	89	5/13/2010	Charcoal	Uranine	1.4
13228	89	5/13/2010	Charcoal	Uranine	6.2
13228	89	5/13/2010	Charcoal	Phloxine B	2.3
9040	90	3/9/2009 1:10:00 PM	Water	Eosin	26
8979	90	3/9/2009 3:20:00 PM	Water	Eosin	20
9044	90	3/9/2009 1:10:00 PM	Water	Eosin	27
9029	90	3/6/2009 to 3/10/2009	Charcoal	Eosin	7.2
9033	90	3/10/2009 11:15:00 AM	Water	Eosin	23
9068	90	3/11/2009 4:15:00 PM	Water	Eosin	14
9070	90	3/12/2009 7:20:00 AM	Water	Eosin	15
9064	90	3/12/2009 3:00:00 PM	Water	Eosin	21
9151	90	3/10/2009 to 3/12/2009	Charcoal	Eosin	12
9072	90	3/13/2009 7:30:00 AM	Water	Eosin	3.4
9073	90	3/14/2009 8:20:00 AM	Water	Eosin	9.7
9074	90	3/15/2009 9:15:00 AM	Water	Eosin	14
9071	90	3/16/2009 9:30:00 PM	Water	Eosin	11
9069	90	3/17/2009 7:30:00 PM	Water	Eosin	13
9165	90	3/6/2009 to 3/18/2009	Charcoal	Eosin	42
9086	90	3/18/2009 11:40:00 AM	Water	Eosin	12
9358	90	4/1/2009 10:05:00 AM	Water	Eosin	15
9397	90	3/25/2009 to 4/1/2009	Charcoal	Eosin	23
9618	90	4/1/2009 to 4/15/2009	Charcoal	Eosin	13
9511	90	4/15/2009 12:25:00 PM	Water	Eosin	10
9510	90	4/15/2009 12:25:00 PM	Water	Eosin	10
9946	90	4/15/2009 to 4/28/2009	Charcoal	Eosin	9.5
9927	90	4/28/2009 9:25:00 AM	Water	Eosin	8.3
6811	90	4/15/2009 to 5/15/2009	Charcoal	Eosin	53
6812	90	4/15/2009 to 5/15/2009	Charcoal	Eosin	56
9620	91	4/1/2009 to 4/15/2009	Charcoal	Phloxine B	2.2
9619	91	4/1/2009 to 4/15/2009	Charcoal	Phloxine B	1
9941	91	4/15/2009 to 4/28/2009	Charcoal	Phloxine B	1.6
6675	91	8/25/2009 to 9/14/2009	Charcoal	Uranine	1.7
6743	91	9/14/2009 to 10/5/2009	Charcoal	Uranine	0.5

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
6743	91	9/14/2009 to 10/5/2009	Charcoal	Uranine	4.4
9167	92	3/6/2009 to 3/18/2009	Charcoal	Phloxine B	2.4
9935	92	4/7/2009 to 4/28/2009	Charcoal	Phloxine B	2.7
6781	92	6/4/2009 to 6/30/2009	Charcoal	Phloxine B	2.9
6683	92	8/25/2009 to 9/14/2009	Charcoal	Uranine	0.8
6683	92	8/25/2009 to 9/14/2009	Charcoal	Phloxine B	3
6683	92	8/25/2009 to 9/14/2009	Charcoal	Uranine	4.8
12082	98	12/7/2009 to 12/11/2009	Charcoal	Eosin	26
12109	98	12/11/2009 to 12/14/2009	Charcoal	Eosin	9.7
12197	98	12/17/2009 to 12/22/2009	Charcoal	Eosin	1.2
12466	98	12/17/2009 to 12/22/2009	Charcoal	Eosin	1.2
12222	98	12/22/2009 to 12/29/2009	Charcoal	Eosin	29
12246	98	12/29/2009 to 1/6/2010	Charcoal	Eosin	4.3
12634	98	1/13/2010 to 1/27/2010	Charcoal	Eosin	1.8
12656	98	1/13/2010 to 1/27/2010	Charcoal	Eosin	1.6
11503	98	1/27/2010 to 2/1/2010	Charcoal	Eosin	0.8
11400	98	2/1/2010 to 2/4/2010	Charcoal	Eosin	11
11441	98	2/4/2010 to 2/8/2010	Charcoal	Eosin	1.1
11874	98	2/18/2010 to 2/22/2010	Charcoal	Uranine	4.6
12005	98	3/4/2010 to 3/11/2010	Charcoal	Eosin	33
12863	98	4/1/2010	Charcoal	Eosin	52
12801	98	4/8/2010	Charcoal	Eosin	8.6
12861	98	4/15/2010	Charcoal	Eosin	12
12832	98	4/15/2010	Charcoal	Eosin	12
13012	98	4/22/2010 to 4/29/2010	Charcoal	Eosin	42
13159	98	5/6/2010	Charcoal	Uranine	6.9
13225	98	5/13/2010	Charcoal	Uranine	6.9
13277	98	5/27/2010	Charcoal	Eosin	1.5
10322	99	10/20/2009 to 11/18/2009	Charcoal	Eosin	26
10405	99	11/18/2009 to 12/7/2009	Charcoal	Eosin	2.6
12111	99	12/11/2009 to 12/14/2009	Charcoal	Eosin	1.4
12488	99	12/17/2009 to 12/22/2009	Charcoal	Eosin	1.1
12198	99	12/17/2009 to 12/22/2009	Charcoal	Eosin	1.6
12467	99	12/17/2009 to 12/22/2009	Charcoal	Eosin	1.2
12270	99	12/29/2009 to 1/6/2010	Charcoal	Eosin	20
12247	99	12/29/2009 to 1/6/2010	Charcoal	Eosin	20
12635	99	1/13/2010 to 1/27/2010	Charcoal	Eosin	104
12635	99	1/13/2010 to 1/27/2010	Charcoal	Eosin	36
12635	99	1/13/2010 to 1/27/2010	Charcoal	Eosin	30

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
11504	99	1/27/2010 to 2/1/2010	Charcoal	Eosin	1.1
11401	99	2/1/2010 to 2/4/2010	Charcoal	Eosin	2.5
11834	99	2/8/2010 to 2/11/2010	Charcoal	Eosin	12
12006	99	3/4/2010 to 3/11/2010	Charcoal	Eosin	4.3
12864	99	4/1/2010	Charcoal	Eosin	13
13076	99	4/22/2010	Charcoal	Eosin	3.4
13158	99	5/6/2010	Charcoal	Uranine	1
13158	99	5/6/2010	Charcoal	Uranine	3.4
13224	99	5/13/2010	Charcoal	Phloxine B	3.4
13224	99	5/13/2010	Charcoal	Uranine	7.2
13224	99	5/13/2010	Charcoal	Uranine	1.5
13278	99	5/27/2010	Charcoal	Eosin	1.2
1390	Cabomba Spring (33)	1/11/2004 to 1/12/2004	Charcoal	Uranine	0.4
1390	Cabomba Spring (33)	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	1.5
1277	Cabomba Spring (33)	1/14/2004 to 1/17/2004	Charcoal	Phloxine B	6.1
1277	Cabomba Spring (33)	1/14/2004 to 1/17/2004	Charcoal	Uranine	0.3
3386	Cabomba Spring (33)	10/27/2005 to 11/4/2005	Charcoal	Uranine	0.09
3386	Cabomba Spring (33)	10/27/2005 to 11/4/2005	Charcoal	Eosin	8.7
6908	Cabomba Spring (33)	4/17/2008 11:00:00 AM to 5/8/2008	Charcoal	Phloxine B	14
6955	Cabomba Spring (33)	5/8/2008 10:50:00 AM to 6/3/2008	Charcoal	Phloxine B	15
7056	Cabomba Spring (33)	6/3/2008 10:45:00 AM to 6/18/2008	Charcoal	Phloxine B	35
7137	Cabomba Spring (33)	6/18/2008 11:20:00 AM to 7/2/2008	Charcoal	Phloxine B	4.5
7187	Cabomba Spring (33)	7/2/2008 10:20:00 AM to 7/16/2008	Charcoal	Phloxine B	3.6
7188	Cabomba Spring (33)	7/2/2008 11:22:00 AM to 7/16/2008	Charcoal	Phloxine B	8.2
7227	Cabomba Spring (33)	7/16/2008 11:22:00 AM to 8/4/2008	Charcoal	Phloxine B	7.1
7226	Cabomba Spring (33)	7/16/2008 11:20:00 AM to 8/4/2008	Charcoal	Phloxine B	4.4
7383	Cabomba Spring (33)	8/4/2008 11:50:00 AM to 8/22/2008	Charcoal	Phloxine B	1.7
7382	Cabomba Spring (33)	8/4/2008 11:45:00 AM to 8/22/2008	Charcoal	Phloxine B	10
7369	Cabomba Spring (33)	8/22/2008 11:45:00 AM to 9/8/2008	Charcoal	Phloxine B	2.6
7368	Cabomba Spring (33)	8/22/2008 11:40:00 AM to 9/8/2008	Charcoal	Phloxine B	27
7430	Cabomba Spring (33)	9/8/2008 11:45:00 AM to 10/14/2008	Charcoal	Phloxine B	8
7492	Cabomba Spring (33)	10/14/2008 3:06:00 PM to 10/27/2008	Charcoal	Phloxine B	3.5
7491	Cabomba Spring (33)	10/14/2008 3:05:00 PM to 10/27/2008	Charcoal	Phloxine B	5
7503	Cabomba Spring (33)	10/27/2008 2:48:00 PM to 11/14/2008	Charcoal	Phloxine B	2.2
8245	Cabomba Spring (33)	12/17/2008 2:33:00 PM to 1/30/2009	Charcoal	Phloxine B	9.5
8247	Cabomba Spring (33)	12/17/2008 2:33:00 PM to 1/30/2009	Charcoal	Phloxine B	12
9152	Cabomba Spring (33)	1/30/2009 to 2/24/2009	Charcoal	Phloxine B	9.5
9340	Cabomba Spring (33)	2/24/2009 to 3/7/2009	Charcoal	Phloxine B	7.1
6809	Cabomba Spring (33)	4/15/2009 to 5/15/2009	Charcoal	Phloxine B	3.4

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
6802	Cabomba Spring (33)	4/15/2009 to 5/15/2009	Charcoal	Phloxine B	7.3
6786	Cabomba Spring (33)	3/7/2009 to 6/5/2009	Charcoal	Eosin	89
6786	Cabomba Spring (33)	3/7/2009 to 6/5/2009	Charcoal	Phloxine B	72
10435	Cabomba Spring (33)	11/23/2009 to 12/2/2009	Charcoal	Eosin	39
10647	Cabomba Spring (33)	12/2/2009 to 12/7/2009	Charcoal	Phloxine B	0.8
10647	Cabomba Spring (33)	12/2/2009 to 12/7/2009	Charcoal	Eosin	19
12142	Cabomba Spring (33)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	11
12164	Cabomba Spring (33)	12/14/2009 to 12/17/2009	Charcoal	Eosin	68
12164	Cabomba Spring (33)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	11
12142	Cabomba Spring (33)	12/14/2009 to 12/17/2009	Charcoal	Eosin	68
12169	Cabomba Spring (33)	12/17/2009 to 12/20/2009	Charcoal	Eosin	56
12186	Cabomba Spring (33)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	168
12186	Cabomba Spring (33)	12/17/2009 to 12/20/2009	Charcoal	Eosin	53
12169	Cabomba Spring (33)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	153
12280	Cabomba Spring (33)	12/20/2009 to 1/4/2010	Charcoal	Eosin	95
12280	Cabomba Spring (33)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	14
11584	Cabomba Spring (33)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	1.8
11584	Cabomba Spring (33)	1/11/2010 to 1/14/2010	Charcoal	Eosin	21
12776	Cabomba Spring (33)	1/26/2010 to 1/28/2010	Charcoal	Eosin	2.6
12776	Cabomba Spring (33)	1/26/2010 to 1/28/2010	Charcoal	Eosin	22
11281	Cabomba Spring (33)	1/28/2010 to 2/2/2010	Charcoal	Eosin	20
11281	Cabomba Spring (33)	1/28/2010 to 2/2/2010	Charcoal	Uranine	2.5
11281	Cabomba Spring (33)	1/28/2010 to 2/2/2010	Charcoal	Eosin	2
11296	Cabomba Spring (33)	2/2/2010 to 2/4/2010	Charcoal	Eosin	5.6
10643	Catfish Hotel Spring (119)	12/2/2009 to 12/7/2009	Charcoal	Uranine	3.8
10643	Catfish Hotel Spring (119)	12/2/2009 to 12/7/2009	Charcoal	Phloxine B	5.3
10657	Catfish Hotel Spring (119)	12/10/2009 to 12/14/2009	Charcoal	Uranine	0.1
12152	Catfish Hotel Spring (119)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	0.9
12158	Catfish Hotel Spring (119)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	0.9
12274	Catfish Hotel Spring (119)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	5.8
12274	Catfish Hotel Spring (119)	12/20/2009 to 1/4/2010	Charcoal	Uranine	0.5
11590	Catfish Hotel Spring (119)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	7.6
12767	Catfish Hotel Spring (119)	1/21/2010 to 1/26/2010	Charcoal	Phloxine B	173
12782	Catfish Hotel Spring (119)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	13
11287	Catfish Hotel Spring (119)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	31
11302	Catfish Hotel Spring (119)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	6.6
5406	COSM Spring Lake Well (137)	9/19/2002 to 9/23/2002	Charcoal	Uranine	0.5
5419	COSM Spring Lake Well (137)	9/23/2002 to 9/27/2002	Charcoal	Uranine	1.1
5397	COSM Spring Lake Well (137)	10/4/2002 to 10/7/2002	Charcoal	Uranine	0.9

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
5423	COSM Spring Lake Well (137)	10/7/2002 to 10/14/2002	Charcoal	Uranine	2
5407	COSM Spring Lake Well (137)	10/7/2002 to 10/14/2002	Charcoal	Uranine	1.9
5415	COSM Spring Lake Well (137)	10/14/2002 to 10/28/2002	Charcoal	Uranine	1.6
10415	COSM Spring Lake Well (137)	11/24/2009 to 12/8/2009	Charcoal	Eosin	0.8
1383	Crater Bottom Spring (118)	1/7/2004 to 1/8/2004	Charcoal	Uranine	0.02
1384	Crater Bottom Spring (118)	1/9/2004 to 1/10/2004	Charcoal	Uranine	0.1
1384	Crater Bottom Spring (118)	1/9/2004 to 1/10/2004	Charcoal	Phloxine B	2.8
1761	Crater Bottom Spring (118)	1/10/2004 to 1/11/2004	Charcoal	Phloxine B	35
1385	Crater Bottom Spring (118)	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	57
1655	Crater Bottom Spring (118)	1/12/2004 to 1/13/2004	Charcoal	Phloxine B	5.9
1386	Crater Bottom Spring (118)	1/13/2004 to 1/14/2004	Charcoal	Uranine	0.3
1386	Crater Bottom Spring (118)	1/13/2004 to 1/14/2004	Charcoal	Phloxine B	27
1274	Crater Bottom Spring (118)	1/14/2004 to 1/17/2004	Charcoal	Phloxine B	303
1303	Crater Bottom Spring (118)	1/17/2004 to 1/21/2004	Charcoal	Phloxine B	73
1402	Crater Bottom Spring (118)	1/21/2004 to 1/25/2004	Charcoal	Phloxine B	80
1704	Crater Bottom Spring (118)	1/25/2004 to 1/29/2004	Charcoal	Uranine	0.3
1704	Crater Bottom Spring (118)	1/25/2004 to 1/29/2004	Charcoal	Phloxine B	40
1559	Crater Bottom Spring (118)	1/29/2004 to 2/2/2004	Charcoal	Uranine	0.2
1559	Crater Bottom Spring (118)	1/29/2004 to 2/2/2004	Charcoal	Phloxine B	45
1807	Crater Bottom Spring (118)	2/2/2004 to 2/6/2004	Charcoal	Phloxine B	16
1807	Crater Bottom Spring (118)	2/2/2004 to 2/6/2004	Charcoal	Uranine	0.8
1996	Crater Bottom Spring (118)	2/6/2004 to 2/10/2004	Charcoal	Phloxine B	18
1996	Crater Bottom Spring (118)	2/6/2004 to 2/10/2004	Charcoal	Uranine	0.6
2027	Crater Bottom Spring (118)	2/10/2004 to 2/14/2004	Charcoal	Uranine	0.4
2027	Crater Bottom Spring (118)	2/10/2004 to 2/14/2004	Charcoal	Phloxine B	14
2073	Crater Bottom Spring (118)	2/14/2004 to 2/18/2004	Charcoal	Phloxine B	9.8
2073	Crater Bottom Spring (118)	2/14/2004 to 2/18/2004	Charcoal	Uranine	0.7
2120	Crater Bottom Spring (118)	2/18/2004 to 2/23/2004	Charcoal	Phloxine B	5.3
2271	Crater Bottom Spring (118)	2/23/2004 to 2/27/2004	Charcoal	Uranine	0.3
2271	Crater Bottom Spring (118)	2/23/2004 to 2/27/2004	Charcoal	Phloxine B	7.3
2303	Crater Bottom Spring (118)	2/27/2004 to 3/2/2004	Charcoal	Uranine	0.3
2303	Crater Bottom Spring (118)	2/27/2004 to 3/2/2004	Charcoal	Phloxine B	10
10438	Crater Bottom Spring (118)	11/23/2009 to 12/2/2009	Charcoal	Eosin	17
10648	Crater Bottom Spring (118)	12/2/2009 to 12/7/2009	Charcoal	Phloxine B	53
10648	Crater Bottom Spring (118)	12/2/2009 to 12/7/2009	Charcoal	Eosin	27
12143	Crater Bottom Spring (118)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	24
12143	Crater Bottom Spring (118)	12/14/2009 to 12/17/2009	Charcoal	Eosin	8
12156	Crater Bottom Spring (118)	12/17/2009 to 12/20/2009	Charcoal	Eosin	58
12156	Crater Bottom Spring (118)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	119

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
12277	Crater Bottom Spring (118)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	43
12277	Crater Bottom Spring (118)	12/20/2009 to 1/4/2010	Charcoal	Eosin	61
11581	Crater Bottom Spring (118)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	15
11581	Crater Bottom Spring (118)	1/11/2010 to 1/14/2010	Charcoal	Eosin	26
12758	Crater Bottom Spring (118)	1/21/2010 to 1/26/2010	Charcoal	Eosin	25
12758	Crater Bottom Spring (118)	1/21/2010 to 1/26/2010	Charcoal	Phloxine B	11
12773	Crater Bottom Spring (118)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	9.6
12773	Crater Bottom Spring (118)	1/26/2010 to 1/28/2010	Charcoal	Eosin	24
11278	Crater Bottom Spring (118)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	11
11278	Crater Bottom Spring (118)	1/28/2010 to 2/2/2010	Charcoal	Eosin	23
10442	Cream of Wheat Spring (122)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	12
10442	Cream of Wheat Spring (122)	11/23/2009 to 12/2/2009	Charcoal	Eosin	28
10645	Cream of Wheat Spring (122)	12/2/2009 to 12/7/2009	Charcoal	Eosin	6
10645	Cream of Wheat Spring (122)	12/2/2009 to 12/7/2009	Charcoal	Phloxine B	5.6
12150	Cream of Wheat Spring (122)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	0.9
12150	Cream of Wheat Spring (122)	12/14/2009 to 12/17/2009	Charcoal	Eosin	0.6
12155	Cream of Wheat Spring (122)	12/17/2009 to 12/20/2009	Charcoal	Eosin	21
12155	Cream of Wheat Spring (122)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	12
12271	Cream of Wheat Spring (122)	12/20/2009 to 1/4/2010	Charcoal	Eosin	23
12271	Cream of Wheat Spring (122)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	12
11587	Cream of Wheat Spring (122)	1/11/2010 to 1/14/2010	Charcoal	Eosin	18
11587	Cream of Wheat Spring (122)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	11
12764	Cream of Wheat Spring (122)	1/21/2010 to 1/26/2010	Charcoal	Phloxine B	11
12764	Cream of Wheat Spring (122)	1/21/2010 to 1/26/2010	Charcoal	Eosin	21
12779	Cream of Wheat Spring (122)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	6.1
12779	Cream of Wheat Spring (122)	1/26/2010 to 1/28/2010	Charcoal	Eosin	16
11284	Cream of Wheat Spring (122)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	6.8
11284	Cream of Wheat Spring (122)	1/28/2010 to 2/2/2010	Charcoal	Eosin	12
10432	Cypress Point Spring (121)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	2.2
10432	Cypress Point Spring (121)	11/23/2009 to 12/2/2009	Charcoal	Eosin	3.1
10650	Cypress Point Spring (121)	12/2/2009 to 12/7/2009	Charcoal	Uranine	0.4
12769	Cypress Point Spring (121)	1/21/2010 to 1/26/2010	Charcoal	Phloxine B	36
11289	Cypress Point Spring (121)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	2.1
5251	Deep Spring (29)	9/20/2002 10:43:00 PM	Water	Uranine	0.3
5255	Deep Spring (29)	9/21/2002 10:43:00 PM	Water	Uranine	0.06
5254	Deep Spring (29)	9/21/2002 3:07:00 PM	Water	Uranine	0.2
5253	Deep Spring (29)	9/21/2002 10:43:00 AM	Water	Uranine	0.05
5252	Deep Spring (29)	9/21/2002 4:43:00 AM	Water	Uranine	0.3
5262	Deep Spring (29)	9/22/2002 10:43:00 PM	Water	Uranine	0.08

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
5257	Deep Spring (29)	9/22/2002 10:43:00 AM	Water	Uranine	0.1
5256	Deep Spring (29)	9/22/2002 4:43:00 AM	Water	Uranine	0.1
5258	Deep Spring (29)	9/22/2002 4:43:00 PM	Water	Uranine	0.03
5263	Deep Spring (29)	9/23/2002 4:43:00 AM	Water	Uranine	0.05
5370	Deep Spring (29)	9/23/2002 11:47:00 PM	Water	Uranine	0.09
5264	Deep Spring (29)	9/23/2002 10:43:00 AM	Water	Uranine	0.05
5368	Deep Spring (29)	9/23/2002 11:47:00 AM	Water	Uranine	0.07
5369	Deep Spring (29)	9/23/2002 5:47:00 PM	Water	Uranine	0.2
5372	Deep Spring (29)	9/24/2002 11:47:00 AM	Water	Uranine	0.3
5371	Deep Spring (29)	12:00:00 PM to 9/24/2002	Charcoal	Uranine	0.2
5320	Deep Spring (29)	10/3/2002 9:11:00 AM	Water	Uranine	0.01
5403	Deep Spring (29)	10/20/2002 12:30:00 PM	Water	Uranine	12
323	Deep Spring (29)	1/5/2004 10:57:00 AM	Water	Rhodamine WT	#Error
328	Deep Spring (29)	1/6/2004 2:57:00 AM	Water	Rhodamine WT	#Error
329	Deep Spring (29)	1/6/2004 6:57:00 AM	Water	Rhodamine WT	#Error
330	Deep Spring (29)	1/6/2004 10:57:00 AM	Water	Rhodamine WT	#Error
1589	Deep Spring (29)	1/11/2004 to 1/12/2004	Charcoal	Eosin	1.9
1602	Deep Spring (29)	1/12/2004 to 1/13/2004	Charcoal	Eosin	6.8
1603	Deep Spring (29)	1/13/2004 to 1/14/2004	Charcoal	Eosin	6.6
1425	Deep Spring (29)	1/14/2004 to 1/17/2004	Charcoal	Eosin	163
1279	Deep Spring (29)	1/14/2004 to 1/17/2004	Charcoal	Eosin	4.4
1304	Deep Spring (29)	1/17/2004 to 1/21/2004	Charcoal	Uranine	2.1
1304	Deep Spring (29)	1/17/2004 to 1/21/2004	Charcoal	Eosin	8.5
1401	Deep Spring (29)	1/21/2004 to 1/25/2004	Charcoal	Eosin	1138
1590	Deep Spring (29)	1/21/2004 to 1/25/2004	Charcoal	Eosin	97
1590	Deep Spring (29)	1/21/2004 to 1/25/2004	Charcoal	Uranine	4.2
1703	Deep Spring (29)	1/25/2004 to 1/29/2004	Charcoal	Eosin	150
1703	Deep Spring (29)	1/25/2004 to 1/29/2004	Charcoal	Uranine	15
1988	Deep Spring (29)	1/29/2004 to 2/1/2004	Charcoal	Eosin	108
1988	Deep Spring (29)	1/29/2004 to 2/1/2004	Charcoal	Uranine	3.1
1563	Deep Spring (29)	2/1/2004 to 2/2/2004	Charcoal	Uranine	9.4
1563	Deep Spring (29)	2/1/2004 to 2/2/2004	Charcoal	Eosin	133
1803	Deep Spring (29)	2/2/2004 to 2/6/2004	Charcoal	Uranine	5.4
1803	Deep Spring (29)	2/2/2004 to 2/6/2004	Charcoal	Eosin	110
2023	Deep Spring (29)	2/6/2004 to 2/14/2004	Charcoal	Uranine	2.1
2023	Deep Spring (29)	2/6/2004 to 2/14/2004	Charcoal	Eosin	98
2079	Deep Spring (29)	2/14/2004 to 2/18/2004	Charcoal	Eosin	127
2079	Deep Spring (29)	2/14/2004 to 2/18/2004	Charcoal	Uranine	1.3

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
2122	Deep Spring (29)	2/18/2004 to 2/23/2004	Charcoal	Eosin	63
2122	Deep Spring (29)	2/18/2004 to 2/23/2004	Charcoal	Uranine	1.2
2264	Deep Spring (29)	2/23/2004 to 2/27/2004	Charcoal	Eosin	84
2264	Deep Spring (29)	2/23/2004 to 2/27/2004	Charcoal	Uranine	1
2307	Deep Spring (29)	2/27/2004 to 3/2/2004	Charcoal	Eosin	70
2307	Deep Spring (29)	2/27/2004 to 3/2/2004	Charcoal	Uranine	0.8
5626	Deep Spring (29)	7/7/2004 9:39:00 PM	Water	Uranine	0.06
5629	Deep Spring (29)	7/8/2004 9:39:00 PM	Water	Uranine	0.08
5627	Deep Spring (29)	7/8/2004 5:39:00 AM	Water	Uranine	0.06
5628	Deep Spring (29)	7/8/2004 1:39:00 PM	Water	Uranine	0.07
5630	Deep Spring (29)	7/9/2004 5:39:00 AM	Water	Uranine	0.1
5635	Deep Spring (29)	7/16/2004 10:07:00 AM	Water	Uranine	0.07
5636	Deep Spring (29)	7/16/2004 6:07:00 PM	Water	Uranine	0.09
5637	Deep Spring (29)	7/17/2004 2:07:00 AM	Water	Uranine	0.08
5638	Deep Spring (29)	7/17/2004 10:07:00 AM	Water	Uranine	0.08
5639	Deep Spring (29)	7/17/2004 6:07:00 PM	Water	Uranine	0.07
5681	Deep Spring (29)	7/18/2004 6:07:00 PM	Water	Uranine	0.6
5680	Deep Spring (29)	7/18/2004 10:07:00 AM	Water	Uranine	0.06
5679	Deep Spring (29)	7/18/2004 2:07:00 AM	Water	Uranine	0.06
5682	Deep Spring (29)	7/19/2004 2:07:00 AM	Water	Uranine	0.05
5683	Deep Spring (29)	7/19/2004 10:07:00 AM	Water	Uranine	0.04
5684	Deep Spring (29)	7/19/2004 6:07:00 PM	Water	Uranine	0.05
5686	Deep Spring (29)	7/20/2004 10:07:00 AM	Water	Uranine	0.05
5687	Deep Spring (29)	7/20/2004 6:07:00 PM	Water	Uranine	0.05
5685	Deep Spring (29)	7/20/2004 2:07:00 AM	Water	Uranine	0.05
5689	Deep Spring (29)	7/21/2004 10:07:00 AM	Water	Uranine	0.04
5688	Deep Spring (29)	7/21/2004 2:07:00 AM	Water	Uranine	0.04
5690	Deep Spring (29)	7/21/2004 6:07:00 PM	Water	Uranine	0.2
5691	Deep Spring (29)	7/22/2004 2:07:00 AM	Water	Uranine	0.05
5692	Deep Spring (29)	7/22/2004 10:07:00 AM	Water	Uranine	0.2
5693	Deep Spring (29)	7/22/2004 6:07:00 PM	Water	Uranine	0.05
5694	Deep Spring (29)	7/23/2004 2:07:00 AM	Water	Uranine	0.05
5695	Deep Spring (29)	7/23/2004 10:07:00 AM	Water	Uranine	0.1
5833	Deep Spring (29)	7/11/2005 12:55:00 PM	Water	Uranine	0.3
5892	Deep Spring (29)	7/11/2005 6:12:00 PM	Water	Uranine	0.4
5891	Deep Spring (29)	7/11/2005 12:12:00 PM	Water	Uranine	0.3
5895	Deep Spring (29)	7/12/2005 12:12:00 PM	Water	Uranine	0.5
5893	Deep Spring (29)	7/12/2005 12:12:00 AM	Water	Uranine	0.4
5894	Deep Spring (29)	7/12/2005 6:12:00 AM	Water	Uranine	0.4

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
5896	Deep Spring (29)	7/12/2005 6:12:00 PM	Water	Uranine	0.5
5897	Deep Spring (29)	7/13/2005 12:12:00 AM	Water	Uranine	0.4
5898	Deep Spring (29)	7/13/2005 6:12:00 AM	Water	Uranine	0.4
5899	Deep Spring (29)	7/13/2005 12:12:00 PM	Water	Uranine	0.4
5900	Deep Spring (29)	7/13/2005 6:12:00 PM	Water	Uranine	0.4
5901	Deep Spring (29)	7/14/2005 12:12:00 AM	Water	Uranine	0.5
5902	Deep Spring (29)	7/14/2005 6:12:00 AM	Water	Uranine	0.5
5903	Deep Spring (29)	7/14/2005 6:12:00 AM	Water	Uranine	0.6
5923	Deep Spring (29)	7/15/2005 12:12:00 AM	Water	Uranine	0.4
5922	Deep Spring (29)	7/15/2005 6:12:00 AM	Water	Uranine	0.3
5928	Deep Spring (29)	7/15/2005 6:12:00 AM	Water	Uranine	0.5
5929	Deep Spring (29)	7/15/2005 6:12:00 AM	Water	Uranine	0.5
5930	Deep Spring (29)	7/15/2005 12:12:00 PM	Water	Uranine	0.5
5940	Deep Spring (29)	7/15/2005 6:12:00 PM	Water	Uranine	0.1
5944	Deep Spring (29)	7/16/2005 6:12:00 PM	Water	Uranine	0.1
5943	Deep Spring (29)	7/16/2005 12:12:00 PM	Water	Uranine	0.1
5941	Deep Spring (29)	7/16/2005 12:12:00 AM	Water	Uranine	0.1
5946	Deep Spring (29)	7/16/2005 12:12:00 PM	Water	Uranine	0.1
5942	Deep Spring (29)	7/16/2005 6:12:00 AM	Water	Uranine	0.2
5945	Deep Spring (29)	7/17/2005 12:12:00 AM	Water	Uranine	0.1
5980	Deep Spring (29)	7/18/2005 3:09:00 PM	Water	Uranine	0.2
5981	Deep Spring (29)	7/18/2005 9:09:00 PM	Water	Uranine	0.2
5985	Deep Spring (29)	7/19/2005 9:09:00 PM	Water	Uranine	0.1
5984	Deep Spring (29)	7/19/2005 3:09:00 PM	Water	Uranine	0.2
5982	Deep Spring (29)	7/19/2005 3:09:00 AM	Water	Uranine	0.1
5983	Deep Spring (29)	7/19/2005 9:09:00 AM	Water	Uranine	0.1
5987	Deep Spring (29)	7/20/2005 9:09:00 AM	Water	Uranine	0.2
5989	Deep Spring (29)	7/20/2005 9:09:00 PM	Water	Uranine	0.2
5986	Deep Spring (29)	7/20/2005 3:09:00 AM	Water	Uranine	0.2
5988	Deep Spring (29)	7/20/2005 3:09:00 PM	Water	Uranine	0.2
5990	Deep Spring (29)	7/21/2005 3:09:00 AM	Water	Uranine	0.2
5993	Deep Spring (29)	7/21/2005 3:09:00 PM	Water	Uranine	0.1
5994	Deep Spring (29)	7/21/2005 9:09:00 PM	Water	Uranine	0.1
5991	Deep Spring (29)	7/21/2005 9:09:00 AM	Water	Uranine	0.1
5992	Deep Spring (29)	7/21/2005 3:09:00 PM	Water	Uranine	0.2
5996	Deep Spring (29)	7/22/2005 9:09:00 AM	Water	Uranine	0.1
5998	Deep Spring (29)	7/22/2005 9:09:00 PM	Water	Uranine	0.2
5997	Deep Spring (29)	7/22/2005 3:09:00 PM	Water	Uranine	0.1
5995	Deep Spring (29)	7/22/2005 3:09:00 AM	Water	Uranine	0.2

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
6002	Deep Spring (29)	7/23/2005 9:09:00 PM	Water	Uranine	0.1
6000	Deep Spring (29)	7/23/2005 9:09:00 AM	Water	Uranine	0.1
5999	Deep Spring (29)	7/23/2005 3:09:00 AM	Water	Uranine	0.1
6001	Deep Spring (29)	7/23/2005 3:09:00 PM	Water	Uranine	0.1
6003	Deep Spring (29)	7/24/2005 3:09:00 AM	Water	Uranine	0.1
6104	Deep Spring (29)	7/25/2005 9:10:00 PM	Water	Uranine	0.09
6103	Deep Spring (29)	7/25/2005 3:10:00 PM	Water	Uranine	0.07
6102	Deep Spring (29)	7/25/2005 9:10:00 AM	Water	Uranine	0.08
6105	Deep Spring (29)	7/26/2005 3:10:00 AM	Water	Uranine	0.09
6106	Deep Spring (29)	7/26/2005 9:10:00 AM	Water	Uranine	0.08
6107	Deep Spring (29)	7/26/2005 3:10:00 PM	Water	Uranine	0.08
6109	Deep Spring (29)	7/26/2005 9:10:00 PM	Water	Uranine	0.08
6108	Deep Spring (29)	7/26/2005 3:10:00 PM	Water	Uranine	0.07
6113	Deep Spring (29)	7/27/2005 9:10:00 PM	Water	Uranine	0.06
6112	Deep Spring (29)	7/27/2005 3:10:00 PM	Water	Uranine	0.04
6110	Deep Spring (29)	7/27/2005 3:10:00 AM	Water	Uranine	0.08
6111	Deep Spring (29)	7/27/2005 9:10:00 AM	Water	Uranine	0.06
6115	Deep Spring (29)	7/28/2005 9:10:00 AM	Water	Uranine	0.06
6116	Deep Spring (29)	7/28/2005 3:10:00 PM	Water	Uranine	0.06
6114	Deep Spring (29)	7/28/2005 3:10:00 AM	Water	Uranine	0.06
6117	Deep Spring (29)	7/28/2005 9:10:00 PM	Water	Uranine	0.07
6118	Deep Spring (29)	7/29/2005 3:10:00 AM	Water	Uranine	0.06
6120	Deep Spring (29)	7/29/2005 3:10:00 PM	Water	Uranine	0.06
6121	Deep Spring (29)	7/29/2005 9:10:00 PM	Water	Uranine	0.07
6119	Deep Spring (29)	7/29/2005 9:10:00 AM	Water	Uranine	0.07
6122	Deep Spring (29)	7/30/2005 3:10:00 AM	Water	Uranine	0.06
6123	Deep Spring (29)	7/30/2005 9:10:00 AM	Water	Uranine	0.05
6124	Deep Spring (29)	7/30/2005 3:10:00 PM	Water	Uranine	0.03
6125	Deep Spring (29)	7/30/2005 9:10:00 PM	Water	Uranine	0.07
6066	Deep Spring (29)	7/31/2005 3:10:00 AM	Water	Uranine	0.06
6126	Deep Spring (29)	7/31/2005 3:10:00 AM	Water	Uranine	0.07
6191	Deep Spring (29)	8/1/2005 10:40:00 PM	Water	Uranine	0.1
6190	Deep Spring (29)	8/1/2005 4:40:00 PM	Water	Uranine	0.09
6189	Deep Spring (29)	8/1/2005 10:40:00 AM	Water	Uranine	0.1
6195	Deep Spring (29)	8/2/2005 10:40:00 PM	Water	Uranine	0.1
6192	Deep Spring (29)	8/2/2005 4:40:00 AM	Water	Uranine	0.1
6193	Deep Spring (29)	8/2/2005 10:40:00 AM	Water	Uranine	0.1
6194	Deep Spring (29)	8/2/2005 4:40:00 PM	Water	Uranine	0.08
6196	Deep Spring (29)	8/3/2005 4:40:00 AM	Water	Uranine	0.1

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
6197	Deep Spring (29)	8/3/2005 10:40:00 AM	Water	Uranine	0.09
2453	Deep Spring (29)	8/10/2005 2:51:00 PM	Water	Uranine	0.1
2454	Deep Spring (29)	8/10/2005 8:51:00 PM	Water	Uranine	0.09
2477	Deep Spring (29)	8/10/2005 8:51:00 PM	Water	Uranine	0.06
2458	Deep Spring (29)	8/11/2005 8:51:00 PM	Water	Uranine	0.06
2455	Deep Spring (29)	8/11/2005 2:51:00 AM	Water	Uranine	0.04
2456	Deep Spring (29)	8/11/2005 8:51:00 AM	Water	Uranine	0.05
2462	Deep Spring (29)	8/12/2005 8:51:00 PM	Water	Uranine	0.06
2460	Deep Spring (29)	8/12/2005 8:51:00 AM	Water	Uranine	0.07
2459	Deep Spring (29)	8/12/2005 2:51:00 AM	Water	Uranine	0.05
2461	Deep Spring (29)	8/12/2005 2:51:00 PM	Water	Uranine	0.06
2465	Deep Spring (29)	8/13/2005 2:51:00 PM	Water	Uranine	0.04
2466	Deep Spring (29)	8/13/2005 8:51:00 PM	Water	Uranine	0.06
2464	Deep Spring (29)	8/13/2005 8:51:00 AM	Water	Uranine	0.05
2463	Deep Spring (29)	8/13/2005 2:51:00 AM	Water	Uranine	0.05
2470	Deep Spring (29)	8/14/2005 8:51:00 PM	Water	Uranine	0.06
2467	Deep Spring (29)	8/14/2005 2:51:00 AM	Water	Uranine	0.05
2468	Deep Spring (29)	8/14/2005 8:51:00 AM	Water	Uranine	0.07
2469	Deep Spring (29)	8/14/2005 2:51:00 PM	Water	Uranine	0.06
2473	Deep Spring (29)	8/15/2005 2:51:00 PM	Water	Uranine	0.08
2474	Deep Spring (29)	8/15/2005 8:51:00 PM	Water	Uranine	0.2
2472	Deep Spring (29)	8/15/2005 8:51:00 AM	Water	Uranine	0.07
2471	Deep Spring (29)	8/15/2005 2:51:00 AM	Water	Uranine	0.06
2614	Deep Spring (29)	8/16/2005 9:56:00 AM	Water	Uranine	0.03
2475	Deep Spring (29)	8/16/2005 2:51:00 AM	Water	Uranine	0.1
2624	Deep Spring (29)	8/16/2005 9:56:00 AM	Water	Uranine	0.03
2476	Deep Spring (29)	8/16/2005 8:51:00 AM	Water	Uranine	0.1
2674	Deep Spring (29)	8/10/2005 to 8/17/2005	Charcoal	Uranine	10
2615	Deep Spring (29)	8/17/2005 3:56:00 AM	Water	Uranine	0.03
2616	Deep Spring (29)	8/17/2005 9:56:00 PM	Water	Uranine	0.02
2617	Deep Spring (29)	8/18/2005 3:56:00 PM	Water	Uranine	0.03
2618	Deep Spring (29)	8/19/2005 9:56:00 AM	Water	Uranine	0.02
2619	Deep Spring (29)	8/20/2005 3:56:00 AM	Water	Uranine	0.03
2621	Deep Spring (29)	8/21/2005 3:56:00 PM	Water	Uranine	0.06
2623	Deep Spring (29)	8/21/2005 9:56:00 PM	Water	Uranine	0.06
2622	Deep Spring (29)	8/22/2005 3:56:00 AM	Water	Uranine	0.08
2760	Deep Spring (29)	8/23/2005 to 8/31/2005	Charcoal	Uranine	25
3080	Deep Spring (29)	9/1/2005 to 9/8/2005	Charcoal	Uranine	1.8
3090	Deep Spring (29)	9/8/2005 to 9/14/2005	Charcoal	Uranine	1.9

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
3150	Deep Spring (29)	9/14/2005 to 9/21/2005	Charcoal	Uranine	0.3
3150	Deep Spring (29)	9/14/2005 to 9/21/2005	Charcoal	Uranine	0.8
3293	Deep Spring (29)	9/21/2005 to 10/4/2005	Charcoal	Uranine	0.5
3293	Deep Spring (29)	9/21/2005 to 10/4/2005	Charcoal	Eosin	3.9
3359	Deep Spring (29)	10/18/2005 to 10/27/2005	Charcoal	Uranine	0.1
3377	Deep Spring (29)	10/27/2005 to 11/4/2005	Charcoal	Eosin	4.5
3377	Deep Spring (29)	10/27/2005 to 11/4/2005	Charcoal	Uranine	0.2
3675	Deep Spring (29)	11/4/2005 to 11/14/2005	Charcoal	Eosin	10
3775	Deep Spring (29)	11/14/2005 to 11/22/2005	Charcoal	Eosin	33
3856	Deep Spring (29)	11/22/2005 to 12/5/2005	Charcoal	Uranine	0.05
3856	Deep Spring (29)	11/22/2005 to 12/5/2005	Charcoal	Eosin	8.6
3959	Deep Spring (29)	12/5/2005 to 12/15/2005	Charcoal	Uranine	0.02
3959	Deep Spring (29)	12/5/2005 to 12/15/2005	Charcoal	Eosin	2.9
4094	Deep Spring (29)	12/15/2005 to 12/28/2005	Charcoal	Eosin	3.3
4094	Deep Spring (29)	12/15/2005 to 12/28/2005	Charcoal	Uranine	0.06
4219	Deep Spring (29)	12/28/2005 to 1/23/2006	Charcoal	Eosin	1.5
4569	Deep Spring (29)	1/23/2006 to 2/21/2006	Charcoal	Eosin	5.3
4569	Deep Spring (29)	1/23/2006 to 2/21/2006	Charcoal	Uranine	0.04
4741	Deep Spring (29)	3/21/2006 to 4/11/2006	Charcoal	Phloxine B	1.7
4863	Deep Spring (29)	4/11/2006 to 5/14/2006	Charcoal	Phloxine B	1.2
4886	Deep Spring (29)	5/14/2006 to 6/12/2006	Charcoal	Phloxine B	0.5
4967	Deep Spring (29)	6/12/2006 to 7/18/2006	Charcoal	Phloxine B	0.2
5043	Deep Spring (29)	7/18/2006 to 8/4/2006	Charcoal	Phloxine B	0.3
5100	Deep Spring (29)	8/8/2006 to 8/24/2006	Charcoal	Phloxine B	1.8
5161	Deep Spring (29)	9/14/2006 to 10/13/2006	Charcoal	Phloxine B	8.1
6911	Deep Spring (29)	4/17/2008 10:45:00 AM to 5/8/2008	Charcoal	Phloxine B	86
6956	Deep Spring (29)	5/8/2008 10:40:00 AM to 6/3/2008	Charcoal	Phloxine B	2.5
7136	Deep Spring (29)	6/18/2008 11:15:00 AM to 7/2/2008	Charcoal	Phloxine B	2
7194	Deep Spring (29)	7/2/2008 10:30:00 AM to 7/16/2008	Charcoal	Phloxine B	2.9
7195	Deep Spring (29)	7/2/2008 10:32:00 AM to 7/16/2008	Charcoal	Phloxine B	2.8
7595	Deep Spring (29)	11/14/2008 11:45:00 AM to 12/17/2008	Charcoal	Phloxine B	1.3
8235	Deep Spring (29)	12/17/2008 2:47:00 PM to 1/29/2009	Charcoal	Phloxine B	25
8237	Deep Spring (29)	12/17/2008 2:47:00 PM to 1/29/2009	Charcoal	Phloxine B	6.5
6783	Deep Spring (29)	4/15/2009 to 6/5/2009	Charcoal	Phloxine B	11
6736	Deep Spring (29)	9/17/2009	Charcoal	Phloxine B	12
10433	Deep Spring (29)	11/23/2009 to 12/2/2009	Charcoal	Eosin	1.8
10433	Deep Spring (29)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	2.2
10659	Deep Spring (29)	12/2/2009 to 12/7/2009	Charcoal	Uranine	0.5
10659	Deep Spring (29)	12/2/2009 to 12/7/2009	Charcoal	Eosin	0.5

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
12151	Deep Spring (29)	12/14/2009 to 12/17/2009	Charcoal	Uranine	0.3
12151	Deep Spring (29)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	5.5
12160	Deep Spring (29)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	9
12160	Deep Spring (29)	12/17/2009 to 12/20/2009	Charcoal	Uranine	18
12275	Deep Spring (29)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	9.1
12275	Deep Spring (29)	12/20/2009 to 1/4/2010	Charcoal	Uranine	14
11591	Deep Spring (29)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	6.9
12768	Deep Spring (29)	1/21/2010 to 1/26/2010	Charcoal	Phloxine B	29
12783	Deep Spring (29)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	13
11288	Deep Spring (29)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	37
11303	Deep Spring (29)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	8.7
5399	Diversion Spring (30)	12:00:00 PM to 10/4/2002	Charcoal	Uranine	0.5
5396	Diversion Spring (30)	10/4/2002 to 10/20/2002	Charcoal	Uranine	0.5
1379	Diversion Spring (30)	1/9/2004 to 1/10/2004	Charcoal	Phloxine B	39
1593	Diversion Spring (30)	1/10/2004 to 1/11/2004	Charcoal	Phloxine B	4.2
1378	Diversion Spring (30)	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	11
1594	Diversion Spring (30)	1/12/2004 to 1/13/2004	Charcoal	Phloxine B	14
1377	Diversion Spring (30)	1/13/2004 to 1/14/2004	Charcoal	Phloxine B	55
1273	Diversion Spring (30)	1/14/2004 to 1/17/2004	Charcoal	Phloxine B	21
1306	Diversion Spring (30)	1/17/2004 to 1/21/2004	Charcoal	Phloxine B	0.7
1404	Diversion Spring (30)	1/21/2004 to 1/25/2004	Charcoal	Uranine	0.8
1404	Diversion Spring (30)	1/21/2004 to 1/25/2004	Charcoal	Phloxine B	54
1706	Diversion Spring (30)	1/25/2004 to 1/29/2004	Charcoal	Phloxine B	17
1706	Diversion Spring (30)	1/25/2004 to 1/29/2004	Charcoal	Uranine	4
1987	Diversion Spring (30)	1/29/2004 to 2/1/2004	Charcoal	Phloxine B	8.7
1987	Diversion Spring (30)	1/29/2004 to 2/1/2004	Charcoal	Uranine	5.7
1987	Diversion Spring (30)	1/29/2004 to 2/1/2004	Charcoal	Eosin	1.6
1565	Diversion Spring (30)	2/1/2004 to 2/2/2004	Charcoal	Phloxine B	21
1565	Diversion Spring (30)	2/1/2004 to 2/2/2004	Charcoal	Eosin	1.6
1565	Diversion Spring (30)	2/1/2004 to 2/2/2004	Charcoal	Uranine	5.7
1801	Diversion Spring (30)	2/2/2004 to 2/6/2004	Charcoal	Uranine	1.5
1801	Diversion Spring (30)	2/2/2004 to 2/6/2004	Charcoal	Phloxine B	5.8
2024	Diversion Spring (30)	2/6/2004 to 2/14/2004	Charcoal	Eosin	3.6
2024	Diversion Spring (30)	2/6/2004 to 2/14/2004	Charcoal	Uranine	0.6
2024	Diversion Spring (30)	2/6/2004 to 2/14/2004	Charcoal	Phloxine B	9.8
2083	Diversion Spring (30)	2/14/2004 to 2/18/2004	Charcoal	Phloxine B	2.6
2082	Diversion Spring (30)	2/14/2004 to 2/18/2004	Charcoal	Phloxine B	2.6
2118	Diversion Spring (30)	2/18/2004 to 2/23/2004	Charcoal	Phloxine B	2.6
2266	Diversion Spring (30)	2/23/2004 to 2/27/2004	Charcoal	Uranine	0.03

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
2266	Diversion Spring (30)	2/23/2004 to 2/27/2004	Charcoal	Phloxine B	1.2
2266	Diversion Spring (30)	2/23/2004 to 2/27/2004	Charcoal	Eosin	0.5
2680	Diversion Spring (30)	8/10/2005 to 8/17/2005	Charcoal	Uranine	3.7
2631	Diversion Spring (30)	8/18/2005 2:51:00 PM	Water	Uranine	0.08
2636	Diversion Spring (30)	8/19/2005 8:51:00 PM	Water	Uranine	0.1
2635	Diversion Spring (30)	8/20/2005 2:51:00 AM	Water	Uranine	0.1
2640	Diversion Spring (30)	8/21/2005 2:51:00 AM	Water	Uranine	0.09
2711	Diversion Spring (30)	8/17/2005 to 8/23/2005	Charcoal	Uranine	0.3
2781	Diversion Spring (30)	8/23/2005 to 9/1/2005	Charcoal	Uranine	0.5
3152	Diversion Spring (30)	9/14/2005 to 9/21/2005	Charcoal	Eosin	7.6
3287	Diversion Spring (30)	9/21/2005 to 10/4/2005	Charcoal	Eosin	11
3357	Diversion Spring (30)	10/18/2005 to 10/27/2005	Charcoal	Eosin	0.9
3382	Diversion Spring (30)	10/27/2005 to 11/4/2005	Charcoal	Eosin	22
3670	Diversion Spring (30)	11/4/2005 to 11/14/2005	Charcoal	Eosin	33
3766	Diversion Spring (30)	11/14/2005 to 11/22/2005	Charcoal	Eosin	64
3875	Diversion Spring (30)	11/22/2005 to 12/5/2005	Charcoal	Eosin	19
3961	Diversion Spring (30)	12/5/2005 to 12/15/2005	Charcoal	Eosin	13
4096	Diversion Spring (30)	12/15/2005 to 12/28/2005	Charcoal	Eosin	9.7
4221	Diversion Spring (30)	12/28/2005 to 1/23/2006	Charcoal	Eosin	7.9
4568	Diversion Spring (30)	1/23/2006 to 2/21/2006	Charcoal	Eosin	4.4
4568	Diversion Spring (30)	1/23/2006 to 2/21/2006	Charcoal	Phloxine B	0.8
4535	Diversion Spring (30)	1/23/2006 to 2/21/2006	Charcoal	Eosin	0.7
4624	Diversion Spring (30)	2/21/2006 to 3/21/2006	Charcoal	Phloxine B	0.9
4655	Diversion Spring (30)	3/31/2006 8:49:00 PM	Water	Uranine	0.1
4733	Diversion Spring (30)	3/21/2006 to 4/11/2006	Charcoal	Phloxine B	2.6
4860	Diversion Spring (30)	4/11/2006 to 5/14/2006	Charcoal	Eosin	1.6
4860	Diversion Spring (30)	4/11/2006 to 5/14/2006	Charcoal	Phloxine B	7.1
4883	Diversion Spring (30)	5/14/2006 to 6/12/2006	Charcoal	Phloxine B	5.7
4966	Diversion Spring (30)	6/12/2006 to 7/18/2006	Charcoal	Phloxine B	26
5064	Diversion Spring (30)	7/18/2006 to 8/4/2006	Charcoal	Phloxine B	5.3
5097	Diversion Spring (30)	8/8/2006 to 8/24/2006	Charcoal	Phloxine B	28
5142	Diversion Spring (30)	8/24/2006 to 9/14/2006	Charcoal	Phloxine B	7.3
5166	Diversion Spring (30)	9/14/2006 to 10/13/2006	Charcoal	Phloxine B	7
6954	Diversion Spring (30)	5/8/2008 10:40:00 AM to 6/3/2008	Charcoal	Phloxine B	15
7046	Diversion Spring (30)	6/3/2008 10:45:00 AM to 6/18/2008	Charcoal	Phloxine B	2.3
7134	Diversion Spring (30)	6/18/2008 11:00:00 AM to 7/2/2008	Charcoal	Phloxine B	4
7191	Diversion Spring (30)	7/2/2008 10:00:00 AM to 7/16/2008	Charcoal	Phloxine B	4.5
7222	Diversion Spring (30)	7/16/2008 10:00:00 AM to 8/4/2008	Charcoal	Phloxine B	3.6
7223	Diversion Spring (30)	7/16/2008 10:02:00 AM to 8/4/2008	Charcoal	Phloxine B	4.1

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
7374	Diversion Spring (30)	8/4/2008 11:05:00 AM to 8/22/2008	Charcoal	Eosin	1.9
7374	Diversion Spring (30)	8/4/2008 11:05:00 AM to 8/22/2008	Charcoal	Phloxine B	2.4
7364	Diversion Spring (30)	8/22/2008 12:05:00 PM to 9/8/2008	Charcoal	Phloxine B	2.9
7364	Diversion Spring (30)	8/22/2008 12:05:00 PM to 9/8/2008	Charcoal	Eosin	2.3
7363	Diversion Spring (30)	8/22/2008 12:00:00 PM to 9/8/2008	Charcoal	Phloxine B	2.4
7363	Diversion Spring (30)	8/22/2008 12:00:00 PM to 9/8/2008	Charcoal	Eosin	1.9
7432	Diversion Spring (30)	9/8/2008 12:00:00 PM to 10/14/2008	Charcoal	Phloxine B	5.5
7432	Diversion Spring (30)	9/8/2008 12:00:00 PM to 10/14/2008	Charcoal	Eosin	1.3
7433	Diversion Spring (30)	9/8/2008 12:05:00 PM to 10/14/2008	Charcoal	Eosin	5.3
7433	Diversion Spring (30)	9/8/2008 12:05:00 PM to 10/14/2008	Charcoal	Phloxine B	5.1
7458	Diversion Spring (30)	10/14/2008 2:56:00 PM to 10/27/2008	Charcoal	Phloxine B	3.2
7459	Diversion Spring (30)	10/14/2008 2:57:00 PM to 10/27/2008	Charcoal	Eosin	0.9
7459	Diversion Spring (30)	10/14/2008 2:57:00 PM to 10/27/2008	Charcoal	Phloxine B	3.2
7494	Diversion Spring (30)	10/27/2008 2:35:00 PM to 11/14/2008	Charcoal	Phloxine B	2.5
7493	Diversion Spring (30)	10/27/2008 2:34:00 PM to 11/14/2008	Charcoal	Phloxine B	5
7493	Diversion Spring (30)	10/27/2008 2:34:00 PM to 11/14/2008	Charcoal	Eosin	1.6
7597	Diversion Spring (30)	11/14/2008 12:15:00 PM to 12/17/2008	Charcoal	Phloxine B	8.1
8240	Diversion Spring (30)	12/17/2008 2:37:00 PM to 1/29/2009	Charcoal	Phloxine B	12
8238	Diversion Spring (30)	12/17/2008 2:37:00 PM to 1/29/2009	Charcoal	Phloxine B	11
9157	Diversion Spring (30)	1/29/2009 to 2/24/2009	Charcoal	Phloxine B	3.3
9158	Diversion Spring (30)	4/18/2008 to 2/24/2009	Charcoal	Phloxine B	12
9342	Diversion Spring (30)	2/24/2009 to 3/7/2009	Charcoal	Phloxine B	1.4
6807	Diversion Spring (30)	4/15/2009 to 5/15/2009	Charcoal	Eosin	1.1
6807	Diversion Spring (30)	4/15/2009 to 5/15/2009	Charcoal	Phloxine B	1.5
6806	Diversion Spring (30)	4/15/2009 to 5/15/2009	Charcoal	Phloxine B	2.1
6806	Diversion Spring (30)	4/15/2009 to 5/15/2009	Charcoal	Eosin	2.4
6807	Diversion Spring (30)	4/15/2009 to 5/15/2009	Charcoal	Uranine	0.3
6806	Diversion Spring (30)	4/15/2009 to 5/15/2009	Charcoal	Eosin	1.8
6784	Diversion Spring (30)	4/15/2009 to 6/5/2009	Charcoal	Phloxine B	27
6784	Diversion Spring (30)	4/15/2009 to 6/5/2009	Charcoal	Eosin	80
10436	Diversion Spring (30)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	1.8
10436	Diversion Spring (30)	11/23/2009 to 12/2/2009	Charcoal	Eosin	20
10649	Diversion Spring (30)	12/2/2009 to 12/7/2009	Charcoal	Phloxine B	99
10649	Diversion Spring (30)	12/2/2009 to 12/7/2009	Charcoal	Eosin	68
12144	Diversion Spring (30)	12/14/2009 to 12/17/2009	Charcoal	Eosin	34
12144	Diversion Spring (30)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	66
12161	Diversion Spring (30)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	22
12161	Diversion Spring (30)	12/17/2009 to 12/20/2009	Charcoal	Eosin	17
12282	Diversion Spring (30)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	25

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
12282	Diversion Spring (30)	12/20/2009 to 1/4/2010	Charcoal	Eosin	41
11586	Diversion Spring (30)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	12
11586	Diversion Spring (30)	1/11/2010 to 1/14/2010	Charcoal	Eosin	11
12778	Diversion Spring (30)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	14
12778	Diversion Spring (30)	1/26/2010 to 1/28/2010	Charcoal	Eosin	23
11283	Diversion Spring (30)	1/28/2010 to 2/2/2010	Charcoal	Eosin	28
11283	Diversion Spring (30)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	30
11298	Diversion Spring (30)	2/2/2010 to 2/4/2010	Charcoal	Eosin	23
11298	Diversion Spring (30)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	12
7323	Fern Bank Spring (45)	8/19/2008 3:45:00 PM to 8/26/2008	Charcoal	Phloxine B	2.2
7323	Fern Bank Spring (45)	8/19/2008 3:45:00 PM to 8/26/2008	Charcoal	Eosin	1.9
7419	Fern Bank Spring (45)	8/26/2008 11:50:00 AM to 10/9/2008	Charcoal	Phloxine B	2.3
7419	Fern Bank Spring (45)	8/26/2008 11:50:00 AM to 10/9/2008	Charcoal	Eosin	30
7483	Fern Bank Spring (45)	10/9/2008 12:00:00 PM to 10/29/2008	Charcoal	Phloxine B	0.7
7483	Fern Bank Spring (45)	10/9/2008 12:00:00 PM to 10/29/2008	Charcoal	Eosin	2.1
7544	Fern Bank Spring (45)	10/29/2008 1:40:00 PM to 11/19/2008	Charcoal	Eosin	2.1
7544	Fern Bank Spring (45)	10/29/2008 1:40:00 PM to 11/19/2008	Charcoal	Phloxine B	0.7
7628	Fern Bank Spring (45)	11/19/2008 1:10:00 PM to 12/18/2008	Charcoal	Eosin	1.9
7628	Fern Bank Spring (45)	11/19/2008 1:10:00 PM to 12/18/2008	Charcoal	Phloxine B	16
8225	Fern Bank Spring (45)	12/18/2008 5:05:00 PM to 1/30/2009	Charcoal	Eosin	9.2
8225	Fern Bank Spring (45)	12/18/2008 5:05:00 PM to 1/30/2009	Charcoal	Phloxine B	7.5
1585	Hotel Spring (32)	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	1.3
1586	Hotel Spring (32)	1/12/2004 to 1/13/2004	Charcoal	Uranine	0.2
1586	Hotel Spring (32)	1/12/2004 to 1/13/2004	Charcoal	Phloxine B	0.8
1281	Hotel Spring (32)	1/13/2004 to 1/14/2004	Charcoal	Phloxine B	3.5
1281	Hotel Spring (32)	1/13/2004 to 1/14/2004	Charcoal	Uranine	0.2
1275	Hotel Spring (32)	1/14/2004 to 1/19/2004	Charcoal	Phloxine B	36
1477	Hotel Spring (32)	1/19/2004 to 1/25/2004	Charcoal	Phloxine B	0.8
1666	Hotel Spring (32)	1/25/2004 to 1/31/2004	Charcoal	Phloxine B	15
1666	Hotel Spring (32)	1/25/2004 to 1/31/2004	Charcoal	Uranine	0.7
1798	Hotel Spring (32)	1/31/2004 to 2/6/2004	Charcoal	Phloxine B	1
1798	Hotel Spring (32)	1/31/2004 to 2/6/2004	Charcoal	Uranine	0.2
2021	Hotel Spring (32)	2/6/2004 to 2/14/2004	Charcoal	Phloxine B	4.4
2021	Hotel Spring (32)	2/6/2004 to 2/14/2004	Charcoal	Uranine	0.8
2078	Hotel Spring (32)	2/14/2004 to 2/18/2004	Charcoal	Phloxine B	0.4
2722	Hotel Spring (32)	8/17/2005 to 8/23/2005	Charcoal	Uranine	0.06
2761	Hotel Spring (32)	8/23/2005 to 8/31/2005	Charcoal	Uranine	0.5
3205	Hotel Spring (32)	9/14/2005 to 9/21/2005	Charcoal	Eosin	2.1
3540	Hotel Spring (32)	10/27/2005 to 11/4/2005	Charcoal	Eosin	4.5

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
3677	Hotel Spring (32)	11/4/2005 to 11/14/2005	Charcoal	Eosin	4
6905	Hotel Spring (32)	4/17/2008 11:15:00 AM to 5/8/2008	Charcoal	Phloxine B	42
6953	Hotel Spring (32)	5/8/2008 10:35:00 AM to 6/3/2008	Charcoal	Phloxine B	11
7059	Hotel Spring (32)	6/3/2008 11:30:00 AM to 6/18/2008	Charcoal	Phloxine B	1.1
7133	Hotel Spring (32)	6/18/2008 11:15:00 AM to 7/8/2008	Charcoal	Phloxine B	21
7239	Hotel Spring (32)	7/8/2008 12:30:00 PM to 8/5/2008	Charcoal	Eosin	1.4
7242	Hotel Spring (32)	7/8/2008 12:32:00 PM to 8/5/2008	Charcoal	Eosin	1.6
7242	Hotel Spring (32)	7/8/2008 12:32:00 PM to 8/5/2008	Charcoal	Phloxine B	3.1
7239	Hotel Spring (32)	7/8/2008 12:30:00 PM to 8/5/2008	Charcoal	Phloxine B	4.8
7388	Hotel Spring (32)	9/9/2008 2:00:00 PM to 10/1/2008	Charcoal	Eosin	2.3
7388	Hotel Spring (32)	9/9/2008 2:00:00 PM to 10/1/2008	Charcoal	Phloxine B	3.9
7437	Hotel Spring (32)	10/1/2008 11:00:00 AM to 10/22/2008	Charcoal	Phloxine B	4
7437	Hotel Spring (32)	10/1/2008 11:00:00 AM to 10/22/2008	Charcoal	Eosin	2.2
7530	Hotel Spring (32)	10/22/2008 11:05:00 AM to 11/14/2008	Charcoal	Phloxine B	3.1
7530	Hotel Spring (32)	10/22/2008 11:05:00 AM to 11/14/2008	Charcoal	Eosin	1.6
7565	Hotel Spring (32)	11/14/2008 12:50:00 PM to 12/9/2008	Charcoal	Phloxine B	4.3
7638	Hotel Spring (32)	12/9/2008 2:30:00 PM to 12/18/2008	Charcoal	Phloxine B	1.7
7639	Hotel Spring (32)	12/9/2008 2:31:00 PM to 12/18/2008	Charcoal	Phloxine B	1.6
8243	Hotel Spring (32)	12/18/2008 12:31:00 PM to 1/30/2009	Charcoal	Phloxine B	6.8
8989	Hotel Spring (32)	1/30/2009 to 2/20/2009	Charcoal	Phloxine B	1.9
9014	Hotel Spring (32)	2/20/2009 to 3/6/2009	Charcoal	Phloxine B	1.7
9022	Hotel Spring (32)	3/6/2009 to 3/10/2009	Charcoal	Phloxine B	1
9938	Hotel Spring (32)	4/15/2009 to 4/28/2009	Charcoal	Eosin	4.8
9985	Hotel Spring (32)	4/28/2009 to 5/12/2009	Charcoal	Eosin	19
9985	Hotel Spring (32)	4/28/2009 to 5/12/2009	Charcoal	Phloxine B	36
6804	Hotel Spring (32)	4/15/2009 to 5/15/2009	Charcoal	Eosin	1.8
6775	Hotel Spring (32)	6/4/2009 to 6/30/2009	Charcoal	Phloxine B	64
6775	Hotel Spring (32)	6/4/2009 to 6/30/2009	Charcoal	Eosin	80
6547	Hotel Spring (32)	7/27/2009 to 8/10/2009	Charcoal	Phloxine B	134
6547	Hotel Spring (32)	7/27/2009 to 8/10/2009	Charcoal	Eosin	95
6605	Hotel Spring (32)	8/10/2009 to 8/25/2009	Charcoal	Phloxine B	79
6606	Hotel Spring (32)	8/10/2009 to 8/25/2009	Charcoal	Phloxine B	121
6606	Hotel Spring (32)	8/10/2009 to 8/25/2009	Charcoal	Eosin	154
6605	Hotel Spring (32)	8/10/2009 to 8/25/2009	Charcoal	Eosin	153
9863	Hotel Spring (32)	10/5/2009 to 12/1/2009	Charcoal	Eosin	23
12066	Hotel Spring (32)	12/7/2009 to 12/10/2009	Charcoal	Eosin	6.6
12066	Hotel Spring (32)	12/7/2009 to 12/10/2009	Charcoal	Phloxine B	21
12115	Hotel Spring (32)	12/9/2009 to 12/14/2009	Charcoal	Phloxine B	21
12097	Hotel Spring (32)	12/10/2009 to 12/14/2009	Charcoal	Eosin	15

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
12097	Hotel Spring (32)	12/10/2009 to 12/14/2009	Charcoal	Phloxine B	21
12115	Hotel Spring (32)	12/9/2009 to 12/14/2009	Charcoal	Eosin	14
12481	Hotel Spring (32)	12/17/2009 to 12/22/2009	Charcoal	Eosin	17
12212	Hotel Spring (32)	12/17/2009 to 12/22/2009	Charcoal	Eosin	15
12481	Hotel Spring (32)	12/17/2009 to 12/22/2009	Charcoal	Phloxine B	3.9
12212	Hotel Spring (32)	12/17/2009 to 12/22/2009	Charcoal	Phloxine B	4.2
12236	Hotel Spring (32)	12/22/2009 to 12/29/2009	Charcoal	Phloxine B	2.4
12245	Hotel Spring (32)	12/22/2009 to 12/29/2009	Charcoal	Phloxine B	3
12236	Hotel Spring (32)	12/22/2009 to 12/29/2009	Charcoal	Eosin	11
12245	Hotel Spring (32)	12/22/2009 to 12/29/2009	Charcoal	Eosin	9
12261	Hotel Spring (32)	12/29/2009 to 1/6/2010	Charcoal	Phloxine B	2.1
12261	Hotel Spring (32)	12/29/2009 to 1/6/2010	Charcoal	Eosin	11
12649	Hotel Spring (32)	1/13/2010 to 1/27/2010	Charcoal	Phloxine B	4.2
12649	Hotel Spring (32)	1/13/2010 to 1/27/2010	Charcoal	Eosin	23
11520	Hotel Spring (32)	1/27/2010 to 2/1/2010	Charcoal	Eosin	5.2
11444	Hotel Spring (32)	2/1/2010 to 2/4/2010	Charcoal	Eosin	2
11430	Hotel Spring (32)	2/1/2010 to 2/4/2010	Charcoal	Eosin	4.2
11449	Hotel Spring (32)	2/4/2010 to 2/8/2010	Charcoal	Eosin	0.9
11851	Hotel Spring (32)	2/8/2010 to 2/11/2010	Charcoal	Eosin	2
12024	Hotel Spring (32)	3/4/2010 to 3/11/2010	Charcoal	Eosin	7.5
12024	Hotel Spring (32)	3/4/2010 to 3/11/2010	Charcoal	Uranine	9.3
12878	Hotel Spring (32)	4/1/2010	Charcoal	Uranine	17
12878	Hotel Spring (32)	4/1/2010	Charcoal	Eosin	23
12816	Hotel Spring (32)	4/8/2010	Charcoal	Uranine	7.8
12816	Hotel Spring (32)	4/8/2010	Charcoal	Eosin	8.8
12862	Hotel Spring (32)	4/15/2010	Charcoal	Eosin	2.8
12860	Hotel Spring (32)	4/15/2010	Charcoal	Uranine	1.8
12860	Hotel Spring (32)	4/15/2010	Charcoal	Eosin	2.9
12847	Hotel Spring (32)	4/15/2010	Charcoal	Uranine	1.7
12847	Hotel Spring (32)	4/15/2010	Charcoal	Eosin	3.3
12862	Hotel Spring (32)	4/15/2010	Charcoal	Uranine	1.6
13098	Hotel Spring (32)	4/22/2010	Charcoal	Uranine	3.5
13098	Hotel Spring (32)	4/22/2010	Charcoal	Eosin	2.2
13090	Hotel Spring (32)	4/22/2010	Charcoal	Eosin	2.2
10441	Kettleman's Spring (125)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	3.9
10441	Kettleman's Spring (125)	11/23/2009 to 12/2/2009	Charcoal	Eosin	11
10383	Kettleman's Spring (125)	12/2/2009 6:30:00 PM	Water	Eosin	0.3
10654	Kettleman's Spring (125)	12/2/2009 to 12/7/2009	Charcoal	Eosin	2.3
10654	Kettleman's Spring (125)	12/2/2009 to 12/7/2009	Charcoal	Phloxine B	3.2

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
10660	Kettleman's Spring (125)	12/10/2009 to 12/14/2009	Charcoal	Phloxine B	0.9
10676	Kettleman's Spring (125)	12/10/2009 to 12/14/2009	Charcoal	Phloxine B	1.1
10660	Kettleman's Spring (125)	12/10/2009 to 12/14/2009	Charcoal	Uranine	19
10676	Kettleman's Spring (125)	12/10/2009 to 12/14/2009	Charcoal	Uranine	25
12147	Kettleman's Spring (125)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	1.6
12167	Kettleman's Spring (125)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	8.2
12283	Kettleman's Spring (125)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	39
12283	Kettleman's Spring (125)	12/20/2009 to 1/4/2010	Charcoal	Uranine	1.7
11593	Kettleman's Spring (125)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	2.9
11275	Kettleman's Spring (125)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	20
11290	Kettleman's Spring (125)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	24
11305	Kettleman's Spring (125)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	3.4
10437	Ossified Forest Spring (126)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	3.8
10642	Ossified Forest Spring (126)	12/2/2009 to 12/7/2009	Charcoal	Eosin	0.9
10642	Ossified Forest Spring (126)	12/2/2009 to 12/7/2009	Charcoal	Phloxine B	0.6
12145	Ossified Forest Spring (126)	12/14/2009 to 12/17/2009	Charcoal	Eosin	1.9
12145	Ossified Forest Spring (126)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	3.3
12272	Ossified Forest Spring (126)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	13
12272	Ossified Forest Spring (126)	12/20/2009 to 1/4/2010	Charcoal	Eosin	14
11588	Ossified Forest Spring (126)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	1.4
12780	Ossified Forest Spring (126)	1/26/2010 to 1/28/2010	Charcoal	Eosin	2
12780	Ossified Forest Spring (126)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	9.2
11285	Ossified Forest Spring (126)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	3.4
11300	Ossified Forest Spring (126)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	0.6
10444	River Bed Spring (127)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	3.7
10444	River Bed Spring (127)	11/23/2009 to 12/2/2009	Charcoal	Eosin	5.4
10445	River Bed Spring (127)	12/1/2009 to 12/8/2009	Charcoal	Eosin	2.2
12149	River Bed Spring (127)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	0.6
12273	River Bed Spring (127)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	6.5
12284	River Bed Spring (127)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	6.4
11589	River Bed Spring (127)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	1.4
12781	River Bed Spring (127)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	3.4
11286	River Bed Spring (127)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	1.4
1538	Salt & Pepper 1 Spring (128)	1/9/2004 to 1/10/2004	Charcoal	Uranine	0.1
1538	Salt & Pepper 1 Spring (128)	1/9/2004 to 1/10/2004	Charcoal	Phloxine B	3.2
2052	Salt & Pepper 1 Spring (128)	1/10/2004 to 1/11/2004	Charcoal	Phloxine B	7.4
2052	Salt & Pepper 1 Spring (128)	1/10/2004 to 1/11/2004	Charcoal	Uranine	0.4
2053	Salt & Pepper 1 Spring (128)	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	13
2053	Salt & Pepper 1 Spring (128)	1/11/2004 to 1/12/2004	Charcoal	Uranine	0.4

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
2057	Salt & Pepper 1 Spring (128)	1/12/2004 to 1/13/2004	Charcoal	Phloxine B	26
1596	Salt & Pepper 1 Spring (128)	1/12/2004 to 1/13/2004	Charcoal	Phloxine B	19
1539	Salt & Pepper 1 Spring (128)	1/13/2004 to 1/14/2004	Charcoal	Phloxine B	5.3
1539	Salt & Pepper 1 Spring (128)	1/13/2004 to 1/14/2004	Charcoal	Uranine	0.1
1276	Salt & Pepper 1 Spring (128)	1/14/2004 to 1/17/2004	Charcoal	Phloxine B	15
1276	Salt & Pepper 1 Spring (128)	1/14/2004 to 1/17/2004	Charcoal	Uranine	0.2
1300	Salt & Pepper 1 Spring (128)	1/17/2004 to 1/21/2004	Charcoal	Uranine	0.2
1300	Salt & Pepper 1 Spring (128)	1/17/2004 to 1/21/2004	Charcoal	Phloxine B	24
1398	Salt & Pepper 1 Spring (128)	1/21/2004 to 1/25/2004	Charcoal	Phloxine B	29
1398	Salt & Pepper 1 Spring (128)	1/21/2004 to 1/25/2004	Charcoal	Uranine	0.3
1699	Salt & Pepper 1 Spring (128)	1/25/2004 to 1/29/2004	Charcoal	Phloxine B	11
1699	Salt & Pepper 1 Spring (128)	1/25/2004 to 1/29/2004	Charcoal	Uranine	0.3
1558	Salt & Pepper 1 Spring (128)	1/29/2004 to 2/2/2004	Charcoal	Phloxine B	3.3
1558	Salt & Pepper 1 Spring (128)	1/29/2004 to 2/2/2004	Charcoal	Uranine	0.2
1797	Salt & Pepper 1 Spring (128)	2/2/2004 to 2/6/2004	Charcoal	Phloxine B	7.3
1797	Salt & Pepper 1 Spring (128)	2/2/2004 to 2/6/2004	Charcoal	Uranine	0.7
1994	Salt & Pepper 1 Spring (128)	2/6/2004 to 2/10/2004	Charcoal	Phloxine B	2.5
1994	Salt & Pepper 1 Spring (128)	2/6/2004 to 2/10/2004	Charcoal	Uranine	0.3
2029	Salt & Pepper 1 Spring (128)	2/10/2004 to 2/14/2004	Charcoal	Phloxine B	1.3
2029	Salt & Pepper 1 Spring (128)	2/10/2004 to 2/14/2004	Charcoal	Uranine	0.6
2076	Salt & Pepper 1 Spring (128)	2/14/2004 to 2/18/2004	Charcoal	Phloxine B	3.5
2076	Salt & Pepper 1 Spring (128)	2/14/2004 to 2/18/2004	Charcoal	Uranine	0.5
2112	Salt & Pepper 1 Spring (128)	2/18/2004 to 2/23/2004	Charcoal	Phloxine B	4.1
2267	Salt & Pepper 1 Spring (128)	2/23/2004 to 2/27/2004	Charcoal	Uranine	0.07
2267	Salt & Pepper 1 Spring (128)	2/23/2004 to 2/27/2004	Charcoal	Phloxine B	1.3
2302	Salt & Pepper 1 Spring (128)	2/27/2004 to 3/2/2004	Charcoal	Phloxine B	1.1
2302	Salt & Pepper 1 Spring (128)	2/27/2004 to 3/2/2004	Charcoal	Uranine	0.3
10434	Salt & Pepper 1 Spring (128)	11/23/2009 to 12/2/2009	Charcoal	Phloxine B	1.3
10434	Salt & Pepper 1 Spring (128)	11/23/2009 to 12/2/2009	Charcoal	Eosin	23
12148	Salt & Pepper 1 Spring (128)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	18
12148	Salt & Pepper 1 Spring (128)	12/14/2009 to 12/17/2009	Charcoal	Eosin	6.4
12166	Salt & Pepper 1 Spring (128)	12/17/2009 to 12/20/2009	Charcoal	Eosin	1.9
12166	Salt & Pepper 1 Spring (128)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	5.2
12278	Salt & Pepper 1 Spring (128)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	6.5
12278	Salt & Pepper 1 Spring (128)	12/20/2009 to 1/4/2010	Charcoal	Eosin	7.9
11582	Salt & Pepper 1 Spring (128)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	9
11582	Salt & Pepper 1 Spring (128)	1/11/2010 to 1/14/2010	Charcoal	Eosin	11
12774	Salt & Pepper 1 Spring (128)	1/26/2010 to 1/28/2010	Charcoal	Eosin	3.2
12774	Salt & Pepper 1 Spring (128)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	1.3

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
11279	Salt & Pepper 1 Spring (128)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	5.8
11279	Salt & Pepper 1 Spring (128)	1/28/2010 to 2/2/2010	Charcoal	Eosin	11
11294	Salt & Pepper 1 Spring (128)	2/2/2010 to 2/4/2010	Charcoal	Eosin	7.2
11294	Salt & Pepper 1 Spring (128)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	3.2
10439	Salt & Pepper 2 Spring (129)	11/23/2009 to 12/2/2009	Charcoal	Eosin	6.4
10644	Salt & Pepper 2 Spring (129)	12/2/2009 to 12/7/2009	Charcoal	Uranine	1.1
10661	Salt & Pepper 2 Spring (129)	12/10/2009 to 12/17/2009	Charcoal	Phloxine B	12
12146	Salt & Pepper 2 Spring (129)	12/14/2009 to 12/17/2009	Charcoal	Eosin	16
12146	Salt & Pepper 2 Spring (129)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	47
10661	Salt & Pepper 2 Spring (129)	12/10/2009 to 12/17/2009	Charcoal	Eosin	16
12165	Salt & Pepper 2 Spring (129)	12/17/2009 to 12/20/2009	Charcoal	Eosin	3.1
12165	Salt & Pepper 2 Spring (129)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	3.9
12279	Salt & Pepper 2 Spring (129)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	16
12279	Salt & Pepper 2 Spring (129)	12/20/2009 to 1/4/2010	Charcoal	Eosin	20
11583	Salt & Pepper 2 Spring (129)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	6.2
11583	Salt & Pepper 2 Spring (129)	1/11/2010 to 1/14/2010	Charcoal	Eosin	8.2
12775	Salt & Pepper 2 Spring (129)	1/26/2010 to 1/28/2010	Charcoal	Eosin	12
12775	Salt & Pepper 2 Spring (129)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	3
11280	Salt & Pepper 2 Spring (129)	1/28/2010 to 2/2/2010	Charcoal	Eosin	5.5
11280	Salt & Pepper 2 Spring (129)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	2.6
11295	Salt & Pepper 2 Spring (129)	2/2/2010 to 2/4/2010	Charcoal	Eosin	4.1
11295	Salt & Pepper 2 Spring (129)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	2.1
12807	Sink Spring (104)	4/8/2010	Charcoal	Phloxine B	0.7
13165	Sink Spring (104)	5/6/2010	Charcoal	Phloxine B	1.3
13221	Sink Spring (104)	5/13/2010	Charcoal	Uranine	1.8
13221	Sink Spring (104)	5/13/2010	Charcoal	Uranine	8.5
13236	Sink Spring (104)	5/13/2010	Charcoal	Uranine	1.8
13236	Sink Spring (104)	5/13/2010	Charcoal	Uranine	8.5
13236	Sink Spring (104)	5/13/2010	Charcoal	Phloxine B	1.7
13221	Sink Spring (104)	5/13/2010	Charcoal	Phloxine B	1.7
1465	Weissmuller Spring (31)	1/9/2004 to 1/10/2004	Charcoal	Phloxine B	4.9
2063	Weissmuller Spring (31)	1/10/2004 to 1/11/2004	Charcoal	Phloxine B	33
2059	Weissmuller Spring (31)	1/11/2004 to 1/12/2004	Charcoal	Phloxine B	14
1665	Weissmuller Spring (31)	1/12/2004 to 1/13/2004	Charcoal	Phloxine B	4.2
1464	Weissmuller Spring (31)	1/13/2004 to 1/14/2004	Charcoal	Phloxine B	19
1278	Weissmuller Spring (31)	1/14/2004 to 1/17/2004	Charcoal	Phloxine B	35
1301	Weissmuller Spring (31)	1/17/2004 to 1/21/2004	Charcoal	Phloxine B	36
1397	Weissmuller Spring (31)	1/21/2004 to 1/25/2004	Charcoal	Phloxine B	44
1696	Weissmuller Spring (31)	1/25/2004 to 1/29/2004	Charcoal	Phloxine B	14

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
5753	Weissmuller Spring (31)	7/6/2005 5:05:00 PM	Water	Eosin	2.8
5754	Weissmuller Spring (31)	7/6/2005 11:05:00 PM	Water	Uranine	1.1
5756	Weissmuller Spring (31)	7/7/2005 11:05:00 AM	Water	Uranine	0.1
5803	Weissmuller Spring (31)	7/8/2005 5:05:00 AM	Water	Uranine	0.1
5811	Weissmuller Spring (31)	7/9/2005 11:05:00 AM	Water	Uranine	0.2
5818	Weissmuller Spring (31)	7/11/2005 5:05:00 AM	Water	Eosin	0.4
5879	Weissmuller Spring (31)	7/12/2005 2:57:00 AM	Water	Uranine	0.02
5883	Weissmuller Spring (31)	7/13/2005 2:57:00 AM	Water	Uranine	0.2
5885	Weissmuller Spring (31)	7/13/2005 2:57:00 PM	Water	Uranine	0.1
3151	Weissmuller Spring (31)	9/14/2005 to 9/21/2005	Charcoal	Eosin	5.1
3317	Weissmuller Spring (31)	9/21/2005 to 10/4/2005	Charcoal	Eosin	2.9
3384	Weissmuller Spring (31)	10/27/2005 to 11/4/2005	Charcoal	Eosin	8.6
6918	Weissmuller Spring (31)	4/17/2008 10:15:00 AM to 5/8/2008	Charcoal	Phloxine B	81
7049	Weissmuller Spring (31)	6/3/2008 11:00:00 AM to 6/18/2008	Charcoal	Phloxine B	6.9
7135	Weissmuller Spring (31)	6/18/2008 11:10:00 AM to 7/2/2008	Charcoal	Phloxine B	5.3
7183	Weissmuller Spring (31)	7/2/2008 11:00:00 AM to 7/16/2008	Charcoal	Phloxine B	7.7
7220	Weissmuller Spring (31)	7/16/2008 11:00:00 AM to 8/4/2008	Charcoal	Eosin	8
7221	Weissmuller Spring (31)	7/16/2008 11:02:00 AM to 8/4/2008	Charcoal	Phloxine B	5.8
7221	Weissmuller Spring (31)	7/16/2008 11:02:00 AM to 8/4/2008	Charcoal	Eosin	9.2
7220	Weissmuller Spring (31)	7/16/2008 11:00:00 AM to 8/4/2008	Charcoal	Phloxine B	9.5
7376	Weissmuller Spring (31)	8/4/2008 11:15:00 AM to 8/22/2008	Charcoal	Eosin	2.1
7377	Weissmuller Spring (31)	8/4/2008 11:20:00 AM to 8/22/2008	Charcoal	Phloxine B	2.2
7376	Weissmuller Spring (31)	8/4/2008 11:15:00 AM to 8/22/2008	Charcoal	Phloxine B	1.7
7377	Weissmuller Spring (31)	8/4/2008 11:20:00 AM to 8/22/2008	Charcoal	Eosin	1.4
7366	Weissmuller Spring (31)	8/22/2008 11:50:00 AM to 9/8/2008	Charcoal	Phloxine B	2.4
7366	Weissmuller Spring (31)	8/22/2008 11:50:00 AM to 9/8/2008	Charcoal	Eosin	3.4
7427	Weissmuller Spring (31)	9/8/2008 11:50:00 AM to 10/14/2008	Charcoal	Eosin	7.1
7428	Weissmuller Spring (31)	9/8/2008 11:55:00 AM to 10/14/2008	Charcoal	Phloxine B	5.8
7427	Weissmuller Spring (31)	9/8/2008 11:50:00 AM to 10/14/2008	Charcoal	Phloxine B	6.2
7428	Weissmuller Spring (31)	9/8/2008 11:55:00 AM to 10/14/2008	Charcoal	Eosin	7.2
7463	Weissmuller Spring (31)	10/14/2008 3:02:00 PM to 10/27/2008	Charcoal	Phloxine B	3.5
7462	Weissmuller Spring (31)	10/14/2008 3:01:00 PM to 10/27/2008	Charcoal	Phloxine B	6
7463	Weissmuller Spring (31)	10/14/2008 3:02:00 PM to 10/27/2008	Charcoal	Eosin	3.6
7462	Weissmuller Spring (31)	10/14/2008 3:01:00 PM to 10/27/2008	Charcoal	Eosin	5.3
7499	Weissmuller Spring (31)	10/27/2008 2:40:00 PM to 11/14/2008	Charcoal	Eosin	2.2
7500	Weissmuller Spring (31)	10/27/2008 2:41:00 PM to 11/14/2008	Charcoal	Eosin	2.3
7499	Weissmuller Spring (31)	10/27/2008 2:40:00 PM to 11/14/2008	Charcoal	Phloxine B	3.5
7500	Weissmuller Spring (31)	10/27/2008 2:41:00 PM to 11/14/2008	Charcoal	Phloxine B	2.7
7599	Weissmuller Spring (31)	11/14/2008 11:55:00 AM to 12/17/2008	Charcoal	Phloxine B	10

Number	Site	Sample Date	Sample Type	Dye	Concentration (µg/L)
8242	Weissmuller Spring (31)	12/17/2008 2:28:00 PM to 1/29/2009	Charcoal	Phloxine B	6.5
8241	Weissmuller Spring (31)	12/17/2008 2:28:00 PM to 1/29/2009	Charcoal	Phloxine B	5
9154	Weissmuller Spring (31)	1/29/2009 to 2/24/2009	Charcoal	Phloxine B	4.3
9341	Weissmuller Spring (31)	2/24/2009 to 3/7/2009	Charcoal	Phloxine B	2.9
6808	Weissmuller Spring (31)	4/15/2009 to 5/15/2009	Charcoal	Phloxine B	2.2
6808	Weissmuller Spring (31)	4/15/2009 to 5/15/2009	Charcoal	Eosin	1.7
6785	Weissmuller Spring (31)	3/7/2009 to 6/5/2009	Charcoal	Eosin	129
6785	Weissmuller Spring (31)	3/7/2009 to 6/5/2009	Charcoal	Phloxine B	28
6738	Weissmuller Spring (31)	9/17/2009	Charcoal	Eosin	64
10440	Weissmuller Spring (31)	11/23/2009 to 12/2/2009	Charcoal	Eosin	14
10667	Weissmuller Spring (31)	12/10/2009 to 12/14/2009	Charcoal	Eosin	3.5
10584	Weissmuller Spring (31)	12/15/2009 5:45:00 AM	Water	Uranine	0.3
10562	Weissmuller Spring (31)	12/15/2009 5:45:00 AM	Water	Uranine	0.5
12153	Weissmuller Spring (31)	12/14/2009 to 12/17/2009	Charcoal	Phloxine B	90
12153	Weissmuller Spring (31)	12/14/2009 to 12/17/2009	Charcoal	Eosin	32
12168	Weissmuller Spring (31)	12/17/2009 to 12/20/2009	Charcoal	Eosin	30
12168	Weissmuller Spring (31)	12/17/2009 to 12/20/2009	Charcoal	Phloxine B	35
12281	Weissmuller Spring (31)	12/20/2009 to 1/4/2010	Charcoal	Phloxine B	15
12281	Weissmuller Spring (31)	12/20/2009 to 1/4/2010	Charcoal	Eosin	59
11585	Weissmuller Spring (31)	1/11/2010 to 1/14/2010	Charcoal	Eosin	24
11585	Weissmuller Spring (31)	1/11/2010 to 1/14/2010	Charcoal	Phloxine B	15
12777	Weissmuller Spring (31)	1/26/2010 to 1/28/2010	Charcoal	Eosin	22
12777	Weissmuller Spring (31)	1/26/2010 to 1/28/2010	Charcoal	Phloxine B	8.2
11282	Weissmuller Spring (31)	1/28/2010 to 2/2/2010	Charcoal	Eosin	22
11282	Weissmuller Spring (31)	1/28/2010 to 2/2/2010	Charcoal	Phloxine B	5.6
11297	Weissmuller Spring (31)	2/2/2010 to 2/4/2010	Charcoal	Eosin	17
11297	Weissmuller Spring (31)	2/2/2010 to 2/4/2010	Charcoal	Phloxine B	4.7