Final Report for the

Onion Creek Recharge Project
Northern Hays County, Texas

Barton Springs
Edwards Aquifer
CONSERVATION DISTRICT

August 2011

Cover photo: Onion Creek and Antioch BMP after upgrade showing main vault, 36-inch diameter, 12-ft intake pipe for flow measurements, and 36-inch diameter, 32-ft long intake screen. Photo by Brian B. Hunt.

Prepared by the
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Onion Creek Recharge Project
Northern Hays County, Texas

Abstract

The presence of nonpoint source pollution in stormwater flowing in Onion Creek can have a direct impact on water quality in the Barton Springs segment of the Edwards Aquifer in Hays County, Texas. To address this concern, the Barton Springs/Edwards Aquifer Conservation District constructed a concrete vault over the entrance to Antioch Cave in the bed of Onion Creek in 1997. This structure was designed to prevent entry into the cave of contaminated stormwater by closure of a valve on the vault during storm events. The goals of the current project were to improve the efficiency of the system at Antioch by automating the operation of the valve and to install two water-quality monitoring systems on Onion Creek, one at Antioch and the other near the upstream end of the recharge zone. Results of water-quality sampling at Antioch indicate that the system is capable of significant reduction of nonpoint source pollution entering the aquifer through Antioch Cave. During the course of this project, approximately 2,436 lbs of nitrogen from nitrate/nitrite, 295 lbs of total phosphorus, and 190,480 lbs of sediment were prevented from entering Antioch Cave. To monitor the potential movement of nonpoint source pollution in the aquifer, a multiport monitor well was installed near Antioch Cave. With this well, groundwater samples can be collected from multiple vertical zones within the Edwards and Trinity Aquifers. Initial results from this well indicate that there is little, if any, hydraulic connection between the Edwards and Trinity Aquifers. Future studies will determine the degree of hydraulic connection between Antioch Cave and the Edwards zones in the multiport monitor well.

1.0 INTRODUCTION

The Onion Creek Recharge Project was conducted by the Barton Springs/Edwards Aquifer Conservation District (District) to improve the quality of water recharging the Barton Springs segment of the Edwards Aquifer (herein called Barton Springs aquifer) through Antioch Cave. This cave is situated within the bed of Onion Creek about 1.3 miles west-southwest of the center of Buda, Texas (Figure 1-1) and is capable of recharging large amounts of water to the aquifer when it is not filled with sediment and other debris. The most common contaminants in Onion Creek are sediments, bacteria, nutrients, and other nonpoint source pollutants that are brought into Onion Creek during storm events. Because the Barton Springs aquifer provides drinking water to about 60,000 people plus industrial, commercial, and irrigation users, and is the source of water at Barton Springs where endangered species live, the quality of water recharging the aquifer is very important.

In 1997, a Best Management Practices (BMP) structure was constructed over Antioch Cave by the District with funding provided by a Clean Water Act Section 319(h) grant from the U.S.

Environmental Protection Agency (EPA). The grant was administered by the Texas Natural Resources Conservation Commission (TNRCC). These 319(h) grants are awarded to address environmental issues associated with nonpoint source pollution. The purpose of the BMP at Antioch was to control the flow of water into the cave and to prevent clogging of the cave with sediment and storm debris. Opening and closing a valve on the BMP controls the flow of water from Onion Creek into Antioch Cave. During and following storm events, the valve is manually closed to prevent entry of stormwater and associated contaminants into the cave and subsequently into the Edwards Aquifer. When better quality water is flowing in Onion Creek, the valve is opened to allow recharge to occur. The system at Antioch Cave has been permitted by the Texas Commission on Environmental Quality (TCEQ) as a Class V injection well.

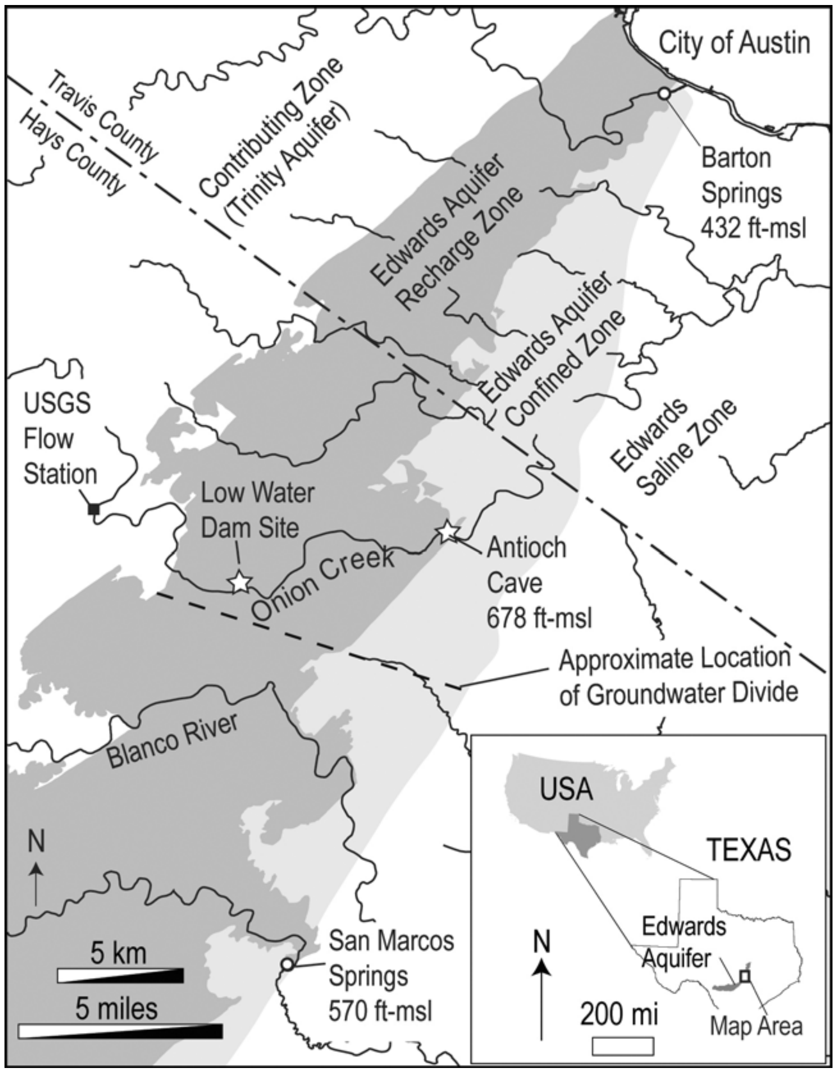


Figure 1-1. Location map of the study area and a portion of the Edwards Aquifer.

In 2006, the District was awarded another 319(h) grant by EPA and TCEQ. The goal of this grant was to provide real-time monitoring of water quality and quantity at Antioch with a Continuous Water Quality Monitoring Network (CWQMN) system, to improve the intake system on the BMP, and to automate the opening and closing of the valve. As completed in

1997, the valve was operated manually by District staff and the grate over the valve was prone to clogging with storm debris. An automated system for opening and closing the valve based on water quality was deemed to be more efficient and protective of the aquifer than a manual system. The automated system was designed to close the valve when the turbidity of water in Onion Creek rises to 100 NTUs. This would prevent entry of contaminated stormwater from entering Antioch Cave. As the storm pulse passes and the turbidity drops below 50 NTUs, the valve opens automatically. An intake screen with a large surface area allows for maximum recharge without being clogged with storm debris.

An additional goal of the project was to provide a second location for real-time monitoring of water quality on Onion Creek. A site was selected about 5 miles upstream of Antioch Cave on City of Austin (COA) Water Quality Protection Lands.

The key accomplishments of this project were:

- Installation of CWQMN at Antioch Cave including
  - Water-quality sonde with temperature (T), dissolved oxygen (DO), gage height, and conductivity meters
  - In-line flow meter for second valve
  - Telemetry of data to TCEQ
- Installation of second valve on Antioch BMP with intake screen
- Automation of Antioch BMP
- Measurement and/or sampling of water in Onion Creek for six storm events
- Reduction of contaminants entering the aquifer during five storm events: 2,436 lbs of nitrogen from nitrate/nitrite, 295 lbs of total phosphorus, and 190,480 lbs of sediment prevented from entering Antioch Cave
- Installation of a multiport monitor well near the Antioch BMP
- Installation of an upstream CWQMN at the Low Water Dam (COA property) including:
  - Water-quality sonde with T, DO, gage height, and conductivity meters
  - Telemetry of data to TCEQ

1.1 BACKGROUND

Onion Creek is a major contributor of recharge water to the Barton Springs aquifer of Central Texas. Because thousands of people depend on this aquifer for their sole source of drinking water, and because the endangered salamanders at Barton Springs need a sufficient quantity of flow of high quality water, the quality of water recharging the aquifer from surface streams is very important. Numerous studies have shown the relationship between these surface streams and the flow of groundwater through the aquifer to water-supply wells and the springs (Slade et al., 1986; Hauwert et al., 2004).

1.1.1 Purpose and Scope of Project

The TCEQ lists the Barton Springs aquifer as an impaired groundwater resource (TNRCC, 1999). Onion Creek is listed on the TCEQ 303(d) list of impaired streams. Increases in sediment, bacteria, and other contaminants in groundwater as a result of storm-flow events in the

Barton Springs aquifer have been documented by analysis of water samples from monitor and water-supply wells and Barton Springs (Fieseler, 1998; Mahler et al., 2006a; Mahler et al., 2011). The purpose of the project was to increase recharge to the Barton Springs aquifer while minimizing the amount of contaminants entering the aquifer during storm events.

To reduce the amount of sediment and other storm-related contaminants entering one of these recharge features, an automated control system was designed and installed at the BMP that was previously constructed over Antioch Cave on Onion Creek (Figures 1-2 and 1-3). Two valves on the BMP control flow into the cave.

Figure 1-2. Photograph ca. 1996 showing recharge and the entrance to Antioch Cave before the BMP was constructed. The debris over the entrance and also sedimentation within the cave decrease the amount of recharge entering the cave. (Photograph from Fieseler, 1998).

Figure 1-3. Photograph ca. 1997 showing the near-finished BMP vault over Antioch Cave; circular openings are 36 inches in diameter. (Photograph from Fieseler, 1998).

The original scope of this project included the installation of a second BMP over a cave or sinkhole elsewhere on Onion Creek or its tributaries. An evaluation of recharge features indicated that the best features were caves situated in the bed of Onion Creek on COA Water Quality Protection Lands. However, these caves do not have the recharge capacity of Antioch Cave, so the efficacy of completing this part of the project was in question. When COA staff indicated that they wouldn't be able to grant access to one of the caves within the timeframe needed for this project, the second BMP was dropped from the scope. In its place, it was agreed by TCEQ, EPA, and the District that detailed monitoring of the aquifer in the vicinity of Antioch Cave to assess both vertical and horizontal recharging flows would be a worthy scope amendment. Such monitoring was accomplished with installation of a multiport monitor well about 0.3 mi east of Antioch Cave.

1.1.2 <u>Previous Work: 1993-1998 Onion Creek Recharge Project</u>

When District staff became aware of the existence of Antioch Cave, they quickly realized the significance of the cave for recharge to the Edwards Aquifer. Figure 1-2 is a photograph of the entrance to Antioch Cave prior to construction of the BMP. In 1992, the District began discussions with TNRCC about using federal 319(h) funds for conducting studies on Onion Creek and constructing a BMP at Antioch to improve the quality and increase the quantity of water entering the cave. A contract for the project was signed with a starting date of September 30, 1993. Construction began on the BMP in August 1997 and was operationally complete by December 1997. A final report on the project was issued in December 1998 (Fieseler 1998). The BMP that was constructed was a steel-reinforced concrete vault. The BMP was situated directly over the cave entrance and is approximately 7 ft high, 8 ft wide and 12 ft long. Figure 1-3 is a photograph of the completed BMP. Figure 1-4 is an aerial photograph of the study site showing the location of the upgraded BMP in the bed of Onion Creek. Figure 1-5 is a schematic cross section of Onion Creek showing the BMP and a portion of Antioch Cave. The BMP has two steel manhole accesses on top and two 36-inch diameter spools to hold 36-inch pneumatically-operated butterfly valves. Only one valve was installed during the original project and the other spool was sealed with a steel plate. Air hoses connected the valve to a 1-ft by 1-ft by 2-ft concrete box on the north bank of Onion Creek. From this box the valve could be opened using either an air compressor or a tank with compressed air. A 4-inch diameter PVC pipe was the conductor pipe for air hoses from the valve in the BMP to the concrete box. In addition, a 6-inch PVC pipe connected the BMP to the concrete box to allow air from the cave to vent to the surface when water is flowing into the cave entrance. Such venting prevents undue pressure build-up in the BMP and allows more water to recharge the aquifer.

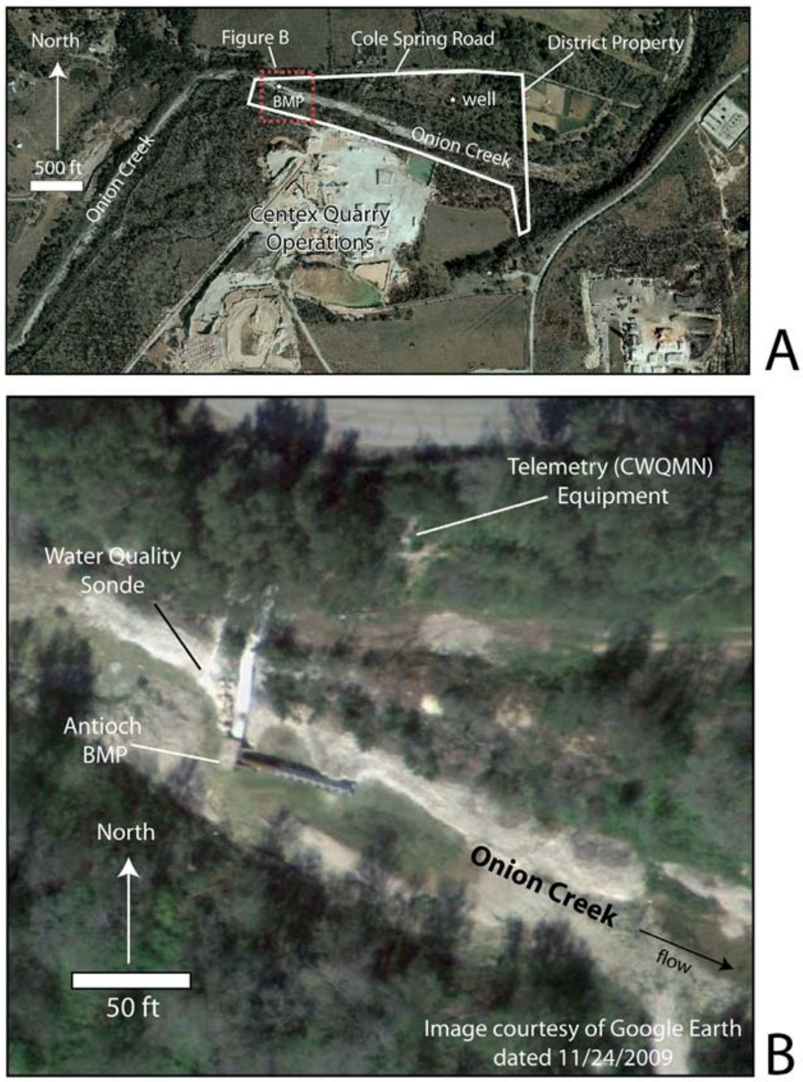


Figure 1-4. A) Aerial photograph showing major features near Antioch Cave including Onion Creek. B) Close-up of aerial photograph showing the BMP after the upgrade.

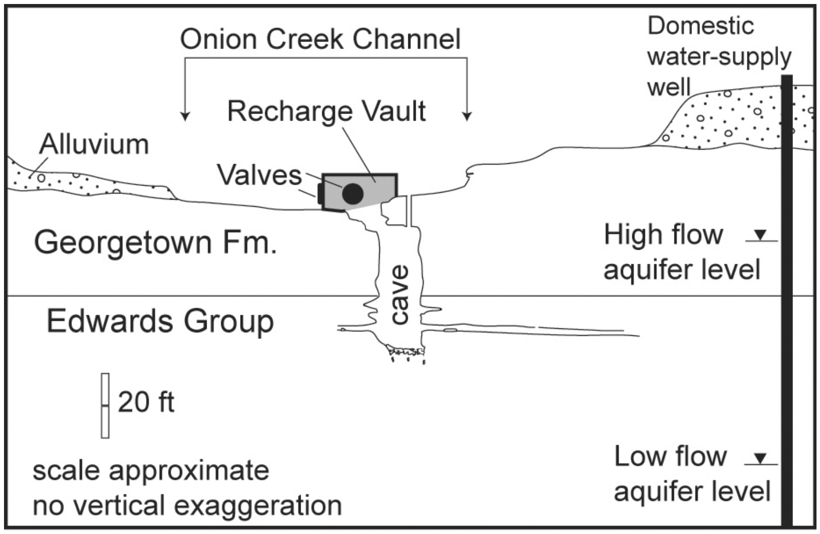


Figure 1-5. Schematic cross section across Onion Creek and Antioch BMP looking upstream.

The following text from the December 1998 final report (Fieseler, 1998) describes the procedures and protocol for opening and closing the valve:

> The 36" butterfly valve remains closed during non-flow conditions. Any spring flow, seepage or low flow recharges via the 4" weep hole. When flooding occurs or whenever the creek is in a flow condition, the valve will remain closed during "first flush" conditions. This first flush condition contains heavy sediment loads, high bacteria counts, and large quantities of trash, debris, and organic material. Once conditions have improved, based on visual observations and turbidity measurements by District personnel, the air compressor will be turned on and the valve opened to allow recharge to occur. The valve will remain open as long as the water level in Onion Creek is approximately one foot deep or greater. Should subsequent flood events and/or first flush pulses occur which increases the turbidity, sediment load, or trash and debris content, or if some hazardous condition presents itself, the valve will be closed until conditions warrant re-opening the valve to continue recharge.

As this description indicates, management of the BMP is labor intensive and is dependent on District staff being available at key times when conditions are changing in Onion Creek. Recommendations were made in the 1998 report for adding a second valve to the BMP and for automating the system. An opportunity for doing this additional work arrived in 2006 when 319(h) funds became available.

1.1.3 <u>Hydrogeologic Setting</u>

The Edwards Aquifer of Texas is a karst aquifer developed in faulted and fractured Cretaceous-age limestones and dolomites. Ford (2004) defines karst as terrain with distinctive hydrology arising from the combination of high rock solubility and well-developed solution channel porosity underground. Karst terrains and aquifers are characterized by sinking streams, sinkholes, caves, springs, and an integrated system of pipe-like conduits that rapidly transport groundwater from recharge features to springs (White, 1988; Todd and Mays, 2005).

The Edwards Aquifer system lies within the Miocene-age Balcones Fault Zone (BFZ) of south-central Texas and consists of an area of about 4,200 mi^2 (Figure 1-1 inset). The aquifer extends about 270 miles from the Rio Grande River along the Mexico/United States border at Del Rio, east to San Antonio, then northeast through Austin to Salado. Groundwater from the Edwards Aquifer is the primary source of water for about 2 million people plus numerous industrial, commercial, and irrigation users. Hydrologic divides separate the Edwards Aquifer into three segments. North of the Colorado River is the Northern segment of the Edwards Aquifer, and south of the southern hydrologic divide near the City of Kyle is the San Antonio segment (Figure 1-1). The Barton Springs segment is situated between the Northern and San Antonio segments. Ryder (1996) and Lindgren et al. (2004) provide detailed and regional information on the overall Edwards Aquifer.

Development of the Edwards Aquifer was influenced significantly by fracturing and faulting associated with the Miocene-age BFZ and dissolution of limestone and dolomite units by infiltrating meteoric water (Sharp, 1990; Barker et al., 1994; Hovorka et al., 1995). In addition, development of the aquifer is also thought to have been influenced by deep dissolution processes along the saline-fresh water interface, what is known as hypogenic speleogenesis (Klimchouk, 2007).

EPA identifies karst aquifers as one of the water supplies most vulnerable to pollution because of rapid groundwater velocities and limited ability to filter contaminants (Schindel et al., 1996). Numerous tracer tests have been performed on portions of the Edwards Aquifer demonstrating that rapid groundwater flow occurs in an integrated network of conduits discharging at wells and springs (Hauwert et al., 2004; BSEACD, 2003). During higher flow conditions, a portion of this groundwater flows from the conduits into the diffuse matrix of the aquifer building up storage in the aquifer. Water from storage flows diffusely to wells or back into the conduit network during lower flow conditions (Mahler et al., 2006b). This dual flow system results in contamination having the potential to rapidly impact wells and springs, as well as slowly accumulate and move within the matrix of the aquifer.

1.1.3.1 Barton Springs Aquifer

The Barton Springs aquifer is the focus of this project. Approximately 60,000 people depend on water from the Barton Springs aquifer as their primary or sole source of drinking water. Groundwater use is characterized as 80% public-supply, 13% industrial (quarry operations), and 7% irrigation (golf courses and athletic fields). The various spring outlets at Barton Springs are the only known habitat for the endangered Barton Springs salamander (*Eurycea sosorum*). To protect existing users of the aquifer and the endangered salamanders, pumping from the Barton Springs aquifer has been capped at 11,600 acre-ft/yr (3.77 billion gallons/yr) under non-drought conditions. During periods of drought, permitted users are required to make significant reductions in groundwater use.

The Barton Springs aquifer is 155 mi^2 in area, with about 80% of the area consisting of unconfined aquifer conditions, although the percentage fluctuates according to hydrologic conditions. The primary discharge point is Barton Springs, located in Barton Creek about ¼ mi upstream of its confluence with the Colorado River (Figure 1-1). The Barton Springs aquifer is bounded to the north by the Colorado River and by the outcrop and saturated thickness of the Edwards Group to the west. The eastern boundary of the aquifer is the interface between fresh and brackish water (>1,000 mg/L total dissolved solids) and is a complex three-dimensional boundary commonly known as the "saline" or "bad-water" interface. The saline zone of the Edwards Aquifer is characterized by a decrease in relative transmissivity (Flores, 1990). Hovorka et al. (1998) describe this boundary as hydrodynamically controlled rather than separated by a distinct hydrologic barrier, although local fault control was noted. The southern hydrologic divide between the Barton Springs aquifer and the San Antonio segment of the Edwards Aquifer is located approximately between Onion Creek and the Blanco River near the City of Kyle. This divide may fluctuate according to hydrologic conditions, as supported by potentiometric-surface elevations and recent tracer testing results (LBG-Guyton Associates, 1994; Hunt et al., 2005; Land et al., 2010; Johnson et al., in preparation).

Mapping of the Barton Springs aquifer has delineated geologic faults and several informal stratigraphic members of the Kainer and Person Formations of the Edwards Group (Rose, 1972), each having distinctive hydrogeologic characteristics (Small et al., 1996). In the District, faults trend predominantly NE-SW and are downthrown to the southeast, with total offset of about 1,100 ft across the study area. As a result of faulting and erosion, the aquifer ranges from about 450 ft at its thickest along the east side, to 0 ft along the west side of the recharge zone (Slade et al., 1986). Dissolution along fractures, faults, and bedding-plane partings and within certain lithologic units has created numerous sinkholes, sinking streams, conduits, caves, and springs.

1.1.3.2 Recharge

The majority of recharge to the aquifer is derived from streams originating on the contributing zone, located up gradient and primarily west of the recharge zone. Water flowing onto the recharge zone sinks into numerous caves, sinkholes, and fractures along its six major (ephemeral to intermittent) losing streams. Slade et al. (1986) estimated that as much as 85% of recharge to the aquifer is from water flowing in these streams. The remaining recharge (15%) occurs as infiltration through soils or direct flow into recharge features in the upland areas of the recharge zone (Slade et al., 1986). However, current studies indicate that upland recharge may constitute a larger fraction of recharge (Hauwert, 2006). Mean surface recharge should approximately equal mean discharge, or about 53 cfs; however, maximum recharge rates during flooding may approach 400 cfs (Slade et al., 1986). Studies have shown that recharge is highly variable in space and time and focused within discrete features (Smith et al., 2001). For example, Onion Creek is the largest contributor of recharge to the Barton Springs aquifer (34% of total creek recharge) with maximum recharge rates up to 160 cfs (Slade et al., 1986). Antioch Cave is located within Onion Creek and is the largest-capacity discrete recharge feature known in the Barton Springs aquifer with an average recharge of 46 cfs and a maximum of 95 cfs during a 100-day study (Fieseler, 1998). Figures 1-6A and 6B are cross-sectional views of the Antioch vicinity from a 3D geologic model (Hunt et al., 2010) (Appendix A, 3-D Model Summary). Figure 1-6C illustrates the potentiometric mound from the high rates of recharge due to the cave and BMP. Increased recharge due to "urban leakage" from leaking water and wastewater lines, septic tanks, and applied lawn irrigation in the contributing and recharge zones is another potential source of water to the aquifer (Sharp, 2010).

In the Barton Springs aquifer, the amount of cross-formational flow (sub-surface recharge) occurring through adjacent aquifers is unknown, although it is thought to be relatively small on the basis of water-budget analysis for surface recharge and discharge (Slade et al., 1985) and multiport monitor well studies (Smith and Hunt, 2009). Under drought and low water-level conditions there could be an increased potential for cross-formational flow from the saline zone. Recent studies (Johnson et al., in preparation) have documented recharge to the Barton Springs aquifer from the Blanco River, previously thought to only provide recharge to the San Antonio segment. In addition, recent studies (Land et al., 2010) have documented the potential for groundwater flow to bypass San Marcos Springs and flow toward Barton Springs. Current investigations are under way by the District to estimate the potential for cross-formational flow to the aquifer from the Trinity and the saline zone of the Edwards units.

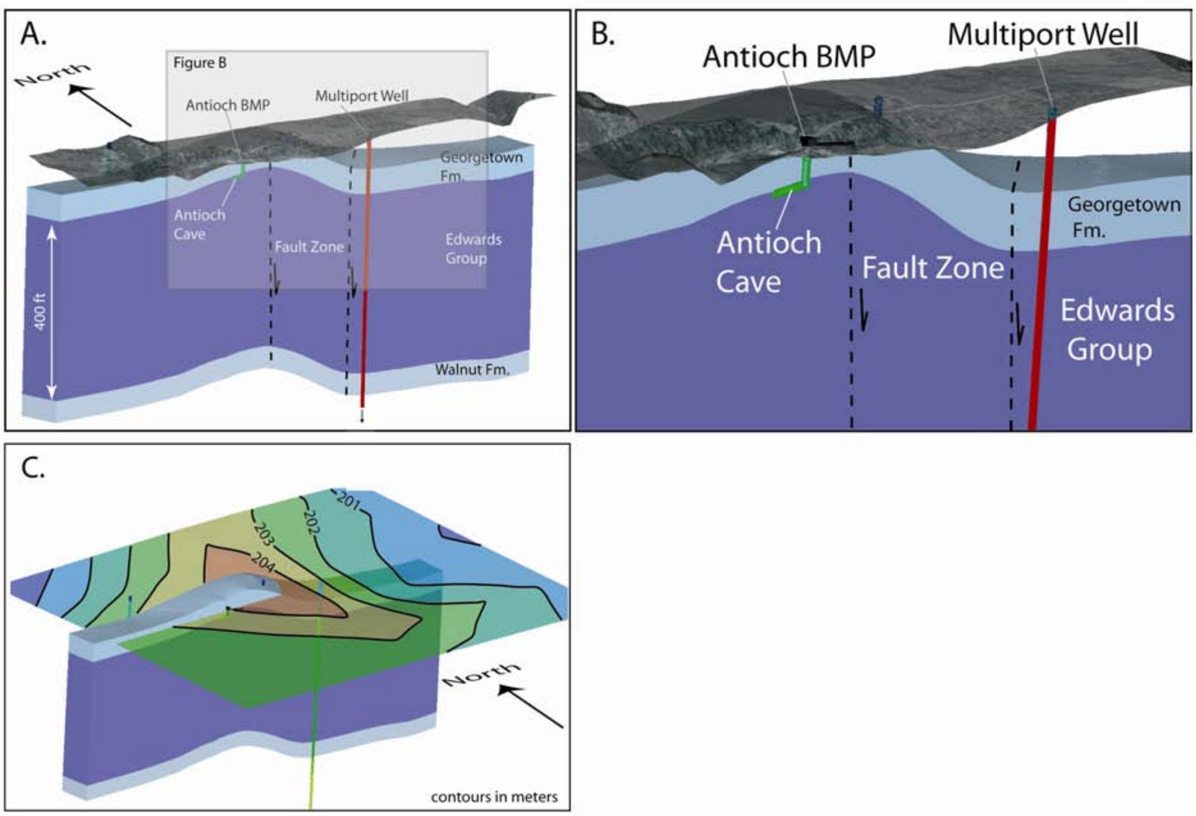


Figure 1-6. A) Oblique cross-sectional view of the Edwards Aquifer in the Antioch vicinity from the 3D geologic model. B) Close-up view illustrating Antioch Cave and the BMP in relation to the fault zone and the Antioch multiport monitor well. C) Oblique cross-sectional view of the Edwards Aquifer with a high-flow potentiometric surface showing groundwater mounding due to high rates of recharge along Onion Creek and Antioch Cave.

1.1.3.3 Groundwater Flow

The Edwards Aquifer is inherently heterogeneous and anisotropic, which strongly influences groundwater flow and storage (Slade et al., 1985; Maclay and Small, 1986; Hovorka et al., 1996 and 1998; Hunt et al., 2005). The Edwards Aquifer can be described as a triple porosity and permeability system consisting of matrix, fracture, and conduit porosity (Hovorka et al., 1995; Halihan and Sharp, 2000; Lindgren et al., 2004) reflecting an interaction between rock properties, structural history, and hydrologic evolution (Lindgren et al., 2004). In the Barton Springs aquifer groundwater generally flows west to east across the recharge zone, converging with preferential groundwater flow paths subparallel to major faulting, and then flowing north toward Barton Springs.

Groundwater dye tracing and other studies demonstrate that a significant component of groundwater flow is discrete, occurring in a well integrated network of conduits, caves, and smaller dissolution features (Hauwert et al., 2002a; Hauwert et al., 2002b). Interpreted flow paths from tracer testing generally coincide with troughs in the potentiometric surface and are parallel to the N40E (dominant) and N45W (secondary) fault and fracture trends presented on geologic maps, indicating the structural influence on groundwater flow. Rates of groundwater flow along preferential flow paths, determined from dye tracing, can be as fast as 4 to 7 mi/day under high-flow conditions or about 1 mi/day under low-flow conditions (Hauwert et al., 2002a).

In one trace, dye injected into Cripple Crawfish Cave on Onion Creek displayed diverging flow paths to Barton and San Marcos Springs (Hunt et al., 2006). This has implications for the groundwater divide separating the Barton Springs and San Antonio segments of the Edwards Aquifer. Traces from Cripple Crawfish Cave and Antioch Cave in Onion Creek have demonstrated divergent flow paths that appear to converge before discharging at Barton Springs. Dye-trace tests were performed three times from Antioch Cave in Onion Creek (Hauwert et al., 2004; Hunt et al., 2005). The first trace was performed under drought conditions (March 2000) and the dye was tentatively detected at a few nearby wells. Subsequent injections under wet, creek-flowing conditions (November 2000 and August 2002) resulted in repeated dye detections in up to 17 water-supply wells, including some public water-supply wells, and at Barton Springs. The paths of flow demonstrated by dye tracing revealed several divergent flow paths that appear to converge before discharging at Barton Springs. Arrival of dye at Barton Springs from Antioch Cave under high-flow (August 2002) conditions was about 7 days travel time with an apparent velocity of about 2 miles per day (Hunt et al., 2005).

1.1.3.4 Water Levels and Storage

Water levels in the Edwards Aquifer are very dynamic and heterogeneous (Figure 1-7). Water levels do not show long-term declines in storage, but generally recover quickly from low levels reached during drought to previous high conditions typical of wet periods (Smith et al., 2001). Water levels and discharge at the springs respond very quickly to recharge events and then decline at variable rates, influenced by both conduit and matrix permeability and storage (Lindgren et al., 2004; Worthington, 2003).

Figure 1-7A shows a potentiometric mound from recharge along Onion Creek and paths of dye injected into Antioch Cave. Figure 1-7B shows the change in water level from high (February 2002) to low flow (August 2006) (Hunt et al., 2007). Even under low-flow conditions, the mound is still present. Note that the greatest flux in water levels appears to extend from Antioch Cave to the north. The presence of a mound beneath Antioch and much of Onion Creek indicates that water recharging along Onion Creek is going into aquifer storage in addition to more direct, conduit flow to Barton Springs. The conduits that have been demonstrated through dye-trace studies to connect with Barton Springs are not of sufficient capacity to carry all of the recharging water directly to Barton Springs. The excess water must be entering storage that consists of a matrix of non-conduit dissolution features and primary porosity.

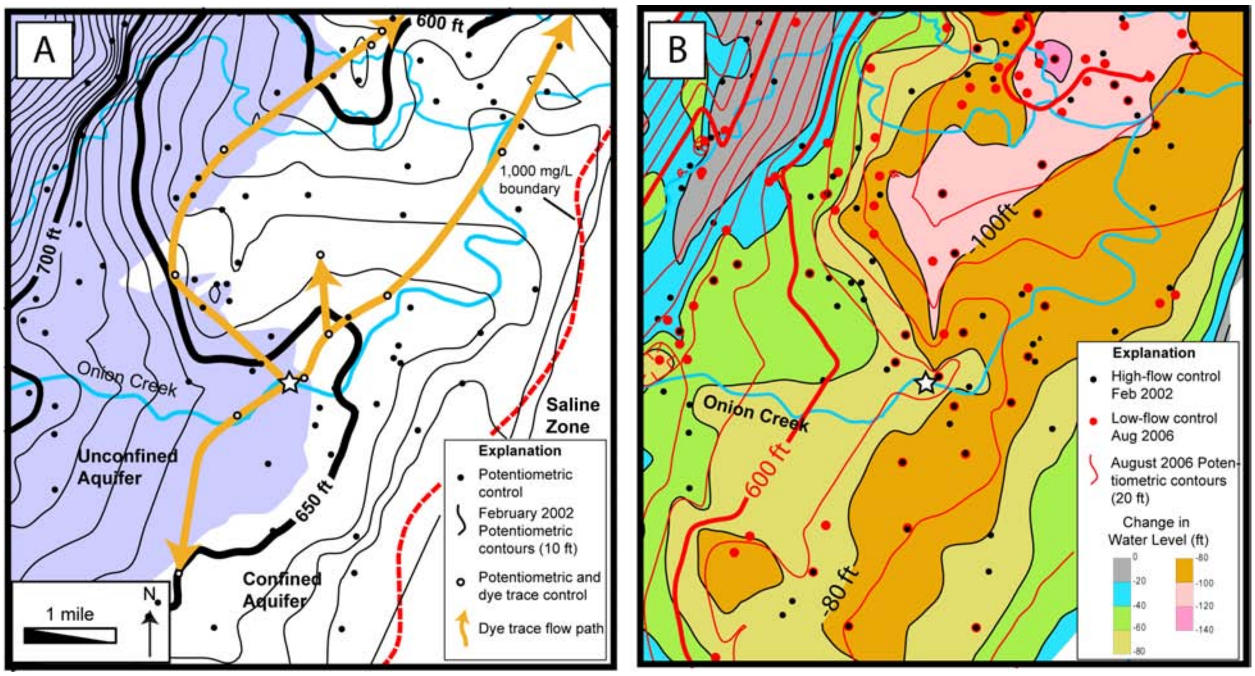


Figure 1-7. A) Regional potentiometric map along Onion Creek during high-flow conditions (February 2002). The 650-ft contour illustrates the mounding effect due to discrete recharge from Antioch Cave. Lines with arrows indicate direction of groundwater flow from dye-trace studies. B) Map of the change in water levels from high (February 2002) to low-flow conditions (August 2006).

1.1.3.5 Geology of the Antioch BMP Vicinity

Antioch Cave is located on District property within the bed of Onion Creek about 1.3 miles west-southwest of the center of Buda, Texas. The cave is located about 800 ft upstream of a significant fault (Mountain City Fault Zone) delineating the eastern extent of the Edwards Aquifer Recharge Zone for this area. Geologic units at the surface include Cretaceous-age limestones (Georgetown and Buda) and claystones (Del Rio and Eagle Ford), that are in places overlain by more recent terrace, alluvium and fill deposits (Figure 1-8). Appendix A discusses the construction and shows the geometry of a 3D volumetric model constructed for the area in the immediate vicinity of the Antioch BMP.

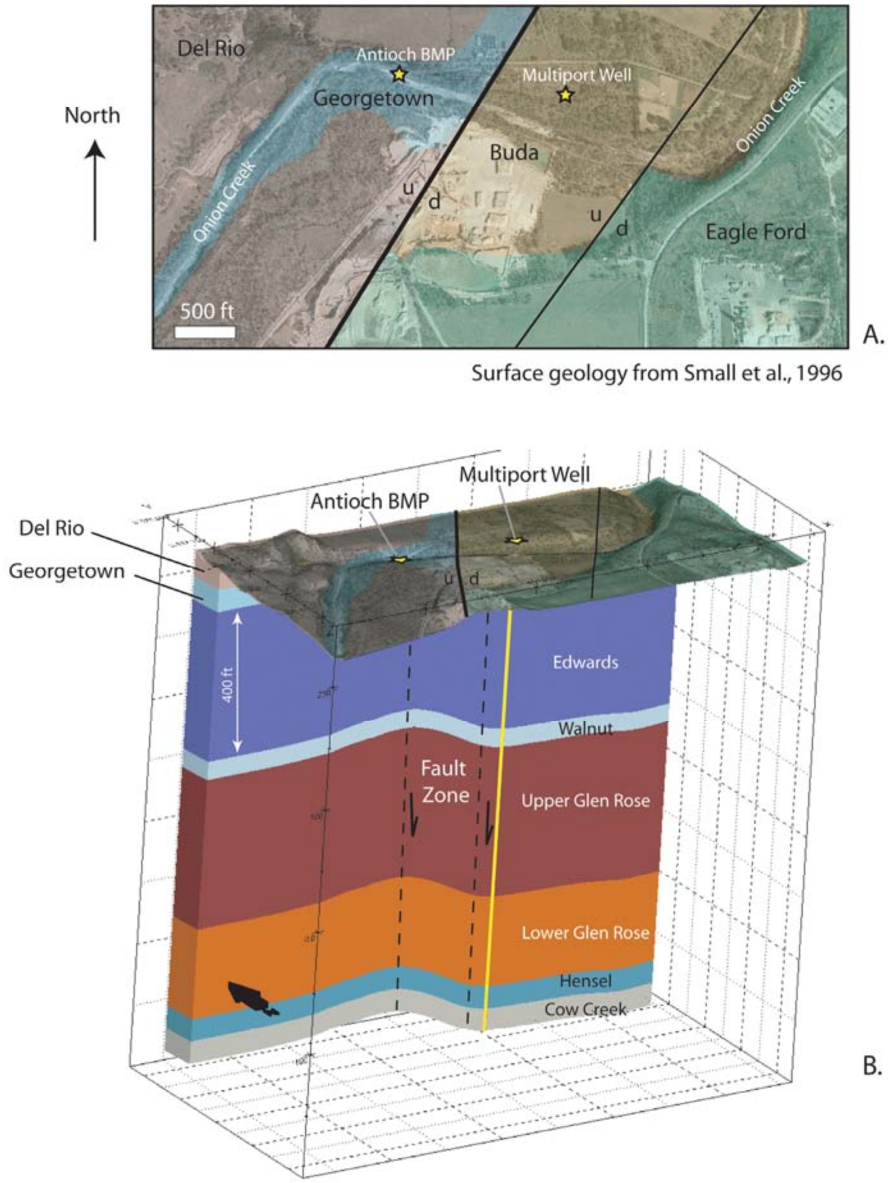


Figure 1-8. A) Surface geologic map and transparent aerial photograph of the Antioch BMP vicinity. B) Oblique view of the 3D geologic model of the Antioch BMP vicinity showing the underlying geologic units and structures.

The entrance and uppermost 20 ft of the cave is formed along a solution-enlarged fracture within the highest stratigraphic unit of the Edwards Aquifer, the Georgetown Formation. The cave continues downward into the Edwards Group to a depth of about 40 ft below the entrance. The cave passage then extends laterally along a bedding plane about 50 ft to the north then about 75 ft to the northwest where it splits into two passages, one continuing northwest for about 150 ft and the other trending west about 175 ft (Figure 1-9). All passages become too tight for a person to continue exploring. The Mountain City Fault Zone, trending NE-SW with about 100 ft of vertical throw, is mapped on the property. The fault zone creates unconfined aquifer conditions on the upthrown side of the fault where the BMP is located, and confined aquifer conditions on the downthrown side where the Antioch multiport well is located (Figure 1-8).

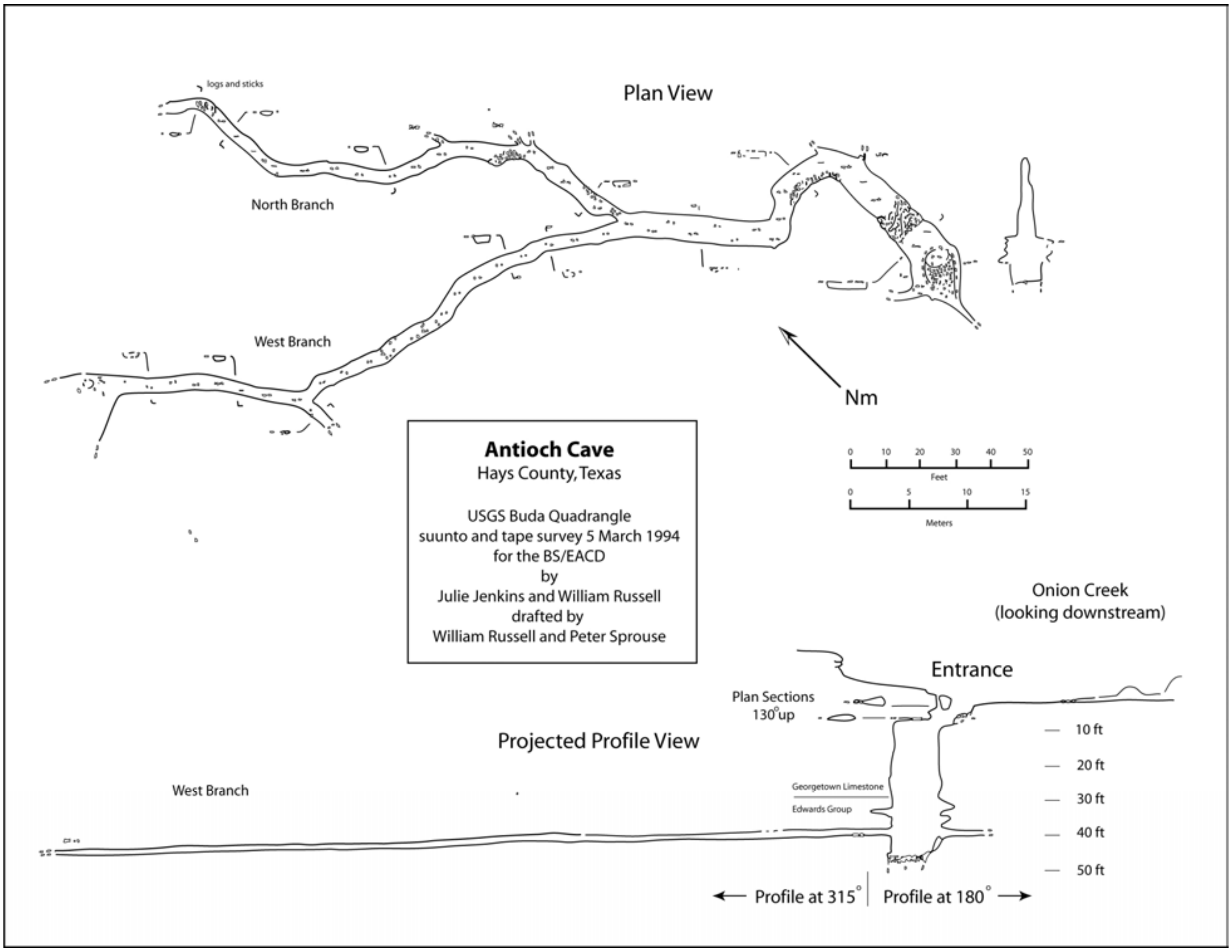


Figure 1-9. Map of Antioch Cave showing plan and profile views.

1.1.3.6 Stormwater Contaminants in Onion Creek

Studies by the USGS (website data) indicate that high levels of bacteria and lead are associated with storm events in Onion Creek. The USGS collected water samples at their Onion Creek Driftwood station during multiple storm events between February 1994 and March 1998. Analyses were conducted for major cations and anions plus selected constituents commonly found in stormwater. Figure 1-10 shows flow in Onion Creek plotted against turbidity plus bacteria counts for three storm events sampled during this time.

A more recent study by the USGS (Mahler et al., 2011) finds that nitrate levels in Barton Springs and the five major streams that cross the recharge zone are significantly higher than samples collected between the early 1990s and November 2008. Samples were collected from these streams and Barton Springs during November 2008 and March 2010. Another conclusion of the study is that the probable source of nitrate in the recharging streams is biogenic (human and animal) sources.

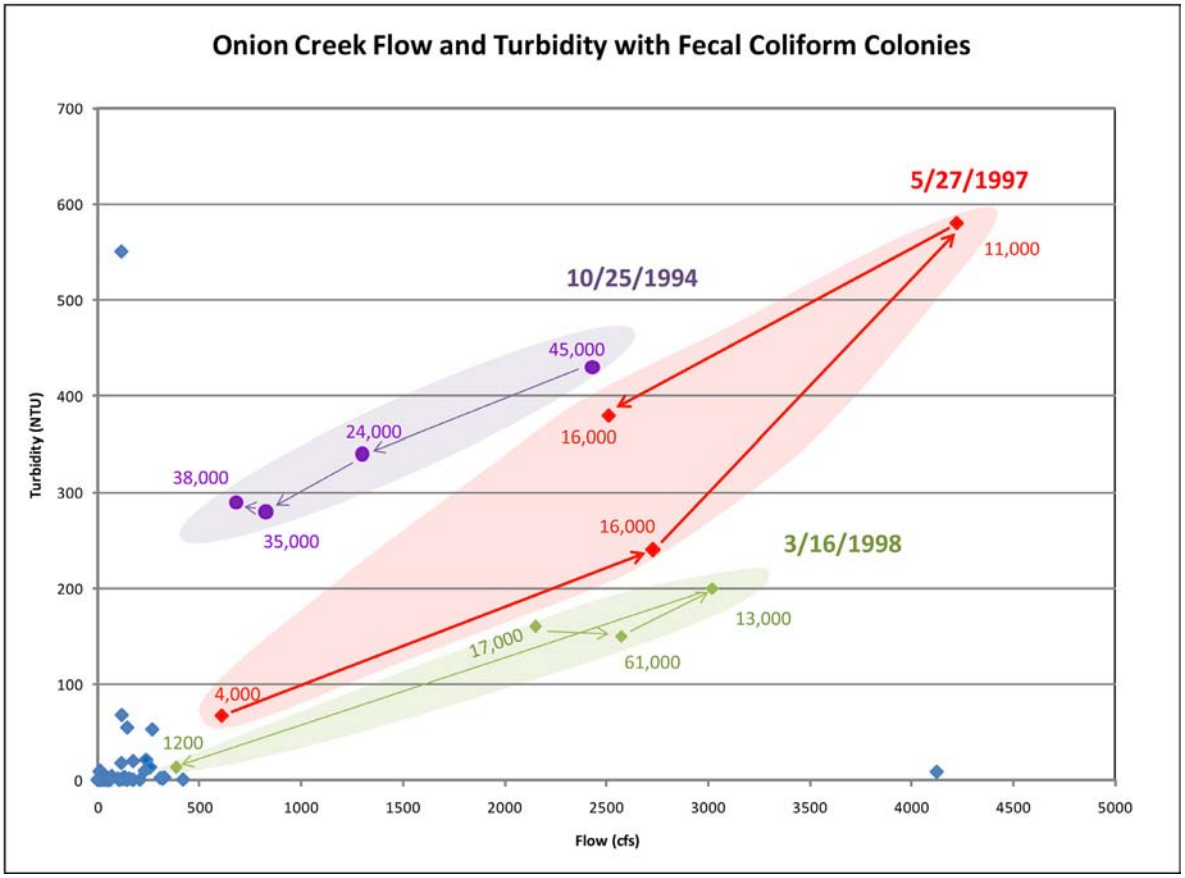


Figure 1-10. Flow in Onion Creek at the USGS Driftwood station showing turbidity plotted against flow plus bacteria (number of fecal coliform colonies) for three storm events. Shaded areas correspond to a particular storm event. Arrows represent the time sequence of sample collection within a storm event. Data from the USGS.

Mahler and Lynch (1999) collected samples of water discharging from Barton Springs to determine the quantity, chemistry, and grain sizes of sediment discharging from the spring following two storm events in November 1995 and May 1996. They calculated that 1,775 lbs and 2,233 lbs of sediment discharged from the spring during the two storm events, respectively. An analysis of the sediment and sediment peaks on the discharge hydrographs suggest that much of the sediments are derived from outside of the aquifer, meaning that the sediments are carried into the aquifer by recharging surface streams. Antioch Cave and other caves are potential pathways for sediment to enter the aquifer and eventually discharge at Barton Springs.

1.2 EDUCATION AND OUTREACH

Over the course of this grant project, District staff gave numerous presentations about the project, published abstracts and papers, and have hosted a number of visits to the Antioch BMP. A list of these is presented in Appendix B.

2.0 METHODOLOGY

This project involved the installation and operation of two CWQMN sites, upgrade of the BMP at Antioch, stormwater sampling, and the installation of a multiport monitor well (Table 2-1). Using CWQMN data and results of stormwater sampling, the amount of contaminant reduction due to operation of the Antioch BMP was calculated. District staff only employed methods and techniques determined to produce measurement data of known and verifiable quality and are generally discussed below for each of these main tasks. The District developed a Quality Assurance Project Plan (QAPP) (Appendix C) for the purpose of collecting compliant data in the field for the CWQMN systems and stormwater samples for the duration of the grant.

Table 2-1. Summary of Monitoring Sites and Equipment

TCEQ Station ID	Site Name	Equipment/Actions	Parameters
Antioch	Antioch BMP	Install second valve and intake screen; automation with CWQMN; stormwater sampling	TSS, TDS, turbidity, nitrate/nitrite (as N), total phosphorus (P)
CAMS 0770	Antioch CWQMN	Install CWQMN station	Temperature, conductivity, DO, turbidity, pressure
CAMS 0727	Low Water Dam CWQMN	Install CWQMN station	Temperature, conductivity, DO, turbidity, pressure
58-58-431	Antioch multiport monitor well	Drill and install multiport monitoring well	Head, TSS , TDS, turbidity, nitrate/nitrite (as N), total phosphorus (P)

2.1 QAPP

The original QAPP was approved by TCEQ on April 16, 2007. Revisions were made to the QAPP annually. The TCEQ conducted an audit of the grant on March 4, 2010, with a focus on data collection. Following the audit process, additional field techniques and methods were incorporated in the subsequent revision of the QAPP. The latest revision of the QAPP, covering April 15, 2010, to April 15, 2011, includes procedures for installation and sampling of a multiport well at the Antioch site.

2.2 CONTINUOUS WATER QUALITY MONITORING NETWORK (CWQMN) SITES

CWQMN systems were installed at two sites in Onion Creek to monitor water quality. Both sites provide real-time continuous data for surface water entering and leaving the recharge zone within the Onion Creek watershed.

All CWQMN sites deployed in the State of Texas are considered and selected according to established TCEQ methods (TCEQ, 2008). District staff and contractors designed, constructed and deployed the CWQMN systems and instruments (multi-parameter, water-level, and velocity sensors) to comply with all established methods and procedures (TCEQ, 2008; TCEQ, 2009).

Data from the sensors are collected and stored in data loggers at each site and transmitted via wireless modem to the TCEQ MetroStar/Leading Environmental Analysis and Display System (LEADS) in Austin, Texas, where the data are processed and archived. Hourly averaged data are then posted to appropriate TCEQ websites for public use and review. Data are validated according to the procedures outlined in the CWQMN QAPP (TCEQ, 2009). Monthly site visits are conducted to verify or calibrate the multi-parameter water-quality sensor, provide complete system maintenance, and monitor the CWQMN site for vandalism and acts of nature.

2.2.1 Antioch CWQMN Site

Water-quality data from Onion Creek at Antioch Cave can be found at:
http://www.tceq.state.tx.us/cgi-bin/compliance/monops/water_daily_summary.pl?cams=770

The Antioch CWQMN site includes the following equipment:

- In-Situ Troll 9500 water-quality sensor (T, conductivity, DO, turbidity, pressure)
- Zeno data logger
- Enfora modem and cellular telephone
- ISCO 2150 flow meter with area velocity/pressure
- Air compressor and tank
- Solar panel and 12-volt battery

District staff began the construction phase for the Antioch CWQMN system in April 2008. This monitoring site was brought onto the TCEQ real-time data collection system on Saturday, August 16, 2008. The Troll 9500 was installed in a perforated 4-inch diameter PVC conduit about 15 ft upstream of the BMP. The flow meter was installed in the 36-inch diameter pipe that connects the intake screen to the BMP. A stainless steel equipment housing was installed above flood stage to house the Zeno data logger, modem, communications equipment, air compressor and tank. Cables connecting the data logger to the probes run through the PVC conduit buried in a trench for a portion of the distance between the BMP and the equipment housing. From September 2009 to September 2010, water-quality measurements were made at Antioch for six storm events.

2.2.2 Low Water Dam CWQMN Site

Water-quality data from Onion Creek Low Water Dam site can be found at:
http://www.tceq.state.tx.us/cgi-bin/compliance/monops/water_daily_summary.pl?cams=727

Construction began on the Low Water Dam CWQMN site (Figure 1-1) within the COA Onion Creek Management Unit on January 14, 2010, and was completed on February 17, 2010. This monitoring site was brought onto the TCEQ real-time data collection system on Wednesday, August 25, 2010. The multi-parameter sensor was installed about 25 ft upstream of the low water dam. The following equipment was installed in a similar configuration as the Antioch CWQMN site:

- In-Situ Troll 9500 water-quality sensor (T, conductivity, DO, turbidity, pressure)
- Zeno data logger
- Enfora modem and cellular telephone
- Solar panel and 12-volt battery

2.3 UPGRADE OF ANTIOCH BMP

The original BMP, constructed at the Antioch site in 1997, was upgraded as part of the current project to improve and automate the function of the BMP. The goal for the BMP when it was constructed was to reduce the amount of nonpoint source pollution entering the aquifer from stormwater flow in Onion Creek. As part of this current project, modifications were made to improve the efficiency of the BMP by automating the opening and closing of the intake valves and by installing an intake screen over the second valve so that less storm debris and sediment could enter the cave and that the intake structure would not get clogged with debris.

An intake structure for the Antioch BMP, consisting of a 36-inch diameter screen and pipe, was installed in September 2008. The screen is 32 ft long and the pipe is 16 ft long. A photograph of the completed BMP is shown on the cover of this report. The function of the intake structure is to allow water to flow into the cave while filtering out most of the debris that is carried in Onion Creek. A second 36-inch diameter valve was installed in the BMP on September 9 (Figure 2-1). The valve controlled by the CWQMN equipment is programmed to close when turbidity of the water in Onion Creek rises to 100 NTU and to open when turbidity drops to 50 NTU. The default position of the valve is open since the turbidity meter is either sensing low turbidity water between storm events or air when there is not flow in the creek. When a storm pulse first arrives and turbidity levels increase above this threshold, the valve will automatically close. After the storm pulse passes and turbidity levels decrease, the automated valve opens to allow water to enter the BMP. As-built design drawings of the BMP upgrade are included in Appendix D.

Figure 2-1. Installation of 2nd valve (automated) on Antioch BMP.

An Isco 2150 velocity meter was installed near the mid-point of the 16-ft long pipe. This velocity meter measures flow of water into the second valve. From the velocity data, a volume of flow can be calculated by multiplying the velocity by the cross-sectional area of the pipe. By measuring the volume of water entering the system when the valve is first opened following a flow event, the mass of storm contaminants prevented from entering the aquifer when the valves are closed can be calculated (Equation 1, Section 2.5, Calculation of Contaminant Reduction). By measuring the volume of flow into the aquifer, aquifer characteristics can be calculated when combined with water-level data from nearby monitor wells.

2.4 STORMWATER SAMPLING

District staff selected stormwater parameters for analysis that include total suspended solids (TSS), total dissolved solids (TDS), turbidity, nitrate and nitrite as nitrogen (N), and total phosphorus (P). Stormwater sample collection followed field sampling procedures for conventional parameters documented in the TCEQ Surface Water Quality Monitoring Procedures Manual (TCEQ, 2008). Details of the procedures and methods are presented in the project QAPP (Appendix C).

Samples were collected from an open channel environment using a Teledyne Isco system (3700 series). An Isco bubbler flow meter (4230 series) initiates the sampling program for the automatic sampler. The flow meter logs water levels every 5 minutes and triggers the automatic sampler to start sampling when there is a rise of water level in the creek indicative of a storm pulse. The sampler and flow meter were placed about 20 feet in elevation above the BMP so that the sampler pump will be capable of delivering samples to the bottles in the sampler, but will not be subjected to flooding by all but the most severe storms. Volumetric calibration of the automatic sampler was performed to verify correct volumes were being collected. The automatic sampler fills two 1-liter bottles for every sample collected.

The collection of samples focused on peak flows from a given storm event with sampling continuing as the storm subsides. Samples were collected at intervals ranging from every 15 minutes to every 6 hours. A selected number of samples thought to represent the storm hydrograph were sent to the lab for analysis. From October 2009 to September 2010, samples were collected from five storm events. Five to seventeen samples were analyzed for each storm event.

2.5 CALCULATION OF CONTAMINANT REDUCTION

Currently the CWQMN system is set to close the intake valve when turbidity values rise to 100 NTU and to re-open when the turbidity value of stormwater drops to 50 NTU. The contaminant reduction equation (1), as presented in the project QAPP, is used to quantify the mass of contamination being prevented from entering the BMP.

$$Q * C_{N,P,S} * T = M_{N,P,S} \quad (1)$$

where

Q = Rate of flow into Antioch BMP when valve is first opened after storm pulse.

$C_{N,P,S,}$ = Concentration of N (nitrate/nitrite), P(phosphorus), or S (sediment) during storm pulse

T = Duration of time that valve on BMP was closed

$M_{N,P,S}$ = Mass of contaminant prevented from entering aquifer

2.6 MULTIPORT MONITOR WELL

The modified BMP was designed to allow as much as 250 cubic feet per second (cfs) of water to recharge the aquifer through the BMP. However, it is not known how much water the cave is physically capable of recharging. Beyond the rather limited extent of the explored cave passage, it is not known which route or routes the water takes to reach the water table. Once the recharge water reaches the saturated zone of the aquifer, its path is predominately to the north and Barton Springs, although dye tracing has shown that under high-flow conditions groundwater moves in various directions away from Antioch (Figure1-7A). Very little is known about the vertical movement of water in the aquifer. The Edwards Aquifer has been divided into eight lithostratigraphic units (Small et al., 1996), each with unique hydrologic properties. However, standard monitor wells are not capable of monitoring vertical components of flow in an aquifer.

To monitor horizontal and vertical flow of water recharging the aquifer through Antioch Cave, a multiport monitor well was installed about 1,700 ft (0.3 mi) east of Antioch Cave. The installation of the multiport monitor well at Antioch has provided a means for characterization of pathways within the aquifer. Movement of water recharged through the Antioch BMP and the nonpoint source pollutants in the aquifer will be monitored in discrete zones within a single monitor well that is completed with multiple monitoring zones.

The multiport well system installed at the site is manufactured by Westbay Instruments of Vancouver, Canada, a Schlumberger company. A similar well was installed by the District at Ruby Ranch about 4 miles west of Antioch in 2008. This well, with 14 monitor zones, was designed to monitor groundwater in the lower units of the Edwards Aquifer and the Upper and Middle Trinity Aquifers. With these types of wells, almost any number of monitoring zones can be installed in a well. Monitoring zones are separated by packers that seal off the annular space between the borehole wall and the well casing (Figure 2-2). Specialized (measurement) ports allow for access to the aquifer for sampling, water-level (pressure) measurements, and aquifer tests. Groundwater samples collected from each zone are representative of the groundwater in the aquifer between the packers. Water-level data from the zones can give an indication of potential direction of vertical movement of water within the aquifer. Aquifer tests, such as slug tests, can be conducted through the pumping ports to identify and characterize zones of higher permeability through which groundwater is more likely to flow. Data from such a well at Antioch will provide needed information about how nonpoint source pollutants are moving through the aquifer and how they might impact water-supply wells and Barton Springs. Sampling of the well will be conducted in conjunction with recharge events to see how the sediments and contaminants in the surface water are transmitted through the aquifer.

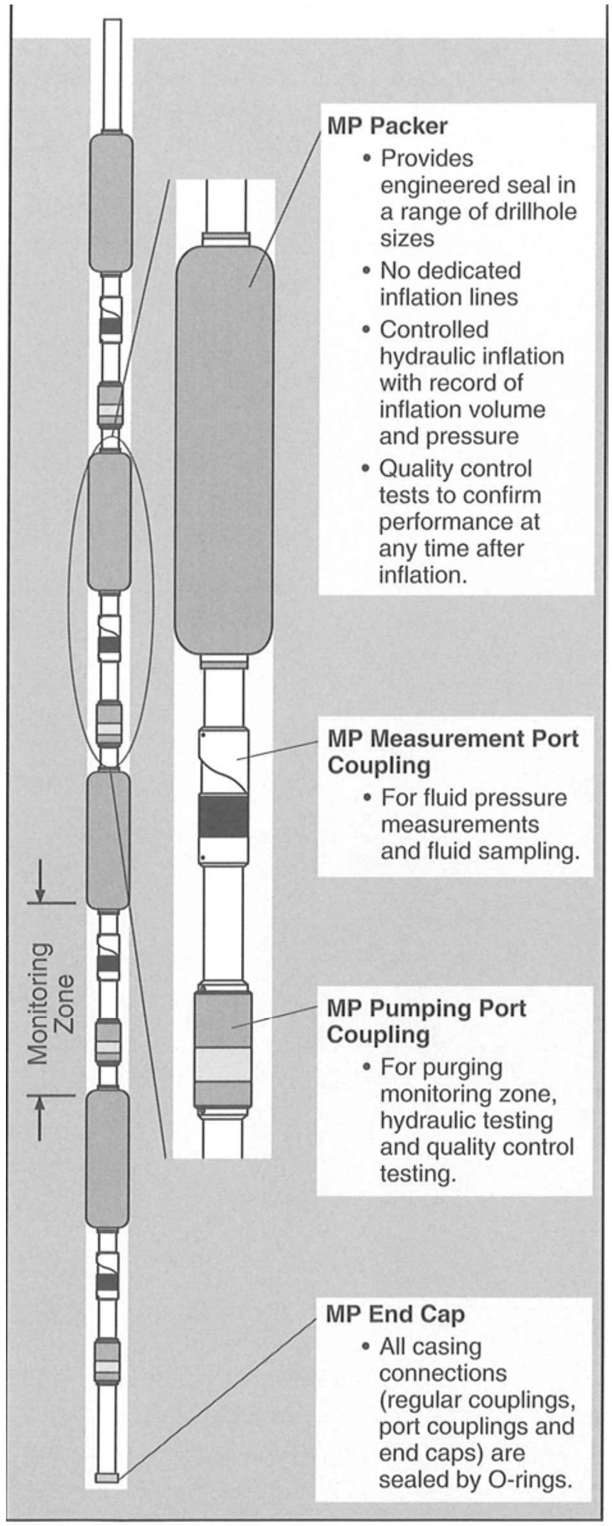


Figure 2-2. Schematic diagram of multiport monitor well components and construction. Diagram courtesy of Schlumberger Water Services, Inc.

2.6.1 Installation of Multiport Well

The procedure for installing this well was to drill a 5 ¼ -inch borehole to a depth of about 1,375 ft using air-rotary drilling techniques. Small amounts of water and drilling foam were used to help circulate drill cuttings to the surface. Eight-inch diameter surface casing was installed to a depth of about 115 ft to seal off the Buda and Del Rio Formations from the monitor zones of the Edwards below. Geophysical logs were run in the completed borehole. A gamma log was used to determine approximate contacts of the various geologic units. A caliper log was run to measure the diameter of the borehole so that packers could be placed where there are no cavities that would interfere with packer inflation. A video log was run on the borehole for lithologic and structural (fracture) inspection for packer placement. Once the geophysical logs are run and interpreted, the well is designed by laying out all of the components of the Westbay® multiport well on paper or on a computer. The main components of the system are packers, measurement ports, pumping ports, end caps, 2-ft, 5-ft, and 10-ft sections of 1 7/8–inch OD diameter PVC casing, regular couplings, and magnetic location collars (Figure 2-2). Each zone consists of a packer at the top and bottom of the zone, one measurement port, one pumping port, a magnetic collar placed 2 ft below the measurement port, and regular couplings to connect the sections of PVC casing. Measurement and pumping ports also serve to connect sections of PVC casing. Zones may be as thin as 5 ft or as thick as hundreds of feet. Packers are set at or near the contacts between desired monitoring zones. These zones typically correspond to the hydrogeologic zones encountered in the well. The measurement ports can be placed anywhere between the packers, but are usually placed about halfway between the packers. A pumping port is typically placed 10 ft below the measurement port. Once the well is designed, the installation process follows these steps:

- Visually inspect and lay out the Westbay® system casing components in sequence (Figure 2-3).
- Record the serial numbers for each packer, measurement port, and pumping port.
- Assemble each casing joint and test the hydraulic seals.
- Lower the casing into the borehole.
- Test the hydraulic integrity of the entire casing string.
- Inflate the packers sequentially from bottom to top, recording the inflation pressure and volume of water used for each packer.
- Measure fluid pressures at each measurement port to confirm proper operation and check the annular hydraulic seals between monitoring zones.

Once the last packer is inflated, a protective casing is placed at the well head plus a concrete pad and protective posts (Figure 2-4).

Drilling of the borehole began on July 26, 2010. By August 18, the borehole had been advanced to a depth of 1,017 ft, but problems with drilling a narrow diameter borehole to such a depth prevented any further drilling until a different set of equipment could be obtained. Using a string of narrow-diameter drill rods, drilling resumed on September 14. By September 16, the borehole had reached a depth of 1,375 ft. Geophysical logging of the borehole indicated that the borehole had reached the bottom of the Cow Creek Limestone, which was the target for the lowermost zone of the monitor well.

Figure 2-3. Photograph of layout of multiport monitor well components prior to installation.

Figure 2-4. Photograph of the wellhead of the completed Antioch multiport monitor well during a sampling and water-level measurement event.

2.6.2 Groundwater Sampling and Water-Level Measurements

The multiport well installed at Antioch consists of 21 monitor zones (Figure 2-5). Eight of these zones are in the Edwards Aquifer, six zones are in the Upper Trinity Aquifer, and seven zones are in the Middle Trinity Aquifer. The uppermost 10 zones of this well were installed to monitor movement of nonpoint source pollutants in the Edwards Aquifer and in the upper portion of the Upper Trinity Aquifer. These zones have been demonstrated to be in hydraulic connection on the basis of results of water-level measurements from the multiport monitor well installed at Ruby Ranch.

Groundwater samples collected during future storm events will be analyzed for the same constituents as the surface-water samples described above. Manufacturer's procedures for collection of groundwater samples from the multiport monitor well are included in Appendix D of the QAPP which is included in this report as Appendix C.

Following completion of a multiport monitor well, the monitor zones are usually developed to purge the annular space and proximal aquifer of residual drilling fluids. Because the contract portion of this project had come to an end prior to completion of the well, it was decided that sampling of the well would not be conducted immediately. Therefore, the zones would be purged by the natural flow of groundwater through the aquifers. Monitoring of the lowermost zone was conducted to verify that this process was taking place. Therefore, samples collected in May and June 2011 are considered to be representative of the natural groundwater of each zone.

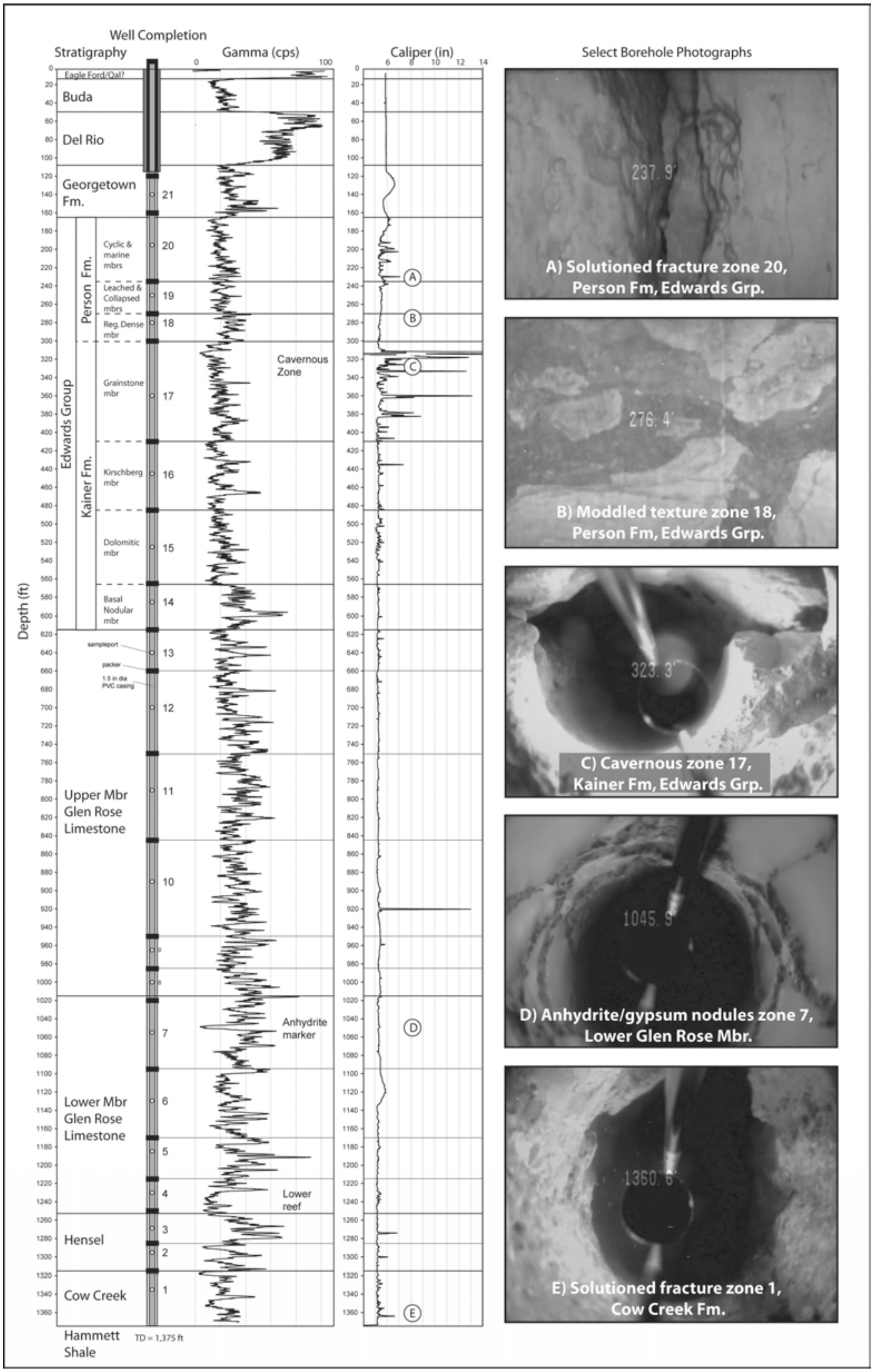


Figure 2-5. Diagram showing multiport monitor well construction, hydrogeologic units encountered in well, gamma and caliper logs, and photographs from the downhole video log.

3.0 RESULTS OF SAMPLING AND DATA COLLECTION

As described in the methodology section, the data collection part of this project consisted of continuous water-quality monitoring with CWQMN systems at Antioch Cave and the Low Water Dam on the COA Onion Creek Management Unit, stormwater sampling at Antioch, and water-level measurements and groundwater sampling in the multiport monitor well near Antioch. Data collection at the Antioch CWQMN began in May 2009. Other than some brief periods when the system was not functioning or data were not transmitted, there is a nearly continuous record of temperature, specific conductivity, turbidity, dissolved oxygen, and gage height for the Antioch CWQMN. However, between May 2009 and September 2009, there was no flow in Onion Creek at Antioch due to a severe drought. A more limited set of data for flow into the Antioch BMP is available. Data collection at the Low Water Dam CWQMN began in February 2010. Only a limited amount of data was collected at the Low Water Dam site before the end of the project so only Antioch data will be discussed in this report. Data from the Antioch and Low Water Dam CWQMN sites are available in the TCEQ LEADS database (see Section 2.2).

3.1 SAMPLING OF STORM EVENTS

A summary of the six storm events recorded at the Antioch CWQMN site is presented in Figure 3-1 which includes data from flow in Onion Creek at the U. S. Geological Survey (USGS) Driftwood station and maximum gage height at the Antioch CWQMN. Table 3-1 is a summary of laboratory data for the five storm events. A complete set of laboratory data is included in Appendix E. Figure 3-2 is a compilation of CWQMN and laboratory data shown in a chart format for each of the six storm events. CWQMN data are shown in Figure 3-2 as continuous lines, and laboratory data are shown as discrete data points. The CWQMN data shown in this figure are gage height, turbidity, and conductivity. Laboratory data include turbidity, nitrogen from nitrate and nitrite, total phosphorus, suspended solids, and total dissolved solids. A description of each of the six storm events is provided below.

Table 3-1. Laboratory analytical results for samples collected at the Antioch BMP for five storm events and one baseflow sample.

Storm Event	Collection Date	Time	Phos. mg/L	Nitrogen mg/L	TSS mg/L	TDS mg/L	Turbidity NTU
2	10/27/2009	1:36	0.094	11.5	66.6	445	69.1
2	10/27/2009	2:36	0.057	0.823	48.4	309	30.7
2	10/27/2009	3:36	0.063	0.825	23.2	363	14.3
2	10/27/2009	6:36	< 0.020	0.859	4.9	401	5.92
2	10/27/2009	12:45	< 0.020	0.977	2.3	411	2.29
2	10/27/2009	18:45	< 0.020	1.11	6.4	398	1.85
2	10/28/2009	2:45	< 0.020	1.35	9.2	387	1.62
3	1/15/2010	21:51	0.218	0.549	91.2	156	63.7
3	1/15/2010	22:14	0.215	0.381	119	141	46.7
3	1/15/2010	22:36	0.259	0.347	124	141	55.3
3	1/15/2010	23:21	0.286	0.228	56.7	129	41.1
3	1/16/2010	0:21	0.229	0.227	55	163	35.6
3	1/16/2010	1:36	0.215	0.245	20.4	160	37
3	1/16/2010	3:06	0.173	1.29	72.8	240	59.7
3	1/16/2010	4:51	0.109	0.865	57.6	193	48.7
3	1/16/2010	6:51	0.058	0.682	34	268	34.9
3	1/16/2010	9:51	0.059	0.658	28.4	300	17.5
3	1/16/2010	15:51	0.033	0.715	16.8	283	18.7
3	1/16/2010	17:22	< 0.020	0.675	27.6	267	12
3	1/16/2010	17:40	< 0.020	0.645	28.4	280	12.1
3	1/16/2010	19:40	< 0.020	0.652	12.8	276	25
3	1/16/2010	23:40	< 0.020	0.639	28.4	275	15.2
3	1/17/2010	5:40	< 0.020	0.685	15.2	276	12.5
3	1/17/2010	13:40	< 0.020	0.723	10.8	281	14
3	1/17/2010	23:40	< 0.020	0.887	7.6	302	9.41
4	1/29/2010	12:00	0.08	1.23	51.2	313	20.3
4	1/29/2010	12:14	< 0.020	1.28	16.8	312	11.7
4	1/30/2010	11:13	< 0.020	0.699	32	280	35
4	1/30/2010	14:13	< 0.020	0.706	27.2	266	22.6
4	1/30/2010	20:13	< 0.020	0.704	24	275	18.8
4	1/31/2010	5:13	< 0.020	0.705	17.6	260	16.8
Baseflow	**3/4/2010**	**14:00**	**< 0.020**	**1.01**	**< 1.0**	**299**	**0.807**
5	5/18/2010	2:56	0.037	0.206	70	223	46.1
5	5/18/2010	3:03	< 0.020	0.332	42.8	220	21.5
5	5/18/2010	3:10	< 0.020	0.372	30	223	23.8
5	5/18/2010	3:27	< 0.020	0.356	16.8	224	19.2
5	5/18/2010	4:07	< 0.020	0.488	13.4	208	15.5
5	5/18/2010	8:37	< 0.020	0.27	25	144	43.9
5	5/18/2010	11:37	< 0.020	0.315	21	158	35.3
5	5/19/2010	2:37	< 0.020	0.176	1.1	269	0.579
5	5/19/2010	14:57	< 0.020	0.171	< 1.0	259	1.02
5	5/19/2010	22:02	< 0.020	0.177	< 1.0	267	1.63
6	9/7/2010	22:00	< 0.020	1.05	13.4	181	11.2
6	9/7/2010	22:24	0.207	2.61	241	153	243
6	9/7/2010	23:24	0.175	1.89	234	155	266
6	9/8/2010	0:39	0.434	0.938	121	112	108
6	9/8/2010	2:09	0.206	0.914	19	103	30.6
6	9/8/2010	3:54	0.234	1.56	295	127	310
6	9/10/2010	12:30	< 0.020	0.636	6.7	236	8.35

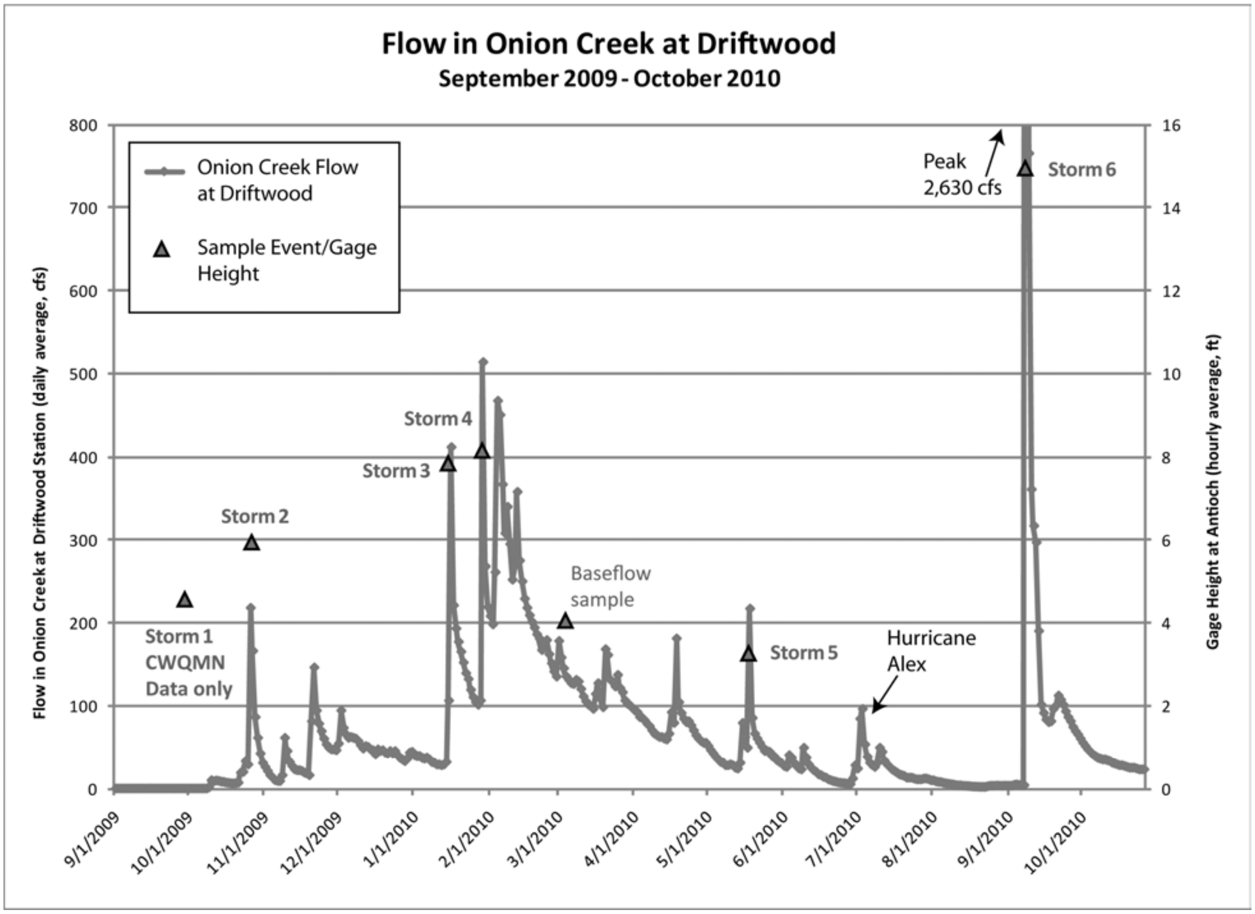
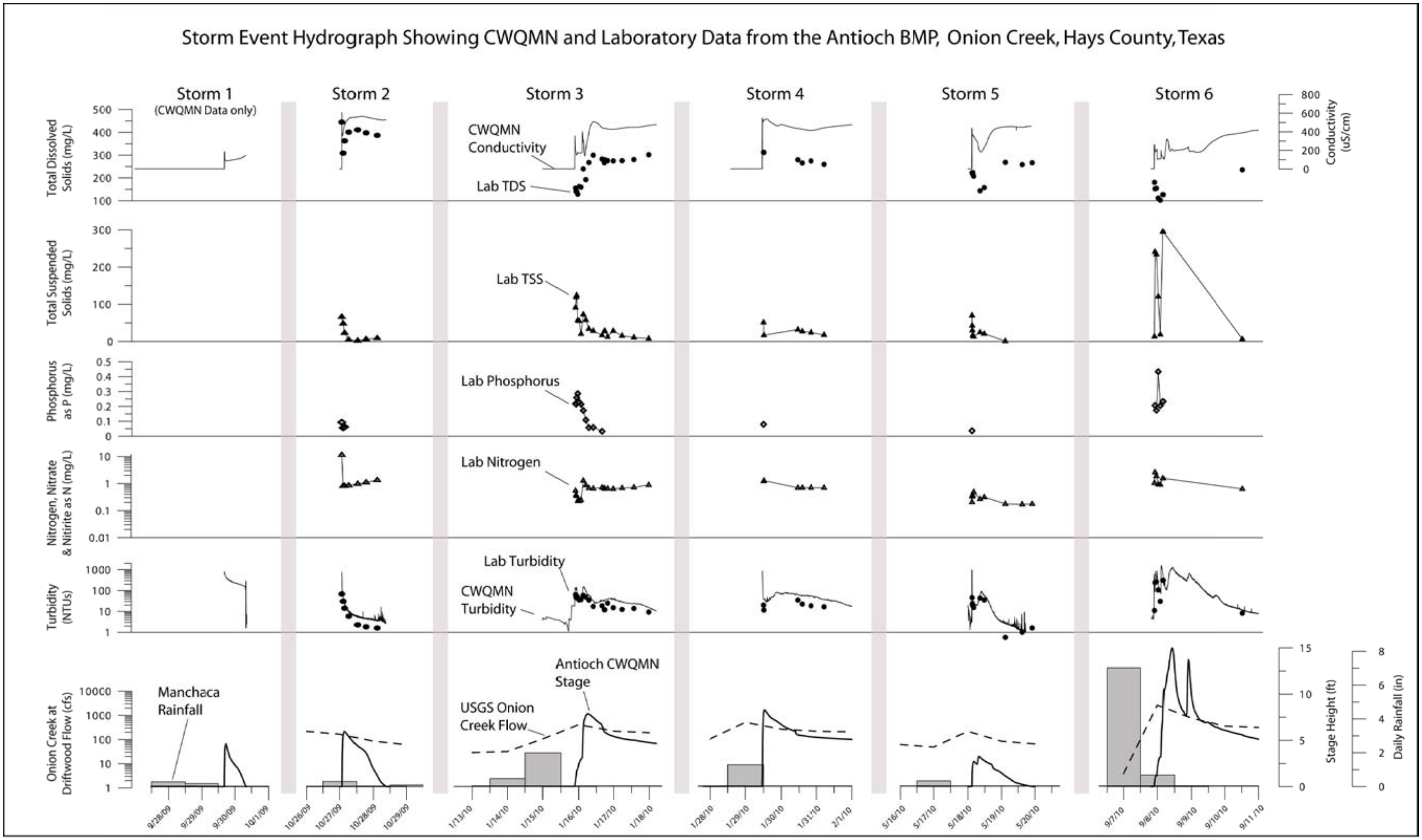


Figure 3-1. Storm events sampled for this project are shown superimposed on hydrograph of Onion Creek at the USGS Driftwood station from August 2009 to October 2010. The Driftwood station is about 13 miles upstream of the Antioch Cave site.



*Results below detection levels are not shown.

Figure 3-2. Antioch CWQMN data for six storm events and laboratory analytical results of surface-water samples collected at the Antioch BMP from five storm events.

3.1.1 Storm Event 1 (September 29 – 30, 2009)

At the beginning of September 2009, most of Texas was experiencing a severe drought that had been going on for close to 2 years. The District had declared an Alarm Stage Drought on June 23, 2008, for the Barton Springs aquifer. By the beginning of December 2008, the District was in Critical Stage Drought and was on the verge of entering into Exceptional Stage Drought in September 2009. Heavy rain, up to 10 inches in some parts of the recharge and contributing zones, fell between September 9 and 12. However, this significant amount of rain did not cause any flow in Onion Creek at the USGS gaging station in Driftwood. Because of the extremely hot and dry conditions at the time of this rain, there was very little runoff of rainfall to the creeks.

On September 28 and 29, light rain of less than ½ inch fell over much of the study area. However, a small area on the north side of Onion Creek, upstream of Antioch, received about 3 inches over a few hours on September 29. This led to flow in some tributaries to Onion Creek starting about 2 miles upstream of Antioch, but there was no flow at the Driftwood station. The flow soon reached the Antioch BMP with a maximum gage height of about 4.6 ft. Water-quality data were collected by the CWQMN system, but the automated sampler was not activated for sample collection. CWQMN data show a short but brief peak for flow at Antioch. Within less than 24 hours, flow had decreased to virtually zero. The turbidity of the water first reaching Antioch was 776 NTU. Turbidity values dropped steadily until the end of the flow event. Conductivity values spiked initially, then declined sharply, then rose steadily until the end of the flow event, which lasted less than 17 hours.

3.1.2 Storm Event 2 (October 27 – 28, 2009)

The second storm event recorded at Antioch occurred following a moderate amount of rain of about 2 inches on October 26, 2009. This followed a very wet September, as described in Section 3.1.1, that had a rainfall total of about 13 inches over much of the recharge and contributing zones. Total rainfall in October was about 6.5 inches as measured at the District office in Manchaca, Texas. The maximum gage height at Antioch during this storm event was 6.2 ft. Turbidity reached a peak of 782 NTU at the very beginning of the storm pulse which quickly declined to less than 50 NTU within 50 minutes. Conductivity values spiked initially, then declined sharply, then rose steadily before leveling off for the remainder of the storm event. Figure 3-3 contains photographs of water in Onion Creek and the top of the BMP about 8 hrs past the peak storm pulse on October 27, 2009.

3.1.3 Storm Event 3 (January 15 – 17, 2010)

The third storm event occurred between January 15 and 17 following a 3-inch rain on January 15 and 16. January was also a very rainy month with a rainfall total of about 4.7 inches, about 2.5 inches above average rainfall for the month. The gage height at Antioch reached a maximum of 7.9 ft within 9 hours of the start of the event. A turbidity peak of 144 NTU occurred about 1 hour after the start of the event. A second peak of 151 NTU occurred about 5 hours after the first peak. Three conductivity peaks occurred during the first 12 hours of the storm event followed by a slow decrease for the next 12 hours, then a slow but steady rise in conductivity.

A

B

Figure 3-3. A) Photograph of the top of the BMP about 8 hrs past the peak storm pulse on October 27, 2009 (view looking upstream). B) Photograph of the top of the BMP with a whirlpool near the corner of the vault due to water entering the original valve.

3.1.4 <u>Storm Event 4 (January 29 – 31, 2010)</u>

The fourth storm event was brought about by 1.6 inches of rain between January 28 and 29. Prior to the storm, flow in Onion Creek at the Driftwood station had been about 100 cfs, but there was no flow at Antioch prior to the storm. The gage height at Antioch reached a maximum of 8.2 ft within about one hour of the start of the event. A turbidity peak of 144 NTU occurred immediately when the storm pulse reached the instruments at Antioch. Two conductivity peaks occurred during the first 12 hours of the storm event followed by a slow decrease for the next 20 hours, then a slow but steady rise in conductivity. Following this storm event, flow at Antioch continued until March 15 when the instruments recorded a gage height of 0 ft. On that date the USGS station on Onion Creek at Driftwood was recording flow of about 100 cfs.

3.1.5 Storm Event 5 (May 18 – 19, 2010)

The fifth storm event followed about 1.7 inches of rain between May 14 and 17. Flow began on May 18 and continued until May 19, for a total of about 42 hours of flow. The peak gage height of 3.3 ft occurred 5 hours after the commencement of flow at Antioch. Of the five storm events sampled for this project, this event had the lowest recorded gage height. A turbidity peak of 962 NTU occurred immediately at the beginning of the storm pulse. Conductivity immediately peaked at the beginning of the storm pulse, then peaked again about an hour later, then decreased for another 5 hours before rising steadily until the end of the flow event.

On June 30, 2010, Hurricane Alex landed in northern Mexico and brought more than 5 inches of rain to parts of the Edwards recharge zone. Flow in Onion Creek at the Driftwood station increased to about 100 cfs, but no flow occurred at Antioch as a result of this rain.

3.1.6 Storm Event 6 (September 7 – 10, 2010)

The sixth storm event was the largest storm event of the project. It followed about 7.5 inches of rain from Tropical Storm Hermine from September 7 through 8. Two days of light rain, that totaled about 0.6 inches, preceded the storm by 4 days, so soil conditions were fairly wet. Hermine arrived in Central Texas on September 7 with about 6.6 inches of rain. The rain continued into September 8 with about 0.9 inches. Flow began at Antioch at about 8:00 pm on September 7. A peak gage height of about 15 ft occurred about 13 hours later. A second gage height peak of about 13 ft occurred about 12 hours later. The maximum flow rate recorded at the USGS Driftwood station was 2,630 cfs (hourly average). Five peaks were recorded at Antioch for turbidity during this storm event. The greatest turbidity reading was 1,210 NTU that occurred 13 hours after the beginning of flow at Antioch. There were three conductivity peaks within the first 26 hours of the storm event followed by a steady rise. Flow at Antioch ended on September 13 for a total duration of about 6 days.

3.2 COMPARISON OF STORM EVENTS

Laboratory and CWQMN data for the five storm events show considerable variation in the relationships between the various parameters analyzed by the laboratory or recorded by the CWQMN system. A comparison of stage height to turbidity data from the CWQMN system at Antioch does not indicate any distinct pattern (Figure 3-4). The analytical results follow mostly irregular paths throughout the progression of each storm event. Many factors need to be considered in the analysis of each storm event. Antecedent conditions such as soil moisture and the amount of water in Onion Creek can significantly affect stormwater runoff and subsequent flow in the creek. The intensity of rainfall and location of that rain can also affect the amount of flow and the variation in contaminant load of the stormwater.

Unlike the storm events sampled for this project at Antioch, each storm event in the USGS study (Figure 1-10) shows a clear trend with high turbidity levels associated with high flow rates. However, both studies show that each storm event is unique with respect to contaminant loads.

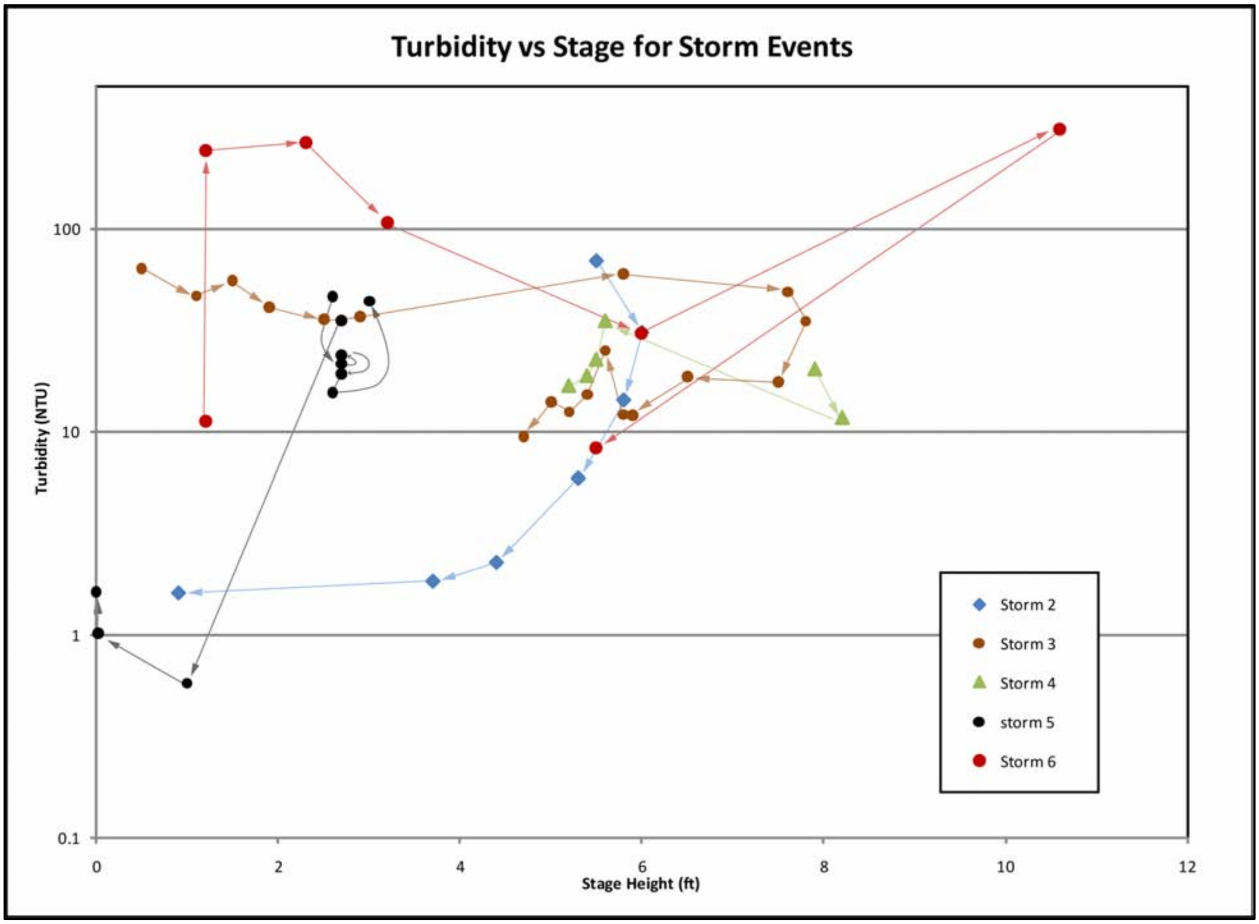


Figure 3-4. Plot of stage in Onion Creek at Antioch against turbidity for samples analyzed by the laboratory for five storm events. Arrows indicate time sequence of samples within a storm event.

Figure 3-5 shows the results of laboratory analyses of samples from five storm events. Values for a given parameter vary considerably during the first 10 hours of the storm event. Values tend to either rise or fall slightly after the first 10 hours. This pattern applies to each of the five storm events. A sample was collected from Onion Creek at Antioch on March 4, 2010 that is considered to be representative of baseflow conditions. Laboratory analytical results for TDS, nitrogen, and TSS (nitrate/nitrite) were 299 mg/L, 1.01 mg/L, and below detection level, respectively (Table 3-1). The trends of each of these parameters for each storm event show that over time, the values are heading in the direction of the baseflow sample values.

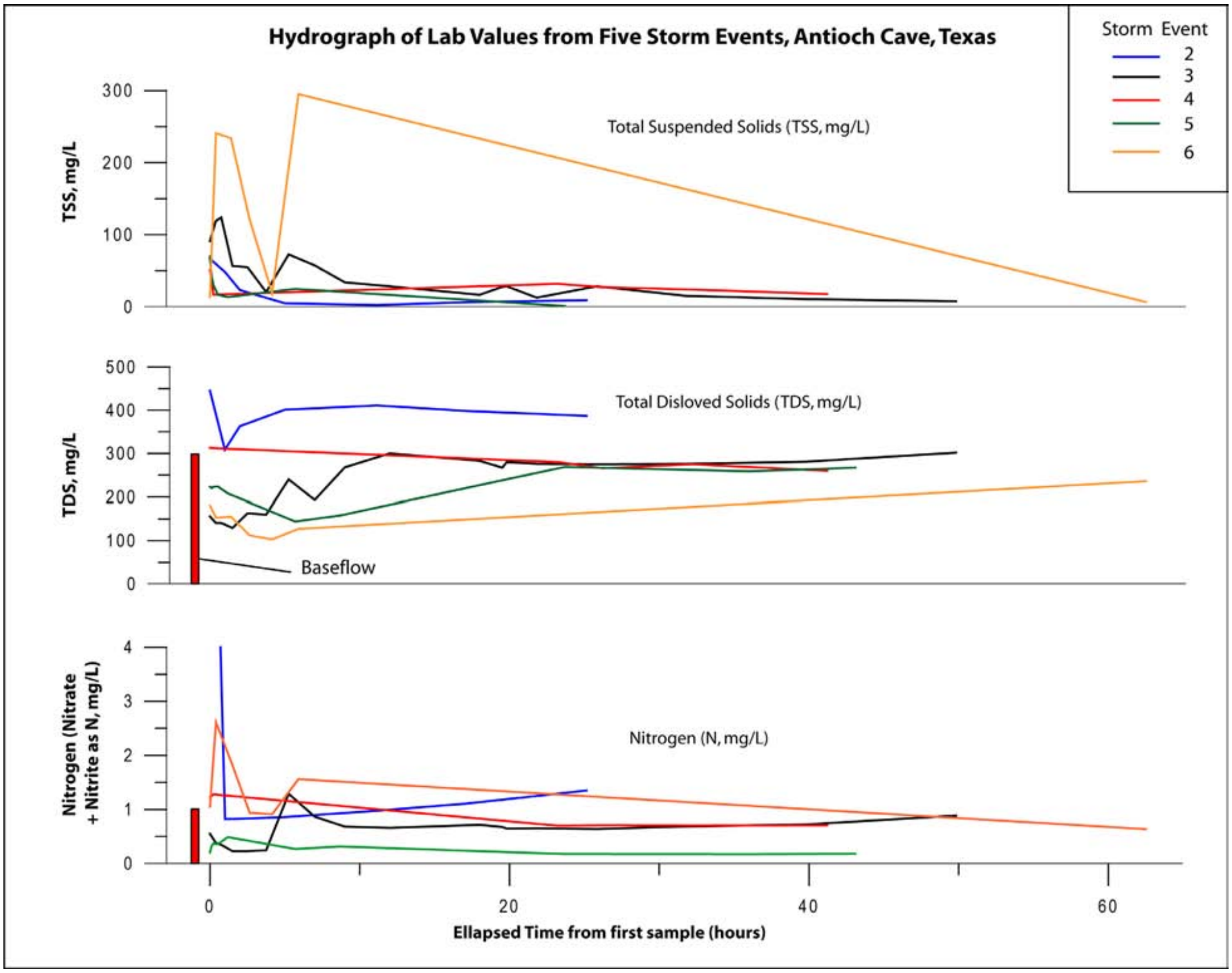


Figure 3-5. Hydrograph of laboratory results for five storm events at Antioch Cave. Also shown are the results from the baseflow sample as a bar graph. TSS was below the detection limit for baseflow.

3.3 CONTAMINANT REDUCTION FROM OPERATION OF BMP

The principal goal of the BMP constructed over Antioch Cave has been to reduce the amount of stormwater contaminants entering the aquifer through Antioch Cave. This had been accomplished with the construction of the original BMP and has been improved with the recent upgrades made to the BMP.

As stated in the methodology section above, the amount of contaminants not entering the aquifer due to operation of the BMP can be calculated by measuring the flow of water entering the BMP the moment the valve is opened and multiplying that by the concentration of contaminants in the water and by the duration of time that the automated valve was closed. The manually operated valve (original valve) is left in the closed position following passage of each storm pulse. The automated valve is closed when turbidity from a storm pulse goes above 100 NTU and is opened when turbidity drops below 50 NTU. Of these parameters, the most difficult to determine is the amount of flow that would be going into the aquifer during the peak storm pulse if both valves are open. This is accomplished, in part, by measuring the flow into the new valve and intake screen when the valve is first opened following passage of the peak storm pulse, which is the point at which turbidity in Onion Creek drops below 50 NTU. An Isco 1250 velocity meter is situated in the 16-ft long, 36-inch diameter pipe placed between the intake screen and the new valve. Because the velocity meter was damaged during a storm event, there are limited velocity data from storm events. Figure 3-6 shows flow in meters per second (m/s) for the January 15-16, 2010 storm event (Storm Event 3). At about 17:45, the valve opened automatically and the instrument recorded a velocity of 3.93 m/s that converts to a flow rate of about 86 cfs (2.4 cubic meters per second [cms]). As soon as possible after the new valve is opened, the original valve is manually opened to maximize flow into the cave. Although it is difficult to measure flow into the original valve, the combined flow into the cave is certainly greater than the measured flow into the new valve. For this evaluation, an estimated total flow into the system of 100 cfs is used for the contaminant reduction calculations. This assumes that the additional flow into the original valve is a least 14 cfs. This is a minimum flow value and it is likely that total flow into the system is greater than 100 cfs, but additional studies are needed to better determine this flow. The intake system for the BMP was designed to handle up to 250 cfs. However, it is not known what the upper limit of flow into the cave is.

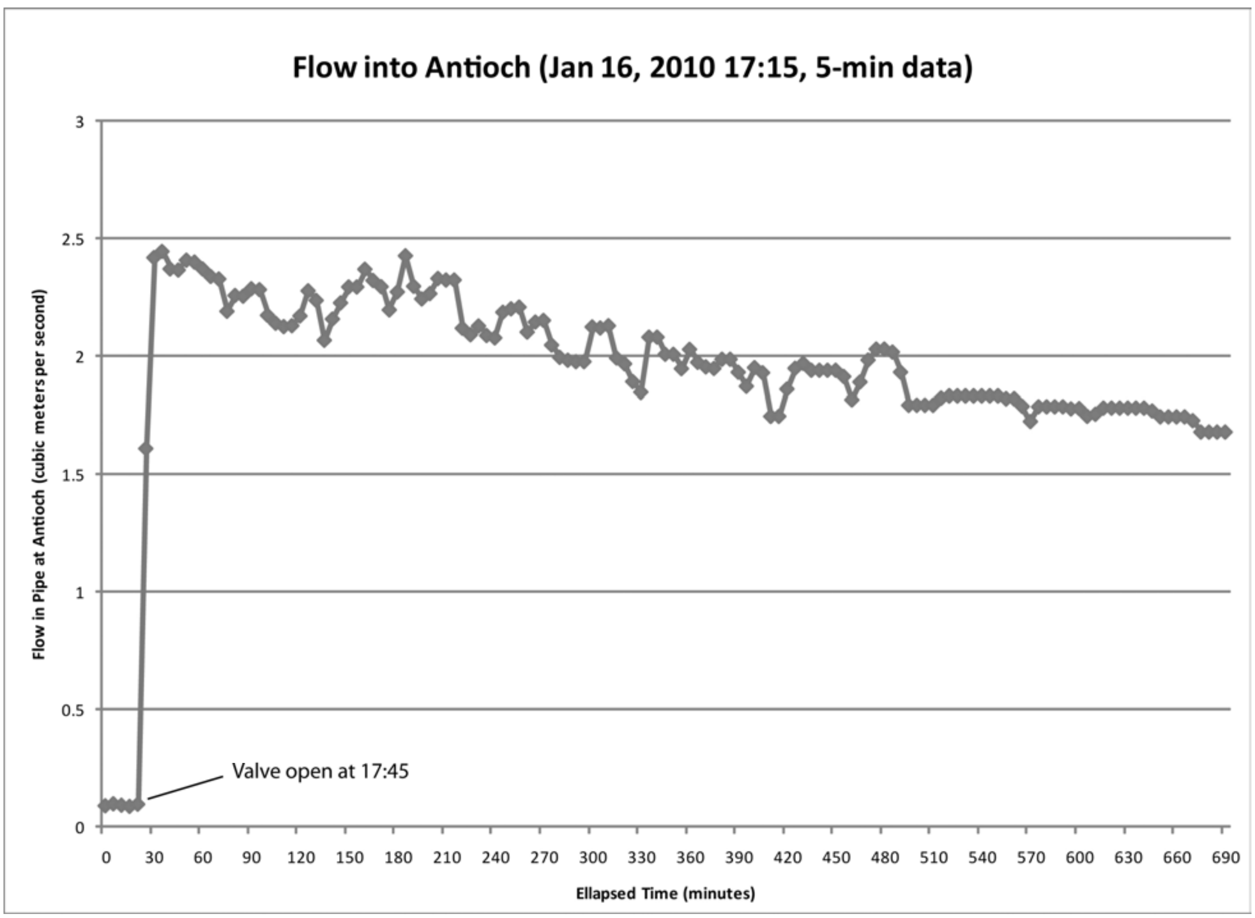


Figure 3-6. Graph of rate of flow through main valve on Antioch BMP after opening of valve during Storm Event 3.

The results of the contaminant reduction calculations are shown in Table 3-2. Calculations were made from data for five storm events. The first storm event recorded at Antioch with the CWQMN system did not include laboratory analytical data because the automated sampler was not yet programmed to operate during a storm event. The average duration of the storm events for which the turbidity level of the water in Onion Creek was greater than 100 and 50 NTU was 20 hours. The longest time that the valve was closed was 40.7 hours, and the shortest time was 0.8 hours. As shown in Table 3-2, concentrations of contaminants and the amount of contaminant reduction varied considerably between storm events. Storm Event 6, with the longest duration of valve closure and the highest level of contaminants, except for nitrogen in Storm Event 2, had the highest amount of contaminant reduction with 1,361 lbs (617 kg) of nitrogen, 228 lbs (104 kg) of phosphorus, and 140,597 lbs (63,763 kg) of sediment. These numbers show that by closing the valves on the BMP during storm events, a significant amount of contaminants from nonpoint sources can be prevented from entering the aquifer. This is certain to provide some protection to nearby water-supply wells and ultimately to lessen degradation of groundwater in much of the Barton Springs aquifer and Barton Springs. Contaminant reduction due to operation of the BMP also applies to other contaminants that were not included in the analytical program such as bacteria, lead, biological oxygen demand (BOD), and pesticides.

Table 3-2. Mass of contaminant reduction from operation of Antioch BMP for five storm events.

Storm	Start	End	Duration	Duration	Average Peak Storm Values[2] (mg/L)			Contaminant Reduction[3] in **lbs** (kg)		
Event	(NTU>100)	(NTU<50)	(days)	(hours)	N[1]	P[1]	TSS	N[1]	P[1]	TSS
1	Samples not collected for laboratory analysis									
2	10/27/09 1:41	10/27/09 2:27	0.03	0.8	6.16	0.075	57.5	**106** (48)	**1.3** (0.6)	**990** (449)
3	1/15/10 21:30	1/16/10 8:15	0.45	10.7	0.53	0.195	70.0	**128** (58)	**47** (21)	**16,905** (7,666)
4	1/29/10 11:15	1/31/10 0:30	1.55	37.3	0.92	0.02	30.2	**770** (349)	**17** (7.6)	**25,271** (11,461)
5	5/18/10 2:56	5/18/10 12:31	0.40	9.6	0.33	0.005	31.2	**71** (32)	**1.1** (0.5)	**6,717** (3,046)
6	9/9/10 14:26	9/7/10 21:46	1.69	40.7	1.49	0.25	153.9	**1,361** (617)	**228** (104)	**140,597** (63,763)
		Total Duration	**4.1**	**99.0**			**Totals (lbs)**	**2,436**	**295**	**190,480**
							Totals (kg)	1,105	134	86,385

Notes:
1- N is nitrogen from nitrate and nitrite; P is total phosphorus.
2- For period during which the valve was closed.
3- Mass of contaminants not entering Antioch Cave while valves are closed.

3.3.1 BMP Operation During Storm Event 3

Laboratory analytical and CWQMN data for Storm Event 3 are shown in Figure 3-7, including the amount of contaminant reduction for each parameter and an indication of where on the hydrograph the automated valve closed and opened. Based on 15-minute CWQMN data, the first storm water to reach the CWQMN multiparameter sensor had a turbidity value of 139 NTU. The automated valve closed immediately upon sensing a turbidity level of 100 NTU or greater. For the next 5 hours, the turbidity of the stormwater in Onion Creek decreased to 48 NTU. It is presumed that the valve opened due to a turbidity value of 50 NTU or less. However, turbidity then rose above 100 NTU within less than 30 minutes and presumably closed the valve again. The valve stayed shut for another 5 hours until turbidity dropped below 50 NTU again.

As shown in Tables 3-1 and 3-2 and Figure 3-7, the amount of sediment, nitrogen (from nitrate and nitrite), and phosphorus prevented from entering the aquifer during Storm Event 3 was 16,907, 128, and 47 lbs, respectively. Greater amounts of contaminants could be kept out of the aquifer by having the valve open at a lower turbidity level, but that would also decrease the amount of water recharging the aquifer. The results of Storm Event 3 indicate that below a turbidity of 50 NTU the decrease in total suspended solids is at a slower rate than at levels above 50 NTU. Further review of the 100 and 50 NTU levels for closing and opening the valve will be done when additional data are available from future storm events.

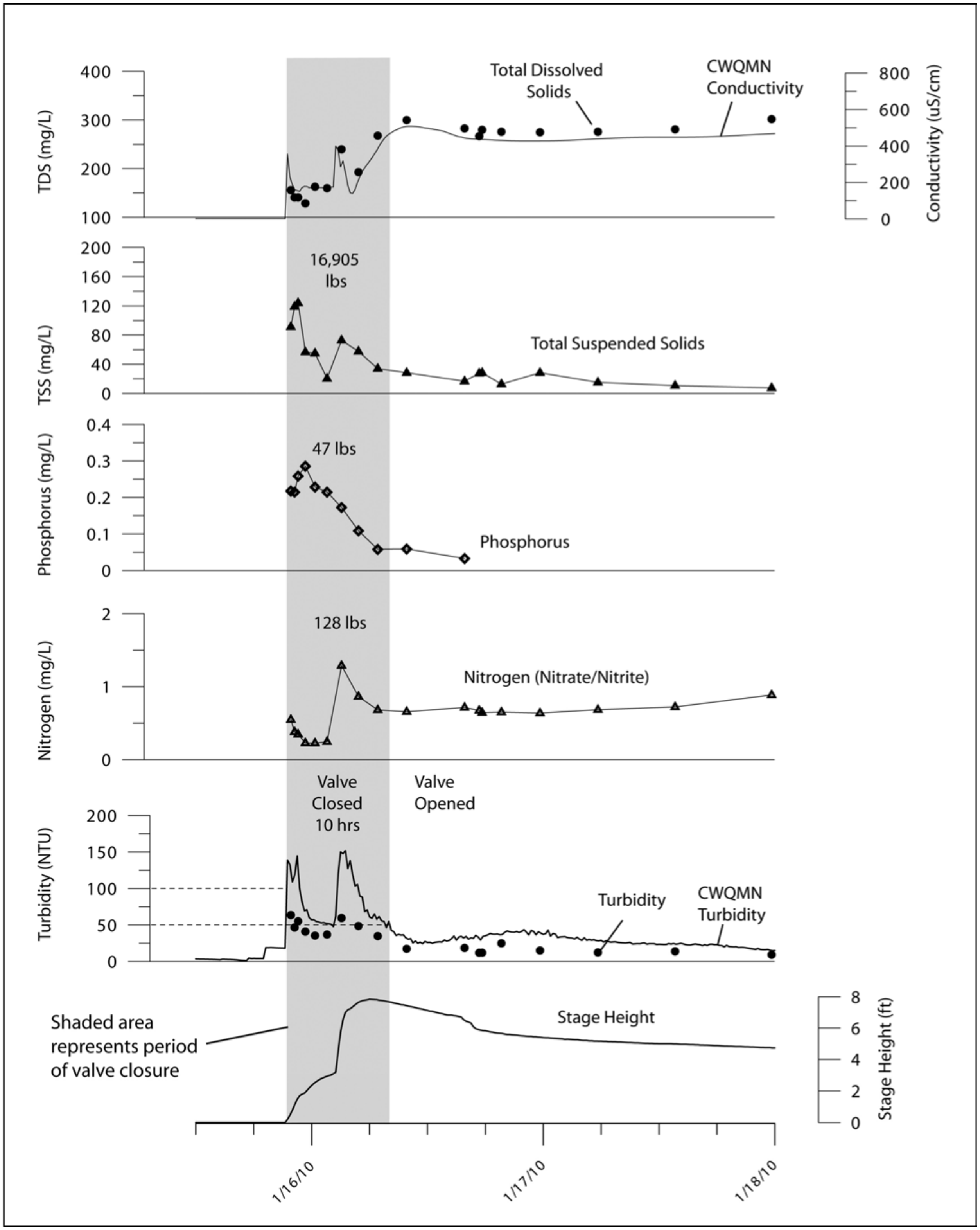


Figure 3-7. CWQMN and laboratory analytical data for Storm Event 3.

3.4 RESULTS FROM MULTIPORT MONITOR WELL

Because the well was completed several weeks after the end of the 319(h) contract, groundwater samples were not collected during the period of the contract. Groundwater samples were collected from 19 of the 21 zones in the multiport well in May and June 2011 as part of the District's annual summer sampling program. The Texas Water Development Board (TWDB) paid for most of the analytical costs for these samples. Water-level measurements were made immediately after completion of the well and have been made six times since then.

3.4.1 <u>Head Measurements</u>

A head (water-level or potentiometric) profile of a multiport monitor well consists of measuring water pressures (heads) in all or most zones of the well within a short period of time, usually over an hour or two. These values give an accurate indication of the hydraulic potential for vertical flow within the aquifer units. It does not indicate that there is actual flow, but only the potential for flow and its direction if there is a permeable pathway. Figure 3-8 shows well construction details, head measurements taken on five dates over a 10-month period, and TDS values for each of the sampled zones. In the vertical sense, there is a clear break in heads between zones 11 and 12. This suggests that there is some change in lithology at this depth that separates the upper zones (12-21) from the lower zones (1-11). The break between zones 11 and 12 also shows how different the upper zones vary temporally from the lower zones. The upper zones all show a slight increase of about 2 ft in heads from September 30, 2010, followed by a drop of about 12 ft from October 29 to December 2. The lower zones exhibit head changes of only about 2 to 5 ft over this period. These data indicate that the uppermost units of the Upper Glen Rose Limestone (represented by zones 12 and 13 in this well) are hydraulically connected to the Edwards units, and that there is a significant hydraulic barrier in these units close to the boundary between zones 11 and 12. Head values in the Edwards units and the uppermost Upper Glen Rose vary by less than 1 ft between adjacent zones, indicating that there is vertical communication throughout these units. However, beds of low permeability could restrict vertical flow locally. Zone 18, which corresponds to the grainstone member of the Person Formation, is one such zone of likely low permeability. Air bubbles were observed issuing from small pores in the rock on the digital camera log more than a week after air-rotary drilling was completed (the suspected source of the air). When an attempt was made to sample this zone 10 months later, the sampler pulled only air from the sampling port. At some distance from this well there are likely to be vertical pathways for flow from zones above zone 18 to the zones below zone 18. These pathways could either be where the low permeability unit is missing, where it has higher permeability, or where there could be a vertical pathway along a fault. The air within zone 18 could eventually dissipate and come into equilibrium with adjacent zones and units.

The decline in heads in the upper zones (12-21) is due to rapidly decreasing recharge to the aquifer brought about by dry conditions at the surface since the heavy rains of Tropical Storm Hermine that brought about 7 inches of rain to the area in early September 2010 (Section 3.1.6).

3.4.2 Multiport Monitor Well Sampling

Sampling of groundwater in the multiport monitor well was conducted in May and June of 2011 as part of a program with the TWDB to assess groundwater quality across the state. District staff collected samples from 19 of the 21 zones in the well and transported them to an accredited laboratory for analysis. Groundwater samples could not be obtained from zones 18 and 21 due to the presence of remnant air from the drilling process. Parameters included in the analyses were major cations and anions, and isotopes of strontium, oxygen, deuterium, tritium, and carbon-14.

Selected results of laboratory analyses and head measurements are included in Table 3-3 and Figure 3-8. Nitrogen from nitrate and nitrite was only detected in the upper zones of the Edwards (15-17, 19, and 20) with a range of values from 1.06 to 1.29 mg/L. TDS values show a sharp distinction between the Edwards and uppermost Trinity (zones 13-17, 19, and 20) and the lower units of the Glen Rose Limestone (zones 5-12). The Edwards zones and the uppermost Trinity zone (13) have a range of TDS from 273 to 446 mg/L. The high TDS zones have TDS values ranging from 2,141 to 3,567 mg/L. The lowermost zones in the well (1-4) have TDS values ranging from 553 to 963. Low TDS in the Edwards zones is expected because the zones have a high amount of circulation as surface water recharges the aquifer then flows toward pumping wells and Barton Springs. High TDS in most of the Upper Trinity can be attributed to numerous low permeability units and the presence of evaporites. Low TDS in the lowermost zones is attributed to circulation of groundwater from recharge zones about 20 miles west of the study area. Studies of another multiport monitor well about 4 miles west of the Antioch well have indicated that groundwater in the Hensel and Cow Creek formations in this area comes from areas to the west where these formations outcrop (Smith and Hunt, 2009). Geochemical and head data from the two multiport monitor wells suggest that the high TDS zones are hydraulically isolated from the low TDS zones above and below and that there is very little mixing between the high TDS units and the low TDS units. However, data from the monitoring zones at the interfaces between high and low TDS units suggest that local mixing is possible.

3.4.3 Future Sampling and Aquifer Testing

During future storm events, District staff will measure the effects on the aquifer of opening and closing the valves on the Antioch BMP. Head measurements will be made in the uppermost 10 zones of the well to see the impacts from significant impulses of recharge through Antioch Cave. Water-quality samples will also be collected from these zones to determine if water from Onion Creek recharging through the cave is reaching any of the monitor zones. During some period when there is moderate flow in Onion Creek, a tracer will be injected into Antioch Cave to determine where that water is going. Groundwater samples will be collected from the multiport monitor well, other adjacent wells, wells between Antioch and Barton Springs, and from Barton Springs. Data from such a study should give an indication of how nonpoint source pollution could be moving through the aquifer and reaching Barton Springs. Previous dye-trace studies have shown a connection between Antioch Cave and Barton Springs. In addition to collecting samples from the multiport monitor well, the District will continue the operation of the two CWQMN sites and will collect additional samples of stormwater at the Antioch BMP. Results of these studies will be posted on the District web site at bseacd.org.

Table 3-3. Table of head data (ft above mean sea level) and field and laboratory parameters from the Antioch multiport well.

Westbay Zones	Spec Cond* (uS/cm)	TDS** (mg/L)	Nitrogen*** (mg/L)	Head 9/30/10	Head 10/29/10	Head 12/2/10	Head 5/18/11
20	576	273	1.09	631.9	632.3	621.3	585.9
19	524	279	1.16	631.7	632.3	620.9	585.1
17	546	288	1.24	631.4	632.9	620.8	583.2
16	561	304	1.29	631.0	632.8	620.3	582.5
15	551	302	1.06	630.6	633.0	619.8	581.9
14	720	446	<0.02	630.4	632.7	619.7	581.7
13	718	439	<0.02	630.2	632.7	619.4	581.5
12	3,520	3,567	<0.02	630.5	632.0	620.7	583.2
11	3,010	2,884	<0.02	616.4	615.3	614.8	613.8
10	3,443	3,037	<0.02	616.8	615.5	615.6	615.8
9	3,225	2,853	<0.02	620.9	620.6	620.9	619.3
8	3,100	2,993	<0.02	621.5	621.7	621.9	619.0
7	3,463	3,268	<0.02	621.5	622.1	621.9	618.7
6	2,475	2,141	<0.02	622.3	622.8	623.4	620.8
5	2,504	2,658	<0.02	624.3	624.7	624.7	621.2
4	810	553	<0.02	625.4	626.4	624.8	619.8
3	1,110	711	0.02	630.6	632.5	629.4	622.4
2	1,400	963	<0.02	630.5	632.4	629.2	622.2
1	1,320	927	<0.02	625.9	627.0	625.1	619.6

*Measured with InSitu 9500 multi-parameter water-quality sensor
**Calculated from laboratory results
***Laboratory results for nitrogen from nitrate and nitrite

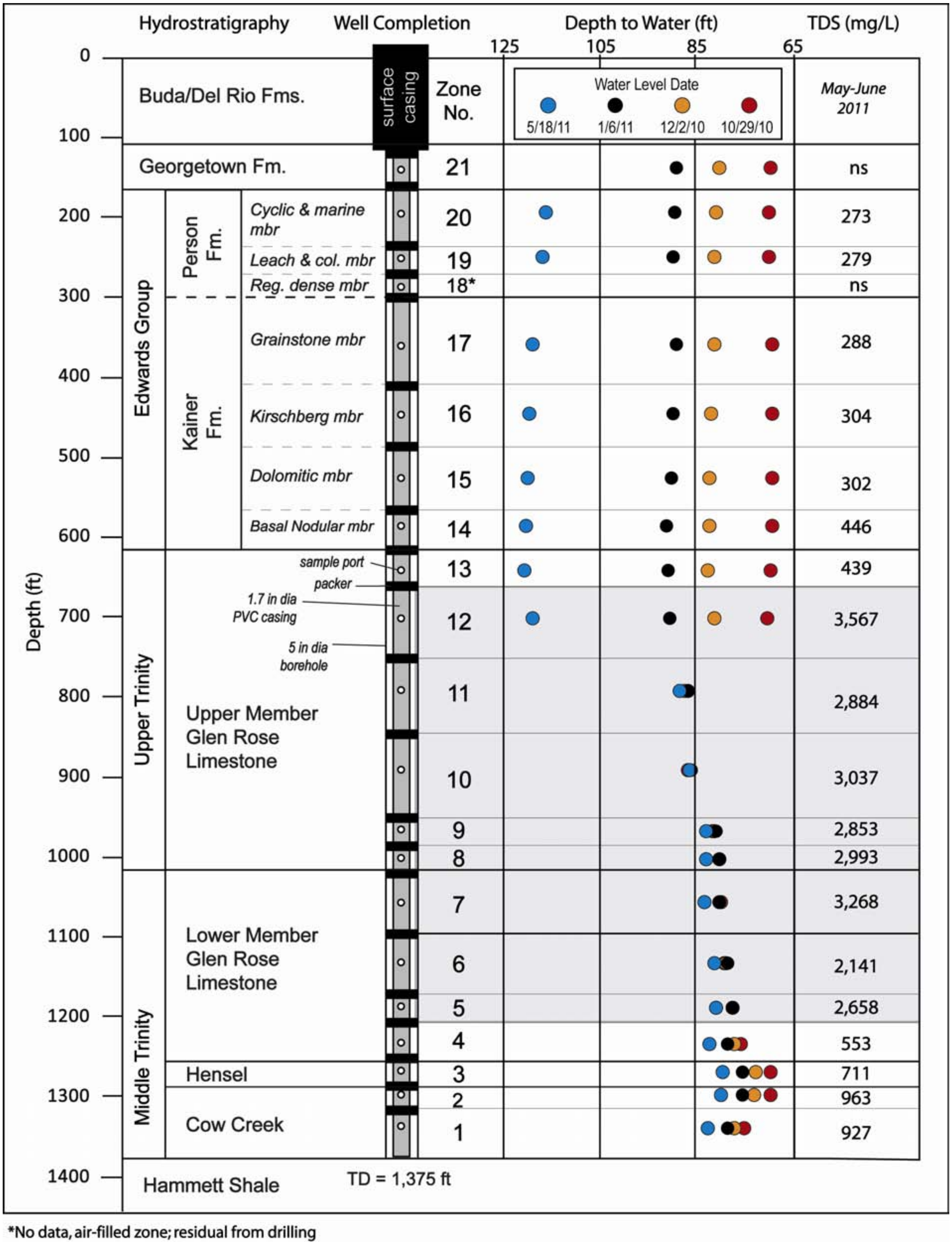


Figure 3-8. Diagram showing multiport monitor well construction, hydrogeologic units encountered in well, water-level results for five measurement events, and TDS values.

4.0 CONCLUSIONS

The upgraded BMP at Antioch Cave has demonstrated that such a system is capable of reducing the amount of stormwater contaminants entering the Barton Spring aquifer through Antioch Cave. These contaminants can potentially impact water-supply wells and water quality at Barton Springs where endangered salamanders live. The key findings and conclusions derived from this study are summarized below:

- The upgraded Antioch BMP is capable of significantly reducing the amount of nonpoint source contaminants entering the aquifer through Antioch Cave.
- It is estimated that during the period of operation of the upgraded BMP, 2,436 lbs of nitrogen (as nitrate and nitrite), 295 lbs of total phosphorus, and 190,480 lbs of total suspended solids (TSS) were prevented from entering the aquifer.
- Although bacteria concentrations were not a parameter monitored during this study, previous studies suggest that bacteria are a significant contaminant in Onion Creek during storm events and were reduced as a result of the operation of the BMP.
- Data from additional storm events are needed to provide a better estimate of potential flow into Antioch Cave. From these data, a better estimate of contaminant reduction can be made.
- The best water-quality indicators of storm flow are turbidity and TSS.
- Automation of the BMP has improved the efficiency of the system by opening and closing the main valve at the appropriate times, rather than the limited times when District staff can visit the site.
- Installation of a flow meter near the main valve provides more accurate and reliable data for determining volume of flow into the BMP. This flow value is also used to estimate how much stormwater is not entering the BMP.
- The two CWQMN systems installed in Onion Creek provide flow and water-quality data for water entering and leaving the recharge zone.
- Data provided by the CWQMN systems and laboratory analyses of grab samples can be used to compare future water quality in Onion Creek as the Onion Creek watershed becomes more developed.
- During moderate to severe drought conditions, significant rainfall is needed for water to flow in Onion Creek. During non-drought conditions, much less rainfall is needed to get water flowing or to increase the rate of flow in Onion Creek.
- Head and geochemical data from the multiport monitor well during drought conditions indicate that most of the zones within the Edwards are in hydrologic communication with each other. This also includes two zones (zones 12 and 13) in the upper-most upper member of the Glen Rose Limestone.
- Groundwater quality of the zones completed in the Edwards is good with low conductivity, nitrogen was slightly elevated above baseflow in Onion Creek, and phosphorus was not detected.
- The majority of the upper member of the Glen Rose Limestone appears to act as an aquitard between the Edwards and Lower Glen Rose, Hensel, and Cow Creek formations.

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Appendix A

Three-Dimensional Geologic Model of the Barton Springs segment of the Edwards Aquifer and the Antioch Cave vicinity, Central Texas

Brian B. Hunt, P.G., Nathanael Banda, and Brian A. Smith, Ph.D., P.G.
Barton Springs/Edwards Aquifer Conservation District

Natural complexity of hydrologic issues and features often makes it a challenge to communicate with a non-technical audience using two-dimensional maps and figures. An effective tool for understanding and communicating the complexity of an aquifer system is three-dimensional (3D) visualization models. The purpose of this appendix is to describe the data, tools and process used to construct a realistic geologic framework for the both the region and the local scale in the vicinity of the Antioch Cave BMP.

The goals of this 3D modeling effort are to establish a geologic framework in which subsequent data sets, such as water levels or physiochemical parameters, can be evaluated and displayed in its geologic context. The broader goal is to support scientific evaluations and to create an engaging and easily interpretable format for decision-making and public consumption of information, outreach and education.

<u>Data and Methods</u>

The software used to create 3D models from geologic input data is called MVS, or Mining Visualization Software®, developed by the C-Tech Corporation (Figure 1). The regional 3D geologic framework, sources of data, and methods of construction presented in this appendix are described in Hunt et al. (2010) and are similar to what was done for the local scale model of the Antioch vicinity. Below is an abbreviated discussion of the data and methods used to create the local scale 3D model.

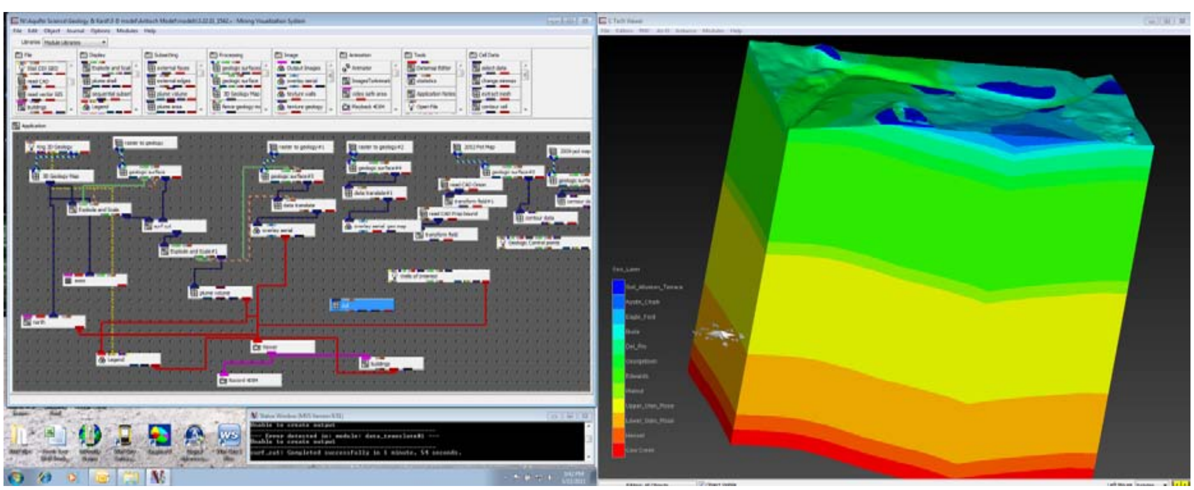

Figure 1. Screen capture showing the MVS software network on the left, and the visualization of the network on the right.

The extent of the model was chosen to include the Antioch BMP feature and the Antioch Westbay Monitor Well. The local scale 3D model measures about 1,000 (N-S) by 2,100 meters (E-W). All data used in the 3D geologic models use the Universal Transverse Mercator (UTM) coordinate system zone 14 North (N) and the North American Datum of 1983 (NAD83). All units vertical and horizontal are in meters.

Surface data

A five-meter grid resolution Digital Terrain Model (smoothed elevation), which represents the bare ground surface, was obtained for the Antioch BMP vicinity. Elevation resolution was sub-meter in scale and varied from 202 to about 235 meters above sea level. The geologic map of the Barton Springs segment of the Edward Aquifer (Small et la., 1996), were used to define control points along key geologic contacts and were also overlayed onto the surface of the final 3D model. Aerial imagery was obtained using Microsoft's Virtual Earth.

Subsurface data

Subsurface geologic data was derived from the BSEACD's existing geologic control point database (BSEACD, unpublished), although data from the geologic map was used to fill in data gaps in the study area. Thicknesses of geologic units from the Antioch Westbay Well were applied to constrain surface and subsurface contacts to generate additional subsurface control. Table 1 shows the thicknesses applied that were derived from the Antioch Westbay Well.

Table 1. Unit thicknesses derived from the Antioch Westbay Multiport well (58-58-431).
Geologic picks derived from Al Broun, P.G. and Brian Hunt, P.G.

Unit	Depth to Top (ft)	Thickness (ft)	Thickness (m)
Eagle Ford		30	9
Buda	18	30	9
Del Rio	48	60	18
Georgetown	108	57	17
Edwards Group	165	401	122
Walnut	566	49	15
Upper Glen Rose	615	400	122
Lower Glen Rose	1015	240	73
Hensel	1255	60	18
Cow Creek	1315	60	18
Hammett	1375	40	13

Modeling Approach

The modeling approach was to collect and format the data into an established hierarchy (stratigraphy) MVS recognizes, build the grid of the model, and then interpolate the data into surfaces and volumes. The layered geologic model does not discretely model faults. The elevation surface was then used to cut the geologic layers and create a realistic surface expression of the model. Aerial photos, geologic maps, and other data are then layered into the model.

Results

The results of this modeling effort are an accurate and visually appealing regional (Figure 2) and local scale 3D geologic model (Figures 3 and 4) that closely matches our conceptual model and published geologic maps and cross-sections (Hunt et al., 2010). Faults are not explicitly modeled, yet the modeled formations reflect major faulting (Figure 4). Once the geologic framework is built, it is relatively simple to display and view hydrologic data within the model. Figure 4 contains a series of model images including a potentiometric map for the Antioch area. Output from the model can be freely and readily distributed and viewed by the general public.

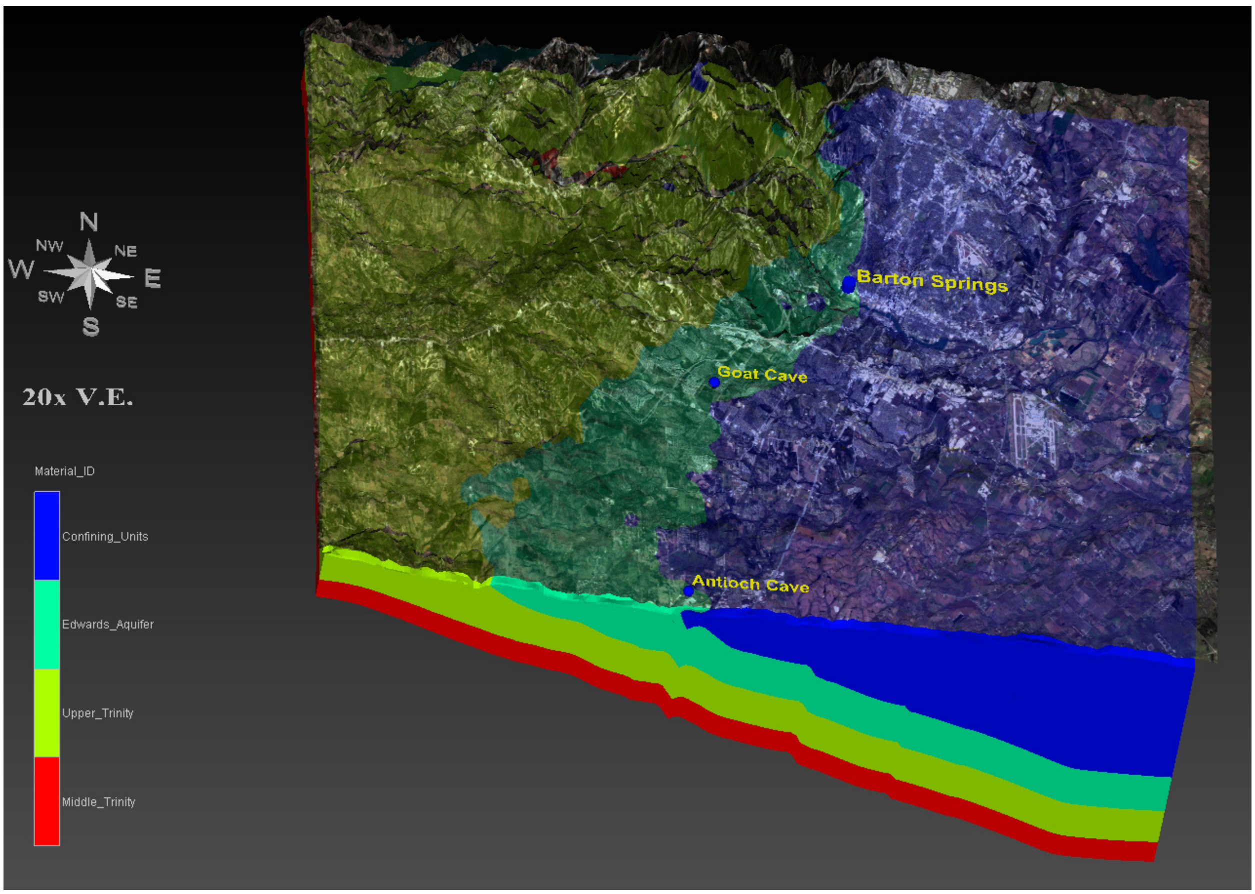

Figure 2. Image of the regional 3D geologic model. The satellite image is partially transparent so the geologic units are visible. Modified from Hunt et al., 2010.

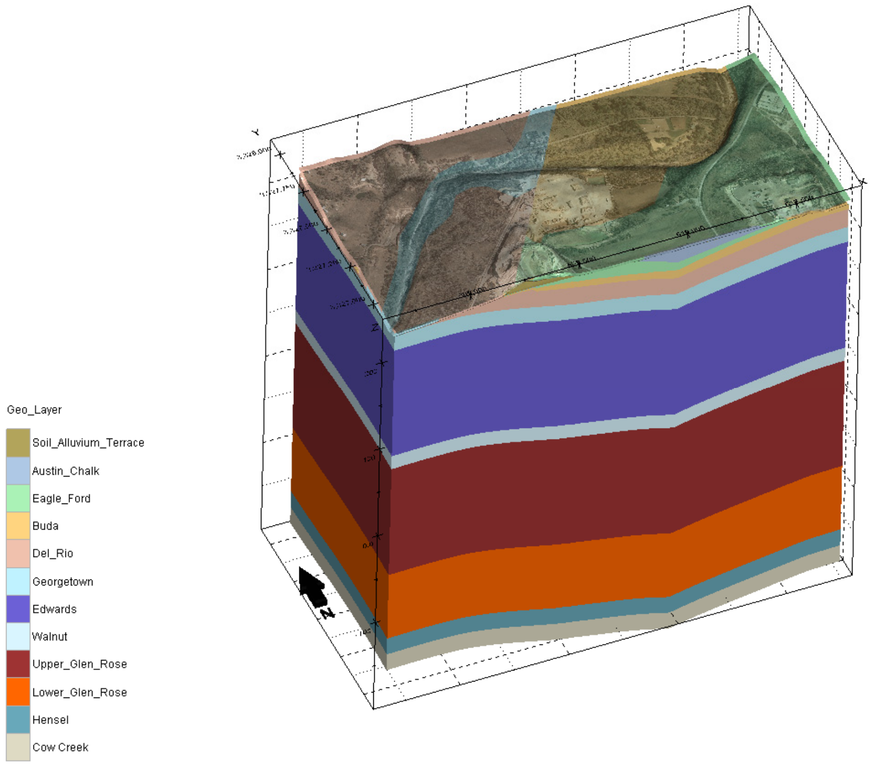

Figure 3. Image of the local scale 3D geologic model showing all 12 geologic layers.

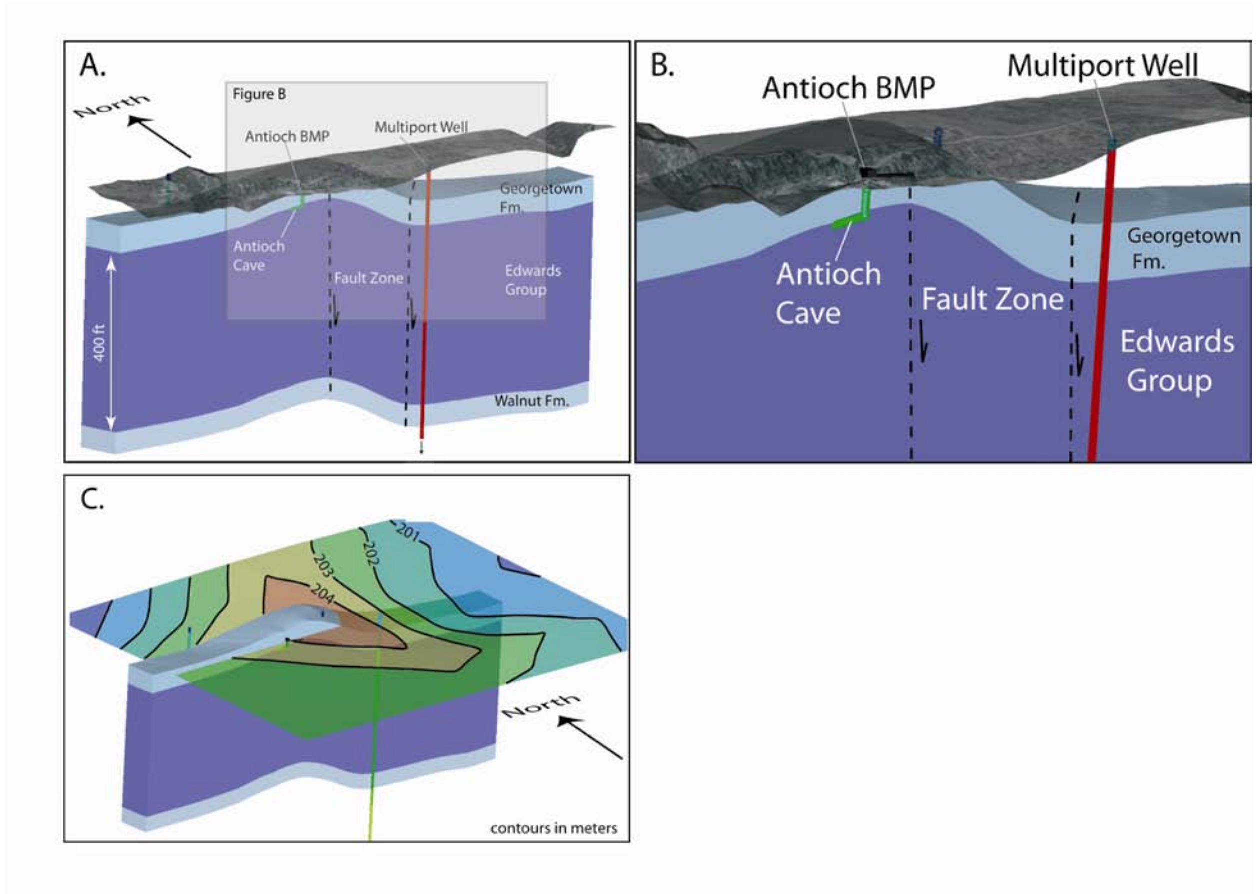

Figure 4. Series of images showing details of the geology in the Edwards Aquifer. Image C shows a potentiometric surface from high-flow conditions in the model.

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Acknowledgments

Support from the BSEACD Board of Directors and BSEACD General Manager Kirk Holland, P.G., Daniel B. Stephens, and C-Tech Development Corporation is acknowledged. Geologic picks from Al Broun, P.G.

APPENDIX B

EDUCATION AND OUTREACH ACTIVITIES

Over the course of this grant project, District staff have given numerous presentations about the project, published abstracts and papers, and have hosted a number of visits to the Antioch BMP. A list of these is presented below.

<u>Presentations, Abstracts, and Papers</u>

Presentation about enhanced recharge at Antioch Cave to Edwards Aquifer Recovery Implementation Plan meeting, November 12, 2008, Trinity University, San Antonio, TX.

Smith, Brian A., Brian B. Hunt, and Joseph Beery, 2009, Recharge Enhancement and Protection of a Karst Aquifer in Central Texas: River Systems Institute, Texas State University, Land Water People Conference, San Marcos, TX, November 15-17, 2009.

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Smith, Brian A., Brian B. Hunt, and Joseph Beery, 2011, Antioch Cave: A Successful Class V UIC Stormwater Injection System, Edwards Aquifer, Central Texas: 2011 Underground Injection Control Conference, Groundwater Protection Council, Austin, TX, January 24-27, 2011.

<u>Field Trips</u>

Visit by geologists from Cyprus, February 4, 2008.

Smith, Brian and Brian Hunt, 2009, Recharge and Discharge Features of the Edwards and Trinity Aquifer, Central Texas: Fieldtrip Guidebook, Karst Horizons, 15th International Congress of Speleology, Kerrville, Texas, June 22, 2009.

Visit by water specialists from Brazil, hosted by USGS, September 15, 2010.

Visit by Dr. Ben Swartz of Texas State University and about 10 of his geology students, October 19, 2010.

Visit by staff of the Texas Water Development Board, November 10, 2010.

<u>Video</u>

Visit to Antioch Cave by Jim Swift and camera crew from KXAN TV. Special interest story was shown on KXAN Evening News on November 18, 2009.

Participated with the City of Austin Channel 6 in preparing a video about the Edwards Aquifer for use in high schools. Video of Antioch Cave was shot on November 23, 2010. A film clip is located at: http://www.cityofaustin.org/watershed/groundwater.htm.

Appendix C

Onion Creek Recharge Project
Quality Assurance Project Plan

Barton Springs/Edwards Aquifer
Conservation District
Austin, Texas 78748

Funding Source:

Nonpoint Source Protection Program CWA §319(h)
Prepared in cooperation with the Texas Commission on Environmental Quality
and the U.S. Environmental Protection Agency
Federal ID #C9-996146-11

Effective Period: April 15, 2010 – April 15, 2011

Questions concerning this quality assurance project plan should be directed to:

Brian A. Smith
Barton Springs/ Edwards Aquifer Conservation District
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Austin, TX 78748
512-282-8441
brians@bseacd.org

A1 Approval Page

Barton Springs/Edwards Aquifer Conservation District

Brian A. Smith	Date	Brian Hunt, QA Officer	Date

LCRA Environmental Laboratory Services

Alicia Gill, Laboratory Manager	Date	Hollis Pantalion, Laboratory QA Officer	Date

Barton Springs/Edwards Aquifer Conservation District will secure written documentation from additional project participants (e.g., subcontractors, laboratories) stating the organization's awareness of and commitment to requirements contained in this quality assurance project plan and any amendments or revisions of this plan. BSEACD will maintain this documentation as part of the project's quality assurance records. This documentation will be available for review.

A2 Approval Page

Texas Commission on Environmental Quality

Compliance Support Division

Stephen Stubbs, QA Manager Date Quality Assurance Section	Kyle Girten, QA Specialist Date Quality Assurance Team

Water Quality Planning Division

Section Manager Date Planning and Implementation Section	Team Leader Date Nonpoint Source Team
Clyde Bohmfalk, Project Manager Date NPS Team	Jennifer Delk, Project QAS Date NPS Program

A2 Table of Contents

A3 Distribution List

BSEACD will provide copies of this project plan and any amendments or revisions of this plan to each project participant defined in the list below. BSEACD will document receipt of the plan by each participant and maintain this documentation as part of the project's quality assurance records. This documentation will be available for review.

Texas Commission on Environmental Quality
P.O. Box 13087
Austin, Texas 78711-3087

Kyle Girten, Quality Assurance Specialist
MC-176
(512) 239-0425

Clyde Bohmfalk, NPS Project Manager
MC-147
(512) 239- 0849

Barton Springs/Edwards Aquifer Conservation District
1124 Regal Row
Austin, TX 78748

Brian A. Smith, Project Manager
(512) 282-8441

Brian Hunt, Quality Assurance Officer
(512) 282-8441

LCRA Environmental Laboratory Services
3505 Montopolis
Austin, TX 78744

Alicia Gill, Laboratory Manager
(512) 356-6022

Hollis Pantalion, Laboratory Quality Assurance Officer
(512) 356-6022

U.S. Environmental Protection Agency Region 6
Section Name
1445 Ross Avenue
Suite # 1200
Dallas, TX 75202-2733

Randall Rush, Project Officer
(214) 665-7107

List of Acronyms

AWRL	Ambient Water Reporting Limit
BMP	Best Management Practice
BSEACD	Barton Springs/Edwards Aquifer Conservation District
CAMS	Continuous Ambient Monitoring Station
CAR	Corrective Action Report
COC	Chain of Custody
CRP	Clean Rivers Program
CWA	Clean Water Act
CWQMN	Continuous Water Quality Monitoring Network
DOC	Demonstration of Capability
DMP	Data Management Plan
DMRG	Data Management Reference Guide
DQO	Data Quality Objective
EPA	Environmental Protection Agency
GIS	Geographic Information System
LCS	Laboratory Control Sample (formerly Laboratory Control Standard)
LCSD	Laboratory Control Sample Duplicate (formerly Laboratory Control Standard Duplicate)
LOD	Limit of Detection
LOQ	Limit of Quantitation (formerly reporting limit)
NCR	Nonconformance Report
NELAC	National Environmental Laboratory Accreditation Conference
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NTU	Nephelometric Turbidity Units
PO	Project Officer
QA/QC	Quality Assurance/Quality Control
QAM	Quality Assurance Manual
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QAS	Quality Assurance Specialist

QMP	Quality Management Plan
RPD	Relative Percent Difference
SLOC	Station Location Form
SOP	Standard Operating Procedure
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TSS	Total Suspended Solids
TSWQS	Texas Surface Water Quality Standards
WQI	Water Quality Inventory

A4 Project/Task Organization

TCEQ

Compliance Support Division

Kyle Girten
TCEQ Lead QA Specialist
Assists the TCEQ Project Manager in QA related issues. Serves on planning team for NPS projects. Participates in the planning, development, approval, implementation, and maintenance of the QAPP. Determines conformance with program quality system requirements. Coordinates or performs audits, as deemed necessary and using a wide variety of assessment guidelines and tools. Concurs with proposed corrective actions and verifications. Monitors corrective action. Provides technical expertise and/or consultation on quality services. Provides a point of contact at the TCEQ to resolve QA issues. Recommends to TCEQ management that work be stopped in order to safe guard project and programmatic objectives, worker safety, public health, or environmental protection.

Water Quality Planning Division

TCEQ NPS Program Manager
Responsible for management and oversight of the TCEQ NPS Program. Oversees the development of QA guidance for the NPS program to be sure it is within pertinent frameworks of the TCEQ. Monitors the effectiveness of the program quality system. Reviews and approves all NPS projects, internal QA audits, corrective actions, reports, work plans, and contracts. Enforces corrective action, as required. Ensures NPS personnel are fully trained and adequately staffed.

Clyde Bohmfalk
TCEQ NPS Project Manager
Maintains a thorough knowledge of work activities, commitments, deliverables, and time frames associated with projects. Develops lines of communication and working relationships between the BSEACD, the TCEQ, and the EPA. Tracks deliverables to ensure that tasks are completed as specified in the contract. Responsible for ensuring that the project deliverables are submitted on time and are of acceptable quality and quantity to achieve project objectives. Serves on planning team for NPS projects. Participates in the development, approval, implementation, and maintenance of the QAPP. Assists the TCEQ QAS in technical review of the QAPP. Responsible for verifying that the QAPP is followed by BSEACD. Notifies the TCEQ QAS of particular circumstances which may adversely affect the quality of data derived from the collection and analysis of samples. Enforces corrective action.

TCEQ NPS Project Quality Assurance Specialist
Assists Lead QAS with NPS QA management. Serves as liaison between NPS management and Agency QA management. Responsible for NPS guidance development related to program quality assurance. Serves on planning team for NPS projects. Participates in the development, approval, implementation, and maintenance of the QAPP.

TCEQ NPS Data Manager
Responsible for tracking and verifying of NPS data. Maintains data storage system for NPS quality assured datasets. Coordinates correction of data errors with TCEQ NPS Project Managers and BSEACD

Data Managers. Provides training and guidance to BSEACD on technical data issues. Serves on planning team for NPS projects. Reviews and approves data-related portions of project-specific QAPPs. Performs technical reviews of project-specific Data Management Plans. Develops and maintains Standard Operating Procedures for NPS data management.

Barton Springs/Edwards Aquifer Conservation District (BSEACD)

Brian Smith
BSEACD Project Manager
Responsible for ensuring tasks and other requirements in the contract are executed on time and are of acceptable quality. Monitors and assesses the quality of work. Coordinates attendance at conference calls, training, meetings, and related project activities with the TCEQ. Responsible for verifying the QAPP is followed and the project is producing data of known and acceptable quality. Ensures adequate training and supervision of all monitoring and data collection activities. Complies with corrective action requirements.

Brian Hunt
BSEACD QAO
Responsible for coordinating development and implementation of the QA program. Responsible for writing and maintaining the QAPP. Responsible for maintaining records of QAPP distribution, including appendices and amendments. Responsible for maintaining written records of sub-tier commitment to requirements specified in this QAPP. Responsible for identifying, receiving, and maintaining project quality assurance records. Responsible for coordinating with the TCEQ QAS to resolve QA- related issues. Notifies the BSEACD Project Manager and TCEQ Project Manager of particular circumstances which may adversely affect the quality of data. Responsible for validation and verification of all data collected according to Section D2 procedures and acquired data procedures after each task is performed. Coordinates the research and review of technical QA material and data related to water quality monitoring system design and analytical techniques. Conducts laboratory inspections. Develops, facilitates, and conducts monitoring systems audits.

Nathaniel Banda
BSEACD Data Manager
Responsible for the acquisition, verification, and transfer of data to the TCEQ. Oversees data management for the study. Performs data quality assurances prior to transfer of data to TCEQ. Responsible for transferring data to the TCEQ in the acceptable format. Ensures data are submitted according to workplan specifications. Provides the point of contact for the TCEQ Data Manager to resolve issues related to the data.

Joseph Beery
BSEACD Field Supervisor
Responsible for supervising all aspects of the sampling and measurement of surface waters and other parameters in the field. Responsible for the acquisition of water samples and field data measurements in a timely manner that meet the quality objectives specified in Section A7 (Table A7.1), as well as the requirements of Sections B1 through B8. Responsible for field scheduling, staffing, and ensuring that staff are appropriately trained as specified in Sections A6 and A8.

LCRA Environmental Laboratory Services

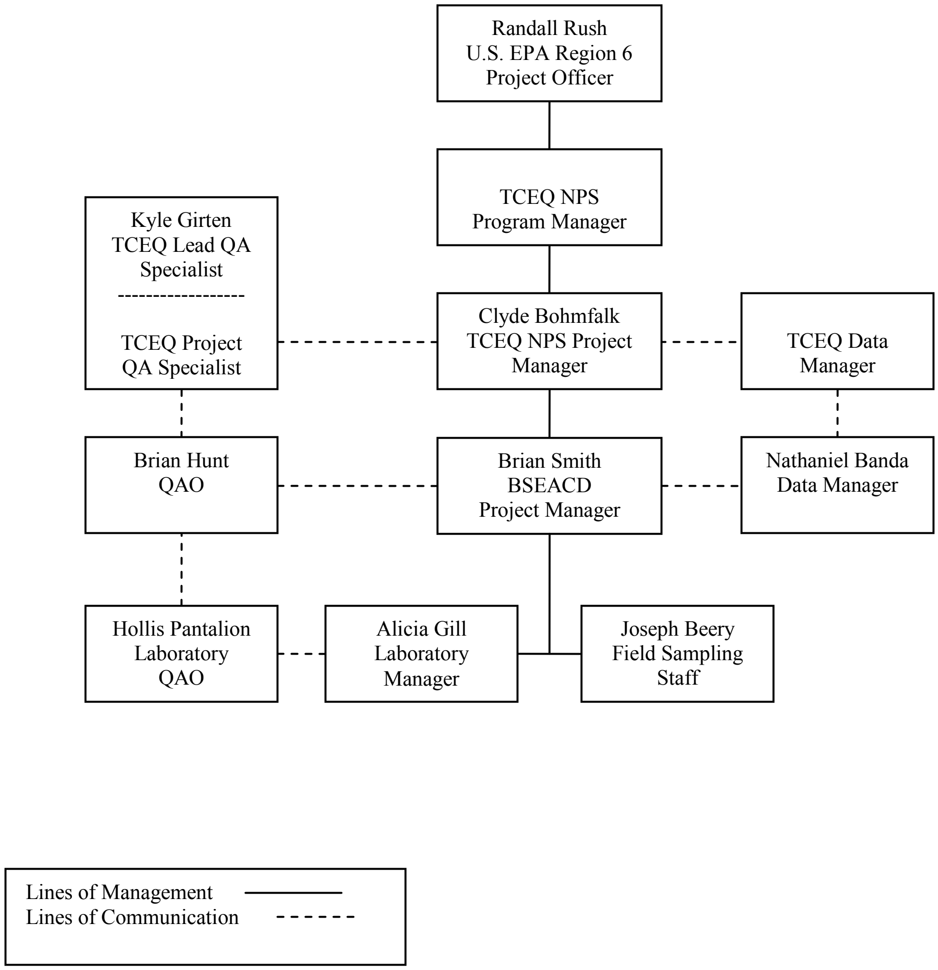
Alicia Gill Laboratory Manager
Responsible for supervision of laboratory personnel involved in generating analytical data for this project. Responsible for ensuring that laboratory personnel involved in generating analytical data have adequate training and a thorough knowledge of the QAPP and all SOPs specific to the analyses or task performed and/or supervised. Responsible for oversight of all operations, ensuring that all QA/QC requirements are met, and documentation related to the analysis is completely and accurately reported. Enforces corrective action, as required. Develops and facilitates monitoring systems audits.

Hollis Pantalion
Laboratory QAO
Monitors the implementation of the QAM and the QAPP within the laboratory to ensure complete compliance with QA objectives as defined by the contract and in the QAPP. Conducts internal audits to identify potential problems and ensure compliance with written SOPs. Responsible for supervising and verifying all aspects of the QA/QC in the laboratory. Performs validation and verification of data before the report is sent to BSEACD. Insures that all QA reviews are conducted in a timely manner from real-time review at the bench during analysis to final pass-off of data to the QA officer.

U.S. EPA Region 6

Randall Rush
EPA Project Officer
Responsible for managing the CWA Section 319 funded grant on the behalf on EPA. Assists the TCEQ in approving projects that are consistent with the management goals designated under the State's NPS management plan and meet federal guidance. Coordinates the review of project workplans, draft deliverables, and works with the State in making these items approvable. Meets with the State at least semi-annually to evaluate the progress of each project and when conditions permit, participate in a site visit on the project. Fosters communication within EPA by updating management and others, both verbally and in writing, on the progress of the State's program and on other issues as they arise. Assists the regional NPS coordinator in tracking a State’s annual progress in its management of the NPS program. Assists in grant close-out procedures ensuring all deliverables have been satisfied prior to closing a grant.

Figure A4.1. Organization Chart - Lines of Communication



A5 Problem Definition/Background

The Edwards Aquifer, located in south-central Texas, is one of the most prolific karst aquifers in the United States and is an important groundwater resource for municipal, industrial, domestic, agricultural, recreational, and ecological needs. The aquifer extends about 270 miles from the Rio Grande River along the Mexico/United States border at Del Rio, east to San Antonio, then northeast through Austin to Salado. Hydrologic divides separate the Edwards Aquifer into three major segments: the San Antonio, Barton Springs, and Northern segments and numerous subsections.

The Barton Springs segment of the Edwards Aquifer is the focus of this project (Appendix A). Approximately 50,000 people depend on water from the Barton Springs aquifer as their sole source of drinking water, and the various spring outlets at Barton Springs are the only known habitats for the endangered Barton Springs salamander.

Up to 85 percent of recharge to the aquifer is derived from streams originating on the contributing zone, located up gradient and west of the recharge zone. Water flowing onto the recharge zone sinks into numerous caves, sinkholes, and fractures recharging the aquifer. Groundwater then moves northeast toward wells and Barton Springs. Onion Creek contributes about one third of all recharge, with most of that recharge occurring within several discrete recharge features within the creek bottom (Appendix A).

EPA identifies karst aquifers as one of the most vulnerable to pollution because of their rapid groundwater velocities and limited ability to filter contaminants. Numerous tracer tests have been performed on the Barton Springs aquifer demonstrating that rapid groundwater flow occurs in an integrated network of conduits discharging at wells and springs. A portion of this groundwater flows from the conduits into the diffuse matrix of the aquifer building up storage in the aquifer. Water from storage flows diffusely to wells or back into the conduit network. This dual flow system results in contamination having the potential to rapidly impact wells and springs, as well as slowly accumulate and move within the matrix of the aquifer.

The TCEQ lists the Barton Springs aquifer on a list of impaired groundwater resources. Onion Creek is listed on the 303(d) list of impaired streams. Increases in sediment, bacteria, and other contaminants in groundwater as a result of storm-flow events in the Barton Springs aquifer have been documented by analysis of water samples from monitor and water-supply wells.

To reduce the amount of sediment and other storm-related contaminants entering one of these recharge features, an automated control system has been designed and installed at the BMP that was previously constructed over Antioch Cave on Onion Creek. Two valves on the BMP controls flow into the cave.

During periods of storm water flow in the creek, valves will be closed to prevent entry of sediment-laden water into the recharge feature. Continuous water quality monitoring network (CWQMN) systems have been installed at the Antioch site and at the low water dam site within the Onion Creek Management Area, which will monitor turbidity and other parameters in water flowing in the creek. When turbidity reaches a level indicative of storm-water flow, 100 Nephelometric Turbidity Units (NTU), the valve on the Antioch BMP will be automatically closed. When turbidity drops to a level consistent with no storm-water flow, 50 NTU, the valve will be opened, allowing better quality water to enter the aquifer. Operation of these systems will decrease the amount of sediment and other storm-water related contaminants entering the aquifer. This will improve the quality of water in the aquifer that thousands of users rely upon and that the endangered salamanders need for survival.

To monitor the influence of recharge via Antioch Cave on the Edwards Aquifer, a multiport monitor well will be installed near Antioch Cave. The movement of non-point source pollution in the various units of the Edwards Aquifer will be monitored in this well. Details about this type of monitor well are described in Section A6.

A6 Project/Task Description

CWQMN Installation

The installation of the two CWQMN systems in the Onion Creek watershed will monitor water quality at two locations, one in the upper portion of the recharge zone, and the second at the lower portion of the recharge zone within the Barton Springs segment of the Edwards Aquifer (Barton Springs aquifer)
This project's goal is to improve water quality in the Barton Springs aquifer by facilitating timely and efficient responses to recharge events by continuously monitoring water quality in the Onion Creek Watershed and excluding "first flush" flows of contaminated storm water into a recharge feature on Onion Creek. This will be accomplished using a BMP with a valve that automatically opens when a storm water pulse has passed to allow recharge of clean surface water into the aquifer. The valve will be triggered based on CWQMN data from the site. The valve will close when turbidity is determined to be high, currently at 100 NTU. The valve will reopen when turbidity lowers to acceptable concentrations of 50 NTU.

This implementation assessment project will provide operation and maintenance of an automated remote water-quality monitoring site, Antioch Cave BMP, for up to three years. Two CWQMN sites have been installed on Onion Creek, one at the Antioch BMP location and the second 8 miles upstream of Antioch at the Onion Creek Management Area low water dam. Each CWQMN site in the Onion Creek Watershed will analyze ambient water for DO, turbidity, temperature, and conductivity. Continuous water-quality monitoring will be conducted in accordance with TCEQ's established CWQMN quality assurance project plan (QAPP). Data will be transmitted to TCEQ electronically to be uploaded into the LEADS system.

Surface Water Sampling

Water samples from the Antioch BMP on Onion Creek will also be collected by using an automatic sampler during three to five storm flow events and manual (grab) samples will be collected when possible for base flow samples between storm events.

Samples will be analyzed for TSS, TDS, turbidity, nitrate and nitrite as N, and total phosphate. An automated sampler will collect samples when triggered by a storm event. Water-quality data will be used to determine the amount of pollutant loads (nitrate/nitrite, phosphorus, and sediment) that are prevented from entering the aquifer by operation of the Antioch BMP. This will be accomplished by first calculating the amount of contaminants in Onion Creek during the storm pulse and then calculating the amount of water not entering the aquifer when the valve is closed. This volume will be determined by taking the flow rate of water entering the BMP when the valve is first opened following a storm event multiplied by the length of time the valve was closed. The masses of nitrate/nitrite, phosphorous, and sediment prevented from entering the aquifer will be calculated with the following formula:

$$Q * C_{N,P,S} * T = M_{N,P,S}$$

where

Q = Rate of flow into Antioch BMP when valve is first opened following storm pulse

$C_{N,P,S}$ = Concentration of N (nitrate/nitrite), P (phosphorous), or S (sediment) during storm pulse

T = Duration of time that valve on BMP was closed

$M_{N,P,S}$ = Mass of contaminant prevented from entering aquifer

See Section B1 for monitoring to be conducted under this QAPP.

Installation of Multiport Monitor Well

The modified BMP was designed to allow as much as 250.0 cubic feet per second (cfs) of water to recharge the aquifer. However, it is not known how much water the cave is capable of recharging. Beyond the rather limited extent of the explored cave passage, it is not known which route or routes the water takes to reach the water table. Once the recharge water reaches the saturated zone of the aquifer, its path is predominately to the north and Barton Springs. Nothing is known about the vertical movement of water in the aquifer. The Edwards Aquifer has been divided into eight lithostratigraphic units, each with unique hydrologic properties. However, standard monitor wells are not capable of monitoring vertical components of flow in an aquifer. The installation of a multiport monitor well at Antioch will allow for characterization of the aquifer's pathways in a vertical sense. Movement of water recharged through the Antioch BMP and the non-point source pollutants in the aquifer can be monitored in discrete zones within a single monitor well that is completed with multiple monitoring zones.

The preferred multiport well system for this installation is manufactured by Westbay Instruments of Vancouver, Canada, a Schlumberger company. Westbay® multiport wells have been installed at numerous environmental sites around the U.S. and the world, including the District. With these types of wells, almost any number of monitoring zones can be installed in a well. Monitoring zones are separated by packers that seal off the annular space between the borehole wall and the well casing. Specialized ports that are built into the casing allow for access to the aquifer for sampling, water-level (pressure) measurements, and aquifer tests. Groundwater samples collected from each zone are representative of the groundwater in the aquifer between the packers. Water-level data from the zones can give an indication of potential direction of vertical movement of water within the aquifer. Aquifer tests, such as slug tests, can identify zones of higher permeability through which groundwater is more likely to flow. Data from such a well at Antioch will provide needed information about how non-point source pollutants are moving through the aquifer and how they might impact water-supply wells and Barton Springs. Sampling of the well will be conducted in conjunction with recharge events to see how the sediments and contaminants in the surface water are transmitted through the aquifer. Groundwater samples will be analyzed for the same constituents as the surface water samples. Manufacturer's procedures for collection of groundwater samples from the multiport monitor well are included in Appendix D.

A multiport well installed at this site will be completed with about 10 to 12 monitoring zones. Total depth of the well will be about 600 ft with the bottommost zone installed in the uppermost unit of the Glen Rose Limestone. The location of each monitoring zone will be determined following geophysical logging of the completed borehole.

Revisions to the QAPP

Revisions may be made to this QAPP following selection of the second site to address sampling and monitoring activities that might vary between sites.

Until the work described is completed, this QAPP shall be revised as necessary and reissued annually on the anniversary date, or revised and reissued within 120 days of significant changes, whichever is sooner. The most recently approved QAPPs shall remain in effect until revisions have been fully approved; reissuances (i.e., annual updates) must be submitted to the TCEQ for approval before the last version has expired. If the entire QAPP is current, valid, and accurately reflects the project goals and organization's policy, the annual reissuance may be done by a certification that the plan is current. This can be accomplished by submitting a cover letter stating the status of the QAPP and a copy of new, signed approval pages for the QAPP.

Amendments

Amendments to the QAPP may be necessary to reflect changes in project organization, tasks, schedules, objectives, and methods; address deficiencies and nonconformances; improve operational efficiency; and/or accommodate unique or unanticipated circumstances. Requests for amendments are directed from the BSEACD Project Manager to the TCEQ Project Manager in writing using the QAPP Amendment shell. The changes are effective immediately upon approval by the TCEQ NPS Project Manager and Quality Assurance Specialist, or their designees, and the EPA Project Officer.

Amendments to the QAPP and the reasons for the changes will be documented, and revised pages will be forwarded-to all persons on the QAPP distribution list by the BSEACD QAO. Amendments shall be reviewed, approved, and incorporated into a revised QAPP during the annual revision process or within 120 days of the initial approval in cases of significant changes.

A7 Quality Objectives and Criteria

The objectives of the data collection efforts of this project are as follows:

Continuous water quality monitoring will be conducted to operate a valve over a recharge feature for the Barton Springs segment of the Edwards Aquifer. Continuous water quality monitoring will also obtain information about water quality in Onion Creek and water quality entering the aquifer. CWQMN Data will be telemetered to TCEQ to be uploaded into the LEADS system.

Data from automatic samplers will be used to calculate the pollutant loads associated with stormwater runoff events in Onion Creek.

Manual grab samples will be collected to determine the amount of sediment and contaminants that enter the aquifer through Antioch Cave when the valve is open. These values will be compared to values for storm flow when the valve on the Antioch BMP is closed. Such a comparison will give us a better understanding of the quality of water entering the aquifer along Onion Creek. With that knowledge, we can better understand non-point source pollution in the Onion Creek watershed. Grab samples, that will be representative of base flow conditions, will be collected following each sampled storm event. The only exceptions will be for back-to-back storm events for which there will insufficient time to coordinate sampling.

Onion Creek Recharge Project will employ only methods and techniques which have been determined to produce measurement data of a known and verifiable quality and which are sufficient to meet the objectives of the project.

Measurement Quality Objectives (MQOs) and Data Quality Objectives (DQOs) to support the Continuous Water Quality Monitoring Network (CWQMN) objectives are specified in Tables A7.2 and A7.3, respectively. Data Quality Objectives for automatic sampling data are in table A7.1. The quality control (QC) program has been developed with these objectives in mind. Methods used for water-quality measurements in the CWQMN are based on *Standard Methods used for the Examination of Water and Wastewater*, 20th Edition, 1998 unless otherwise specified.

Table A7.1 Measurement Performance Specifications for Automatic and Manual (Grab Sample) Monitoring

PARAMETER	UNITS	MATRIX	METHOD	PARAMETER CODE	AWRL	Limit of Quantitation (LOQ)	Recovery at LOQ (%)	PRECISION (RPD of LCS/LCSD)	BIAS %Rec. of LCS	Completeness (%)	Field / Lab
Specific Conductivity	uS/cm	water	SM 2510B and TCEQ SOP	00095	NA	NA	NA	NA	NA	90	Lab
Nitrate/Nitrite – N	mg/l	water	SM4500 NO3-H	00630	.05	0.02	70-130	20	80-120	90	Lab
Total Phosphorus	mg/L	water	EPA 365.4	00665	.06	0.06	70-130	20	80-120	90	Lab
TSS_SM	mg/L	water	SM 2540 D	00530	4	1	NA	20	80-120	90	Lab
TDS_SM	mg/l	water	SM 2540 C	70300	10	10	NA	20	80-120	90	Lab
TURB_W Turbidity	NTU	water	SM 2130 B	82079	NA	NA	NA	NA	NA	90	Lab

References: *US EPA Methods for Chemical Analysis of Water and Wastewater*, Manual #EPA-600/4-79-020. American Public Health Association, American Water Works Association and Water Environment Federation, *Standard Methods for the Examination of Water and Waste Water*, 20th Ed., Texas Commission on Environmental Quality *Surface Water Quality Monitoring Procedures*, Volume 1.

** Based on range statistic as described in Standard Methods, 21st Edition, Section 9020-B, Quality Assurance/Quality Control - Intralaboratory Quality Control Guidelines. This criterion applies to bacteriological duplicates with concentrations >10 MPN/100mL or > 10 org./100 mL.

Table A7.2 DQOs for Continuous Water-Quality Monitoring Sondes (Multi-Probes)

Parameter	Parameter Code	Units	Measurement Equipment	Method	Calibration Verification Sample (CVS)**
DO	00300	mg/L	In-Situ MP Troll 9500	ASTM#D888-05 Method C	% Saturation ≤ 6.0% ± 0.50 mg/L
SC	00094	US/cm	In-Situ MP Troll 9500	Std. Mthds. 2510, EPA 120.1	≤ 5.0% RPE
Depth	NA	Feet @ 30psi	In-Situ MP Troll 9500	NA	NA
Turbidity	NA	NTU	In-Situ MP Troll 9500	Optical	NA
Temperature	00010	Celsius	In-Situ MP Troll 9500	EPA 170.1	NA

**CVS criteria for use in the 305(b) and 303(d) Lists per SWQM DQOs.
NA = Not Applicable

Table A7.3 MQOs for 500 KHz Acoustic Doppler Current Profiler (ADCP) Flow Meters

Parameter	SOP	Flow Meter	Units	Method	Range[1]	Range[2]	Resolution	Accuracy
Volumetric Flow Rate Water Velocity	00094	Shallow Water (Intermittent Streams)	CFS	Doppler Ultrasonic, frequency 500kHz	0.033 to 5.0 ft	-5 to 20 ft/s	+0.01 ft + 0.1 ft/s	TBD

1- vertical beam; 2- water velocity
CFS = cubic feet per second
TBD = To be determined. This information will be provided in an amendment to the QAPP.

Precision

Precision is the degree to which a set of observations or measurements of the same property, obtained under similar conditions, conform to themselves. It is a measure of agreement among replicate measurements of the same property, under prescribed similar conditions, and is an indication of random error.

Field splits are used to assess the variability of sample handling, preservation, and storage, as well as the analytical process, and are prepared by splitting samples in the field. Control limits for field splits are defined in Section B5.

Laboratory precision is assessed by comparing replicate analyses of laboratory control samples in the sample matrix (e.g. deioinized water, sand, commercially available tissue). Precision results are compared against measurement performance specifications and used during evaluation of analytical performance. Program-defined measurement performance specifications for precision are defined in Table A7.1.

Bias

Bias is a statistical measurement of correctness and includes multiple components of systematic error. A measurement is considered unbiased when the value reported does not differ from the true value. Bias is determined through the analysis of laboratory control samples and LOQ Check Standards prepared with verified and known amounts of all target analytes in the sample matrix (e.g. deioinized water, sand, commercially available tissue) and by calculating percent recovery. Results are compared against measurement performance specifications and used during evaluation of analytical performance. Program-defined measurement performance specifications for bias are specified in Table A7.1.

Representativeness

Representativeness is the degree to which data accurately and precisely represents a characteristic of a population, a process condition, or an environmental condition. The data will be considered representative of the target population or phenomenon to be studied. Site selection, the appropriate sampling regime, the sampling of all pertinent media according to TCEQ SOPs, and use of only approved analytical methods will assure that the measurement data represents the conditions at the site. Continuous data collected for water-quality assessment are considered to be spatially and temporally representative of the full range of water quality conditions over time. Continuous water-quality data are collected on a routine frequency and are separated by even time intervals. Depending on data storage capabilities, readings will be made between every 1 to 10 minutes. The intent of the stormwater sampling component is to define the water-quality profile(s) of stormwater events within the Onion Creek watershed with the parameters listed in Table A7.1. Stormwater samples will be collected by an automatic sampling device for the duration of the stormwater event. For a single stormwater event within the Onion Creek watershed, four to seven samples will accurately represent the over-all water quality of that storm event. Although data may be collected during varying regimes of weather and flow, the continuous water-quality data sets will not be biased toward unusual conditions of flow, runoff, or season. Stormwater samples will be representative of water quality during storm events or of base-flow (non-storm) conditions. The goal for meeting total representation of Onion Creek will be tempered by the potential funding for complete representativeness.

Completeness

The completeness of the data is basically a relationship of how much of the data is available for use compared to the total potential data. Ideally, 100% of the data should be available. However, the possibility of unavailable data due to accidents, insufficient sample volume, broken or lost samples, etc. is to be expected. Therefore, it will be a general goal of the project(s) that 90% data completion is achieved.

Comparability

Confidence in the comparability of routine data sets for this project and for water quality assessments is based on the commitment of project staff to use only approved sampling and analysis methods and QA/QC protocols in accordance with quality system requirements and as described in this QAPP and in TCEQ SOPs. Comparability is also guaranteed by reporting data in standard units, by using accepted rules for rounding figures, and by reporting data in a standard format as specified in Section B10.

Limit of Quantitation

AWRLs (Table A7.1 and A7.2) are used in this project as the *limit of quantitation* specification, so the Water Quality Standards can be used as the benchmarks to compare data against. Laboratory *limits of quantitation* (Table A7.1 and A7.2) must be at or below the AWRL for each applicable parameter.

Laboratory Measurement Quality Control Requirements and Acceptability Criteria are provided in Section B5.

Analytical Quantitation

To demonstrate the ability to recover at the limit of quantitation, the laboratory will analyze an LOQ check standard on each day samples are run.

Laboratory Measurement Quality Control Requirements and Acceptability Criteria are provided in Section B5.

DQOs for CWQMN

Additional DQOs for the CWQMN portion of this project are provided in Section A7 of the CWQMN QAPP.

A8 Special Training/Certification

Staff responsible for operating the automated samplers and flow meters will undergo a training session by the project equipment vendor.

Field personnel will receive training in proper sampling and field analysis. Before actual sampling or field analysis occurs, they will demonstrate to the QA officer (in the field), their ability to properly operate the automatic samplers and retrieve the samples. The QA officer will sign off each field staff in their field logbooks.

BSEACD and subcontractors must ensure that laboratories analyzing samples under this QAPP meet the requirements contained in Section 5.4.4 of the NELAC standards (concerning Review of Requests, Tenders and Contracts).

The District will follow and adhere to Section A8 of the CWQMN QAPP.

A9 Documents and Records

See Section B10 of the CWQM QAPP for electronic management of Continuous Water Quality Monitoring Network Data.

The District will follow and adhere to the CWQM QAPP for Section A9 as described in A9.1 through A9.4.

Laboratory Test Reports
Test/data reports from the laboratory must document the test results clearly and accurately. Routine data reports will be consistent with the NELAC standards (Section 5.5.10) and include the information necessary for the interpretation and validation of data. The requirements for reporting data and the procedures are provided below.

- Report title
- Name and address of laboratory
- Name and address of client and project name
- Sample results
- Units of measurement
- Sample matrix
- Dry weight or wet weight (as applicable)
- Station information
- Date and time of collection
- LOQ and LOD (formerly referred to as the reporting limit and the method detection limit, respectively), and qualification of results outside the working range (if applicable)
- An explanation of failed QC and any non-standard conditions that may have affected quality
- A signature and title of laboratory director or designee

Electronic Data
Only CWQMN data will be reported electronically to TCEQ. Data will be submitted to the TCEQ in the format specified by the TCEQ Project Manger. The Data Summary as contained in Appendix C of this document will be submitted with the data.

In-situ water quality and water level measurements are logged once every 15 minutes by the data logger. The data is then transmitted to the MeteoStar/LEADS system in Austin, Texas where the data is ingested, archived, and posted to the appropriate TCEQ internet site.

A station location request (SLOC) will be submitted to the TCEQ Project Manager for each sampling site to obtain a station identification number.

Records and Documents Retention Requirements

Document/Record	Location	Retention	Form
QAPP, amendments, and appendices	Org.	5 years	Paper
QAPP distribution documentation	Org.	5 years	Paper
Training records	Org.	5 years	Paper
Field notebooks or field data sheets	Org.	5 years	Paper
Field equipment calibration/maintenance l	Org.	5 years	Paper
Chain of custody records	Org.	5 years	Paper
Field SOPs	Org.	5 years	Paper
Laboratory QA manuals	Lab	5 years	Electronic
Laboratory SOPs	Lab	5 years	Electronic
Laboratory procedures	Lab	5 years	Electronic
Instrument raw data files	Lab	5 years	LIMS Electronic
Instrument readings/printouts	Lab	5 years	Paper + Electronic
Laboratory data reports/results	Lab	5 years	Electronic
Laboratory equipment maintenance logs	Lab	5 years	Electronic
Laboratory calibration records	Lab	5 years	LIMS Electronic
Corrective action documentation	Lab	5 years	Electronic

B1 Sampling Process Design (Experimental Design)

Sample Design Rationale

CWQMN

Data collected by the CWQMN system will be used to trigger the opening and closing of the valve on the Antioch BMP. As a storm pulse is recognized by high turbidity readings on the CWQMN instruments, a signal will be sent automatically to the valve control mechanism for the valve to close. As turbidity readings drop below a pre-set level that indicates approach to base flow conditions, the valve will be opened to allow the cleaner water in Onion Creek to recharge the aquifer. Additional sample design rationales for the CWQMN portion of this project are described in Section B1 of the CWQMN QAPP.

Automatic Sampling (Stormwater)

The sample design rationale for stormwater sampling for this study is based on the intent to quantify the amount of sediment and other contaminants that are prevented from entering the Edwards Aquifer by the automated operation of an existing BMP situated over Antioch Cave (CAMS 0770). Monitoring sites are specified in Table B1.1. Since the valves on the BMP will be closed during periods of high storm flow, the amount of sediment and other contaminants in the surface water during this period needs to be determined. The stormwater sampling program will focus on the collection of samples that represent the highest amount of flow from a given storm and the collection of samples as the storm pulse subsides to develop a water-quality profile of the stormwater event. It is anticipated that between three to five storm events will be sampled at the Antioch BMP for the duration of the project. For each of these events, representative samples will be collected to define contamination loading along the hydrograph. The first sampling event is a first order look at the contaminant loading as a function of the hydrograph by collecting in general, one to three near the maximum stream flow, one or two samples will be collected as the storm pulse is rapidly subsiding, and another one or two samples will be collected when turbidity levels of the water are close to stabilizing. The second and following sampling events will focus primarily on collecting more samples for the contaminant peak and the recession It is estimated that the number of days between peak flow and the time at which sediment load and turbidity have decreased to the point that the valve on the BMP should be opened could vary between 2 to 10 days. The sampling schedule will be set to cover this amount of time initially. As data are collected from the first storm events, the sampling schedule will be refined.

An ISCO 3700 series automatic sampler and an ISCO 4230 bubbler flow meter will be installed at Antioch. The bubbler flow meter will measure the water level (stage) in Onion Creek at the Antioch BMP. The flow meter will be programmed to log water level every 5 minutes to trigger the automatic sampler to start sampling and could be used to pace the sample intervals based on water level. The sampler and flow meter will be placed at such a distance and elevation from the BMP so that the sampler pump will be capable of delivering samples to the bottles in the sampler. Because that location might not be above the maximum flood stage for that section of Onion Creek, there is a possibility that the sampler could be inundated under extremely high flood conditions. If that occurs, the sampler will be inspected and repaired or replaced if necessary.

The automatic sampler will be programmed to collect samples starting when the increase in water level indicates that the beginning of storm flow has reached Antioch. The actual amount of water-level rise indicative of a storm event will be determined once a bubbler flow meter or other water-level measurement instrument is installed at Antioch. Samples will be collected every 15 minutes to 6 hours depending on the anticipated duration of the storm flow. Sampling will continue until the water level drops below 75 percent of the peak flow compared to flow at the start of sampling, or until 10 days after start of sampling, which ever comes first. The cutoff for sample collection will also be evaluated once the BMP is instrumented for water-level measurements. The cutoff point is likely to vary considerably for each storm event.

Each sample will be acidified as appropriate, iced and transported to the laboratory where they will be stored at $< 6\ ^{0}$ C prior to analysis.

Grab Samples (Base Flow)

Either before a predicted storm event, or well after a storm event, District staff will manually collect an instream sample (grab sample) that will be representative of base flow conditions in Onion Creek. Grab samples will be handled and analyzed as described above for automatic samples. Base flow conditions need to be determined to better understand conditions during storm events. To the extent practicable, grab samples will be collected following each sampled storm event. Possible exceptions will be for back-to-back storm events for which there will be insufficient time to coordinate sampling.

Monitoring and Support Equipment

In addition to the sampling equipment mentioned above, the Antioch site will include the following equipment:

In-Situ Troll 9500 water quality probe (temperature, conductivity, DO, turbidity, pressure)
In-Situ Level Troll 500 (temperature, pressure)

Zeno data logger
Enfora modem and cellular telephone
ISCO 2150 flow meter with area velocity/pressure
Air compressor and tank

This equipment will be part of TCEQ's Continuous Water Quality Monitoring Network (CWQMN). The equipment that will be installed on or near the Antioch BMP will be the Troll 9500, Troll 500, and flow meter. An equipment shed or box will be installed above flood stage to house the Zeno data logger, modem, communications equipment, air compressor and tank. Cables to connect the data logger to the probes will be run through a PVC conduit that will be buried in a trench for a portion of the distance between the BMP and the equipment shed.

Data collected with the above equipment (temperature, conductivity, DO, turbidity, pressure, and stream flow) will be to telemetered to the TCEQ LEADS System with a cellular telephone.

The following equipment will be installed at the Onion Creek Management Area CWQMN site as described above for the Antioch site:

In-Situ Troll 9500 multi-parameter water quality probe (temperature, conductivity, DO, turbidity, pressure)
Zeno data logger
Enfora modem and cellular telephone

Table B1.1 Monitoring Sites

TCEQ Station ID	Site Description	Latitude Longitude	Start Date	End Date	Sample Matrix	Monitoring Frequencies (per year)		
						Total Suspended Solids	Nutrients	Comments
CAMS 0770	Antioch Cave BMP	30 04 35.10 97 51 51.52	15 days from QAPP approval	April 30, 2011	water	2 to 4	2 to 4	3 to 5 sampling events will be tied to rainfall, stage to discharge relationship,
CAMS 0727	Onion Creek Management Area Low Water Dam	30 03 18.22 97 58 11.49	15 days from QAPP approval	April 30, 2011	water			CWQMN only
Pending*	Multiport monitor well at Antioch	30 04 32.74 97 51 32.74	15 days from QAPP approval	April 30, 2011	water	1 sample from each Edwards monitoring zone	1 sample from each Edwards monitoring zone	

**SLOC numbers have been requested.*

B2 Sampling Methods

The District will follow and adhere to Section B2 of the CWQMN QAPP, excluding the Continuous Monitoring Auto Analyzer or equivalent equipment.

Field Sampling Procedures

A MOM for the automated flow meter, multi-parameter probe, and automated sampler data collection is attached as Appendix C of this document.

Storm-water sample collection will follow the field sampling procedures for conventional and microbiological parameters documented in the TCEQ Surface Water Quality Monitoring Procedures Manual (most recent addition).

The sample volumes, container types, minimum sample volume, preservation requirements, and holding time requirements are specified in Table B2.2.

Table B2.1 Methods and Equipment for Continuous Water-Quality Monitoring

River Basin	Station Location	MeteoStar /LEADS Data Averaging Time	Sampling Method	Measurement Equipment	Telemetry	Station Parameters
Colorado	Antioch Cave BMP	5 minute	Sonde: In situ	Troll 9500 Isco 2150	Wireless Modem	Surface Temperature Surface SC Surface DO Surface Turbidity Stream Stage
Colorado	Sky Ranch Onion Creek OCMA Low Water Dam	5 minute	Sonde: In-situ	Troll 9500	Wireless Modem	Surface Temperature Surface SC Surface DO Surface Turbidity Stream Stage

Table B2.2 Stormwater and Base Flow Monitoring

Parameter	Matrix	Sample Type	Container	Preservation	Sample Volume	Holding Time
Total Dissolved Solids	Water	Grab	500 mL HDPE	Ice, <6 °C not frozen	500 mL	7 days
Nitrite+nitrate-N	water	Grab	250 mL HDPE	Ice, <6 °C not frozen, H2SO4, pH<2	250 mL	28 days
Total Phosphorus-P	water	Grab	250 mL HDPE	Ice, <6 °C not frozen, H2SO4, pH<2	250 mL	28 days
Total Suspended Solids	water	Grab	1000 mL HDPE	Ice, <6 °C not frozen	1000 mL	7 days
Turbidity	water	Grab	500 mL HDPE	Ice, <6 °C not frozen	250 mL	48 hours

Processes to Prevent Cross Contamination

Procedures outlined in the *TCEQ Surface Water Quality Procedures Manual* outline the necessary steps to prevent cross-contamination of samples. These include such things as direct collection into sample containers and the use of commercially pre-cleaned sample containers.

Documentation of Field Sampling Activities

Field sampling activities are documented on the Field Data Reporting Form as presented in Appendix D. For all visits, station ID, location, sampling time, sampling date, sampling depth, preservatives added to samples, and sample collector's name/signature are recorded. Values for all measured field parameters collected from the sonde are recorded. Detailed observational data are recorded including water appearance, weather, unusual odors, specific sample information, missing parameters, and flow severity.

Recording Data

For the purposes of this section and subsequent sections, all personnel follow the basic rules for recording information as documented below:

1. Legible writing in indelible, waterproof ink with no modifications, write-overs or cross-outs;
2. Changes should be made by crossing out original entries with a single line, entering the changes, and initialing and dating the corrections.
3. Close-outs on incomplete pages with an initialed and dated diagonal line.

Deficiencies, Nonconformances and Corrective Action Related to Sampling Requirements

Deficiencies are defined as unauthorized deviation from procedures documented in the QAPP. Nonconformances are deficiencies which affect quality and render the data unacceptable or indeterminate.

Deficiencies related to sampling methods requirements include, but are not limited to, such things as sample container, volume, and preservation variations, improper/inadequate storage temperature, holding-time exceedances, and sample site adjustments.

Deficiencies are documented in logbooks, field data sheets, etc. by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the BSEACD Project Manager. The BSEACD Project Manager will notify the BSEACD QAO of the potential nonconformance within 24 hours. The BSEACD QAO will initiate a Nonconformance Report (NCR) to document the deficiency.

The BSEACD Project Manager, in consultation with BSEACD QAO (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the BSEACD Project Manager in consultation with BSEACD QAO will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the BSEACD QAO by completion of a Corrective Action Report.

Corrective Action Reports (CARs) document: root cause(s); programmatic impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and, the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TCEQ immediately both verbally and in writing.

B3 Sampling Handling and Custody

See Section B10 of the CWQMN QAPP for electronic managing of Continuous Water Quality Monitoring Network data. Water quality is measured *in situ* for the sonde instrumentation.

Sample Labeling

Samples from the field are labeled on the container with an indelible marker. Label information includes:

1. Site identification
2. Date and time of collection
3. Preservative added, if applicable
4. Sample type (i.e., analysis(es)) to be performed

Sample Handling

The following sampling and related equipment will be required for each sampling event:

- Sample bottles for the required analyses, duplicates, field blanks, etc.
- ISCO samplers
- De-ionized water
- Ice chest

- Ice
- Field data sheets and/or field log book
- Chain-of-custody forms
- Sample labels

Immediately after filling, sample bottles will be dried and labeled.
Sample-bottle labels that are adhesive backed and capable of being attached directly to the sample containers will be used. The following information will be entered on the sample label as a minimum:

Date
Time
Location
Sample type
Sampler name
Sample identification (ID) number
Preservative (if necessary)

Other information may be entered on the sample label if space permits. However, any information entered on the label will not obscure the required information. Sample labels will be either be preprinted and filled out or may be written directly on sample bottles / containers with waterproof ink.

Sample Tracking

Proper sample handling and custody procedures ensure the custody and integrity of samples beginning at the time of sampling and continuing through transport, sample receipt, preparation, and analysis.

A sample is in custody if it is in actual physical possession or in a secured area that is restricted to authorized personnel. The COC form is used to document sample handling during transfer from the field to the laboratory and among contractors. The following information concerning the sample is recorded on the COC form (See Appendix E).

1. Date and time of collection
2. Site identification
3. Sample matrix
4. Number of containers
5. Preservative used
6. Was the sample filtered?
7. Analyses required
8. Name of collector
9. Custody transfer signatures and dates and time of transfer

Deficiencies, Nonconformances and Corrective Action Related to Chain-of Custody

Deficiencies are defined as unauthorized deviation from procedures documented in the QAPP. Nonconformances are deficiencies which affect quality and render the data unacceptable or indeterminate. Deficiencies related to chain-of-custody include but are not limited to delays in transfer, resulting in holding time violations; incomplete documentation, including signatures; possible tampering of samples; broken or spilled samples, etc.

Deficiencies are documented in logbooks, field data sheets, etc. by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the BSEACD Project Manager. The BSEACD Project Manager will notify the BSEACD QAO of the potential nonconformance within 24 hours. The BSEACD QAO will initiate a Nonconformance Report (NCR) to document the deficiency.

The BSEACD Project Manager, in consultation with BSEACD QAO (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the BSEACD Project Manager in consultation with BSEACD QAO will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the BSEACD QAO by completion of a Corrective Action Report.

Corrective Action Reports (CARs) document: root cause(s); programmatic impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and, the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TCEQ immediately both verbally and in writing.

B4 Analytical Methods

The analytical methods are listed in Table A7.1 of Section A7. Laboratories collecting data under this QAPP are compliant with the NELAC Standards.

Copies of laboratory SOPs are retained by BSEACD and are available for review by the TCEQ. Laboratory SOPs are consistent with EPA requirements as specified in the method.

The District will follow and adhere to Section B4 of the CWQMN QAPP, excluding the Continuous Monitoring Auto Analyzer or equivalent equipment.

Standards Traceability

All standards used in the field and laboratory are traceable to certified reference materials. Standards and reagent preparation is fully documented and maintained in a standards log book. Each documentation includes information concerning the standard or reagent identification, starting materials, including concentration, amount used and lot number; date prepared, expiration date and preparer=s initials/signature. The bottle is labeled in a way that will trace the standard or reagent back to preparation. Standards or reagents used are documented each day samples are prepared or analyzed.

Deficiencies, Nonconformances and Corrective Action Related to Analytical Method

Deficiencies are defined as unauthorized deviation from procedures documented in the QAPP. Nonconformances are deficiencies which affect quality and render the data unacceptable or indeterminate.

Deficiencies related to chain-of-custody include but are not limited to delays in transfer, resulting in holding time violations; incomplete documentation, including signatures; possible tampering of samples; broken or spilled samples, etc.

Deficiencies are documented in logbooks, field data sheets, etc. by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the BSEACD Project Manager. The BSEACD Project Manager will notify the BSEACD QAO of the potential nonconformance within 24 hours. The BSEACD QAO will initiate a Nonconformance Report (NCR) to document the deficiency.

The BSEACD Project Manager, in consultation with BSEACD QAO (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the BSEACD Project Manager in consultation with BSEACD QAO will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the BSEACD QAO by completion of a Corrective Action Report.

Corrective Action Reports (CARs) document: root cause(s); programmatic impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and, the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TCEQ immediately both verbally and in writing.

B5 Quality Control

The District will follow and adhere to the Section B5 of the CWQMN QAPP, excluding the Continuous Monitoring Auto Analyzer or equivalent equipment.

Sampling Quality Control Requirements and Acceptability Criteria

Field Split - A field split is a single sample subdivided by field staff immediately following collection and submitted to the laboratory as two separately identified samples according to procedures specified in the SWQM Procedures. Split samples are preserved, handled, shipped, and analyzed identically and are used to assess variability in all of these processes. Field splits apply to conventional samples only. One field split will be taken for every 10 sample.

The precision of field split results is calculated by relative percent difference (RPD) using the following equation:

$$RPD = (X1-X2)/((X1+X2)/2))$$

A 30% RPD criteria will be used to screen field split results as a possible indicator of excessive variability in the sample handling and analytical system. If it is determined that elevated quantities of analyte (i.e., > 5 times the RL) were measured and analytical variability can be eliminated as a factor, than variability in field split results will primarily be used as a trigger for discussion with field staff to ensure samples are being handled in the field correctly. Some individual sample results may be invalidated based on the examination of all extenuating information. The information derived from field splits is generally considered to be event specific and would not normally be used to determine the validity of an entire batch; however, some batches of samples may be invalidated depending on the situation. Professional judgment during data validation will be relied upon to interpret the results and take appropriate action. The qualification (i.e., invalidation) of data will be documented on the Data Summary. Deficiencies will be addressed as specified in this section under Deficiencies, Nonconformances, and Correction Action related to Quality Control.

Laboratory Measurement Quality Control Requirements and Acceptability Criteria

Method Specific QC requirements – QC samples, other than those specified later this section, are run (e.g., sample duplicates, surrogates, internal standards, continuing calibration samples, interference check samples, positive control, negative control, and media blank) as specified in the methods. The requirements for these samples, their acceptance criteria or instructions for establishing criteria, and corrective actions are method-specific.

Detailed laboratory QC requirements and corrective action procedures are contained within the individual laboratory quality manuals (QMs). The minimum requirements that all participants abide by are stated below.

LOQ Check Standard – An LOQ check standard consists of a sample matrix (e.g., deionized water, sand, commercially available tissue) free from the analytes of interest spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes. It is used to establish intra-laboratory bias to assess the performance of the measurement system at the lower limits of analysis. The LOQ check standard is spiked into the sample matrix at a level less than or near the LOQ for each analyte for each batch samples that are run.

The LOQ check standard is carried through the complete preparation and analytical process. LOQ Check Standards are run at a rate of one per analytical batch. A batch is defined as samples that are analyzed together with the same method and personnel, using the same lots of reagents, not to exceed the analysis of 20 environmental samples.

The percent recovery of the LOQ check standard is calculated using the following equation in which %R is percent recovery, SR is the sample result, and SA is the reference concentration for the check standard:

$$\%R = SR/SA * 100$$

Measurement performance specifications are used to determine the acceptability of LOQ Check Standard analyses as specified in Table A7.1.

Laboratory Control Sample (LCS) - An LCS consists of a sample matrix (e.g., deionized water, sand, commercially available tissue) free from the analytes of interest spiked with verified known amounts of analytes or a material containing known and verified amounts of analytes. It is used to establish intra-laboratory bias to assess the performance of the measurement system. The LCS is spiked into the sample matrix at a level less than or near the mid point of the calibration for each analyte. In cases of test methods with very long lists of analytes, LCSs are prepared with all the target analytes and not just a representative number, except in cases of organic analytes with multipeak responses.

The LCS is carried through the complete preparation and analytical process. LCSs are run at a rate of one per analytical batch. A batch is defined as samples that are analyzed together with the same method and personnel, using the same lots of reagents, not to exceed the analysis of 20 environmental samples.

Results of LCSs are calculated by percent recovery (%R), which is defined as 100 times the measured concentration, divided by the true concentration of the spiked sample.

The following formula is used to calculate percent recovery, where %R is percent recovery; SR is the measured result; and SA is the true result:

$$\%R = SR/SA * 100$$

Measurement performance specifications are used to determine the acceptability of LCS analyses as specified in Table A7.1.

Laboratory Duplicates – A laboratory duplicate is prepared by taking aliquots of a sample from the same container under laboratory conditions and processed and analyzed independently. A laboratory control sample duplicate (LCSD) is prepared in the laboratory by splitting aliquots of an LCS. Both samples are carried through the entire preparation and analytical process. LCSDs are used to assess precision and are performed at a rate of one per batch. A batch is defined as samples that are analyzed together with the same method and personnel, using the same lots of reagents, not to exceed the analysis of 20 environmental samples.

For most parameters, precision is calculated by the relative percent difference (RPD) of LCS duplicate results as defined by 100 times the difference (range) of each duplicate set, divided by the average value (mean) of the set. For duplicate results, X_1 and X_2, the RPD is calculated from the following equation:

$$RPD = (X_1 - X_2)/\{(X_1+X_2)/2\} * 100$$

Measurement performance specifications are used to determine the acceptability of duplicate analyses-as specified in Table A7.1. The specifications for bacteriological duplicates in Table A7.1 apply to samples with concentrations > 10 org./100mL.

Laboratory equipment blank - Laboratory equipment blanks are prepared at the laboratory where collection materials for metals sampling equipment are cleaned between uses. These blanks document that the materials provided by the laboratory are free of contamination. The QC check is performed before the metals sampling equipment is sent to the field. The analysis of laboratory equipment blanks should yield values less than the LOQ. Otherwise, the equipment should not be used.

Matrix spike (MS) –Matrix spikes are prepared by adding a known mass of target analyte to a specified amount of matrix sample for which an independent estimate of target analyte concentration is available. Matrix spikes are used, for example, to determine the effect of the matrix on a method's recovery efficiency.

Percent recovery of the known concentration of added analyte is used to assess accuracy of the analytical process. The spiking occurs prior to sample preparation and analysis. Spiked samples are routinely prepared and analyzed at a rate of 10% of samples processed, or one per batch whichever is greater. A batch is defined as samples that are analyzed together with the same method and personnel, using the same lots of reagents, not to exceed the analysis of 20 environmental samples. The information from these controls is sample/matrix specific and is not used to determine the validity of the entire batch. The MS is spiked at a level less than or equal to the midpoint of the calibration or analysis range for each analyte. Percent recovery (%R) is defined as 100 times the observed concentration, minus the sample concentration, divided by the true concentration of the spike.

The results from matrix spikes are primarily designed to assess the validity of analytical results in a given matrix and are expressed as percent recovery (%R). The laboratory shall document the calculation for %R. The percent recovery of the matrix spike is calculated using the following equation in which %R is percent recovery, SSR is the observed spiked sample concentration, SR is the sample result, and SA is the reference concentration of the spike added:

$$\%R = (SSR - SR)/SA * 100$$

Measurement performance specifications for matrix spikes are not specified in this document.

The results are compared to the acceptance criteria as published in the mandated test method. Where there are no established criteria, the laboratory shall determine the internal criteria and document the method used to establish the limits. For matrix spike results outside established criteria, corrective action shall be documented or the data reported with appropriate data qualifying codes.

Method blank –A method blank is a sample of matrix similar to the batch of associated samples (when available) that is free from the analytes of interest and is processed simultaneously with and under the same conditions as the samples through all steps of the analytical procedures, and in which no target analytes or interferences are present at concentrations that impact the analytical results for sample analyses. The method blank is carried through the complete sample preparation and analytical procedure. The method blank is used to document contamination from the analytical process. The analysis of method blanks should yield values less than the LOQ. For very high-level analyses, the blank value should be less then 5% of the lowest value of the batch, or corrective action will be implemented.

Deficiencies, Nonconformances and Corrective Action Related to Quality Control

Deficiencies are defined as unauthorized deviation from procedures documented in the QAPP. Nonconformances are deficiencies which affect quality and render the data unacceptable or indeterminate. Deficiencies related to chain-of-custody include but are not limited to delays in transfer, resulting in holding time violations; incomplete documentation, including signatures; possible tampering of samples; broken or spilled samples, etc.

Deficiencies are documented in logbooks, field data sheets, etc. by field or laboratory staff and reported to the cognizant field or laboratory supervisor who will notify the BSEACD Project Manager. The BSEACD Project Manager will notify the BSEACD QAO of the potential nonconformance within 24 hours. The BSEACD QAO will initiate a Nonconformance Report (NCR) to document the deficiency.

The BSEACD Project Manager, in consultation with BSEACD QAO (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined the activity or item in question does not affect data quality and therefore is not a valid nonconformance, the NCR will be completed accordingly and the NCR closed. If it is determined a nonconformance does exist, the BSEACD Project Manager in consultation with BSEACD QAO will determine the disposition of the nonconforming activity or item and necessary corrective action(s); results will be documented by the BSEACD QAO by completion of a Corrective Action Report.

Corrective Action Reports (CARs) document: root cause(s); programmatic impact(s); specific corrective action(s) to address the deficiency; action(s) to prevent recurrence; individual(s) responsible for each action; the timetable for completion of each action; and, the means by which completion of each corrective action will be documented. CARs will be included with quarterly progress reports. In addition, significant conditions (i.e., situations which, if uncorrected, could have a serious effect on safety or on the validity or integrity of data) will be reported to the TCEQ immediately both verbally and in writing.

B6 Instrument/Equipment Testing, Inspection and Maintenance

The District will follow and adhere to Section B6 of the CWQMN QAPP, excluding the Continuous Monitoring Auto Analyzer or equivalent equipment.

Automated sampler testing and maintenance requirements are contained with Appendix H of this document.

All instream sampling equipment testing and maintenance requirements are detailed in the TCEQ Surface Water Quality Monitoring Procedures. Equipment records are kept on all field equipment and a supply of critical spare parts is maintained by the BSEACD Field Supervisor.

All laboratory tools, gauges, instrument, and equipment testing and maintenance requirements are contained within laboratory QAM(s). Testing and maintenance records are maintained and are available for inspection by the TCEQ. Instruments requiring daily or in-use testing may include, but are not limited to, water baths, ovens, autoclaves, incubators, refrigerators, and laboratory pure water. Critical spare parts for essential equipment are maintained to prevent downtime. Maintenance records are available for inspection by the TCEQ.

B7 Instrument/Equipment Calibration and Frequency

The District will follow and adhere to Section B7 of the CWQMN QAPP, excluding the Continuous Monitoring Auto Analyzer or equivalent equipment.

Calibration requirements for the automated monitoring equipment is included in Appendix I of this document.

Instream field Equipment calibration requirements are contained in the TCEQ Surface Water Quality Monitoring Procedures Manual. Post calibration error limits and the disposition resulting from error are adhered to. Data not meeting post-error limit requirements invalidates associated data collected subsequent to the pre-calibration and are not submitted to the TCEQ.

Detailed laboratory calibrations are contained within the QAM(s).

B8 Inspection/Acceptance of Supplies and Consumables

New batches of supplies are tested before use to verify that they function properly and are not contaminated. The laboratory QAM provides additional details on acceptance requirements for laboratory supplies and consumables.

The District will follow and adhere to Section B8 of the CWQMN QAPP, excluding the Continuous Monitoring Auto Analyzer or equivalent equipment.

B9 Non-direct Measurements

Non-direct measurements from computer databases, spreadsheets, programs, etc., specifically historical data acquisition, will not be used to meet the laboratory objectives of this QAPP.

B10 Data Management

The District will follow and adhere to Section B10 of the CWQMN QAPP, excluding the Continuous Monitoring Auto Analyzer or equivalent equipment.

Data Path

Samples are collected and are transferred to the laboratory for analyses as described in Sections B1 and B2. Analytical data will be sent electronically via email from the laboratory to BSEACD. Sampling information (e.g. site location, date, time, sampling depth, etc.) is used to generate a unique sampling event in an interim database built on an autogenerated alphanumeric key field. Measurement results from both the field data sheets and laboratory data sheets are manually entered into the interim database for their corresponding event. Customized data entry forms facilitate accurate data entry. Following data verification and validation, the data are exported in a format specified by the TCEQ project Manager.

Record-keeping and Data Storage

BSEACD recordkeeping and document control procedures are contained in the water quality sampling and laboratory standard operating procedures (SOPs) and this QAPP. Original field and laboratory data sheets are stored in the BSEACD offices in accordance with the record-retention schedule in Section A9. One copy of the database is backed up each Friday on magnetic tape and is stored off-site. If necessary, disaster recovery will be accomplished by information resources staff using the backup database.

Data Verification/Validation

The control mechanisms for detecting and correcting errors and for preventing loss of data during data reduction, data reporting, and data entry are contained in Sections D1, D2, and D3.

Forms and Checklists

See Appendix D for the Field Data Reporting Form. See Appendix E for the Chain-of-Custody Form.

Data Handling

Data are processed using the Microsoft Access 2000 suite of tools and applications. Data integrity is maintained by the implementation of password protections which control access to the database and by limiting update rights to a select user group. No data from external sources are maintained in the database. The database administrator is responsible for assigning user rights and assuring database integrity.

Hardware and Software Requirements

Hardware configurations are sufficient to run Microsoft Access 2000 under the Windows NT operating system in a networked environment. Information resources staff are responsible for assuring hardware configurations meet the requirements for running current and future data management/database software as well as providing technical support. Software development and database administration are also the responsibility of the information resources department. Information resources develops applications based on user requests and assures full system compatibility prior to implementation.

Information Resource Management Requirements

BSEACD information technology (IT) policy is contained in IT SOPs which are available for review at BSEACD offices.

C1 Assessment and Response Actions

Table C1.1 Assessments and Response Actions

Assessment Activity	Approximate Schedule	Responsible Party	Scope	Response Requirements
Status Monitoring Oversight, etc.	Continuous	BSEACD Project Manager	Monitoring of the project status and records to ensure requirements are being fulfilled.	Report to TCEQ in Quarterly Report
Laboratory Inspections	Dates to be determined by the TCEQ lab inspector	TCEQ Lab Inspector	Analytical and quality control procedures employed at the laboratory and the contract laboratory	30 days to respond in writing to the TCEQ to address corrective actions
Monitoring Systems Audit	Dates to be determined by TCEQ	TCEQ QAS	The assessment will be tailored in accordance with objectives needed to assure compliance with the QAPP. Field sampling, handling and measurement; facility review; and data management as they relate to the NPS Project	30 days to respond in writing to the TCEQ to address corrective actions
Laboratory Inspection	Based on work plan and or discretion of BSEACD	BSEACD QAO	Analytical and quality control procedures employed at the laboratory and the contract laboratory	30 days to respond in writing to the BSEACD QAO to address corrective actions
Monitoring Systems Audit	Based on work plan and or discretion of BSEACD	BSEACD QAO	The assessment will be tailored in accordance with objectives needed to assure compliance with the QAPP. Field sampling, handling and measurement; facility review; and data management as they relate to the NPS Project	30 days to respond in writing to the BSEACD QAO to address corrective actions
Site Visit	Dates to be determined by TCEQ	TCEQ PM	Status of activities. Overall compliance with work plan and QAPP	As needed

Corrective Action

The BSEACD Project Manager is responsible for implementing and tracking corrective action procedures as a result of audit findings. Records of audit findings and corrective actions are maintained by both the TCEQ PM and the BSEACD QAO.

If audit findings and corrective actions cannot be resolved, then the authority and responsibility for terminating work is specified in the TCEQ QMP and in agreements or contracts between participating organizations.

C2 Reports to Management

Reports to TCEQ Project Management

All reports detailed in this section are contract deliverables and are transferred to the TCEQ in accordance with contract requirements.

Quarterly Progress Report - Summarizes the BSEACD's activities for each task; reports problems, delays, and corrective actions; and outlines the status of each task's deliverables.

Monitoring Systems Audit Report and Response - Following any audit performed by the Basin Planning Agency, a report of findings, recommendations and response is sent to the TCEQ in the quarterly progress report.

Monitoring System Audit Response - BSEACD will respond in writing to the TCEQ within 30 upon receipt of a monitoring system audit report to address corrective actions.

Contractor Evaluation - BSEACD participates in a Contractor Evaluation by the TCEQ annually for compliance with administrative and programmatic standards.

Monitoring Report- Provides data collected for the project and a summary of the data.

Final Project Report - Summarizes the BSEACD's activities for the entire project period including a description and documentation of major project activities; evaluation of the project results and environmental benefits; and a conclusion.

Reports to BSEACD Project Management

All laboratory analytical reports and applicable QA/QC data related to field and laboratory analysis will be collected and archived by the BSEACD and LCRA ELS.

Reports by TCEQ Project Management

Contractor Evaluation - BSEACD participates in a Contractor Evaluation by the TCEQ annually for compliance with administrative and programmatic standards. Results of the evaluation are submitted to the TCEQ Financial Administration Division, Procurement and Contracts Section.

D1 Data Review, Verification, and Validation

For the purposes of this document, data verification is a systematic process for evaluating performance and compliance of a set of data to ascertain its completeness, correctness, and consistency using the methods and criteria defined in the QAPP. Validation means those processes taken independently of the data-generation processes to evaluate the technical usability of the verified data with respect to the planned objectives or intention of the project. Additionally, validation can provide a level of overall confidence in the reporting of the data based on the methods used.

All data obtained from field and laboratory measurements will be reviewed and verified for conformance to project requirements, and then validated against the data quality objectives which are listed in Section A7. Only those data which are supported by appropriate quality control data and meet the measurement performance specification defined for this project will be considered acceptable and used in the project.

The procedures for verification and validation of data are described in Section D2, below. The BSEACD Field Supervisor is responsible for ensuring that field data are properly reviewed and verified for integrity. The Laboratory Supervisor is responsible for ensuring that laboratory data are scientifically valid, defensible, of acceptable precision and bias, and reviewed for integrity. The BSEACD Data Manager will be responsible for ensuring that all data are properly reviewed and verified, and submitted in the required format to the project database. The BSEACD QAO is responsible for validating a minimum of 10% of the data produced in each task. Finally, the BSEACD Project Manager, with the concurrence of the BSEACD QAO, is responsible for validating that all data to be reported meet the objectives of the project and are suitable for reporting to TCEQ.

The District will follow and adhere to Section D1 of the CWQMN QAPP for data review, verification, and validation of CWQMN data.

D2 Verification and Validation Methods

All data will be verified to ensure they are representative of the samples analyzed and locations where measurements were made, and that the data and associated quality control data conform to project specifications. The staff and management of the respective field, laboratory, and data management tasks are responsible for the integrity, validation and verification of the data each task generates or handles throughout each process. The field and laboratory tasks ensure the verification of raw data, electronically generated data, and data on chain-of-custody forms and hard copy output from instruments.

Verification, validation and integrity review of data will be performed using self-assessments and peer review, as appropriate to the project task, followed by technical review by the manager of the task. The data to be verified are evaluated against project performance specifications (Section A7) and are checked for errors, especially errors in transcription, calculations, and data input. If a question arises or an error is identified, the manager of the task responsible for generating the data is contacted to resolve the issue. Issues which can be corrected are corrected and documented electronically or by initialing and dating the associated paperwork. If an issue cannot be corrected, the task manager consults with higher level project management to establish the appropriate course of action, or the data associated with the issue are rejected.

The BSEACD Project Manager and QAO are each responsible for validating that the verified data are scientifically valid, defensible, of known precision, bias, integrity, meet the data quality objectives of the project, and are reportable to TCEQ. One element of the validation process involves evaluating the data again for anomalies. Any suspected errors or anomalous data must be addressed by the manager of the task associated with the data, before data validation can be completed.

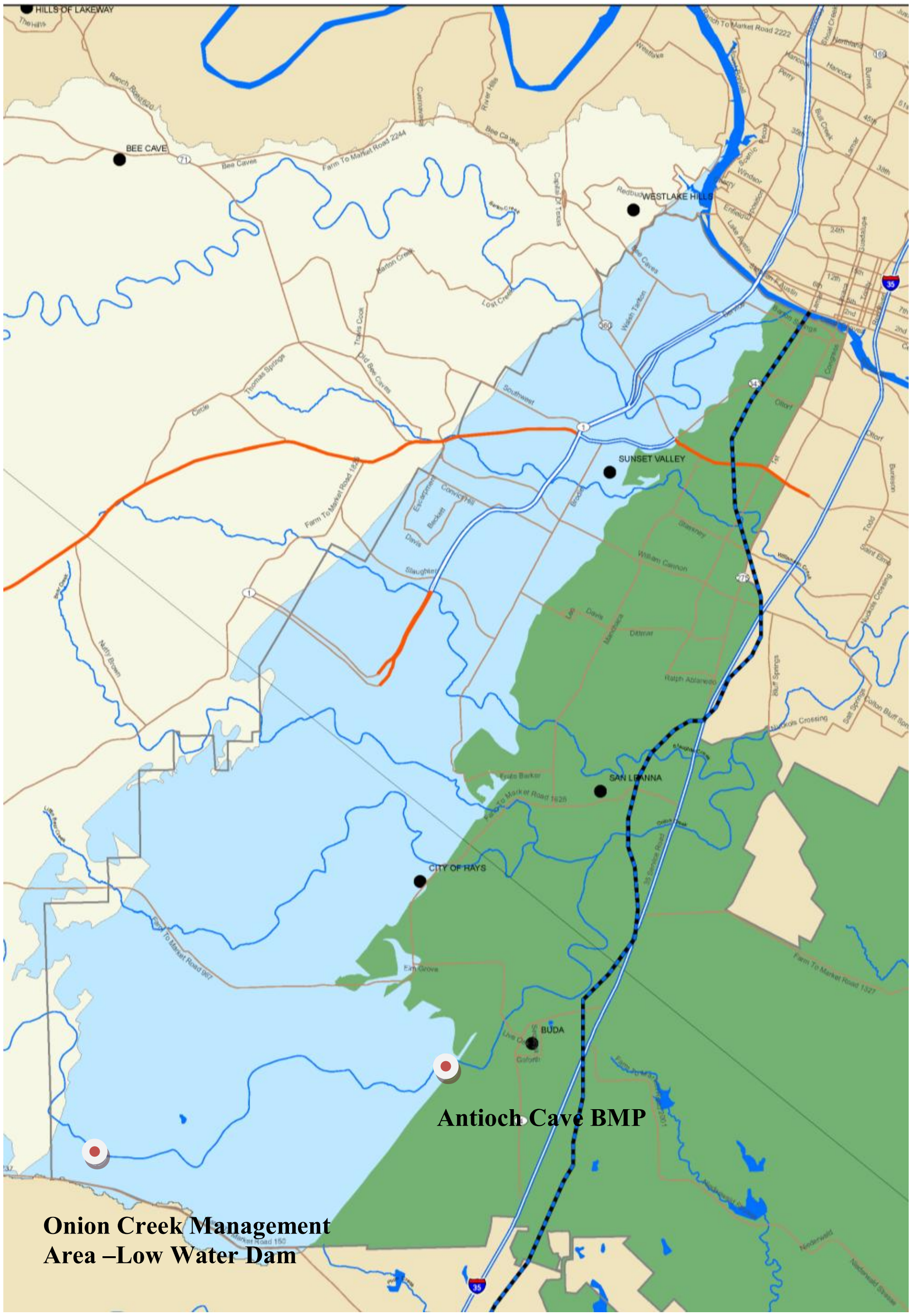
A second element of the validation process is consideration of any findings identified during the monitoring systems audit conducted by the TCEQ QAS assigned to the project. Any issues requiring corrective action must be addressed, and the potential impact of these issues on previously collected data will be assessed. Finally, the BSEACD Project Manager, with the concurrence of the QAO validates that the data meet the data quality objectives of the project and are suitable for reporting to TCEQ.

The District will follow and adhere to Section D2 of the CWQMN QAPP for verification and validation of CWQMN data.

D3 Reconciliation with User Requirements

Data collected from this project will be analyzed by the BSEACD to report the performance of the BMP and the measured reductions in NPS loadings. The percentage of pollutant removal achieved as a result of the storm water ponds performance will be one of several criteria examined by BSEACD in the design and sizing of similar BMPs to be constructed in other segments of Onion Creek. Neither BMP nor instream monitoring data that do not meet requirements will not be used in the project or submitted to the SWQMIS.

Appendix A. Area Location Map


HILLS OF LAKEWAY
BEE CAVE
WESTLAKE HILLS
SUNSET VALLEY
SAN LEANNA
CITY OF HAYS
BUDA
Antioch Cave BMP
Onion Creek Management
Area –Low Water Dam

Appendix B. Workplan

Work plan approved under fiscal year 2006, 319h grant application.

Appendix C. Data Summary

NPS DATA SUMMARY

A completed checklist must accompany all data sets submitted to the TCEQ by the Contractor.

Data Quality Review

A. Are all the "less-than" values reported at or below the specified reporting limit? ____________

B. Have checks on correctness of analysis or data reasonableness performed? ____________
  e.g.: Is ortho-phosphorus less than total phosphorus? ____________
  Are dissolved metal concentrations less than or equal to total metals? ____________

C. Have at least 10% of the data in the data set been reviewed against the field and laboratory data sheets? ____________

D. Are all *Storetcodes* in the data set listed in the QAPP? ____________

E. Are all *StationIds* in the data set listed in the QAPP? ____________

Documentation Review

A. Are blank results acceptable as specified in the QAPP? ____________

B. Was documentation of any unusual occurrences that may affect water quality included in the *Event* table's *Comments* field? ____________

C. Were there any failures in sampling methods and/or deviations from sample design requirements that resulted in unreportable data? If yes, explain on next page.

D. Were there any failures in field and laboratory measurement systems that were not resolvable and resulted in unreportable data? If yes, explain on next page.

Describe any data reporting inconsistencies with performance specifications. Explain failures in sampling methods and field and laboratory measurement systems that resulted in data that could not be reported to the TCEQ. (attach another page if necessary):

Date Submitted to TCEQ: ____

TAG Series: ____

Date Range: ____

Data Source: ____

Comments (attach file if necessary): ____
____
____
____
____

Contractor's Signature: ____

Date: ____

Appendix D. Manufacturer's Operator Manuals

In-Situ Inc.

Level TROLL®

OPERATOR'S MANUAL

Level **TROLL** 300
Level **TROLL** 500
Level **TROLL** 700
Baro**TROLL**

September 2007

In-Situ Inc.

Multi-Parameter
Water Quality TROLL®

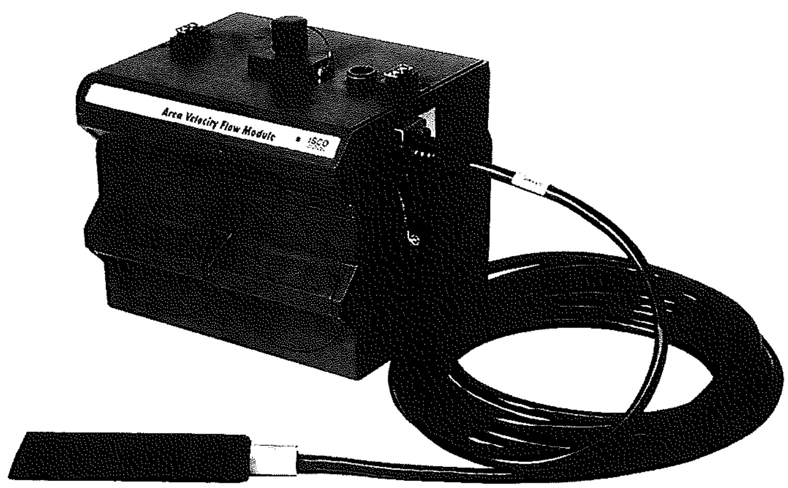
Multi-Parameter TROLL 9500

WQP-100

OPERATOR'S MANUAL

2150 Area Velocity Flow Module and Sensor

Installation and Operation Guide



TELEDYNE ISCO
A Teledyne Technologies Company

Part #60-2003-092 of Assembly #60-2004-038

Revision K, January 2005

OPERATIONS MANUAL

Westbay MOSDAX Sampler Probe - Model 2532

Schlumberger
WATER SERVICES

Appendix E. Field Data Reporting Form

Onion Creek Recharge Project
Water Quality Data Sheet

Event Data

Station ID ______
Location ______
Sampling Date(s) ______
Sampling Time ______
Sampler's Name ______
Sampling Depth ______
Isco Serial # ______

Detailed Observations

Flow Severity ______
Water Apperance ______
Unusual Odors ______

Continuous Water Quality Data

Specific Conductance ______
Temperature ______
Dissolved Oxygen ______
Turbidity ______
Flow (ft^3/sec) ______
Velocity (ft/sec) ______
Missing Parameters ______

Specific Sample Information

Number of Sample Bottles ______
Sampling Duration ______
Sampling Interval ______
Preservatives added to samples ______

Isco Sample Bottle #	Date / Time	Submit to Lab	Isco Sample Bottle #	Date / Time	Submit to Lab
Bottle # 1			Bottle # 13		
Bottle # 2			Bottle # 14		
Bottle # 3			Bottle # 15		
Bottle # 4			Bottle # 16		
Bottle # 5			Bottle # 17		
Bottle # 6			Bottle # 18		
Bottle # 7			Bottle # 19		
Bottle # 8			Bottle # 20		
Bottle # 9			Bottle # 21		
Bottle # 10			Bottle # 22		
Bottle # 11			Bottle # 23		
Bottle # 12			Bottle # 24		

Appendix F. Chain-of-Custody Form

Environmental Laboratory Services
The Solution Lab

LCRA ENVIRONMENTAL LABORATORY SERVICES (ELS)
CHAIN OF CUSTODY RECORD

NOTE: Relinquishing sample(s) to ELS obligates the submitter to all Standard Terms and Conditions stated on the back of this form.

Target Due Date:___________________
Work Order No.:___________________
COC No.:___________________
Page _____ of_________

Results To: ____ Sampled By: ____________________
NAME ADDRESS CITY STATE ZIP
Bill To:____ PO No.: ____________________
NAME ADDRESS CITY STATE ZIP
Phone No.:__________ Fax No.: ___________ Method of Transport:_____________ TAT Requested: ________ Working days E-mail: ____________________
Relinquished By: _________ Date: _____ Time: _____ Received By: ________ Date: ______ Time: _____ Relinquished By: _________ Date: ______ Time: _____

Report Requirements
☐ Hardcopy ☐ E-mail ☐ Fax
☐ EDD (Generic)

Regulatory Requirements
☐ None ☐ NELAP
☐ __________

Received at ELS By:__________ Date: ___ Time: _____
☐ Received on Ice Temp: ______ °C
Login Review: ______________ Date: __________

ELS Mgmt. Approval for RUSH: ____________________
Surcharge for RUSH: ________%

ELS ID:	SAMPLE DESCRIPTION Custody Seals (circle): Cooler Bottles None	MATRIX	SAMPLE COLLECTION DATE	TIME	CONTAINERS NUMBER	SIZE	TYPE	ANALYSIS REQUESTED - Place an "x" in the box below to indicate request.								PRESERVATIVES	pH

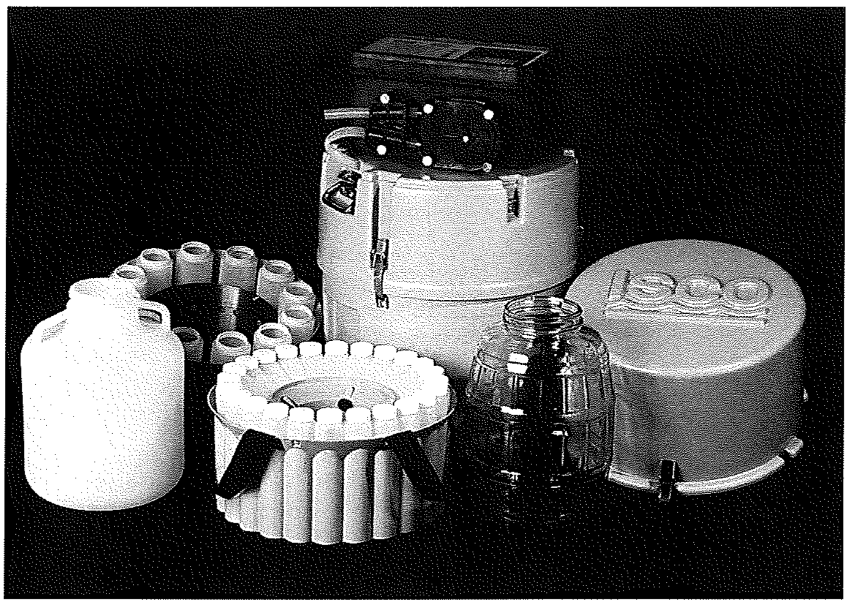
Special Instructions: ____
ELS Comments: ____

White - ELS Pink - Customer http://els.lcra.org • 3505 Montopolis • Austin, Texas • 78744-1417 • (512) 356-6022 • Fax (512) 356-6021 • 1-800-776-5272, Ext. 6022 Form 1156 Rev. 7/08

Appendix G. Automated Sampler Testing with Maintenance and Calibration Requirements

3700 Portable Samplers

Installation and Operation Guide



TELEDYNE ISCO
A Teledyne Technologies Company

Part #60-3703-267 of Assembly #60-3704-101

Revision EE, March 20, 2007

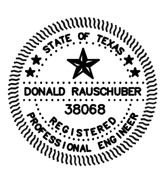
Appendix D

As-Built Designs of Antioch Upgrade

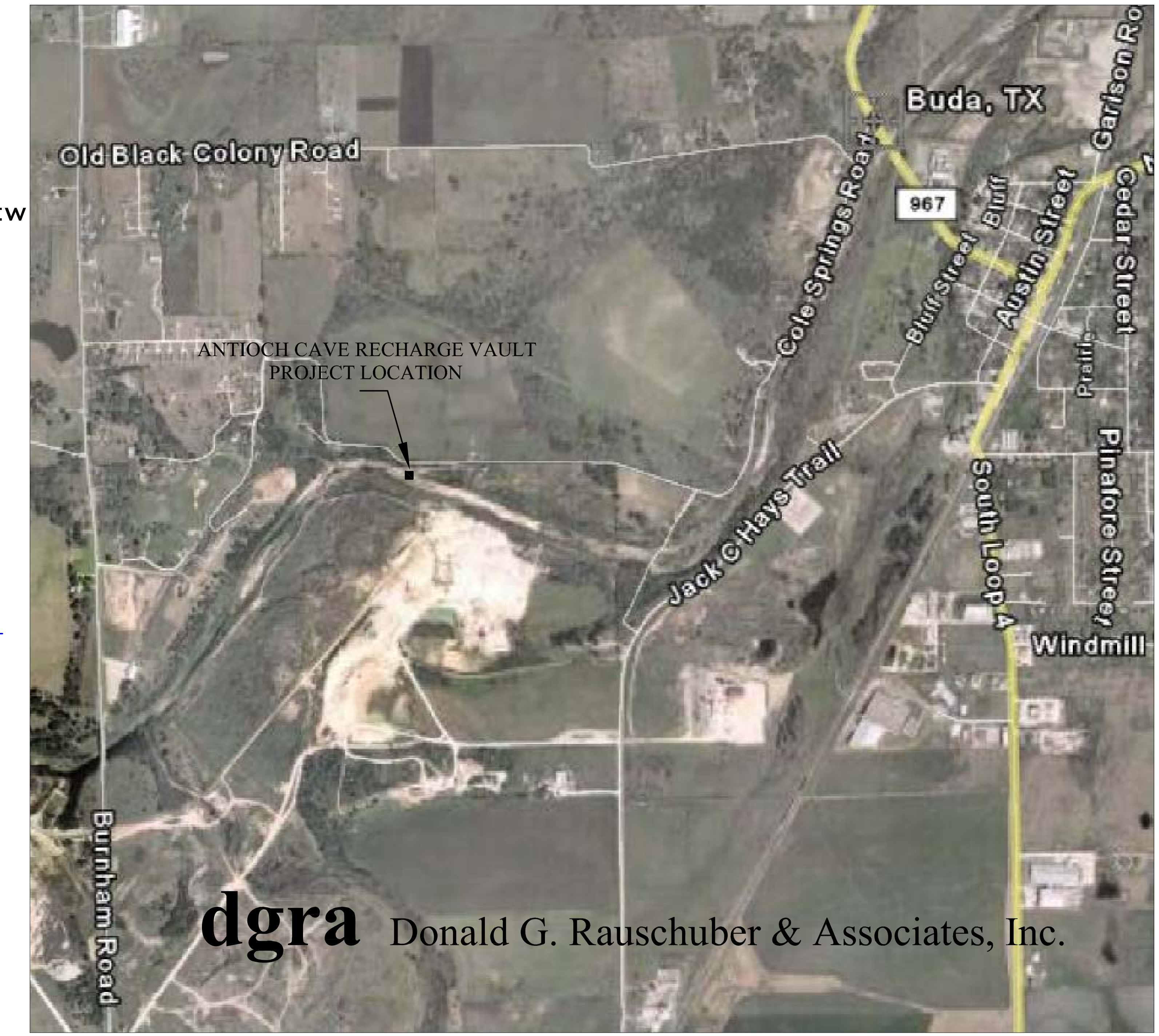
RECORD DRAWINGS
BARTON SPRING/EDWARDS AQUIFER CONSERVATION DISTRICT
ANTIOCH CAVE BMP MODIFICATIONS

SHEET INDEX:

1. COVER SHEET
2. INTAKE SCREEN ASSEMBLY - PLAN VIEW
3. INTAKE SCREEN ASSEMBLY - PROFILE VIEW
4. CONSTRUCTION DETAILS
5. AERIAL VIEW DETAILS



SUBMITTED FOR APPROVAL:
DON RAUSCHUBER, P.E.



OWNER:

BARTON SPRINGS/EDWARDS AQUIFER CONSERVATION DISTRICT
1411 REGAL ROW
AUSTIN, TEXAS 78748
512-282-8441
CONTACT: BRIAN SMITH, PH.D.

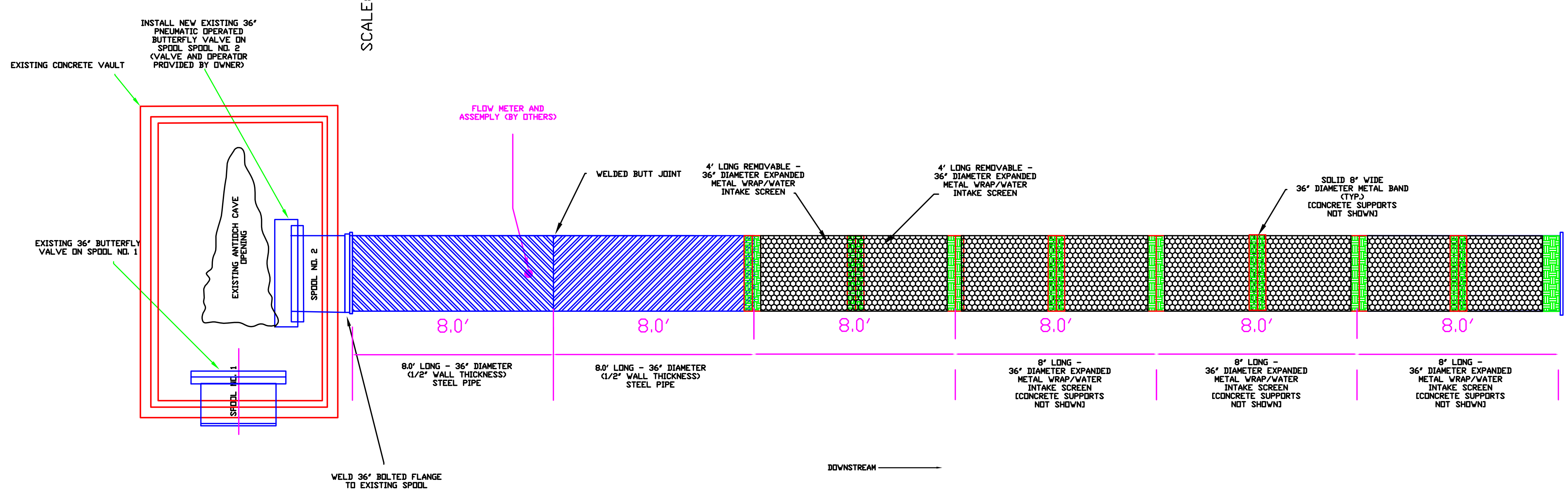
KIRK HOLLAND, GENERAL MANATER

CIVIL ENGINEER:

DGRA, INC.
P.O. BOX 2777
GEORGETOWN, TX 78627
512-763-1170 (F) 800-823-7572
CONTACTS: DON RAUSCHUBER, P.E.

PLAN VIEW
(INTAKE SCREEN PROVIDED BY OWNER)

– SCALE –
1" = 5.0'



NO.	DATE	REMARKS

REVISIONS

dgra Donald G. Rauschuber & Associates, Inc.
Consultants ■ Water Engineering ■ Municipal Engineering

SURVEYED	DESIGNED	DRAWN	CHECKED	DATE	FILE NAME:
NONE	DGR	DGR		040111	BSEACD

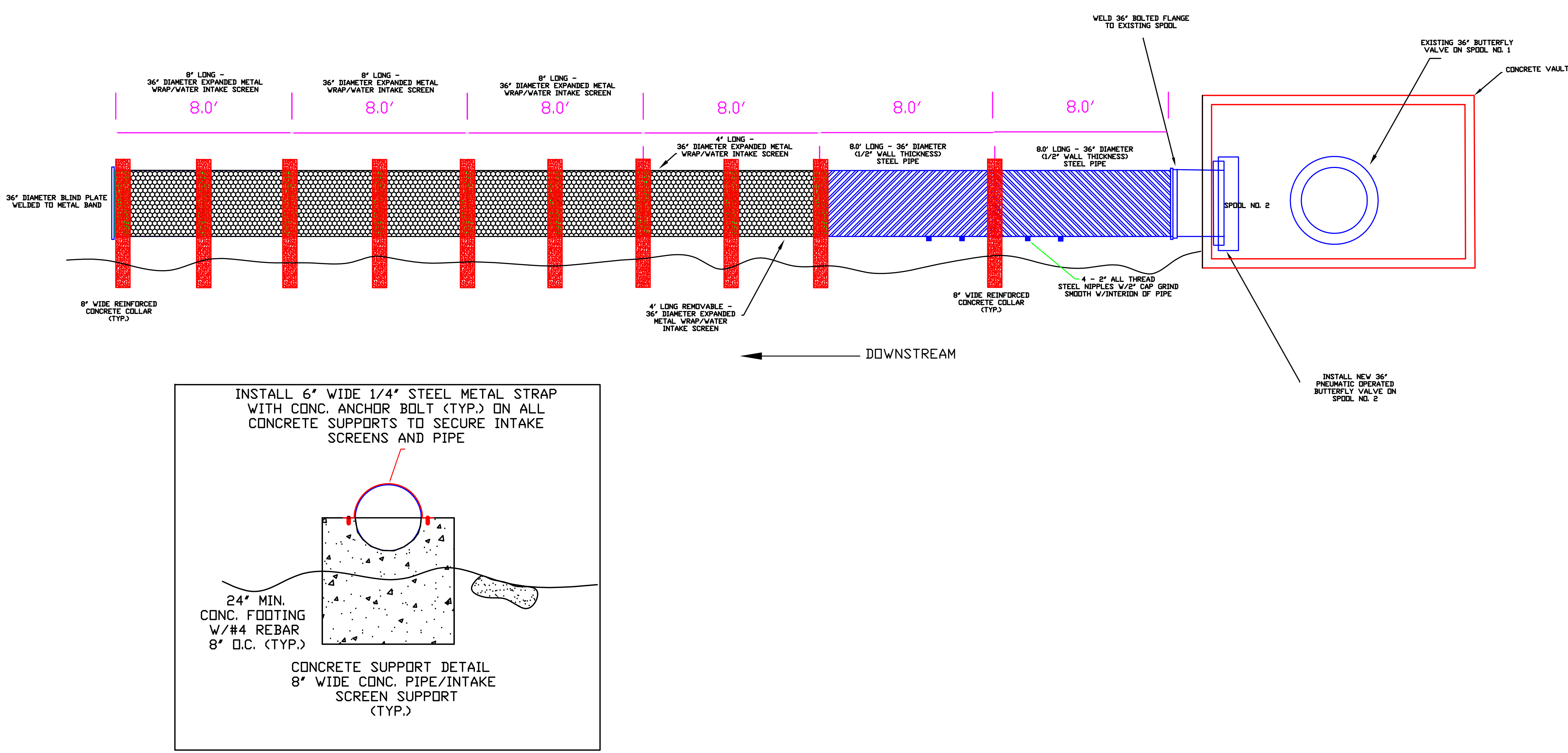
BARTON SPRINGS EDWARDS AQUIFER CONSERVATION DISTRICT
ANTIOCH CAVE BMP MODIFICATIONS
INTAKE SCREEN ASSEMBLY - PLAN VIEW

STATE OF TEXAS ★ DONALD RAUSCHUBER 38068 REGISTERED PROFESSIONAL ENGINEER

DRAWING SCALE 1"=5.0'

SHEET 2 OF 5

PROFILE VIEW
(INTAKE SCREEN PROVIDED BY OWNER)



REVISIONS

NO.	DATE	REMARKS

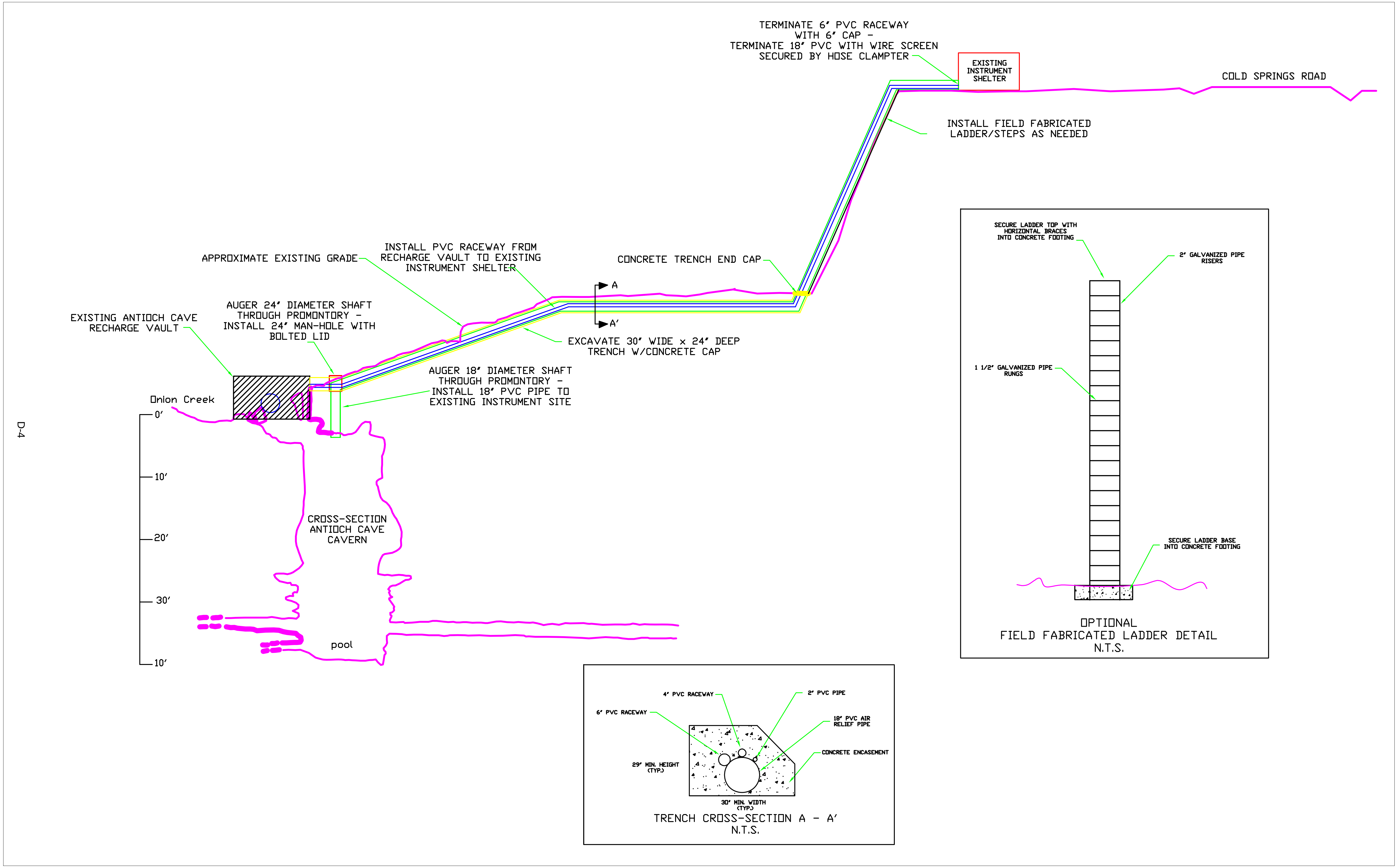
dgra Donald G. Rauschuber & Associates, Inc.
Consultants ▪ Water Engineering ▪ Municipal Engineering

SURVEYED	DESIGNED	DRAWN	CHECKED	DATE	FILE NAME:
NONE	DGR	DGR		040111	BSEACD

BARTON SPRINGS EDWARDS AQUIFER CONSERVATION DISTRICT
ANTIOCH CAVE BMP MODIFICATIONS
INTAKE SCREEN ASSEMBLY - PROFILE VIEW

DRAWING SCALE 1"=5.0'

SHEET 3 OF 5



NO.	DATE	REMARKS

REVISIONS

dgra Donald G. Rauschuber & Associates, Inc.
Consultants ■ Water Engineering ■ Municipal Engineering

SURVEYED	DESIGNED	DRAWN	CHECKED	DATE	FILE NAME:
NONE	DGR	DGR		040111	THECOVE

BARTON SPRINGS EDWARDS AQUIFER CONSERVATION DISTRICT ANTIOCH CAVE BMP MODIFICATIONS CONSTRUCTION DETAILS

STATE OF TEXAS ★ DONALD RAUSCHUBER 38068 REGISTERED PROFESSIONAL ENGINEER

DRAWING SCALE 1"=15'

SHEET 4 OF 5

dgra

Donald G. Rauschuber & Associates, Inc.
Consultants ■ Water Engineering ■ Municipal Engineering

SURVEYED	DESIGNED	DRAWN	CHECKED	DATE	FILE NAME
NONE	DGR	DGR		072008	THECOVE

NO.	DATE	REVISIONS

BARTON SPRINGS EDWARDS AQUIFER CONSERVATION DISTRICT ANTIOCH CAVE RECHARGE PROJECT AERIAL VIEW DETAILS

DRAWING SCALE 1"=30'

SHEET 5 OF 5

Appendix E- Laboratory Analytical Data

ClientSampID	Storm Event	CollectionDate	Time	Analyte	DF	Units	RptVal	PQL	MDL
Antioch	2	10/27/2009	1:36	Nitrogen, Ammonia (As N)	1	mg/L	0.056	0.02	0.005
Antioch	2	10/27/2009	1:36	Phosphorus, Total (As P)	1	mg/L	0.094	0.02	0.006
Antioch	2	10/27/2009	1:36	Nitrogen, Nitrate & Nitrite	10	mg/L	11.5	0.2	0.039
Antioch	2	10/27/2009	1:36	Suspended Solids (Residue, Non-Filterable)	2	mg/L	66.6	2	1
Antioch	2	10/27/2009	1:36	Total Dissolved Solids (Residue, Filterable)	10	mg/L	445	25	10
Antioch	2	10/27/2009	1:36	Turbidity	1	NTU	69.1	0.1	0.016
Antioch	2	10/27/2009	2:36	Nitrogen, Ammonia (As N)	1	mg/L	< 0.020	0.02	0.005
Antioch	2	10/27/2009	2:36	Phosphorus, Total (As P)	1	mg/L	0.057	0.02	0.006
Antioch	2	10/27/2009	2:36	Nitrogen, Nitrate & Nitrite	1	mg/L	0.823	0.02	0.004
Antioch	2	10/27/2009	2:36	Suspended Solids (Residue, Non-Filterable)	2	mg/L	48.4	2	1
Antioch	2	10/27/2009	2:36	Total Dissolved Solids (Residue, Filterable)	10	mg/L	309	25	10
Antioch	2	10/27/2009	2:36	Turbidity	1	NTU	30.7	0.1	0.016
Antioch	2	10/27/2009	3:36	Nitrogen, Ammonia (As N)	1	mg/L	< 0.020	0.02	0.005
Antioch	2	10/27/2009	3:36	Phosphorus, Total (As P)	1	mg/L	0.063	0.02	0.006
Antioch	2	10/27/2009	3:36	Nitrogen, Nitrate & Nitrite	1	mg/L	0.825	0.02	0.004
Antioch	2	10/27/2009	3:36	Suspended Solids (Residue, Non-Filterable)	1.2	mg/L	23.2	1.2	0.6
Antioch	2	10/27/2009	3:36	Total Dissolved Solids (Residue, Filterable)	10	mg/L	363	25	10
Antioch	2	10/27/2009	3:36	Turbidity	1	NTU	14.3	0.1	0.016
Antioch	2	10/27/2009	6:36	Nitrogen, Ammonia (As N)	1	mg/L	< 0.020	0.02	0.005
Antioch	2	10/27/2009	6:36	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Antioch	2	10/27/2009	6:36	Nitrogen, Nitrate & Nitrite	1	mg/L	0.859	0.02	0.004
Antioch	2	10/27/2009	6:36	Suspended Solids (Residue, Non-Filterable)	1.3	mg/L	4.9	1.3	0.7
Antioch	2	10/27/2009	6:36	Total Dissolved Solids (Residue, Filterable)	10	mg/L	401	25	10
Antioch	2	10/27/2009	6:36	Turbidity	1	NTU	5.92	0.1	0.016
Antioch	2	10/27/2009	12:45	Nitrogen, Ammonia (As N)	1	mg/L	< 0.020	0.02	0.005
Antioch	2	10/27/2009	12:45	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Antioch	2	10/27/2009	12:45	Nitrogen, Nitrate & Nitrite	1	mg/L	0.977	0.02	0.004
Antioch	2	10/27/2009	12:45	Suspended Solids (Residue, Non-Filterable)	1.3	mg/L	2.3	1.3	0.7
Antioch	2	10/27/2009	12:45	Total Dissolved Solids (Residue, Filterable)	10	mg/L	411	25	10
Antioch	2	10/27/2009	12:45	Turbidity	1	NTU	2.29	0.1	0.016
Antioch	2	10/27/2009	18:45	Nitrogen, Ammonia (As N)	1	mg/L	< 0.020	0.02	0.005
Antioch	2	10/27/2009	18:45	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Antioch	2	10/27/2009	18:45	Nitrogen, Nitrate & Nitrite	1	mg/L	1.11	0.02	0.004
Antioch	2	10/27/2009	18:45	Suspended Solids (Residue, Non-Filterable)	4	mg/L	6.4	4	2
Antioch	2	10/27/2009	18:45	Total Dissolved Solids (Residue, Filterable)	10	mg/L	398	25	10
Antioch	2	10/27/2009	18:45	Turbidity	1	NTU	1.85	0.1	0.016
Antioch	2	10/28/2009	2:45	Nitrogen, Ammonia (As N)	1	mg/L	< 0.020	0.02	0.005
Antioch	2	10/28/2009	2:45	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Antioch	2	10/28/2009	2:45	Nitrogen, Nitrate & Nitrite	1	mg/L	1.35	0.02	0.004

Appendix E- Laboratory Analytical Data

ClientSampID	Storm Event	CollectionDate	Time	Analyte	DF	Units	RptVal	PQL	MDL
Antioch	2	10/28/2009	2:45	Suspended Solids (Residue, Non-Filterable)	4	mg/L	9.2	4	2
Antioch	2	10/28/2009	2:45	Total Dissolved Solids (Residue, Filterable)	10	mg/L	387	25	10
Antioch	2	10/28/2009	2:45	Turbidity	1	NTU	1.62	0.1	0.016
BOTTLE 1-2	3	1/15/2010	21:51	Turbidity	1	NTU	63.7	0.1	0.016
BOTTLE 1-2	3	1/15/2010	21:51	Total Dissolved Solids (Residue, Filterable)	10	mg/L	156	50	45
BOTTLE 1-2	3	1/15/2010	21:51	Suspended Solids (Residue, Non-Filterable)	4	mg/L	91.2	4	2
BOTTLE 1-2	3	1/15/2010	21:51	Phosphorus, Total (As P)	1	mg/L	0.218	0.02	0.006
BOTTLE 1-2	3	1/15/2010	21:51	Nitrogen, Nitrate & Nitrite	1	mg/L	0.549	0.02	0.004
BOTTLE 3-4	3	1/15/2010	22:14	Turbidity	1	NTU	46.7	0.1	0.016
BOTTLE 3-4	3	1/15/2010	22:14	Total Dissolved Solids (Residue, Filterable)	10	mg/L	141	50	45
BOTTLE 3-4	3	1/15/2010	22:14	Suspended Solids (Residue, Non-Filterable)	10	mg/L	119	10	5
BOTTLE 3-4	3	1/15/2010	22:14	Phosphorus, Total (As P)	1	mg/L	0.215	0.02	0.006
BOTTLE 3-4	3	1/15/2010	22:14	Nitrogen, Nitrate & Nitrite	1	mg/L	0.381	0.02	0.004
BOTTLE 5-6	3	1/15/2010	22:36	Turbidity	1	NTU	55.3	0.1	0.016
BOTTLE 5-6	3	1/15/2010	22:36	Total Dissolved Solids (Residue, Filterable)	10	mg/L	141	50	45
BOTTLE 5-6	3	1/15/2010	22:36	Suspended Solids (Residue, Non-Filterable)	10	mg/L	124	10	5
BOTTLE 5-6	3	1/15/2010	22:36	Phosphorus, Total (As P)	1	mg/L	0.259	0.02	0.006
BOTTLE 5-6	3	1/15/2010	22:36	Nitrogen, Nitrate & Nitrite	1	mg/L	0.347	0.02	0.004
BOTTLE 7-8	3	1/15/2010	23:21	Turbidity	1	NTU	41.1	0.1	0.016
BOTTLE 7-8	3	1/15/2010	23:21	Total Dissolved Solids (Residue, Filterable)	10	mg/L	129	50	45
BOTTLE 7-8	3	1/15/2010	23:21	Suspended Solids (Residue, Non-Filterable)	6.7	mg/L	56.7	6.7	3.3
BOTTLE 7-8	3	1/15/2010	23:21	Phosphorus, Total (As P)	1	mg/L	0.286	0.02	0.006
BOTTLE 7-8	3	1/15/2010	23:21	Nitrogen, Nitrate & Nitrite	1	mg/L	0.228	0.02	0.004
BOTTLE 9-10	3	1/16/2010	0:21	Turbidity	1	NTU	35.6	0.1	0.016
BOTTLE 9-10	3	1/16/2010	0:21	Total Dissolved Solids (Residue, Filterable)	10	mg/L	163	50	45
BOTTLE 9-10	3	1/16/2010	0:21	Suspended Solids (Residue, Non-Filterable)	10	mg/L	55.0	10	5
BOTTLE 9-10	3	1/16/2010	0:21	Phosphorus, Total (As P)	1	mg/L	0.229	0.02	0.006
BOTTLE 9-10	3	1/16/2010	0:21	Nitrogen, Nitrate & Nitrite	1	mg/L	0.227	0.02	0.004
BOTTLE 11-12	3	1/16/2010	1:36	Turbidity	1	NTU	37.0	0.1	0.016
BOTTLE 11-12	3	1/16/2010	1:36	Total Dissolved Solids (Residue, Filterable)	10	mg/L	160	50	45
BOTTLE 11-12	3	1/16/2010	1:36	Suspended Solids (Residue, Non-Filterable)	4	mg/L	20.4	4	2
BOTTLE 11-12	3	1/16/2010	1:36	Phosphorus, Total (As P)	1	mg/L	0.215	0.02	0.006
BOTTLE 11-12	3	1/16/2010	1:36	Nitrogen, Nitrate & Nitrite	1	mg/L	0.245	0.02	0.004
BOTTLE 13-14	3	1/16/2010	3:06	Turbidity	1	NTU	59.7	0.1	0.016
BOTTLE 13-14	3	1/16/2010	3:06	Total Dissolved Solids (Residue, Filterable)	10	mg/L	240	50	45
BOTTLE 13-14	3	1/16/2010	3:06	Suspended Solids (Residue, Non-Filterable)	4	mg/L	72.8	4	2
BOTTLE 13-14	3	1/16/2010	3:06	Phosphorus, Total (As P)	1	mg/L	0.173	0.02	0.006
BOTTLE 13-14	3	1/16/2010	3:06	Nitrogen, Nitrate & Nitrite	1	mg/L	1.29	0.02	0.004
BOTTLE 15-16	3	1/16/2010	4:51	Turbidity	1	NTU	48.7	0.1	0.016

Appendix E- Laboratory Analytical Data

ClientSampID	Storm Event	CollectionDate	Time	Analyte	DF	Units	RptVal	PQL	MDL
BOTTLE 15-16	3	1/16/2010	4:51	Total Dissolved Solids (Residue, Filterable)	10	mg/L	193	50	45
BOTTLE 15-16	3	1/16/2010	4:51	Suspended Solids (Residue, Non-Filterable)	4	mg/L	57.6	4	2
BOTTLE 15-16	3	1/16/2010	4:51	Phosphorus, Total (As P)	1	mg/L	0.109	0.02	0.006
BOTTLE 15-16	3	1/16/2010	4:51	Nitrogen, Nitrate & Nitrite	1	mg/L	0.865	0.02	0.004
BOTTLE 17-18	3	1/16/2010	6:51	Turbidity	1	NTU	34.9	0.1	0.016
BOTTLE 17-18	3	1/16/2010	6:51	Total Dissolved Solids (Residue, Filterable)	10	mg/L	268	50	45
BOTTLE 17-18	3	1/16/2010	6:51	Suspended Solids (Residue, Non-Filterable)	4	mg/L	34.0	4	2
BOTTLE 17-18	3	1/16/2010	6:51	Phosphorus, Total (As P)	1	mg/L	0.058	0.02	0.006
BOTTLE 17-18	3	1/16/2010	6:51	Nitrogen, Nitrate & Nitrite	1	mg/L	0.682	0.02	0.004
BOTTLE 19-20	3	1/16/2010	9:51	Turbidity	1	NTU	17.5	0.1	0.016
BOTTLE 19-20	3	1/16/2010	9:51	Total Dissolved Solids (Residue, Filterable)	10	mg/L	300	50	45
BOTTLE 19-20	3	1/16/2010	9:51	Suspended Solids (Residue, Non-Filterable)	4	mg/L	28.4	4	2
BOTTLE 19-20	3	1/16/2010	9:51	Phosphorus, Total (As P)	1	mg/L	0.059	0.02	0.006
BOTTLE 19-20	3	1/16/2010	9:51	Nitrogen, Nitrate & Nitrite	1	mg/L	0.658	0.02	0.004
BOTTLE 21-22	3	1/16/2010	15:51	Turbidity	1	NTU	18.7	0.1	0.016
BOTTLE 21-22	3	1/16/2010	15:51	Total Dissolved Solids (Residue, Filterable)	10	mg/L	283	50	45
BOTTLE 21-22	3	1/16/2010	15:51	Suspended Solids (Residue, Non-Filterable)	4	mg/L	16.8	4	2
BOTTLE 21-22	3	1/16/2010	15:51	Phosphorus, Total (As P)	1	mg/L	0.033	0.02	0.006
BOTTLE 21-22	3	1/16/2010	15:51	Nitrogen, Nitrate & Nitrite	1	mg/L	0.715	0.02	0.004
BOTTLE 1-2	3	1/16/2010	17:22	Turbidity	1	NTU	12.0	0.1	0.016
BOTTLE 1-2	3	1/16/2010	17:22	Total Dissolved Solids (Residue, Filterable)	10	mg/L	267	50	45
BOTTLE 1-2	3	1/16/2010	17:22	Suspended Solids (Residue, Non-Filterable)	4	mg/L	27.6	4	2
BOTTLE 1-2	3	1/16/2010	17:22	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
BOTTLE 1-2	3	1/16/2010	17:22	Nitrogen, Nitrate & Nitrite	1	mg/L	0.675	0.02	0.004
BOTTLE 3-4	3	1/16/2010	17:40	Turbidity	1	NTU	12.1	0.1	0.016
BOTTLE 3-4	3	1/16/2010	17:40	Total Dissolved Solids (Residue, Filterable)	10	mg/L	280	50	45
BOTTLE 3-4	3	1/16/2010	17:40	Suspended Solids (Residue, Non-Filterable)	4	mg/L	28.4	4	2
BOTTLE 3-4	3	1/16/2010	17:40	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
BOTTLE 3-4	3	1/16/2010	17:40	Nitrogen, Nitrate & Nitrite	1	mg/L	0.645	0.02	0.004
BOTTLE 5-6	3	1/16/2010	19:40	Turbidity	1	NTU	25.0	0.1	0.016
BOTTLE 5-6	3	1/16/2010	19:40	Total Dissolved Solids (Residue, Filterable)	10	mg/L	276	50	45
BOTTLE 5-6	3	1/16/2010	19:40	Suspended Solids (Residue, Non-Filterable)	4	mg/L	12.8	4	2
BOTTLE 5-6	3	1/16/2010	19:40	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
BOTTLE 5-6	3	1/16/2010	19:40	Nitrogen, Nitrate & Nitrite	1	mg/L	0.652	0.02	0.004
BOTTLE 7-8	3	1/16/2010	23:40	Turbidity	1	NTU	15.2	0.1	0.016
BOTTLE 7-8	3	1/16/2010	23:40	Total Dissolved Solids (Residue, Filterable)	10	mg/L	275	50	45
BOTTLE 7-8	3	1/16/2010	23:40	Suspended Solids (Residue, Non-Filterable)	4	mg/L	28.4	4	2
BOTTLE 7-8	3	1/16/2010	23:40	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
BOTTLE 7-8	3	1/16/2010	23:40	Nitrogen, Nitrate & Nitrite	1	mg/L	0.639	0.02	0.004

Appendix E- Laboratory Analytical Data

ClientSampID	Storm Event	CollectionDate	Time	Analyte	DF	Units	RptVal	PQL	MDL
BOTTLE 9-10	3	1/17/2010	5:40	Turbidity	1	NTU	12.5	0.1	0.016
BOTTLE 9-10	3	1/17/2010	5:40	Total Dissolved Solids (Residue, Filterable)	10	mg/L	276	50	45
BOTTLE 9-10	3	1/17/2010	5:40	Suspended Solids (Residue, Non-Filterable)	4	mg/L	15.2	4	2
BOTTLE 9-10	3	1/17/2010	5:40	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
BOTTLE 9-10	3	1/17/2010	5:40	Nitrogen, Nitrate & Nitrite	1	mg/L	0.685	0.02	0.004
BOTTLE 11-12	3	1/17/2010	13:40	Turbidity	1	NTU	14.0	0.1	0.016
BOTTLE 11-12	3	1/17/2010	13:40	Total Dissolved Solids (Residue, Filterable)	10	mg/L	281	50	45
BOTTLE 11-12	3	1/17/2010	13:40	Suspended Solids (Residue, Non-Filterable)	4	mg/L	10.8	4	2
BOTTLE 11-12	3	1/17/2010	13:40	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
BOTTLE 11-12	3	1/17/2010	13:40	Nitrogen, Nitrate & Nitrite	1	mg/L	0.723	0.02	0.004
BOTTLE 13-14	3	1/17/2010	23:40	Turbidity	1	NTU	9.41	0.1	0.016
BOTTLE 13-14	3	1/17/2010	23:40	Total Dissolved Solids (Residue, Filterable)	10	mg/L	302	50	45
BOTTLE 13-14	3	1/17/2010	23:40	Suspended Solids (Residue, Non-Filterable)	4	mg/L	7.6	4	2
BOTTLE 13-14	3	1/17/2010	23:40	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
BOTTLE 13-14	3	1/17/2010	23:40	Nitrogen, Nitrate & Nitrite	1	mg/L	0.887	0.02	0.004
Bottles 1-2 #1	4	1/29/2010	12:00	Turbidity	1	NTU	20.3	0.1	0.016
Bottles 1-2 #1	4	1/29/2010	12:00	Total Dissolved Solids (Residue, Filterable)	10	mg/L	313	50	45
Bottles 1-2 #1	4	1/29/2010	12:00	Suspended Solids (Residue, Non-Filterable)	4	mg/L	51.2	4	2
Bottles 1-2 #1	4	1/29/2010	12:00	Phosphorus, Total (As P)	1	mg/L	0.080	0.02	0.006
Bottles 1-2 #1	4	1/29/2010	12:00	Nitrogen, Nitrate & Nitrite	1	mg/L	1.23	0.02	0.004
Bottles 3-4 #2	4	1/29/2010	12:14	Turbidity	1	NTU	11.7	0.1	0.016
Bottles 3-4 #2	4	1/29/2010	12:14	Total Dissolved Solids (Residue, Filterable)	10	mg/L	312	50	45
Bottles 3-4 #2	4	1/29/2010	12:14	Suspended Solids (Residue, Non-Filterable)	4	mg/L	16.8	4	2
Bottles 3-4 #2	4	1/29/2010	12:14	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 3-4 #2	4	1/29/2010	12:14	Nitrogen, Nitrate & Nitrite	1	mg/L	1.28	0.02	0.004
Bottles 1-2 #3	4	1/30/2010	11:13	Turbidity	1	NTU	35.0	0.1	0.016
Bottles 1-2 #3	4	1/30/2010	11:13	Total Dissolved Solids (Residue, Filterable)	10	mg/L	280	50	45
Bottles 1-2 #3	4	1/30/2010	11:13	Suspended Solids (Residue, Non-Filterable)	4	mg/L	32.0	4	2
Bottles 1-2 #3	4	1/30/2010	11:13	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 1-2 #3	4	1/30/2010	11:13	Nitrogen, Nitrate & Nitrite	1	mg/L	0.699	0.02	0.004
Bottles 5-6 #4	4	1/30/2010	14:13	Turbidity	1	NTU	22.6	0.1	0.016
Bottles 5-6 #4	4	1/30/2010	14:13	Total Dissolved Solids (Residue, Filterable)	10	mg/L	266	50	45
Bottles 5-6 #4	4	1/30/2010	14:13	Suspended Solids (Residue, Non-Filterable)	4	mg/L	27.2	4	2
Bottles 5-6 #4	4	1/30/2010	14:13	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 5-6 #4	4	1/30/2010	14:13	Nitrogen, Nitrate & Nitrite	1	mg/L	0.706	0.02	0.004
Bottles 7-8 #5	4	1/30/2010	20:13	Turbidity	1	NTU	18.8	0.1	0.016
Bottles 7-8 #5	4	1/30/2010	20:13	Total Dissolved Solids (Residue, Filterable)	10	mg/L	275	50	45
Bottles 7-8 #5	4	1/30/2010	20:13	Suspended Solids (Residue, Non-Filterable)	4	mg/L	24.0	4	2
Bottles 7-8 #5	4	1/30/2010	20:13	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006

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ClientSampID	Storm Event	CollectionDate	Time	Analyte	DF	Units	RptVal	PQL	MDL
Bottles 7-8 #5	4	1/30/2010	20:13	Nitrogen, Nitrate & Nitrite	1	mg/L	0.704	0.02	0.004
Bottles 9-10 #6	4	1/31/2010	5:13	Turbidity	1	NTU	16.8	0.1	0.016
Bottles 9-10 #6	4	1/31/2010	5:13	Total Dissolved Solids (Residue, Filterable)	10	mg/L	260	50	45
Bottles 9-10 #6	4	1/31/2010	5:13	Suspended Solids (Residue, Non-Filterable)	4	mg/L	17.6	4	2
Bottles 9-10 #6	4	1/31/2010	5:13	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 9-10 #6	4	1/31/2010	5:13	Nitrogen, Nitrate & Nitrite	1	mg/L	0.705	0.02	0.004
Antioch	Baseflow	3/4/2010	14:00	Turbidity	1	NTU	0.807	0.1	0.016
Antioch	Baseflow	3/4/2010	14:00	Total Dissolved Solids (Residue, Filterable)	10	mg/L	299	50	45
Antioch	Baseflow	3/4/2010	14:00	Suspended Solids (Residue, Non-Filterable)	1	mg/L	< 1.0	1	0.5
Antioch	Baseflow	3/4/2010	14:00	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Antioch	Baseflow	3/4/2010	14:00	Nitrogen, Nitrate & Nitrite	1	mg/L	1.01	0.02	0.004
Bottles 1-2	5	5/18/2010	2:56	Turbidity	1	NTU	46.1	0.1	0.016
Bottles 1-2	5	5/18/2010	2:56	Total Dissolved Solids (Residue, Filterable)	10	mg/L	223	50	45
Bottles 1-2	5	5/18/2010	2:56	Suspended Solids (Residue, Non-Filterable)	2	mg/L	70.0	2	1
Bottles 1-2	5	5/18/2010	2:56	Phosphorus, Total (As P)	1	mg/L	0.037	0.02	0.006
Bottles 1-2	5	5/18/2010	2:56	Nitrogen, Nitrate & Nitrite	1	mg/L	0.206	0.02	0.004
Bottles 3-4	5	5/18/2010	3:03	Turbidity	1	NTU	21.5	0.1	0.016
Bottles 3-4	5	5/18/2010	3:03	Total Dissolved Solids (Residue, Filterable)	10	mg/L	220	50	45
Bottles 3-4	5	5/18/2010	3:03	Suspended Solids (Residue, Non-Filterable)	2	mg/L	42.8	2	1
Bottles 3-4	5	5/18/2010	3:03	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 3-4	5	5/18/2010	3:03	Nitrogen, Nitrate & Nitrite	1	mg/L	0.332	0.02	0.004
Bottles 5-6	5	5/18/2010	3:10	Turbidity	1	NTU	23.8	0.1	0.016
Bottles 5-6	5	5/18/2010	3:10	Total Dissolved Solids (Residue, Filterable)	10	mg/L	223	50	45
Bottles 5-6	5	5/18/2010	3:10	Suspended Solids (Residue, Non-Filterable)	2	mg/L	30.0	2	1
Bottles 5-6	5	5/18/2010	3:10	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 5-6	5	5/18/2010	3:10	Nitrogen, Nitrate & Nitrite	1	mg/L	0.372	0.02	0.004
Bottles 7-8	5	5/18/2010	3:27	Turbidity	1	NTU	19.2	0.1	0.016
Bottles 7-8	5	5/18/2010	3:27	Total Dissolved Solids (Residue, Filterable)	10	mg/L	224	50	45
Bottles 7-8	5	5/18/2010	3:27	Suspended Solids (Residue, Non-Filterable)	2	mg/L	16.8	2	1
Bottles 7-8	5	5/18/2010	3:27	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 7-8	5	5/18/2010	3:27	Nitrogen, Nitrate & Nitrite	1	mg/L	0.356	0.02	0.004
Bottles 9-10	5	5/18/2010	4:07	Turbidity	1	NTU	15.5	0.1	0.016
Bottles 9-10	5	5/18/2010	4:07	Total Dissolved Solids (Residue, Filterable)	10	mg/L	208	50	45
Bottles 9-10	5	5/18/2010	4:07	Suspended Solids (Residue, Non-Filterable)	2	mg/L	13.4	2	1
Bottles 9-10	5	5/18/2010	4:07	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 9-10	5	5/18/2010	4:07	Nitrogen, Nitrate & Nitrite	1	mg/L	0.488	0.02	0.004
Bottles 15-16	5	5/18/2010	8:37	Turbidity	1	NTU	43.9	0.1	0.016
Bottles 15-16	5	5/18/2010	8:37	Total Dissolved Solids (Residue, Filterable)	10	mg/L	144	50	45
Bottles 15-16	5	5/18/2010	8:37	Suspended Solids (Residue, Non-Filterable)	2	mg/L	25.0	2	1

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ClientSampID	Storm Event	CollectionDate	Time	Analyte	DF	Units	RptVal	PQL	MDL
Bottles 15-16	5	5/18/2010	8:37	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Bottles 15-16	5	5/18/2010	8:37	Nitrogen, Nitrate & Nitrite	1	mg/L	0.270	0.02	0.004
17-18	5	5/18/2010	11:37	Turbidity	1	NTU	35.3	0.1	0.016
17-18	5	5/18/2010	11:37	Total Dissolved Solids (Residue, Filterable)	10	mg/L	158	50	45
17-18	5	5/18/2010	11:37	Suspended Solids (Residue, Non-Filterable)	2	mg/L	21.0	2	1
17-18	5	5/18/2010	11:37	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
17-18	5	5/18/2010	11:37	Nitrogen, Nitrate & Nitrite	1	mg/L	0.315	0.02	0.004
21-22	5	5/19/2010	2:37	Turbidity	1	NTU	0.579	0.1	0.016
21-22	5	5/19/2010	2:37	Total Dissolved Solids (Residue, Filterable)	10	mg/L	269	50	45
21-22	5	5/19/2010	2:37	Suspended Solids (Residue, Non-Filterable)	1	mg/L	1.1	1	0.5
21-22	5	5/19/2010	2:37	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
21-22	5	5/19/2010	2:37	Nitrogen, Nitrate & Nitrite	1	mg/L	0.176	0.02	0.004
5-6	5	5/19/2010	14:57	Turbidity	1	NTU	1.02	0.1	0.016
5-6	5	5/19/2010	14:57	Total Dissolved Solids (Residue, Filterable)	10	mg/L	259	50	45
5-6	5	5/19/2010	14:57	Suspended Solids (Residue, Non-Filterable)	1	mg/L	< 1.0	1	0.5
5-6	5	5/19/2010	14:57	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
5-6	5	5/19/2010	14:57	Nitrogen, Nitrate & Nitrite	1	mg/L	0.171	0.02	0.004
13-14	5	5/19/2010	22:02	Turbidity	1	NTU	1.63	0.1	0.016
13-14	5	5/19/2010	22:02	Total Dissolved Solids (Residue, Filterable)	10	mg/L	267	50	45
13-14	5	5/19/2010	22:02	Suspended Solids (Residue, Non-Filterable)	1	mg/L	< 1.0	1	0.5
13-14	5	5/19/2010	22:02	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
13-14	5	5/19/2010	22:02	Nitrogen, Nitrate & Nitrite	1	mg/L	0.177	0.02	0.004
Antioch 1	6	9/7/2010	22:00	Turbidity	1	NTU	11.2	0.1	0.016
Antioch 1	6	9/7/2010	22:00	Total Dissolved Solids (Residue, Filterable)	10	mg/L	181	50	45
Antioch 1	6	9/7/2010	22:00	Suspended Solids (Residue, Non-Filterable)	1.4	mg/L	13.4	1.4	0.7
Antioch 1	6	9/7/2010	22:00	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Antioch 1	6	9/7/2010	22:00	Nitrogen, Nitrate & Nitrite	1	mg/L	1.05	0.02	0.004
Antioch 2	6	9/7/2010	22:24	Turbidity	1	NTU	243	0.1	0.016
Antioch 2	6	9/7/2010	22:24	Total Dissolved Solids (Residue, Filterable)	10	mg/L	153	50	45
Antioch 2	6	9/7/2010	22:24	Suspended Solids (Residue, Non-Filterable)	10	mg/L	241	10	5
Antioch 2	6	9/7/2010	22:24	Phosphorus, Total (As P)	1	mg/L	0.207	0.02	0.006
Antioch 2	6	9/7/2010	22:24	Nitrogen, Nitrate & Nitrite	2	mg/L	2.61	0.04	0.008
Antioch 3	6	9/7/2010	23:24	Turbidity	1	NTU	266	0.1	0.016
Antioch 3	6	9/7/2010	23:24	Total Dissolved Solids (Residue, Filterable)	10	mg/L	155	50	45
Antioch 3	6	9/7/2010	23:24	Suspended Solids (Residue, Non-Filterable)	10	mg/L	234	10	5
Antioch 3	6	9/7/2010	23:24	Phosphorus, Total (As P)	1	mg/L	0.175	0.02	0.006
Antioch 3	6	9/7/2010	23:24	Nitrogen, Nitrate & Nitrite	2	mg/L	1.89	0.04	0.008
Antioch 4	6	9/8/2010	0:39	Turbidity	1	NTU	108	0.1	0.016
Antioch 4	6	9/8/2010	0:39	Total Dissolved Solids (Residue, Filterable)	10	mg/L	112	50	45

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ClientSampID	Storm Event	CollectionDate	Time	Analyte	DF	Units	RptVal	PQL	MDL
Antioch 4	6	9/8/2010	0:39	Suspended Solids (Residue, Non-Filterable)	10	mg/L	121	10	5
Antioch 4	6	9/8/2010	0:39	Phosphorus, Total (As P)	1	mg/L	0.434	0.02	0.006
Antioch 4	6	9/8/2010	0:39	Nitrogen, Nitrate & Nitrite	1	mg/L	0.938	0.02	0.004
Antioch 5	6	9/8/2010	2:09	Turbidity	1	NTU	30.6	0.1	0.016
Antioch 5	6	9/8/2010	2:09	Total Dissolved Solids (Residue, Filterable)	10	mg/L	103	50	45
Antioch 5	6	9/8/2010	2:09	Suspended Solids (Residue, Non-Filterable)	2	mg/L	19.0	2	1
Antioch 5	6	9/8/2010	2:09	Phosphorus, Total (As P)	1	mg/L	0.206	0.02	0.006
Antioch 5	6	9/8/2010	2:09	Nitrogen, Nitrate & Nitrite	1	mg/L	0.914	0.02	0.004
Antioch 6	6	9/8/2010	3:54	Turbidity	1	NTU	310	0.1	0.016
Antioch 6	6	9/8/2010	3:54	Total Dissolved Solids (Residue, Filterable)	10	mg/L	127	50	45
Antioch 6	6	9/8/2010	3:54	Suspended Solids (Residue, Non-Filterable)	10	mg/L	295	10	5
Antioch 6	6	9/8/2010	3:54	Phosphorus, Total (As P)	1	mg/L	0.234	0.02	0.006
Antioch 6	6	9/8/2010	3:54	Nitrogen, Nitrate & Nitrite	1	mg/L	1.56	0.02	0.004
Antioch 7	6	9/10/2010	12:30	Turbidity	1	NTU	8.35	0.1	0.016
Antioch 7	6	9/10/2010	12:30	Total Dissolved Solids (Residue, Filterable)	10	mg/L	236	50	45
Antioch 7	6	9/10/2010	12:30	Suspended Solids (Residue, Non-Filterable)	1	mg/L	6.7	1	0.5
Antioch 7	6	9/10/2010	12:30	Phosphorus, Total (As P)	1	mg/L	< 0.020	0.02	0.006
Antioch 7	6	9/10/2010	12:30	Nitrogen, Nitrate & Nitrite	1	mg/L	0.636	0.02	0.004