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**Water quality study of the Barton Springs segment of the Edwards Aquifer, southern Travis and northern Hays counties, Texas**

**BSEACD Report of Investigations 2001-0801**

Barton Springs/Edwards Aquifer Conservation District

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WATER QUALITY STUDY OF THE
BARTON SPRINGS SEGMENT OF THE EDWARDS AQUIFER,
SOUTHERN TRAVIS AND NORTHERN HAYS COUNTIES, TEXAS

Artesian Zone Wells- O
Recharge Zone Wells- *

Barton Springs/Edwards Aquifer Conservation District
City of Austin Watershed Protection Department

BSEACD Report of Investigations 2001-0801
August 2001
(Reprinted March 2009)
Cover:

Piper diagram of water chemistry of wells. This figure is the same as figure 16 in the report.

Suggested citation:

WATER QUALITY STUDY OF THE
BARTON SPRINGS SEGMENT OF THE EDWARDS AQUIFER,
SOUTHERN TRAVIS AND NORTHERN HAYS COUNTIES, TEXAS

Prepared by the Barton Springs/Edwards Aquifer Conservation District
and the
City of Austin Watershed Protection Department

Prepared in cooperation and financed, in part, from the Texas Commission on
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PREFACE

This report is a reprint of a portion of a report titled: “Water Quality and Flow Loss Study of the Barton Springs Segment of the Edwards Aquifer, Southern Travis and Northern Hays Counties” completed in August 2001. The original report addressed three main topics including: water levels, flow loss, and water quality. This report is a reproduction of the information pertaining to the water quality portion only. Text, tables, and figures pertaining to the water quality investigation are generally the same as in the original 2001 report. Changes to the original report include the addition of an abstract, reformatting of the Introduction, and corrections to well numbers and figures.

Although the original report was submitted to the Environmental Protection Agency and the Texas Natural Resources Conservation Commission (TNRCC), now the Texas Commission for Environmental Quality (TCEQ), to satisfy grant requirements, the report had very little distribution. Accordingly, the motivation for publishing the water quality chapter of this report in 2009 is to broadly distribute the information that was a baseline study of the water quality in the Barton Springs segment of the Edwards Aquifer.

ACKNOWLEDGEMENTS

Barton Springs/Edwards Aquifer Conservation District (BSEACD or District) is a groundwater conservation district created by the Texas State Legislature in 1987 with a mandate to conserve, protect, and enhance the groundwater resources of the Barton Spring segment of the Edwards Aquifer. The District has the power and authority to undertake various studies and to implement structural facilities and non-structural programs to achieve its statutory mandate.

An Environmental Protection Agency (EPA) 319h grant for nonpoint source pollution was awarded to the BSEACD through the TNRCC (contract No. 905900). The grant provided $157,150 in funds to conduct a hydrogeological and water quality assessment. A Quality
Assurance Project Plan (QAPP) was prepared for the study and was approved by TNRCC and EPA in June 2001.

BSEACD contributions include: General supervision by Dr. Stovy L. Bowlin, BSEACD General Manager of the District; Dr. Brian A. Smith, Senior Hydrogeologist/Project Manager; Brian B. Hunt, Hydrogeologist; Beckie J. Morris, Hydrogeologist; Stefani R. Helmcamp, Hydrogeologic Technician; C. Clover Clamons, Planner/Quality Assurance Officer; Shu Liang, Information Systems Program Manager; Jason L. West, GIS Technician; Mark E. Mathis, Environmental Analyst; Joseph A. Beery, Education Technician; Tammy A. Flow, Administrative Assistant; Meredith Laird, Summer Intern. Nico M. Hauwert, COA Hydrogeologist prepared the initial plan for this study and together with David Johns, COA Hydrogeologist, contributed the flow loss chapter of the 2001 report.

The District would like to thank all well owners and water system managers that allowed District access for sampling and water-level measurements. Also, the District would like to thank the U.S. Geological Survey (USGS), the Texas Water Development Board (TWDB), and the City of Austin (COA) for providing historical water quality data.
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WATER QUALITY STUDY OF THE
BARTON SPRINGS SEGMENT OF THE EDWARDS AQUIFER, SOUTHERN TRAVIS AND NORTHERN HAYS COUNTIES, TEXAS

Brian A. Smith, Ph.D., P.G., Beckie Morris, Brian B. Hunt, Stefani Helmcamp, Nico Hauwert, and David Johns

ABSTRACT
Water-quality data were collected for the Barton Springs segment of the Edwards Aquifer to evaluate baseline aquifer conditions. Samples were collected from 34 wells and springs during one sampling event in June and July 2001. The samples were analyzed for an extensive list of analytes that include: metals (total and dissolved); anions; cations; pesticides; herbicides; polychlorinated biphenyls (PCBs); volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs); and other basic water-quality parameters. Results indicate that contaminant levels in most of the sampled wells and springs are low compared to EPA MCLs. Nine parameters were detected at levels above TNRCC Surface Water Standards. However, contaminant concentrations could vary significantly under different flow conditions. And, lower levels of contaminants may be present in some samples that could not be detected due to limitations of laboratory Method Detection Levels. The chemistry of the different types of water (Recharge and Artesian Zones, and Springs) can be recognized when plotted on Piper diagrams. This type of analysis can give some indication of influences of the Glen Rose Formation and the saline water zone on portions of the aquifer. This study adds to the baseline of water quality data for Barton Springs segment of the Edwards Aquifer.
INTRODUCTION

The Edwards Aquifer is a major groundwater resource for central Texas that is divided into three primary segments: the southern, or San Antonio segment; the Barton Springs segment; and the northern segment. The Barton Springs segment of the Edwards Aquifer is located south of the Colorado River at Austin and extends south to the Buda and Kyle areas, east to Interstate 35 and west to FM 1826. The aquifer provides water to a large and diverse population that includes domestic, agricultural, industrial, and commercial users. A portion of the Barton Springs segment includes a number of small cities and rural communities containing approximately 44,000 people that are completely dependent upon groundwater (BSEACD, 1997). In recognition of this dependency, the federal government designated the portion of the Barton Springs segment south of Williamson Creek as a Sole Source Aquifer. Because groundwater is a relatively inexpensive source of potable water, its use is a very important resource for the local economy. The Barton Springs segment supplements the City of Austin's (COA) water supplies through its discharges to Town Lake on the Colorado River. The COA pumps about 25% of its water supply from Town Lake into the Green Water Treatment Plant. The contribution of Barton Springs to Town Lake varies from as little as 1% to as much as 100% of the flow when there is no discharge from Tom Miller Dam. The Barton Springs segment primarily discharges from Barton Springs, which is the only known habitat for the federally-listed endangered Barton Springs salamander, Eurycea sosorum. Barton Springs and Barton Springs Pool are important recreational resources that receive about 350,000 paid visits per year.

The Barton Springs segment is a limestone aquifer with its Recharge Zone consisting of a karst terrain characterized by caves, sinkholes, sinking streams to focused discharge (spring) sites. As karst areas mature, groundwater flow tends to enhance the permeability of the aquifer from recharge to discharge areas through solution, erosion, and collapse, and consequently focuses flow along relatively narrow flow paths consisting of trunk conduits. Based on current information, groundwater flow in the Barton Springs segment appears to represent a combination of rapid flow along discrete conduits and slower diffuse flow through interparticle pore spaces, fossil molds, bedding plane openings, and smaller vugs (Hauwert et al., 1998; BSEACD, 2001). The rapid rate of infiltration, recharge, and subsequent groundwater flow makes this resource very susceptible to contamination. The Barton Springs segment is also located in one of the most rapidly growing regions of the State. Rapid urbanization and highway construction is underway and more is proposed over the sensitive Edwards Aquifer Recharge Zone and Contributing Zone; therefore increasing the potential for
contamination of the aquifer. The Texas Natural Resource Conservation Commission (TNRCC) 1990 Update to the Nonpoint Source Water Pollution Management Report for the State of Texas includes Onion Creek and Barton Creek on its list of impacted waters. These creeks contribute the greatest amount of recharge to the aquifer (Slade et al., 1986). Potential sources of contamination to the Barton Springs segment include: private on-site septic systems and municipal sewage collection lines; underground storage tanks; petroleum pipelines; suburban development; roadway construction; golf courses; and urban runoff. In a recent water research study, the District measured some localized groundwater quality degradation (Hauwert and Vickers, 1994). The available yield of potable water in the Barton Springs segment may be further diminished by the effects of growth over the Recharge Zone, which can be expected to diminish the quality of the underlying groundwater available for use without treatment. Studies by the City of Austin (1990) and the Center for Research in Water Resources (Barrett et al., 1996) measured water quality of runoff from varying levels in impervious cover, population density, and traffic densities on roadways. The BSEACD measured groundwater-quality degradation under urban areas of the Barton Springs segment in samples collected after rain events (Hauwert and Vickers, 1994, and addendum 1995).

Water-quality data for the Barton Springs segment is particularly important since many land-use changes are occurring in this area that could impact the water quality of the aquifer. In 2001, rapid urbanization and extensive highway construction is underway and more is being proposed over the sensitive Recharge Zone. Highway expansion may foster the development and construction of new subdivisions and shopping centers, and increase vehicular traffic. Groundwater-quality studies can help planners, managers, and scientists establish baseline conditions and determine potential impacts in the Barton Springs segment.

**Purpose and Scope of the Project**

The objectives of this project were to collect water-quality data for the Barton Springs segment to evaluate current aquifer conditions so comparisons can be made with previous and future conditions. Knowledge of previous and current conditions of the aquifer will be of significant importance to policy makers, planners, regulators, scientists, and resource managers to protect groundwater quality in the Barton Springs segment, to enhance the quantity of groundwater available for extraction, and to maintain springflow during times of drought.
The scope of this water-quality investigation encompasses the collection of groundwater data from samples of 34 wells and springs during one sampling event in June and July 2001 (Figure 1). The samples were analyzed for an extensive list of analytes that include: metals (total and dissolved); anions; cations; pesticides; herbicides; polychlorinated biphenyls (PCBs); volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs); and other basic water-quality parameters. Existing data from other sources will be compiled to provide additional water-quality data for comparison of different sites through time. The major questions addressed include: What spatial changes in major constituents, nutrients, and organic compounds exist across the study area? What differences in water quality characterize the rural areas, urban areas, springs, Recharge Zone and Artesian Zone? What variation in water quality occurring over seasonal cycles is evident from historical data?

**Previous Investigations**

Groundwater samples have been collected annually since 1978 from about 13 wells and springs in the study area by the USGS. These samples were analyzed for a diverse list of parameters. No comprehensive report of their data results have been prepared although the COA analyzed some of the USGS data in addition to some of their own results (City of Austin, 1997). A groundwater-quality assessment was prepared for the TWDB in 1994 that compared BSEACD data from 1990 to 1994 of about 35 wells and springs (Hauwert and Vickers, 1994). This project noted differences in groundwater quality from the saline water zone, from Glen Rose formation leakage, from well construction practices, and from urban areas. This study identified possible anomalies but lacked sufficient data to produce statistically valid comparisons. None of the recent studies have examined the combined groundwater-quality data.

**Hydrogeologic Setting**

The Edwards Aquifer is a karst aquifer. Karst terranes are areas characterized as containing caves, sinkholes, sinking streams and springs. Karst features are typically found in carbonate rocks such as limestone and dolomite due to the greater relative solubilities of these rock types.

**Stratigraphy and Hydrogeological Characteristics**

Previous investigations of the framework and hydrogeology of the Barton Springs segment have been conducted by Brune and Duffin (1983), Baker et al. (1986) and Slade et al. (1986). Geologic mapping of the study area include Hill and Vaughan (1896-7), the Bureau of Economic Geology
(BEG) (Garner and Young, 1976), unpublished maps by Snyder with the COA, the USGS (DeCook, 1963), and the University of Texas at Austin (UT) (Kolb, 1981; Dunaway, 1962). The latest published map was created by the USGS and BSEACD with partial funding from the TWDB (Small et al., 1996). This publication maps the members of the Edwards Group as first described by Rose (1972) over the entire Barton Springs segment. As a result, this map represents the most current and up to date geologic map of the study area and was used as the geological framework for this study.

Where complete sections are present, the thickness of the Edwards Aquifer thins from about 500 feet in the southeast to about 315 feet in the northwest portion of the study area. This thinning can be attributed to erosion of the top of the Edwards Group prior to deposition of the overlying Georgetown Limestone (Rose, 1972). The Edwards Aquifer thins towards a thickness of zero on the far western side, due to more recent erosion of the Edwards Group and its overlying units.

In the study area the Edwards Aquifer consists of the Georgetown Formation and the Edwards Group of formations. In the Barton Springs segment, the Edwards Group is divided into the Person Formation, consisting of the Marine, Leached and Collapsed undivided, and Regional Dense members, which overlays the Kainer Formation consisting of the Grainstone, Kirschberg, Dolomitic, and Basal Nodular members (Rose 1972, Small et al., 1996). The reader is referred to Small et al. (1996) for a complete description of the units.

Basic Hydrogeology of the Barton Springs Segment

The majority of the water that recharges the Barton Springs segment originates as rainfall runoff in the Contributing Zone west of the outcrop of the Edwards Aquifer (Slade et al., 1985; Barrett and Charbeneau, 1996). The Glen Rose Formation of the Trinity Group is generally exposed throughout the Contributing Zone. Water enters the aquifer primarily through sinkholes and fractures in six major creek channels of Barton, Williamson, Slaughter, Bear, Little Bear, and Onion Creeks, as well as minor creeks such as Eanes Creek that cross the Recharge Zone. Groundwater flows generally northward to Barton Springs under confined conditions within the Artesian Zone east of the Recharge Zone. In the Artesian Zone, the Edwards Aquifer is overlain by the less permeable Del Rio Clay and other limestone and clay units, which serve to confine the aquifer and protect the aquifer from surface contamination. The Artesian Zone is generally understood to consist of only the potable water portion of the confined Edwards Aquifer. East of the Artesian Zone is the saline or bad water zone, a
nonpotable confined portion of groundwater within the Edwards Group generally located along IH-35.

The Barton Springs segment is characterized by “leaky” boundaries. The northern boundary is assumed to be the Colorado River since it represents the regional base level. The potentiometric surface from Brune and Duffin (1983) shows the surface converging at, or above the elevation of the Colorado River to the north and south. The sharp increase in total dissolved constituents, such as sodium, chloride, and other mineral constituents, to greater than 1,000 mg/l and a decrease in transmissivity (the ability of an aquifer to transmit water) at the saline water zone boundary marks a leaky boundary on the eastern edge of the Barton Springs segment (Flores, 1990; BSEACD, 1997). The western boundary of the Recharge Zone is limited to the updip extent of the saturated Edwards Group rocks and also probably consists of a leaky boundary from the juxtaposed Trinity Aquifer to the west. Evidence for this leakage is based on increases in sulfate and fluoride and similarities in water levels in Edwards and Glen Rose wells along the western edge of the Barton Springs segment. Recent groundwater models for the Trinity Aquifer required significant lateral groundwater leakage into the Edwards Aquifer in order to simulate observed hydrogeologic conditions (Mace, 2000). The groundwater divide between the Barton Springs segment and San Marcos Springs source area of the San Antonio segment of the Edwards Aquifer has been estimated in various locations between the Blanco River and Highway 967 at Buda based on potentiometric-surface elevations (Slade et al., 1986; Stein, 1995; Petitt and George, 1956; Garza, 1962; Guyton, 1958). The groundwater divide may move over time depending on groundwater-flow conditions and pumpage (Stein, 1995).

Influence of Geologic Structure on Hydrogeology and Karst Development

The geologic framework of the study area strongly influences groundwater flow (Slade et al., 1986). Alexander (1990) reports a correlation of specific-capacity of a well to its proximity to a lineament (faults or fractures). Recent mapping of the Barton Springs segment has delineated geologic faults and the surface exposure of several informal stratigraphic members within the Edwards Group, each having distinctive hydrogeologic characteristics (Small et al., 1996).

Faults and fracture zones can influence groundwater flow and water quality in the Edwards Aquifer (Baker et al., 1986; Kastning, 1986). Faults and other fractures represent zones of weakness along which solution is enhanced. Many of the springs discharge along or near faults, including Barton Springs. Some faults may place permeable water-bearing units against lower permeable units and
may act as a barrier or boundary, and locally restrict the groundwater flow and productivity of the Edwards Aquifer (Maclay and Small, 1983). In addition, faults may place two normally isolated aquifers adjacent to one another, resulting in the mixing of different water types. Elevated levels of sulfate, strontium and fluoride found in the Edwards Aquifer along the eastern side of the potable Barton Springs segment probably represent lateral leakage across major faults from the Glen Rose (Senger and Kreitler, 1984). It is believed that these major faults place water-producing intervals of the Glen Rose adjacent to the lower section of the Edwards Aquifer. The influence of fractures is particularly apparent for solutional enlargement within the less permeable strata. As a result, the permeability distribution in the Edwards Aquifer is typically not equal in all directions (anisotropic). As limestone areas develop into more mature karst terrains, these conduits can be expected to enlarge and more effectively connect recharge areas with discharge areas. Along these areas where the conduits are well connected, single recharge points in creek bottoms can introduce large volumes of creekflow into the aquifer.

METHODOLOGY

Data collected by BSEACD following approval of the Quality Assurance Project Plan (QAPP) include water-quality samples collected in June and July 2001. The procedures for data collection prescribed in the draft QAPP were followed during these data collection activities. Data collected by other agencies, such as the U.S. Geological Survey (USGS), Texas Water Development Board (TWDB), and COA have been used to compare to data collected by BSEACD.

Site Selection
The 34 sampling sites, which include 28 wells and 6 springs, are listed on Table 1. In order to select sampling sites that would be most representative of the Barton Springs segment, several selection criteria were established for candidate sites. For example, prior to the time of sampling, data from the District’s groundwater tracing studies were reviewed to identify wells that recovered traces over 1 mile away from a specific injection feature. Wells with good repeated tracer recoveries from different injection points are likely to lie on preferred groundwater flow paths that are representative of a larger part of the Barton Springs segment. Potentiometric surface maps of water-level elevations taken over brief periods of time were also examined. Troughs in the potentiometric surface often indicate the approximate location of preferred groundwater-flow paths, which are potentially good.
sampling locations. High-capacity pumping wells are also preferred sampling sites since their cones of depression tend to draw from a wider area.

Prior to sampling, surface geology, well log, and well depth information for each sampling well were reviewed to eliminate any wells that extend significantly below the Edwards Aquifer. Existing water-quality data from potential sampling sites were also reviewed. Wells with high levels of sulfate, strontium, and fluoride may be connected with underlying aquifers. It is important to select only those sampling points which have not been compromised by contaminants entering the well bore, and are representative of the water within the Edwards Aquifer. Although accessibility for water-level measuring is not critical to the sampling process, wells chosen for sampling should have access for water-level-measuring equipment whenever possible.

**Preparation**

Adequate preparation is essential to any sampling project to ensure timely completion of the sampling tasks and the elimination of mistakes. All personnel involved in sample collection were instructed on how to collect representative samples prior to conducting the field investigation. Before sampling, information was gathered about each site to insure accessibility and identify possible personnel hazards. Access was arranged with well owners prior to sampling as part of the site selection process and compliance with State law and BSEACD rules.

All sampling equipment and supplies such as approved sample containers measuring devices, ice chests, safety equipment were assembled prior to the beginning of sampling. An organizational checklist of the basic sampling components was used. The following were addressed prior to sampling:

- Availability and working order of necessary sampling and measurement equipment,
- Identification of sampling points, number of samples and volumes to be taken,
- Identification of analytical parameters and appropriate sample containers and preservation techniques for appropriate containers and preservation methods; and,
- Logistics of sample storage and transportation to the laboratory.
Well Purging

The primary goal of any groundwater sampling project is the collection of samples from the subject wells and springs which are representative of the aquifer being studied. In order to accomplish this, all stagnant or standing water should be removed from the well prior to sampling. Water standing in a non-pumping well has little, if any, vertical mixing, which could cause stratification of the water. Stagnant water may also contain foreign material introduced from the surface, resulting in a sample not representative of true aquifer water quality.

As a general rule, the evacuation or removal of three to five casing or borehole volumes of water from a well is sufficient to purge the well of stagnant water and replace it with representative aquifer water. The method used for purging was to continuously pump the well, while monitoring the produced water, until parameters such as temperature, conductivity, and pH stabilized. These measurements were repeated every 5 minutes until they became consistent. Temperature was considered consistent when two temperature readings, taken 5 minutes apart, were within 0.1 degree centigrade. The pH reading was considered consistent if two readings, taken 5 minutes apart, were within 0.2 units. The conductivity was considered consistent when two conductivity readings, taken 5 minutes apart, were within 10%.

If a sufficient amount of water was removed to purge the well (three casing volumes) and the parameters had not yet stabilized, the values were recorded and the samples collected. After sample collection, temperature, conductivity, and pH were measured and recorded again. Conductivity measurements associated with the actual collection of the water samples were provided to the laboratory on chain-of-custody (COC) forms. These readings help the laboratory accurately determine the dilution factor when analyzing the sample. Field analytical screening was not used to select locations or to screen samples for laboratory analysis.

Sample Storage and Transport

Detailed reports on all sampling activities were kept by sampling personnel in field notebooks and on water-quality sampling forms. The date, time, location and identification of each sample was noted. The sample collector's name, sampling conditions, sample preservation, and any problems encountered during sampling were also included. To ensure proper identification of samples, all sample containers were sealed and labeled immediately upon collection.
Sample analyses were made within the recommended holding times. The documentation of actual sample storage and transportation was handled according to the chain-of-custody procedures. Before sample transportation, ice chests were drained of melted water and refilled with ice. Glass, or other approved sample containers were arranged within the ice chest to prevent breakage, and field or laboratory personnel were responsible for transporting the samples to the Lower Colorado River Authority (LCRA) Environmental Laboratory Services (laboratory) for analysis.

**Quality Control**

The use of duplicates, equipment blanks, and trip blanks for monitoring field quality assurance/quality control (QA/QC) performance is analogous to the use of similar procedures by laboratories to monitor internal QC. The goal of field QC was to ensure that sample protocol was being followed and that situations leading to error are recognized before they can seriously affect the data. The use of field QC samples can help identify changes in samples that occurred during sample collection, handling, storage, transportation, and laboratory procedures.

**Duplicate Samples**

One duplicate sample was collected for every 20 samples. Field staff were taught to accurately prepare necessary field duplicates.

**Trip Blanks**

In the unlikely event that shipping containers or the laboratory atmosphere adds contaminants to the samples, trip blanks were analyzed. Trip blanks were prepared and analyzed for each cooler containing samples from more than one site that was submitted for volatile and semi-volatile organic constituent analysis, but did not exceed 10% of the site samples analyzed for the entire sampling period. The trip blanks consisted of laboratory grade deionized water that was poured into bottles at the laboratory for analysis of organic constituents.

**Equipment Blanks**

Equipment blanks were used to determine if any contaminants were contributed from the sampling devices. Since only dedicated pumps were used at well sites, sampling devices of concern were generally limited to Teflon tubing and filtering devices. The equipment blanks were poured into open containers in the field. All sampling devices were decontaminated. After standard decontamination, a rinsate of deionized water was run through the device and collected for analysis.
This rinsing and collecting was performed in the field by District personnel. The rinsate sample was handled in an identical manner to other samples. Portions of the rinsate were transferred to appropriate sample containers for chemical analysis. One equipment blank for every 20 samples was prepared in the field and transported to the laboratory with the subject samples.

*Spike Samples*

The laboratory utilized matrix-spiked samples as an internal quality control check. Matrix spikes and matrix spike duplicates were performed by the laboratory, as required by the specified EPA analytical methodologies. The laboratory documented precision and accuracy checks to allow the analyst or the supervisor to know when corrective action is needed.

*Quality Control Samples*

To ensure adequate quality control, a laboratory must periodically introduce QC samples into its inventory of samples to be analyzed. The laboratory maintained a record of each internal quality control analysis. The laboratory follows the procedures listed in their QA manual, Section 7.0 (BSEACD QAPP, 2001). This helps verify during a systems audit that no preventable problem was allowed to affect the quality of the data.

*Sample Handling and Custody Requirements*

The goal of sample custody is to account for the sample from the moment the water is placed in a sample container until all analytical tests have been completed and any remaining sample is discarded. Proper sample custody is a joint effort of the sampling crew, the sample transporter, and the laboratory staff.

The main documentation of proper sample custody for all events up to and including the arrival of the sample at the laboratory is the COC form. Field sample numbers are also written in permanent ink on the sample containers. Custodial responsibility for the COC form passes from the individual that performs the sampling, to the transporting agent(s), to the designated custodian at the laboratory where analysis will occur, and finally to any LCRA or designated agent that retrieves, archives, or disposes of any remaining post analysis sample.

The COC form identifies the sample as being from a specific groundwater source, in addition to entries made by field personnel regarding the sample, sample site, and sampling conditions.
WATER QUALITY

A water-quality database for the Barton Springs segment was constructed that compiles water-quality data from various sources including the TWDB and BSEACD.

The database follows EPA database structure (Definitions for the Minimum Set of Data Elements for Ground Water Quality, EPA 813/B-92-002, July 1992) and database structure developed by the Texas Joint Water Quality Committee (Texas Ground-Water Data Dictionary, Blodgett, 1996). Each parameter, its field format, and unit of measurement is associated with an EPA STORET code. The goal of the database is to compile data in a common format to allow data analysis for this study, as well as for future studies.

The water-quality data were analyzed by BSEACD for outliers that may suggest possible data errors. The database is intended to combine the existing data to characterize the water quality in the Barton Springs segment and identify anomalies that may or may not require further examination. The database is intended as an available framework for consistent input of future data between agencies that collect data for the Barton Springs segment.

The data collected in this study and pre-existing data were used in an ArcInfo Graphical Information System (GIS) to map the occurrence and variation in significant water-quality constituents across the Barton Springs segment. This analysis helps examine areas of anomalous nitrate-nitrogen concentrations and other constituents. The data were analyzed for spatial correlations in specific parameters, for example: areas where elevated levels of sulfate, strontium, and fluoride may suggest leakage from the Glen Rose Formation, and areas where elevated sodium and chloride indicate some influence from the saline water zone.

For this project, groundwater samples were collected and analyzed from 34 wells and springs during one sampling event. The water-quality results can be compared to a number of standards including:

- EPA drinking water standards (maximum concentration levels [MCL]),
- State standards for municipal drinking water supplies and surface water,
• Background levels established from statistical analysis of the sampling results for each parameter and from historical long-term data, and
• The presence or absence of constituents such as most pesticides that are not expected to be present in any concentration within the natural aquifer system.

General Chemistry

Analyses of groundwater samples collected from the 34 wells and springs included: field parameters (temperature, pH, conductivity, and dissolved oxygen); metals (total and dissolved); anions; cations; pesticides; herbicides; PCBs; VOCs; SVOCs; and other basic water-quality parameters. A total of about 265 compounds were analyzed by the laboratory. The majority of the compounds were not detected in any samples above the Method Detection Limit (MDL). The MDL is the lowest level at which the laboratory can detect a compound with any degree of certainty. Most of the compounds that were not detected were VOCs, SVOCs, pesticides, herbicides, and PCBs. Analytical results for metals and other water-quality parameters are presented in Tables 2 through 4. A complete listing of the laboratory analytical results are included in Appendix A. The following is a discussion of some of the key water-quality parameters.

Chloride

Chloride is found in all natural waters, but chloride in groundwater is primarily associated with sedimentary rocks, especially evaporites. In groundwater, when chloride is the most dominant anion, sodium is often the predominant cation. Human influences can also impact the amount of chloride found in groundwater. Chlorine is used to purify drinking water by killing bacteria. Also, chlorine is used in the production of herbicides, pesticides, drugs, dyes, metals, and plastic. However, leakage from the saline water zone accounts for most of the elevated chloride levels measured in Edwards waters (Hauwert and Vickers, 1994).

Only two wells and one spring, located in the Artesian Zone (58-58-216, 58-50-216 and 58-42-922, respectively), had elevated (>40 mg/L) chloride concentrations. These elevated levels indicate that the saline water zone is affecting these three sites. All of the sites that had chloride concentrations greater than 20 mg/L were located north of William Cannon Drive. Twenty of the 34 samples had chloride levels of 20 mg/L or less. Average chloride concentration of the samples was 21.09 mg/L. The spatial distribution of chloride concentrations are presented in Figure 2.
Fluoride

Fluoride is found in most natural waters, but concentrations are generally low. This mineral tends to be found in carbonate rocks, along with volcanic rocks or sedimentary rocks derived from volcanic rocks. The amount of calcium found in groundwater can sometimes create a balance with fluoride concentrations. In other words, higher fluoride concentrations tend to occur when the groundwater has lower calcium concentrations. Groundwater taken from the saline water zone and deeper Glen Rose Aquifer can be distinguished by fluoride concentrations greater than 0.5 mg/L (Hauwert and Vickers, 1994). Human activities also impact the amount of fluoride in groundwater such as the manufacturing and production of glass, steel, aluminum, pesticides and fertilizers.

Out of the 34 samples collected, 7 may be affected either by the Glen Rose Aquifer or the saline water zone. The fluoride concentrations in these samples ranged from 0.64 to 3.87 mg/L. The EPA Drinking Water Standard is 4 mg/L and the TNRCC’s Surface Water Standards are 0.5 mg/L. Of the 7 wells with elevated fluoride concentrations (>0.5 mg/L), only one (58-50-222) is located within the Recharge Zone. The average concentration of fluoride in all 34 samples was 0.53 mg/L. The spatial distribution of fluoride concentrations are presented in Figure 3.

Sulfate

The most extensive source for sulfate in groundwater is evaporitic sedimentary rocks. When sulfide minerals weather, the sulfur is oxidized to release sulfate ions into solution. Groundwater in semiarid regions tends to be comparatively high in dissolved solids and sulfate is a predominate anion in most of these regions. Sulfates tend to indicate older, trapped groundwater. Samples taken from the saline water zone and from deeper within the Glen Rose Aquifer can be distinguished by sulfate concentrations greater than 50 mg/L (Hauwert and Vickers, 1994). Human factors influencing the amount of sulfates found in groundwater include sewage, various industrial wastewaters, production of sulfuric acid, metals, fertilizers, fungicides, insecticides, batteries, and medicine.

High sulfate concentrations in six wells indicated possible influence from either the saline water zone or the Glen Rose Formation. The six wells had concentrations ranging from 55.2 mg/L to 251 mg/L. The EPA does not regulate sulfate concentrations, but suggests a maximum level of 250 mg/L. Two of those wells (58-50-222, 58-50-123) were within the Recharge Zone, so they were most likely affected by the Glen Rose Formation. Sulfate concentrations for the other 28 wells showed no
discernable pattern. The average concentration of sulfate was 42.99 mg/L. The spatial distribution of sulfate concentrations are presented in Figure 4.

**Nitrogen, Nitrate and Nitrite**

Nitrate nitrogen is commonly introduced to groundwater by decaying organic matter, human and animal wastes, and fertilizers. Nitrate is considered a nutrient because it encourages algal growth and growth of other organisms which typically produce undesirable tastes and odors in groundwater. The EPA set drinking water standards at 10 mg/L based on ratios between high nitrate levels and the development of methemoglobinemia, a deadly disease for infants. The amount of nitrate measured in groundwater is generally dependent on amounts of rainfall (Schepers and Martin, 1986). The nitrate anion \( \text{NO}_3^{-2} \) is the most common ionic form of nitrogen detected in groundwater. The nitrite and ammonium ions tend to be unstable in groundwater and therefore are less likely to be present. For this study, it is assumed that of the nitrogen reported as coming from nitrate and nitrite, all of it is from nitrate.

Out of the five sites that showed the highest concentrations of nitrate (>2 mg/L), four were located within the Cold Springs subsegment. The remaining well (58-50-223) had the highest concentration of 3.17 mg/L and lies within the Sunset Valley subsegment. EPA Drinking Water Standards are 10 mg/L and the TNRCC Surface Water Standards are 1 mg/L. Two of the five sites with elevated nitrate concentration are springs. All of the springs sampled had nitrate values between 1.0 mg/L to 2.5 mg/L. The remaining sites showed no discernable pattern of nitrate distribution. The average nitrate concentration for all of the sites was 1.16 mg/L. Average nitrate concentrations for the wells in the Artesian Zone were 0.92 mg/L, 1.19 mg/L for the Recharge Zone, and 1.6 mg/L for the six springs. The spatial distribution of nitrate concentrations are presented in Figure 5.

**Sodium**

Sodium is an abundant element generally derived from igneous, metamorphic, and sedimentary rocks, with the highest levels in clay minerals, halite, and other evaporates. In addition, the production of table salt, industrial, agricultural and medical products can introduce sodium into the environment.
The higher levels of sodium found in groundwater samples from the Barton Springs segment are probably influenced by the saline water zone, the Glen Rose Formation, development in areas west of the Recharge Zone. Three samples with concentration ranging from 14.7 to 33 mg/L are from wells on the western side of the Recharge Zone. The three samples (58-42-922, 58-50-216, and 58-58-216) with the highest concentrations (27.9 mg/L, 23 mg/L, and 81.2 mg/L, respectively) are located within the Artesian Zone.

Out of fourteen sampling sites north of William Cannon Dr., eleven showed above average (>15 mg/L) sodium concentrations. Only three sites south of William Cannon Drive showed elevated concentrations (58-50-852, 58-50-847 and 58-58-216). Well 58-58-216 showed the highest sodium levels of 81.2 mg/L found during this study. The high sodium concentration probably indicates that the saline water zone is affecting this well. The EPA does not have standards for sodium. The average sodium concentration was 13.0 mg/L. The spatial distribution of sodium concentrations are presented in Figure 6.

**Strontium**

Strontium is a relatively abundant element found in igneous rocks and sedimentary rocks such as shale and carbonates. This element is similar to calcium, but is much less soluble. Strontium may be introduced into the environment through the production of flares or fireworks, medicine, batteries, and paint. Most of the samples collected had strontium concentrations between 0.15 mg/L and 9.1 mg/L, but six wells had concentrations of 21.3 mg/L to 50 mg/L. The six wells with higher levels of strontium found in the groundwater samples possibly indicates Glen Rose groundwater mixing with Edwards groundwater. Groundwater from the two aquifers is able to mix due to faulting that allows both vertical and lateral leakage. High and low flow conditions within the Edwards Aquifer can affect the ability of the waters to mix.

All but one of the six sites that had the highest strontium levels (>15 mg/L) lie within the Artesian Zone. The one well (58-50-222) that is in the Recharge Zone is probably affected by the Glen Rose. The other five may be affected by both the Glen Rose and the saline water zone. Barton, Old Mill, and Eliza Springs had higher elevations of strontium than the three other springs that were sampled. The average strontium concentration for all 34 samples was 6.89 mg/L. The EPA does not have standards for strontium. The spatial distribution of strontium concentrations are presented in Figure 7.
Other Analytes

Of the other analytes listed in Table 2 through 4, dissolved arsenic, antimony, selenium, and thallium were detected at levels below EPA MCLs and TNRCC Surface Water Standards. Nine other analytes were detected at levels below EPA MCLs, but above TNRCC Surface Water Standards. Dissolved copper was detected in three samples at levels above the TNRCC standard of 100 µg/L, with the highest concentration of 1,310 µg/L. Dissolved lead was detected in three samples at levels above the TNRCC standard of 5 µg/L, with the highest concentration of 145 µg/L. All of the samples had concentrations of barium above the TNRCC standard of 10 µg/L, with the highest concentration of 256 µg/L. Cadmium was detected in three samples with one sample at 2.05 µg/L, which is above the TNRCC standard of 1 µg/L. Chromium was detected in one sample at a level above the TNRCC standard of 10 µg/L, with a concentration of 38.7 µg/L. Zinc was detected in 21 samples at levels above the TNRCC standard of 5 µg/L, with the highest concentration of 2,350 µg/L. Fluoride was detected in five samples at levels above the TNRCC standard of 0.5 mg/L, with the highest concentration of 3.87 mg/L. Nitrate (as nitrogen) was detected in 22 samples at levels above the TNRCC standard of 1 mg/L, with the highest concentration of 3.17 mg/L. And dissolved aluminum was detected in one sample at a level above the TNRCC standard of 30 µg/L, with a concentration of 980 µg/L.

Of the 34 samples collected, there were no detections of any pesticides, herbicides, or PCBs. Some pesticides and herbicides have been detected in groundwater in the Barton Springs segment in previous studies by the USGS in which lower PQLs were achieved by their laboratory than those achieved for this study (USGS, 1998). Only two VOCs (toluene and acetone) were detected in any of the samples collected for this current investigation. Well 58-50-216 had a detection of toluene at a concentration of 241 µg/L, which is below the MCL of 1,000 µg/L. Toluene was the only petroleum hydrocarbon detected in any of these samples. Acetone was detected in six samples with concentrations ranging from 0.5 to 2.1 µg/L, all of which are below the laboratory PQL. Acetone was also detected in the two trip blanks that were supplied by the laboratory, with concentrations of 0.7 and 0.8 µg/L.

Only one SVOC (bis-2 [ethylhexyl]phthalate) was detected in three samples (58-50-216, 58-58-121, and 58-50-123) at concentrations of 27.2, 22.1, and 16.3, respectively. Bis-2 (ethylhexyl)phthalate is
a common plasticizer that is frequently detected in the environment. It can also be introduced into samples through the sampling process or in the laboratory.

**Well 58-50-216**
One well that almost consistently had higher concentrations of key parameters is 58-50-216 (Tables 2 through 4). This is a USGS monitor well located on Highway 290 about one quarter mile east of South Lamar Boulevard. Because of its location along a major highway, there is a potential for infiltration of contaminants. There is also a possibility of cross contamination of sampling equipment due to potentially high contaminant levels at the surface. The USGS collected a sample from this well about 1 month prior to collection by BSEACD in July 2001. A comparison of analytical results from the two sampling events should provide insight into the nature of contamination found in this well.

**Groundwater Analysis 1998-2001**
As part of this project, thousands of analyses of samples from wells and springs from various sources were reviewed to determine if they could be used for comparison to analytical results from the District’s sampling event in June and July 2001. The QAPP requires that any data used for comparison purposes be of the same level of quality as data collected under the QAPP. The only data that could be considered as equal in quality for sample collection and laboratory procedures are those samples collected by BSEACD in 1998, 1999, and 2000, and analyzed by the LCRA Environmental Laboratory Services. These samples were collected under a program administered by the TWDB. All other available data were lacking in documentation that described QA/QC procedures under which the samples were collected and analyzed.

The Figures 8 through 13 display six parameters that were analyzed for their concentrations between 1998 and 2001. The groundwater quality for most of the sites sampled did not vary much from year to year. Four of the parameters, chloride, sulfate, nitrate, and sodium, seemed to show a definite increase in concentrations between 2000 and 2001. Fluoride and strontium showed decreases in concentrations over the same time period. But, not all of the parameters had the same trends throughout the four years of sampling. Rainfall did appear to influence certain parameters at particular sites which would indicate high connectivity to recharge points.

**Buda Well and Ruby Ranch Well Conductivity**
Conductivity is a measure of the capacity of water to conduct an electric current, and can vary with the concentration and degree of ionization of the constituents in the water (EPA, 1986). In general, conductivity represents the mineral content of the water. Conductivity can be influenced by the amount of total dissolved solids (TDS), which comprise inorganic salts (primarily calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. Other sources of TDS can include runoff from urban areas such as fertilizers and pesticides. Generally, the amount of dissolved solids present in water increases proportionally with its electrical conductivity. Concentrations of TDS in water vary considerably in different geological regions resulting from differences in the solubilities of minerals that make up the aquifer.

The BSEACD installed Campbell Scientific 247W Conductivity and Temperature probes at eight of the continuous monitor well sites. Figure 14 presents conductivity data for the Buda Well (1/1/97-8/20/01), which is located in the Artesian Zone, and Figure 15 displays conductivity data for the Ruby Ranch Well (10/28/99-8/20/00) located in the Recharge Zone. Generally, conductivity, or mineralization of the water, increases from the Recharge Zone to the Artesian Zone. Intensive faulting in the Edwards Aquifer has created barriers for groundwater flow to the east resulting in higher conductivity values in this area.

There are several noticeable trends in the change in conductivity in relation to fluctuations in water levels and rainfall for the Buda and Ruby Ranch Wells. Generally, as water levels increase after major rain events, conductivity tends to decrease. This suggests that rainwater, which is less mineralized, recharges the aquifer and can dilute high concentrations of organics, carbonic acid, nutrients and other ions that exist in the aquifer system, which eventually results in lower conductivity values. Figure 15 shows a drop in conductivity in the Ruby Ranch Well after a major rain event on November 3, 2000. This may represent significant hydraulic connectivity between the surface and the well at this monitoring site. Another trend displayed in Figure 14 shows conductivity and water level increasing in the Buda Well after the November 3, 2000 rain event. This relationship may be the result of water recharging the aquifer and moving groundwater from low permeability portions of the aquifer into areas with higher TDS into fractures and conduits that flow towards the Buda Well. These two different responses to the same rain event reveal the complexity of the aquifer system. Rainwater can enter the system through several different pathways, either directly through recharge features or by diffuse routes, which both can influence conductivity within a well.
There are also several occasions when conductivity generally correlates with the water level, as shown mostly in the Buda Well, and may be a result of increased pumping in this area. Due to the complexity of the aquifer system, the trends in both wells vary over time making it difficult to determine and justify specific reasons for conductivity fluctuations. There are various factors and circumstances that influence changes in water level and conductivity throughout the Edwards Aquifer, and additional investigation and research needs to be completed to better understand the overall nature of the aquifer.

**Piper Diagram Chemical Analysis**

When analytical results of groundwater samples are plotted on Piper diagrams, some patterns can be seen that help distinguish one grouping of samples from another. Samples from this study were divided into Recharge Zone, Artesian Zone, and Spring sources. Although there is some overlap between samples from each zone, some distinctions can be made between these groups. Piper diagrams are presented in Figures 16 through 21. Piper diagrams display groundwater samples based on cations (calcium [Ca], magnesium [Mg], and sodium [Na]), and on anions (bicarbonate alkalinity [HCO3], sulfate [SO4], chloride [Cl], strontium [Sr], and fluoride [F]).

Groundwater from each of the three sources mentioned above show fairly similar chemistry when grouped by calcium, magnesium, and sodium concentrations, as seen in Figures 16 through 21. The only significant difference between the samples in each group is that water from the springs is slightly lower in magnesium and lightly higher in calcium than groundwater from the Recharge and Artesian Zones.

From Figures 16 and 17 it can be seen that the samples from the springs, Recharge Zone wells, and some of the Artesian Zone wells have a similar distribution of the bicarbonate, sulfate, and chloride anions. Although some of the Artesian Zone well samples have higher sulfate concentrations and lower bicarbonate concentrations.

Figures 18 and 19 show that samples from the springs and Recharge Zone wells have very low concentrations of strontium. Whereas, the samples from Artesian Zone wells generally have higher strontium concentrations. This is also illustrated in Figures 20 and 21, which show that fluoride concentrations in all samples are fairly low, but chloride concentrations are high in spring water and
samples from the Recharge Zone. Samples from the Artesian Zone vary considerably in the concentration of strontium and chloride, but are generally higher than in samples from the other two groups.

There are many factors that affect the concentrations of these cations and anions in groundwater. Some of these factors are: the influence of water from the Glen Rose Formation; influence of water from the saline water zone; influx of fresh water from recharge features; and, length of time the water has been in the ground. Further analysis of these data is needed to determine the significance of the differences and similarities of groundwater from each of these groupings.

CONCLUSIONS

Water-quality data were collected for the Barton Springs segment to evaluate current aquifer conditions. These data have been compared to data that have previously been collected in the study area, and are being made available to various parties that have an interest in groundwater resources in the Barton Spring segment. The additional knowledge gained by this study will be of significant importance to policy makers, planners, regulators, scientists, and resource managers to protect groundwater quality in the Barton Springs segment, to enhance the quantity of groundwater available for extraction, and to maintain springflow during times of drought. Some of the conclusions drawn from this study are as follows:

- Groundwater sampling and analysis for this study indicate that contaminant levels in most of the sampled wells and springs are low compared to EPA MCLs. Nine parameters were detected at levels above TNRCC Surface Water Standards.
- Samples were collected under one set of flow conditions. Contaminant concentrations could vary significantly under different flow conditions. And, lower levels of contaminants may be present in some samples that could not be detected due to limitations of laboratory Method Detection Levels.
- The chemistry of the different types of water (Recharge and Artesian Zones, and Springs) can be recognized when plotted on Piper diagrams. This type of analysis can give some
indication of influences of the Glen Rose Formation and the saline water zone on portions of
the aquifer.

A considerable amount of information has been gained by this study, and a better understanding of
the aquifer has been realized by comparing recent data with data from previous studies. All aspects
of this study show the need for further investigation in these areas. Annual sampling and analysis of
groundwater is needed to provide a timely warning of serious increases in contaminant levels that can
impact those that rely on the aquifer for drinking water and that can threaten aquatic life.
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TABLES
Table 1. Water Quality Sampling Sites

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* reported as 58-50-223 in August 2001 report, and figures in this report
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EPA Standards (MCLs)
- NR - Not regulated
- D - Duplicate sample

Secondary EPA Standards
- NR - Not regulated
- D - Duplicate sample

TNRCC Surface Water Standards
- NR - Not regulated
- D - Duplicate sample

J - Analyte detected below Practical Quantitation Limit
ND - Not detected above Method Detection Limit

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Table 3. Metals – Total and Dissolved
## Table 3. Metals – Total and Dissolved

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**EPA Standards (MCLs)**
- NR - Not regulated
- AL=1300ug/L
- AL=15ug/L

**Secondary EPA TNRCC aquatic standards**
- NR - Not regulated
- 50ug/L

J - Analyte detected below Practical Quantitation Limit
ND - Not detected above Method Detection Limit
* - Value exceeds Maximum Contaminant Level

NR - Not regulated
D- Duplicate sample
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<td>16.9</td>
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<td>26.6</td>
<td>236</td>
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<td>1.19</td>
<td>ND</td>
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<td>58-50-847</td>
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<td>2</td>
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<td>18.2</td>
<td>2.09</td>
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<td>223</td>
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<td>0.01 J</td>
<td>0.318</td>
<td>ND</td>
<td>0.2 J</td>
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<td>Well Number</td>
<td>TDS Number</td>
<td>Filterable Solids Non-Filterable</td>
<td>Suspended Solids Non-Filterable</td>
<td>Bromide Dissolved</td>
<td>Chloride Dissolved</td>
<td>Fluoride Dissolved</td>
<td>Sulfate Dissolved</td>
<td>Total Alkalinity as Mg/L as CaCO3</td>
<td>Ammonia Total Kjeldahl Nitrogen, Nitrate &amp; Nitrite Total As P Phosphorus Total Organic Carbon mg/L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
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<td>----------------------------------</td>
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<td>22</td>
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<td>0.142</td>
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<td>0.168</td>
<td>23.4</td>
<td>248</td>
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<td>ND</td>
<td>1.62</td>
<td>ND</td>
<td>0.37 J</td>
</tr>
<tr>
<td>58-57-3DB</td>
<td>235</td>
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<td>11.9</td>
<td>0.111</td>
<td>5.87</td>
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<td>0.0248</td>
<td>ND</td>
<td>1.02</td>
<td>ND</td>
<td>0.33 J</td>
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<tr>
<td>58-57-9HC</td>
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<td>ND</td>
<td>0.59 J</td>
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<tr>
<td>58-58-102</td>
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<td>ND</td>
<td>0.0711</td>
<td>10.5</td>
<td>0.409</td>
<td>23.8</td>
<td>228</td>
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<td>1.26</td>
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<td>0.35 J</td>
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<td>277</td>
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<td>10.4</td>
<td>0.417</td>
<td>23.7</td>
<td>225</td>
<td>0.0328</td>
<td>0.014 J</td>
<td>1.27</td>
<td>ND</td>
<td>0.25 J</td>
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<td>1.85</td>
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<td>3.87</td>
<td>251</td>
<td>225</td>
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<td>0.012 J</td>
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<td>0.37 J</td>
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<td>1.25</td>
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<tr>
<td>58-58-423</td>
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<td>15.2</td>
<td>0.0617</td>
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<tr>
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<td>13.2</td>
<td>0.157</td>
<td>24</td>
<td>231</td>
<td>0.02 J</td>
<td>0.0261</td>
<td>1.27</td>
<td>ND</td>
<td>0.663</td>
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<td>81.1</td>
<td>268</td>
<td>ND</td>
<td>ND</td>
<td>0.25</td>
<td>ND</td>
<td>0.46 J</td>
</tr>
</tbody>
</table>

EPA Standards: NR NR NR NR 4mg/L NR NR NR NR 10mg/L NR NR
Secondary EPA Standards: 500mg/L NR NR 250mg/L NR NR NR NR NR NR NR
TNRCC Surface Water Standards: NR NR NR NR 0.5mg/L NR NR NR NR 1mg/L NR NR

J - Analyte detected below Practical Quantitation Limit
ND - Not detected above Method Detection Limit
NR - Not regulated
D - Duplicate sample
Figure 1. Water-Quality Sampling Sites

Barton Springs segment of the Edwards aquifer
Figure 2. Chloride Distribution (2001)
Barton Springs/Edwards Aquifer Conservation District
Figure 5. Nitrogen, Nitrate and Nitrite Distribution (2001)
Barton Springs/Edwards Aquifer Conservation District
Figure 6. Sodium Distribution (2001)
Barton Springs/Edwards Aquifer Conservation District
Figure 7. Strontium Distribution (2001)
Barton Springs/Edwards Aquifer Conservation District

Site Strontium Levels (mg/L)
△ >15
△ 10-15
△ <10

BS/EDACD Boundary
Major Roads
Major Creeks
County Boundary
Hydrologic Zones
ARTESIAN CONTRIBUTING
RECHARGE
Figure 8. Chloride Dissolved (1998-2001)
Figure 9. Fluoride Dissolved (1998-2001)
Figure 10. Sulfate Dissolved (1998-2001)
Figure 11. Dissolved Nitrogen, Nitrate and Nitrite

Dissolved Nitrogen, Nitrate & Nitrite (mg/L)

State Well Number

- 58-42-811
- 58-42-914
- 58-42-915
- 58-42-916
- 58-42-920
- 58-42-921
- 58-42-922
- 58-50-123
- 58-50-201
- 58-50-211
- 58-50-216
- 58-50-222
- 58-50-223
- 58-50-416
- 58-50-417
- 58-50-511
- 58-50-520
- 58-50-704
- 58-50-731
- 58-50-733
- 58-50-847
- 58-50-852
- 58-50-855
- 58-50-858
- 58-50-5CR
- 58-57-307
- 58-57-3DB
- 58-57-9HC
- 58-57-5CR
- 58-58-102
- 58-58-121
- 58-58-216
- 58-58-403
- 58-58-424
- 58-58-508
Figure 13. Strontium Dissolved (1998-2001)

State Well Numbers:
- 58-42-811
- 58-42-914
- 58-42-915
- 58-42-916
- 58-42-920
- 58-42-922
- 58-50-123
- 58-50-201
- 58-50-211
- 58-50-216
- 58-50-222
- 58-50-223
- 58-50-416
- 58-50-417
- 58-50-511
- 58-50-520
- 58-50-704
- 58-50-731
- 58-50-733
- 58-50-847
- 58-50-852
- 58-50-855
- 58-51-5CR
- 58-57-307
- 58-57-3DB
- 58-57-9HC
- 58-57-9HC
- 58-58-102
- 58-58-121
- 58-58-216
- 58-58-403
- 58-58-423
- 58-58-424
- 58-58-508
Figure 14. Water Level vs. Conductivity: Buda Well

Rainfall (Inches) vs. Water Level / Conductivity (msl / uS/cm)
Figure 15. Water Level vs. Conductivity: Ruby Ranch Well

Rainfall
Water Level
Conductivity

Rainfall (Inches)
Water Level / Conductivity (mS / uS/cm)
Figure 16. Piper Diagram of Wells
Ca, Mg, Na, SO4, HCO3, and Cl

Artesian Zone Wells - O

Recharge Zone Wells - *
Figure 17.  Piper Diagram of Springs
Ca, Mg, Na, HCO₃, Sr, and Cl
Artesian Zone Wells - O

Recharge Zone Wells - *
Figure 19. Piper Diagram of Springs
Ca, Mg, Na, SO4, Sr, and Cl
Figure 20.  Piper Diagram of Wells  
Ca, Mg, Na, F, Sr, and Cl

Artesian Zone Wells- O

Recharge Zone Wells- *
Figure 21. Piper Diagram of Springs
Ca, Mg, Na, F, Sr, and Cl