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Implementation of Best Management Practices to Reduce Nonpoint Source Loadings to Onion Creek Recharge Features

Antioch Cave BMP and Aquifer Recharge Facility

A Pollution Prevention and Recharge Enhancement Project of the

Barton Springs/Edwards Aquifer Conservation District

Prepared in Cooperation with the
Texas Natural Resource Conservation Commission and the U.S. Environmental Protection Agency

Final Report

Combining and Incorporating
a
Technical Report, Summary Report, Workshop Manual, and Survey Report

on the EPA 205(J)(5) Matching Funds Grant Project Entitled

Implementation of Best Management Practices to Reduce Nonpoint Source Loadings to Onion Creek Recharge Features

December 16, 1998

Report Prepared by:
Ronald G. Fieseler, Project Manager
BS/EACD Senior Environmental Analyst

A Pollution Prevention and Recharge Enhancement Project of the

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The preparation of this report was 60% financed through $203,420 in grant funds from the U.S. Environmental Protection Agency through the Texas Natural Resource Conservation Commission.

Acknowledgments

The United States Environmental Protection Agency (EPA) approved a FY92 Section 319(h) matching funds grant application by the Barton Springs/Edwards Aquifer Conservation District (BS/EACD) which was administered under the Texas Natural Resource Conservation Commission (TNRCC) Contract No. 4200000012. The contract period (including time extensions) was from September 30, 1993 to March 31, 1998. The grant fund was originally $271,550, which was subsequently increased by $67,483 of remaining FY 88 matching funds. This was a total of $339,033 which 60% ($203,420) was provided by the EPA and 40% ($135,613) was provided by local funding.

The grant study was completed under the overall supervision of Bill E. Couch, AICP, General Manager of the BS/EACD. Ronald G. Fieseler, BS/EACD Senior Environmental Analyst, was the Project Manager. The report was prepared by Mr. Fieseler, with assistance from Donald G. Rauschuber (Project Engineer), Nico Hauwert (BS/EACD Hydrogeologist and Project QA/QC Officer, and Shu Liang, BS/EACD Senior GIS Specialist.

The project team expresses deep appreciation to the EPA for providing the unique opportunity to work on this comprehensive project. The team greatly appreciates the support provided by the EPA grant project officers, successively, Gary Fisher, Petra Sanchez, and Len Pardee, and by EPA Water Quality Branch Chief Joan E. Brown.

The project team expresses deep appreciation to the TNRCC for planning and directing NPS programs in the State of Texas and for their involvement and guidance in this comprehensive project. The team greatly appreciates the administrative support provided by current and former TNRCC staff members including Anthony Grigsby, Clyde Bohmfalk, Charles Dvorsky, Arthur Talley, Kerry McCollough, Dick Respess, Valerie Robinson, Kelvin Moore, Laurie Curra, Anne Rogers, Stephen Stubbs, Sally Gutierrez, and Hos Evans.

The project team thanks the BS/EACD Board of Directors for their commitment of District resources to the project. We also want to thank current and former BS/EACD staff members including Steve Schriver, Robert Botto, June Tweed, Robin Nesbitt, Stovy Bowlin, Tom Heathman, Shawn Vickers, Tammy Charlson, Joseph Beery, Elsa Rodriguez, Barbara Jensen, and Debra Smith for their time and dedication in preparing and reviewing documents, collecting samples, working at the BMP sites, and performing background and administrative work.

Other individuals and businesses deserving the thanks of the project team include: Jim Bailey and Mark O'Connor of Centex Materials for providing site access during the land acquisition negotiations, the employees of the Centex Materials Buda Plant (particularly Pat Beck and Pete Villalpando) for their courtesy and cooperation with our many visits and requests for assistance, Rudy Muñiz and the employees at Muñiz Construction, Byron Benoit, his son James, and all the employees of Associated Drilling, Pedernales Electric Cooperative, Tommy Thompson and the employees of Rainey Engineering and the DeZurik Corporation, Robert Brandes, P.E., and Donald G. Rauschuber and Associates.

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1.0 PROJECT INTRODUCTION

1.1 Introduction

The Barton Springs segment of the Edwards Aquifer, a karst limestone aquifer, is recharged by surface water in the watersheds of Barton Creek and Onion Creek and its tributaries (Williamson Creek, Slaughter Creek, Bear Creek and Little Bear Creek). The quality of water within the aquifer is directly dependent on the quality of surface water in these watersheds. The recharge occurs primarily within the creeks as they cross the aquifer's recharge zone, and specifically through faults, fractures and caves located on or adjacent to the stream beds. Across the recharge zone of the aquifer, an average of approximately 37,000 acre-feet of surface water is recharged annually. The Recharge Zone of the aquifer covers approximately 90 square miles; however, a majority of the water available for recharge originates in the contributing zone, a much larger drainage area (264 square miles) just west of the recharge zone (see Figure 1-1). As a general rule, the creeks over the recharge zone are normally dry except for storm-induced stream flow and flood events, some spring or seepage flow, and occasional ponding, all of which are short-term events and may last no longer than a few weeks or months. Upstream of the Recharge Zone, spring flow from the Glen Rose limestone provides a generally steady baseflow and results in a relatively high quality of surface water flowing in the creeks which supports limited contact recreation, provides high quality aquatic habitat, and contributes some recharge near the contact between the Glen Rose and Edwards.

The Barton Springs segment of the Edwards Aquifer currently serves as the sole source of drinking water for approximately 45,000 people in southern Travis and northern Hays Counties. Of the total amount of surface water recharged to the aquifer, approximately 85 percent returns to the surface water system as flow from springs along the Colorado River (Town Lake), including Barton Springs. During winter months, Barton Springs supplies approximately 80 percent of the flow into Town Lake, which provides the water supply for the City of Austin's Green Water Treatment Plant on Town Lake. Protection of the water quality within the recharge contributing creeks and in the Barton Springs segment of the Edwards Aquifer is of paramount importance. Adverse effects on water quality resulting from ongoing development within the watershed already have been observed. Based on the experience gained during the past ten to fifteen years by various agencies in monitoring, analysis, planning and modeling of the aquifer and on the results of designing, installing, monitoring and evaluating various nonpoint source pollution controls in the Austin area, it was apparent that additional NPS programs were needed to assure satisfactory protection of the water quality of the aquifer and that both traditional and innovative measures to control nonpoint sources of pollution currently were available for implementation.

The attention of the Barton Springs/Edwards Aquifer Conservation District (BS/EACD or District) was drawn toward two cave entrances which are significant recharge features in the main channel of Onion Creek over the Recharge Zone. Onion Creek is a critical watershed listed on the statewide List of Nonpoint Source Impacted Waters. The Barton Springs segment of the Edwards Aquifer is an EPA-designated Sole-Source aquifer, and is considered by the Texas Natural Resource Conservation Commission (TNRCC) to be one of Texas' most susceptible aquifers to NPS groundwater pollution. The District looked at these two caves with an eye toward implementing appropriate Best Management Practices (BMPs) to address nonpoint source pollution concerns as well as ensure the continued availability of the caves as recharge features.

1.2 Identification of NPS Situation at Two Caves in Onion Creek

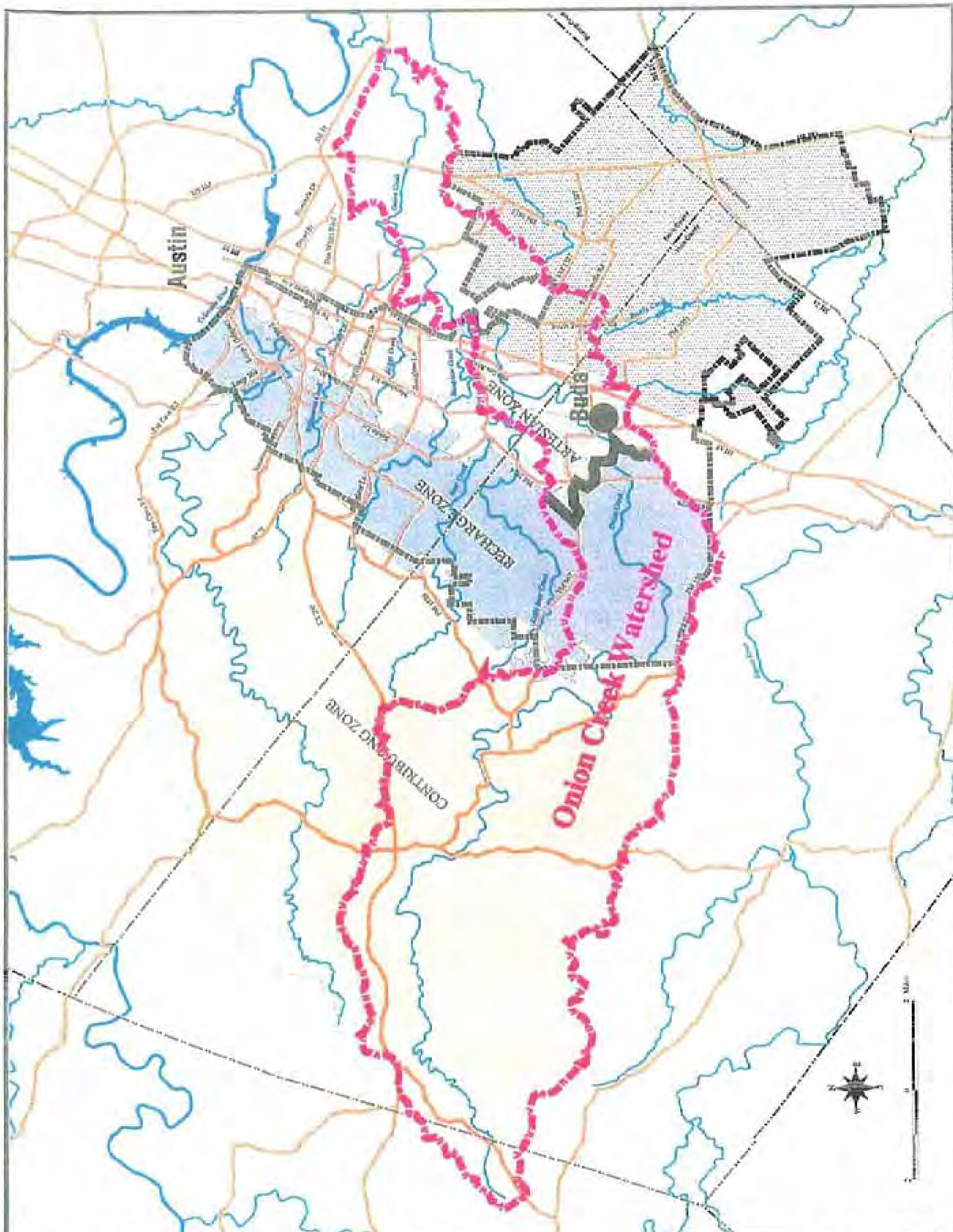
United States Geological Survey (USGS) studies (Slade et al., 1985) have shown that approximately 34 percent of the aquifer's recharge originates from the Onion Creek watershed west of Buda, while 28 percent originates from the Barton Creek watershed. District studies (Rauschuber et al, 1990) have shown that recharge from the Onion Creek watershed provides groundwater to the majority of the Sole-Source users of the aquifer. Therefore, the potential for pollution of the creeks, the aquifer, and the springs, from NPS pollution within the Onion Creek and Barton Creek watersheds is a primary concern of the BS/EACD and the TNRCC.

The Onion Creek watershed has a total drainage area of approximately 165 square miles upstream of Buda. Within this area, a 9.6 mile segment of Onion Creek traverses the Recharge Zone of the Aquifer and drops 155 feet with an average slope of 16.2 feet per mile. The aquifer's recharge zone located within the Onion Creek watershed has a total area of about 26.2 square miles. The Onion Creek watershed above the recharge zone, referred to herein as the contributing zone, is about 138.8 square miles in area.

Onion Creek flow is very erratic and varies from months of very little or no flow to major flood events approaching 9000 cfs. Investigations performed by the District (Rauschuber et al, 1992) indicate that, on the average, about 43,100 acre-feet of water per year enters the recharge zone from the Onion Creek contributing zone. Of this quantity, approximately 28,700 acre-feet of water is recharged to the aquifer. Recharge within Onion Creek's recharge zone, estimated at 160 cfs, occurs predominantly through faults, fractures, sinkholes, and caves and are generally bounded by local and regional faults. Individually, these features have a moderate to high recharge potential.

However, two significant recharge features, Crippled Crawfish Cave and Antioch Cave (see Figures 2-2 and 2-3, 2-4, respectively), located within the normal flow line of Onion Creek, provide a substantial percentage of total recharge within this area. District studies (Rauschuber et al, 1992) show that these caves provide a direct conduit from Onion Creek to the aquifer and potentially supply up to 20 percent of the recharge by volume from Onion Creek, and possibly up to 80 to 90 percent of the sediment load entering the aquifer from Onion Creek. District studies have shown that the sediment load from Onion Creek's contributing zone totals about 0.66 tons per acre per year of drainage area. This is equivalent to 69,700 tons of sediment per year or an average of 46 acre-feet of sediment per annum. In addition, tons of other organic and inorganic materials (debris), such as leaves, branches, and litter, are transported by stream flow into the recharge zone. Field observations of floods within the study area indicate that initial flood surges, generally lasting from one to three days, transport 95 to 98 percent of the sediment load.

Many smaller recharge features, such as cracks, fissures and faults, retard the migration of non-soluble pollutants into the aquifer. However, due to their larger entrance openings, Antioch Cave and Crippled Crawfish Cave are directly susceptible to NPS pollutant loadings, particularly sediment and suspended organic and inorganic materials. These two caves are primary recharge points - as long as the entrances are open and accessible for recharging water. Anecdotal evidence from local residents and on-site observations by District staff indicate that the cave entrances may be plugged with debris from time to time, with a corresponding reduction in recharge capability. Specific needs were identified by the District for implementation of BMPs to control nonpoint source pollution at the two cave sites. It was believed that the BMPs proposed for implementation



Hydrological Zones

Figure 1.1

under this project could reduce NPS pollution from creek flow entering the caves, and they could provide the technical documentation and basis for implementing similar NPS controls wherever potential recharge caves are encountered in waterways. With regard to the need for this proposed NPS implementation project, the following key points are noted:

- Onion Creek (Segment 1427) and Town Lake (Segment 1429) are listed as known problems on the Texas Water Commission's (TWC) Draft 1990 Statewide List of Nonpoint Source Impacted Waterbodies (Table 1-1). The pollutants of concern for both water bodies are fecal coliform, sediment, trash and debris, and nutrients.
- The City of Austin's "Nonpoint Source Assessment Report" (July 1990) submitted for TWC's update of the Statewide List of NPS Affected Waterbodies listed Onion Creek and Town Lake as water bodies affected or threatened by nonpoint source pollution. Both of these water bodies have been affected to some degree by nonpoint source pollution and are threatened by additional nonpoint source pollution associated with runoff from new developments. The information presented in Table 1-2 has been compiled from monitored and evaluated data.
- The water quality in Onion Creek has been poorly studied. However, heavy rains often result in flooding, which always contains heavy sediment loads, extensive trash and debris, and high levels of bacteria. Sediment and fecal coliform regularly limit recreational uses in Onion Creek and Barton Springs after storm events. There is some concern with respect to pesticides since 21 different pesticide compounds, including Chlordane, have been detected in stormwater in the Austin area. Further degradation by nonpoint source pollution can be expected as land uses change from natural conditions or rangeland uses to more residential and commercial uses.
- Potential NPS categories for Onion Creek and Barton Springs include: natural; rangeland; highway and land development construction; runoff from residential and commercial developments and highways; land disposal of wastewater and septic tanks; quarrying and mining, and stream bank erosion. Runoff from residential and commercial developments and highways/roadways represents a potentially significant problem. Most of the runoff from these activities within the Onion Creek watershed is discharged as surface runoff in a diffuse manner. The Onion Creek drainage is currently undergoing significant changes in land uses as development pressures increase and ranches are being subdivided for development.
- Some information was available on the potential effectiveness of traditional BMPs for controlling the expected potential pollution, but it was thought by District staff that more innovative measures may be required to address the unique characteristics of each cave site.
- Data indicates that Onion Creek, via Barton Springs, contributes a significant quantity of water to Town Lake, and presumably a correspondingly significant NPS load, especially sediment.
- According to the TWC Report, "Groundwater Quality of Texas" (March 1989), the Balcones Fault Zone portion of the Edwards Aquifer, which includes the entire recharge zone of the Barton Springs segment of the Edwards Aquifer, is considered to be the Texas aquifer most susceptible to nonpoint source pollution associated with stormwater runoff.
- A major portion of the Barton Springs segment of the Edwards Aquifer has been designated as a Sole Source Drinking Water Supply Aquifer by the (EPA).

There is a clear need to provide high levels of protection for Onion Creek and the other watersheds contributing recharge to the Barton Springs segment of the Edwards Aquifer. This implementation

project specifically addressed NPS problems associated with stormwater runoff in Onion Creek, but would also be applicable in other waterways. Parameters of primary concern were sediment, organic and inorganic debris, nitrogen, and bacteria.

There was limited water quality data available describing the characteristics of NPS pollution in Onion Creek. Table 1.2 shows the water quality for Barton Creek and Barton Springs during non-storm conditions. Although considerable development has occurred along Barton Creek, much of the upper drainage on the contributing zone is relatively undisturbed rangeland or large lot development. It was thought that Onion Creek, which is even less developed, would yield water quality results similar to these levels under non-storm flow conditions. Onion Creek has a very large drainage area and is known for occasional massive flooding with heavy bacteria, sediment, and debris loads, which was the primary concern, although water samples would be tested for a variety of constituents in order to perhaps identify other contaminants of significance.

Table 1.3 contains a statistical summary of important water quality constituents for Onion Creek within the area where the BMPs were to be constructed. These samples were taken from the USGS Gaging Station # 08158800 at Onion Creek and FM 967 just west of Buda and about one half mile downstream of the recharge zone. In general, the water quality of Onion Creek is very good during low or non-flood conditions. However, it is clear that constituent concentrations were much higher during storm-related, flood conditions. Preventing and reducing these substances from entering the aquifer via natural recharge through cave/cavern systems will enhance and protect the water quality of the aquifer. The District wished to design, install, and operate BMPs which would protect the aquifer from contamination during times of high pollution potential, yet allow for maximum recharge of more desirable water.

TABLE 1-1

NPS POLLUTION PROBLEMS RELATED TO ONION CREEK AND THE BARTON SPRINGS SEGMENT OF THE EDWARDS AQUIFER

(source: Texas Water Commission's (TWC) Draft 1990 Statewide List of Nonpoint Source Impacted Waterbodies)

Water Body	Segment	Pollutant of Concern	Problem Status
Onion Creek	1427	Fecal Coliform	Known
		Sediment	Known
		Trash & Debris	Known
		Algae/Nutrients	Potential
		Pesticides	Concern
		Oil & Grease	Potential
Town Lake	1429	Fecal Coliform	Known
		Trash & Debris	Known
		Sediment	Known
		Algae/Nutrients	Known
		Pesticides	Known
		Oil & Grease	Known
		Lead	Known

TABLE 1-2

BARTON CREEK AND BARTON SPRINGS NORMAL (NON-STORM) WATER QUALITY

(source: Storm Runoff and Baseflow Water Quality Modeling Studies, COA, March 1990)

Parameter	Barton Creek	Barton Springs
Total Suspended Solids	1 mg/l	2 mg/l
Total Phosphates	0.01 mg/l	0.02 mg/l
Total Nitrogen	0.35 mg/l	1.83 mg/l
Chemical Oxygen Demand	9 mg/l	1.8 mg/l
Lead	0.0003 mg/l	0.0006 mg/l

TABLE 1-3

AVERAGE CONCENTRATIONS FOR SELECTED WATER QUALITY CONSTITUENTS ONION CREEK AND FM 967, (BUDA GAGE, USGS # 08158800)

(source: USGS, Water-Data Report, Texas 1978 – 1983)

Constituent	Units	No. of Observations	Average Concentration	Maximum Observed Concentration	Minimum Observed Concentration
Flow	cfs	25	967.72	8320.00	0.13
Specific Conductance	µS/cm	25	360.96	545.00	115.00
Temperature	Deg. Cent.	25	19.90	31.50	6.00
Turbidity	NTU	23	169.45	1,200.00	0.00
Oxygen dissolved	mg/l	21	8.70	11.20	5.60
5 Day BOD	mg/l	23	2.48	12.00	0.10
Fecal Coliform	col/100ml	19	17,976.32	130,000.00	0.00
Fecal Coliform .7 UM-MF	col/100ml	23	9,118.17	46,000.00	2.00
Fecal Streptococci	col/100ml	23	21,362.35	84,000.00	14.00
Hardness Total	mg/l	20	155.70	250.00	0.00
Hardness Dissolved	mg/l	20	20.45	44.00	0.00
Calcium Dissolved	mg/l	20	49.55	79.00	0.00
Magnesium Dissolved	mg/l	20	7.83	16.00	0.00
Sodium Dissolved	mg/l	20	5.97	15.00	0.00
Potassium Dissolved	mg/l	20	2.09	4.00	0.00
Alkalinity	mg/l	5	101.20	190.00	41.00
Sulfate Dissolved	mg/l	20	20.84	44.00	0.00
Chloride Dissolved	mg/l	20	9.95	22.00	0.00
Fluoride Dissolved	mg/l	19	0.15	0.20	0.10
Solids (sum of constituents)	mg/l	20	184.6	304.00	0.00
Nitrogen Nitrite	mg/l	24	0.03	0.25	0.00
Nitrogen NO_2+NO_3 total	mg/l	24	0.27	1.50	0.00
Nitrogen Ammonia	mg/l	24	0.06	0.29	0.00
Nitrogen Organic Total	mg/l	24	0.97	6.50	0.07
Phosphorus Total	mg/l	24	0.07	0.30	0.01
Organic Carbon Total	mg/l	23	12.71	77.00	1.30
Arsenic Dissolved	µg/l	19	0.89	3.00	0.00
Barium Dissolved	µg/l	17	26.94	200.00	0.00
Cadmium Dissolved	µg/l	17	0.82	3.00	0.00
Chromium Dissolved	µg/l	17	1.76	10.00	0.00
Cobalt Dissolved	µg/l	4	0.00	0.00	0.00
Copper Dissolved	µg/l	17	1.29	5.00	0.00
Iron Dissolved	µg/l	17	29.47	190.00	0.00
Lead Dissolved	µg/l	17	1.65	15.00	0.00
Manganese Dissolved	µg/l	17	9.53	80.00	0.00
Mercury Dissolved	µg/l	17	0.01	0.10	0.00
Nickel Dissolved	µg/l	4	0.00	0.00	0.00
Selenium Dissolved	µg/l	17	0.24	1.00	0.00
Silver Dissolved	µg/l	17	0.12	1.00	0.00
Strontium Dissolved	µg/l	4	0.00	0.00	0.00
Zinc Dissolved	µg/l	17	5.24	18.00	0.00

1.3 Development of Project Proposal and Grant Funding Submission

As a result of these concerns and findings, the BS/EACD developed an application for an EPA 319(h) matching funds grant directed at reducing NPS pollution loadings entering the aquifer through cave entrances located on Onion Creek. The BS/EACD submitted the application to the Texas Natural Resource Conservation Commission (TNRCC) for FY 1992 319(h) funding.

The project was based on the availability of $271,550 of EPA Section 319(h) funds for FY92. For the project, the BS/EACD committed to matching funds and in-kind services in a total amount of $108,620. The TNRCC acted as the contracting agency with the EPA, with the BS/EACD contracting with the TNRCC as the lead agency for the project. The project's contractual starting date was September 30, 1993 with a project ending date of August 31, 1996.

This project was designed with three primary tasks: (1) evaluate, design, construct, and implement appropriate NPS BMPs at two cave sites on Onion Creek, (2) document effectiveness of the BMPs, and, (3) provide expanded education, technical assistance, and technology transfer to other public and private entities charged with NPS pollution abatement activities. Later in the project, a fourth task was added, (4) purchase and use of water quality monitoring equipment, utilizing $67,483 in matching funding remaining at the TNRCC from the FY88 EPA Non-Point Source Program.

This project was conducted by the BS/EACD and its consulting engineers, with technical assistance and direction provided by the Texas Natural Resource Conservation Commission. The principal individuals involved in this project were:

District General Manager:	Mr. William "Bill" E. Couch, AICP
District Project Manager:	Mr. Ron Fieseler, Senior Environmental Analyst
District Principal Investigator:	Mr. Don Rauschuber, P.E.
District Principal Investigator:	Mr. Robert Brandes, Ph.D., P.E.
TNRCC Project Coordinator(s):	Mr. Arthur Talley, P.E., and Kelvin Moore

2.0 PROJECT IMPLEMENTATION

2.1 BS/EACD Responsibility

The BS/EACD was responsible for the overall performance of the project including the preparation and submission of the BMP design, site plan, and the Quality Assurance Project Plan (QAPP), the construction of the BMP and its monitoring facilities, the implementation of field sampling activities and evaluation of the water quality data, preparing and conducting technology transfer presentations, and preparation of reports documenting the results of the overall effort. Photographs of the project are included in Appendix A.

2.2 Start-Up

Although the Project utilized FY92 EPA 319(h) funding, contract negotiations with the TNRCC were quite lengthy, with the final signing not occurring until October 28, 1993 with a contractual starting date of September 30, 1993. As the project progressed, some delays were encountered, particularly with site access negotiations with landowners, QAPP revisions and approval, and contractual delays. This necessitated two time extensions requests from the District, both of which were approved, with the final project ending date being March 31, 1998.

2.3 Project Site Access

Following the signing of the project contract with TNRCC, negotiations began with landowners for obtaining access to the two caves. Mr. Orr granted temporary written permission for access to Crippled Crawfish Cave and Centex Materials allowed access to Antioch Cave pending legal review of the access agreement.

During lengthy negotiations with Centex materials over site access and easements for construction of the structural BMPs, Centex offered to sell the property containing Antioch Cave and approximately one half mile of Onion Creek. The EPA agreed with the District that such a land acquisition would be consistent with the purposes of the 319(h) program and could be incorporated appropriately as local in-kind matching funds (see EPA letter in Appendix B). The District eventually acquired ownership of this 38.6 acre parcel, which lies at the east end of the Recharge Zone (see Figure 2-1). Centex continued to allow site access through their quarry wet plant during the construction phase of the project until a new access route was established in accordance with a five year access easement.

The District installed a gate on the north side of the property and cleared brush, debris, and old quarry spoils to provide an access route to the monitoring equipment shed on the north bank of Onion Creek near Antioch Cave. This is now the primary access for monitoring and sampling purposes. Electric service is also provided and accessed along this route.

Figure 2-1

PHILIP J. ALLEN LEAGUE SURVEY # 5
CENTEX TO B.S.E.A.C.D.
Area = 1682461 sq.ft
38.624 Acres
MORTON M. McCARVER SURVEY # 4
APPLIED GEOMATICS
Land Surveying/Mapping/GPS/GIS
LEGEND
CERTIFICATE OF SURVEY

2.4 Site Investigations

2.4.1 Crippled Crawfish Cave

Several visits to the Crippled Crawfish Cave for site analysis occurred along with a review of the landowner's plans for the 500 acre parcel in which the cave is located. A map of the cave had been prepared during the first explorations in 1991 (see Figure 2-2) (Rauschuber et al, 1992). It was determined by District staff that: (1) access to the cave and any monitoring or sampling equipment would be essentially impossible during times of high water flow in Onion Creek, (2) practical sites for placing monitoring and sampling equipment were only available in flood-prone areas, (3) installation of electric power was not practical, (4) access for construction vehicles down the creek bank and in the creek bed itself was not practical in that it would require more tree clearing and road building than the owner would permit, (5) the cave was not in imminent danger of any nearby or grossly unacceptable pollution threat, (6) the site was in no danger of being subdivided or extensively developed, and (7) the owner intends to maintain the property in a natural state for personal, family, and business reasons (he is operating a bed and breakfast whose customers value an undeveloped tract of land for hiking, birding, bicycling, etc.).

Given the above findings, District staff eventually determined that the Best Management Practice appropriate for this site was the maintenance of existing conditions. This non-structural control would rely primarily on the good stewardship of the owner, Mr. Orr, and the continued vigilance of the District regarding changing hydrogeologic, pollution potential, and land use conditions within the Onion Creek drainage upstream from Crippled Crawfish Cave. The owner has made it clear to the District staff that he intends to leave the cave in a natural condition. He is also agreeable to revisiting the possible installation of a structural control should existing conditions deteriorate and pollution potential increases.

2.4.2 Antioch Cave

District staff and consulting engineers visited Antioch Cave many times to assess and discuss project options. The site is complex hydrogeologically, geologically, and topographically and required extensive study to properly address pollution problems and design appropriate BMPs.

Accurate surveys were made of the surface and cave site, complete with elevations and cross sections necessary for engineering design considerations. A map of the cave had been prepared during the first explorations in 1991 and 1992 (see Figure 2-3) which was discussed in an earlier report (Rauschuber et al, 1992). Additional explorations in 1994 to gather additional data for the grant project resulted in the map by William Russell (1994) shown in Figure 2-4.

Engineering calculations were reviewed and recalculated based on the site surveys to assess the recharge potential, hydraulic capacities, and floodwater flow rates, volume, and forces. The combined site investigations revealed that Antioch Cave was a tremendously important recharge site and could be protected while simultaneously enhancing recharge. Unlike Crippled Crawfish Cave, Antioch Cave had few inherent problems, and those could be solved with relative ease. District staff recommended, and the TNRCC agreed, that Antioch Cave should be the primary focus of the project.

Figure 2-2

Map of Crippled Crawfish Cave, Hays County, Texas

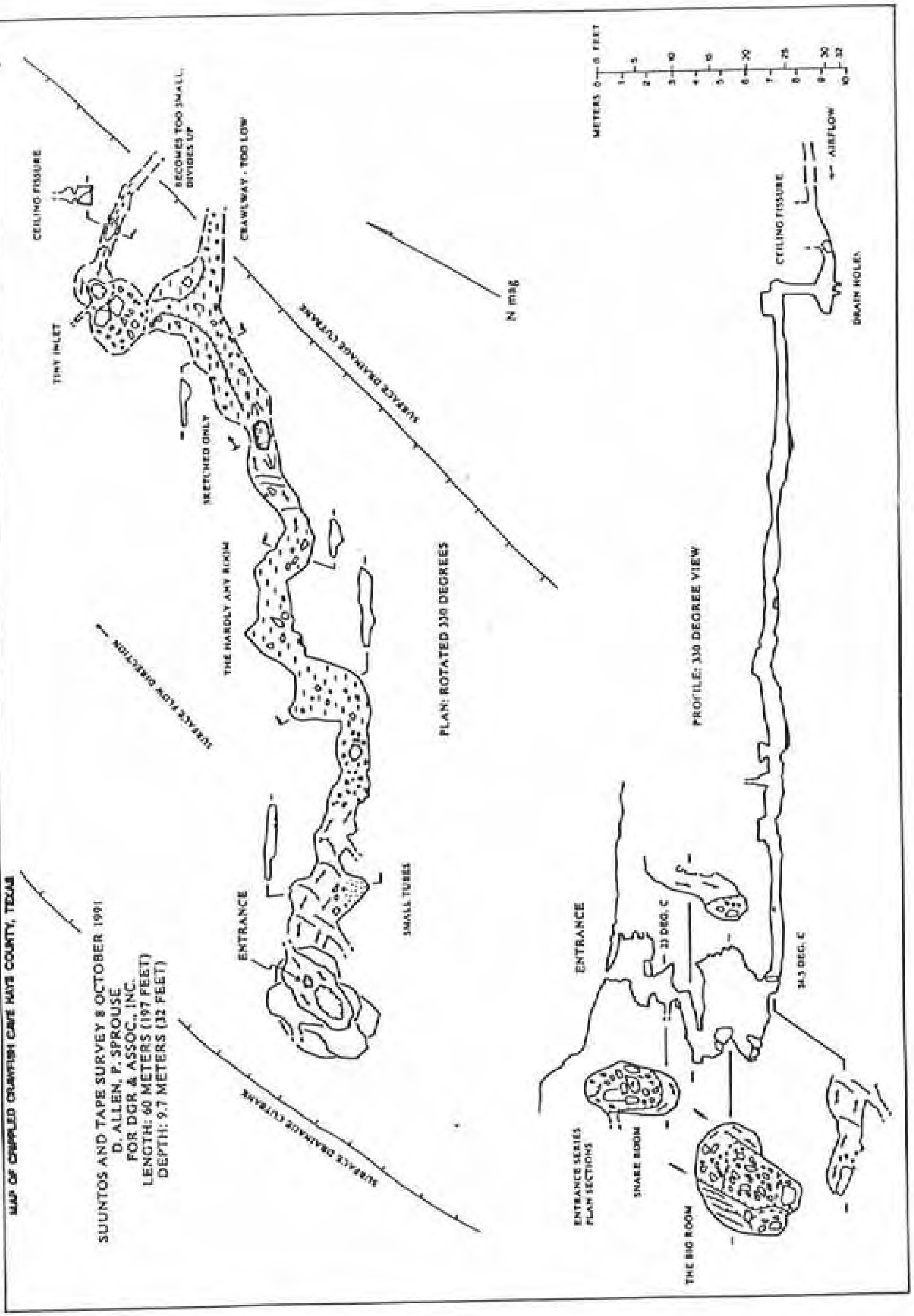


Figure 2-3

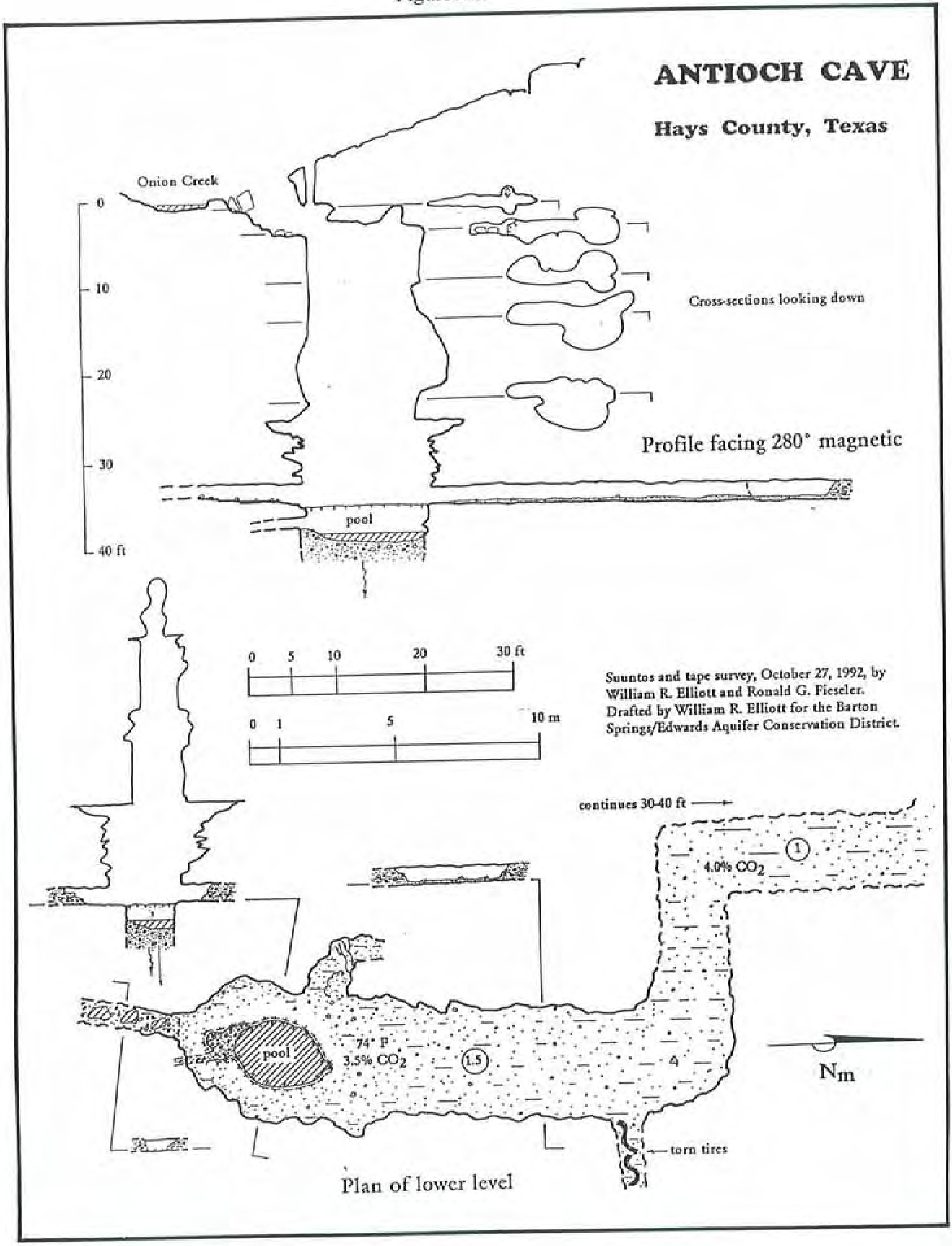
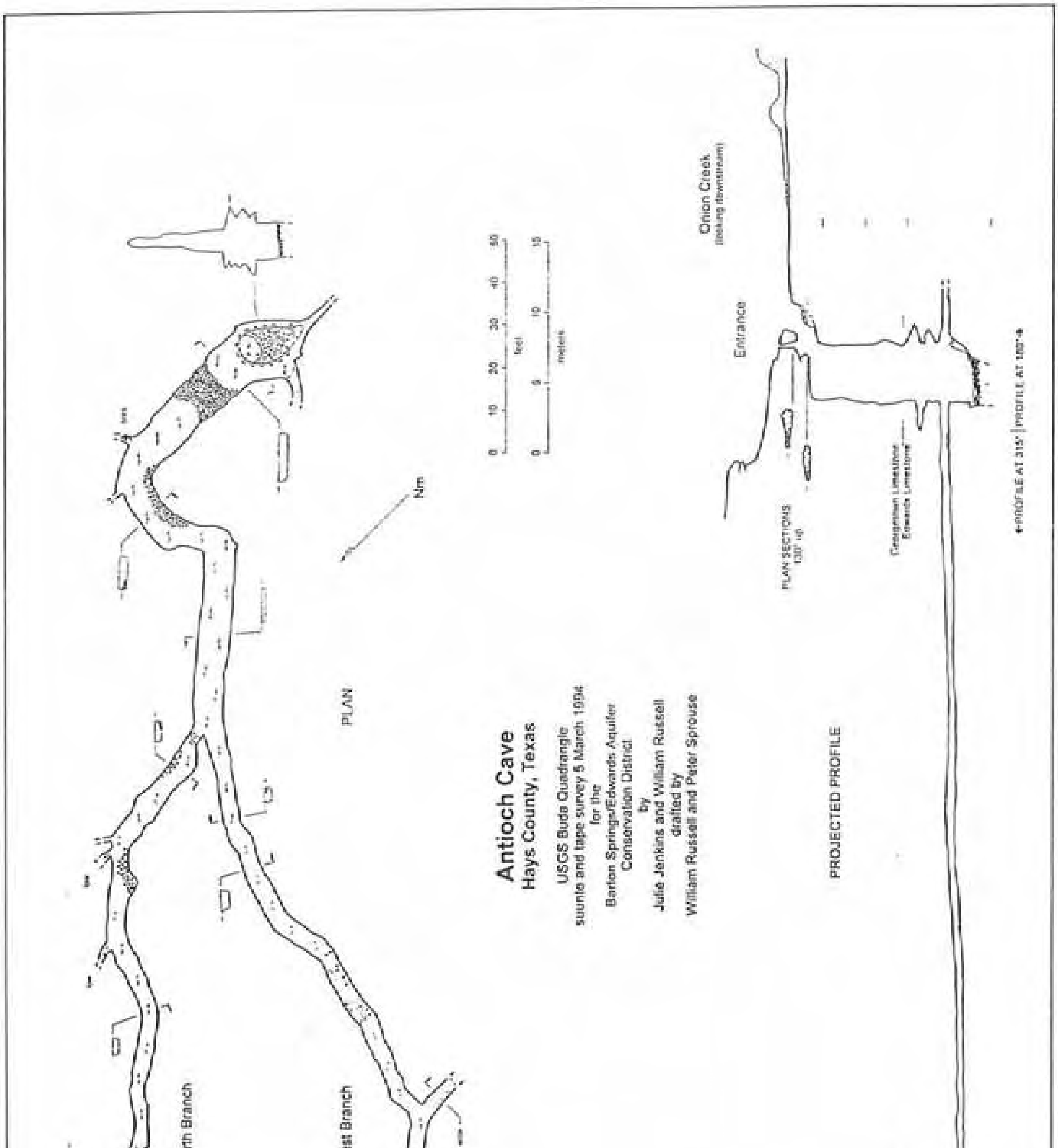

ANTIOCH CAVE
Hays County, Texas
Onion Creek
0
10
20
30
40 ft
Cross-sections looking down
Profile facing 280° magnetic
pool
0 5 10 20 30 ft
0 1 5 10 m
Suuntos and tape survey, October 27, 1992, by William R. Elliott and Ronald G. Fieseler. Drafted by William R. Elliott for the Barton Springs/Edwards Aquifer Conservation District.
continues 30-40 ft
1
4.0% CO2
74° F
3.5% CO2
1.5
4
pool
Nm
torn tires
Plan of lower level

Figure 2-4


Antioch Cave
Hays County, Texas
USGS Buda Quadrangle
suunto and tape survey 5 March 1994
for the
Barton Springs/Edwards Aquifer
Conservation District
by
Julie Jenkins and William Russell
drafted by
William Russell and Peter Sprouse
PLAN
PROJECTED PROFILE
North Branch
West Branch
West Branch
Onion Creek
(looking downstream)
Entrance
PLAN SECTIONS
Georgetown Limestone
Edwards Limestone
0 10 20 30 40 50
feet
0 5 10 15
meters
Nm

2.5 Quality Assurance Project Plan

District staff members prepared a Quality Assurance Project Plan (QAPP). This was submitted for TNRCC and EPA approval. Following TNRCC and EPA reviews, several revisions and re-submissions were made prior to its approval in November 1997. The QAPP is included as Appendix C and is available under separate cover by request.

2.6 Permitting

The District was required to comply with the application, permitting, and licensing requirements of other agencies. The District wanted the project to be a model of compliance and made every effort to work with all involved entities. In some cases, it was necessary to request an exception or exemption to the requirements due to the size, scope, and purpose of the project.

<u>Texas Natural Resource Conservation Commission: Edwards Rules</u>
The District applied for an exception to the Water Pollution Abatement Plan (WPAP) requirements of the TNRCC Edwards Rules. This request was based on the purpose of the project, to build a pollution abatement facility to improve water quality entering the Barton Springs segment of the Edwards Aquifer. The TNRCC agreed with the District's opinion that the proposed project would provide protection equivalent to that which would be provided under a WPAP. The exception was approved (see Appendix B) subject to the use of temporary sedimentation and erosion controls appropriate to the site.

<u>Texas Natural Resource Conservation Commission: Water Rights</u>
The District wrote the TNRCC to inquire about the necessity to obtain water rights permits on Onion Creek in order to enhance the quality and quantity of creek water recharging the aquifer through the cave entrances. The TNRCC advised the District that such permits were not necessary (see Appendix B).

<u>Corps of Engineers: Section 404 Permit, Clean Water Act</u>
The District contacted the US Army Corps of Engineers to inquire about the necessity of permitting the proposed project under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. The Corps reviewed the project and determined that it was not applicable to Section 10, but that it was subject to Section 404. The Corps authorized the project under nationwide permit number 26 and re-authorized it again after the initial two year authorization expired (see Appendix B).

<u>US Fish & Wildlife Service: Section 7 Consultation</u>
The District wrote the US Fish & Wildlife Service to request a review of the Antioch Cave Project with regards to the impacts on species listed under the Endangered Species Act, specifically the Barton Springs salamander. The USF&WS performed an informal Section 7 consultation and determined that the project would not harm the Barton Springs salamander, and that in fact, may prove beneficial to the species due to increased recharge and improved water quality (see Appendix B.)

<u>City of Austin: Site Plan Requirement, Development Code</u>
The District made application to the City of Austin (COA) for a Site Plan Exemption and provided documentation to justify the exemption, again based on the premise that the project

would improve water quality rather than decrease it, and that the District was utilizing appropriate temporary sedimentation and erosion controls during the construction phase. This request was granted by the COA (see Appendix B.)

2.7 Onion Creek/Antioch Cave BMPs

Non-Structural BMPs

As part of the project, the District acquired 38.6 acres from Centex Materials. This property lies along either side of approximately one-half mile of Onion Creek at the eastern edge of the Recharge Zone. District ownership has effectively placed this piece of property under an environmental and conservation stewardship and removed it from use by an active quarry and limestone mining operation or from possible future subdivision and development. The preservation of green space, riparian habitat, creek areas, and critical recharge features is an excellent and effective non-structural BMP for environmental protection.

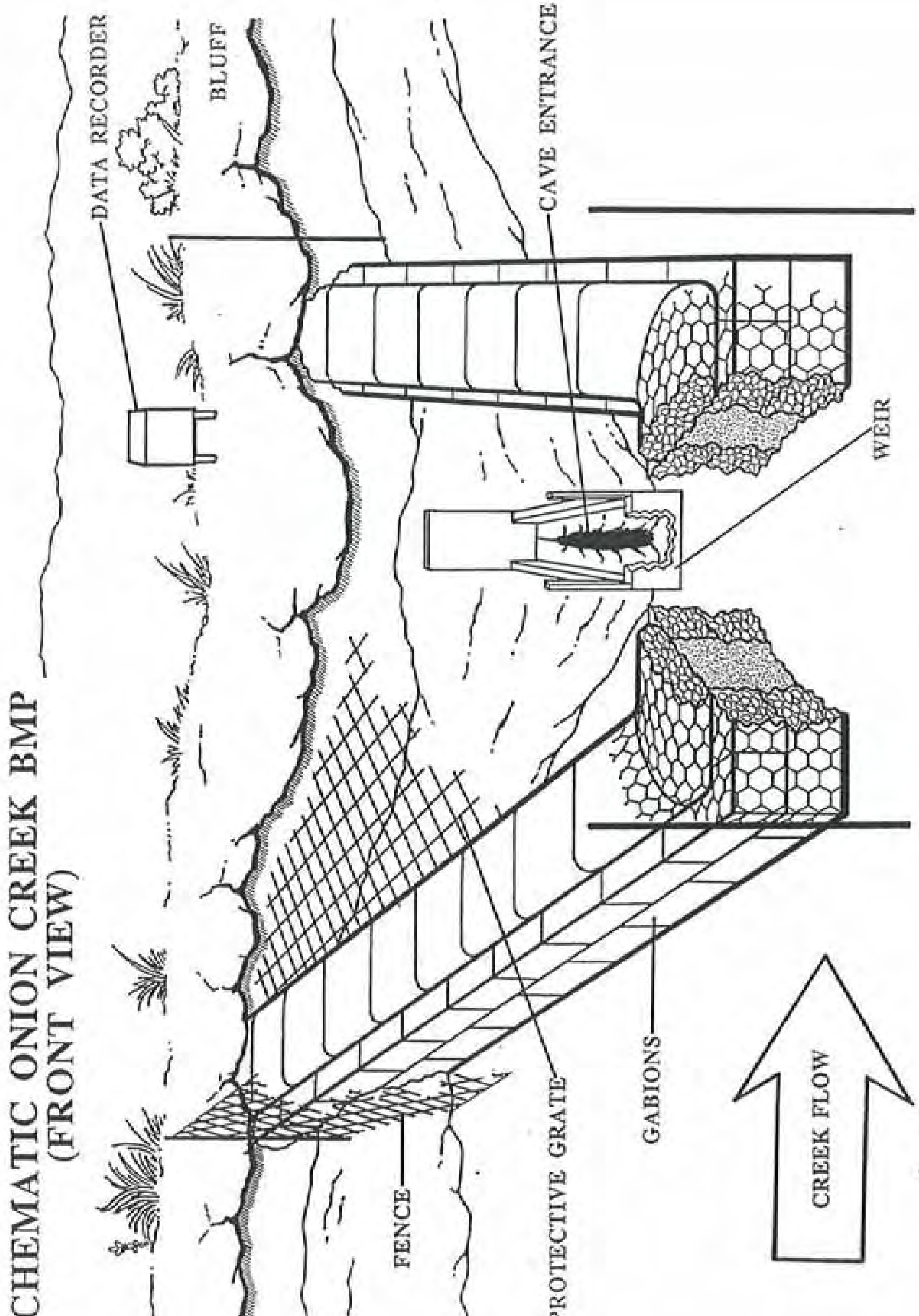
Antioch Cave Structural BMP Design

District staff and the Project Engineer, Don Rauschuber, reviewed current BMP designs and discussed possible innovative designs for applicability with the site specific conditions at Antioch Cave. Initially, it was thought that vertical sand filter placed between rock gabion walls would provide the required removal of sediment and other suspended solids. To trap large debris and prevent unauthorized entry, a large metal grill was planned over the cave entrance. Some artists renditions were prepared to illustrate this conceptual design (see Figure 2-5).

At the onset of the Antioch Cave project, when the use of vertical sand filters was under consideration, similar vertical sand filters had been installed at permanent structural controls built to mitigate highway stormwater runoff. These were being studied under an EPA FY 89-90 205(J)(5) matching funds grant administered by the District with the cooperation of the City of Austin, the Lower Colorado River Authority, and the Texas Department of Transportation. The results of the study (Barton Springs/Edwards Aquifer Conservation District, 1996) indicated that vertical sand filters had limited application and were maintenance intensive. This led to a re-evaluation of the proposed BMPs initially intended for installation at Antioch Cave.

Don Rauschuber and the Project Manager, Ron Fieseler met several times to discuss alternative BMP installations. These discussions led to the conceptualization and development of an innovative and unique design which would achieve the project goals and address other concerns. The new BMP would: (1) withstand the forces imposed by high volume and high velocity flood conditions, (2) control the quality of water entering the aquifer, (3) allow for maximum recharge, (4) provide for safe and easy flow monitoring and water quality sampling, (5) prevent unauthorized entry into the cave, (6) have low maintenance requirements, (7) be reliable and easy to use, (8) have minimum physical and visual impact on Onion Creek and the adjacent property, and (9) present few, if any, potential hazards or danger to persons navigating Onion Creek during flow conditions. Figure 2-6 is a photograph of the BMP as installed.

Figure 2-5


SCHEMATIC ONION CREEK BMP
(FRONT VIEW)
DATA RECORDER
BLUFF
CAVE ENTRANCE
WEIR
FENCE
PROTECTIVE GRATE
GABIONS
CREEK FLOW

Description

Engineering drawings were prepared and submitted to the TNRCC (see Appendix D). The BMP consists of a concrete vault measuring approximately 7' high, 8'wide, and 12' long. It has a two piece lid with a steel manhole access in each piece. Two 36" diameter flanged steel spools are imbedded in the vault, one on the south side and one on the east side. The spool on the south side has a 36" butterfly valve bolted on the inside of the vault and a steel grill welded on the outside. The butterfly valve is opened and closed by means of a compressed air operated cylinder. The other spool currently has a solid steel plate bolted to it, but is available for installation of a second valve if necessary. To ensure continued recharge during low flow conditions, a 4" PVC pipe is located at the lowest part of the south side and serves as a "weep hole". Two PVC pipes exit the north side of the vault. The 6" diameter pipe is the vent line, which allows the vault to "breath" as necessary to prevent undue pressure build-up and to allow atmospheric conditions to exist in the vault. A 4" diameter pipe conducts air hoses into the vault to operate the valve cylinder. A 2" diameter PVC pipe leads from the 4" pipe around the base of the vault to the southwest corner and contains monitoring and sampling hoses. Two buttresses were added to the east wall for extra strength. A 6'x6' monitoring shed has been build on steel post legs on the north creek bank and has electric power service. The shed contains the air compressor, bubbler flow meter, a refrigerated automatic water sampler, and other monitoring equipment.

Operational Practices

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.

2.8 BMP Construction

The Project Engineer, Don Rauschuber, was responsible for the construction of the BMP. His primary subcontractor was Muñiz Concrete & Contracting, an approved minority-owned business. The 36" valve and related components were bought from DeZurik Corp. through Rainey Equipment (Houston) and U.S. Filter (Austin). A variety of local vendors were used for purchases of miscellaneous tools and supplies. Centex Materials provided rock for the construction entrance and a variety of equipment and employee assistance. The District employed Associated Drilling (Manchaca) and their winch truck to set the extremely heavy valve and two concrete lids. Ron Fieseler, Project Manager, supervised the on-site work and performed a variety of construction tasks as well. Other District staff members contributed time and labor as necessary.

Figure 2-6

Antioch Cave BMP as installed in 1997.

The construction began on August 5, 1997. The concrete work was completed by the end of August. Installation of the valve, hoses, monitoring equipment, monitoring shed construction and access, electric service installation, testing, , installation of the concrete lids, and other detail work continued into December 1997. Although some minor work remained, the site was operationally complete by mid-December. The total approximate cost of the BMP (excluding monitoring equipment installed on site) was $85,000. This included construction, District staff time, contractors, 36 inch valve and associated equipment, equipment rental, and miscellaneous.

2.9 Equipment Task - $67,483

As previously mentioned, the project was amended to include a fourth task. This task was the purchase and use of water quality monitoring equipment, utilizing $67,483 in federal and local matching funding remaining at the TNRCC from the FY88 EPA Non Point Source Program. District staff researched, ordered, and took delivery of a variety of equipment during the summer and fall of 1997. This equipment included bubbler flow meters, automatic samplers, refrigerated automatic samplers, rain gages, stream flow gaging equipment, data loggers and water depth probes, still and video cameras, photo scanner and printers, color scanner/printer/copier, spectrophotometer, pH/conductivity meter, storage shed, air compressor, dehumidifier, equipment trailer, and a variety of accessories, small tools, and water quality supplies.

Some of the equipment was installed at the Antioch Cave BMP and Ruby Ranch Onion Creek low water crossing monitoring sheds. Other equipment is being used in the District laboratory and some portable equipment is regularly taken into the field by District staff. Some equipment is intended for installation at other monitoring sites planned under other NPS studies. Some equipment will be kept in storage as backup.

3.0 RECHARGE ENHANCEMENT

3.1 Previous Studies

The recharge characteristics of Onion Creek have been previously studied and reported (Rauschuber, et al., 1990 and 1992) and include the following information.

The Onion Creek watershed west of Buda consists of 26.2 square miles over the Recharge Zone and 138.8 square miles over the Contributing Zone, totaling 165 square miles. Flow in Onion Creek is very erratic and, with the exception of some spring flow in the Contributing Zone, depends almost entirely on rainfall events. Field and analytical investigations reported by Rauschuber, et al. 1992 indicate a maximum infiltration rate for Onion Creek over the Recharge Zone of 160 cfs. Of this, 135 cfs is lost to recharge above Barber Falls and 25 cfs is lost below.

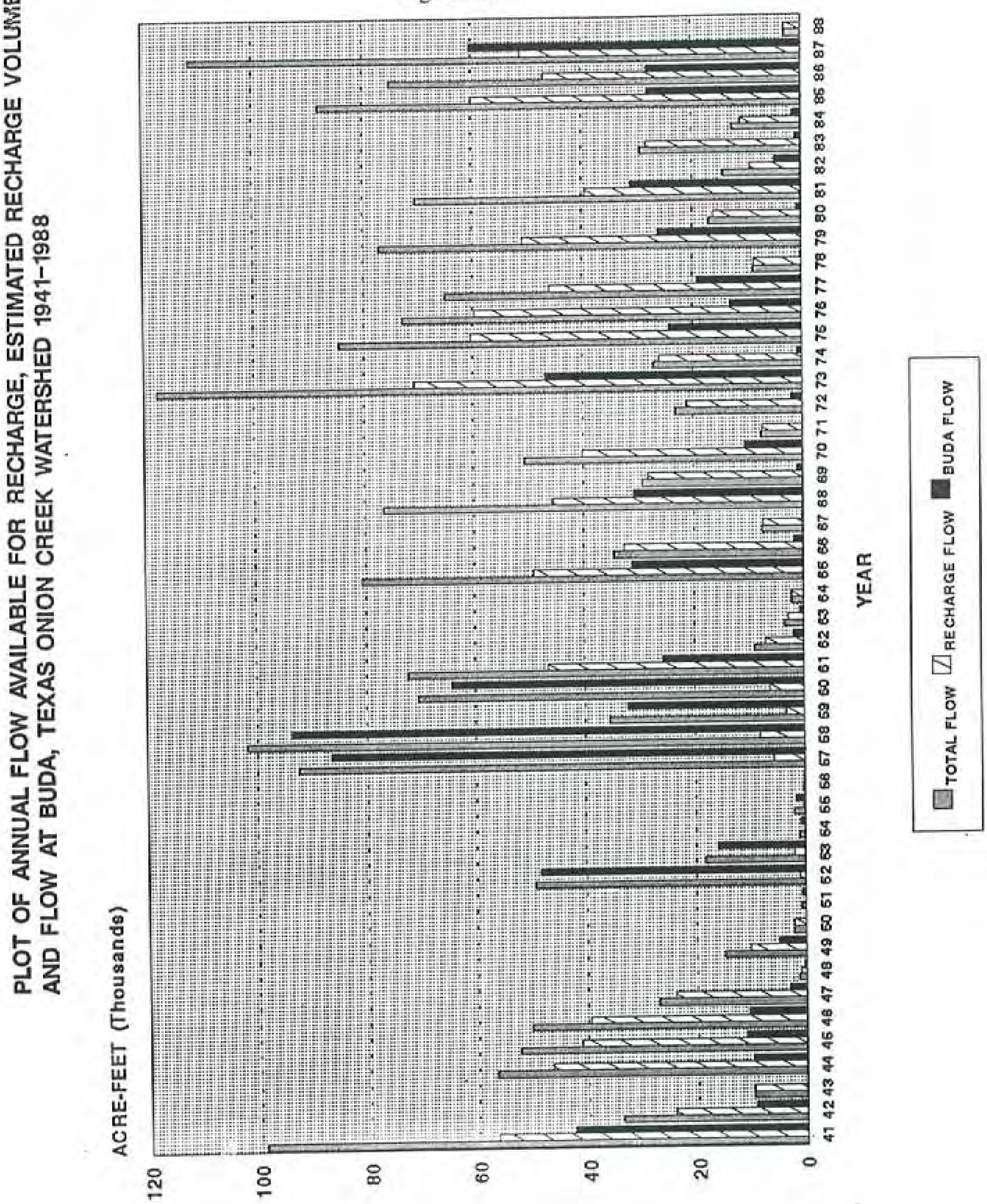
Flow rates entering the Recharge Zone vary from zero (the most common condition) to a maximum recorded peak of 8,990 cubic feet per second (cfs) in June 1985. Between June 1979 and early 1990, average discharge recorded at Onion Creek near Driftwood (and near the beginning of the Recharge Zone) was 31,590 acre feet (af) per year. The average discharge recorded at Onion Creek near Buda (and just below the Recharge Zone) between July 1979 and September 1983 was approximately 21,400 af per year. This indicates that an annual average of approximately 10,000 af was recharged during that four-year period. Additional calculations for flow at the Buda USGS gage for the period of 1941 through 1988 (with a minimum flow of 406 af in 1956 and a maximum flow of 122,259 af in 1973) resulted in a calculated long-term average annual flow available for recharge of 43,100 af (Figure 3-1). Calculations based on the 43,100 af and the 160 cfs numbers (assuming 160 cfs was recharged during flows higher than 160 cfs and all flows below 160 cfs) resulted in an estimated annual recharge of 28,700 af over the 38 year period.

3.2 Recharge Considerations in BMP Design

In addition to the primary goal of reducing NPS pollution loading entering the Barton Springs segment of the Edwards Aquifer through recharge features on Onion Creek, another goal of the project was to increase the quantity of water being recharged. It was considered critical to the success of the project to design and construct a BMP over the entrance to Antioch Cave which would not only improve the quality of water entering the aquifer, but would allow the cave to retain or even improve its capability for recharge.

The design revolved around the need to allow large quantities of high quality water to enter the cave for long periods of time in as safe a manner as possible, while eliminating as much of the sediment, debris, and other pollutants as possible with little or no maintenance required. The final design incorporated a concrete box with a 4 inch diameter weep hole for low flows and a 36 inch diameter, manually operated valve for high flows. The 36 inch opening is protected by a welded grill.

Figure 3-1

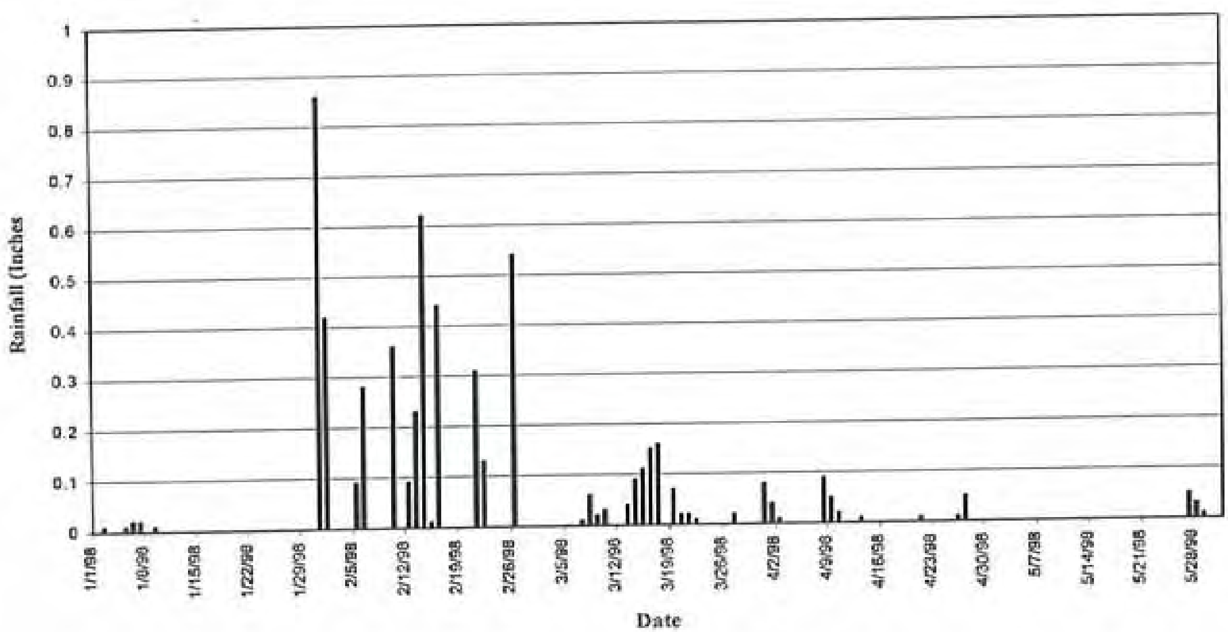

PLOT OF ANNUAL FLOW AVAILABLE FOR RECHARGE, ESTIMATED RECHARGE VOLUME, AND FLOW AT BUDA, TEXAS ONION CREEK WATERSHED 1941–1988
ACRE-FEET (Thousands)
120
100
80
60
40
20
0
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88
YEAR
TOTAL FLOW
RECHARGE FLOW
BUDA FLOW

3.3 Results of Operation

During the first three months of 1998, northern Hays, southern Travis county, and the Onion Creek watershed received considerable rainfall. Figure 3-2 charts data from the rain gage nearest Antioch Cave. The upper Onion Creek watershed received even heavier rain than indicated for March 15-16, which resulted in the highest recorded flood level of 12.5 feet. District staff monitored the flow and water quality conditions at Antioch Cave on an almost daily basis (see Figure 3-3). Once turbidity dropped to an acceptable level (generally 100 nephelometric turbidity units (NTUs) or less) or after flood debris was greatly reduced, staff would open the valve to allow recharge to occur. It should be pointed out that the 4 inch weep hole was providing continual recharge, but since it was at the bottom of the creek, flood debris was carried downstream and only sediment and dissolved constituents were entering the aquifer. Since turbid conditions only lasted one to two days, the turbid water passing through the weep hole constituted a very small percentage of overall recharge.

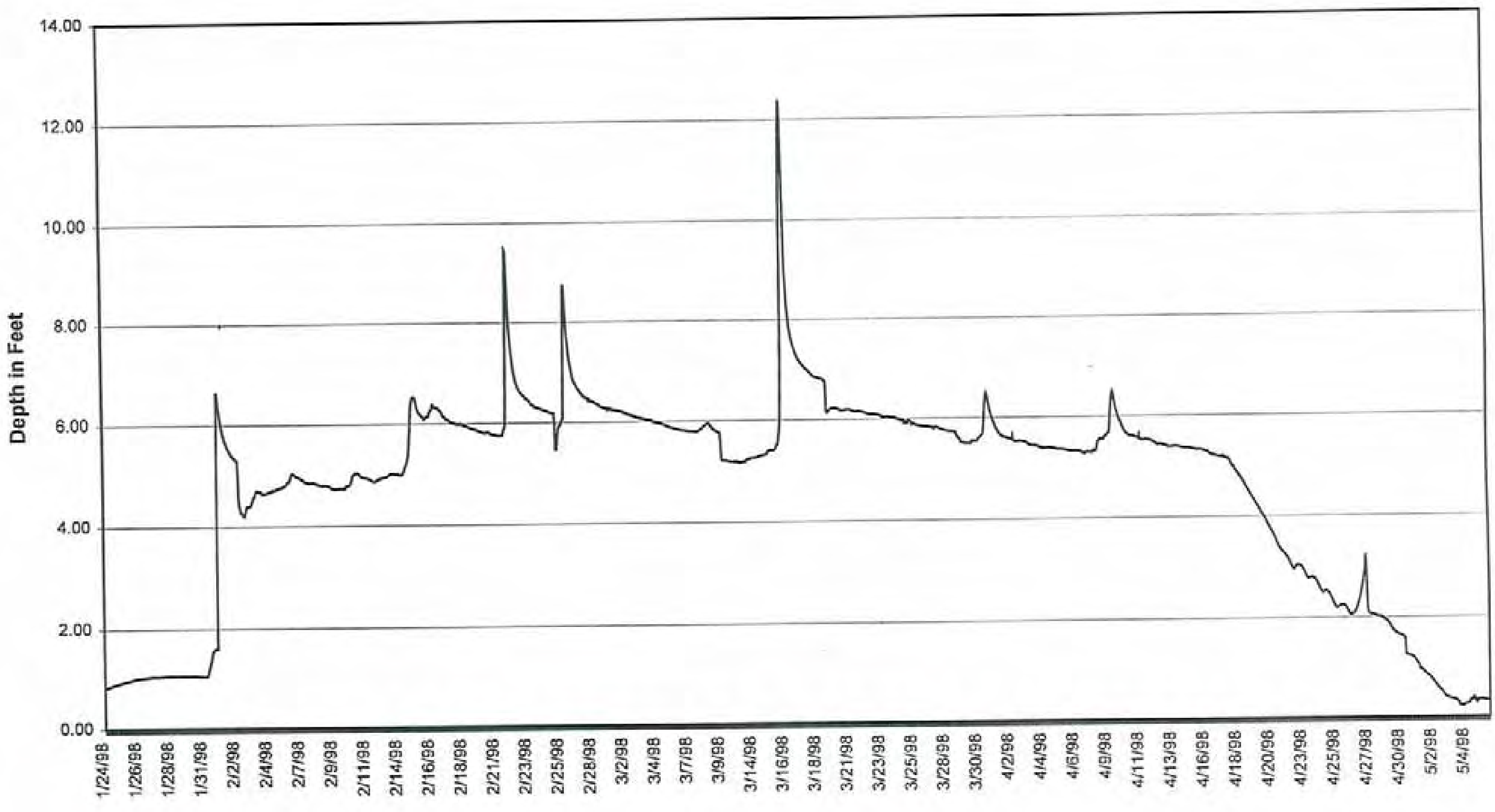
Figure 3-2

BS/EACD Weather Station - Frate Barker Rd. west of Manchaca Rd.



The 36 inch valve was open for a total of 2509 hours between January 8 and May 6, 1998. This is a total of approximately 104.5 days. Water depths at Antioch Cave varied from 12.5 feet to only 3 inches and was recorded on an ISCO bubbler flow meter and were divided into one hour increments. Don Rauschuber, Project Engineer, using these water depths and orifice flow equations for both the 4 inch weep hole and the 36 inch valve, calculated the total recharge for that 104.5 day period to be 9,656 af or 3,146, 482,426 gallons. Recharge flow averaged 46.6 cfs for the entire period, with the highest flows reaching 94.5 cfs.

Figure 3 - 3
Hydrograph of
Onion Creek at Antioch Cave



Permitted pumpage from the District regulated water wells totaled approximately 1,600,000,000 gallons for FY 1998. In just three and a half months, the Antioch Cave recharge facility recharged almost twice that amount of water. In addition, given the lack of rainfall since March 1998 and the developing drought conditions, this additional recharge almost certainly helped delay the declaration of Drought Stage One (Drought Alert) by the District Board of Directors. It may be that the District can avoid Stage Two (Drought Alarm) if the recent, scattered, summer rainfall reduces demand on the aquifer long enough to move into the fall months when rain is usually more plentiful. If so, the Antioch Cave recharge facility will have played a major role in the process and will have served the District in a beneficial manner.

It is clear that, in the present configuration, the Antioch Cave recharge facility is capable of recharging enormous amounts of water. With an average recharge rate in early 1998 of 46.6 cfs, it has far exceeded the previously mentioned estimate of 25 cfs for the Recharge Zone below Barber Falls. This is a direct result of the installation and operation of the recharge facility, in that the cave entrance is now available for recharge whenever suitable flow is present, and is not partially or completely plugged with debris as was common in the past.

3.4 Potential for Additional Recharge

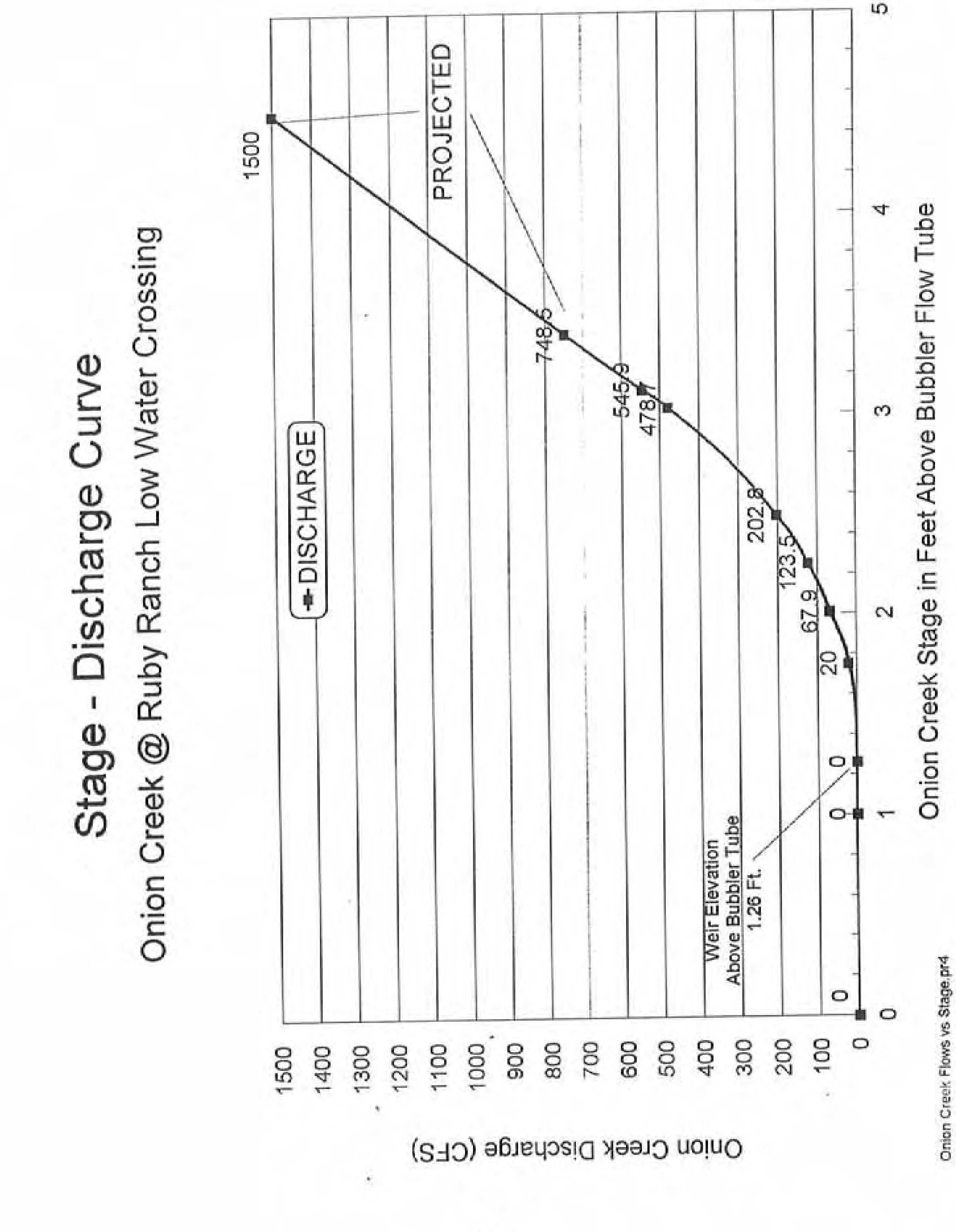
District staff and Don Rauschuber conducted flow measurements and recorded water depths at two sites on Onion Creek during the course of the project. One site was at the Ruby Ranch Low Water Crossing on Onion Creek approximately in the middle of the Recharge Zone. The other site is 200 feet upstream from Antioch Cave. A flow-rating curve was developed for the Ruby Ranch site (see Figure 3-4). More data is needed for the creation of a flow-rating curve for the Antioch Cave site, however, the area is currently experiencing a period of extended drought. Rain events since early March 1998 have not been sufficient to produce flow in the creek. Once renewed flow occurs in Onion Creek, District staff will take additional flow measurement.

District staff will use the data to help determine the flow loss for the reach of Onion Creek between the two sites, which includes Barber Falls. In addition, flow loss upstream to the Driftwood gage can be more accurately calculated. Until additional data is collected and calculations made, the District cannot accurately determine how much the new recharge facility at Antioch Cave will increase the previously calculated Onion Creek recharge capability of 160 cfs. However, it is estimated from the data presently available that the BMP has increased the overall recharge capability of Onion Creek by 20-25%.

District staff has noted during BMP operations that the cave was easily taking all the water entering the two existing openings in the BMP. The BMP was designed and built to accommodate a second 36 inch valve should one be warranted. There were many days when the flow in Onion Creek was greater than what could be recharged through the single valve, so the possibility exists of additional recharge with a second valve. Additional study will be necessary prior to any second installation in order to answer several questions, including: is the cave capable of recharging the additional water?, has the recent recharge had any physical effect on the cave?, and what is the cost/benefit ratio?

In addition, the District could review the situation at Crippled Crawfish Cave. With its small entrance, this cave is more easily plugged with debris than Antioch Cave. There is potential for increasing recharge at that site, although, due to the small entrance and limited passage size, it would be considerably less significant than what we have realized at Antioch Cave. Still, a suitably designed BMP based on lessons learned at Antioch Cave could be beneficial.

Figure 3-4



Stage - Discharge Curve
Onion Creek @ Ruby Ranch Low Water Crossing
DISCHARGE
PROJECTED
1500
748.5
545.9
478.7
202.8
123.5
67.9
20
0
0
0
Weir Elevation
Above Bubbler Tube
1.26 Ft.
Onion Creek Discharge (CFS)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
0
1
2
3
4
5
Onion Creek Stage in Feet Above Bubbler Flow Tube
Onion Creek Flows vs Stage.pr4

4.0 WATER QUALITY MONITORING, SAMPLING, & TESTING

4.0 Preparation

Although the project utilized FY92 EPA 319(h) funding, contract negotiations with the TNRCC were quite lengthy, with the final signing not occurring until October 28, 1993 with a contractual starting date of September 30, 1993. One of the first orders of business was the preparation of the QAPP and its submission for TNRCC and EPA approval. As the project progressed, some delays were encountered with the QAPP. Following TNRCC and EPA reviews of the QAPP, several revisions and re-submissions were made prior to its approval in November 1997. Had the QAPP been approved earlier, there would have been opportunity to conduct more extensive background sampling. The District did take samples in the spring of 1997 which were not covered by the QAPP and were therefore not included as part of the grant. However, monitoring the effectiveness of the BMP could clearly not occur until the BMP was built. Construction of the BMP began in August 1997 and was operationally complete in December 1997, so the delayed QAPP had little overall impact on the project as a whole.

While awaiting approval of the QAPP, several water quality related tasks were completed which did not require the presence of an approved QAPP:

- An assessment of monitoring and sampling needs was made, along with a review of equipment availability and suitability. Applicability of equipment for use in a variety of NPS projects and other scientific studies was also given consideration. A list of equipment to be purchased was generated and orders placed utilizing the $67,483 previously mentioned for Task 4, Equipment Purchase.

- The monitoring equipment sheds at Ruby Ranch Low Water Crossing and Antioch Cave were built. Equipment was installed at these sites and tested. Rainfall and flow data was collected. Cross-sections of Onion Creek were surveyed and a flow-rating curve generated for the Ruby Ranch site. One rainfall event occurred in the summer of 1997 prior to approval of the QAPP. The District collected water samples and had them analyzed at the Edwards Aquifer Research and Data Center. This lab work was not billed to the grant, but supplied valuable background information to supplement actual grant funded sampling.

- A mapping team was sent into Antioch Cave to continue the cave survey and make further explorations and observations to provide additional information on the recharge capabilities and hydraulic capabilities of the cave (see Appendix E). During this mapping trip, it was noted that the air in the cave was quite good compared to previous explorations when a high concentration of CO_2 was experienced by those in the cave. Drager Tube CO_2 measurements during the 1992 explorations indicated concentrations of 4.0% while the 1994 visit had only 0.01% (essentially normal atmospheric concentrations). The cave exhibits "breathing" or air flow common to many caves. This is generally related to diurnal barometric pressure changes. Both branches of the cave were almost blocked by sediment or sticks and debris, which could be washed clear by extensive recharge of clean water. Further exploration would then be possible.

The project team was only able to sample and monitor the effectiveness of the Antioch Cave BMP and recharge facility during the January – March 1998 time period. Luckily, the short time period available for sampling (due to the November 1997 approval of the QAPP and the end of the project on March 31, 1998) resulted a series of rain events which generated flow in Onion Creek. The team met the goal of this grant study by sampling stormwater runoff passing through the BMP during 6 separate storm events.

4.2 Monitoring and Sampling

The QAPP was approved in November 1997. Monitoring and sampling equipment was in place and ready for the first sampling event. The BMP valve and equipment was operationally complete in December and electric service connected.

A rainfall event occurred in late December 1997 which caused a short term flood event. District staff used this event to test the valve against the water pressure. Still and video cameras were used to record the operation. Some water samples were taken but were only tested at the District laboratory. The valve mechanism worked as expected, but due to the holiday season and the shortage of District staff to check on the site, the valve was left closed. Due to relatively dry conditions, the flow subsided fairly quickly.

A heavy rain fell on the upper portions of the Contributing Zone of Onion Creek on January 6, 1998 resulting in a flood surge. Sampling began that night and other samples were taken at varying water levels.

Additional rain events occurred periodically during late January, February, and March and resulted in additional flood events of varying magnitudes. When a flood surge was expected with accompanying sediment and debris, the valve would be closed. Some smaller flow increases occurred with negligible increases in turbidity. Overall, six separate storm-generated flow events were sampled. Grab samples were taken for five of the six events and automatic grab samples were taken for three. A total of nine sample sets were taken and delivered to the Edwards Aquifer Research and Data Center (EARDC) for 323 individual analyses. Field measurements and additional grab samples were taken for each of the flow events by District staff and some events were measured on successive days for a total of 565 individual measurements or analyses by District staff. District measurements and supplementary District analysis and the EARDC analyses are reproduced and/or tabulated in Appendix E.

4.3 Procedures and Equipment

The water depth at the site was recorded on an ISCO bubbler flow meter. The project team used flow equations to relate water depth to stream flow and quantity of recharge entering the aquifer through the BMP's 36 inch valve and 4 inch weep hole. The bubbler outlet is at the southwest corner of the BMP.

Grab samples were taken utilizing (1) an ISCO refrigerated automatic sampler which was programmed to sample on a time based interval and (2) an ISCO peristaltic grab sampling pump. The sampling point is at the southwest corner of the BMP, about one foot upstream from the 36 inch valve. Only one sampling point was used. This was due to the fact that water would either

be entering or bypassing the BMP depending on whether the 36 inch valve was open or closed. Samples were taken during a variety of flow regimes, from first flush to very low flows in order to characterize the water quality at a variety of water levels. Staff manually sampled whenever possible in order to more accurately locate the sample in the hydrograph. On four occasions, the automatic sampler was programmed to sample on a timed interval in an effort to sample across the hydrograph during a flood event. Only one of these samples was submitted to the EARDC lab, but three were analyzed in the District lab and one was discarded when a rain event failed to occur and creek flow did not increase.

All measurements of field parameters, sampling, preservation, and transportation were carried out in accordance with the approved QAPP. Samples were collected and preserved by Ron Fieseler, Project Manager, and Nico Hauwert, Project QA/QC Officer and transported to the EARDC and Chem-Solve laboratories.

4.3 Quality Assurance

The District took extra grab samples of each storm event for analysis in the District laboratory as an additional QA check to compare District results with the other lab. More formal QA procedures utilizing splits and spikes were undertaken during the course of the sampling. These QA samples were sent to a second laboratory, Chem-Solve, in Austin. District measurements and analysis and the EARDC and Chem-Solve analyses are reproduced and/or tabulated in Appendix E. Each laboratory conducted QA/QC analyses in accordance with their own QA/QC procedures. Although some parameters exceeded acceptable performance limits, the comparison was generally acceptable overall.

4.4 Results

The quality of water flowing down Onion Creek is generally very good. As expected, concentrations of some constituents were higher during flood (first flush) conditions. Most of these were reduced as the water cleared.

Many of the metals concentrations were below detection limits. Oil and Grease (O&G), Total Petroleum Hydrocarbons (TPH), Diazinon screening, herbicide (2,4-D) screening, and PCB/Organochlorine pesticide screening were all below detection limits.

Sulfate, calcium, magnesium, potassium, manganese, iron, and strontium showed varying concentrations. Potassium, manganese, and iron concentrations were reduced as the water cleared. However, sulfate, calcium, magnesium, and strontium showed increases over time, which was to be expected as the contact time of the water with the Glen Rose and Edwards limestone increased.

As expected, turbidity, suspended solids, bacteria; and trash and debris were extremely high during flood surges, but tended to drop rapidly after the first flush passed and the water began to clear. Not too surprisingly, with an existing volume of water flowing down the creek, the constituent concentrations of subsequent flow events varied with the intensity of the rainfall. Most trash and debris were allowed to float downstream as part of the first flush, but a small quantity inevitably passes through the BMP and into the aquifer. After the first flood event had

subsided, an estimated one cubic foot of organic material, trapped by the five inch square mesh steel grill over the 36 inch valve opening, was removed and discarded by District staff.

Turbidity, trash and debris, and suspended solids entering the aquifer through Antioch Cave were reduced over 90% and possibly as much as 95-98%, depending on how soon the valve was opened following a flow event. Bacteria counts showed reductions from 30-90%.

Antioch Cave Water Quality Data
Table 4 - 1

				BS/EACD Laboratory and Field Measurements											BS/EACD Laboratory & Field Measurements								
Date	Creek Conditions, Rain, Water Depth Observations and Comments	Bottle # if applic.	Time Sampled	Staff Sampling	Sample point	Date Tested	Time Tested	Staff Testing	pH	Conduct	Temp.	Turbidity	Dissolve Oxygen	BS/EAC Nitrate	BS/EAC Chloride	BS/EAC Fluoride	BS/EAC Sulfate	BS/EAC Sulfide	BS/EAC Iron	Alkalinity	BS/EACD T. Colifor	BS/EACD E. Coli	Patho-screen
					[pump/creek]					(uS/cm)	Deg.	(NTU)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	col/100 ml	col/100 ml	pres./abs.
12/22/97			14:45	SB	Creek	1/8/98	10:05	JB						1.1	20.1	0.45	72.039		0.02				
1/6/98	Rain, Flood, Creek 10-12' deep		21:10	RF	pump	1/8/98	10:05	JB	8.29	424	18.5	999(OR	7.65		10.6				0.48	140		<1000	P
1/6/98	Brown water, heavy debris		21:10	RF	Creek	1/6/98	21:10	RF				89(Bank)											
1/7/98	Flood, 8-10' deep, less debris/sed.		11:50	RF/NH	Creek	1/7/98	11:50	RF/NH	8.68	173	14.0	420	9.94/9.74										
1/7/98	Flood, 8-10' deep, less debris/sed.		11:50	RF/NH	pump	1/8/98	10:05	JB	8.78	175	14.2	402	7.52		13.8				0.28	88		<1000	P
1/8/98	6' deep, clearing, opened valve		11:00	RF	pump	1/8,14/9	13:05	JB	8.60	258	12.3	91	10.30	0.8	3.8	0.31	25	0.023	0.1	155	388	340	P
1/8/98	5.52' deep		14:50	RF/SB	pump	1/8/98	14:50	RF/SB	8.62	274	14.0	74	7.70							155			
1/8/98	5.35' deep		17:10	NH	pump	1/8/98	17:10	NH	8.70	341	13.2	29	7.17							175			
1/8/98	5.35' deep		17:10	NH	creek	1/8/98	17:10	NH	8.63	348	12.4	26	8.73							185			
1/9/98	5.3' deep		15:15	NH	pump	1/9/98	19:10	JB						1.0	15.6	0.40	34	0.010	0.1	169	1626	1384	P
1/12/98	5.15' deep, clear		13:27	RF	pump	1/12/98	19:10	JB/NH	8.54	423	18.3	0	7.50	1.1	5.6	0.39	38	0.002	0.01	205	207	23	A
1/21/98	1.67' deep, low flow, clear		16:20	RF	pump	1/22/98	:15/11:00 A	JB	8.65	371	20.2	3	9.00	1.5	5.0	0.51	61	0.007	0.03	160	123	50	P
2/2/98	Rain on 2/1, rise to 6.62', sampled at 5.81', clear		15:30	RF	pump	2/2/98	15:30	Rf	8.67	450	16.5	8	7.20							190			
2/3/98	4.5' deep, clear		17:15	RF	pump	2/3/98	14:20	JB	8.55	425	17.0	13	8.44	0.6	6.6	0.25	8	0.006	0.03	180	68	27	P
2/5/98	Rain event, automatic sampler 4.5'-5' deep	3	22:00	RF	pump	2/11/98	11:00	SB						1.3	15.2	0.44	38	0.000	0.02				
2/5/98	over the course of the sample event.	4	22:00	RF	pump	2/19/98	9:45	MM						0.7	13.1		35		0.01	182			
2/6/98	The creek was basically stable and remained	9	2:00	RF	pump	2/11/98	11:00	SB						1.1	12.4	0.36	38	0.003	0.02				
2/6/98	clear, with a rise of only 2-3 inches.	10	2:00	RF	pump	2/19/98	9:45	MM						1.2	14.5		35		0.02	179			
2/6/98	"	15	6:00	RF	pump	2/11/98	11:00	SB						1.8	14.5	0.44	37	0.004	0.02	148			
2/6/98	"	16	6:00	RF	pump	2/19/98	9:45	MM						0.7	12.8		34		0.01	180			
2/6/98	"	21	10:00	RF	pump	2/11/98	11:00	SB						1.2	14.2	0.35	37	0.000	0.02	172			
2/6/98	"	22	10:00	RF	pump	2/19/98	9:45	MM						1.1	13.1		36		0.01	186			
2/21/98	8' deep, raining, water rises to 9.45' in 2.5 hrs.	17	23:07	RF	pump	2/24/98	15:51	MM						1.4	10.1	0.07	33	0.044	0.04	172			
2/22/98	Flood, 7' deep, light brown water	7	3:07	RF	pump	2/20/98	9:30	SB						1.1	8.1	0.22	35	0.008	0.05	200			
2/22/98		14	11:07	RF	pump	2/24/98	15:51	MM						0.3	9.1	0.49	21		0.19	132			
2/23/98	Flood, 6.5' deep, almost clear		9:50	RF	pump	2/24/98	9:50	SB	7.58	382	14.1	49	9.16		7.9	0.16	29	0.024	0.09	174	344	324	P
2/25/98	6.47' deep, raining, water rising, staying clear		14:30	RF	pump	2/26/98	9:30	SB	8.39	379	19.8	9	10.75	1.2	9.9	0.30	32	0.004	0.01	209	63	3	P
2/26/98	8.75' deep at 0630, 7.32' deep at 1430, clear		14:30	RF	pump	3/3/98	9:30	SB						1.3	12.1	0.03	29		0.02				
2/27/98	Flood, 6.5' deep, clear		20:30	NH	pump	3/3/98	9:30	SB						0.7	9.4	0.09	26	0.002	0.02		508	508	P
3/2/98	Flood, 6.17' deep, clear		18:25	RF	pump	3/3/98	9:30	SB	8.50	355	16.7	5	8.40	1.0	12.8	0.07	33		0.01	204	10	1	A
3/16/98				RF	pump	3/16/98	9:44	MM						0.0	13.9	0.12	33	0.006	0	179	230	200	P
3/16/98	Auto. Sampling. Heavy rain, flood, 6' deep.	2	7:30	RF	pump	3/24/98	10:45	SB				351		0.6	9.3	0.11	35		0.02	185			
3/16/98	Rising to 12.5' by 1330. Sed & debris	18	19:30	RF	pump	3/24/98	10:45	SB				365			6.0				0.53	164			
3/17/98	Flood, 7.25' deep, starting to clear	22	1:30	RF	pump	3/24/98	10:45	SB				457			6.1				0.51	161			

Antioch Cave Water Quality Data
Table 4 - 1

EARDC Laboratory

Bold type = holding time exceeded

Date	Total Coliform (col/100 ml)	Fecal Coliform (col/100 ml)	Fecal Streptococ (col/100 ml)	Bio-chem. Oxy. deman (BOD) (mg/l)	hem. Ox Demand (COD) (mg/l)	Total Org Carbon (TOC) (mg/l)	Total Dissolved Solids (mg/l)	Total Suspende Solids (mg/l)	Volatile Suspende Solids (mg/l)	Total Solid (mg/l)	Total Volatil Solids (mg/l)	Nitrogen mmonia (mg/l)	itroge Nitrate (mg/l)	Nitroge Nitrite (mg/l)	Phosphoru Ortho (mg/l)	Phosphoru Total (mg/l)	Total Kjeldah Nitrogen (mg/l)	Sulfate Total (mg/l)	Calcium Total (mg/l)	agnesiu Total (mg/l)	Potassiu Total (mg/l)	Manganes Total (mg/l)	Iron Total (mg/l)
12/22/97																							
1/6/98	Not Submitted	Not Submitted	Not Submitted	2	3.8	4.3	188	708	190	113	13	<0.1	0.12	0.12	0.12	0.49	<0.5	30.1	35.5	8.7	4	0.29	0.34
1/6/98																							
1/7/98																							
1/7/98	TNTC	CG	3240	4	13	4.7	149	136	48	184	93	<0.1	0.14	<0.1	0.06	0.28	<0.5	30	32	4.4	3.4	0.08	2.8
1/8/98	TNTC	CG	1510	<2.0	<10.0	3.8	201	25	9	254	41	<0.1	0.19	<0.1	0.04	0.06	<0.5	22.8	44.5	8.2	2.5	0.018	0.85
1/8/98																							
1/8/98																							
1/8/98																							
1/9/98																							
1/12/98	TNTC	112	54	<2.0	<10.0	1.6	383	1	<1.0	325	112	<0.1	0.43	<0.1	<.002	<0.05	<0.5	27.4	59.5	14.2	1.4	<0.002	<0.02
1/21/98																							
2/2/98	CG	45	101	<2	<10	2.1	279	2	1	309	81	<.1	0.3	<.1	<.02	<.05	<.5	29	63	14	1.1	<0.002	<0.1
2/3/98																							
2/5/98																							
2/5/98																							
2/6/98																							
2/6/98																							
2/6/98																							
2/6/98																							
2/6/98																							
2/6/98																							
2/21/98																							
2/22/98	Not Submitted	Not Submitted	Not Submitted	Not Determined	ot Determine	3.3	ot Determine	166	34	429	91	<0.1	0.31	<0.1	0.02	0.11	0.26	19.2	83.5	10.4	ot Determine	0.07	2.23
2/22/98																							
2/23/98	Not Submitted	Not Submitted	Not Submitted	Not Determined	ot Determine	3.2	ot Determine	14	6	316	37	<0.1	0.29	<0.1	<0.02	<0.02	0.25	20.1	83.5	11.2	ot Determine	0.095	<0.02
2/26/98																							
2/26/98																							
2/27/98	Not Submitted	Not Submitted	Not Submitted	3	26	3.5	540	123	15	300	60	<0.1	0.25	<.01	<0.02	0.09	<0.5	18.6	84	9.4	2.3	<0.002	<0.1
3/2/98	Not Submitted	Not Submitted	Not Submitted	3	<10.0	1.6	291	4	7	274	157	<0.1	0.3	<.01	<0.02	0.02	<0.5	26.9	87	15	1.07	<0.002	<0.1
3/16/98																							
3/16/98																							
3/16/98																							
3/17/98																							

QA/QC Analyses

	Total Coliform	Fecal Coliform	Fecal Streptococ	BOD	COD	TOC	Total Dissolved Solids	Total Suspende Solids	Volatile Suspende Solids	Total Solid	Total Volatil Solids	Nitrogen mmonia	itroge Nitrate	Nitroge Nitrite	Phosphoru Ortho	Phosphoru Total	Total Kjeldah Nitrogen	Sulfate Total	Calcium Total	agnesiu Total	Potassiu Total	Manganes Total	Iron Total
Spiked Sample from Environmental Resource Associates													NO3+NO2-N										
Certified Value	n/a	n/a	n/a	82.8	138	53.9	592	24.9	n/a	n/a	n/a	5.83	7.30		n/a	3.05	5.44	66.7	78.8	26.6	82	0.488	0.55
Performance Acceptance Limits	n/a	n/a	n/a	50.5 - 108	117 - 159	45.8 - 62.0	507 - 659	20.8 - 28.2	n/a	n/a	n/a	4.98 - 6.76	5.51 - 9.13		n/a	2.62 - 3.46	4.46 - 6.6	57.4 - 76.0	67.6 - 89.6	22.9 - 30.3	69.7 - 94.5	330 - 461	415 - 567
Chem-Solve Laboratory Results Sample Dated 1/29/98	n/a	n/a	n/a	58	114	48	n/a	n/a	n/a	n/a	n/a	4.1	1.98		0.063	n/a	n/a	n/a	n/a	n/a	n/a	0.42	0.43
EARDC Laboratory Results Sample Dated 1/29/98	n/a	n/a	n/a	8	<10	50.9	155	<1	<1	57	48	5.4	<.1		0.13	8.8	5.8	10.6	<.1	<.02	<.1	0.37	0.03
Sample Splits																							
Chem-Solve Laboratory Results Sample Dated 2/2/98				<1	<5	1.7						0.11	2.3	<.05	<.05	0.65						<.005	<.005
EARDC Laboratory Results Sample Dated 2/2/98	CG	45	101	<2	<10	2.1	279	2	1	309	81	<.1	0.3	<.1	<.02	<.05	<.5	29	63	14	1.1	<0.002	<0.1
Chem-Solve Laboratory Results Sample Dated 3/2/98				<1	<5	1.5						0.19	1.7	<.05	0.087	0.34						<.005	<.005
EARDC Laboratory Results Sample Dated 3/2/98				3	<10.0	1.6	291	4	2	274	157	<0.1	0.3	<.01	<0.02	0.02	<0.5	26.9	67	15	1.07	<0.002	<0.1

Antioch Cave Water Quality Data
Table 4 - 1

EARDC Laboratory

Bold type = holding time exceeded

Date	Arsenic Total (mg/l)	Cadmiu Total (mg/l)	Copper Total (mg/l)	Lead Total (mg/l)	Nickel Total (mg/l)	Seleniu Total (mg/l)	Strontiu Total (mg/l)	Zinc Total (mg/l)	Diazinon Screen ug/l	Herbicid (2,4-D) Screen ug/l	CB/Chlor Pesticide Screen ug/l	Total Petro. Hydrocarbon (TPH) (mg/l)	Oil and Grease (O&G) (mg/l)
12/22/97													
1/6/98	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.11	<0.05	<0.5	<2.0	<1.0	<2.0	<1.0
1/6/98													
1/7/98													
1/7/98	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.05	<0.05	<0.5	<2.0	<1.0	<2.0	<1.0
1/8/98	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.12	<0.05	<0.5	<2.0	<1.0	<2.0	<1.0
1/8/98													
1/8/98													
1/8/98													
1/9/98													
1/12/98	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.25	<0.05	<0.5	<2.0	<1.0	<2.0	<1.0
1/21/98													
2/2/98	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.27	<0.05					
2/3/98													
2/5/98													
2/5/98													
2/6/98													
2/6/98													
2/6/98													
2/6/98													
2/6/98													
2/6/98													
2/21/98													
2/22/98	<0.02	<0.001	<0.07	<0.01	<0.02	<0.02	0.13	<0.02					
2/22/98													
2/23/98	<0.02	<0.001	<0.07	<0.01	<0.02	<0.02	0.12	<0.02					
2/25/98													
2/26/98													
2/27/98	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.18	<0.05					
3/2/98	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.2	<0.05					
3/16/98													
3/16/98													
3/16/98													
3/17/98													

QA/QC Analyses

	Arsenic	Cadmiu	Copper	Lead	Nickel	Seleniu	Strontiu	Zinc	Diazinon	Herbicid	CB/Chlor	Total Petro.	Oil and Grease
	0.130	0.0802	0.113	0.180	0.389	0.122	0.321	0.611	n/a	n/a	n/a	n/a	n/a
	.0994 - .137	.0756 - .106	.0027 - .15	.155 - .225	.319 - .459	.0815 - .144	.263 - .379	.501 - .721	n/a	n/a	n/a	n/a	n/a
	0.094	0.095	0.07	0.058	0.14	n/a	0.42	0.67	n/a	n/a	n/a	n/a	n/a
	0.017	0.09	0.09	0.2	0.45	0.026	<.1	0.01	n/a	n/a	n/a	n/a	n/a
	<.005	<.005	<.005	<.005	<.005		0.35	<.005					
	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.27	<0.05					
	<.005	<.005	<.005	<.005	<.005		0.21	<.005					
	<0.02	<0.002	<0.07	<0.02	<0.02	<0.02	0.2	<0.05					

5.0 TECHNOLOGY TRANSFER PROGRAM

5.1 Task Objectives

A technology transfer program was implemented to provide a mechanism for effectively distributing, within the State, the NPS technology and management practices implemented, modified, improved, or suggested as a result of this project.

It is the intent of this goal to assist local entities around the State with implementation of NPS controls by providing the basic implementation methods of the local NPS best management and technology efforts as implemented within the Barton Springs Edwards Aquifer recharge area. A result of this technology transfer will be improved protection of surface and groundwater quality from NPS pollution by the increase in statewide distribution and implementation of effective NPS control technology within the State.

5.2 Technology Transfer Activities & Their Achievement or Process of Implementation

Workplan Technology Transfer Activities

(1) A summary report was to be prepared and submitted to the TNRCC.

This report will fulfill the requirements of this task.

(2) The District was to present or make available BMP technology developed under this grant to at least three meetings or conferences of associations, organizations, or governmental agencies responsible for or involved with nonpoint source pollution abatement.

The District has exceeded the requirements of this task. Formal technology transfer presentations on the project were made on four occasions and several less formal briefings and field trips have been conducted. Each presentation consisted of an oral review of the project, augmented with a series of color slides. Questions were accepted during and after the slides. Interest in the subject matter was very high at all events and the project presentations were very well received.

(a) Ron Fieseler, Project Manager, made a presentation to the 1993 National Cave Management Symposium held in Carlsbad, New Mexico in October 1993.
(b) Bill Couch, District General Manager, made a presentation at Conserve 93, a national conference on water quality and conservation sponsored by the National Water Well Association which was held in Las Vegas, Nevada in December, 1993.
(c) Ron Fieseler, Project Manager, made a presentation at a TNRCC NPS BMP Seminar held in Austin, Texas on August,13 1997.
(d) Ron Fieseler, Project Manager, made a presentation at a TNRCC Nonpoint Source and Water Quality Conference held in Brownsville, Texas on March 12, 1998.
(e) The District has made several informal briefings and led several small field trips to the project site for the benefit of local elected officials, organizations, agency staff, students, and others interested in the project.

(f) The District continues to offer presentations and field trips regarding the project upon request.

(g) The District has utilized still and video cameras to record the project. A selection of photos is included with this report as Appendix A. A comprehensive slide presentation is being developed. One VCR video tape has been completed on the early exploration of Antioch Cave and is available for loan upon request.

(3) The District was to provide a copy of the summary report to all groundwater districts within the state.

Upon completion and submission of this report to the TNRCC, additional copies will be prepared and mailed to all groundwater districts within the state.

(4) The District was to participate in an annual groundwater protection/wellhead protection program and prepare a feedback and monitor questionnaire in cooperation with the TNRCC for submission to the EPA.

Upon completion and submission of this report to the TNRCC, the District will make itself available to participate, if requested, in the next TNRCC scheduled groundwater or wellhead protection program, and will be prepared to cooperate with the TNRCC on a feedback questionnaire.

(5) The District was to present the results of this project at annual meetings of the Texas Water Conservation Associations, Texas Alliance of Groundwater Districts, and the Texas Section of the American Water Works Association.

Upon completion and submission of this report to the TNRCC, the District will make presentations at the next available meetings of the three associations.

(6) The District was to issue press releases and news reports regarding progress and results of the project.

Upon completion and submission of this report to the TNRCC, the District will prepare and submit press releases to the local media as appropriate.

(7) The District was to solicit feedback from entities who use this BMP technology.

The District will prepare and attach a questionnaire soliciting feedback and information from entities who receive a copy of the project report.

(8) The District was to prepare engineering design criteria for distribution to the previously mention entities.

The District has included engineering drawings and specifications with this report as Appendix D.

5.3 Reports

This Final Report serves as a combination report for all contractual reporting requirements (other than quarterly and interim reports) and as such, serves as the workshop manual and summary report required by the workplan.

Due to the water quality sampling and analysis being conducted at the end of the project, there was insufficient time to schedule a presentation on the project results and conduct a feedback survey prior to preparation and submission of this report. However, as mentioned above, (1) the District will be prepared to cooperate with the TNRCC on a feedback questionnaire at a groundwater/wellhead protection conference, and (2) the District will prepare and attach a questionnaire soliciting feedback and information from entities who receive a copy of the project report. Any information generated under either of these two processes will be provided to the TNRCC and the EPA.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The project team presents the following conclusions and recommendations:

- This study provides detailed information concerning the work plan and quality assurance of a storm water monitoring project. It further presents procedures and methods for testing and characterizing an innovative BMP. This information may be useful in implementing other BMP structural controls and planning the monitoring and evaluation of future BMPs.

- The water quality of storm-generated floodwater runoff from a watershed such as Onion Creek is generally good with the exception of trash and debris, suspended solids, and bacteria. One can effectively improve the quality of the creek floodwater before it enters a major recharge feature, such as Antioch Cave, by implementation of a structural BMP.

- This BMP has proven effective in reducing the trash and debris, suspended solids, and bacteria entering the aquifer through Antioch Cave. Trash and debris and suspended solids were reduced over 90% and possibly as much as 95-98%, depending on how soon the valve was opened following a flow event. Bacteria counts showed reductions from 30-90%.

- This type of BMP should prove efficient and cost-effective for implementation at similar significant recharge features subject to flow or flood conditions.

- A BMP for a significant recharge feature should be designed to allow the first flush to bypass the site and provide time for sedimentation prior to allowing recharge to occur.

- The innovative BMP designed and built by the District at Antioch Cave is easily maintained, operationally simple, and virtually tamper-proof. The opportunity for unauthorized entry is minimized and operational safety is maximized.

- The acquisition by the District of 38.6 acres and approximately one half mile of Onion Creek at the eastern edge of the Recharge Zone and the corresponding removal of the property from potential harm from active quarry operations and/or future development is an effective non-structural BMP.

- Regularly scheduled maintenance and post-storm-event maintenance is essential to the successful operation of any BMP.

- It is recommended that continued observations be made at Antioch Cave in order to determine how the BMP functions over an extended period of time and multiple storm events.

- It is recommended that opportunities for automating the valve operation be investigated.

- It is recommended that further hydraulic analysis and cave research be conducted to assess the potential need for the installation of a second valve to increase the opportunity for additional recharge.

- It is recommended that the status of Crippled Crawfish Cave be reviewed on a periodic basis (approximately annually) for possible changes which may warrant implementation of appropriate BMPs to ensure continued recharge and pollution prevention.

7.0 BIBLIOGRAPHY

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