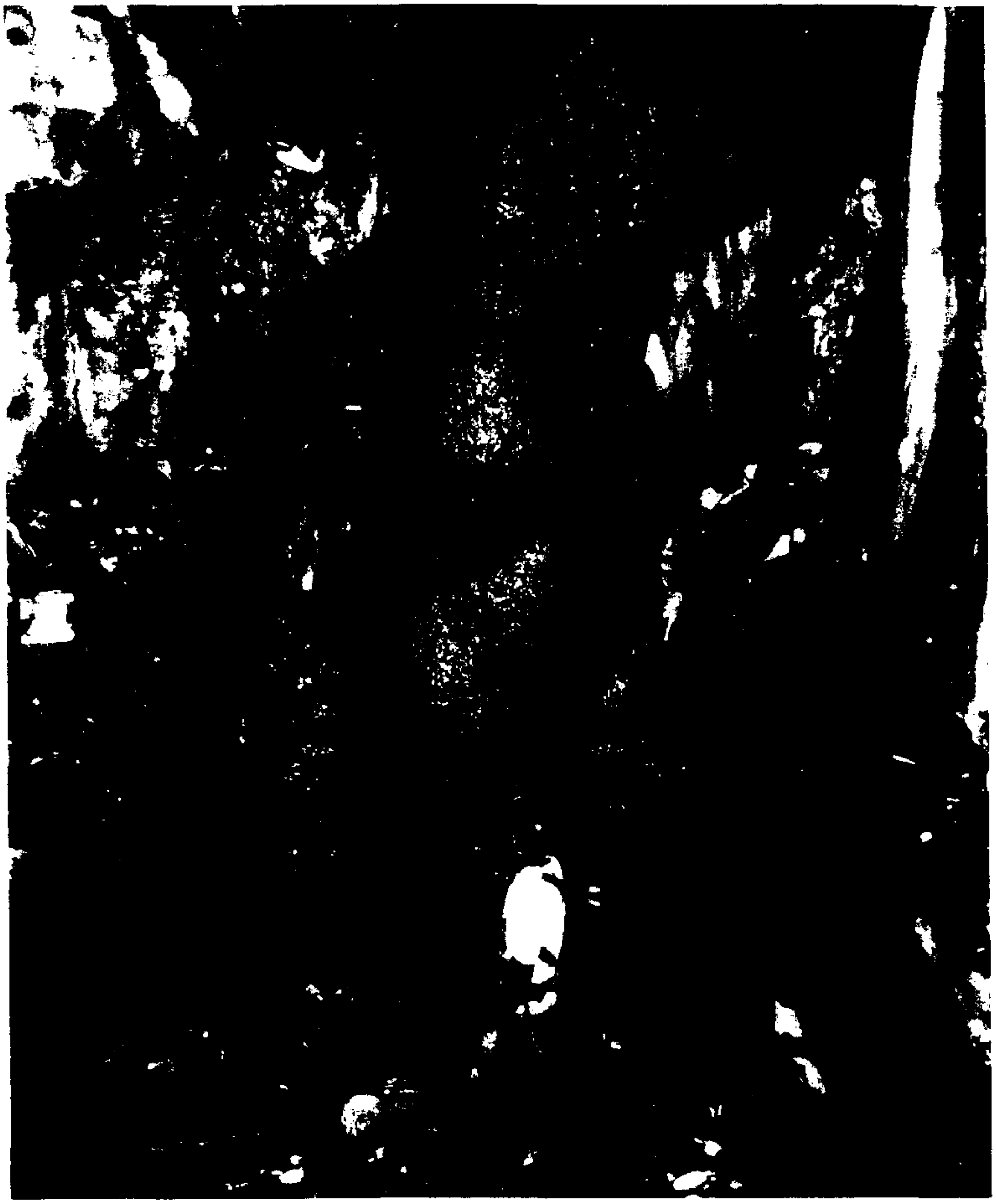
Barton Springs/Edwards Aquifer Hydrogeology and Groundwater Quality



Submitted To:

Texas Water Development Board

Prepared By:

Barton Springs/Edwards Aquifer
Conservation District

Barton Springs/Edwards Aquifer
Hydrogeology and Groundwater Quality

(TWDB Grant Contract No. 93-483-346)

Prepared for:

The Texas Water Development Board

Submitted By:

Barton Springs/Edwards Aquifer Conservation District

Nico M. Hauwert, Hydrogeologist
Shawn Vickers, Environmental Analyst

September 1994

Cover:

Jeff Hoese examines trash around a flowstone waterfall at the bottom of the entrance to Midnight Cave on November 20, 1993. This cave is located in southern Travis County. The trash includes household garbage, used oil filters, corroded 55-gallon drums, glass pesticide bottles, partially-filled turpentine cans, and automobile parts. Note the trash on the higher ledges of the cave, during high aquifer conditions, the cave fills with water causing some of the trash to float onto the higher ledges. Cleanup efforts were coordinated by the Austin Nature Preserves, with assistance from the Barton Springs/Edwards Aquifer Conservation District, the Austin Parks and Recreation Department's Public Safety Office, and the Texas Cave Management Association. Volunteers, including members from the University Speleological Association, the Texas Speleological Society, and other individuals, removed an estimated 3,000 cubic feet of trash from November 1993 through July 1994. Cleanup efforts are expected to continue into 1995. Photograph by Nico M. Hauwert.

Barton Springs/Edwards Aquifer Conservation District
1124-A Regal Row
Austin, Texas 78748
(512) 282-8441

Bill E. Couch, AICP
General Manager

Board of Directors

Patrick Cox - President
Precinct 1

Jack Goodman - Vice President
Precinct 4

Sue Johnson - Secretary
Precinct 5

Don Turner
Precinct 2

Alton Laws
Precinct 3

ACKNOWLEDGMENTS

The Barton Springs/Edwards Aquifer Conservation District would like to thank the well and spring owners who participated in the study. Without their interest and cooperation, would not have been possible. The Board of Directors of the Barton Springs/Edwards Aquifer Conservation District and General Manager Bill Couch directed the staff and resources to complete this study. The Texas Water Development Board provided grant funding essential for equipment and expenditures for research. Critical review of the report was provided by David Johns of the City of Austin Environmental and Conservation Services Department, Raymond Slade of the United States Geological Survey, Max Woodfin, an independent writer and consultant under contract with BS/EACD, and Bill Couch, Ron Fieseler, and Robert Botto of the BS/EACD. Ron Guillett of Applied Microbial Technology, Dr. Roger Case of the Edwards Aquifer Research and Data Center, Buck Henderson of the Lower Colorado River Authority, Phil Nordstrom of the Texas Water Development Board, and Raymond Slade of the United States Geological Survey provided valuable input for selecting water-quality parameters, establishing sampling protocol, and interpreting the results. Dr. Ambrose Charles and Dr. Awinash Bhatkar of the Texas Department of Agriculture, and Luis Saldana of the Travis County Agricultural Extension Service provided valuable information for assessing the pesticides results. Joe Vickers, Byron Benoit, members of Associated Drilling Company, and Geo Projects International assisted in installing the water-level monitoring wells. Joe Christian donated use of a site for the District weather station. Pat Reynolds provided rainfall data that he collected from 1991 through 1992. Steve Wiley, Dale Kuhn, Rick Wilder, Lee Parham, and W.L. Stribling of the Texas Water Well Drillers Team performed downhole camera logging of some of the wells described in this report. Ernest Robles of the City of Sunset Valley assisted in the collection of some water-level data. Robert Botto of the BS/EACD analyzed many of the samples tested in the District lab for verification purposes. Stovy Bowlin of BS/EACD assisted in computer generation of many of the illustrations. Appreciation is also given to other past and present BS/EACD staff and volunteers, including Keg Alexander, Stephan Schuster, Carl Hill, Dolores Bustillos-Tracy, Shu Liang, Yvette Beltran-Southwell, Ron Fieseler, Don Rauschuber, Tammy Charlson, Debra Smith, Cheri Vogel, Carolyn Runyon, Veronica Luna, and Kevin Considine who assisted in the data collection, research, and administration of this project.

EXECUTIVE SUMMARY

This study examines hydrogeologic and water-quality data of the Barton Springs segment of the Edwards Aquifer collected by the Barton Springs/Edwards Aquifer Conservation District from 1990 to 1994. Ten water-level stations are continuously monitored by the District. The water-level changes in the ten monitor wells varied in response to recharge and drawdown events. Monitor wells 58-57-9A (Miller), 58-50-801 (Dowell), 58-58-123 (Porter), 58-58-4CM (Centex) and 58-50-216 (Target) have shown rapid responses to some recharge events, indicating a good hydraulic connection to areas of recharge during certain flow conditions. Well 58-50-301 (Lovelady) shows a very gradual response to recharge events, indicating that it is fed by diffuse flow. Two areas of concentrated groundwater flow are hypothesized, the Manchaca and Sunset Valley flow routes, primarily based on potentiometric surface configurations, and supported with supplemental geologic and water-quality information. These areas are probably water-saturated conduits or transmissive zones that approximately correspond to major fault locations where more rapid groundwater movement is anticipated to occur. The two areas of concentrated flow may be connected as part of a single major route of flow to Barton Springs, or may be two separate routes of groundwater flow. Further delineation and verification of the hydrologic characteristics of these areas should be performed using additional water-level measurements and groundwater tracing techniques.

Thirty-seven wells and springs were sampled in this study. Twenty-two wells were sampled during drought conditions in May through October, 1990. Twenty of the same wells were re-sampled during high water-level conditions in March 1993. Two wells and springs were added in March 1993, and 13 different wells and springs were sampled in March 1994. One well sampled in the bad-water zone showed high levels of dissolved solids, sodium, chloride, magnesium, gross alpha, and boron. Ten wells showed significant contributions from the deeper Glen Rose waters, based on high levels of sulfate, strontium, fluoride, and magnesium. One well screened in the Glen Rose on the western edge of the Edwards Aquifer recharge zone showed levels of these indicator parameters close to concentrations found in typical Edwards Aquifer waters, possibly indicating local interaction between the Glen Rose, Edwards Aquifer, and/or freshly recharging waters.

Above-normal concentrations of petroleum hydrocarbons, sediment, indicator bacteria, metals, or pesticides were measured in wells near the heavily developed portions of the Edwards Aquifer, north of Sunset Valley, in the Rollingwood area, near majors highways, and in most springs sampled. Old Mill Springs, one of the Barton Springs, measured significant levels of petroleum hydrocarbons and lead. No petroleum hydrocarbons were measured in the main Barton Springs (58-42-914) under the same conditions. Near the edge of the recharge zone, between Sunset Valley

and Barton Springs, specific wells and springs contained high amounts of sediment, indicator bacteria, arsenic, aluminum, and significant levels of petroleum hydrocarbons. Cold Springs, a major discharge point for the Rollingwood area, showed high levels of total arsenic, significant levels of indicator bacteria, and detectable levels of some pesticides. High levels of petroleum hydrocarbons and significant levels of lead were measured in one well near Highway 290. Recently drilled wells tended to show higher levels of suspended solids and dissolved solids. Two out of four newly drilled wells that were sampled for lead showed elevated concentrations, possibly from the leaching of lead present in the brass fittings and parts of submersible pumps and brass couplings.

TABLE OF CONTENTS

Board of Directors i
Acknowledgments ii
Executive Summary iii
Table of Contents v
List of Tables vi
List of Figures vi

I. Introduction 1
  A. Karst Hydrogeology 1
  B. Previous Studies 2
  C. Purpose and Methodology of the Study 5
    1. Purpose and Scope 5
    2. Water-Level and Weather Monitoring Sites 6
    3. Selection of Groundwater Quality Parameters 7
    4. Site Selection for Groundwater Sampling 7
    5. Sampling Protocol 8

II. Results of the Study 11
  A. Hydrogeology 11
  B. Water Quality 13
    1. General Chemistry 13
    2. Nutrients 17
    3. Trace Metals 18
    4. Sediment 22
    5. Petroleum Hydrocarbons and Organics 26
    6. Pesticides 28
    7. Indicator Bacteria 30
    8. Radionucleides 32

III. Summary 33

IV. Figures 37

V. List of References Cited 87

VI. Appendices

  A. Water-Level Elevations from Individual Monitor Wells
  B. Water-Quality Results from 1990, 1993, and 1994 Sampling
  C. District Procedures for Sampling and Groundwater Analysis

List of Tables

1. Wells with Continuous Water-Level Monitoring Stations 6
2. Specific Water-Quality Data from Additional Wells Sampled 21
3. Summary of Sedimentation in the Edwards Aquifer near Sunset Valley 24
4. Water-Quality Characterization of Wells and Springs Sampled 34

List of Figures

IB-1. Study Area
IC-1. Water-Level and Weather Monitoring Sites
IC-2. Water-Quality Sampling Sites
IC-3. Groundwater Sampling Dates and Rainfall Events During March 1993
IC-4. Groundwater Sampling Dates and Rainfall Events During March 1994
IIA-1. Water-Levels and Precipitation, Measured from Continuous Monitoring Stations:
(a) November 1991-September 1992
(b) September 1992-July 1993
(c) July 1993-May 1994
(d) December 1993-August 1994
IIA-2. Generalized Potentiometric Surface (March 1993)
IIA-3. Generalized Potentiometric Surface (March 1994)
IIA-4. Wells Used for Hydrologic Information in the Sunset Valley Area
IIA-5. Potentiometric Map of the Sunset Valley Area (July 1-2, 1993).
IIA-6. Water-Levels Measured in Specific Wells in the Sunset Valley/Barton Creek Area
IIA-7. Water-Level Responses of Selected Wells to the Draining of Barton Springs Pool:
(a) July 1-2, 1993
(b) December 12-14, 1993
IIB-1. Field pH Measured in Wells and Springs (1990, 1993, and 1994)
IIB-2. Lateral Distribution of pH Values (March 1993 and 1994)
IIB-3. Groundwater Temperature (March 1993 and 1994)
IIB-4. Field Conductivity (1990, 1993 and 1994)
IIB-5. Lateral Variations in Residual Total Dissolved Solids (March 1993 and 1994)
IIB-6. Residual Total Dissolved Solids vs. Field Conductivity (1990, 1993, and 1994)
IIB-7. Calculated Total Dissolved Solids vs. Field Conductivity (1994)
IIB-8. Major Cations (1990, 1993, and 1994)
IIB-9. Dissolved Calcium vs. Magnesium (1990, 1993, 1994)
IIB-10. Bicarbonate Alkalinity (1990, 1993, and 1994)

IIB-11. Field Total Alkalinity vs. Lab Total Alkalinity
IIB-12. Chloride Concentrations (1990, 1993, and 1994)
IIB-13. Sulfate Concentrations (1990, 1993, and 1994)
IIB-14. Fluoride Concentrations (1990, 1993, and 1994)
IIB-15. Piper Diagram - 1993
IIB-16. Piper Diagram - 1994
IIB-17. Sodium vs. Strontium (1990, 1993, and 1994)
IIB-18. Sulfate vs. Chloride (1990, 1993, and 1994)
IIB-19. Nitrate Nitrogen Concentrations (1990, 1993, and 1994)
IIB-20. Lateral Distribution of Nitrate Nitrogen Concentrations (1993 and 1994)
IIB-21. Kjeldahl Nitrogen Concentrations (1990, 1993, and 1994)
IIB-22. Ammonia Nitrogen Concentrations (1990, 1993, and 1994)
IIB-23. Total Phosphate and Orthophosphorus (1990, 1993, and 1994)
IIB-24. Dissolved Aluminum, and Total Boron (1990, 1993, and 1994)
IIB-25. Dissolved and Total Arsenic Concentrations (1993, 1994)
IIB-26. Lateral Distribution of Arsenic Measured in the Sunset Valley Area (1993-1994)
IIB-27. Dissolved and Total Lead (1993, 1994)
IIB-28. Total Suspended Solids (1993 and 1994)
IIB-29. Total Suspended Solids in Wells in the South Austin and Sunset Valley Areas
IIB-30. Organics and Petroleum Hydrocarbons
IIB-31. Indicator Bacteria (1993 and 1994)
IIB-32. Gross Alpha Concentrations (1990, 1993, 1994)
IIB-33. Lateral Distribution of Measured Gross Alpha Values (1990, 1993, and 1993)

IIB-11. Field Total Alkalinity vs. Lab Total Alkalinity
IIB-12. Chloride Concentrations (1990, 1993, and 1994)
IIB-13. Sulfate Concentrations (1990, 1993, and 1994)
IIB-14. Fluoride Concentrations (1990, 1993, and 1994)
IIB-15. Piper Diagram - 1993
IIB-16. Piper Diagram - 1994
IIB-17. Sodium vs. Strontium (1990, 1993, and 1994)
IIB-18. Sulfate vs. Chloride (1990, 1993, and 1994)
IIB-19. Nitrate Nitrogen Concentrations (1990, 1993, and 1994)
IIB-20. Lateral Distribution of Nitrate Nitrogen Concentrations (1993 and 1994)
IIB-21. Kjeldahl Nitrogen Concentrations (1990, 1993, and 1994)
IIB-22. Ammonia Nitrogen Concentrations (1990, 1993, and 1994)
IIB-23. Total Phosphate and Orthophosphorus (1990, 1993, and 1994)
IIB-24. Dissolved Aluminum, and Total Boron (1990, 1993, and 1994)
IIB-25. Dissolved and Total Arsenic Concentrations (1993, 1994)
IIB-26. Lateral Distribution of Arsenic Measured in the Sunset Valley Area (1993-1994)
IIB-27. Dissolved and Total Lead (1993, 1994)
IIB-28. Total Suspended Solids (1993 and 1994)
IIB-29. Total Suspended Solids in Wells in the South Austin and Sunset Valley Areas
IIB-30. Organics and Petroleum Hydrocarbons
IIB-31. Indicator Bacteria (1993 and 1994)
IIB-32. Gross Alpha Concentrations (1990, 1993, 1994)
IIB-33. Lateral Distribution of Measured Gross Alpha Values (1990, 1993, and 1993)

I. Introduction

A. Karst Hydrogeology

Karst aquifers, like the Barton Springs segment of the Edwards Aquifer, consist of two zones, the *epikarst zone* and the *phreatic zone.* The epikarst is made up of the unsaturated vadose zone, which lies above the water table. Water may be present in perched zones within the epikarst and epikarst conduits may become flooded during periods of high water levels and during recharge events. Karst aquifers are recharged as rainwater travels through the epikarst zone to the water table. Below the water table is the phreatic zone, which is water saturated. The majority of the groundwater flow and storage occurs in this zone.

Groundwater flow in carbonate rocks occurs in a continuum between two types of flow: diffuse flow and conduit flow (Atkinson, 1976). Diffuse flow is the intergranular movement of water through minute pores and fractures, which can be predicted quantitatively using the Darcy flow equation. Darcy flow relates hydraulic head to discharge volumes in aquifer systems. Groundwater flow in diffuse systems is generally slow and laminar. The sum volume of the connected pores constitutes the majority of storage available in most carbonate aquifers. Springs draining predominantly diffuse flow systems tend to be relatively constant in discharge volume and water quality.

Where fractures are present in the saturated zone, a portion of the flow may be transmitted along small openings along the fracture plane. Fractures can be vertical or horizontal along bedding-plane partings. Fractures may hydraulically connect widely spaced areas and promote rapid groundwater flow. The transmissivity of an aquifer where fracture flow predominates is anisotropic because a limited amount of water is available in storage along the fracture plane. Fractures, and particularly faults, represent planes of weakness, and therefore tend to encourage the enlargement of the openings by solution and erosion of the crushed material.

Conduit flow occurs where solution and/or collapse processes have enlarged openings, generally along fractures and more soluble stratigraphic layers. As conduit flow develops, smaller conduits generally join to form larger conduits, similar to dendritic streams (Palmer, 1991). Travel times can be extremely rapid depending on the "plumbing" of the system. Spring discharges from conduit systems tend to be "flashy" and more varied in water quality. Following a major recharge event, increases in flow and water levels are observed almost instantly as pulses in areas connected by fully submerged conduits (Atkinson, 1976). The floodwaters may not actually reach the observation well or spring until sometime later, as marked by changes in water-quality, changes in temperature, the arrival of injected tracers, or other indicators. The volume of a conduit system can be measured by the amount of discharge that occurs at a spring from the initial flood pulse to the actual arrival of the floodwater. (Ashton, 1966).

The shape of the potentiometric surface of a karst aquifer may indicate areas where groundwater flow is concentrated along enlarged horizontal conduits (Thrailkill, 1985; and Quinlan, 1990). Darcy's Law relates the degree of hydraulic connection between a well and a discharge point from the same aquifer system to the slope of the levels between them. Major flow conduits and other highly transmissive zones may sometimes be indicated by natural troughs in the potentiometric surface. Similarly, during a pump test or other major discharge event, the greatest drawdown in a fractured karst aquifer will tend to occur in the direction of fracturing and conduit development.

B. Previous Studies

The Barton Springs segment of the Edwards Aquifer (or "the Barton Springs segment") consists of the Edwards Group and overlying Georgetown Formation within the Balcones Fault Zone, where water containing less than 1,000 mg/l of dissolved solids is present, that is hydraulically connected to Barton and other springs discharging from the south side of the Colorado River (Figure IB-1). The surface area of the Barton Springs segment encompasses 155 square miles (Slade, Dorsey and Steward, 1986). The aquifer includes a *recharge zone* where the Edwards Group or Georgetown Formation outcrops at the surface, and an *artesian zone* where overlying confining layers, including the Del Rio clay, are present. The recharge zone contains about 90 square miles of surface area and is roughly 20 miles long and 5 miles wide. Within the recharge zone, the aquifer is generally under unconfined conditions, although hydraulic conditions may be restricted to some extent by specific layers within the Edwards Aquifer, including the regional dense member. The bad-water zone is a portion of the artesian zone, roughly positioned east of Interstate 35 (IH35) and Congress Avenue, which contains groundwater with dissolved solids above the 1,000 mg/l. The sharp transition between the bad-water zone and the remainder of the artesian zone is probably set in place by major faults that nearly offset the entire thickness of the Edwards Aquifer. The bad-water zone does not appear to contribute significantly to discharge at Barton Springs, except during periods of low flow (Slade, Dorsey and Stewart, 1986). The Walnut and Glen Rose Formations underlie the Edwards Aquifer within the recharge and artesian zones, but are exposed at the surface west of the recharge zone. Most surface drainage across this area, called the *contributing zone*, enters the recharge zone through Onion, Little Bear, Bear, Slaughter, Williamson, and Barton creeks.

Numerous studies have examined the hydrogeology and geochemistry of the Barton Springs segment of the Edwards Aquifer. Other research has studied the northern segment of the Edwards

Aquifer, which is located just north of the study area across the Colorado River, and the aquifer segment discharging to the San Marcos springs across the groundwater divide to the south. A few of these studies are summarized below.

Maclay and Small (1984) and Russell (1987) distinguished the stratigraphic layers of the Edwards Aquifer that favor cavern development and those layers less resistant to solubility and erosion. Almost all of the recognized caves in the Barton Springs segment are limited to three horizontal cavernous zones, which are: (1) a 10-feet thick *upper cavernous zone* in the Marine member of the Person Formation, (2) a 50-feet thick *central cavernous zone* near the top of the Kainer Formation and base of the Person Formation that includes the units overlying and underlying the regional dense member, the grainstone member, and possible Kirschberg equivalents at the top of the dolomitic member, and (3) a 20-feet thick *lower cavernous zone* positioned near the base of the dolomitic member of the Kainer formation. The Georgetown formation and regional dense member are units of relatively low permeability and solubility, and generally do not promote horizontal conduit development.

Slade, Dorsey, and Stewart (1986) collected water level, streamflow, springflow, and water-quality data to characterize the hydrogeology of the Barton Springs segment. This U.S. Geological Survey (USGS) study measured a nearly immediate drop in several monitor wells southwest of Barton Springs, in response to the draining of the Barton Springs pool, as far as three miles away in the general direction of faulting. The observed decline in water level was greatest within the monitor wells during periods of low aquifer levels. Wells less than a mile away in the Rollingwood area west of the pool showed no responses to this event. Surface water flow was measured along major creeks extending across the recharge zone to note areas of recharge and discharge. The USGS study also documented increases in turbidity in Barton Springs pool following a rain event in 1980.

Data collected by the USGS was used in other studies to quantify the recharge and discharge volumes of the Barton Springs segment. The USGS used a two-dimensional numerical groundwater model to estimate recharge and discharge volumes that matched their collected data (Slade, Ruiz, and Slagle, 1986). Woodruff (1984) performed a water-budget analysis using measured streamflow and springflow data collected by the USGS from July 1979 to December 1982. Average annual rainfall was about 25% higher during that period of measurement. Rauschuber (1992) assessed the effects of recharge enhancement on the water balance of the Barton Springs segment.

A hydrologic balance for Town Lake indicated an 11% increase in flow between Tom Miller Dam and the Colorado River below Town Lake in addition to the measurable springflows that are made up primarily of Barton Springs flows (Stecher and others, 1992). This increase may be attributed to unmeasured springs discharging primarily from the Edwards Aquifer below the water level of Town Lake. The water balance indicates that about 50% of the average flow of Barton Springs, or about 25 cubic feet per second, may be accounted for by additional springs discharging from the Edwards Aquifer on the south side of Town Lake.

Senger and Kreitler (1984) interpreted water-quality data collected by the USGS and Senger using trilinear diagrams and other relations. The study was able to distinguish three types of Edwards waters:

(i) freshly recharged groundwaters originating from the outcrop area of the Edwards Aquifer and characterized by low strontium, sodium, chloride, and sulfate;

(ii) waters leaking into the Edwards Aquifer from the Glen Rose at fault interfaces. The Glen Rose waters are typically high in sulfate, chloride, and strontium, and low in sodium; and

(iii) waters from the bad-water zone of the Edwards Aquifer. Waters of the bad-water zone are typically high in strontium, sodium, and sulfate, becoming higher in sodium chloride farther downdip.

Senger (and others, 1990) examined the hydrochemistry of the northern segment of the Edwards Aquifer using data available at the TWDB. Senger found a trend from calcium/magnesium-bicarbonate rich waters in the outcrop area, changing to a mixed cation bicarbonate rich water in the shallow confined portion, and becoming enriched in sodium and chloride downdip.

Tillman (1989) performed a statistical analysis of water-level elevations from selected wells with springflow for Barton Springs. Tillman found a significant correlation between three wells (58-58-101, 58-57-903, and 58-50-801) screened in the Barton Springs segment with the flow rate at Barton Springs.

Alexander (1990) collected water samples and measured yields in wells within the Barton Springs segment. His study indicated a general correlation between well yields and proximity to lineaments interpreted by three separate investigators (Woodruff and others, 1989). In addition, Alexander found that 10 out of 13 of the highest producing wells were located southeast of southwest-northeast trending lineaments.

Groundwater sampling of 15 wells in the Barton Springs segment has been conducted by the United States Geological Survey for a study funded by the City of Austin since 1985 (Texas Ground Water Committee JWQMP, 1993). The 15 monitored wells are sampled under baseflow conditions and, beginning in 1994, two of the 15 wells will be sampled during rain events to observe short-term changes in water quality related to recharge events. The sampling results show a strong decrease in the water quality at Barton Springs following storm events (Barton Springs Task Force, 1991). The City of Austin investigators believed that a major fault (referred to in this report as the Barton Springs Fault) hydraulically connects Barton Springs and areas near Barton Creek and Loop 360. The USGS and the Barton Springs/Edwards Aquifer Conservation District independently measured significant flow losses from one to 12 cubic feet per second within Barton Creek in the vicinity of the fault crossing (Johns, 1991, and Slade, Dorsey and Stewart, 1986). The Barton Springs Task Force investigators identified several possible contributing sources of poor water quality to Barton Springs, including stormwater runoff, package wastewater treatment plants, septic tanks, wastewater main releases, pets and wild animals, recreational users, and transients.

C. Purpose and Methodology of the Study

1. Purpose and Scope

This study by the Barton Spring/Edwards Aquifer Conservation District (District), builds on previous investigations into the hydrogeology and water-quality of the Barton Springs segment. The District collected water level and water-quality information during the course of this study in order to:

i) characterize the existing water quality and hydrogeology within the Barton Springs Segment of the Edwards Aquifer;

ii) measure variations in the water levels and water quality of the aquifer between periods of high and low aquifer conditions;

iii) identify, document, and monitor impairment of the drinking water quality and recreational use of the aquifer due to potential contamination sources such as septic tanks, hazardous material storage and disposal, construction activities, urban runoff, and agricultural operations; and

iv) attempt to define flow paths and hydrogeologically separate systems using water-level responses and water-quality characteristics.

2. Water-Level and Weather Monitoring Sites

Several criteria were used in selecting locations for water-level monitor wells. Wells with a well-documented history were generally selected. Such documentation might include driller well logs, geophysical well logs, spring-flow measurements, previous water-quality analysis, or water-level measurements. Some locations were chosen near large pumping, recharge, and discharge areas. The locations of these wells are spatially separated to provide representative information across the Barton Springs segment. When possible, some well locations were selected near major faults or near suspected flow routes where water-levels responses are expected to be more dynamic. Ten wells are continuously monitored by the District for groundwater levels within the Barton Springs segment (Table 1 and Figure IC-1). One location, a monitor well near Barton Springs, is operated and maintained by the USGS. Additional wells throughout the study area were used to obtain periodic water-level information. Wells and springs are referred to in this report by a permanent seven digit number assigned by the Texas Water Development Board or by a temporary number assigned by the BS/EACD.

A District-operated weather station is located near the center of the study area, bordering the Bear Creek and Slaughter Creek watersheds. This weather station provides continuous measurement of rainfall, barometric pressure, relative humidity, wind speed, and wind direction.

Table 1. Wells with Continuous Water-Level Monitoring Stations

CONTINUOUS WATER-LEVEL MONITOR WELLS						
State or Temp. Well Number	Name	Latitude	Longitude	Top of Casing Elevation (feet above msl)	Well Depth (feet)	Initial Date of Continuous Measurement by BS/EACD (d/mo/yr)
58-57-9A	Miller	30°02'18"	97°53'30"	833	320	11/15/91
58-50-801	Dowell	30°08'35"	97°48'34"	662	277	11/4/91
58-50-301	Lovelady	30°12'37"	97°46'58"	640	388	11/3/91
58-58-101	Franklin	30°04'59"	97°50'32"	707	244	5/9/91
58-42-903	Barton Springs	30°15'48"	97°46'16"	459	57	5/24/91
58-42-8TW	Eyecare Center	30°15'41"	97°47'43"	634	402	1/29/94
58-58-123	Porter	30°06'33"	97°50'30"	707	510	2/15/94
58-50-216	Target	30°15'56"	97°47'33"	692	580	6/14/94
58-50-411	Circle C	30°11'12"	97°50'57"	771	469	7/28/94
58-58-4CM	Centex	30°03'30"	97°52'07"	725	206	8/23/94

3. Selection of Groundwater-Quality Parameters

Groundwater-quality parameters selected included major and minor ions, metals, radioactive isotopes, organics, some common pesticides, suspended solids, and indicator bacteria. Major ions and metals were used to characterize the overall water quality of the aquifer, determine leakage from adjacent aquifers, to define groundwater flow paths and aquifer subsegments, and to identify areas where these parameters exceed drinking water standards. Many of the pesticide types were selected for analysis because they had been measured in surface waters over the Barton Springs segment (Raymond Slade, USGS, personal communication) and listed in the Texas Natural Resource Conservation Commission interagency pesticide database (Texas Groundwater Protection Committee, 1992). Total petroleum hydrocarbon was selected as a parameter to measure contamination from petroleum storage tanks and other hydrocarbon sources. The list of groundwater parameters was expanded in the March 1994 sampling to include total phosphate, total coliform, fecal streptococci, total metals, gross beta, tritium, and additional pesticides.

4. Site Selection for Groundwater Sampling

Wells and springs were selected for the study based on several criteria. Sample points were spaced across the Barton Springs segment to note lateral changes in water quality. One spring discharges from the overlying Buda Formation, but immediately recharges into the Barton Springs segment. A second well, known to be screened in the underlying Glen Rose Aquifer, was selected for comparison purposes. Because the Barton Springs segment thins considerably from erosion on the western side of the study area and water use is consequently limited in this area, few samples could be collected here. Some criteria for the selection of groundwater monitoring locations in karst terranes are outlined in Groundwater Monitoring in Karst Terranes: Recommended Protocols and Implicit Assumptions by James F. Quinlan (1989). Major spring discharge points from the aquifer were selected because they tend to be hydraulically connected to points deep in the aquifer through conduits. Wells were selected in known or suspected locations of major faulting and potentiometric surface troughs wherever possible in an attempt to sample locations of major flow within the Barton Springs segment. Major water supply systems, screened in the Edwards Aquifer, were selected because they tend to draw water from a larger area and therefore are probably a more representative water source. In addition, water-supply systems can readily utilize the water-quality information collected and tend to have a well-documented history. This study utilized all of the wells used in the 1990 study (BS/EACD, 1991), except for two water-supply systems, Chaparral Park (state well number 58-49-911) and Creedmoor-Maha WSC (state well number 58-50-847). Water-quality analysis from Chaparral Park indicated significant mixing of Glen Rose waters was occurring, probably from nearby wells, and was therefore excluded. Well 58-50-847 was not re-sampled in 1993 due to access problems. Finally, some sites were chosen from which groundwater-quality problems were reported or which may be downgradient of known or suspected contamination. Figure IC-2 maps the locations of 37 groundwater sampling sites used in the study. Additional wells were sampled for selected parameters where specific contamination was suspected.

5. Sampling Protocol

The procedures for sampling performed in 1993 and 1994 followed procedures described in the Texas Water Development Board (TWDB) manual UM-51: A Field Manual for Ground Water Sampling (Nordstrom, 1990). Twenty-two wells were sampled in 1990 according to the same TWDB field sampling procedures, although the specific procedures and results are described in BS/EACD, 1991. A District hydrogeologist performed sampling in all of the 35 baseline wells and springs sampled in either 1993 or 1994 for this study. A Hach pH, temperature, and conductivity meter was used to measure field parameters in 1993. In 1994, an Horiba U-10 was used to measure pH, temperature, conductivity, and turbidity. The field instruments were calibrated daily prior to sampling. During March 1994, samples were collected in association with rainfall events, although this was not a criteria for samples collected in March 1993. Figures IC-3 and IC-4 relate the sampling events to rainfall measured at the District weather station during March 1993 and March 1994. Sampling procedures required that the wells be purged three well volumes, or until field parameters stabilized, prior to sampling. Measurements of pH, temperature, and conductivity, flow rate and purged volume from the discharge were recorded at the sampling site. Total and phenol alkalinity were measured in the field using a Hach digital titrator. After purging, samples were collected and preserved or filtered as required. Bacteria samples were collected directly from the spigot, if possible, after disinfecting the spigot with a flame. The use of polyvinyl tubing was often required for purging and sampling to avoid flooding of the well house and to fill sample bottles where the spigot was positioned near the ground. It was noted that significant retention had occurred onto the tubing after sampling three wells (58-50-1CW1, 58-50-2EM, and 58-50-2HB) that were enriched in hydrocarbons, arsenic, and aluminum, respectively. Re-sampling of some wells were performed for specific parameters where previous measurement of organic carbon and petroleum hydrocarbons were believed to have been influenced by cross-contamination. Analytical results that were affected by possible cross-contamination of arsenic or aluminum were not included in this report. The sampling procedures were subsequently revised to discard tubing after use on one well. The samples were placed in an ice-filled cooler and delivered to the lab within 16 hours with an accompanying chain-of-custody form. A split of each sample was analyzed in the District lab for iron, sulfate, chloride, nitrate nitrogen, and fluoride, as well as the presence of total and fecal coliform or E. coli. The specific District sampling and laboratory procedures are described in Appendix C.

Three independent laboratories performed the analyses in this study. Forty-four samples collected in 1990 and 1993 from 23 wells and one spring were analyzed by the Lower Colorado River Authority Laboratory (LCRA) in Austin. In 1994, 10 samples from seven wells and springs (58-42-922, 58-50-1CW1, 58-50-2E, 58-50-3BL, 58-50-502, 58-57-3BW, and 58-57-5JO) were submitted to Applied Microbial Technology, Inc. (AMT) in Georgetown. Also in 1994, six samples from six wells and springs (58-42-916, 58-49-9EM, 58-50-201, 58-50-2EM, 58-50-2HB, and 58-50-511) were submitted to the Edwards Aquifer Research and Data Center (EARDC) in San Marcos for analysis. The detection limits, precision, and capabilities of each lab to perform specific analyses varied. Ion balance and calculated dissolved solids were reported by AMT and EARDC for the 13 samples collected in March 1994, as a general measure of the accuracy of the sampling and analysis (Appendix B). Well 58-50-2HB showed an anomalous ion balance of 2.31 due to interference from sediment. The ion balance of the remaining 12 wells sampled in March 1994 ranged from 0.92 to 1.275 and averaged 1.08, which is about 8% higher than expected. The ratio of the calculated dissolved solids to the residual dissolved solids ranged from 0.88 to 1.16 from the same 12 samples, averaging 1.01, which is about 1% higher than expected. Section IIB-I describes the difference between the calculated and residual dissolved solids in greater detail. The ion balance and total dissolved solids methods of comparison assume that all of the significant constituents were measured and that the source waters are balanced with respect to cations and anions.

Three independent laboratories performed the analyses in this study. Forty-four samples collected in 1990 and 1993 from 23 wells and one spring were analyzed by the Lower Colorado River Authority Laboratory (LCRA) in Austin. In 1994, 10 samples from seven wells and springs (58-42-922, 58-50-1CW1, 58-50-2E, 58-50-3BL, 58-50-502, 58-57-3BW, and 58-57-5JO) were submitted to Applied Microbial Technology, Inc. (AMT) in Georgetown. Also in 1994, six samples from six wells and springs (58-42-916, 58-49-9EM, 58-50-201, 58-50-2EM, 58-50-2HB, and 58-50-511) were submitted to the Edwards Aquifer Research and Data Center (EARDC) in San Marcos for analysis. The detection limits, precision, and capabilities of each lab to perform specific analyses varied. Ion balance and calculated dissolved solids were reported by AMT and EARDC for the 13 samples collected in March 1994, as a general measure of the accuracy of the sampling and analysis (Appendix B). Well 58-50-2HB showed an anomalous ion balance of 2.31 due to interference from sediment. The ion balance of the remaining 12 wells sampled in March 1994 ranged from 0.92 to 1.275 and averaged 1.08, which is about 8% higher than expected. The ratio of the calculated dissolved solids to the residual dissolved solids ranged from 0.88 to 1.16 from the same 12 samples, averaging 1.01, which is about 1% higher than expected. Section IIB-I describes the difference between the calculated and residual dissolved solids in greater detail. The ion balance and total dissolved solids methods of comparison assume that all of the significant constituents were measured and that the source waters are balanced with respect to cations and anions.

II. Results of the Study

A. Hydrogeology

Figure IIA (1a-1d) shows the correlation of water levels measured in some of the monitor wells with rainfall events. More detailed water-level fluctuations are presented in Appendix A. Monitor wells 58-50-301(Lovelady), 58-50-801 (Dowell), 58-57-9A (Miller), and 58-58-101(Franklin), and 58-58-123 (Porter) are screened within the artesian zone of the Barton Springs segment. In the artesian zone, the aquifer is confined by overlying layers and water is stored under pressure by compression of the rock matrix and pore water. Under confined conditions, water-levels tend to experience fluctuations, because they react more radically to local pumping and even changes in barometric pressure. In early 1992, monitor wells 58-50-801 (Dowell well) and 58-57-9A (Miller well) showed rapid rises and falls in water levels, on the order of 20 and 10 feet respectively, following single rain events of about one-to-two inches in magnitude. For sustained rains greater than two inches in magnitude, the water level rise in these two wells tends to be accompanied by a lesser decline. Well 58-58-123 (Porter) showed a rise of eight feet following a rain event in May 1994 (Appendix A). Monitor well 58-58-123 was intentionally drilled near a prominent fracture trace and is reported to produce large volumes of water (Albert Ogden, personal communication). Since the three wells (58-58-9A, 58-50-801, and 58-58-123) are under confined conditions, the observed water level response indicates the movement of a pressure pulse through the aquifer and shows that the wells are well connected hydraulically to areas of recharge. Water level declines in well 58-50-801 (Dowell) can often be matched with declines in well 58-58-123 (Porter, Appendix A). The water-level reponses in both wells are probably the result of nearby large volume public water supply wells. Monitor well 58-50-301 (Lovelady) demonstrates a smaller response to rainfall events, and shows a gradual rather than sharp increase with sustained rainfall. This well receives diffuse flow through smaller pores and fractures, and can be considered less hydraulically connected to areas of recharge than the Miller or Dowell wells. Well 58-58-101 (Franklin) is located about 1,000 feet northwest of the City of Buda's primary municipal water-supply well, and shows sharp declines associated with the pumping of this municipal well. The site of monitor well 58-42-8TW (Eye Care Center) is semi-confined by the overlying Del Rio clay, although this clay is eroded above adjacent faulted blocks. Well 58-42-8TW may be located on a groundwater divide between the Barton Springs and Cold Springs discharge segment, because it shows small variations in water levels over time. Monitor well 58-50-411 (Circle C) shows a daily fluctuation of about 0.1 feet, probably in response to local pumpage.

Water levels in several wells are periodically measured throughout the year to provide more detailed mapping of the potentiometric surface and to note short and long-term fluctuations in water levels.

Potentiometric maps, based on water levels measured in March 1993 and March 1994, are presented in Figures IIA-2 and IIA-3. Water levels were about 40 to 50 feet lower in March 1994 than in March 1993 due to extended dry weather conditions in the recharge and contributing zones during late 1993 and early 1994. The actual potentiometric surface of the aquifer is probably more irregular than represented in small-scale potentiometric maps. The potentiometric surface representations and more detailed maps by Slade, Dorsey and Stewart (1986) for other years, show a depression or trough lined parallel to Manchaca Road. In karst limestones, preferred flow routes tend to form as solution development focuses along specific soluble stratigraphic zones, particularly where intersecting faults, fractures, and other irregularities provide zones of weakness. These preferred flow routes may be indicated by troughs in the potentiometric surface. Note that the Barton Springs segment is under artesian conditions in the vicinity of this trough.

Detailed water-level measurements were taken from wells in the Sunset Valley area on July 1 and 2, 1993, to provide greater delineation of the local potentiometric surface in that area (Figure IIA-4). Figure IIA-5 shows a well-defined depression or trough in the potentiometric surface aligned parallel to a fault extension of the Barton Springs Fault. Much of this area is contained in the recharge zone of the Barton Springs segment, where overlying clays are absent. Deposition of sediment in some wells near the fault supports the concept that conduit flow occurs subparallel to the fault (see section IIB-4). A higher than normal degree of sediment accumulation suggests the presence of significant solution-cavity development and a sufficient groundwater velocity to facilitate the movement of sediment from a source area. The potentiometric trough shown on Figure IIA-5 appears to define a highly transmissive zone, which will be referred to here as the Sunset Valley subsurface flow route. Based on the information collected for this study, it is not yet known if the Sunset Valley subsurface flow route is a continuation of the Manchaca subsurface flow route, or if it is a separate system. Further investigation of these systems using more closely-spaced water-level measurements and groundwater tracing is being planned by the District.

Water-level measurements were collected from numerous wells in the Loop 360-Sunset Valley area during 1993 to note temporal changes (Figure IIA-6). On two occasions, water-level changes were measured in several wells before and after the draining of Barton Springs pool to measure hydraulic connection between this area and Barton Springs, which is located about 3 miles away (Figures IIA-7 (a) and (b)). Based on a limited number of water-level measurements, drawdowns on the order of about 0.1 to 0.22 feet appeared to have been associated with the draining of Barton Springs pool on July 1 and December 13, 1993. Rising water levels noted on July 1 in some of the wells were probably due to a 1.2 inch rain occurring less than a week before. Continuous measurements recorded by the USGS in nearby well 58-50-216 indicated as much as 0.5 feet of drawdown occurred following the draining of Barton Springs pool (Senger and Kreitler, 1984). Continuous measurements, recorded at two-hour intervals, were taken from well 58-50-216 by the District from June 14, 1994, to August 15, 1994, and thereafter recorded at daily intervals (Appendix A). The water levels show a slightly erratic, but fairly continuous decline, unlike the distinct decline shown during different periods by the previous study. This gradual decline may be attributed to the frequency of pool draining events at Barton Springs, which was twice per week in 1994, or to other differences in aquifer conditions between the separate periods of measurement. Well 58-50-216 showed a rapid response to rain events on July 10 and August 9, 1994 raising about a foot following a two inch rain. This response suggest a good hydraulic connection to recharge areas.

Probably the best observable model for a major conduit where concentrated flow historically occurred is Airman's Cave, an abandoned route of concentrated flow positioned in the epikarst zone just east of the Sunset Valley flow route. Airman's Cave is a man-sized conduit that formed sub-parallel to existing faults and fractures along a bedding plane in the uppermost section of the Person formation of the Edwards Group. As the longest cave in Travis County, more than two miles of passage have been mapped (Russell, 1975). Although generally dry, Airman's Cave carried large volumes of water during high water-level conditions in 1991 and 1992. During this period, water moving through Airman's Cave discharged into Barton Creek through two temporary springs at an estimated rate of 2 to 10 cubic feet per second (1,000 to 5,000 gallons per minute). This observed flow through Airman's Cave illustrates how flow routes may change during differing water-level stages.

B. Water Quality

I. General Chemistry

Thirty-seven wells and springs were sampled in March 1993 and March 1994. The results are presented in Appendix B. Twenty of the 22 wells sampled during a period of elevated water-levels in March 1993 had been previously sampled at the end of a three-year dry period, from May to October 1990. The re-sampling of the same wells provided some measure for the variation of water-quality parameters between wet and dry periods. In specific areas where certain kinds of groundwater contamination were identified or suspected, additional samples were collected to delineate the area impacted, measure levels of contamination, and identify possible contamination sources. In some cases these additional samples were collected prior to the plugging of a well.

Values of pH measured consistently higher in the high flow conditions of 1993 than during low-flow conditions of 1990, except in the Buda area where pH values were lower in 1993 than in 1990 (Figures IIB-1 and IIB-2). pH values averaged 7.17 in 1990, 7.24 in March 1993 and 7.24 from a separate set of wells in March 1994. pH measured in wells near Onion Creek was low, generally about 7 or less. Meteoric water tends to be slightly acid, but will become more alkaline through contact with carbonate rocks. Low pH values, therefore, may imply close hydraulic connection with recharge areas. The highest pH values of nearly 8 were measured just west of Interstate 35. One well, 58-50-854, measured in the bad-water zone, showed a higher-than-average value of 7.33 in 1993.

Groundwater temperature measurements from 1990, 1993, and 1994 are graphed in Figure IIB-3. Groundwater temperature measurements averaged 23.9° Celsius (C) from May through October 1990, 22.2°C in March 1993, and 21.6° C in March 1994. Based on 35 measurements in March 1993 and March 1994, the average groundwater temperature is about 22°C (72° Fahrenheit), and ranged from 19.3°C to 25.4°C. One well, 58-50-852, had an anomalously high water temperature of 25.4°C, in March 1993. According to District records, this well has historically shown higher-than-average temperature, and similar high water temperatures have been measured in nearby wells. The reason for high temperature anomalies is not clear, but may be the result of hydraulic connection to surface recharge, insufficient purging, or natural geothermal anomalies.

The amount of dissolved solids present in water increases proportionally with its electrical conductivity. Field conductivity generally did not change significantly between high and low aquifer conditions (Figure IIB-4). The sum of dissolved solids in water can be measured more accurately by the amount of residue remaining after evaporation of the water. The geographic variation in residual dissolved solids is shown on Figure IIB-5. Dissolved solids and conductivity were significantly higher within two wells (58-50-852 and 58-50-854) screened into or adjacent to waters of the bad-water zone. Old Mill Springs (58-42-922) shows a high value of dissolved solids, suggesting that it receives significant contributions from the bad-water zone during certain flow conditions. Two out of three recently-drilled wells, 58-49-9EM and 58-57-3BW, showed significantly higher levels of residual dissolved solids, probably as a result of residual drilling fluids or ground materials in the well. Figure IIB-6 shows the relation between measured field conductivity and residual dissolved solids. The most accurate method of measuring the total dissolved solids is by measuring and summing the individual constituents. This calculated dissolved solids was computed by the participating laboratories for the 1994 samples and shows a better correlation to measured field conductivity (Figure IIB-7). Based on the samples collected in this study, the value for total dissolved solids (TDS) in mg/l can be estimated from the field conductivity by:

$$\text{TDS in mg/l} = 0.7\ (\text{Conductivity in uS/cm}) - 100\ \text{mg/l}$$

The three most prominent cations found in the groundwater of the Edwards Aquifer are calcium, magnesium, and sodium. The concentrations of these three cations measured in 1990, 1993, and 1994 are shown in Figure IIB-8. Wells 58-50-854 and 58-58-219, demonstrate that sodium becomes the most prominent cation in the bad-water zone. Water-quality changes occurred in wells located near the bad-water zone occured between dry periods in 1990 and wet periods in 1993. The changes included a general increase in calcium, and a decrease in sodium. Well 58-58-202, located near the bad-water zone, typifies the change from sodium-dominated during low-water conditions in 1990, becoming calcium-and magnesium-dominated during periods of high-water conditions in March 1993. These changes are apparently as a result of dilution from more recently recharged waters.

The ratio of calcium to magnesium concentrations may indicate if the source rock is dolomitic or limestone (White, 1988). Wells sampled near Interstate 35 contained a lower ratio of calcium to magnesium (Figure IIB-9), possibly indicating a dolomitic host rock. The stratigraphic units present in the bad-water zone of the Edwards Aquifer are known to be enriched in dolomite (Folk and Land, 1975; Maclay and Small, 1978). A second source of magnesium-rich waters could be upper dolomitic Glen Rose units that are displaced adjacent to the Edwards Aquifer by major faults that parallel the bad-water line.

The total alkalinity consists almost entirely of the bicarbonate ion (HCO_3) in unpolluted, carbonate waters, although other basic constituents such as the carbonate and hydroxyl ions, may be present to a lesser extent (White, 1988). Bicarbonate alkalinity was measured in the laboratory (Figure IIB-10). The phenol alkalinity or carbonate ion (CO_3) is only present when the pH exceeds 8.3, and was not detected in the field samples tested. Degassing of carbon dioxide over time can cause significant changes to the alkalinity and pH following sampling, which is why field measurement of the two parameters is important. Figure IIB-11 compares lab measurement of bicarbonate alkalinity (HCO_3) with the field measurements of total alkalinity ($CaCO_3$). The ratio of HCO_3 to $CaCO_3$ should be 1.2 as indicated by the line on Figure IIB-11. The field measurements generally agree with lab measurements, but may differ to lab measurements due to changes in the alkalinity following sampling.

Chloride concentrations measured in the study are presented in Figure IIB-12. Chloride values are significantly increased in well 58-50-854, located within the bad-water zone. Leakage from the bad-water zone accounts for most of the elevated chloride levels measured in Edwards waters, although elevated chloride levels have also been observed in other areas from leaking wastewater systems (Alhajjar and others, 1990). In this Wisconsin study, 17 different septic fields tested had average chloride concentrations of 11 times the background levels of adjacent soils, sands, and glacial deposits.

Sulfate and fluoride concentrations measured are shown in Figures IIB-13 and IIB-14. Waters from the bad-water zone and deeper Glen Rose aquifer can be distinguished by sulfate and fluoride values greater than 50 mg/l and 0.5 mg/l, respectively, as illustrated by wells 58-49-911, 58-50-852, 58-50-854, 58-50-855, 58-58-202, 58-58-403, 58-58-508, 58-49-9EM, 58-50-2E, and 58-50-2HB.

Piper diagrams of the major ions measured are shown in Figures IIB-15 and IIB-16. Well 58-50-854 (labeled as #14) typifies water-quality trends from the bad-water zone: a higher proportion of sodium , chloride, magnesium, alkalinity and a lower proportion of calcium and sulfate than typical Edwards waters. Wells 58-49-911, 58-58-202, 58-49-9EM, and 58-50-2E (labeled as #s 6, 20, 27, and 30) show strong mixing of deep-lying Glen Rose waters: a higher proportion of sulfate, chloride, and magnesium, and a lower proportion of calcium, sodium and potassium, and alkalinity than typical Edwards waters.

Distinction between the freshly-recharging Edwards waters, the deeper Glen Rose waters, and bad-water zone can also be done using the proportions of either sodium and strontium, or chloride and sulfate (Figures IIB-17 and IIB-18), based on relations noted by Senger (and others, 1984 and 1990). Wells 58-50-847, 58-50-852, 58-50-855, 58-58-508 (labeled as #s 12, 13, 15, and 24, respectively) located just west of Interstate 35 showed proportions of these ions more similar to Glen Rose waters than to waters from the bad-water zone. Wells 58-58-202 and 58-58-219 (labeled as #s 20 and 21, respectively), located just west of IH35, show a mixing of Glen Rose and saline waters from the bad-water zone. Note the water-quality shift of wells 58-58-202 (#20), well 58-50-854 (#14), well 58-58-508 (#24), and well 58-50-852 (#13) towards more typical Glen Rose waters and less bad-water zone type from the drier 1990 to wetter conditions in 1993. This trend indicates that these wells in and just west of the bad-water zone are not entirely stagnant, and show some degree of hydraulic connection with discharge areas. As the hydraulic head in the Barton Springs segment decreases during dry years, more discharge from the bad-water zone can occur, allowing more lateral seepage from the Glen Rose aquifer. Other wells such as 58-58-219 (#21), 58-58-403 (#22), show very little variation between wet and dry years. Wells 58-50-2E and 58-50-2HB (labeled as #s 30 and 32), located within the recharge zone, also showed an influence of Glen Rose waters. Both wells are located on or near faults along which either vertical or lateral leakage of water may be occurring. Edwards Aquifer well 58-49-911 (labeled as #6) shows contribution of

Glen Rose waters, but likely from leakage of nearby wells screened in the lower Glen Rose aquifer, rather than from natural leakage. One well, 58-50-7BK (labeled as #5), fully screened in the Glen Rose, showed a water type closer to Edwards Aquifer water than typical Glen Rose water, based on the four indicator parameters. Senger (and others, 1984 and 1990) also found that Glen Rose groundwaters east of the Mount Bonnell Fault did not appear to contain levels of sodium or sulfate typical of the deep-lying Glen Rose east of the fault. Again well 58-50-854 typifies the bad-water zone. Old Mill spring, 58-42-922 (labeled as #26), shows a strong influence of waters from the bad-water zone, mixing with more representative waters from the Edwards Aquifer. The four indicator ions show wells and springs 58-42-811, 58-50-223, 58-50-416, 58-50-731, 58-58-416, 58-50-2EM, and Buda spring 58-50-3BL (labeled as #s 1, 7, 8, 10, 23, 31, and 33, respectively) are well connected to fresh recharge sources. Decreases in the concentration of the four ions during the wet spring of 1993 relative to the drier late-1990, suggest that less influence from the Glen Rose and bad-water zone occur during periods of high flow.

2. Nutrients

Nitrate nitrogen appeared to be one of the more variable parameters measured in the study, over space and time (Figure IIB-19 and IIB-20). The two highest levels of nitrate nitrogen, at 9.5 and 3.8 mg/l, were encountered in wells 58-58-114 and 58-50-733, located near Bear Creek in the Manchaca area. Levels of nitrate nitrogen between 2 and 4 mg/l were encountered in two wells (58-50-223 and 58-50-2HB) of the Sunset Valley area, and at Old Mill (58-42-922) and Cold Springs (58-42-916). Other nitrate levels measured in this study were less than 2 mg/l. Levels of nitrate nitrogen may originate from a variety of sources including animal excrement, fertilizers, wastewater discharge, solid wastes, and even natural vegetation. The amount of nitrate measured in groundwaters is generally highly dependent on amounts of rainfall (Schepers and Martin, 1986). Organic carbon present in the substrate may significantly reduce the amount of available nitrate (Smith and Duff, 1988). Kreitler and Jones (1975) distinguished nitrogen sources from septic tanks, animal wastes, and natural soils based on ratios of nitrogen isotopes. Kreitler and Jones concluded that excessive nitrate concentrations measured in limestone and gravel aquifers, averaging 250 mg/l, resulted from decomposition of vegetation and oxidation of nitrogen-enriched soils. The EPA drinking water standard for nitrate nitrogen is set at 10 mg/l, based on associations between high nitrate levels and the development of methemoglobinemia, (blue babies disease) in young infants. Other studies indicate high nitrate levels may contribute to nervous system disorders, birth defects, and cancer (Keeney, 1986).

Although not depicted on Figure IIB-20, the USGS has reported that the highest levels of nitrate encountered in the Barton Springs segment has been near Brodie Lane, south of Slaughter Lane

(Raymond Slade, USGS, personal communication). A number of possible sources of wastewater leakage are found in this area. A large number of septic tank systems are used in the Palomino Park area north of Shady Hollow. Planning is underway to replace these systems with an organized sewage collection system feeding into the Slaughter Creek interceptor, a major wastewater line which follows the creekbed of Slaughter Creek. The Shady Hollow wastewater treatment plant discharged treated effluent to Slaughter Creek just southeast of that intersection, and was taken off line in the spring of 1994.

Other nutrients included in the study include kjeldahl, ammonia, nitrite nitrogen, orthophosphorus, and total phosphate. Ammonia nitrogen, an indicator of possible sewage leaks, consistently measured above 1 mg/l in well 58-50-854. Anomalously high levels of ammonia nitrate measured in well 58-50-416 in 1990 were likely a laboratory error, because they far exceed the reported levels of kjeldahl nitrogen measured at the same time, and ammonia nitrate was not detected during resampling in 1993. Orthophosphorus is commonly found in laundry detergents, and therefore is also a possible indicator of wastewater leaks. Backdoor Springs (58-42-811) and well 58-50-223 both showed relatively high levels of orthophosphorus. Note that Backdoor Springs also measured levels of fecal coliform, indicating that this spring may be impacted by wastewaters. Total phosphate (PO4) was measured to be about 0.015 or less in seven of the 13 wells and springs sampled in March 1994. Three of the 13 wells and springs (springs 58-42-922 and 58-50-3BL, and well 58-57-3BW) showed moderate phosphate levels between about 0.02 to 0.08 mg/l. Three of the 13 sampling sites (58-50-1CW1, 58-50-2EM, and 58-50-2HB) measured notably higher phosphate levels between 0.09 and 0.18 mg/l. No analysis of total phosphate was performed on the 1990 and 1993 samples. Concentrations of these nutrient parameters are shown in Figures IIB-21 through IIB-23.

3. Trace Metals

Concentrations of boron measured in 1990, 1993, and 1994 are graphed in Figure IIB-24. Levels of dissolved boron typically measured below 0.05 mg/l in Edwards waters, but measured significantly higher in wells and springs influenced by the bad-water zone and urban runoff (Figure IIB-24). Boron measured significantly higher (0.5 mg/l or greater) in and near the bad-water zone during drought conditions in 1990 as shown by wells 58-50-854, 58-58-403, and 58-58-219. Of the 22 wells in 1993, only 58-50-854 showed high levels of boron. The decrease in boron from dry to wetter years supports that less leakage from the bad-water zone occurs during periods of high water levels, as hypothesized by Senger (1986). In 1994, total boron was measured rather than dissolved boron. Total boron measured above 0.5 mg/l in one spring and one well (58-42-916 and 58-50-2HB), possibly as a constituent of urban runoff.

Levels of dissolved aluminum measured less than 0.04 mg/l in 1990 but measured between 0.90 to 0.24 mg/l in 1993 (Figure IIB-24). This apparent rise may be due to water-quality changes related to higher water conditions, but may also be the result of sampling or laboratory errors, thus comparisons of dissolved aluminum between wet and dry years is inconclusive. Concentrations of total aluminum measured from one to above six mg/l in several wells and springs (58-42-916, 58-49-9EM, 58-50-2EM, 58-50-2HB). Most of these wells also showed significant levels of suspended solids (see Figure IIB-28). No dissolved aluminum was measured in the same wells and springs, illustrating the importance of sediment in the transport of aluminum. Four aluminum analysis from samples collected in 1994 (58-50-1CW1, 58-50-201, 58-50-511, and 58-57-5JO) are not reported due to possible sampling error.

Iron and manganese were not measured in high levels together, except for well 58-50-1CW1, where 2.1 mg/l of total iron and 0.43 mg/l of total manganese (largely consisting of dissolved metals) were measured. Three wells located near the bad-water line (58-50-854, 58-58-219, and 58-58-508) contained significant dissolved iron levels between 0.08 mg/l and 0.32 mg/l, when sampled during low aquifer flow conditions in 1990. Of these three wells, only well 58-58-219 showed elevated dissolved iron levels during high aquifer flow conditions in March 1993. The iron measured in the three wells may be related to greater influx of Glen Rose waters in this zone during low-flow conditions.

Dissolved arsenic measured below the detection limit, which varied from 0.001 to 0.01 mg/l, in 26 of the 37 wells sampled from 1990 to 1994. Measurements of arsenic from eight wells sampled in March 1994 , (58-49-9EM, 58-50-1CW1, 58-50-201, 58-50-2HB, 58-50-502, 58-50-511, 58-57-3BW, and 58-57-5JO) were inconclusive due to possible sampling errors. Dissolved and/or total arsenic was measured in four of the 37 baseline water-quality wells and springs (Figure IIB-25). Total arsenic at Cold Springs (58-42-916) measured 0.452 mg/l, or about nine times above EPA's maximum contaminant level of 0.05 mg/l. Dissolved arsenic measured 0.032 mg/l at the same spring. Total arsenic measured below the drinking water standards and detection limit of 0.05 mg/l in well 58-50-2EM, although dissolved arsenic measured near that value at 0.037 mg/l. Six additional wells were sampled for arsenic in the vicinity of 58-50-2EM, four of which contained measurable levels of arsenic (See Figure IIB-26 and Table 2). Of these four additional wells, the highest levels of total arsenic were measured in well 58-50-2NB3, at levels of 0.31 mg/l. These elevated arsenic levels measured in the vicinity of Highway 290 and west of Loop 360 probably originate from some source in roadway or urban runoff. Currently, roadway runoff from the Highway 290 area is channeled to Gaines and Barton Creeks, where recharge occurs in the creekbeds. Arsenic concentrations seem to be typically elevated in runoff from urbanized areas as indicated by USGS measurements in the streamflow of two Austin area urban watersheds: Shoal Creek and Boggy Creek, where arsenic levels up to 0.053 mg/l were detected (Veenhuis and Slade, 1990). A review of much of the existing literature on the constituents of highway runoff was performed by Barrett and others (1993). One water-quality study of roadway runoff measured total and dissolved arsenic at a range from 0.000 mg/l to 0.145 mg/l, averaging 0.050 mg/l for dissolved arsenic and 0.058 for total arsenic (Wanielista and others, 1980). A study is currently being conducted by the University of Texas Center for Research in Water Resources (CRWR) to measure the various constituents of roadway runoff in Austin. In this CRWR study, researchers intend to measure arsenic levels in roadway runoffs. A major use of arsenic has been as a defoliant for cotton crops, the use of which has been voluntarily canceled by the manufacturer, although existing stocks could be used until December 31, 1993 (Dr. Ambrose Charles of the Texas Department of Agriculture, National Pesticide Tele-Communications Network, and TNRCC Agricultural Section). Since there is no known cotton production over the recharge zone of the Barton Springs segment, the observed arsenic must originate from another source. Arsenic is still legally applied in urban and suburban areas for gopher and rodent control. Arsenic may also have been used in automotive parts such as in car batteries.

Based on 36 of the 37 wells sampled, levels of dissolved lead were not detected above levels of 0.005 mg/l in uncontaminated waters. In the March 1994 sampling, both total lead and dissolved lead were tested for in all 13 wells and springs sampled. In most of the 13 wells where lead was detected, the total lead was significantly higher than the dissolved lead, illustrating the importance of sediments in the role of transporting trace metals (Figure IIB-27). In two wells and one spring (58-42-922, 58-49-9EM, and 58-50-1CW1), measured total or dissolved lead was above 0.01 mg/l (Figure IIB-27). Old Mill Spring, 58-42-922, contained total and dissolved lead levels of 0.024 and 0.015 mg/l. Samples from well 58-50-1CW1 contained 0.014 mg/l of total lead and 0.0097 mg/l dissolved lead. Elevated levels of lead are typically found in petroleum-contaminated waters, and significant levels of petroleum hydrocarbons were measured in both Old Mill Spring and well 58-50-1CW1 (see Section IIB-5).

The highest lead levels were encountered in a 2-1/2 month-old well, 58-49-9EM, where 0.036 mg/l of total lead was measured (more than twice the EPA action standard of 0.015 mg/l). No dissolved lead was detected above 0.002 mg/l in this well. A purged sample collected from newly drilled well 58-57-3SW showed elevated total lead levels at 0.012 mg/l (Table 2). The EPA issued a warning on April 18, 1994, that excessive levels of lead have been found in wells less than one year old equipped with certain pumps containing brass fittings or parts, including those manufactured by

Table 2. Specific Water-Quality Data from Additional Wells Sampled

Temporary/ State Well Number	Depth to Water (feet below toc)	Date Sampled	Sampling Entities	Total Organic Carbon EPA9060 (mg/l)	Volatile Scan EPA 8240 /EPA 625 (yes/no)	Semi-Volatiles EPA 8260/ EPA 8270/ EPA 624 (yes/no)	Total Organic Halogens (mg/l)	Total Petroleum Hydrocarbons EPA 418.1 (mg/l)	Toluene (mg/l)
58-42-914	---	4/18/94	BS/EACD	0.87	no	no	---	<0.03	---
58-42-915	---	5/6/93	USGS	27	no	no	---	---	
58-42-915	--	5/9/93	USGS	9.1	yes	---	---	---	<0.003
58-42-915	190	5/12/93	USGS	19	no	yes	---	---	---
58-42-915	197.34	7/1/93	BS/EACD-COA	0.9	no	no	---	2.1	---
58-50-2NB1	151.55	7/9/93	BS/EACD - ESA	154	no	no	66	<0.05 / 0.2	<0.001
58-50-2NB1	180.17	11/30/93	TNRCC-ESA-BS/EACD	1.9	yes	yes		<0.10	<0.002
58-50-2NB2	124.13	7/9/93	BS/EACD - ESA	140	no	no	27	<0.05 / 0.3	<0.001
58-50-2NB2	---	11/30/93	TNRCC-ESA	---	yes	yes		---	0.965 / 1.2
58-50-2NB3	119.79	7/9/93	BS/EACD - ESA	96	no	no	<2.0	<0.05	<0.001
58-50-2NB4	176.34	7/9/93	BS/EACD - ESA	119	no	no	<2.0	<0.05	<0.001
58-50-2WN	---	10/1/93	BS/EACD	3.3	no	yes	---	0.52	<0.001
58-57-3SW	98.6	4/27/94	BS/EACD	---	no	no	---	---	---

Temporary/ State Well Number	Date Sampled	Arsenic EPA7060 EPA6010 (mg/l)	Barium EPA6010 (mg/l)	Lead EPA7421 EPA6010 (mg/l)	Total Coliform (colonies/ 100 ml)	Fecal Coliform (colonies/ 100 ml)	Fecal Strep (colonies/ 100 ml)
58-42-914	4/18/94	---	---	---	---	---	---
58-42-915	5/6/93	---	---	---	---	---	---
58-42-915	5/9/93	---	---	---	---	---	---
58-42-915	5/12/93	---	---	---	---	---	---
58-42-915	7/1/93	---	---	---	---	---	---
58-50-2NB1	7/9/93	0.065	0.061	<0.051	90	<10	---
58-50-2NB1	11/30/93	0.0054	---	---	---	---	---
58-50-2NB2	7/9/93	<0.065	0.22	<0.051	500	<10	---
58-50-2NB2	11/30/93	---	---	---	---	---	---
58-50-2NB3	7/9/93	0.31	0.42	<0.051	11700	<10	---
58-50-2NB4	7/9/93	<0.065	0.041	<0.051	63000	<10	---
58-50-2WN	10/1/93	0.0046	---	0.0034	20	16	6
58-57-3SW	4/27/94	---	---	0.012	---	---	---

Entities

Barton Springs/Edwards Aquifer Conservation District

United States Geological Survey

City of Austin

Texas Natural Resource Conservation Commission

Environmental Services Agency, Dallas, Texas

Aeromotor, Goulds, Sta-Rite, and F. E. Myers (EPA, 1994). The EPA recommends the following alternatives if lead levels are detected in water-supply wells above the action level of 0.015 mg/l:

- "Install a point-of-use treatment device that removes lead. For more information on which types of treatment devices remove lead, contact the Water Quality Association at (708) 505-0180 or NSF International at (313) 769-5106.

- Use bottled water for drinking and cooking. Make sure that you use a brand that does not contain lead, however. For more information on bottled water, you can contact the Food and Drug Administration at (301) 443-4188, NSF International at (313) 769-5106, or the International Bottled Water Association at (703) 683-5213; or

- Replace the submersible well pump with a pump that does not contain lead (such as stainless steel and plastic)."

Both of the recently drilled wells in which the District measured elevated lead levels contained Dempster-brand pumps. Well 58-49-9EM also contained brass couplings. Note that both newly-drilled wells were sampled following purging of the well, and that higher levels of lead may be found if sampled prior to purging. Following the EPA warning, the District has been notifying new well owners and collecting samples for lead testing in newly-drilled wells within the District boundaries at the well owner's request.

4. Sediment

Levels of suspended solids measured during March 1993 and March 1994 indicate that low levels are present where the aquifer is confined, but they can be very high in portions of the recharge zone (Figure IIB-28). Within the Sunset Valley area, high levels of suspended solids were measured. Groundwater samples were taken from additional wells to further delineate areas of high sediment contamination (Figure IIB-29). The depths of several open wells were measured to determine amounts of infilling by sediment.

Table 3 summarizes levels of sedimentation measured within the Barton Springs segment. The sediment contamination was documented using several criteria, including:

i) visual observation of sediment or turbidity by driller, well operator, or owner of well or spring. Numerous well drillers and pump installers were interviewed to identify wells where anomalous levels of sediment were encountered.

ii) laboratory measurement of total suspended solids.

iii) field measurement of turbidity using an Horiba U-10 or measurements taken by other agencies.

iv) measurement of changes in the depth of a well due to infilling with sediment.

A brief summary of sediment problems observed in some wells and springs follows:

Slade, Dorsey, and Stewart (1986) measured increases in turbidity in Barton Springs (58-42-914) associated with a four-inch rain in May 1980. The researchers suspected that the amount of sediment was related to the amount of construction activity at that time in the Barton Creek watershed. During 1993, Barton Springs discharged large amounts of sediments following most major rain events in 1993 and 1994. Based on observations by pool employees, the turbidity was generally noticeable about eight to 12 hours after the start of a heavy rain. The spring water generally cleared within 24 hours of the start of rain. Roadway and other construction in the recharge zone of Barton Springs greatly increased in the early 1990's.

Monitor well 58-50-217 was installed by the USGS near the Barton Creek crossing of Loop 360 in August 1978. Sediment was observed in the well by USGS staff during sample collection. Well depth measurements taken by District staff and City of Austin staff on July 1, 1993, indicate that the entire uncased interval, or nearly 100 feet of the well had been filled with sediment.

The operator of the Sunset Valley municipal well, 58-50-223 (also numbered 58-50-215) noted some accumulations of cream-colored sediment in the two water storage tanks since 1990. The deposition rate appeared to gradually increase over time, then rapidly increased after July 1992. In July 1993, the well operator measured a 1- to 1-1/2 foot accumulation in each of the two tanks after they were cleaned eight months before. In mid-July 1993, the well pump seized and the cause was attributed to sediment accumulations in the well.

The driller of wells 58-50-2NB2 and 58-50-2NB3 reported that "truckloads" of sediment were blown out of the wells following their drilling in May 1985. The wells were sampled by BS/EACD staff and representatives of the property owners on July 9, 1993. The initial pump used in sampling seized after about 10 minutes of pumping. Following purging, samples from

Table 3. Summary of Sedimentation in the Edwards Aquifer in the Southwest Austin/Sunset Valley Area

Temporary/ State Well Number	System/ Well Owner Name	Date of Inital Reported Sediment Contamin.	Source of Initial Finding	Field Turbidity (NTU)	Total Suspended Solids (mg/l)	Drilled Well Depth (Feet)	Date Drilled	Measured Well Depth (Feet)	Date Measured	Amount of Screened Interval Filled (percent)
58-42-913	Barton Springs	6/8/80	USGS	82	---	---	---	---	5/8/80	---
58-50-201	Robert Jentsch	none reported	BS/EACD	0	0	290	---	---	3/3/94	---
58-50-217	USGS	-/-/93	USGS	---	---	214	8/-/78	118.8	7/1/93	100
58-50-222	City of Sunset Valley	3/2/94	BS/EACD	---	---	336	-/-/55	267	5/19/94	72
58-50-223	City of Sunset Valley	-/-/90	operator	---	0	360	10/14/76	---	---	---
58-50-2BR2	Barton Ridge	5/27/85	driller	---	---	420	5/27/85	---	---	---
58-50-2E	Leif Johnson	none reported	BS/EACD	11	49	450	9/19/90	---	---	---
58-50-2EM	Ed Maxey	none reported	BS/EACD	16	9.49	---	---	---	---	---
58-50-2HB	Helen Besse	4/18/80	owner	>999	6384.4	440	4/18/80	---	3/3/94	---
58-50-2NB1	FDIC/Amresco	5/6/85	BS/EACD	28 (11/30/93)	8	442	5/6/85	432	7/9/93	
58-50-2NB2	FDIC/Amresco	5/6/85	Driller	---	4900	325	5/6/85	162	7/9/93	100
58-50-2NB3	FDIC/Amresco	5/6/85	Driller	---	18000	323	5/7/85	180	7/9/93	100
58-50-2NB4	FDIC/Amresco	5/6/85	BS/EACD	---	50	350	5/8/85	350	7/9/93	
58-50-2WN	Wolf Nursery	11/3/93	BS/EACD	31	31	350	---	300+	11/3/93	
58-50-416	Linda Roudebush	none reported	BS/EACD	---	7	---	---	---		
58-50-502	R.W. Herndon	none reported	BS/EACD	28	14	300	-/-/37	---	3/15/94	---
58-50-511	Rodney Johnson	none reported	BS/EACD	3	1.39	285	-/-/56	---	---	---
58-50-520	Herb Mendieta	none reported	BS/EACD	---	2	---	---	---		

wells 58-50-2NB2 and 58-50-2NB3 contained 4,900 mg/l and 18,000 mg/l of a cream-colored, carbonate silt. Measurements of the well depths taken by District staff on July 1, 1993, indicated that sediment had filled the entire uncased interval, or about 150 feet, of each well.

The driller of well 58-50-2BR2 reported that large quantities of sediment were encountered during the construction of this well in 1986. No samples have been collected by the District from this well.

Two wells, 58-50-221 and 58-50-212 (or 58-50-222), were retired as municipal wells by the City of Sunset Valley and were considered as possible monitor wells for the District. The driller's log indicates that well 58-50-212 was drilled to a depth of 336 feet in 1955. On May 20, 1994, a downhole camera was lowered into this well by the Texas Water Well Drillers Team. On this date, the well was observed to be only 267 feet deep and was dry, although water has been measured at other times. A three-feet diameter cave was observed a few feet above the existing floor of the well. Sediment entering the well through the cave is believed to have filled the lower 70 feet of the well bore.

The owner of domestic well, 58-50-2HB (previously numbered as 58-50-5K), reported that sediment was present in the well water during periods of heavy rains and severe drought conditions after the well was installed on April 18, 1980. Since the spring of 1993, however, the well has produced sediment almost continually. District staff sampled the well on March 3, 1994 and found the water to be opaque with a cream-colored carbonate silt. Suspended solids from the water samples collected measured 6,384 mg/l.

Moderate levels of sediment (between 5 and 50 mg/l) were measured in wells 58-50-2E, 58-50-2EM, 58-50-2NB1, 58-50-2NB4, 58-50-2WN, 58-50-416, and 58-50-502. All of these wells, except for 58-50-502, lie in the recharge zone of the Edwards Aquifer. Wells 58-50-201, 58-50-511, and 58-50-520 were wells sampled in the artesian zone of the Edwards Aquifer and showed little or no impact from sediment. Moderate to high levels of suspended solids were measured in three recently drilled wells, 58-49-9EM, 58-57-3BW, and 58-57-5JO, likely as a result of materials remaining from drilling operations.

According to several drillers, well servicemen, well owners, and well operators interviewed, sediment problems are generally more apparent in wells during periods of heavy rainfall and during particularly low water-level conditions. It can be expected that during periods of heavy rain, floodwaters can effectively wash loose sediment into recharge areas and contribute to greater flow velocities within the aquifer. The presence of more sediment during low-flow conditions may be a factor of higher accumulations of fine sediment on the surface between rains, or due to concentration of the existing sediment in a well. The sediment that appears in a well or spring during a rain event may either be freshly recharged sediment or reactivated sediment stored in the phreatic or epikarst zone. Drillers have also reported encountering a fine carbonate sediment or "sugar sand" in specific but widely-spaced areas of the recharge zone. Sugar sand is described by drillers as a crushed and ground rock fragments, and may be related to rock ground along fault surfaces (fault gouge). The occurrence of sugar sand has been known to interfere with drilling operations, but has not been known to impair later use of the well. The anomalous volumes of sediment encountered between Sunset Valley and Barton Springs suggest that it is not a result of natural conditions, although more work is needed to identify the source of the sediment. Based on District records, an increase in roadway construction occurred in the early 1990's followed by increases in subdivision developments. These activities seem to correspond to anomalous amounts of sediment observed in wells and springs. District inspections of construction sites noted many sediment releases near areas of recharge during that period. Often, recharge features are filled with sediment on or near construction sites.

5. Petroleum Hydrocarbons and Other Organics

A single parameter, total petroleum hydrocarbons (EPA 418.1), was used to indicate possible hydrocarbon impacts from sources that include leaking petroleum tanks, highway runoff, and historic petroleum pipeline spills (Figure IIB-30). Minor levels of petroleum hydrocarbons detected in collected samples from wells may originate from oils in the well pump. Organic carbon was measured to indicate total concentrations of natural organic carbon, oil, grease, animal fat, solvents, pesticides, herbicides, petroleum hydrocarbons and any phenol breakdown products from hydrocarbon degradation. Non-impacted wells typically show organic carbon levels of about 3 mg/l or less. Several well samples were analyzed for levels of total organic halogens, where solvents were suspected to be present. In some cases, the level of organics in the groundwater seems to be highly variable over time, possibly as a result of aquifer-flow conditions or amount of purging.

Within the study area, a large number of petroleum storage tank sites and known leaking petroleum storage tanks lie along Highway 290 and along Loop 360 east of the recharge zone. Most of the known releases have impacted groundwater present in the overlying Buda limestone formation. The Buda formation is separated to some degree hydraulically from the Edwards formation by the Del Rio clay, which is generally assumed to be impermeable. However, numerous water-producing seams have been reported during highway construction excavating the Del Rio near the intersection of Loop 360 and Highway 290. Thick gypsum seams visible along fault zones in the Del Rio clay suggest that locally the Del Rio clay may transmit significant water through fractures. Several springs near the intersection of Highway 290 and Loop 360 discharge water year-round from the Buda limestone near its contact with the underlying Del Rio. These springs recharge into the Edwards Aquifer a short distance downstream. One of largest springs, numbered 58-50-3BL or "Barton Lodge Spring" was sampled as a part of this study.

Below is a summary of petroleum hydrocarbon and organic halogen contamination documented by the District during 1993 and early 1994:

i) Well 58-50-1CW1 was sampled on March 9, 1994, for a comprehensive analysis of groundwater parameters for this study. The samples had noticeable hydrocarbon fumes, although no phase-separated product was observed. Analysis for organic carbon and petroleum hydrocarbons measured levels of 86 mg/l and 11 mg/l , respectively. This well, along with nearby wells, 58-50-1CW2 and residential well 58-50-1DH, was last sampled by the District for petroleum hydrocarbons on November 2, 1992, following a fuel spill at the nearby Big Wheel Phillips 66 gasoline station that was reported on September 24, 1992. Analysis of the samples collected on November 2, 1992 did not detect petroleum hydrocarbons at a detection limit of 1.0 mg/l in any of the three wells (See Table 2).

ii) Four abandoned wells (58-50-2NB1 through NB4) on FDIC property just northwest of Highway 290 and Loop 360 were sampled on July 9, 1993, as a prerequisite for plugging. The samples collected by Environmental Services Agency (ESA) of Dallas and District staff showed high levels of total organic halogens (66 and 27 mg/l). Wells 58-50-2NB1 and 58-50-2NB2 were re-sampled on November 30, 1993 with ESA, TNRCC, the City of Austin, and District staff present, during significantly lower aquifer conditions. During the second sampling, samples were analyzed using methods EPA 624 (volatiles), EPA 625 (semi-volatiles) by Star Analytical, and verified by the LCRA laboratory using methods EPA8240 (volatiles) and EPA8270 (semi-volatiles). The second sampling measured no levels of petroleum hydrocarbons or organic halogens in well 58-50-2NB1. Samples from well 58-50-2NB2 showed toluene present at levels between 0.965 to 1.2 mg/l and no levels of organic halogens. Applied Microbial Technology analyzed samples collected by the District from well 58-50-2NB1 for total organic carbon, and total petroleum hydrocarbons and measured concentrations of 1.9 mg/l and <0.10, respectively. Suspected sources of contamination include urban runoff, a large number of nearby septic tanks, nearby vehicle maintenance facilities, and petroleum storage tank facilities.

iii) Well 58-50-2WN, north of Highway 290 and about 1 mile west of Loop 360, was sampled by District staff on October 1, 1993. The water samples were submitted to Applied Microbial Technology Lab and showed levels of total petroleum hydrocarbons (EPA 418.1) at 0.52 mg/l. The well was plugged on November 3, 1993.

iv) In May, 1993, United States Geological Survey staff encountered a hydrocarbon sheen while sampling a monitor well, 58-42-915. This well was noteworthy because it sometimes showed a foot decline in water level as a result of draining Barton Springs pool one mile away, indicating good hydrologic connection with the pool (Slade, Dorsey and Stewart, 1986). A sample collected by the District in coordination with the City of Austin Environmental and Conservation Services Department and submitted to the LCRA lab showed that 2.1 mg/l of total petroleum hydrocarbons were present.

v) Old Mill Springs (58-42-922), one of the Barton Springs, was sampled on March 16, 1994, following a 0.35 inch rain. Levels of organic carbon and petroleum hydrocarbons were measured in the samples at levels of 14 and 1.9 mg/l, respectively. A verification sample was collected independent of a rain event on April 18, 1994 . The sample measured organic carbon and petroleum levels of 2.6 and 1.3 mg/l, respectively. On the same day, a sample was also collected from the main Barton Spring (58-42-914), about 25 minutes after the pool gate had been opened for cleaning. The main Barton Spring measured 0.87 mg/l of organic carbon, but no petroleum hydrocarbons at a detection limit of 0.03 mg/l.

6. Pesticides

Low levels of pesticides were measured in a few of the 37 wells and springs sampled. In wells and springs where pesticides were detected, the concentrations were on the order of 1 microgram per liter (ug/l, or about 1 part per billion) or less. None of the pesticide levels measured in this study exceeded EPA maximum contaminant levels or health advisory levels. No geographic correlation of pesticides could be found in this study, which was largely due to variations in the detection limits of the three contracted laboratories as well as the laboratories' capabilities to perform analysis for specified pesticides within the budget constraints of this study. Another factor that may have influenced the detection of pesticides in the samples from March 1994 was that sampling was more closely associated with rain events than those collected in 1993.

Water samples from twenty-two wells and springs sampled in March 1993 were submitted to the LCRA lab for analysis. Nine pesticides including atrazine, 2,4-D, 4,4-DDD, 4,4-DDE, BHC-gamma (lindane), dieldrin, endrin were analyzed for using EPA method 8080 and immunoassay methods at a detection limit of 1 ug/l. None of these pesticides was detected in the 22 samples.

A number of pesticides were measured at levels of about one ug/l or less in some of the wells and springs sampled in March 1994. Cold Springs (58-42-916) showed the highest levels and most variety of pesticides, particularly bromacil (1.065 ug/l), 4-nitrophenol (0.98 ug/l), lindane (0.01 ug/l), endrin ketone (0.053 ug/l), heptachlor (0.019 ug/l), and heptachlor epoxide (0.025 ug/l). Well 58-50-201 showed levels of 2,4-D at 0.232 ug/l; 3,5-dichlorobenzoic at 0.09 ug/l, dichloroprop at 0.331 ug/l, and bromacil at 0.485 ug/l. The pesticides were detected using a gas chromatograph scan at the EARDC lab. Levels of bromacil and 4-nitrophenol were subsequently verified using mass spectroscopy.

Sources for the pesticides measured in this study are not known. The chlorinated pesticides degrade very slowly and may have been introduced into the aquifer from past agricultural and domestic usage. The highest and most widely encountered herbicide compounds were bromacil and 4-nitrophenol. Bromacil has been measured widespread in the groundwaters of Florida and California, where it is used as a herbicide in citrus groves, on railroad tracks, and along powerlines (Disposal Safety of America, 1993). Bromacil has not been found to be a significant concern to water quality in Texas (Bhatkar, 1993). The levels of bromacil encountered in this study were far below the EPA Health Advisory level for bromacil at 90 parts per billion (about 90 ug/l). The compound 4-nitrophenol is a decomposition product of parathion and metyl-parathion (Dr. Roger Case, EARDC, personal communication).

Heptachlor epoxide is an oxidation product of heptachlor, where it is applied to the soil for termite and fire ant control (Farm Chemicals Handbook, 1994). The maximum contaminant level for heptachlor and heptachlor epoxide are 0.4 ug/l and 0.2 ug/l, respectively. The EPA maximum contaminant level for lindane and endrin are 4 ug/l and 0.2 ug/l, respectively. 2-4-D is a selective hormone-type herbicide used primarily for agricultural applications. The maximum contaminant level of 2-4-D is 100 ug/l. Ortho-dichlorobenzene (3,5-dichlorobenzoic) was historically used as an herbicide, insecticide, solvent, and soil fumigant but has been discontinued by Dow Chemical Company. Dichloroprop is commonly used for brush control on rangeland and rights-of-way, as well as for control of aquatic weeds.

Several dozen one-gallon jugs, emptied or partially filled, that previously contained pesticides, including "Super-Tox" and "Co-Ral" were recovered from Midnight and Wildflower caves in southwest Austin in 1993 and 1994. According to the ingredients listed on the bottles, the pesticides included lindane, malathion, trichlorfon, and O-Diethyl-O-(3-chloro-4-methyl-2-oxo-(2H)-1-benzopyral-2-7-yl) phosphorothioate. Disposal of waste materials in recharge features appears to have been relatively common in the area prior to the mid-1980's.

According to the TNRCC spill response database, a 25-gallon spill of 0.06% Dursban brand pesticide was reported from a Chemlawn vehicle on Loop 360 at West Bank Drive, about 2 miles southwest of Cold Springs. The active ingredient in Dursban is chlorpyrifos, an organophosphate compound (Tom Cleveland, Dupont, personal communication).

The Travis County Agricultural Extension Service reported that currently common rangeland herbicides used in the study area include Grazon, active ingredient picloram (4-amino-3,5,6-trichloropicolinic acid) and Reclaim, consisting of clopyralid (3,6-dichloro-2-pyridinecarboxylic acid). No picloram was detected in water samples collected from six wells and springs in 1994, at a detection limit of 0.14 ug/l.

7. Indicator Bacteria

Fecal coliform was used as an indicator bacteria during the March 1994 sampling (Figure IIB-31). Only one well, 58-49-708 and one spring 58-42-821 (Backdoor Springs) sampled in 1994, showed measurable levels of fecal coliform, at 2 colonies per 100 ml each.

During the March 1994 sampling, total coliform, fecal coliform, and fecal streptococci were used as indicator bacteria. All three bacteria are present within the feces of warm-blooded animals. The ratio of fecal coliform to fecal streptococci present in the intestines of humans have different proportions than those found in other warm-blooded animals and therefore this ratio has been used to indicate if the source of bacterial contamination is of human or animal origin (Geldrich and Kenner, 1969). Because the two types of bacteria have very different mortality rates, this relationship must be carefully applied when interpreting sources of groundwater contamination. McFetters (and others, 1979) indicates that the fecal coliform to fecal streptococci ratio can only be used to interpret whether the source is of animal or man origin only within short periods of time after the bacteria have entered the water. Water-quality analysis of stormwater by the City of Austin laboratory indicates that under aquifer recharge conditions, the mortality rate for streptococci is greater than that of coliform (Barton Springs Task Force, 1991).

Water usage from the Barton Springs segment in the Rollingwood area has diminished as the water-quality has degraded, primarily from both chronic and acute releases of wastewater. The abundance of local septic tanks and the poor annular seals around water wells in this area has been suspected of causing chronic contamination. Periodic releases from sewage lift stations and wastewater lines may also have contributed to bacterial contamination in this area. A sewage release that occurred at the City of Austin Bee Cave Sewage Lift Station on October 14, 1993, discharged an estimated 33,000 to 100,000 gallons of sewage into Eanes (Dry) Creek. The discharge volumes were based on observations by residents and estimates from videotape documentation. According to witnesses, a small portion of the spill was recovered by a vacuum truck while the remainder was washed down the creek by spill-response personnel. All of the unrecovered spilled wastewater and wash water recharged into the underlying Barton Springs segment within 0.3 miles of the spill site. According to local residents and city records, this lift station experiences accidental sewage releases on the order of once a year, although generally a much smaller volume is lost.

Cold Springs, numbered 58-42-916, is a major discharge point for groundwater in the Rollingwood area. Comprehensive sampling was performed at Cold Springs on March 3, 1994, as a part of this study. The analysis showed a heavy bacterial count that interfered with a precise count of total coliform. Fecal coliform and fecal streptococci were measured at 8 colonies per 100 ml and 46 colonies per 100 ml, respectively. The levels of indicator bacteria measured high in comparison with non-impacted waters of the Barton Springs segment, but are similar to levels measured in the groundwater near the lower reaches of Barton Creek.

In other areas of the Barton Springs segment, wastewater contamination occurs from insufficient filtering in septic fields, organized wastewater line leaks, and wastewater plant releases. Septic tank usage is dense in the Sunset Valley/Highway 290 area, although many of these neighborhoods are in the process of being connected with organized sewage collection systems. The City of Austin identified Barton Creek West, the Estates of Barton Creek, Lost Creek MUD, Travis Country, and Lake Travis High School as five package wastewater treatment plants located within the Barton Creek watershed (Barton Springs Task Force, 1991). Most of the creeks contributing major recharge to the Barton Springs segment are underlain by wastewater lines.

Wells and springs located in the recharge zone between Sunset Valley and Barton Springs varied considerably in the presence or absence of bacteria. Old Mill Springs (58-42-922) showed a heavy count of fecal stretococci (1,900 colonies/100 ml) but no coliform bacteria. Barton Lodge Spring, a Buda formation spring mixed with some stormwater effluent, showed 36 colonies/100 ml of total coliform, 2 colonies/100 ml of fecal coliform, and 37 colonies/100 ml of fecal streptococci. Well 58-50-2HB, located on the southwest side of Sunset Valley, showed none of the three indicator bacteria. No total coliform was detected at well 58-50-2EM by the contracted laboratory, although the District's verification test showed the presence of total coliform and E. coli. Four abandoned wells (58-50-2NB1 through NB4) on Federal Deposit Information Corporation (FDIC) property just northwest of Highway 290 and Loop 360 were sampled on July 9, 1993. Levels of total coliform were measured from 90 to 63,000 colonies/100 ml in the four wells. Well 58-50-2WN, north of Highway 290 and about 1 mile west of Loop 360, was sampled by District staff on October 1, 1993. The water samples were submitted to Applied Microbial Technology Lab and showed levels total coliform at 20 colonies per 100 ml and fecal coliform at 16 colonies per 100 ml.

8. Radionucleides

Gross alpha radiation generally ranged from 0.5 to about 7 picocuries/liter (pCi/l) in the recharge zone, increasing to 25 picocuries/liter (pCi/l) in the bad-water zone during sampling events in 1990, 1993, and 1994. (Figures IIB-32 and IIB-33). Higher detection limits (5 pCi/l) for analytical results in the 1993 samples prevented comparison of alpha radiation between wet and dry years. Gross beta was measured in March 1994, and ranged from 1.1 pCi/l to 7.3 pCi/l. Wells that received leakage from the deep-lying Glen Rose tended to show higher beta values.

No tritium was measured at a detection limit of 0.02 pCi/l in 13 wells sampled across the aquifer. The test method selected for tritium analysis is sufficient for detecting releases of tritium waste from sources like laboratories, but is too high to detect low levels that may have been associated with global nuclear testing. Levels of measurable tritium in the Barton Springs segment are believed to have increased by atmospheric nuclear testing occurring prior to the Nuclear Test Ban of 1963 (Pearson and others, 1975). Lower levels of tritium have been measured and have been related to travel times of groundwater in the Edwards Aquifer in the Northern Segment (Senger and others, 1990) and in the San Marcos area (Ogden and others, 1986). More sensitive methods of tritium analysis, including hydrogen enhancement, are necessary to measure levels of tritium that are generally present in meteoric and groundwaters (Alan Dutton, Bureau of Economic Geology, personal communication).

III. Summary

Two areas where concentrated flow to Barton Springs is believed to occur are identified, based on the location of deep troughs in the potentiometric surface. The two areas, called the Manchaca and Sunset Valley flow routes, may be separate routes or may be interconnected systems. The Sunset Valley subsurface flow route was further delineated based on more detailed water-table mapping, delineation of wells with high suspended solids, and with water-level declines in response to the draining of Barton Springs pool.

Water-quality samples collected from 37 wells and springs were characterized by source based on concentrations of strontium, sodium, chloride, and sulfate (Table 4). Although in general the levels of measured water-quality parameters were well within drinking water standards in the Barton Springs segment, significant levels of nutrients, fluoride, sediment, arsenic, lead, aluminum, petroleum hydrocarbons, indicator bacteria, and pesticides were encountered in specific areas. Groundwater in the bad-water zone tends to have higher levels of dissolved solids, sodium, chloride, boron, gross alpha radiation, based on one well sampled (58-50-854). Samples collected from 10 wells showed the influence of Glen Rose waters, characterized by high sulfate, strontium, fluoride, and magnesium, and low sodium and chloride. One well screened in the Glen Rose aquifer (58-49-7BK) did not show concentrations of sulfate, chloride, or strontium that previous studies by Senger (and others, 1984) found typical of Glen Rose waters. Instead, this Glen Rose well appears to show the influence of freshly recharging waters, probably because the Glen Rose formation is exposed at the surface in much of this area. A summary of contamination by area and the suspected sources is included below.

Specific wells and springs between Sunset Valley and Barton Springs show elevated levels of sediment, indicator bacteria, arsenic, lead, aluminum, and petroleum hydrocarbons. High levels of sediment influx were noted and measured in numerous wells between Sunset Valley and Barton Springs. Levels of total aluminum between 1.12 and 6 mg/l were measured in wells 58-50-2EM and 58-50-2HB, apparently tied to sediment in these wells. Arsenic levels of 0.037 mg/l and 0.31 mg/l were measured in wells 58-50-2EM and 58-50-2NB3, northwest of the intersection of Loop 360 and Highway 290. Significant levels of petroleum hydrocarbon constituents (on the order of one to two mg/l) were measured in well 58-50-2NB2, 58-42-915, and Old Mill Springs, one of the Barton Springs. No petroleum hydrocarbons were measured from the main Barton Spring (58-42-914) under the same conditions. Possible sources of this contamination include concentrated urban runoff, construction activities, septic tanks, other leaking wastewater systems, and petroleum storage tank releases.

Table 4. Water-Quality Characterization of Wells and Springs Sampled

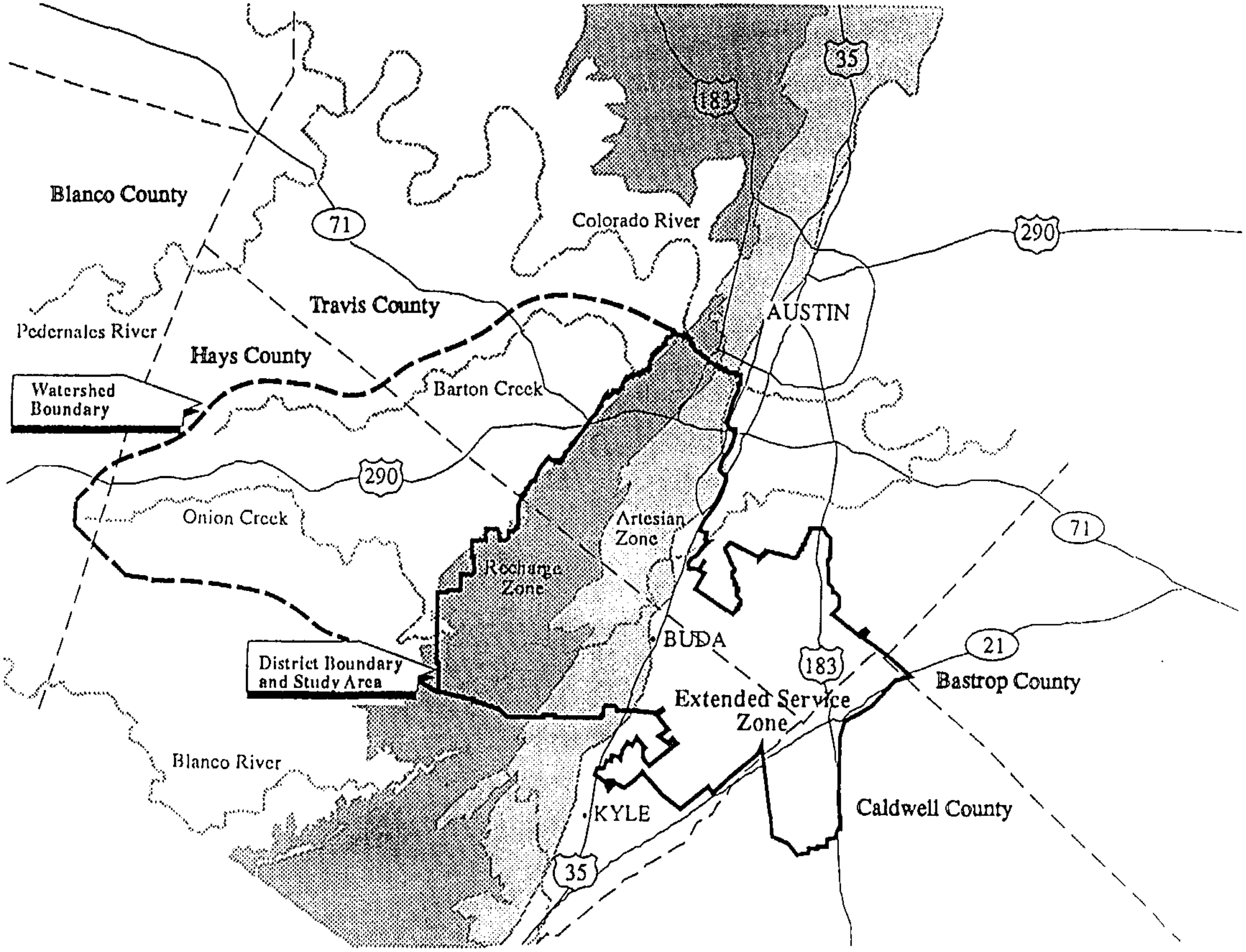
EAWQ NO.	Temporary or State Well Number	Residue Dissolved Solids	Aquifer Sampled			Water Classification				Parameters of Which Elevated Levels Were Encountered
		(mg/l)	Edwards Aquifer	Glen Rose Aquifer	Buda Spring	Recharge Waters	Glen Rose Leakage	Bad-Water Zone	Well 6 months old or less	
	Wells and Springs Sampled in 1990 and/or 1993									
1	58-42-811	554.3	▨			▨				Fecal Coliform
2	58-42-821	392.6	▨			▨				
3	58-42-913		▨			▨				
4	58-49-708	512.1	▨							Fecal Coliform
5	58-49-7BK	565.6		▨						
6	58-49-911		▨				▨			
7	58-50-223		▨			▨				
8	58-50-416	437.7	▨			▨				
9	58-50-520	423.1	▨							
10	58-50-731	423.5	▨			▨				Organic carbon
11	58-50-733	432.7	▨							
12	58-50-847		▨				▨			
13	58-50-852	440.6	▨				▨	▨		strontium
14	58-50-854	1603.1	▨					▨		dissolved solids, gross alpha, sulfate, fluoride
15	58-50-855	433.2	▨				▨			strontium
16	58-57-307	416.1	▨			▨				
17	58-57-811		▨							
18	58-57-901	376.3	▨							
19	58-58-114	430.3	▨			▨				nitrate
20	58-58-202	504	▨				▨	▨		strontium
21	58-58-219	553.2	▨				▨	▨		strontium
22	58-58-403	434.7	▨							
23	58-58-416		▨			▨				
24	58-58-508	478.5	▨				▨			strontium
	Wells and Springs Sampled in March 1994									
25	58-42-916	351.6	▨			▨				arsenic, bacteria, 4-nitrophenol, pesticides
26	58-42-922	510	▨			▨		▨		lead, pet. hydrocarbons
27	58-49-9EM	495.4	▨				▨		▨	lead, sulfate
28	58-50-1CW1	620	▨							petroleum hydrocarbons
29	58-50-201	343.6	▨							bacteria, pesticides
30	58-50-2E	560	▨				▨			sulfate
31	58-50-2EM	228.4	▨			▨				arsenic
32	58-50-2HB	364.0	▨				▨			sediment, herbicides, organic carbon
33	58-50-3BL	340			▨	▨				bacteria
34	58-50-502	350	▨							bacteria
35	58-50-511	300.4	▨							
36	58-57-3BW	340	▨			▨			▨	
37	58-57-5JO	370	▨						▨	

The Rollingwood area generally showed elevated levels of nitrate and trace metals, indicator bacteria, pesticides, and herbicides. Cold Springs, a major discharge point for this area, was found to contain total and dissolved arsenic (at levels of 0.452 mg/l and 0.032 mg/l, respectively), boron at 0.90 mg/l, measurable levels of some pesticides (bromacil, 4-nitrophenol, lindane, endrin ketone, heptachlor, and heptachlor epoxide), and significant levels of coliform and fecal streptococci indicator bacteria. The elevated levels of these parameters are attributed to septic tank leaks, wastewater lift station releases, chemical releases from accidental spills and lawn and golf course runoff, as well as other forms of urban runoff.

Along the western side of the recharge zone, one well (58-50-1CW1) showed high levels of petroleum hydrocarbons (11 mg/l), significant levels of total and dissolved lead (0.014 and 0.0097 mg/l, respectively), high levels of total and dissolved iron (2.1 and 1.6 mg/l, respectively), relatively high levels of total and dissolved manganese (0.43 and 0.39 mg/l, respectively), high levels of chloride (34 mg/l), significant levels of ammonia nitrogen (1.0 mg/l) and orthophosphorus (0.026 mg/l). Petroleum storage tank releases, wastewater leaks, urban runoff, and possibly industrial waste are possible sources for the levels of contaminants measured. Backdoor Springs (58-42-811) contained fecal coliform (2 colonies/ 100 ml) and significant levels of orthophosphorus (0.218 mg/l), indicating impacts from wastewater leakage.

The Buda -San Leanna area may show nitrate levels up to nearly 10 mg/l during periods of high rainfall. Just west of IH-35, wells may show some degradation in water quality in dry years, as a result of greater leakage from the Glen Rose and some flow from the bad-water zone.

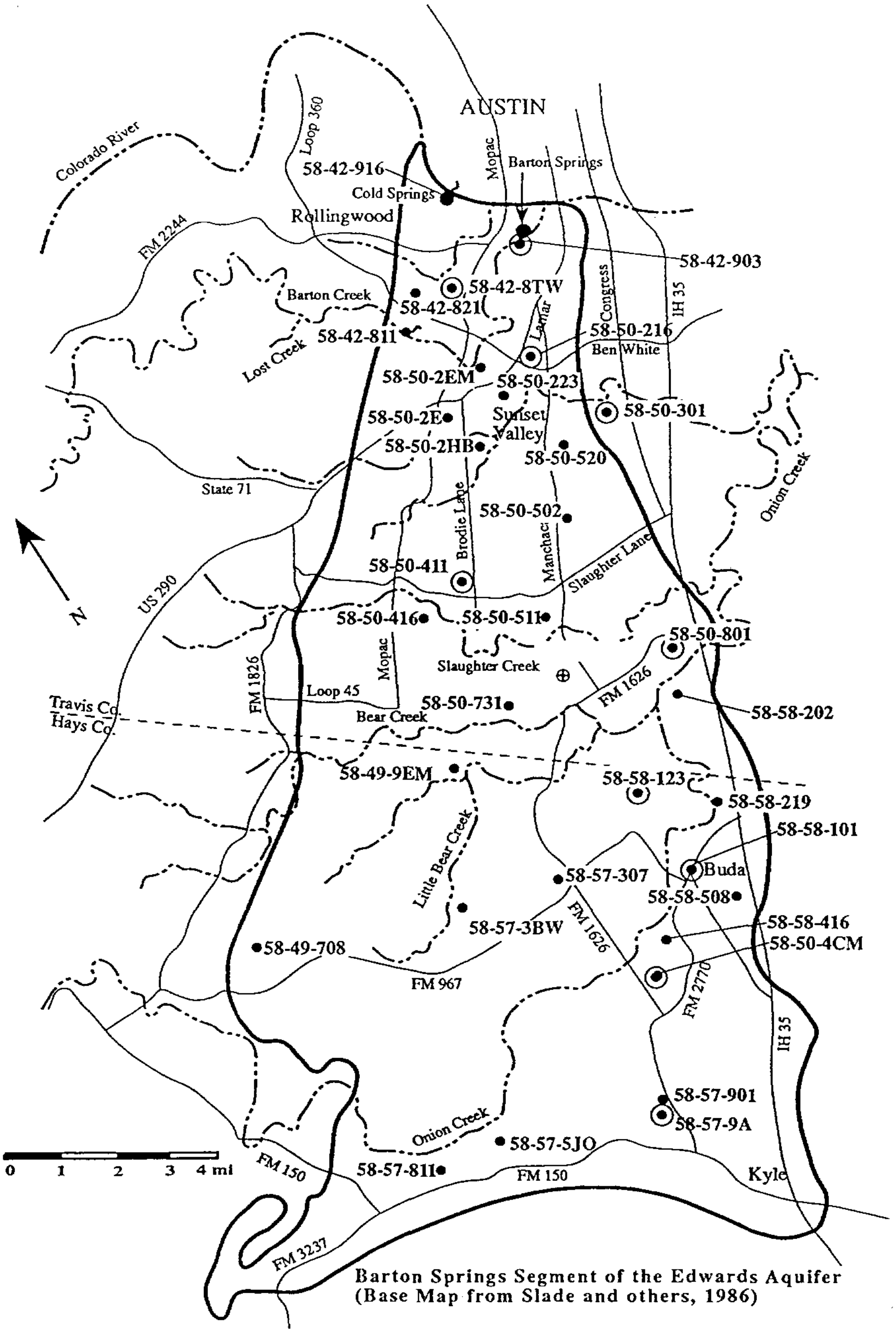
Newly drilled wells tend to show higher levels of sediment and total dissolved solids resulting from the drilling and well-construction processes. Two out of four newly drilled wells sampled showed levels of lead near or above the drinking water standards of 0.015 mg/l, possibly from lead present in the pumps installed.



Study Area

Barton Springs/Edwards Aquifer Water Quality Study

Figure IB-I



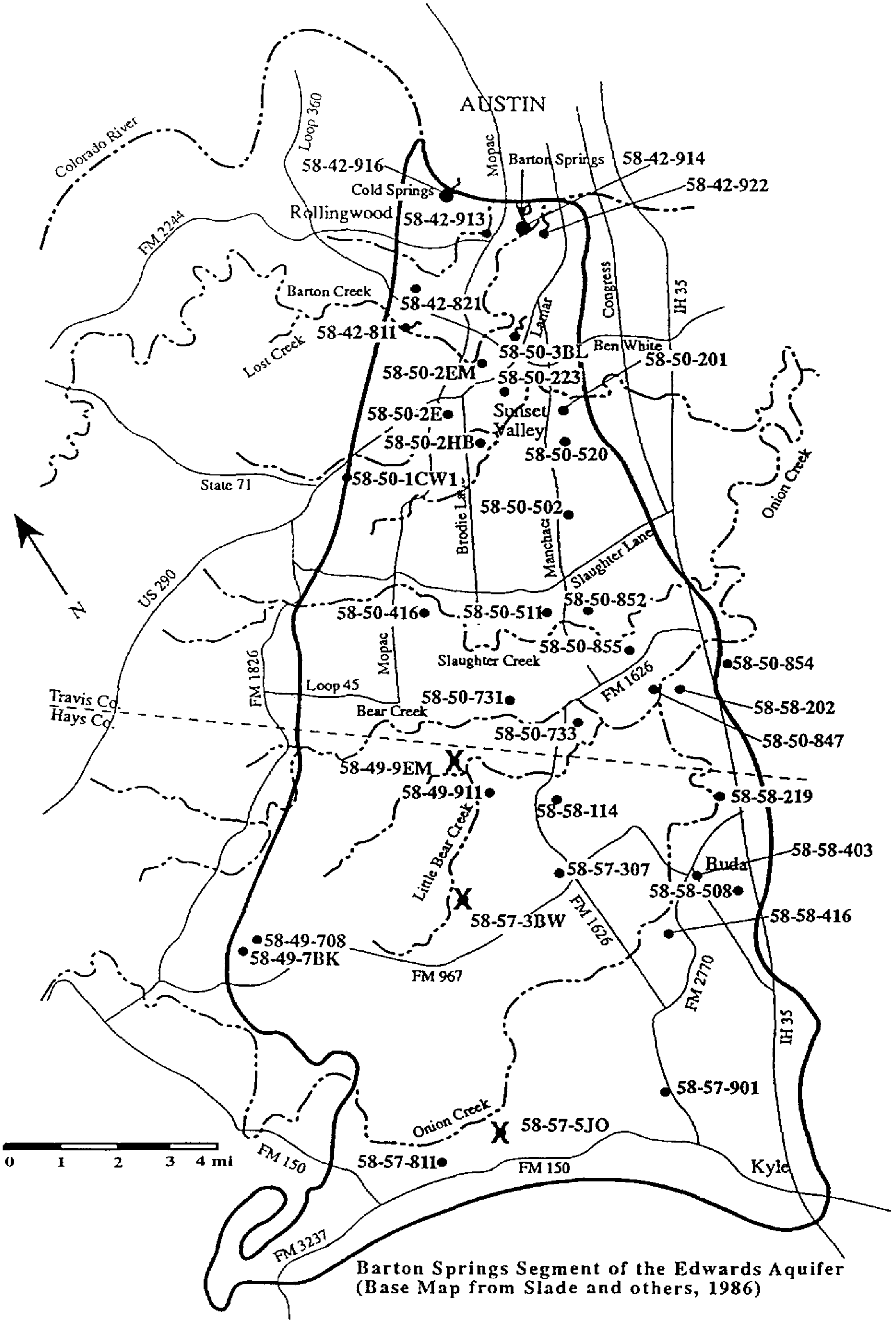
Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

- ● Wells measured for water level in 1993 or 1994
- ⦿ Wells continuously monitored by the District
- ⊕ Weather monitoring station

Water Level and Weather Monitoring Sites

Barton Springs/Edwards Aquifer
Water Quality Study

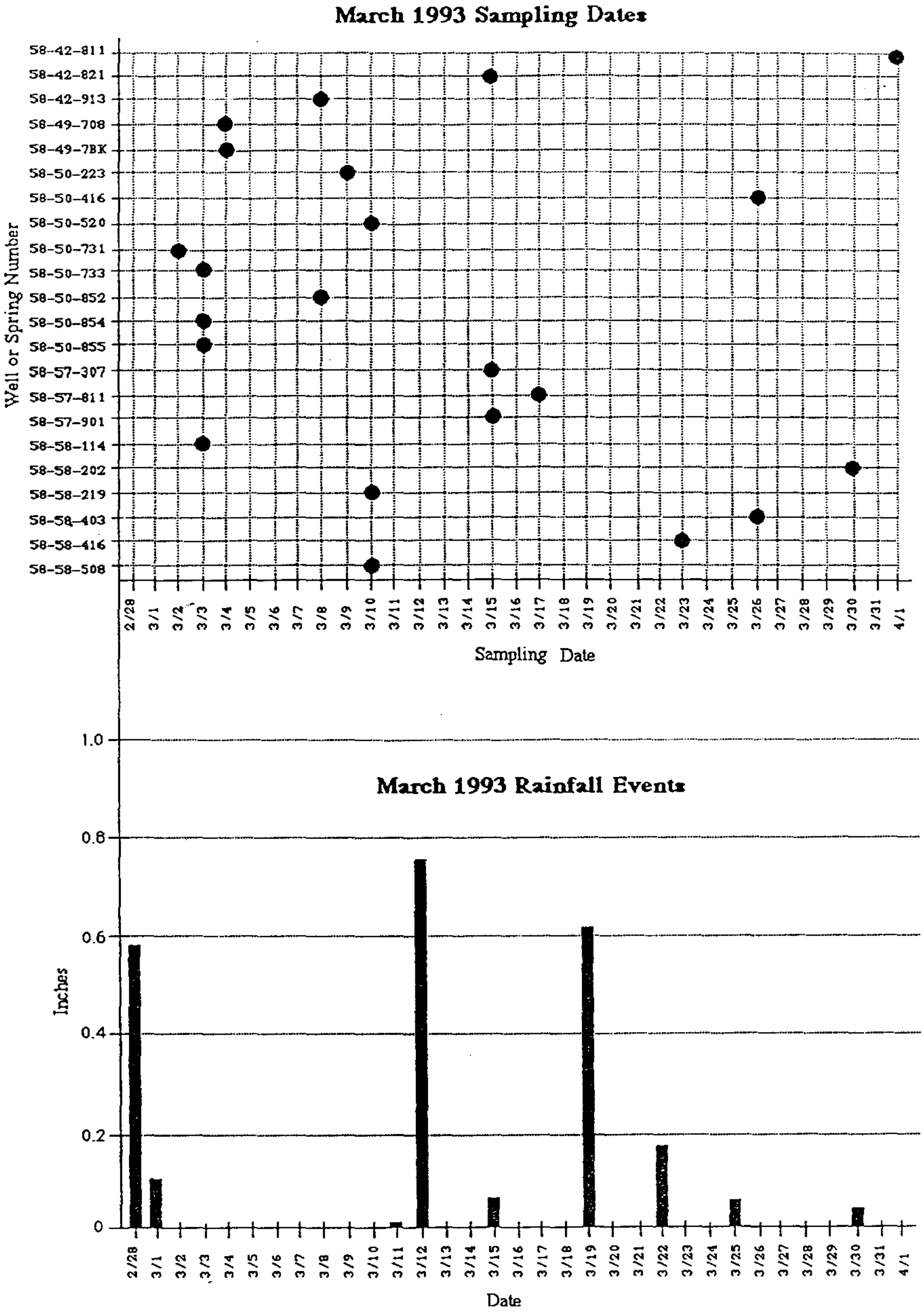
Figure IC-1



Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

● Wells Sampled in 1990, 1993, or 1994 **X** Newly Drilled Wells

	Water Quality Monitoring Sites	Barton Springs/Edwards Aquifer Water Quality Study Figure IC-2

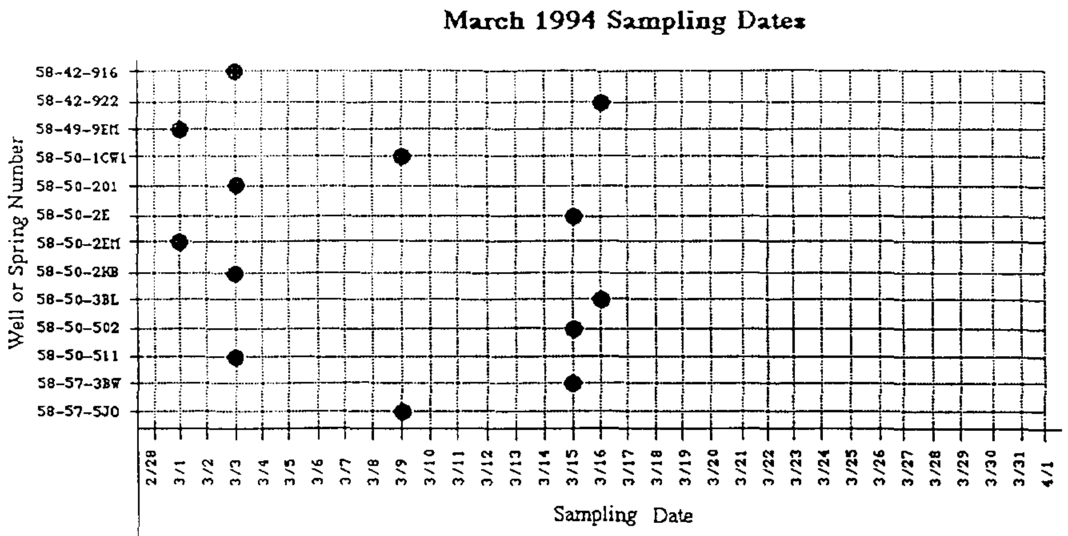


Rainfall measurements taken from the BS/EACD weather station.

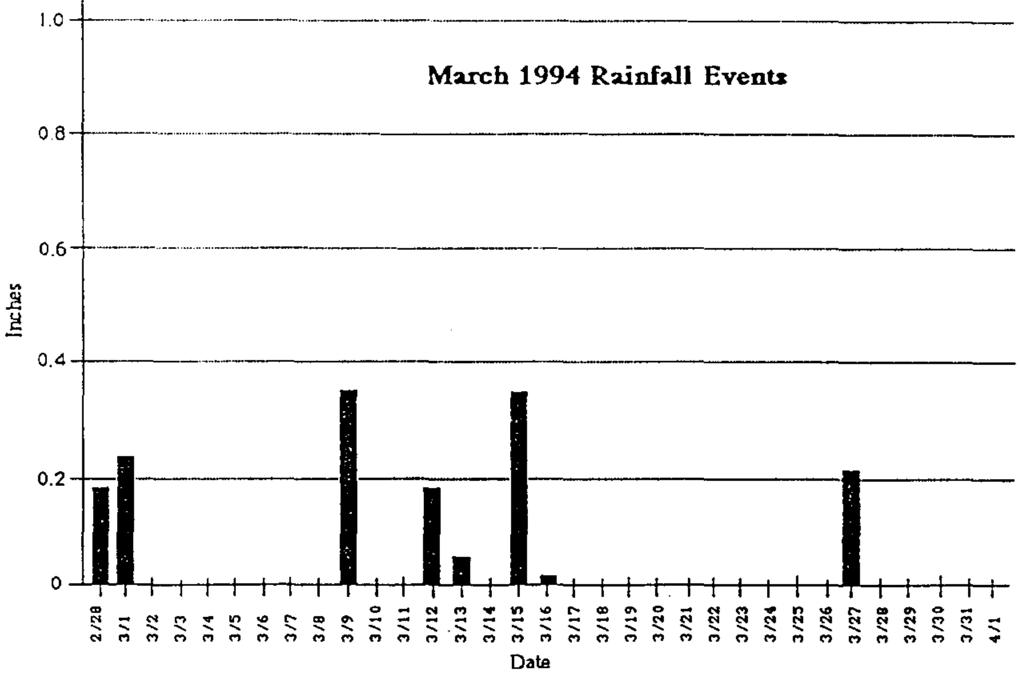
Groundwater Sampling Dates and Rainfall Events During March 1993

Barton Springs/Edwards Aquifer Water Quality Study

Figure IC-3



March 1994 Sampling Dates



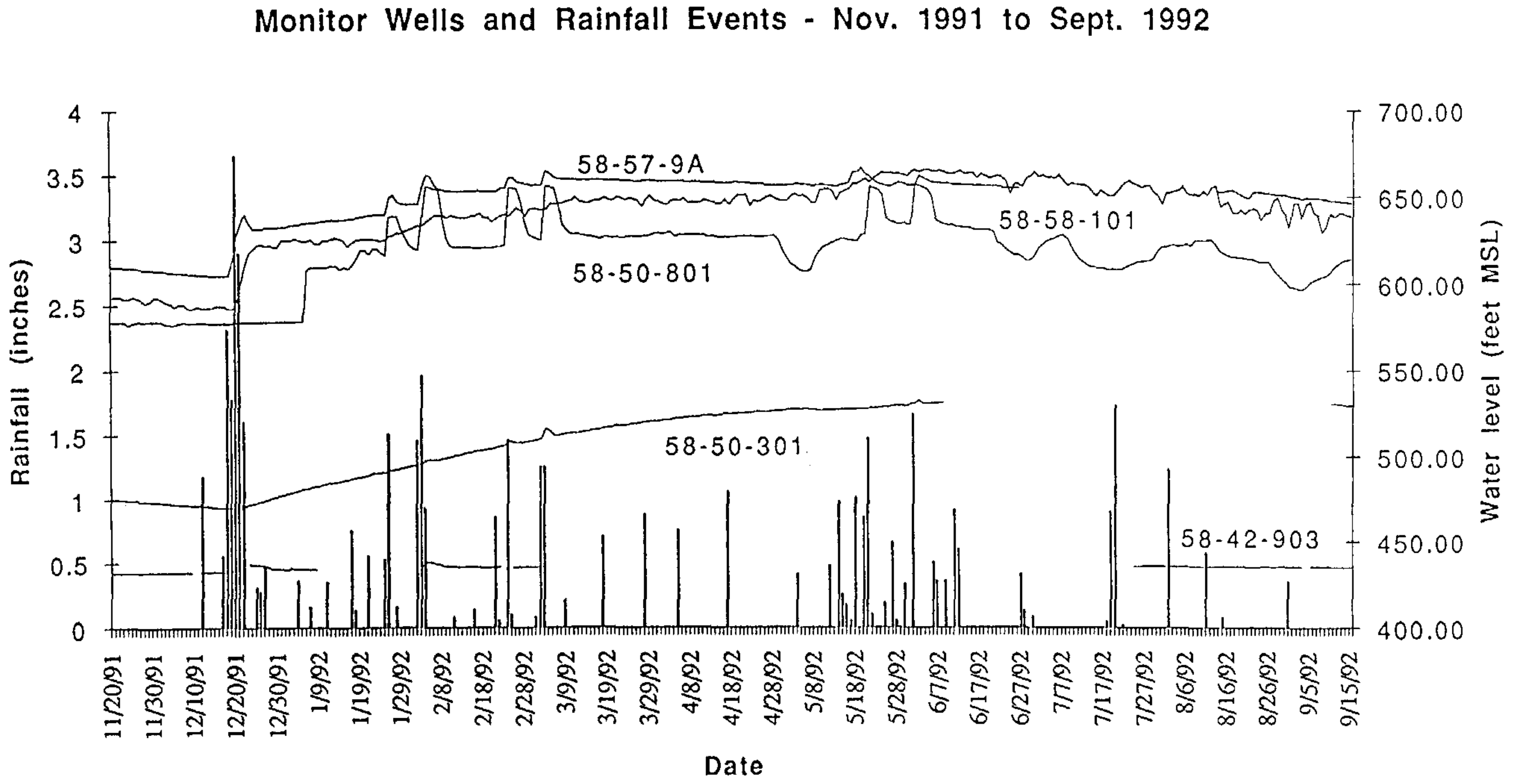
March 1994 Rainfall Events

Rainfall measurments taken from the BS/EACD weather station.

Groundwater Sampling Dates and Rainfall Events During March 1994

Barton Springs/Edwards Aquifer Water Quality Study

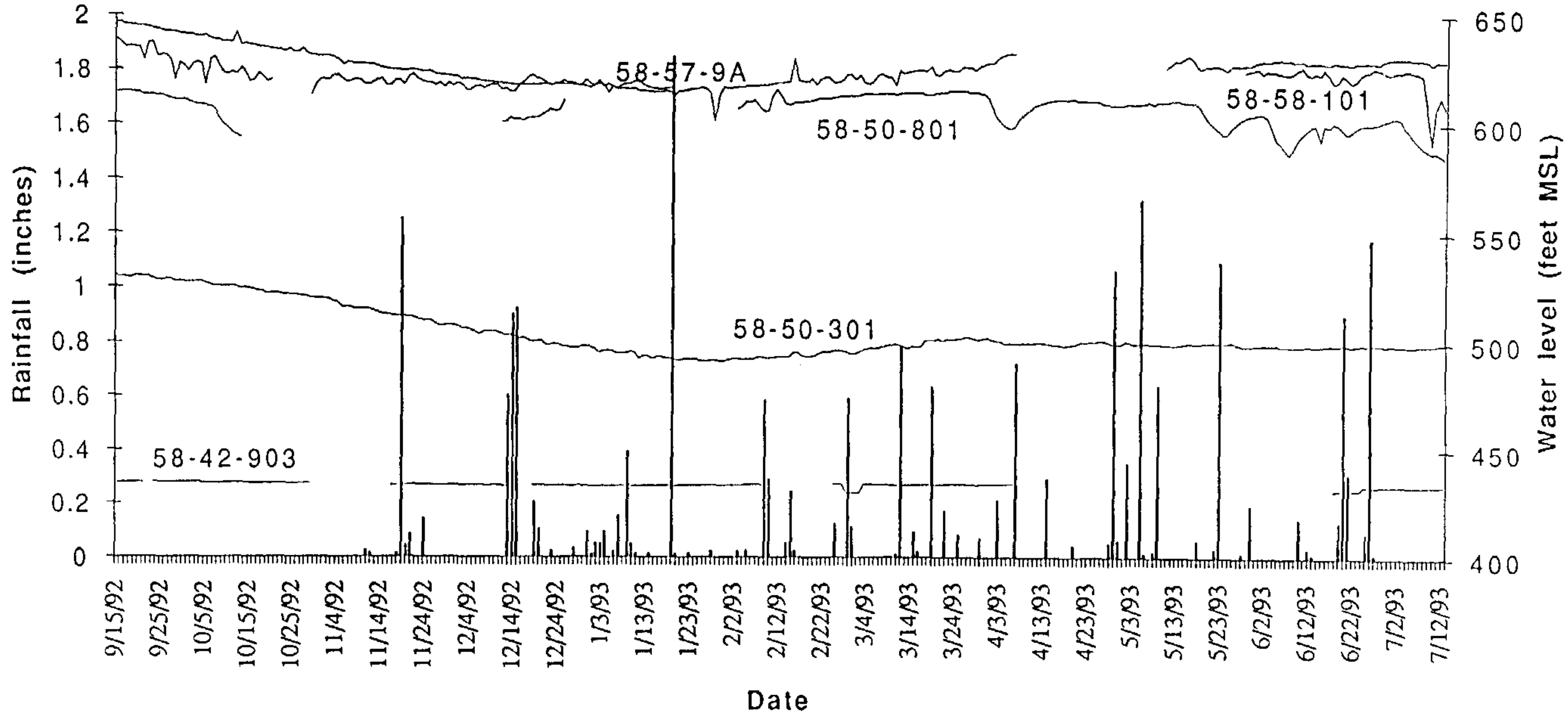
Figure IC-4



Rainfall measurements taken from the BS/EACD weather station.

Figure IIA-1a	**Water-Levels and Precipitation Recorded at Continuous Monitoring Stations**	**Barton Springs/Edwards Aquifer Water Quality Study**

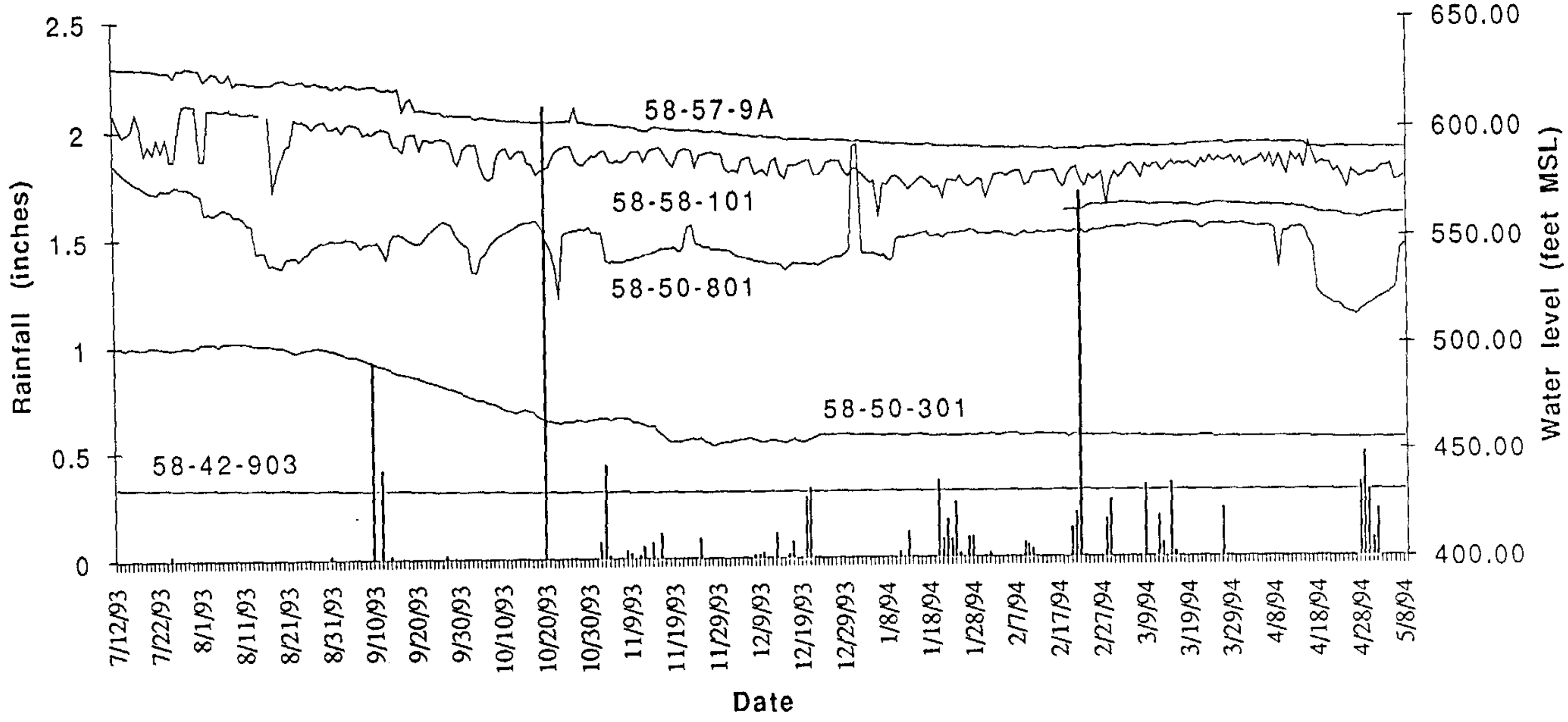
Monitor Wells and Rainfall Events - Sept. 1992 to July 1993



Rainfall measurements taken from the BS/EACD weather station.

Figure IIA-1b	**Water-Levels and Precipitation Recorded at Continuous Monitoring Stations**	**Barton Springs/Edwards Aquifer Water Quality Study**

Monitor Wells and Rainfall Events - July 1993 to May 1994



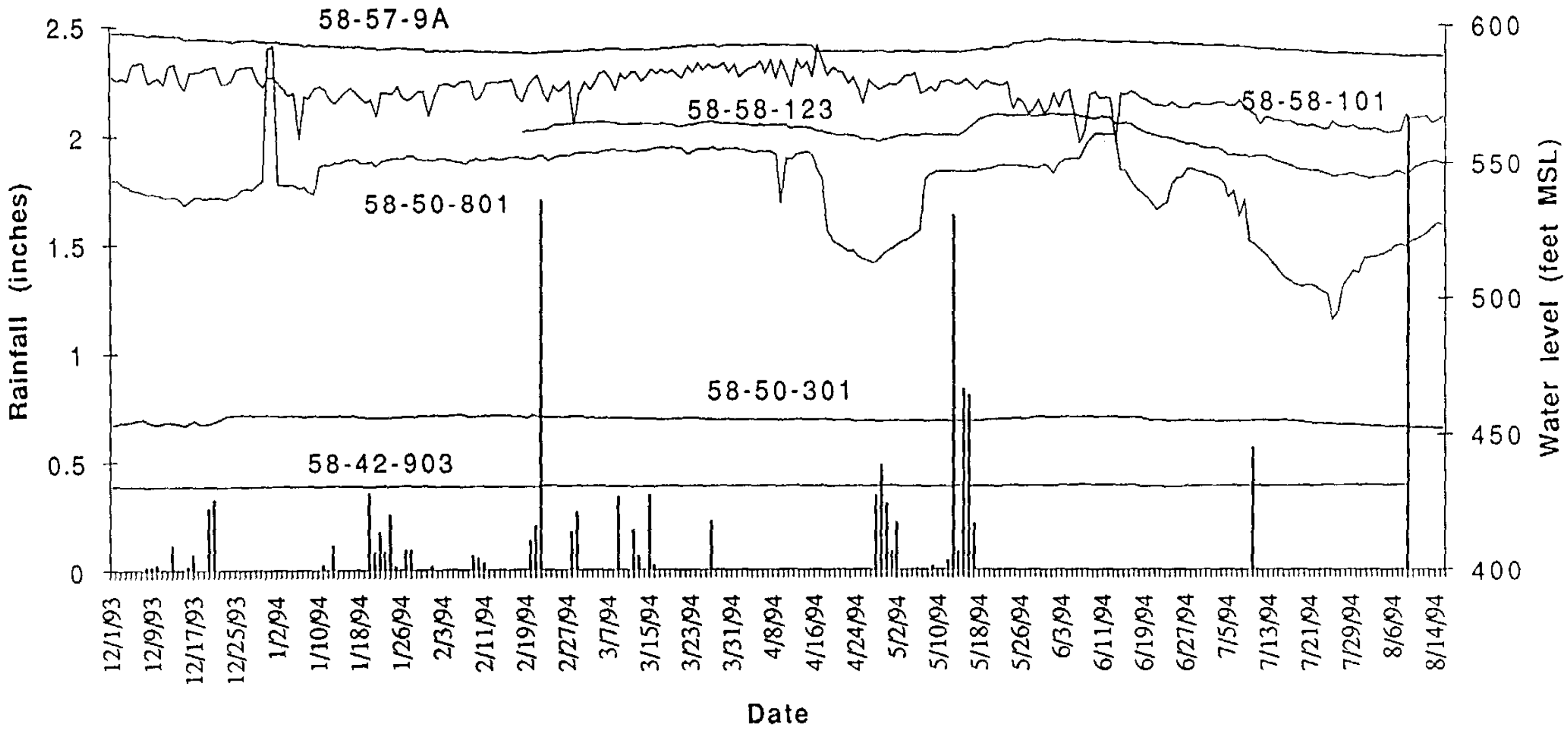
Rainfall measurements taken from the BS/EACD weather station.

Figure IIA-1c

Water-Levels and Precipitation Recorded at Continuous Monitoring Stations

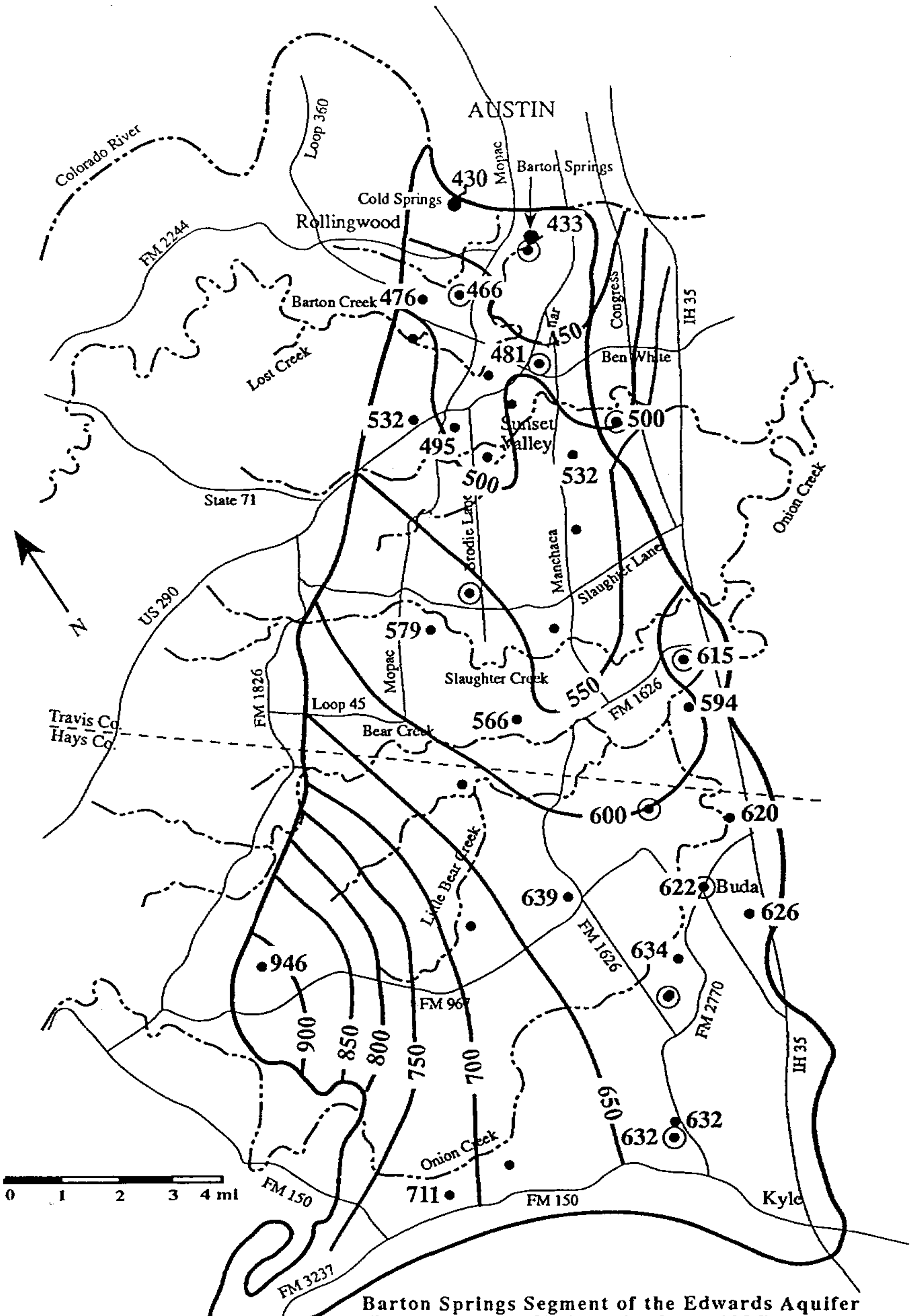
Barton Springs/Edwards Aquifer Water Quality Study

Monitor Wells and Rainfall Events - Dec. 1993 to Aug. 1994



Rainfall measurements taken from the BS/EACD weather station.

Figure IIA-1d	Water-Levels and Precipitation Recorded at Continuous Monitoring Stations	Barton Springs/Edwards Aquifer Water Quality Study



Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

⦿ Wells continuously monitored by the District for water level

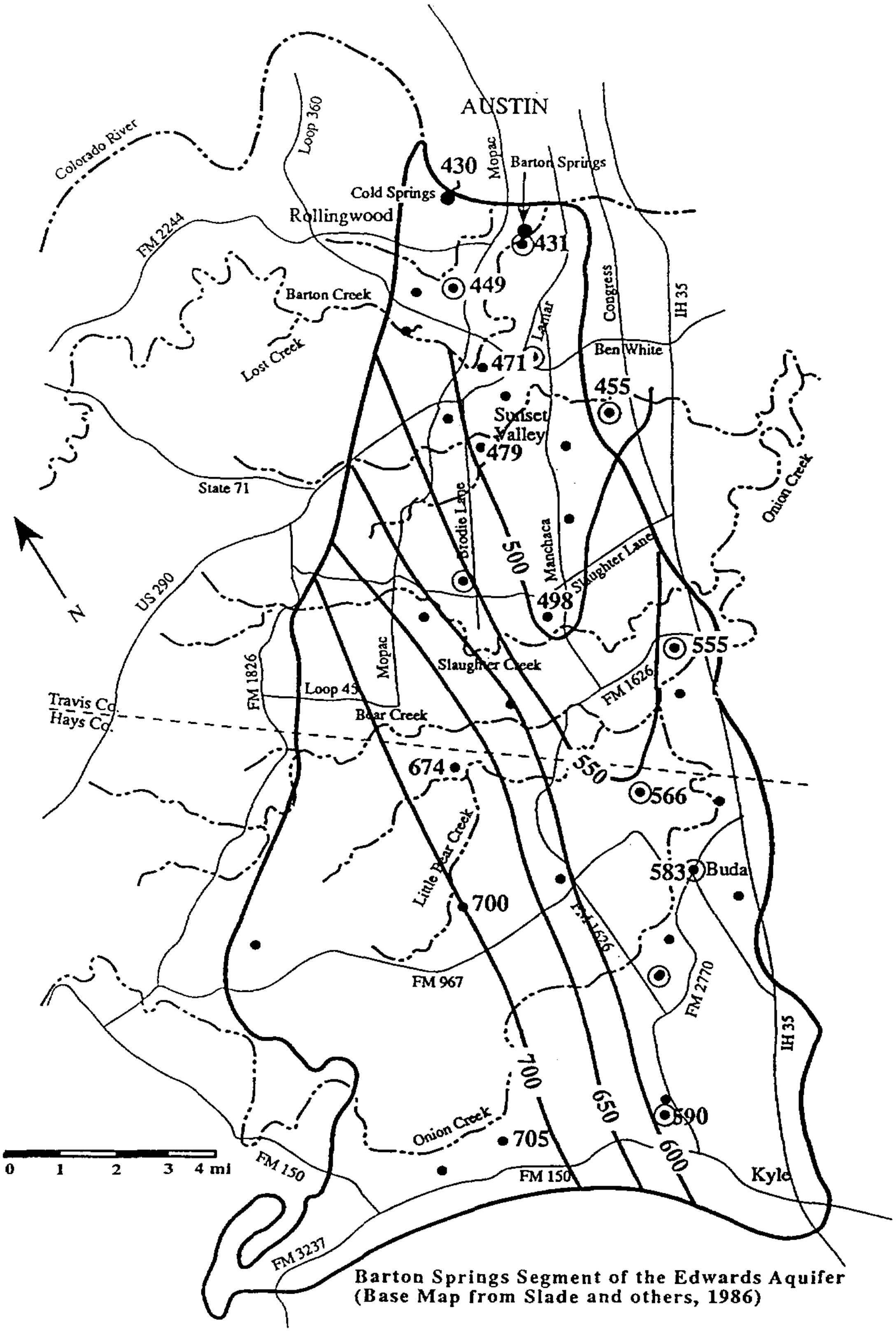
● Wells measured for water level by the District in 1993 or 1994

Contour intervals 50 feet MSL

Generalized Potentiometric Surface - March 1993

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIA-2



Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

⊙ Wells continuously monitored by the District for water level

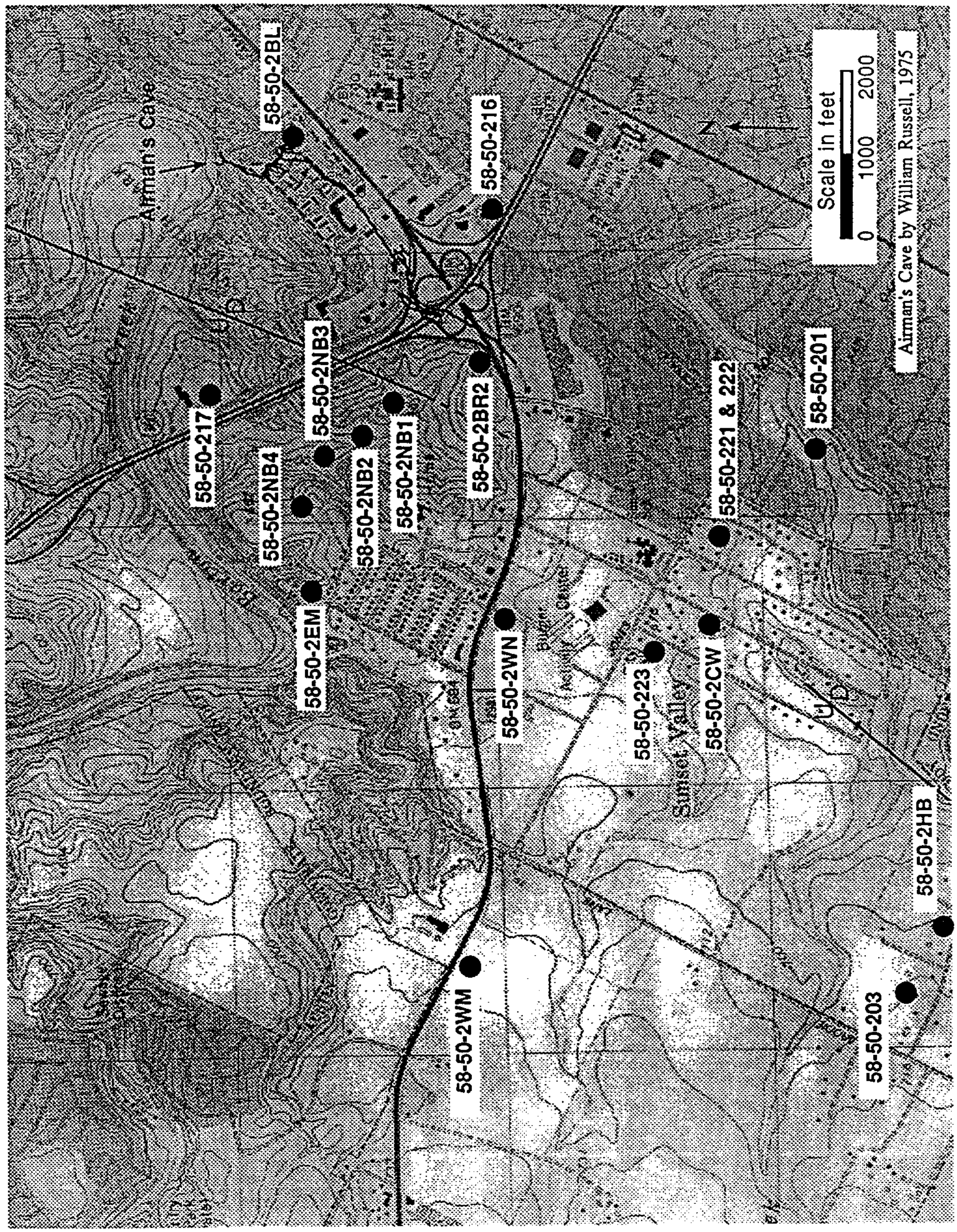
• Wells measured for water level by the District in 1993 or 1994

Contour interval 50 feet MSL

Generalized Potentiometric Surface - March 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIA-3

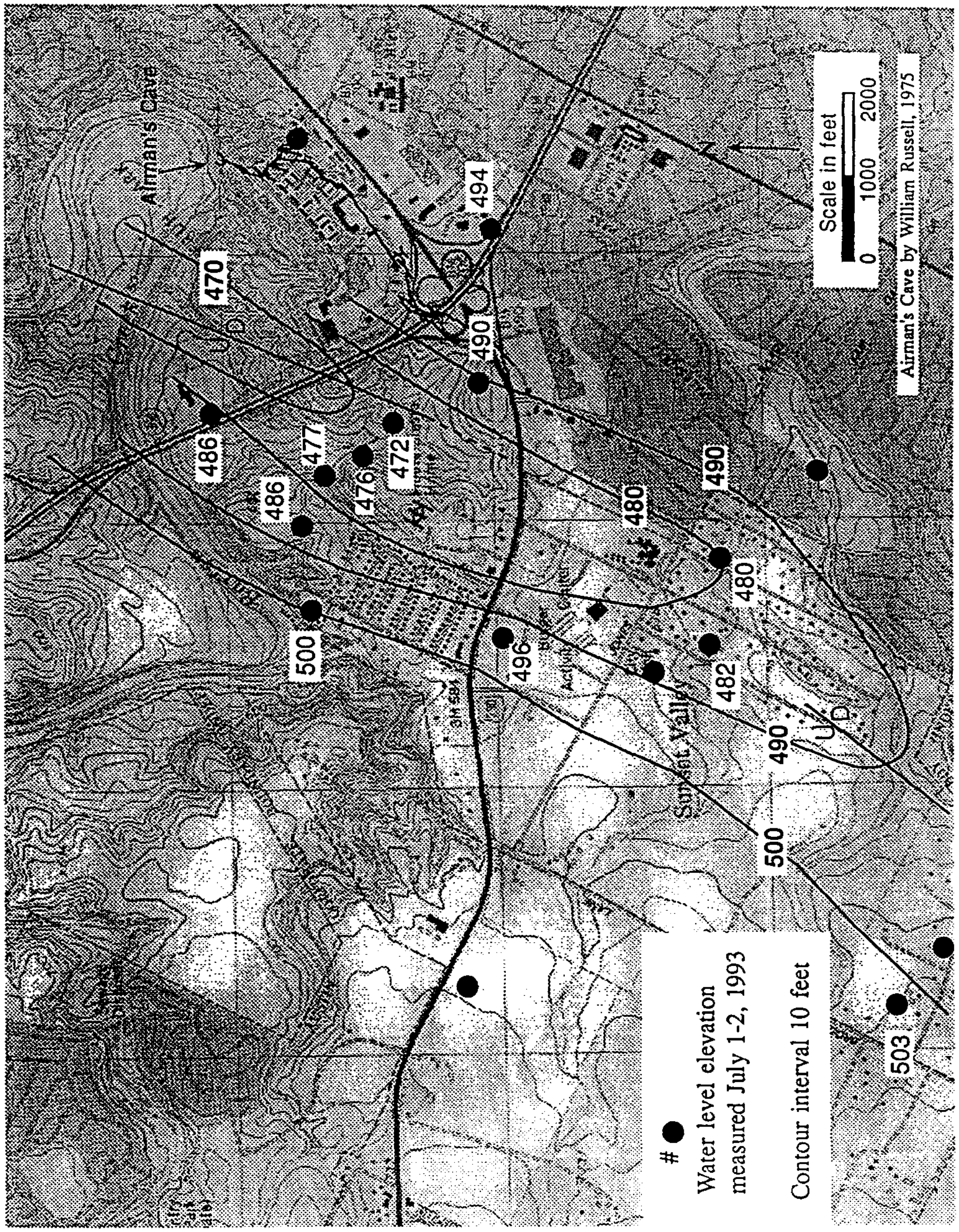


Airman's Cave by William Russell, 1975

Wells Used for Hydrologic Information in the Sunset Valley Area

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIA-4



Potentiometric Map of the Sunset Valley Area (July 1-2, 1993)

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIA-5

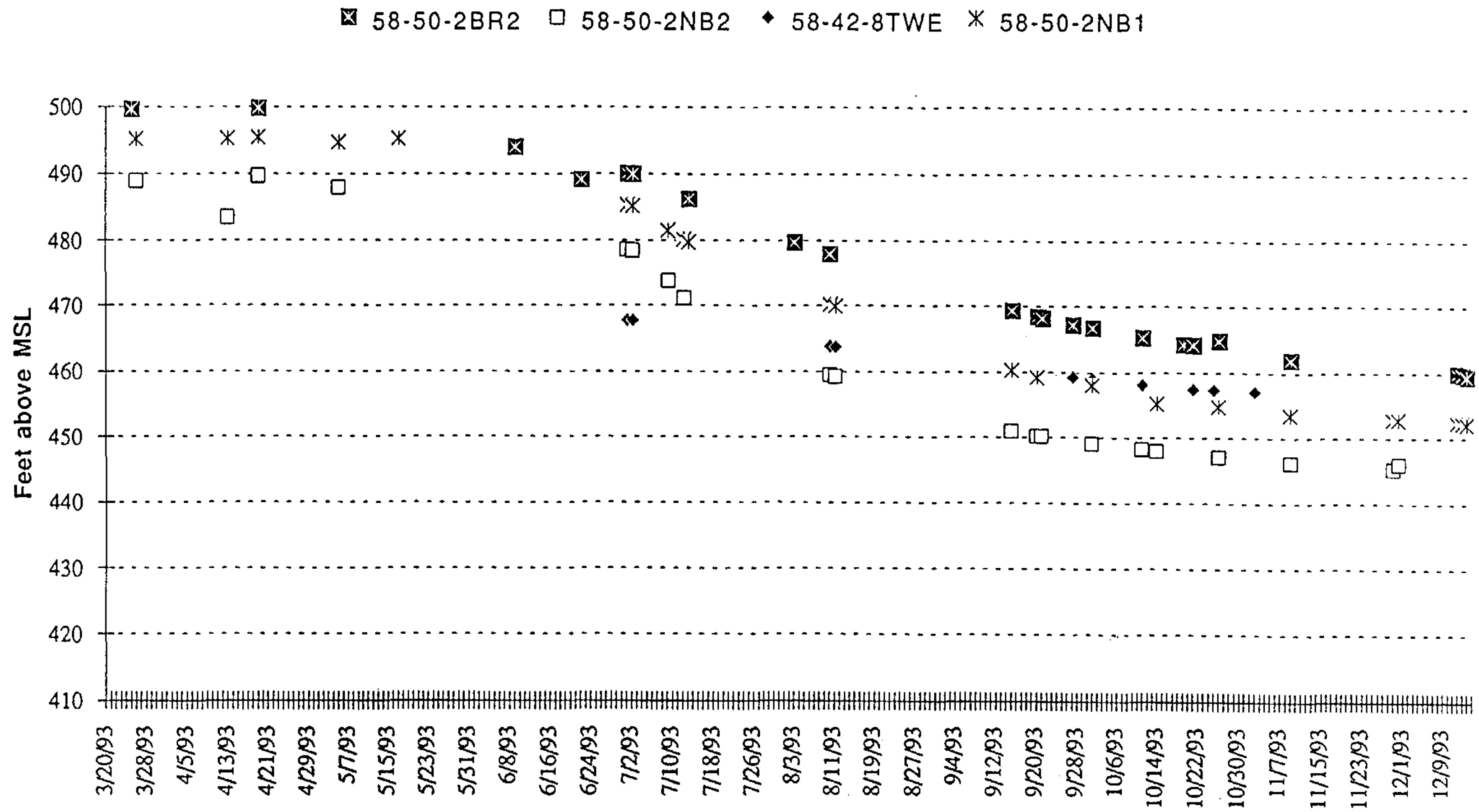
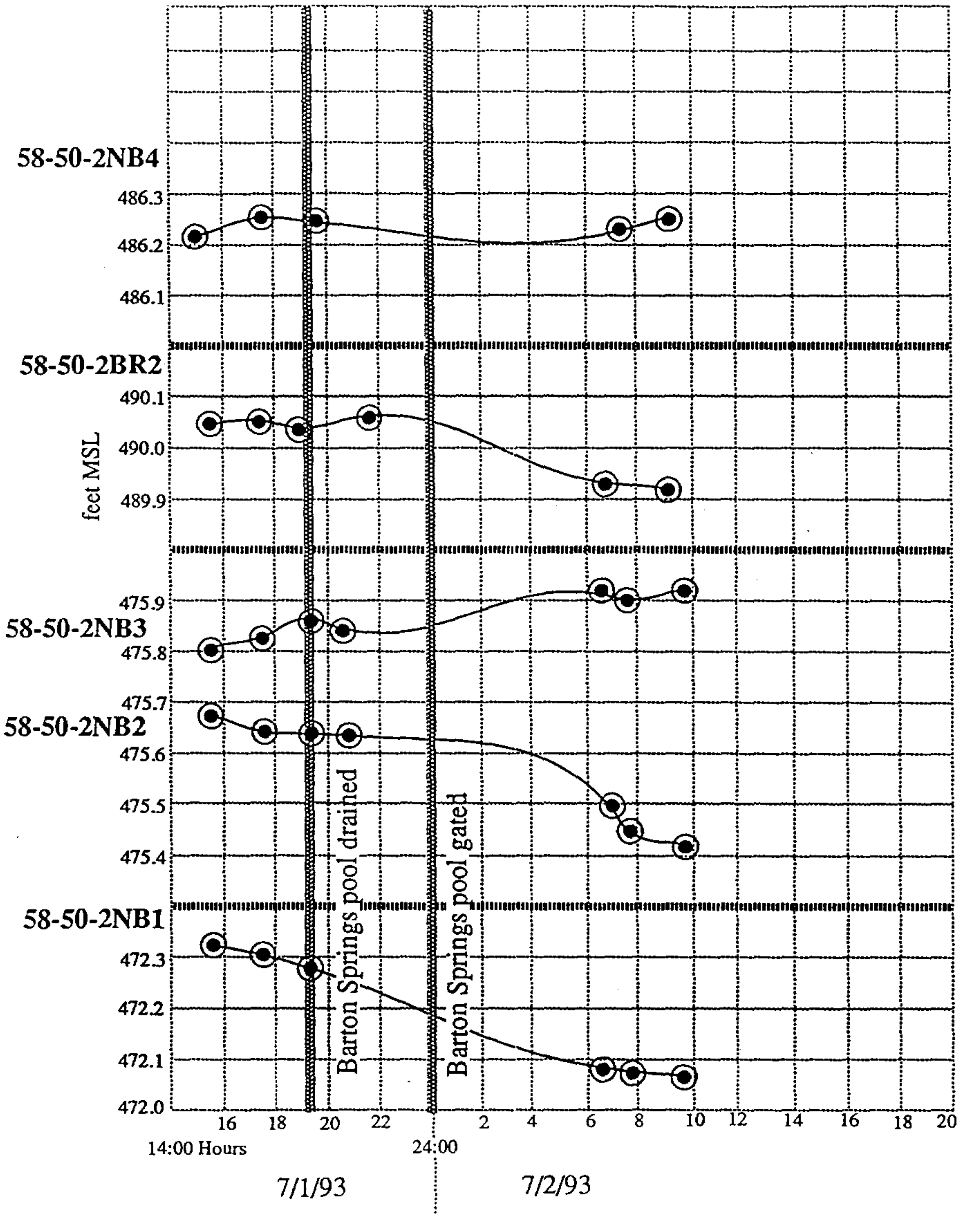


Figure IIA-6

Water Levels in Selected Wells in the Sunset Valley/Barton Creek Areas

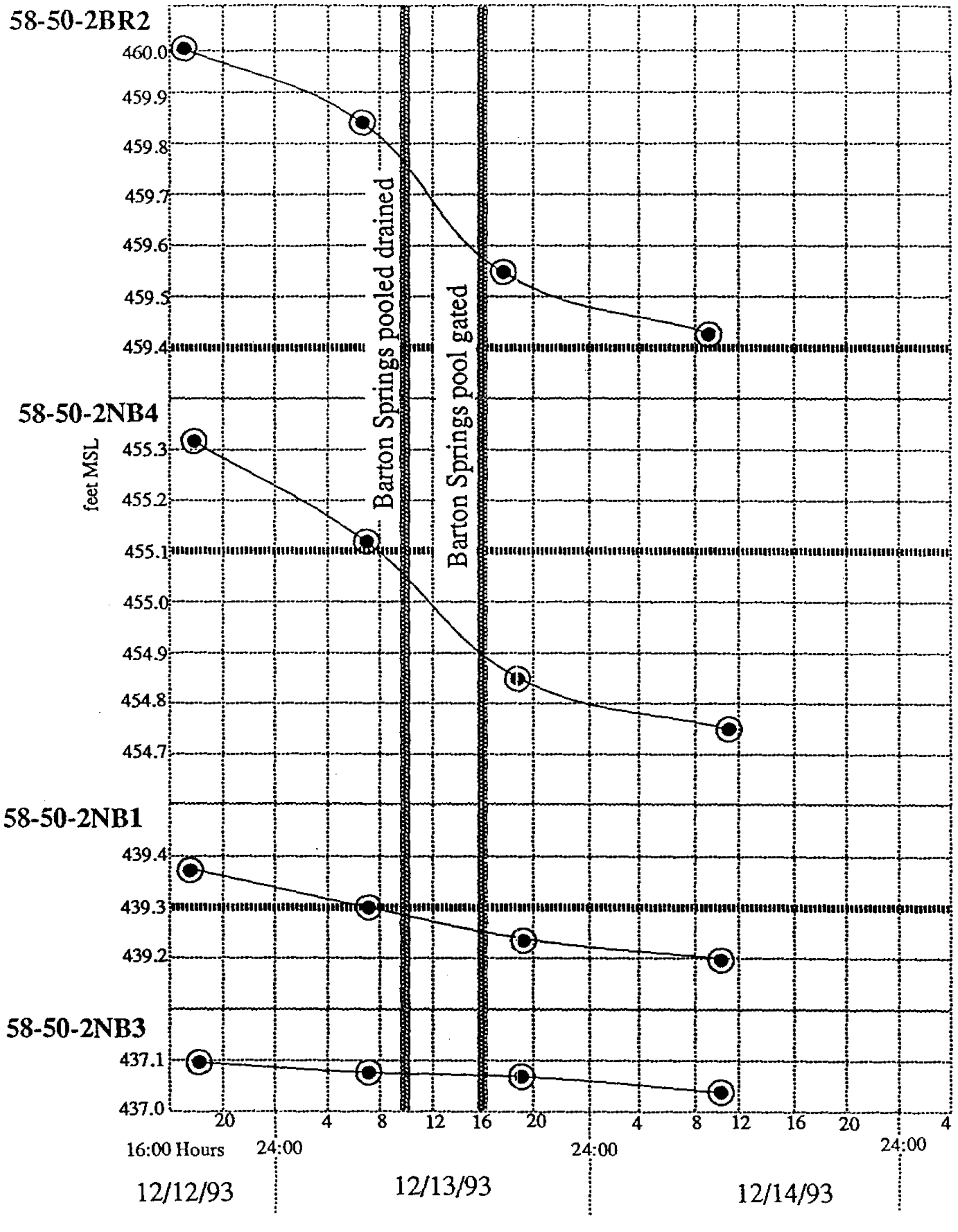
Barton Springs/Edwards Aquifer Water Quality Study



Water Level Responses of Selected Wells to the Draining of Barton Springs Pool - July 1-2, 1993

Barton Springs/Edwards Aquifer Water Quality Study

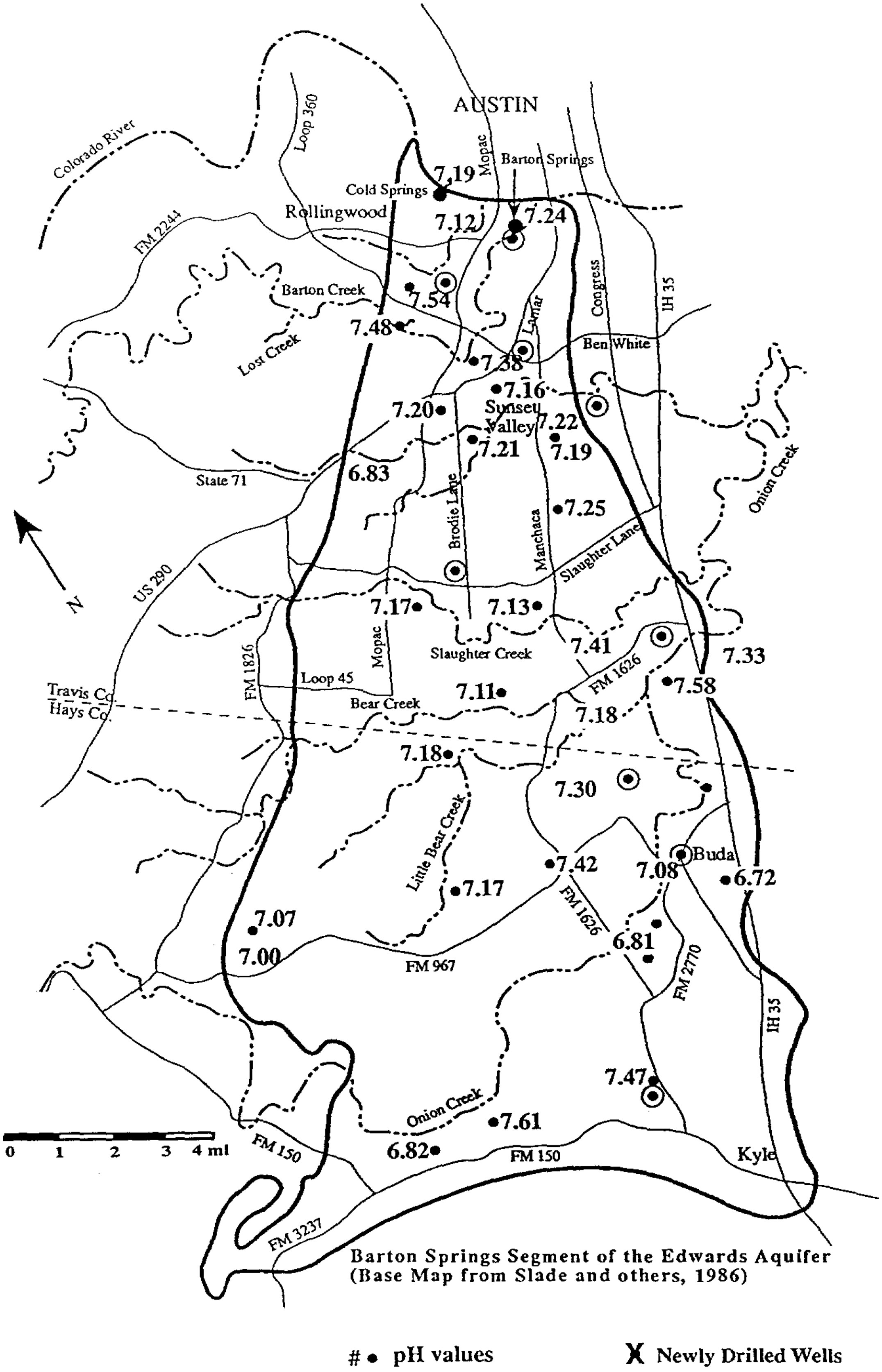
Figure IIA-7a



Water-Level Respones of Selected Wells to the Draining of Barton Springs Pool - December 12-14, 1993

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIA-7b

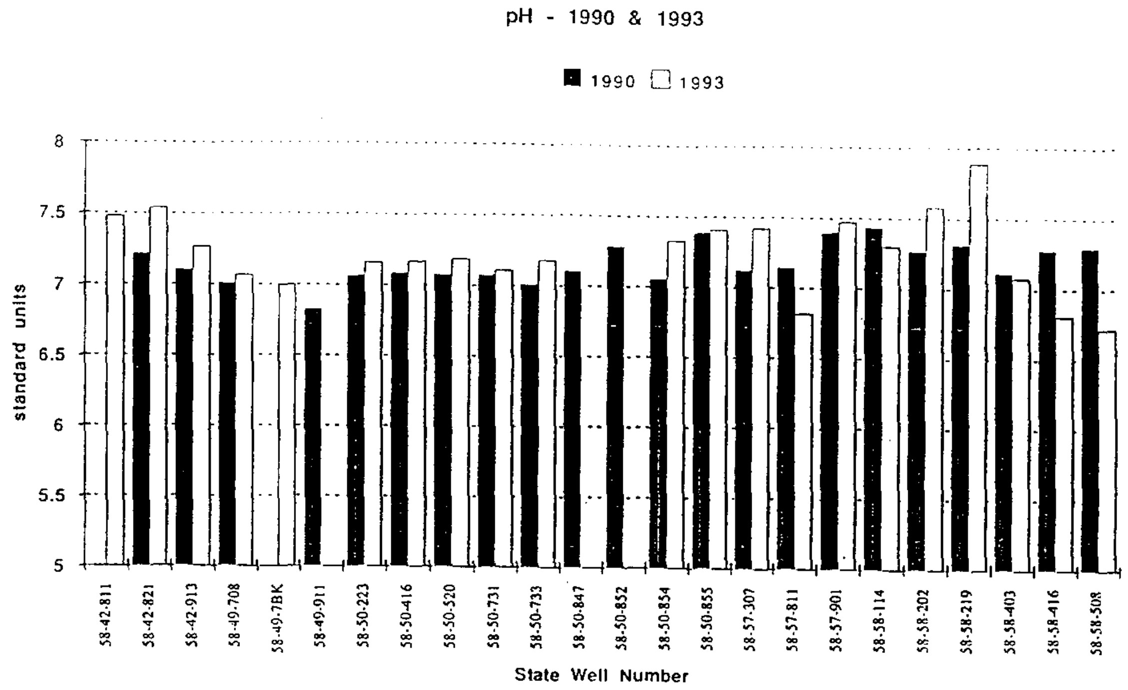


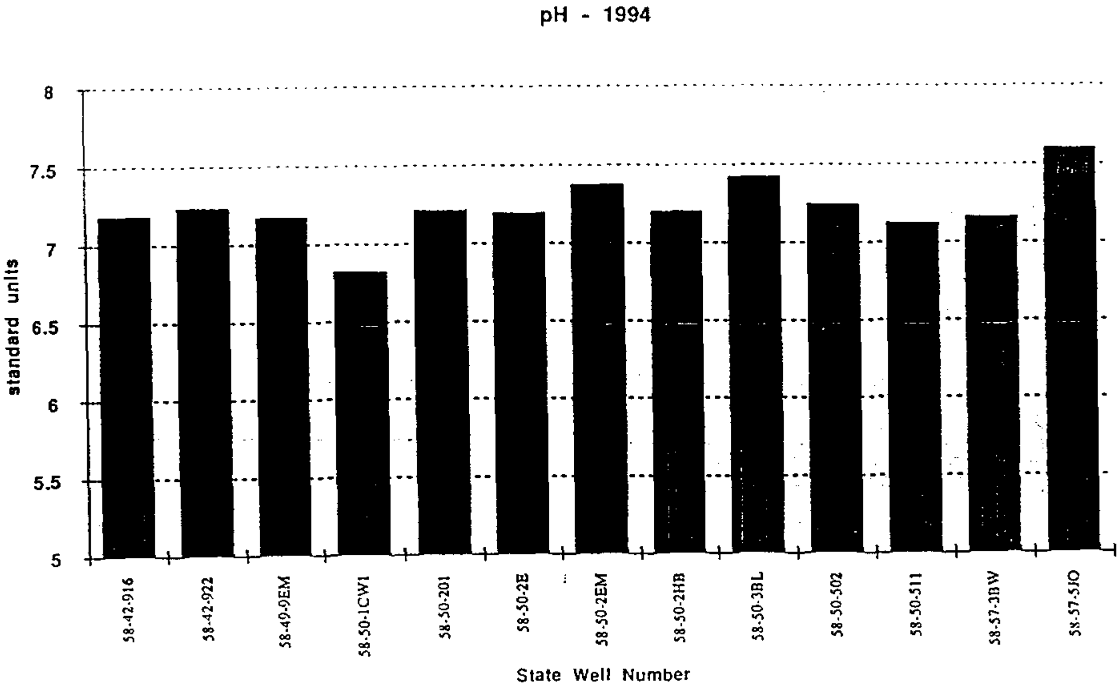
Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

pH Values - March 1993 and March 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-2

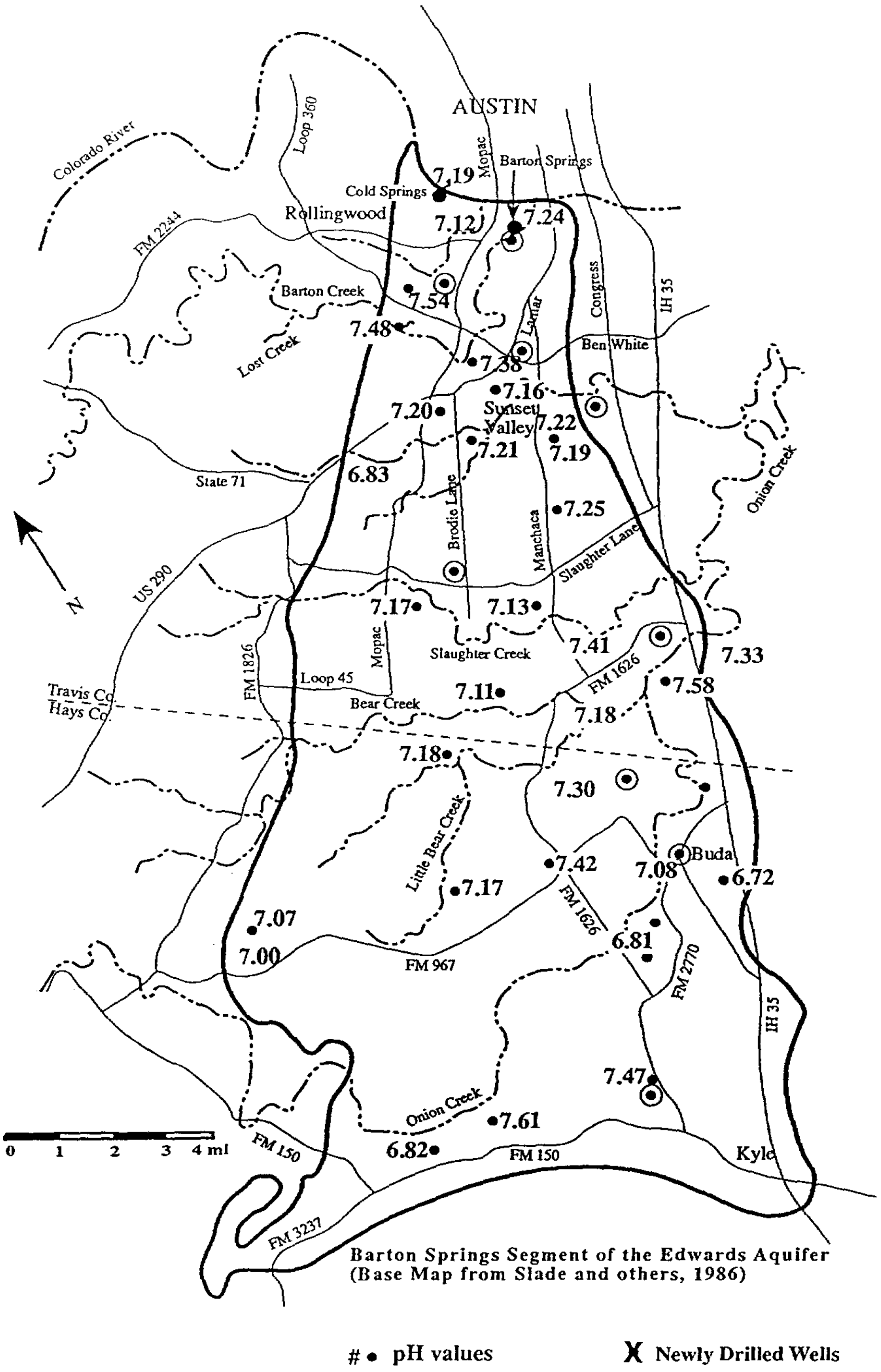




Field pH

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-1

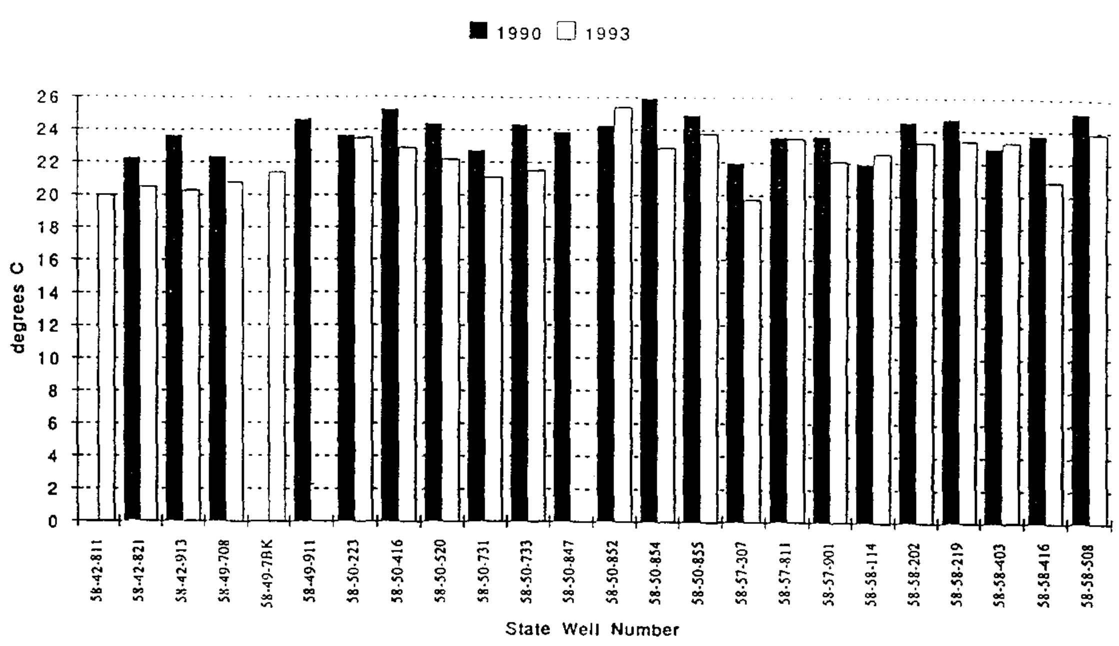


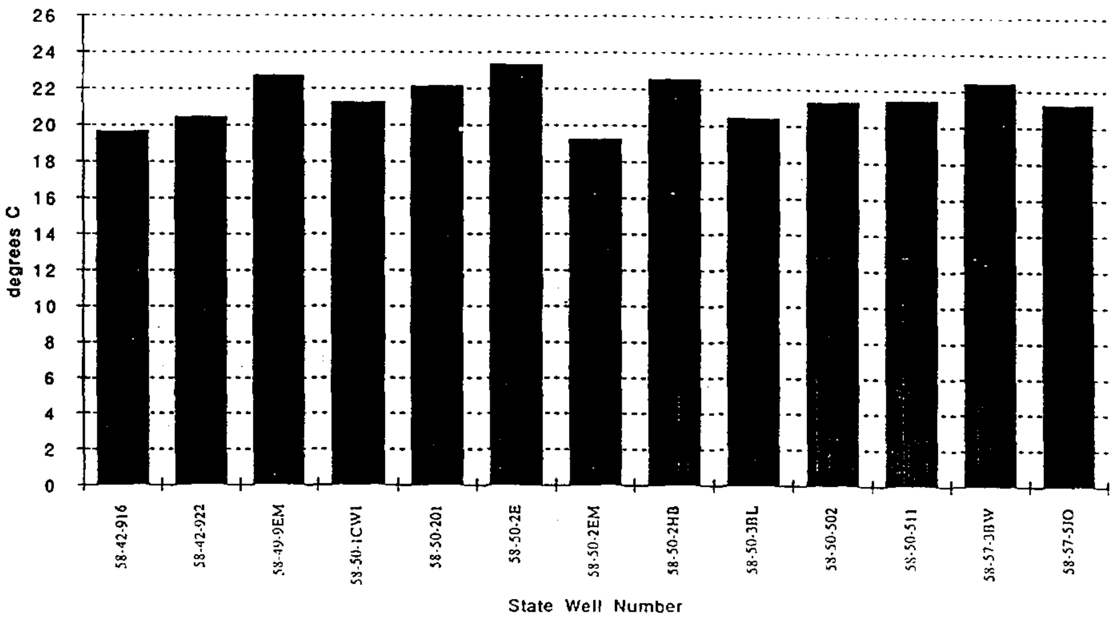
Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

pH Values - March 1993 and March 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-2

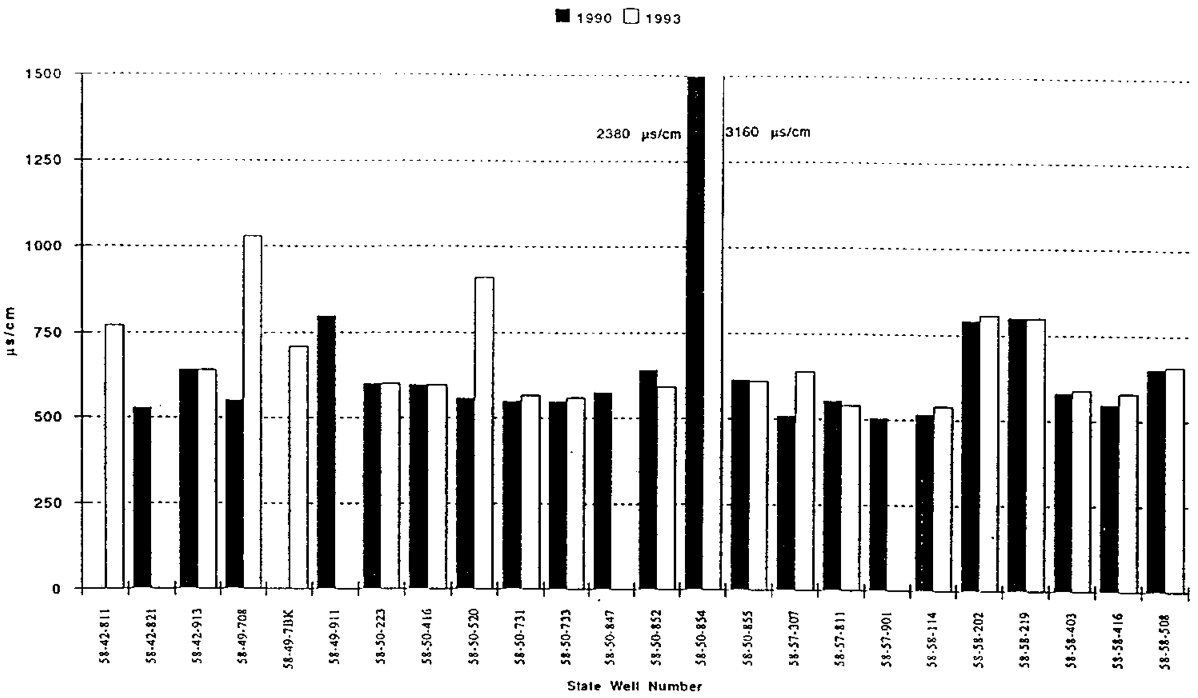

Temperature - 1990 & 1993


Temperature - 1994

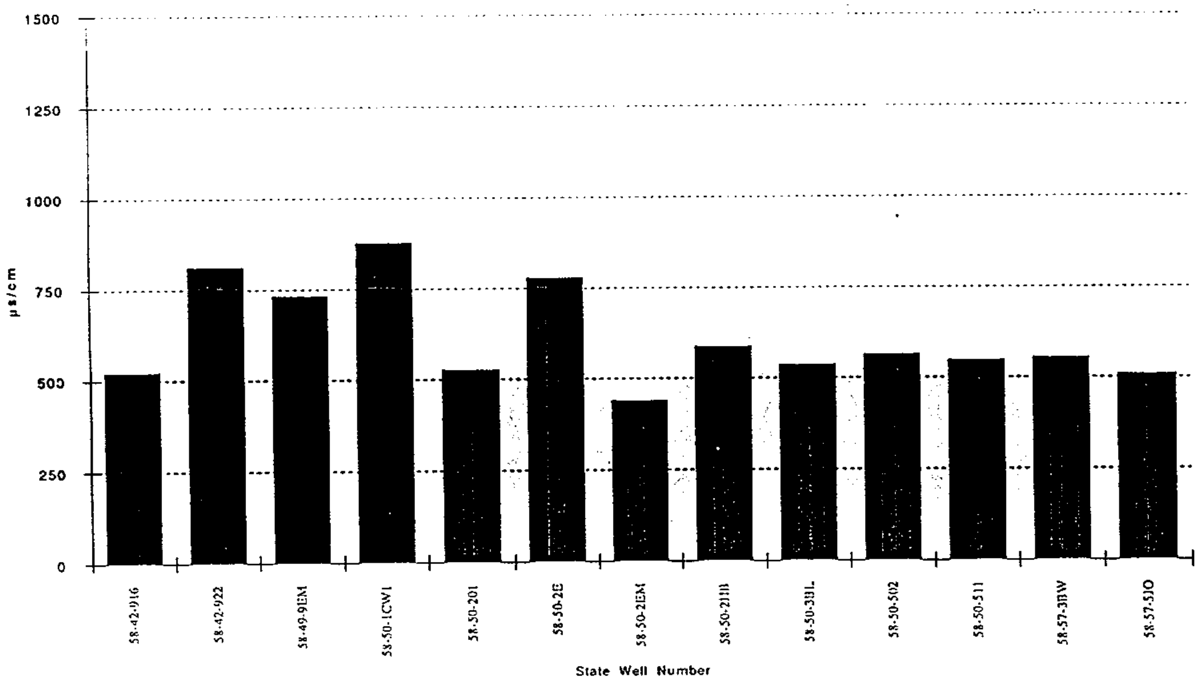
Variations in Groundwater Temperature

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-3



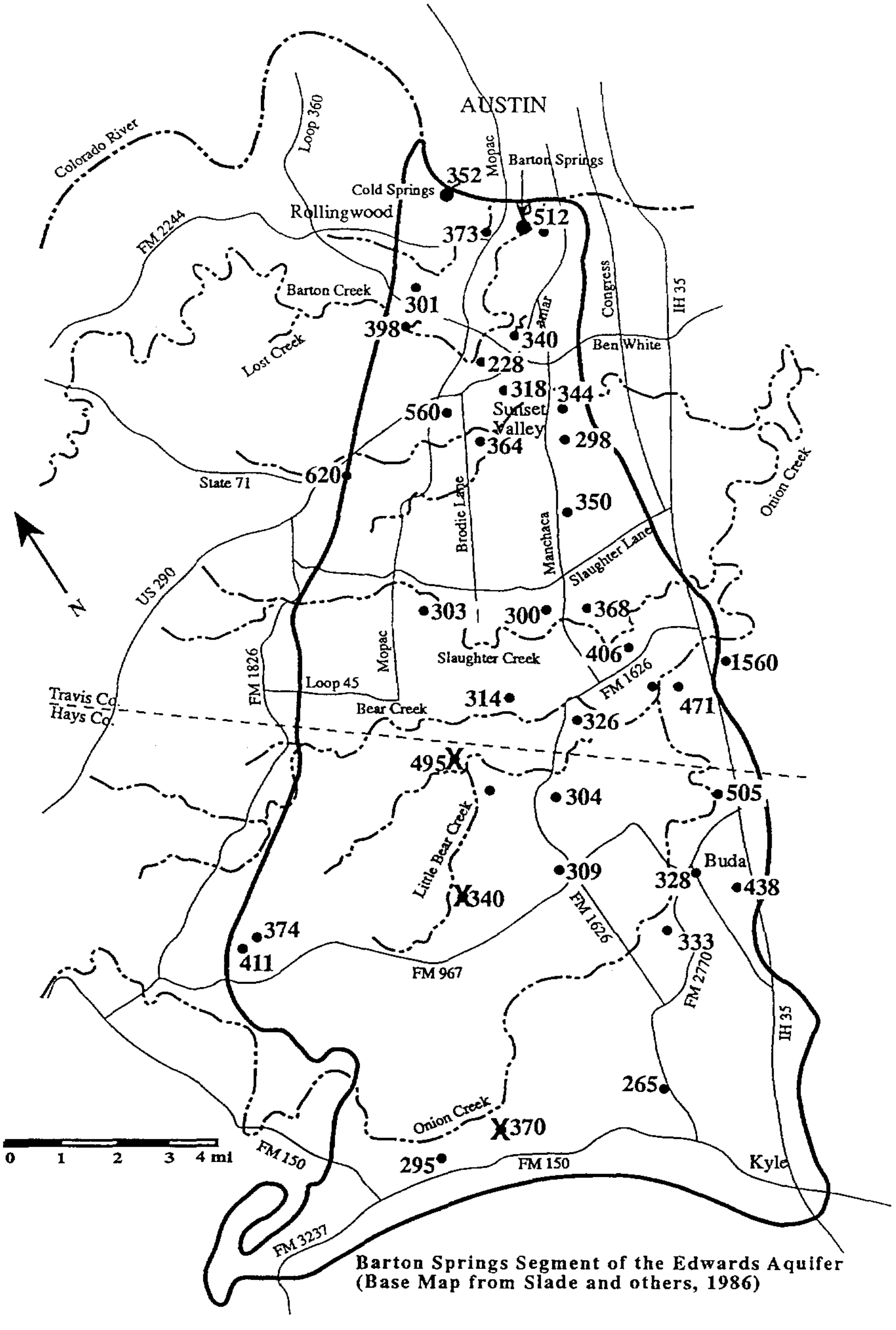
CND 1994



Field Conductivity

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-4



Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

● Residue Total Dissolved Solids

X Newly Drilled Wells

Residual Total Dissolved Solids - March 1993 & 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-5

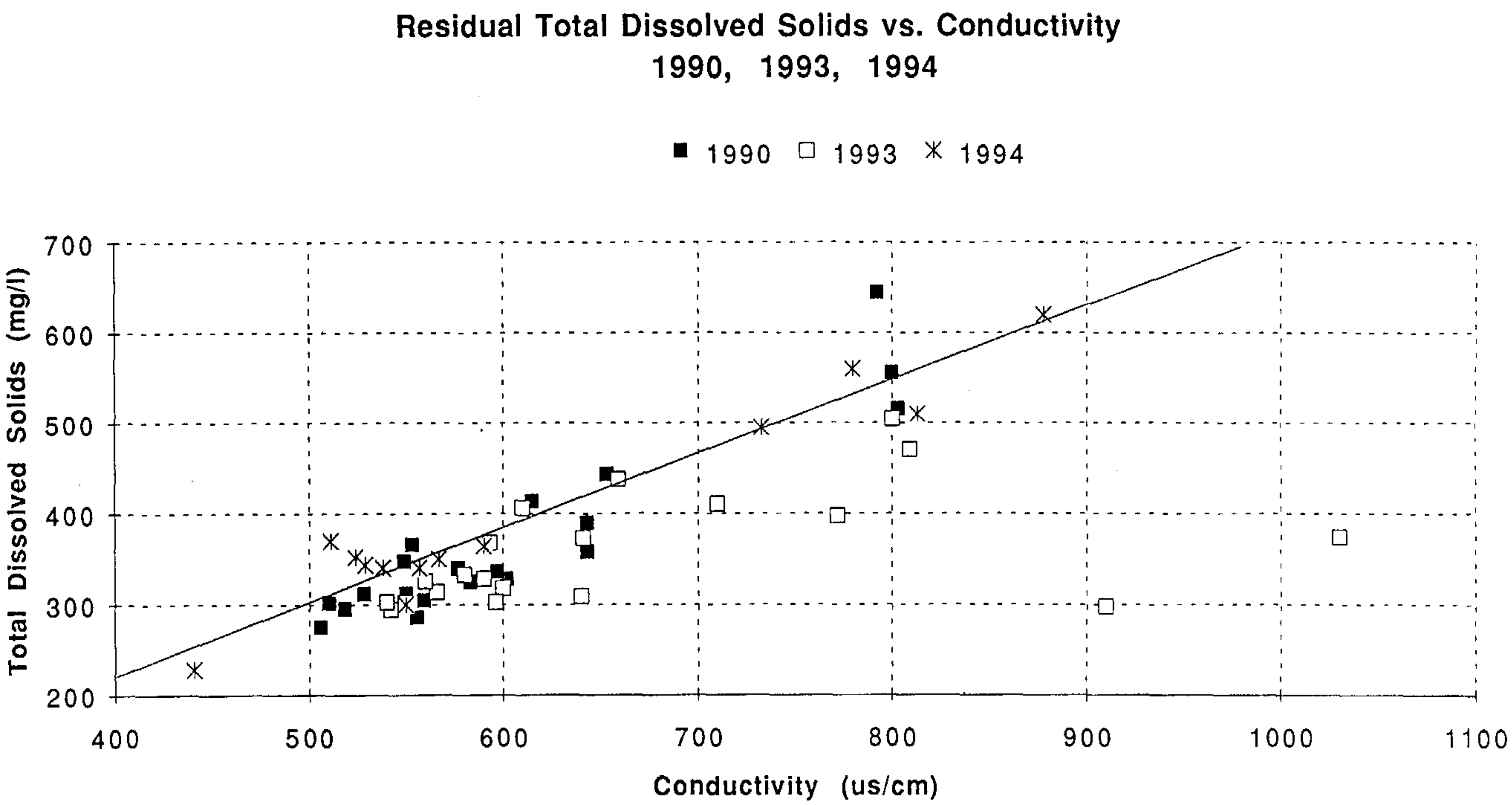


Figure IIB-6	**Residual Total Dissolved Solids vs. Field Conductivity** **1990, 1993 & 1994**	**Barton Springs/Edwards Aquifer** **Water Quality Study**

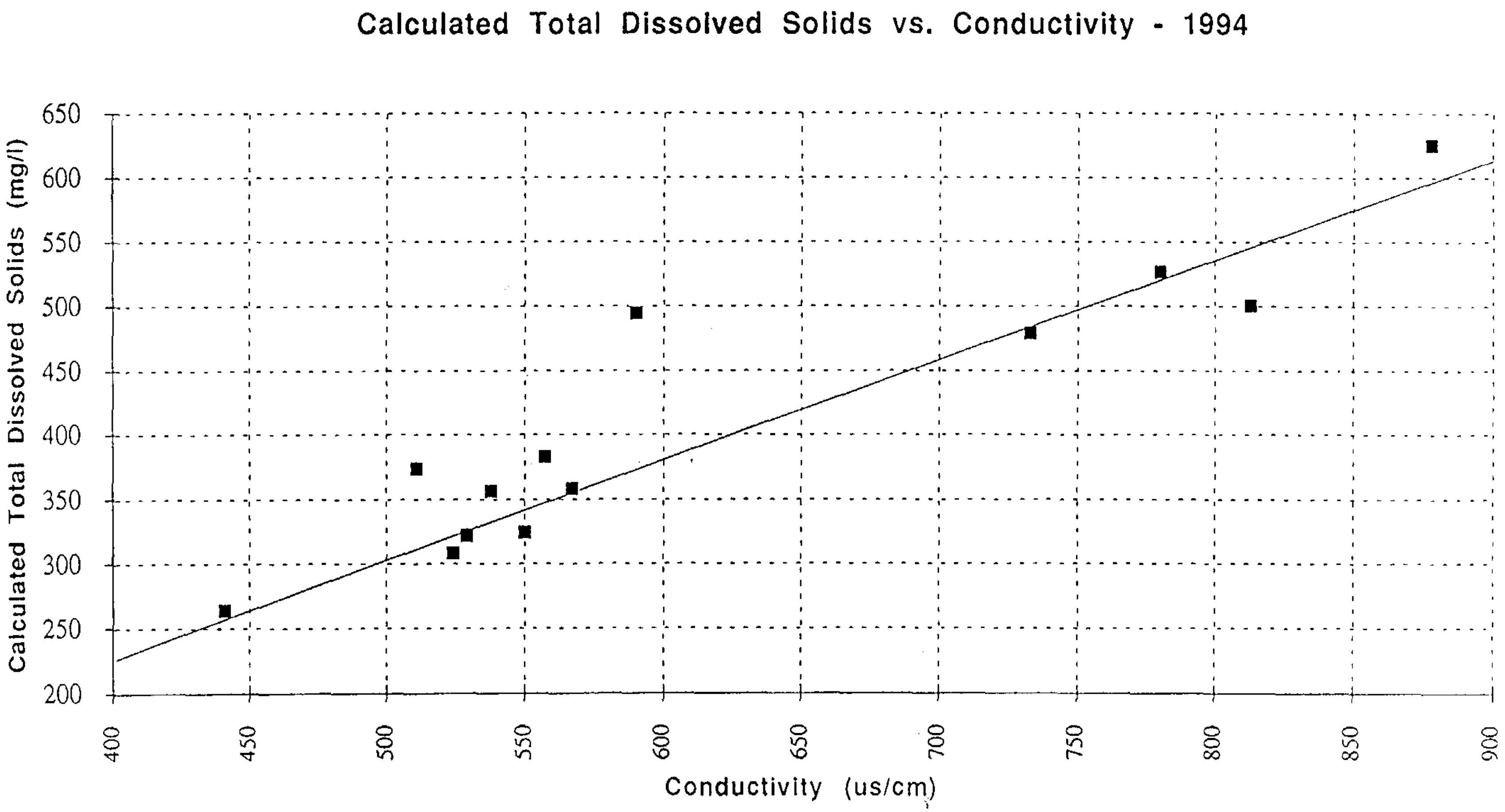
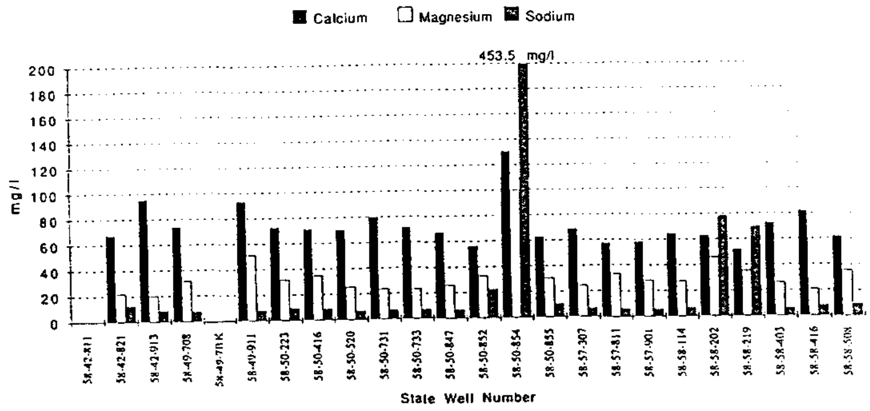


Figure IIB-7

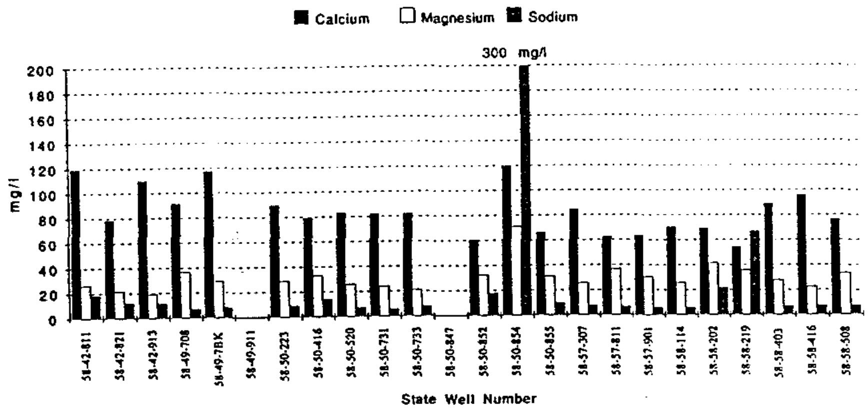
Calculated Total Dissolved Solids vs. Field Conductivity

Barton Springs/Edwards Aquifer
Water Quality Study

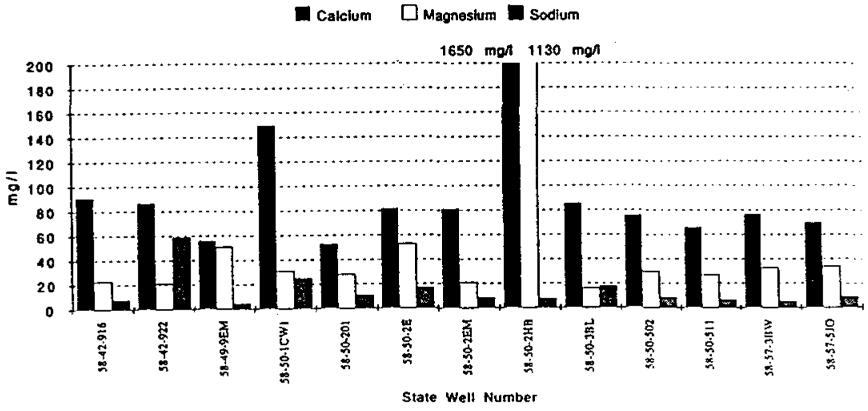
Major Cations - 1990



Major Cations - 1993



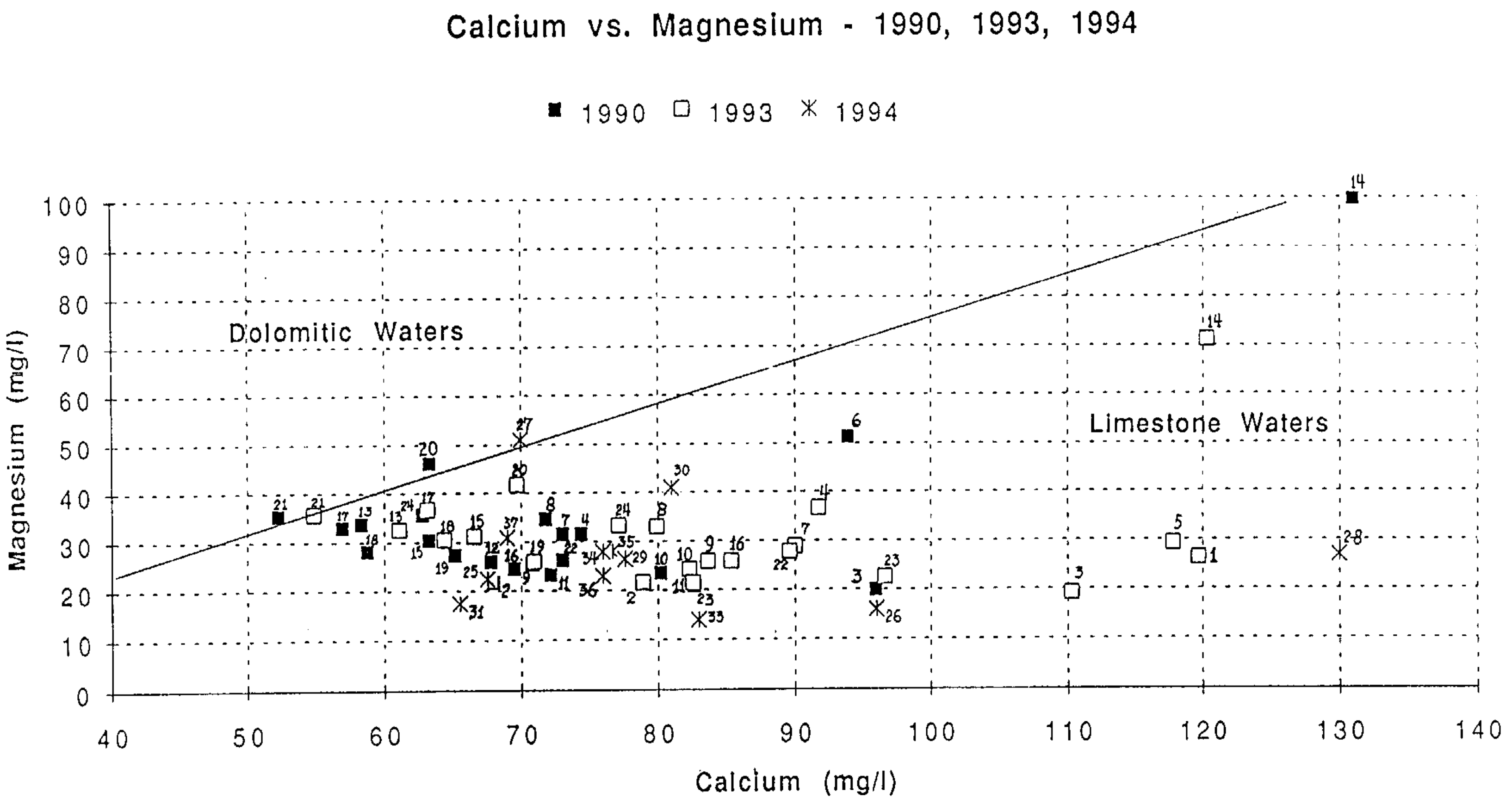
Major Cations - 1994



Major Cations - 1990, 1993, 1994

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-8



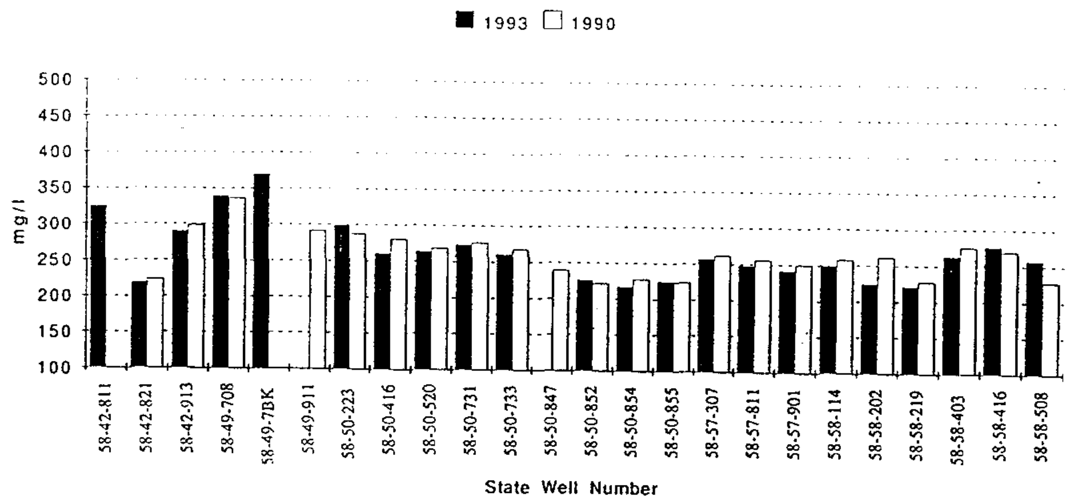
EAWQ NO.	Temp. or State Well Number
1	58-42-811
2	58-42-821
3	58-42-913
4	58-49-708
5	58-49-7BK
6	58-49-911
7	58-50-223
8	58-50-416
9	58-50-520
10	58-50-731
11	58-50-733
12	58-50-847
13	58-50-852
14	58-50-854
15	58-50-855
16	58-57-307
17	58-57-811
18	58-57-901
19	58-58-114
20	58-58-202
21	58-58-219
22	58-58-403
23	58-58-416
24	58-58-508
25	58-42-916
26	58-42-922
27	58-49-9EM
28	58-50-1CW1
29	58-50-201
30	58-50-2E
31	58-50-2EM
32	58-50-2HB
33	58-50-3BL
34	58-50-502
35	58-50-511
36	58-57-3BW
37	58-57-5JO

Figure IIB-9

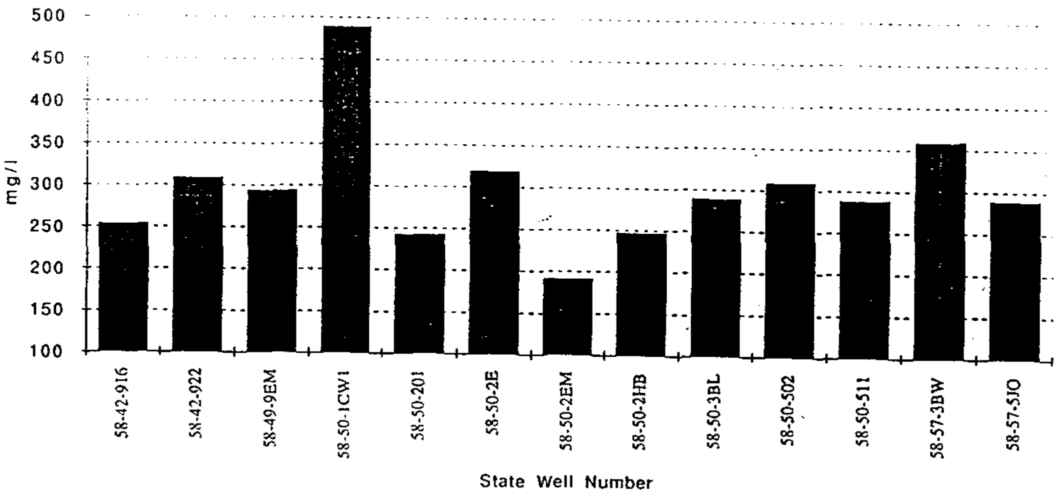
Calcium vs. Magnesium - 1990, 1993, 1994

Barton Springs/Edwards Aquifer
Water Quality Study

Bicarbonate Alkalinity - 1990 & 1993



Bicarbonate Alkalinity - 1994



Bicarbonate Alkalinity

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-10

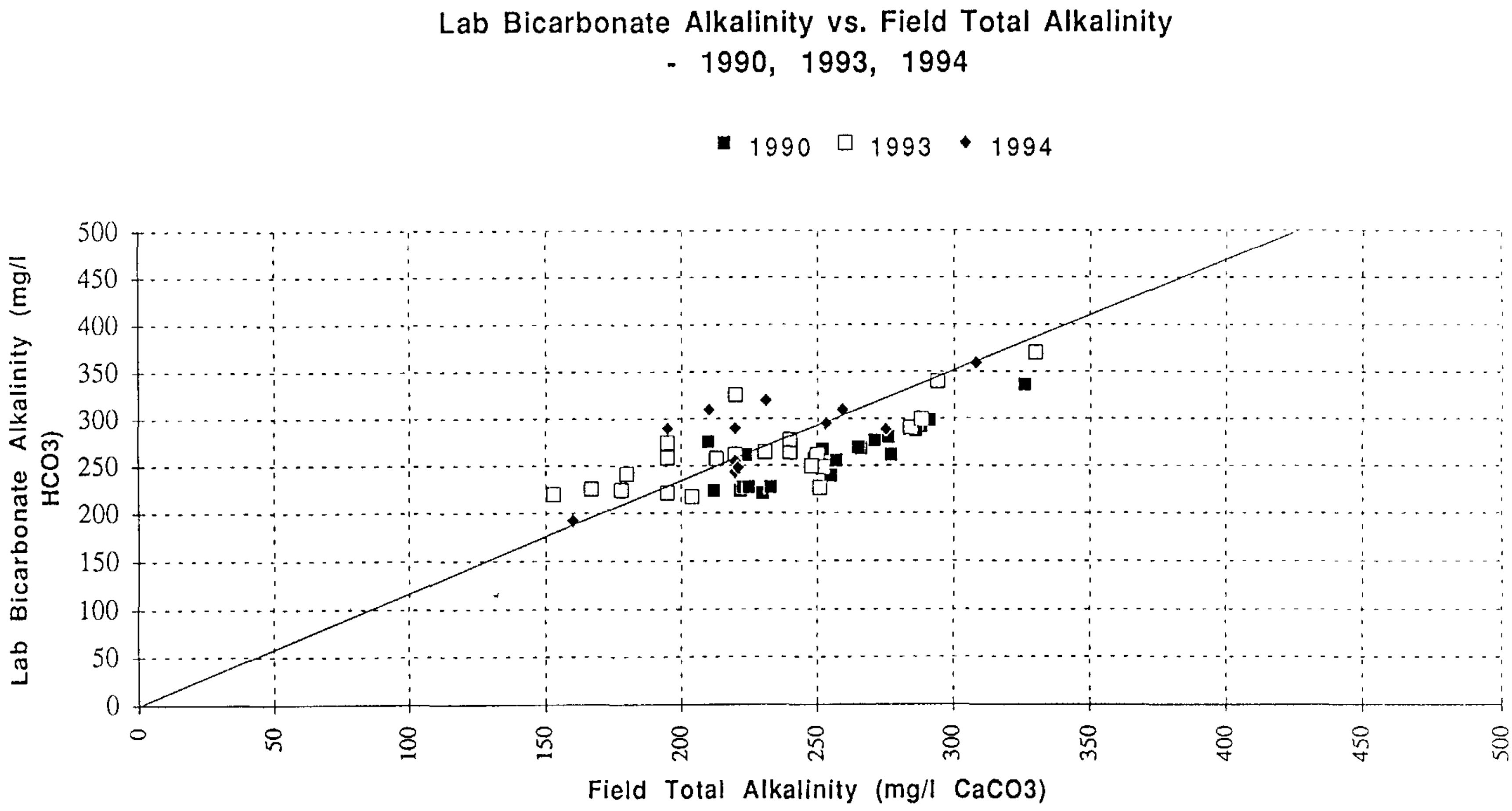
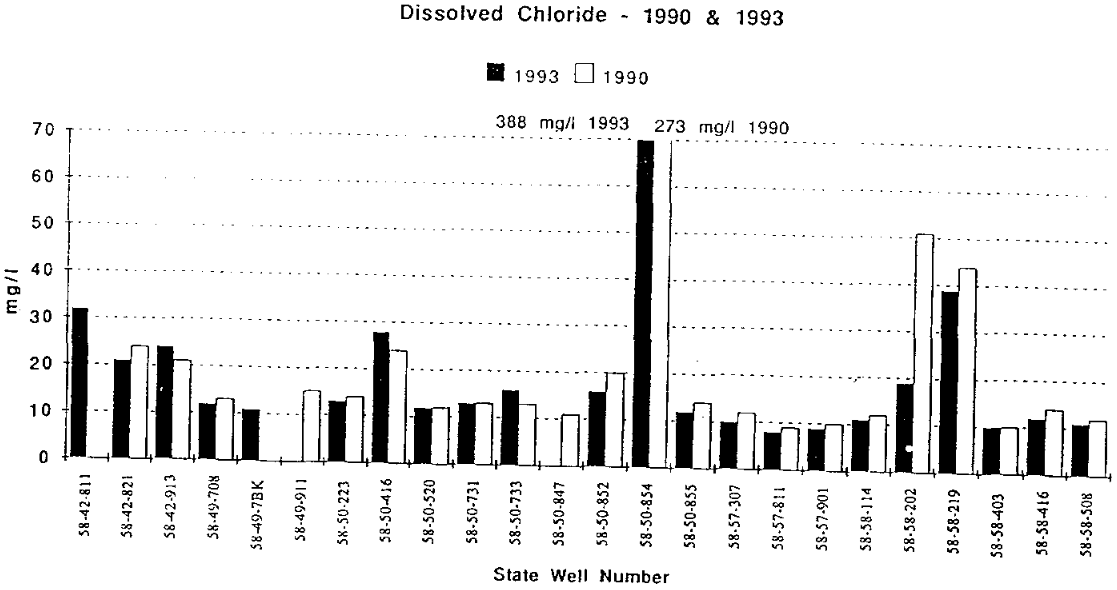
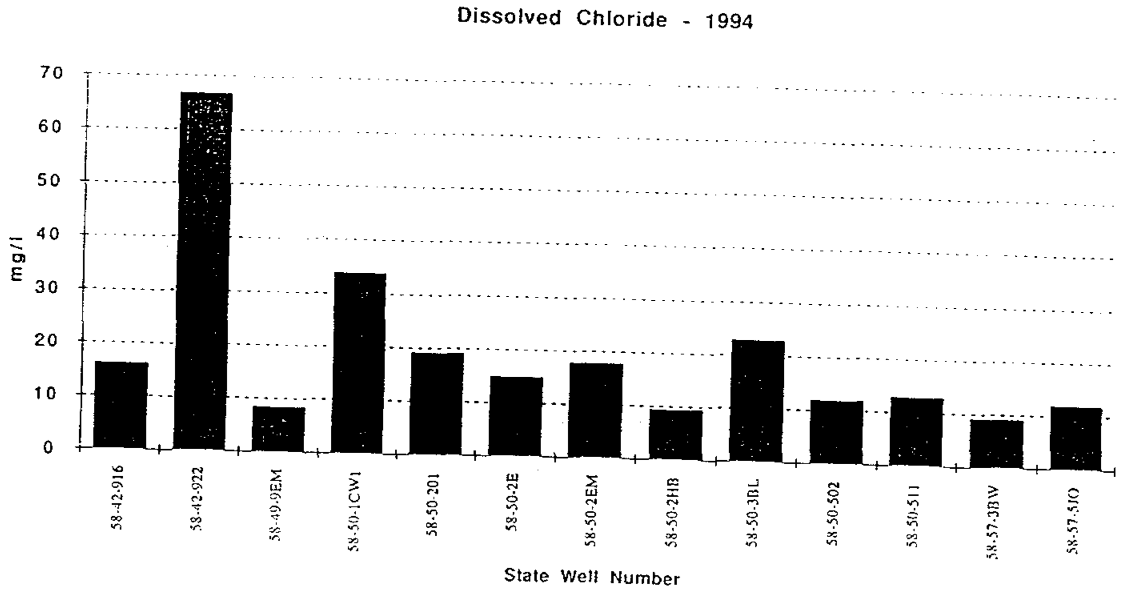


Figure IIB-11

Field Total Alkalinity vs. Lab Bicarbonate Alkalinity

Barton Springs/Edwards Aquifer Water Quality Study

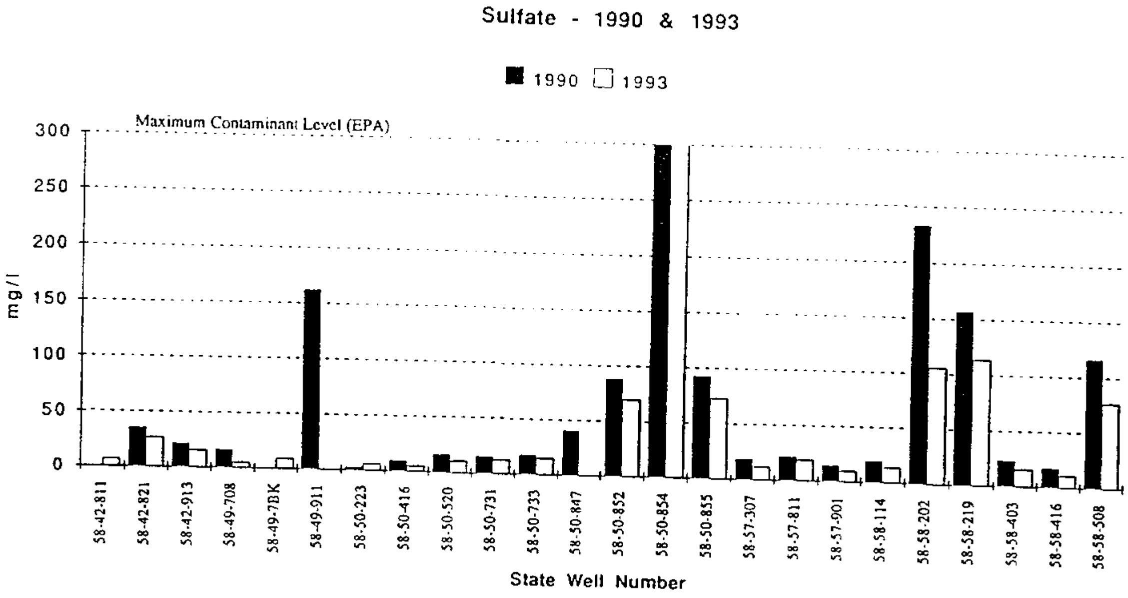

Dissolved Chloride - 1990 & 1993

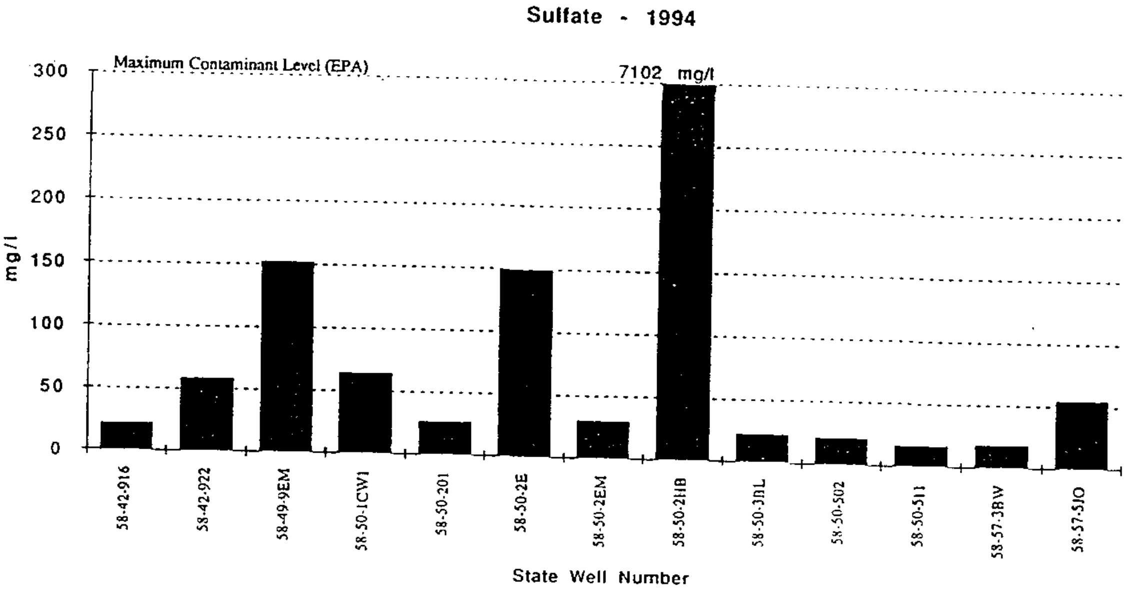

Dissolved Chloride - 1994

Chloride Concentrations

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-12



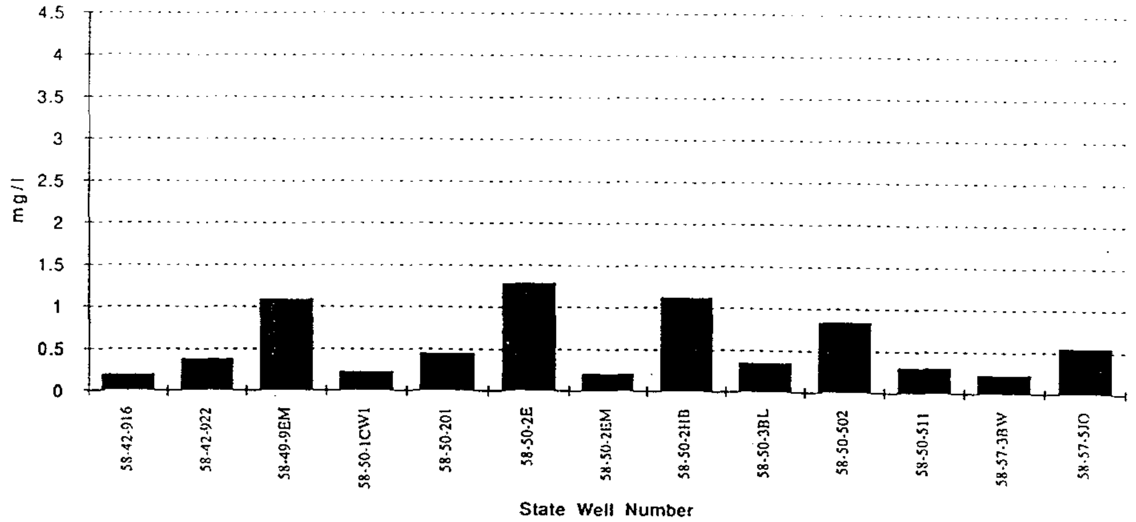


Sulfate Concentrations

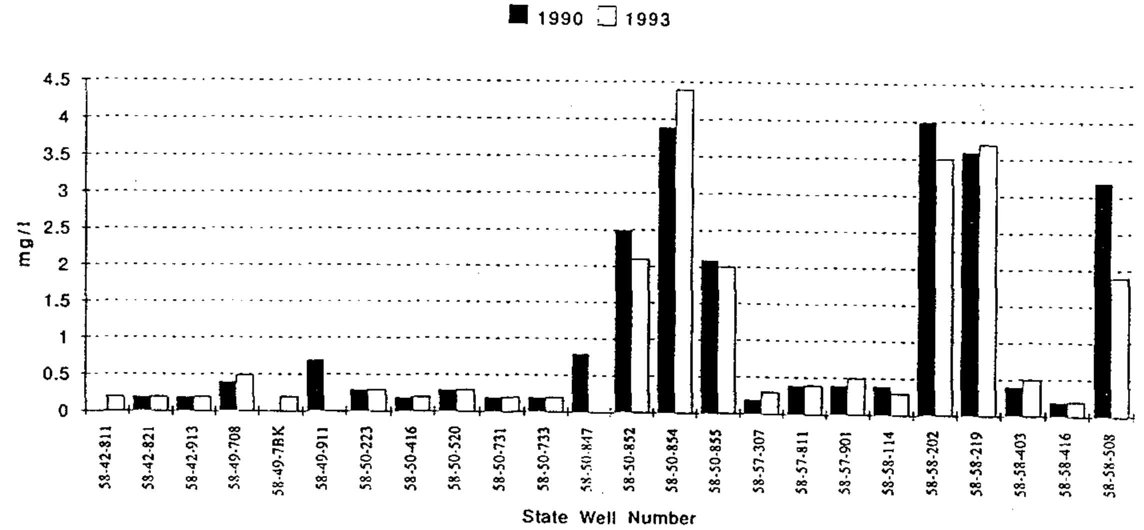
Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-13

Flouride - 1994



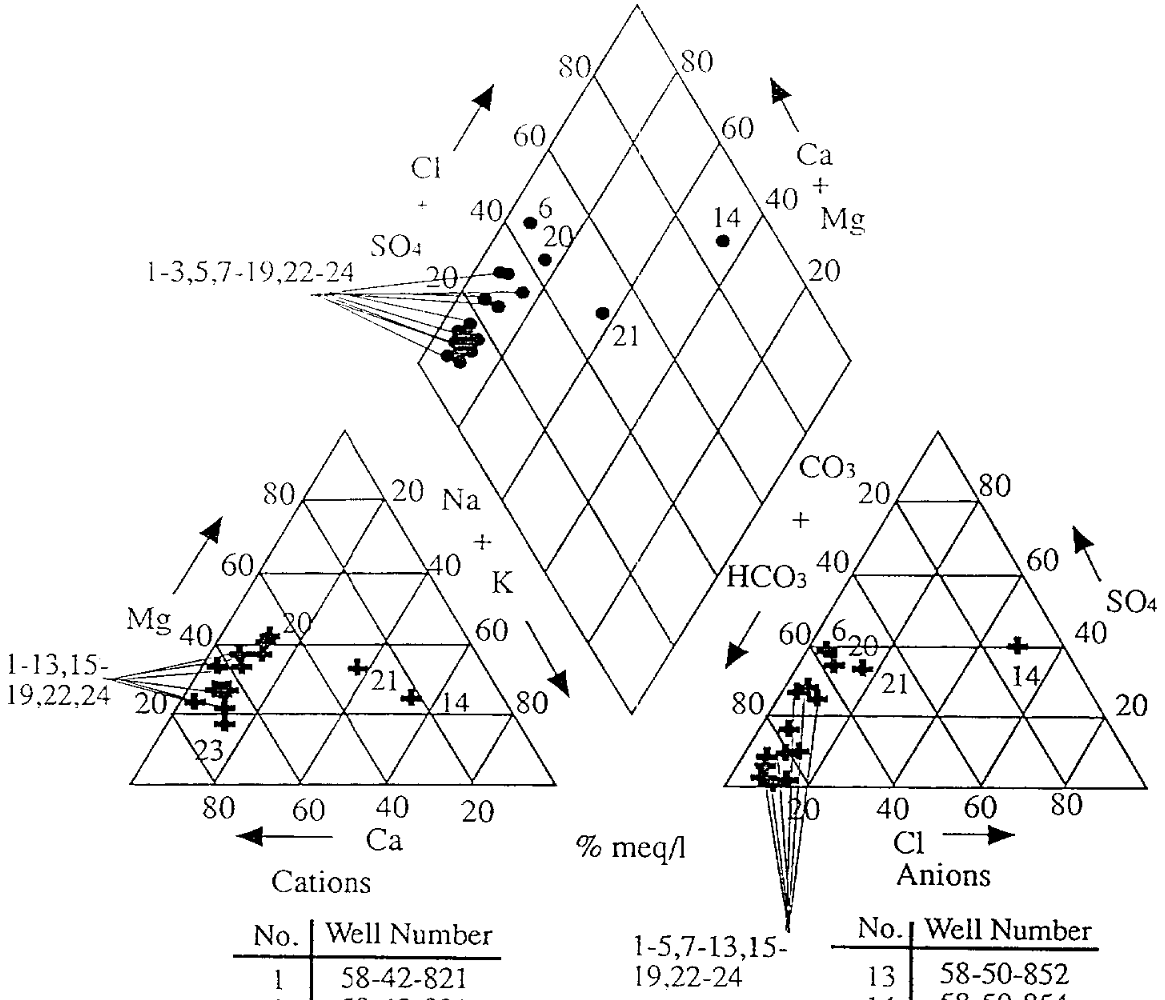
Flouride - 1990 &1993



Flouride Concentrations

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-14

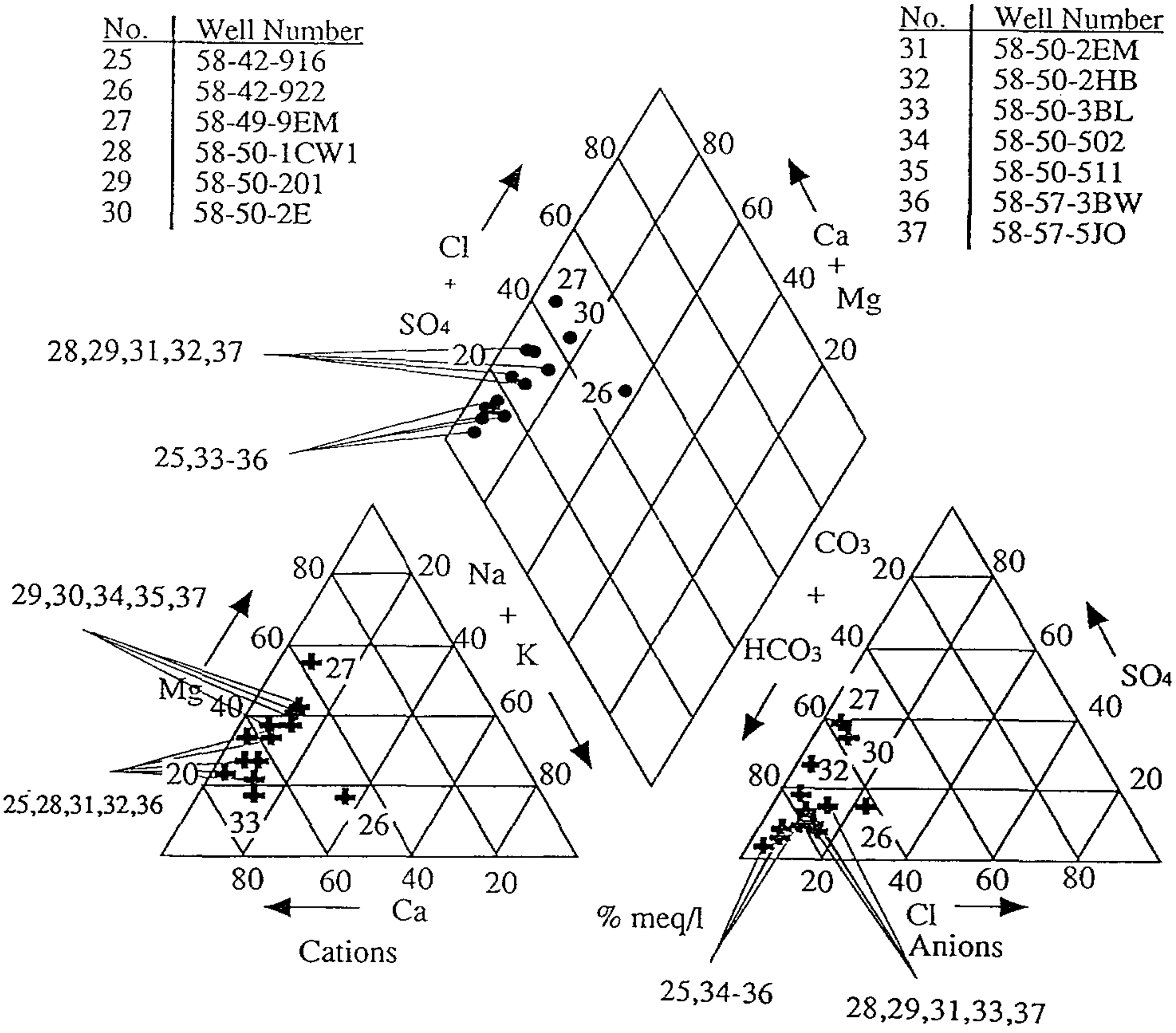


No.	Well Number
1	58-42-821
2	58-42-821
3	58-42-913
4	58-49-708
5	58-49-7BK
6	58-49-911
7	58-50-223
8	58-50-416
9	58-50-520
10	58-50-731
11	58-50-733
12	58-50-847
13	58-50-852
14	58-50-854
15	58-50-855
16	58-57-307
17	58-57-811
18	58-57-901
19	58-58-114
20	58-58-202
21	58-58-219
22	58-58-403
23	58-58-416
24	58-58-508

Piper Diagram - 1993

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-15



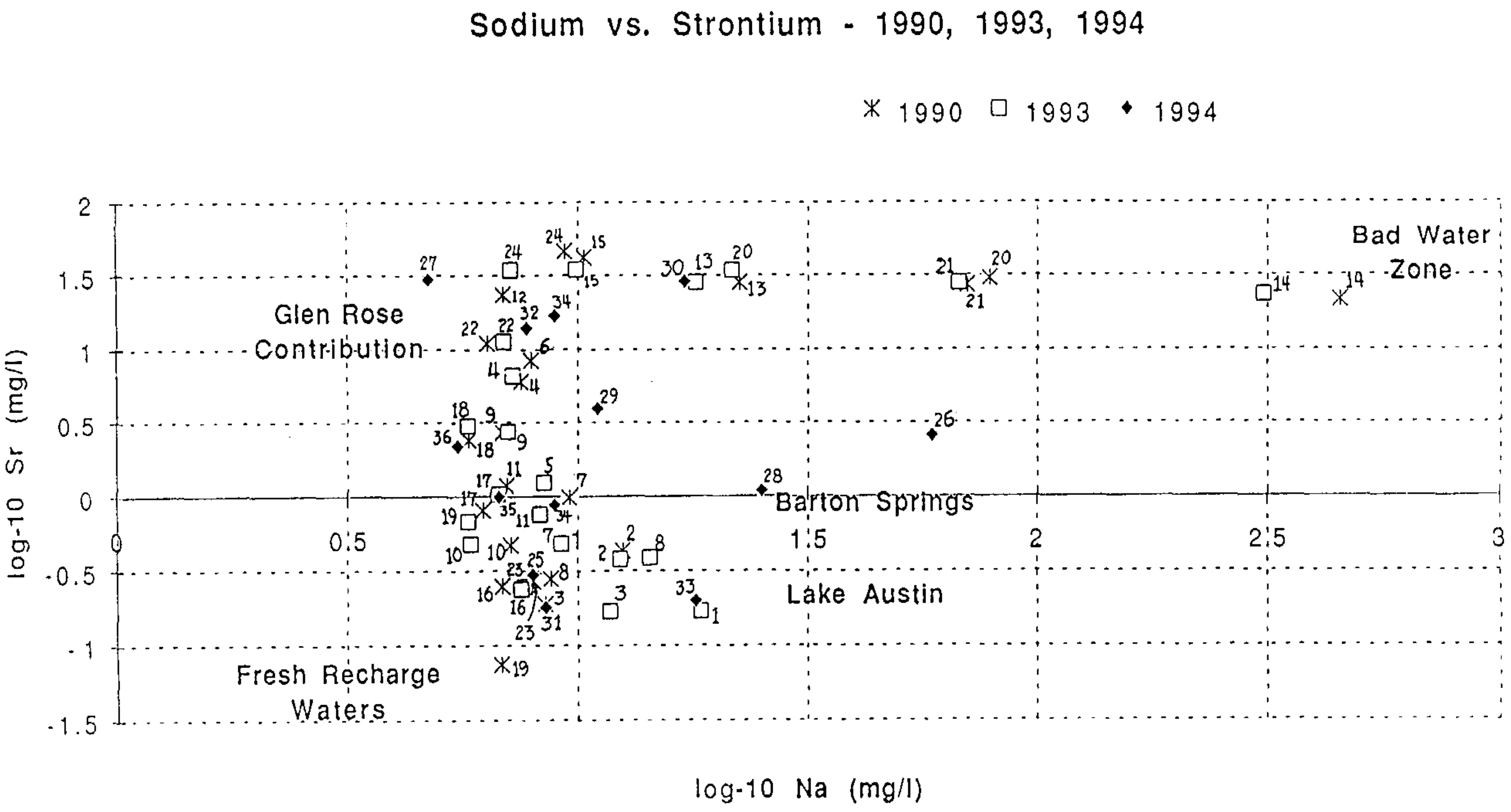
No.	Well Number
25	58-42-916
26	58-42-922
27	58-49-9EM
28	58-50-1CW1
29	58-50-201
30	58-50-2E

No.	Well Number
31	58-50-2EM
32	58-50-2HB
33	58-50-3BL
34	58-50-502
35	58-50-511
36	58-57-3BW
37	58-57-5JO

Piper Diagram - 1994

Barton Springs/Edwards Aquifer
Water Quality Study

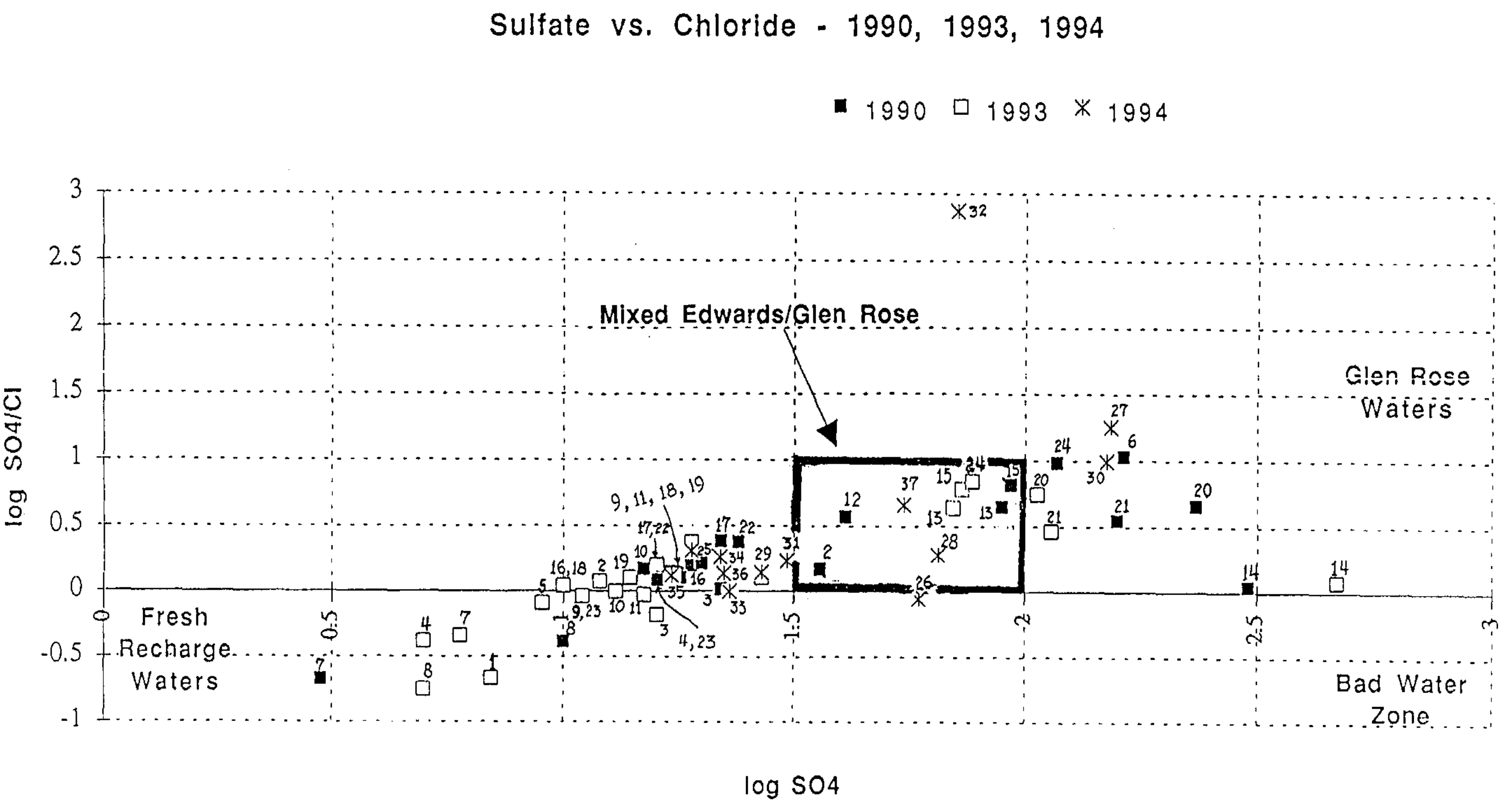
Figure IIB-16



EAWQ NO.	Temp. or State Well Number
1	58-42-811
2	58-42-821
3	58-42-913
4	58-49-708
5	58-49-7BK
6	58-49-911
7	58-50-223
8	58-50-416
9	58-50-520
10	58-50-731
11	58-50-733
12	58-50-847
13	58-50-852
14	58-50-854
15	58-50-855
16	58-57-307
17	58-57-811
18	58-57-901
19	58-58-114
20	58-58-202
21	58-58-219
22	58-58-403
23	58-58-416
24	58-58-508
25	58-42-916
26	58-42-922
27	58-49-9EM
28	58-50-1CW1
29	58-50-201
30	58-50-2E
31	58-50-2EM
32	58-50-2HB
33	58-50-3BL
34	58-50-502
35	58-50-511
36	58-57-3BW
37	58-57-5JO

Figure IIB-17

Sodium vs. Strontium - 1990, 1993, 1994

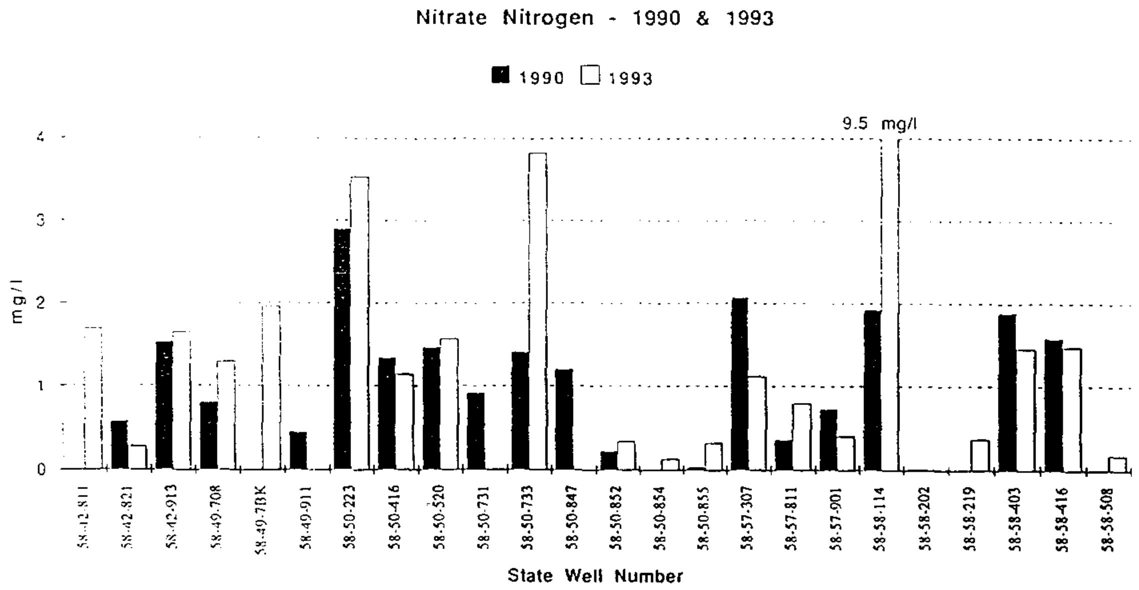


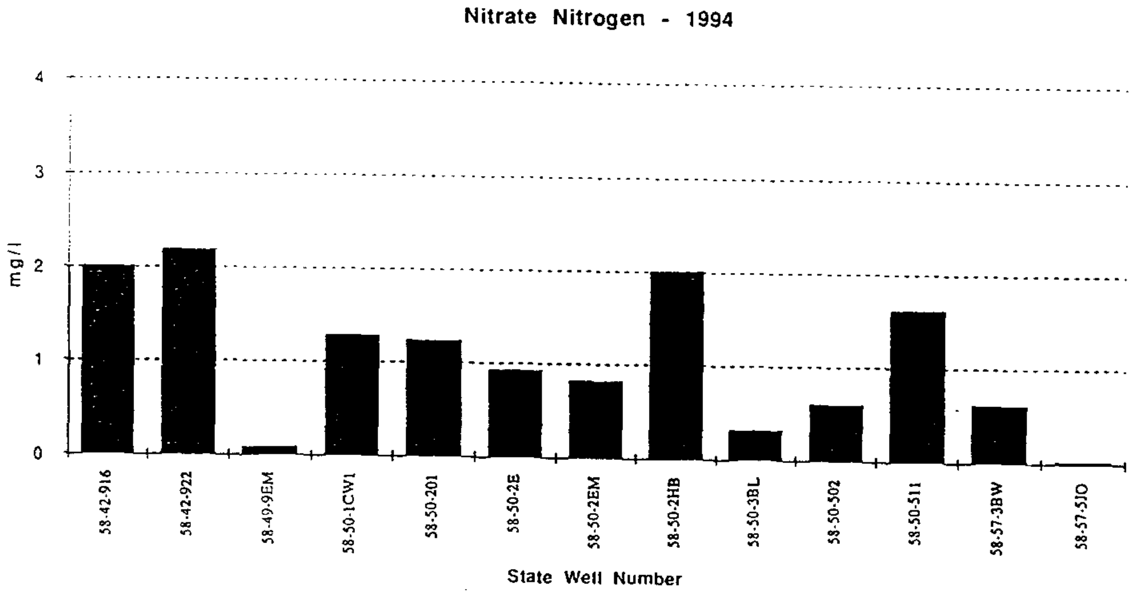
EAWQ No.	Temp. or State Well Number
1	58-42-811
2	50-42-821
3	58-42-913
4	58-49-708
5	58-49-7BK
6	58-49-911
7	58-50-223
8	58-50-416
9	58-50-520
10	58-50-731
11	58-50-733
12	58-50-847
13	58-50-852
14	58-50-854
15	58-50-855
16	58-57-307
17	58-57-811
18	58-57-901
19	58-58-114
20	58-58-202
21	58-58-219
22	58-58-403
23	58-58-416
24	58-58-508
25	58-42-916
26	58-42-922
27	58-49-9EM
28	58-50-1CW1
29	58-50-201
30	58-50-2E
31	58-50-2EM
32	58-50-2HB
33	58-50-3BL
34	58-50-502
35	50-50-511
36	58-57-3BW
37	58-57-5JO

Figure IIB-18

Sulfate vs. Chloride - 1990, 1993, 1994

Barton Springs/Edwards Aquifer
Water Quality Study

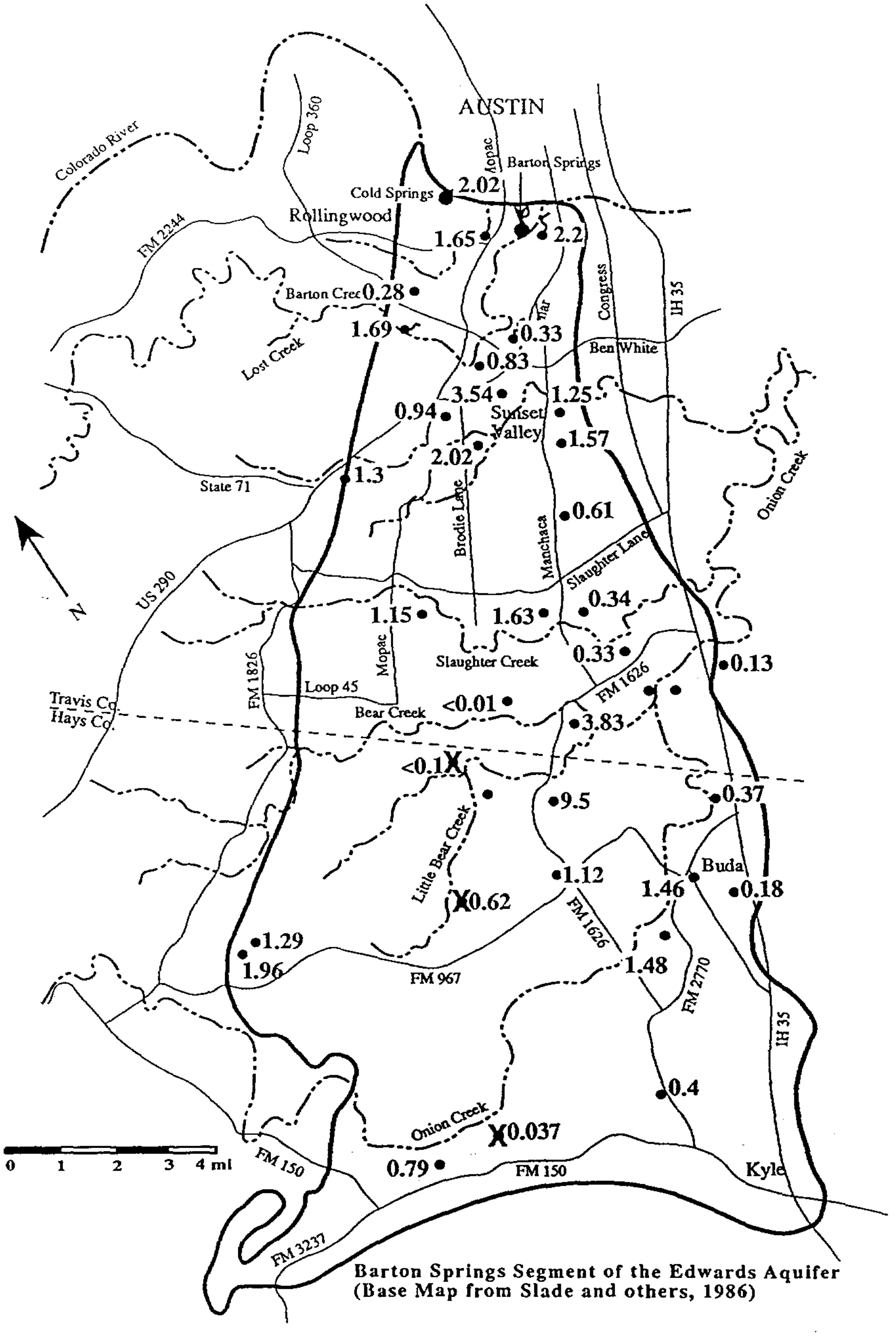

Nitrate Nitrogen - 1990 & 1993


Nitrate Nitrogen - 1994

Nitrate Nitrogen Concentrations

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-19



Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

#● Nitrate Nitrogen levels

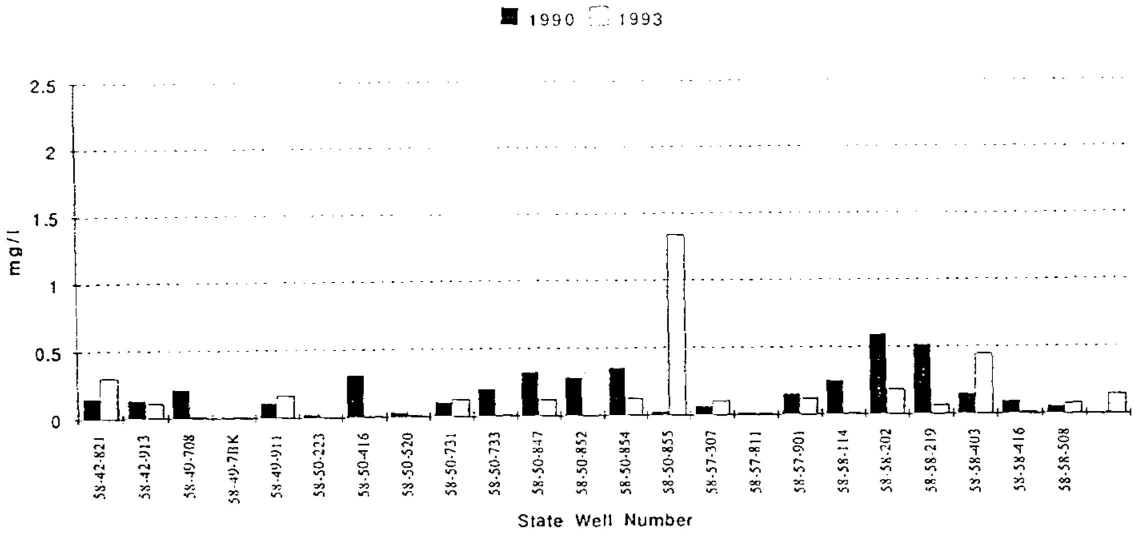
X Newly Drilled Wells

Nitrate Nitrogen - 1993 and 1994

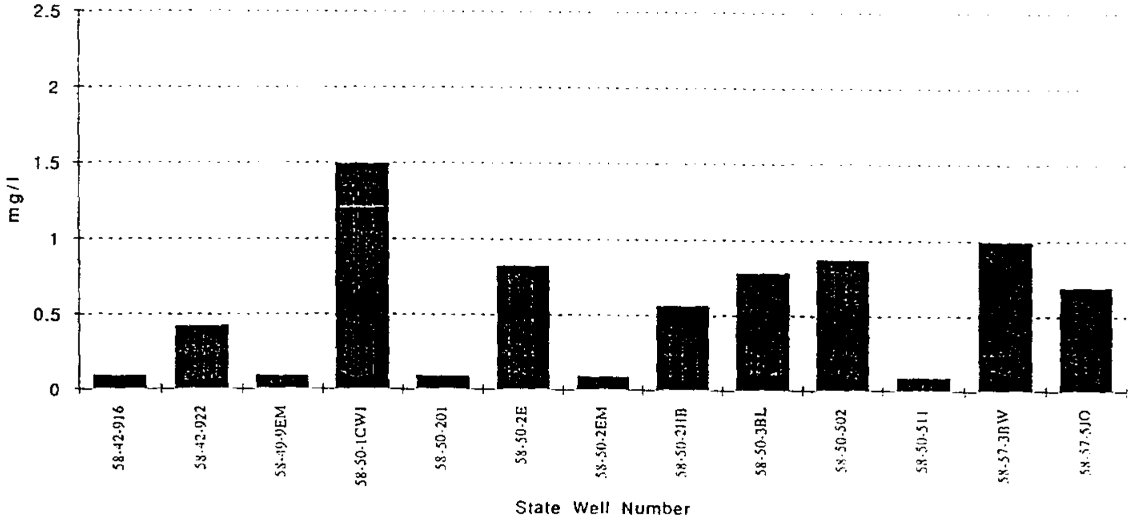
Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-20

Kjeldahl Nitrogen - 1990 & 1993



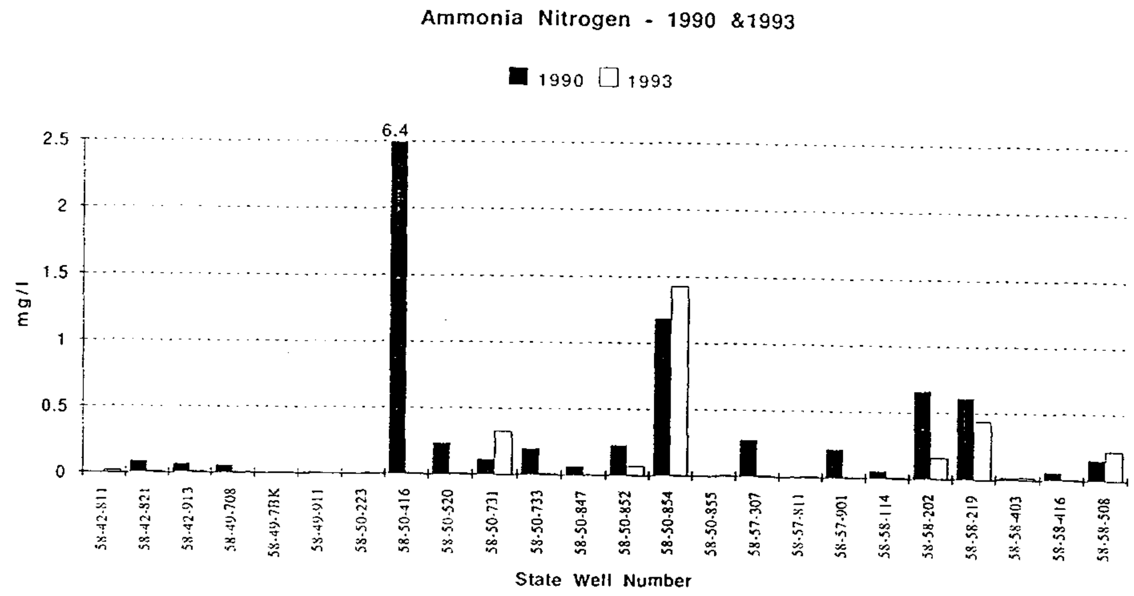
Kjeldahl Nitrogen - 1994

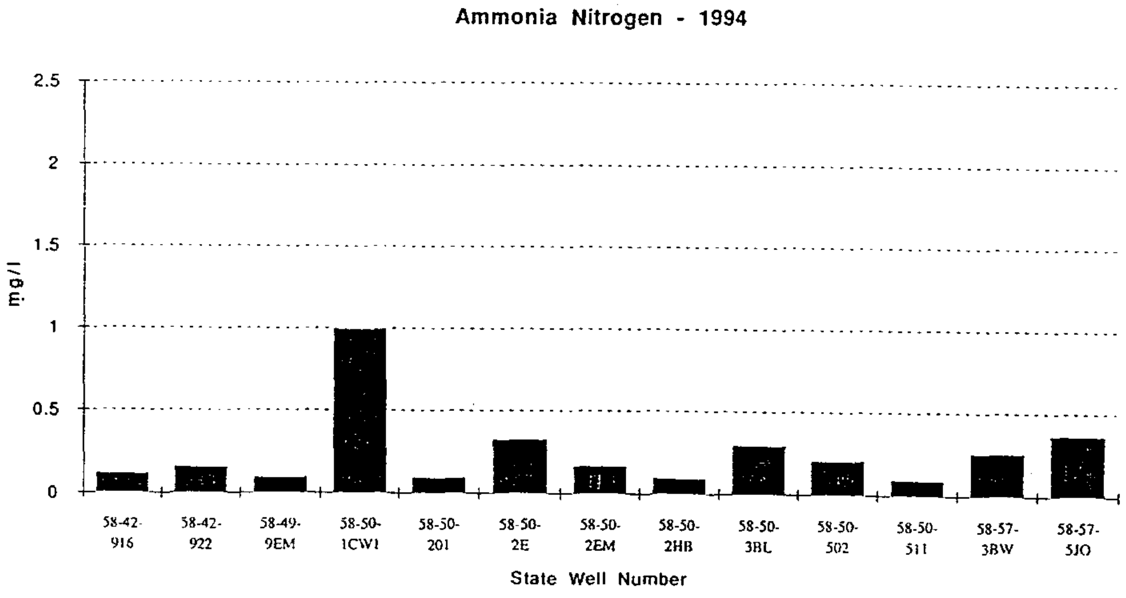


Kjeldahl Nitrogen Concentrations

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-21

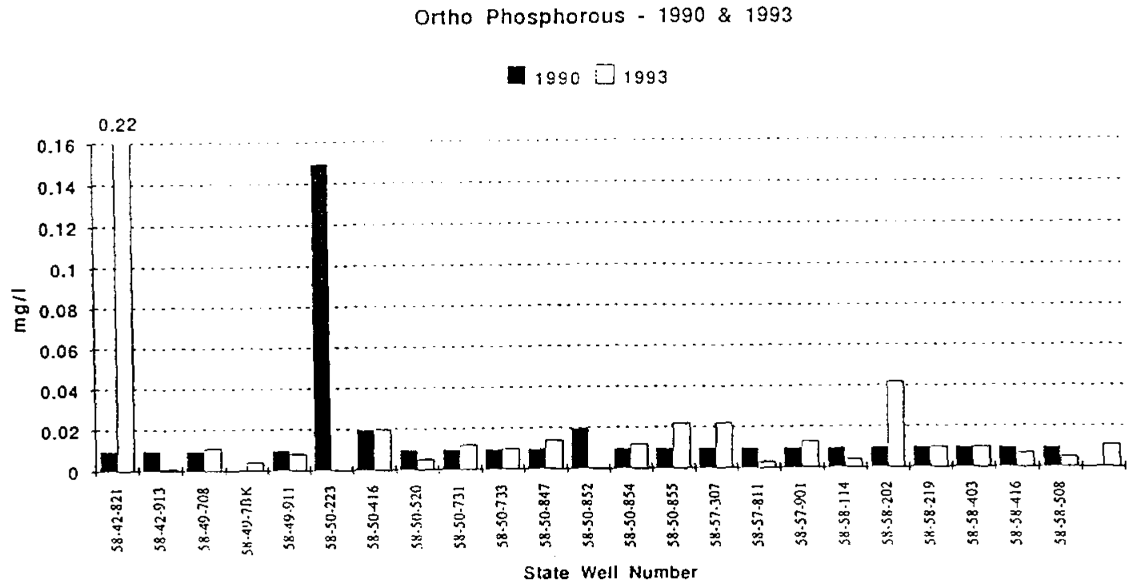


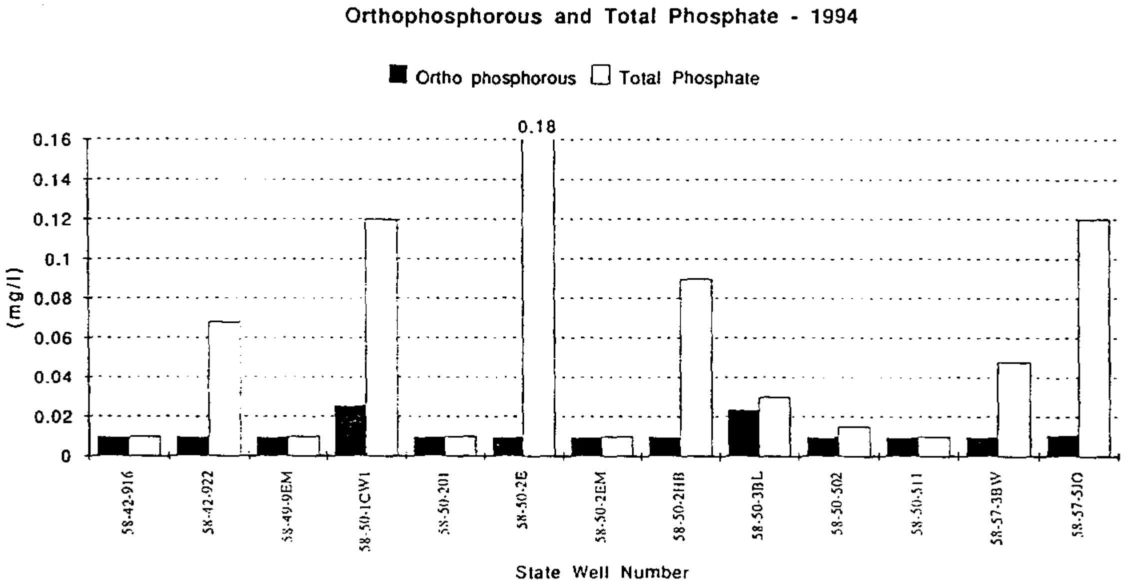


Ammonia Nitrogen Concentrations

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-22

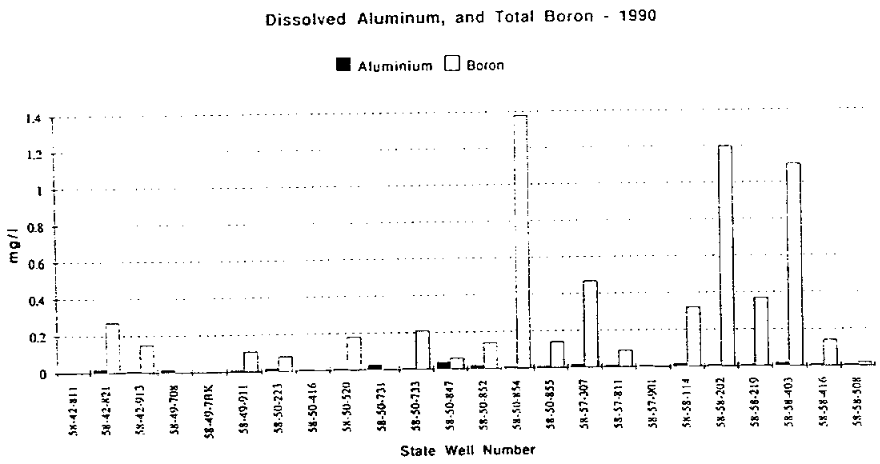


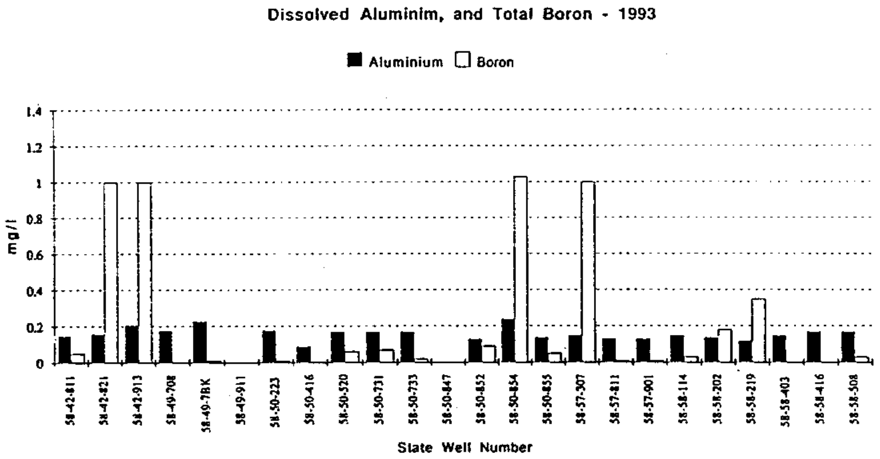


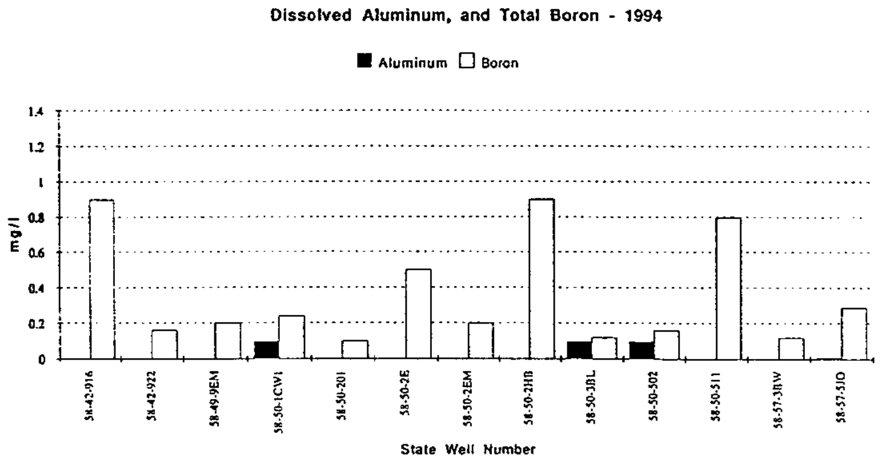
Orthophosphorous and Total Phosphate - 1990, 1993, 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-23


Dissolved Aluminum, and Total Boron - 1990


Dissolved Aluminim, and Total Boron - 1993


Dissolved Aluminum, and Total Boron - 1994

Dissolved Aluminum and Total Boron - 1990, 1993, 1994

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-24

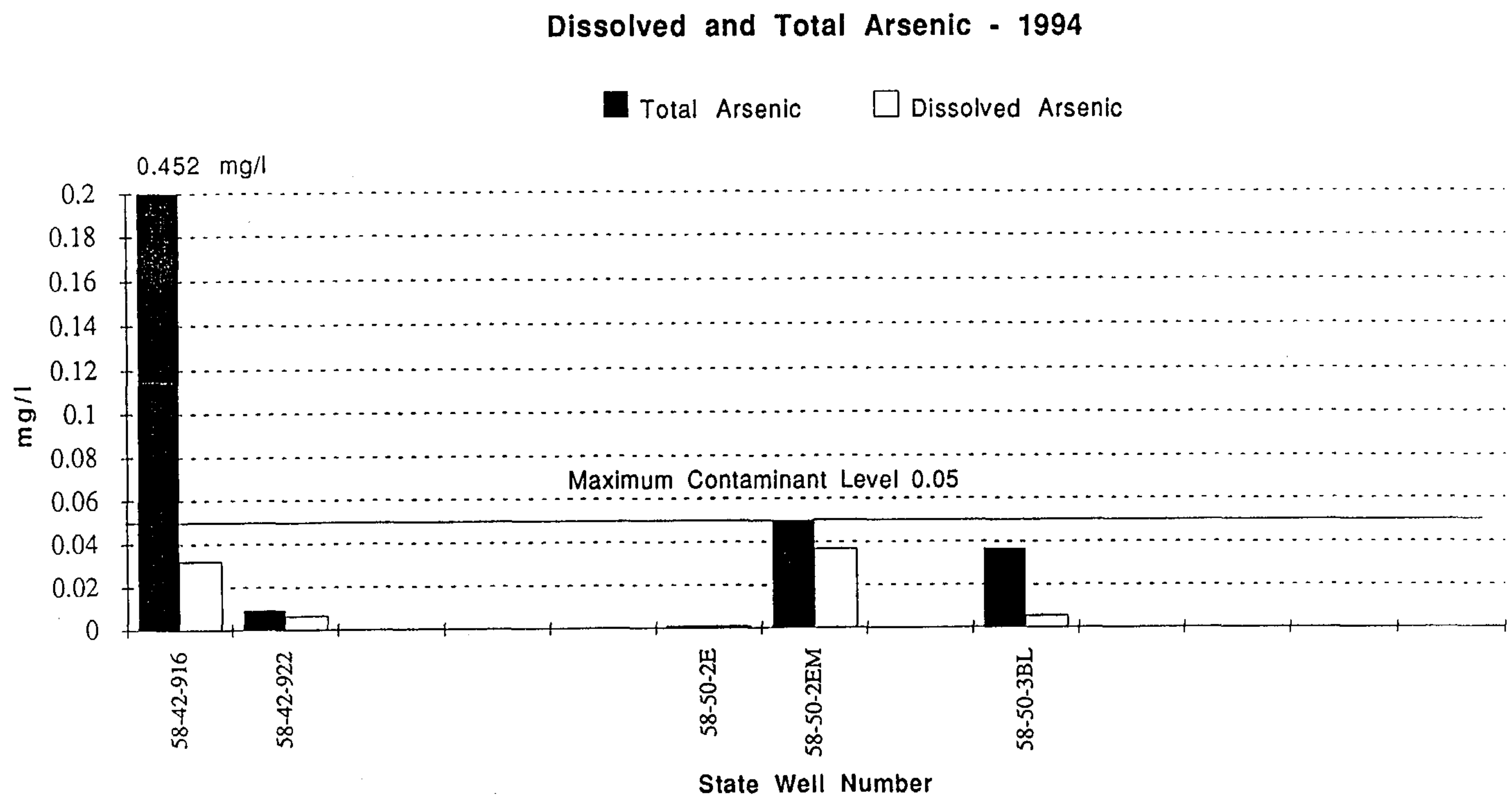
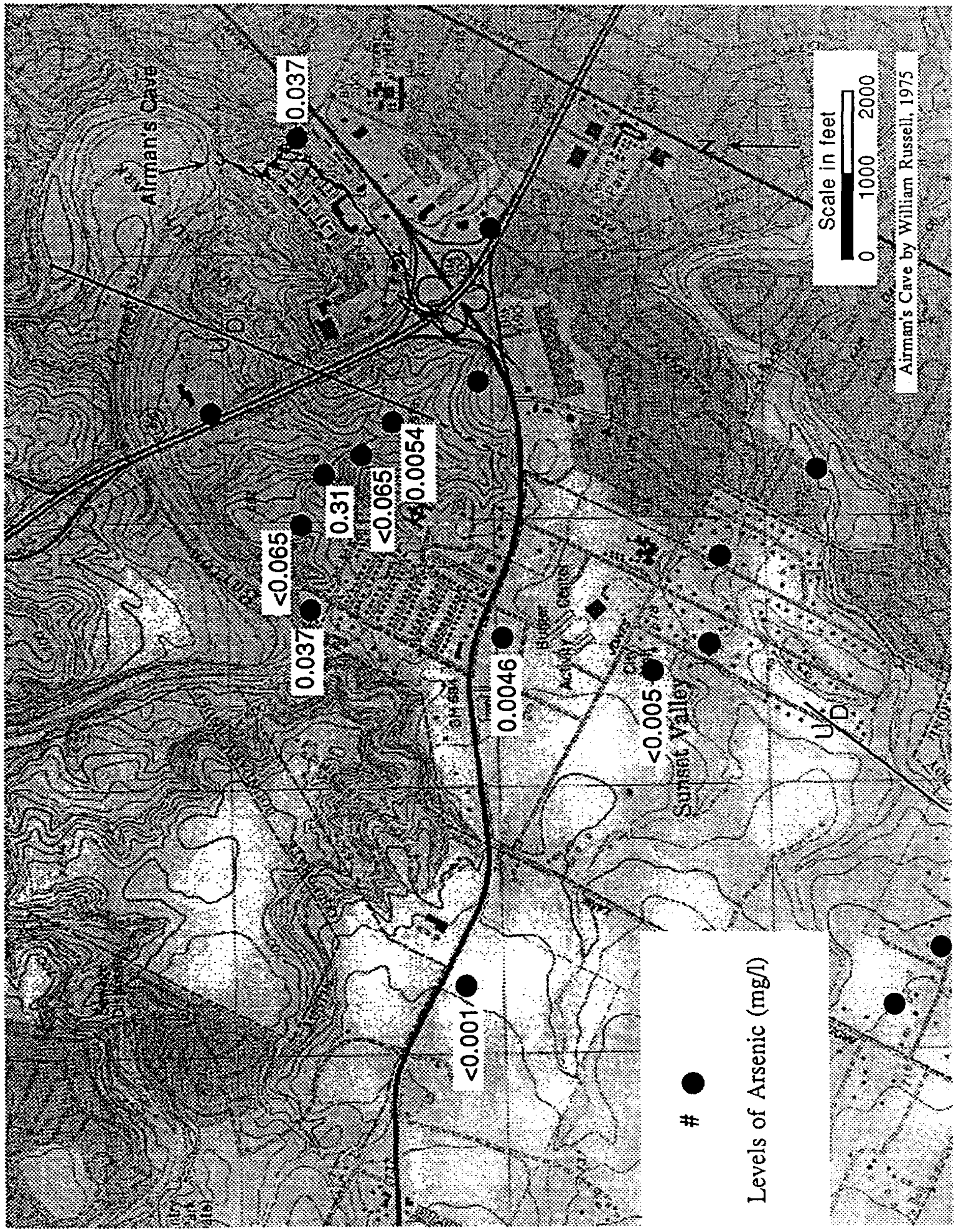


Figure IIB-25

Dissolved and Total Arsenic - 1994

Barton Springs/Edwards Aquifer
Water Quality Study



Distribution of Arsenic in wells in the South Austin and Sunset Valley Areas - 1993 & 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-26

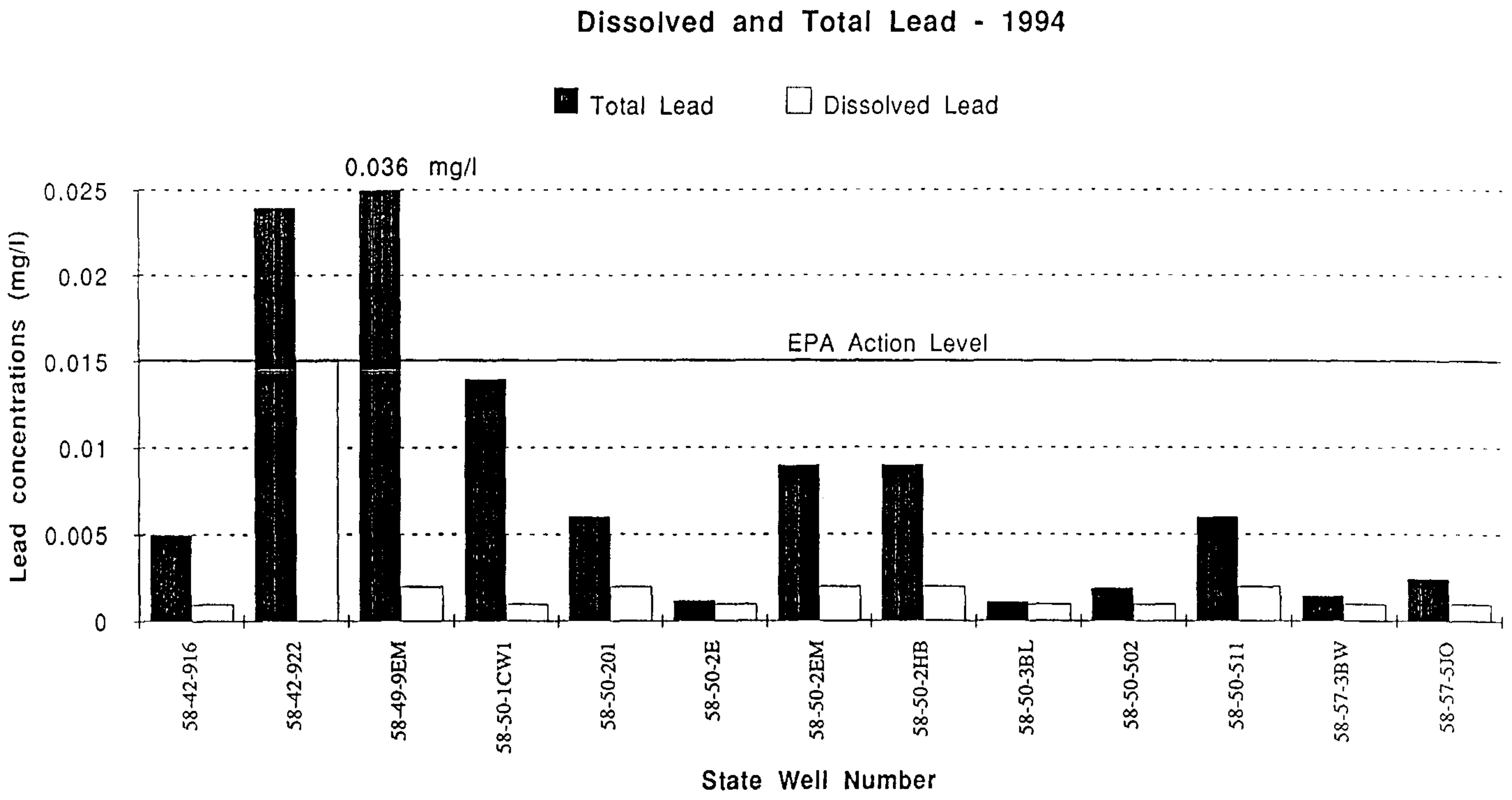
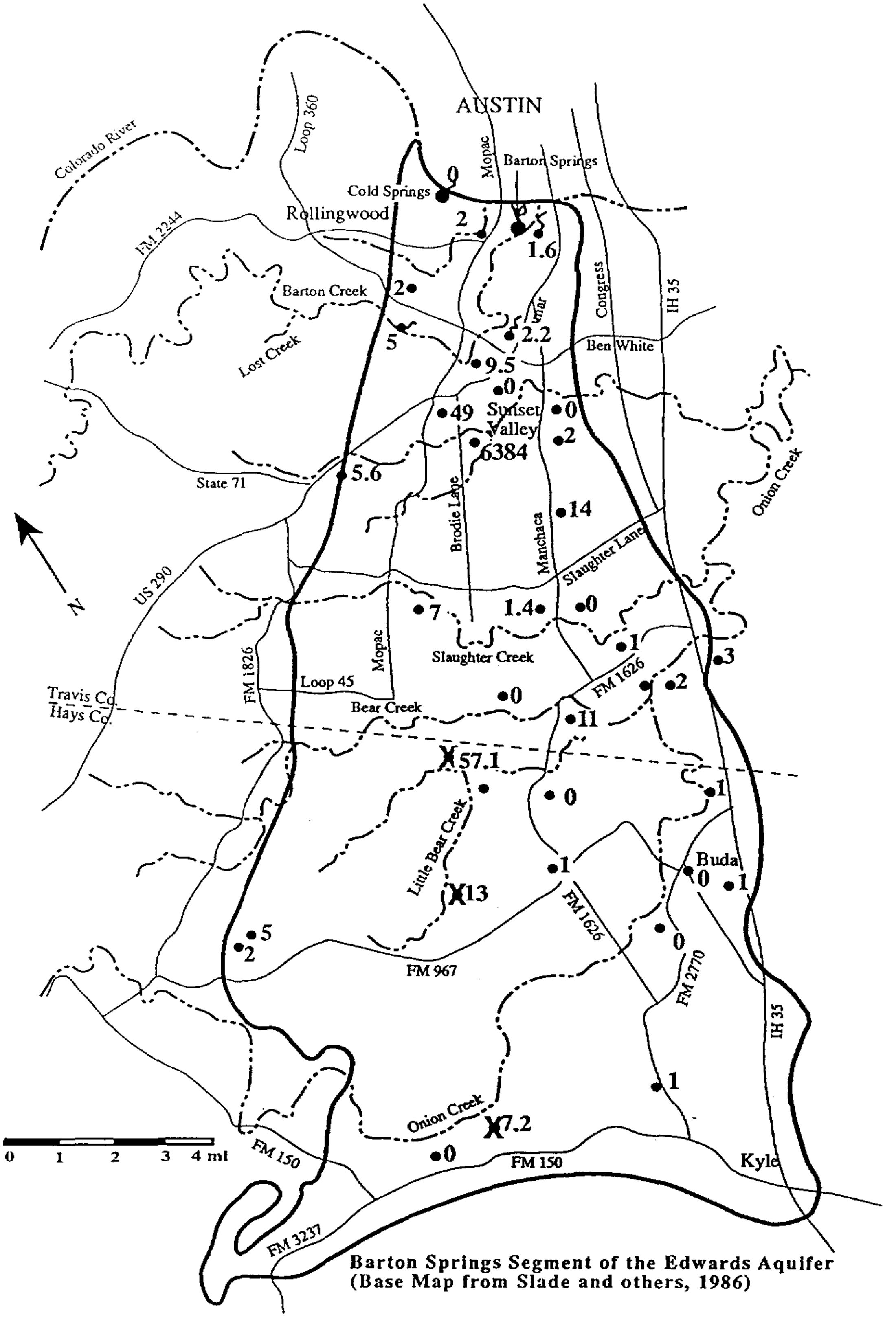


Figure IIB-27

Dissolved and Total Lead - 1994

Barton Springs/Edwards Aquifer
Water Quality Study

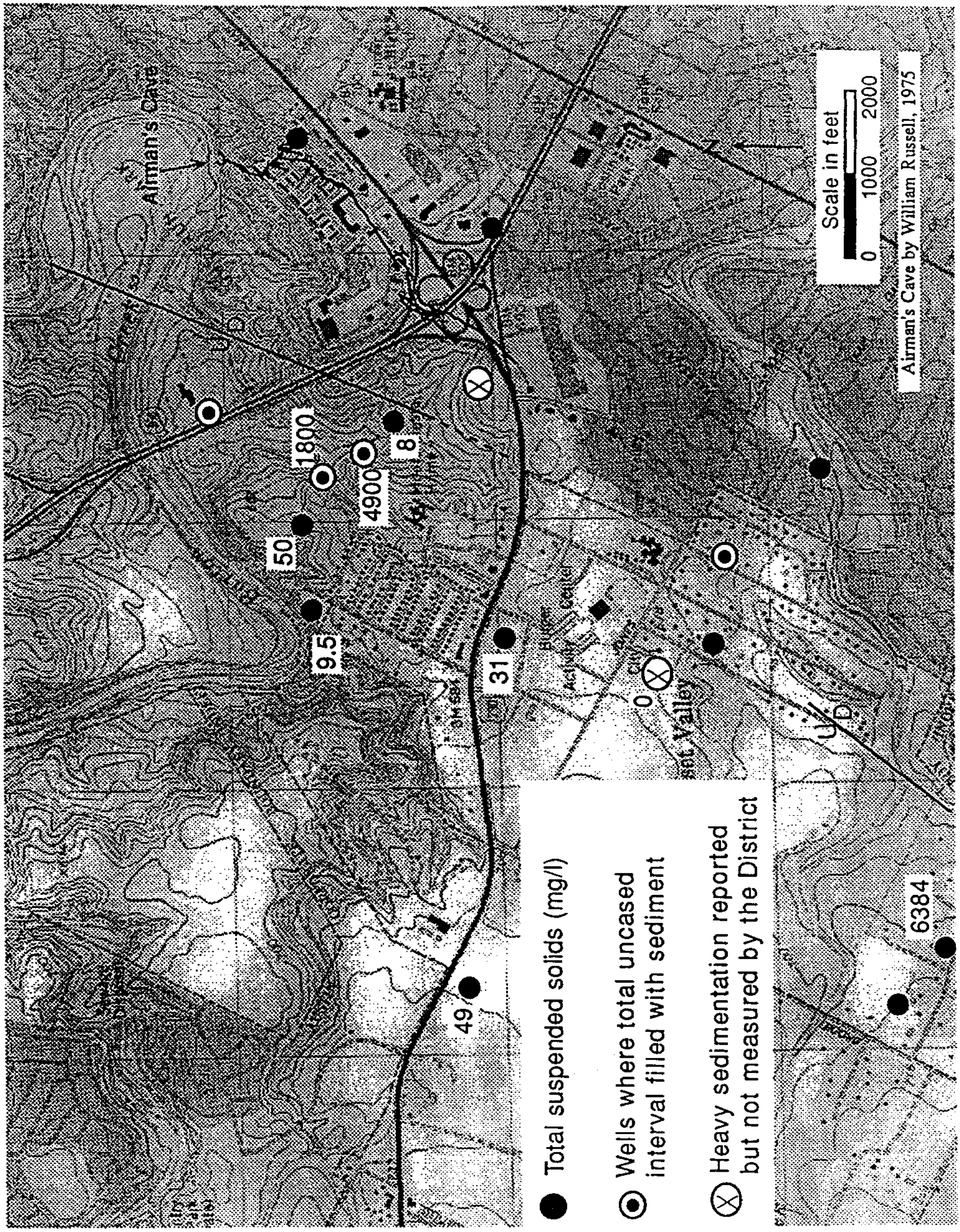


Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

Total Suspended Solids - 1993 and 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-28



Total Suspended Solids in wells in the South Austin and Sunset Valley Areas

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-29

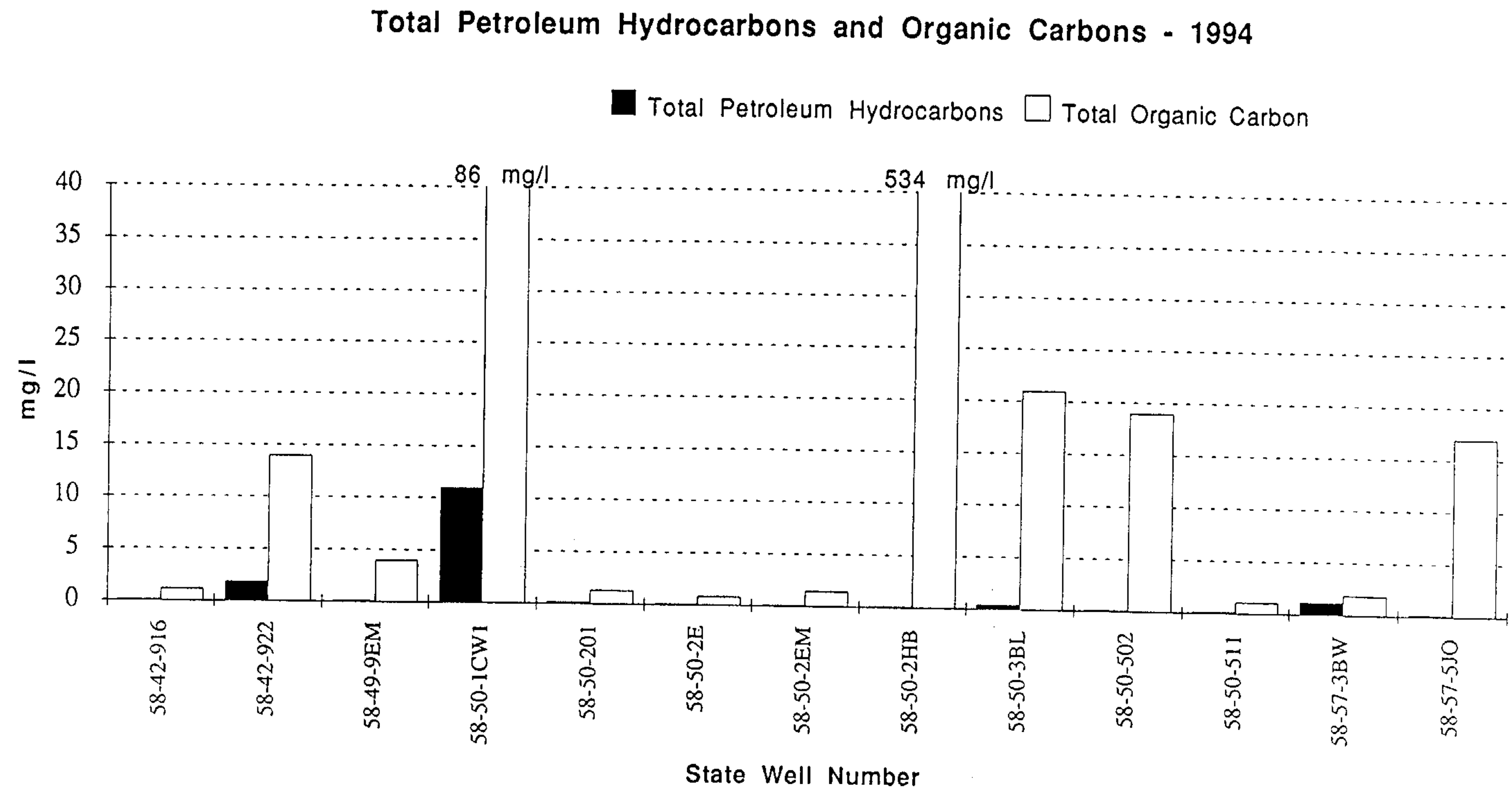
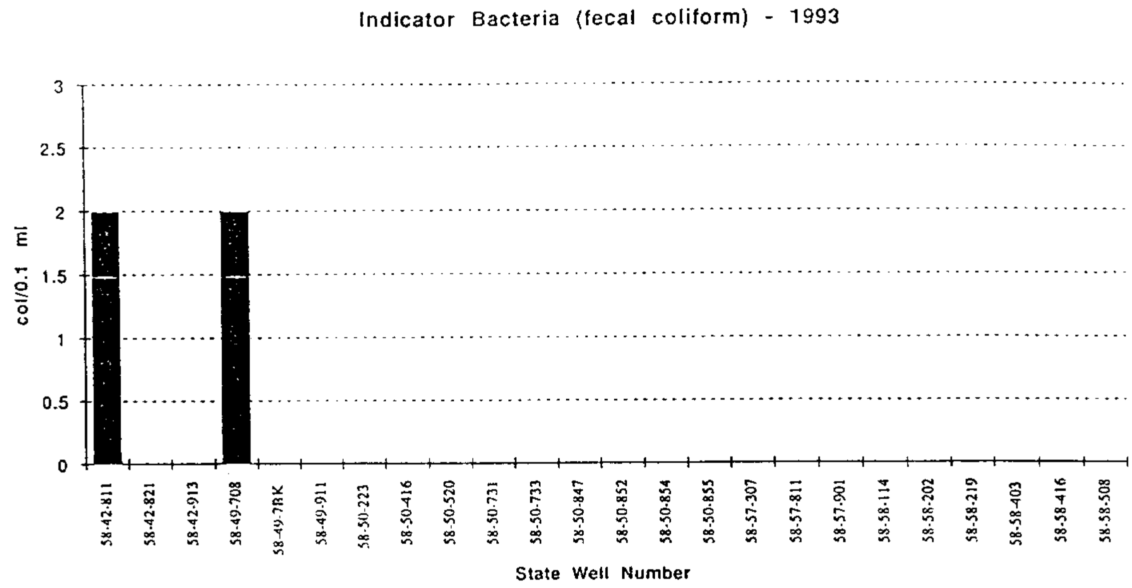
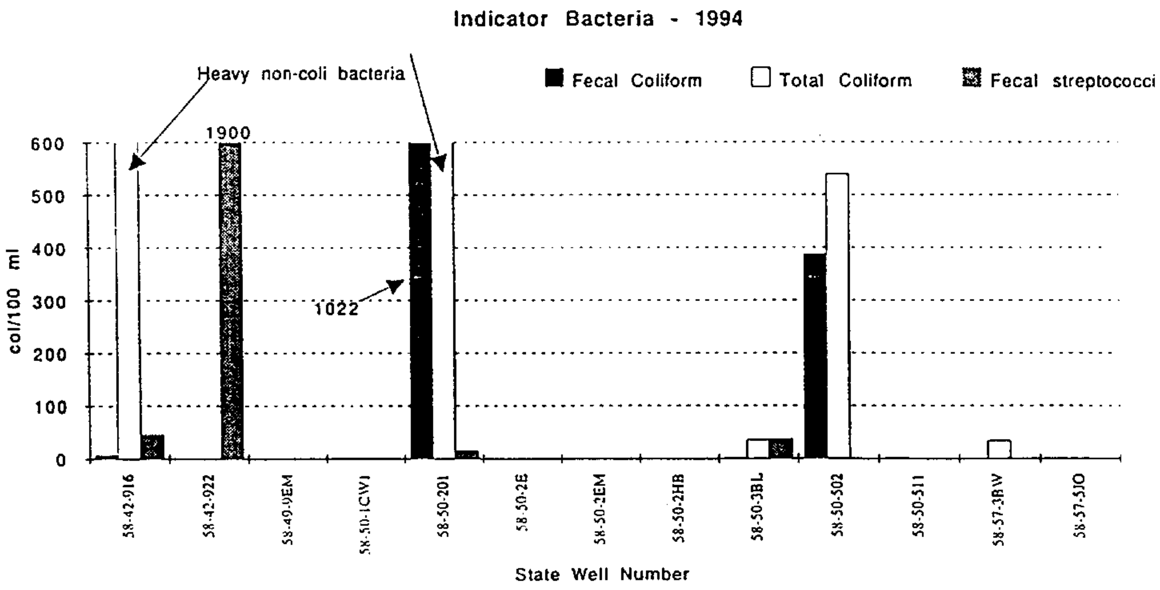


Figure IIB-30

Total Petroleum Hydrocarbons and Organic Carbons - 1994

Barton Springs/Edwards Aquifer
Water Quality Study

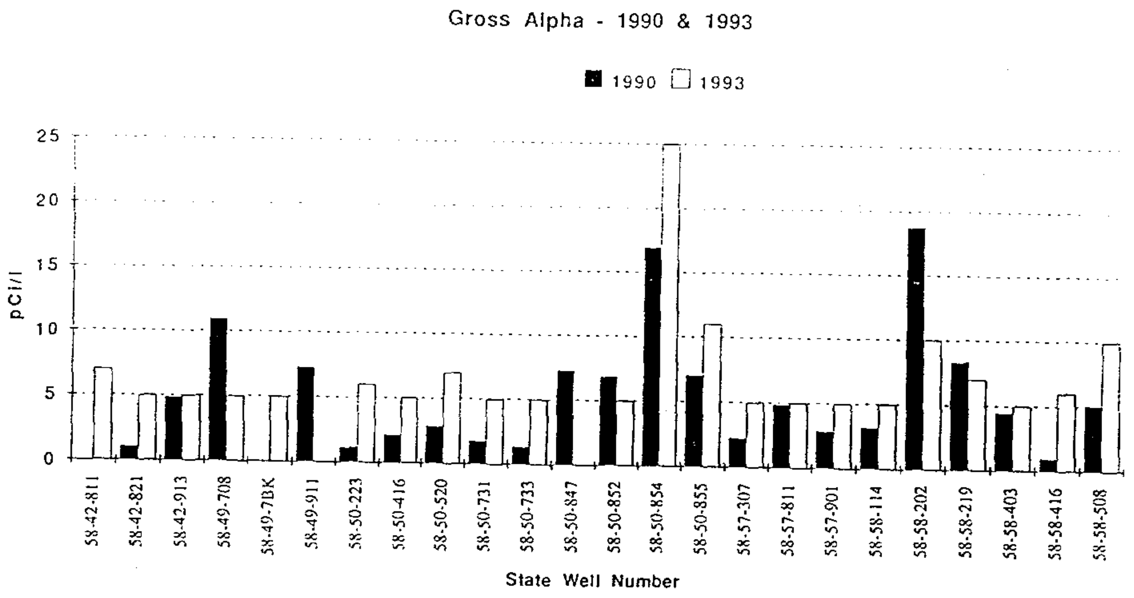


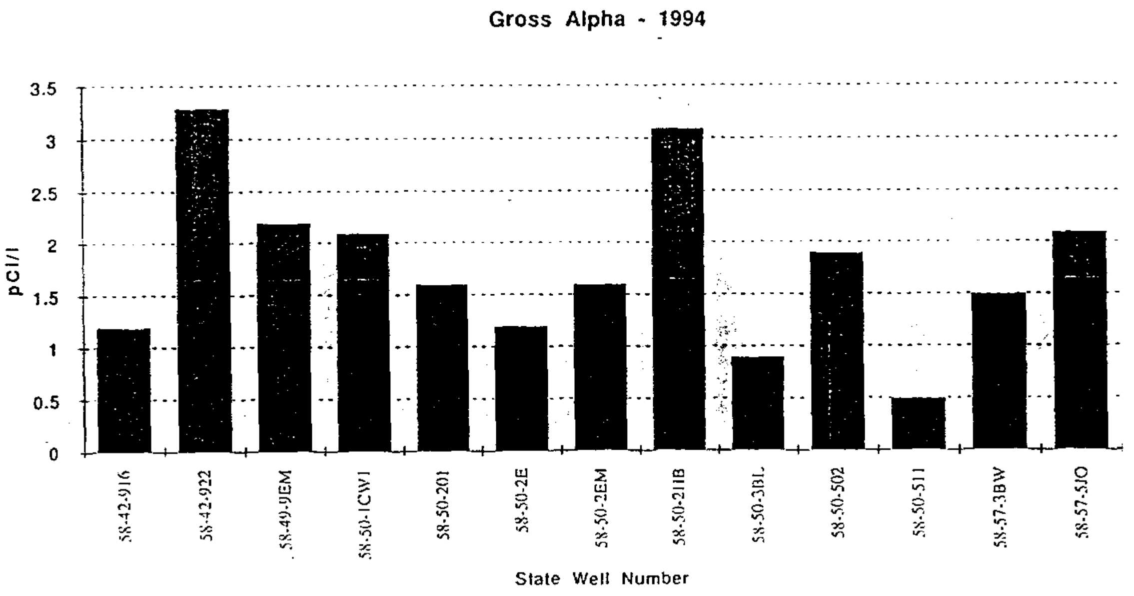


Indicator Bacteria - 1993, 1994

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-31

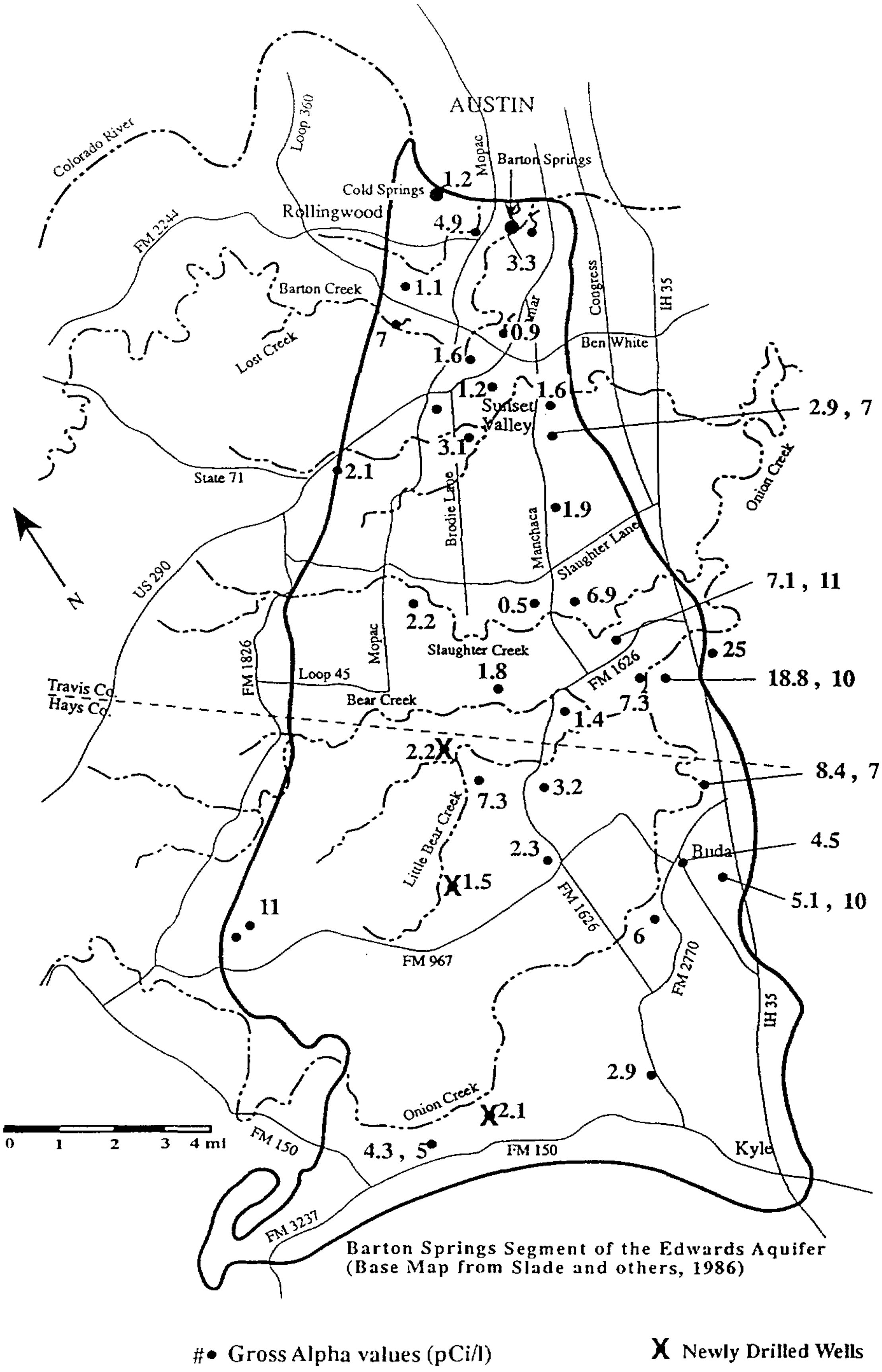




Gross Alpha Concentrations

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-32

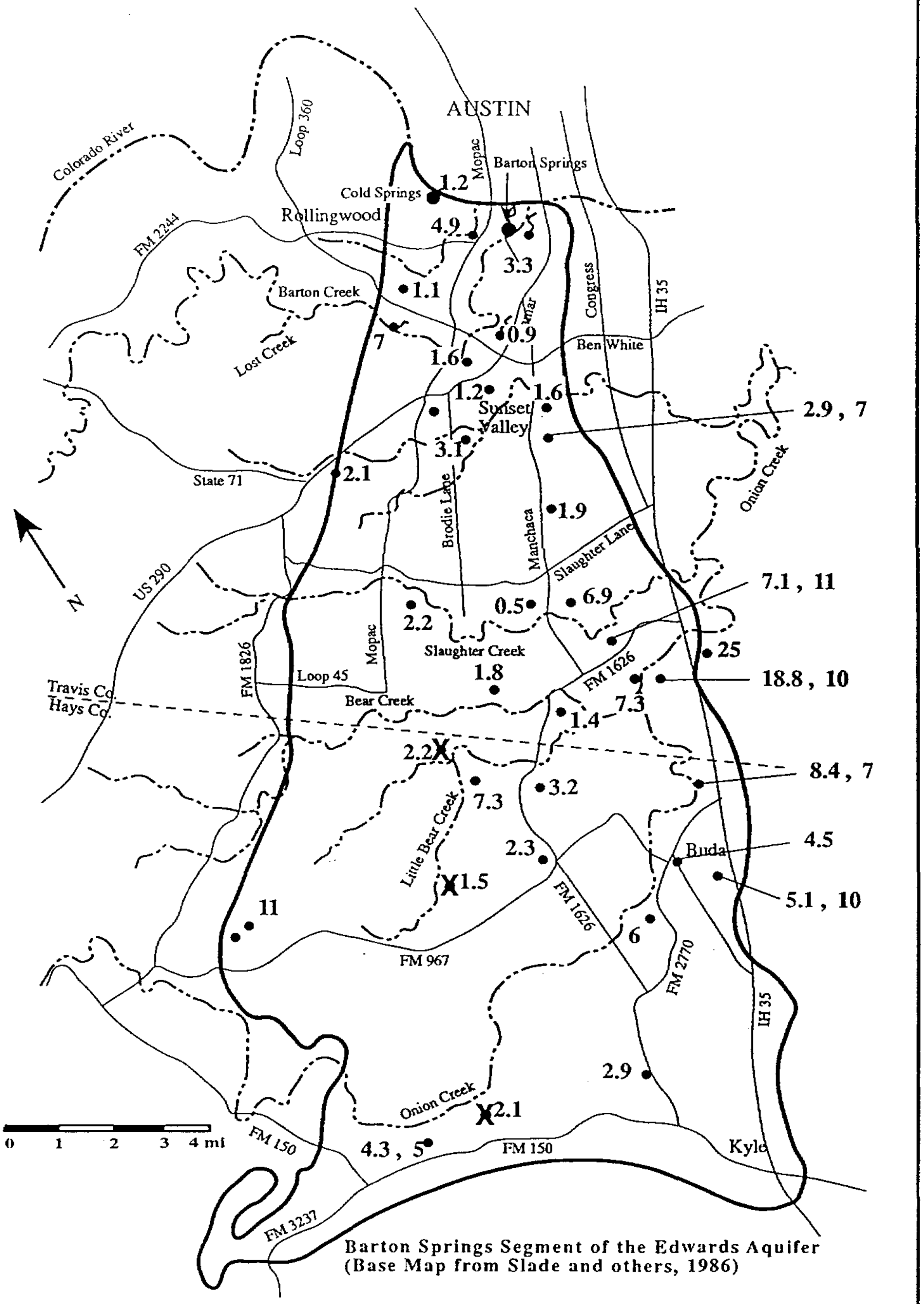


Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

Gross Alpha - 1990, 1993, 1994

Barton Springs/Edwards Aquifer Water Quality Study

Figure IIB-33



Barton Springs Segment of the Edwards Aquifer
(Base Map from Slade and others, 1986)

#● Gross Alpha values (pCi/l)

X Newly Drilled Wells

Gross Alpha - 1990, 1993, 1994

Barton Springs/Edwards Aquifer
Water Quality Study

Figure IIB-33

V. List of References Cited

Alhajjar, Bashar J., Gordon Chesters, and John M. Harkin, 1990, *Indicators of chemical pollution from septic systems*: Ground Water vol. 28 no. 1, pp. 559-568.

Alexander, Kenneth B., 1990, Correlation of structural lineaments and fracture traces to water-well yields in the Edwards Aquifer, Central Texas: Unpublished MA Thesis, Department of Geology of the University of Texas at Austin, 113 p.

Ashton, K., 1966, *The analysis of flow data from karst drainage systems.* Trans. Cave Research Group of Great Britain, Vol. 7, pp. 161-203.

Atkinson, T.C., 1976, *Diffuse flow and conduit flow in limestone terrain in the Mendip Hills, Somerset (Great Britain)*: Journal of Hydrology vol. 35 pp. 93-110.

Barrett, Micheal E., Robert D. Zuber, E.R. Collins, Joseph F. Malina, Jr, and Randall J. Charbeneau, 1993, A Review and Evaluation of Literature Pertaining to the Quantity and Control of Pollution from Highway Runoff and Construction: The University of Texas Center for Research in Water Resources Technical Report CRWR 239.

Barton Springs/Edwards Aquifer Conservation District, 1991, *Final report on the ground water quality monitoring program of the Barton Springs/Edwards Aquifer Conservation District.* Report to the Texas Water Development Board (Contract no. 483-773).

Barton Springs Task Force, 1991, *Report of the Barton Springs Task Force to the Texas Water Commission*:: Unpublished report by the City of Austin dated June 24, 1991.

Bhatkar, Awinash P., 1993, *Evaluation of bromacil as a groundwater contaminant in Texas*: Pesticide Impact Evaluation Report by the Texas Department of Agriculture Division of Pesticide Programs. 6 p.

Disposal Safety of America, 1993, *Bromacil as a Groundwater Contaminant:* Report Prepared for the United Mine Workers of America. 25 p. plus attachments.

Environmental Protection Agency, 1994, *Environmental Fact Sheet on Lead Leaching from Submersible Well Pumps*: EPA747-F-94-001.

Farm Chemicals Handbook, 1994, published by Meister Publishing Company.

Folk, R.L. and L.S. Land, 1975, *Mg/Ca ratio and salinity: two controls over crystallization of dolomite*: American Association of Petroleum Geologists Bulletin, vol. 59, no. 1, p. 60-68.

Geldreich, E.E., and B.A. Kenner, 1969, *Concepts of fecal streptococci in stream pollution*: Journal of the Water Pollution Control Federation, vol. 41, part 2, pp. A336-352.

Johns, David A., 1991, *Timing of stormwater effects on Barton Springs*: From Water Quality Issues for Barton Creek and Barton Springs, Austin Geological Society Field Trip Guidebook.

Keeney, Dennis R., *Nitrate in ground water - agricultural contribution and control*:: Proceedings of the Agricultural Impacts on Ground Water Conference, August 1986, pp. 329-351

Kreitler , Charles W. and David C. Jones, 1975, *Natural soil nitrate: the cause of nitrate contamination of ground water in Runnels County, Texas*: Ground Water, January/February 1975.

Maclay, R.W. and Ted A. Small, 1984, Carbonate geology and hydrology of the Edwards Aquifer in the San Antonio Area: U.S. Geological Survey. 72 pp.

McFetters, Gordon A., G.K. Eisonetti, J.J. Jeseski, C.A. Thompson, and D.J. Stuart, 1974, *Comprehensive survey of individual bacteria and enteric pathogens*:: Applied Microbiology vol. 27 pp. 823-839.

Nordstrom, Phillip L. and Eric O. Adidas, 1990, A Field Manual for Ground Water Sampling: Texas Water Development Board UM-51.

Ogden, Albert E., Ray A. Quick, Samuel R. Rothermel, David L. Rothermel, and Claire C. Snider, 1986, Hydrogeological and Hydrochemical Investigation of the Edwards Aquifer in the San Marcos Area, Hays County, Texas: Southwest Texas State University Edwards Aquifer Research and Data Center Report no. R1-86, Funded by the U.S. Fish and Wildlife Service Office of Endangered Species contract no. 14-16-0002-84-228.

Oudijk, Gil and Karen Mujica, 1989, Handbook for the Identification, Location, and Investigation of Pollution Sources Affecting Ground Water: National Water Well Assoc., Dublin, Ohio. 185 p.

Palmer, Arthur N., 1991, *Origin and morphology of limestone caves:* Geological Society of America Bulletin, vol. 103, pp. 1-212.

Pearson, F.J., P.L. Rettman, and T.A. Wyerman, 1975, *Environmental tritium in the Edwards Aquifer, Central Texas, 1963-1971*: U.S. Geological Survey Open File Report 74-362, 32 p.

Quinlan, James F., 1989, Ground-Water Monitoring in Karst Terranes: Recommended Protocols and Implicit Assumptions: U. S. Environmental Protection Agency/600/X-89/050.

Quinlan, James F., 1990, *Special problems of ground-water monitoring in Karst Terranes*, Ground Water and Vadose Zone Monitoring, ASTM STP 1053, D.M. Nielsen and A.I. Johnson, Editors, American Society for Testing and Materials, Philadelphia, pp. 275-304.

Russell, W. H., 1975, *Airman's Cave*: The Texas Caver, vol. 20, pp. 164-179. Map surveyed by members of Balcones and University Grottos, coordinated by W. Russell and Wes Loder, and drafted by P. Sprouse.

Russell, William H., 1987: *Edwards stratigraphy and oil spills in the Austin, Texas area*: The Texas Caver, April 1987.

Schepers, James, and Derrel Martin, 1986, *Public perceptions of ground water quality and the producers dilemma:* Proceedings of the Agricultural Impacts on Ground Water Conference, August 1986, pp. 399-411.

Senger, Rainer K. and Charles W. Kreitler, 1984, Hydrogeology of the Edwards Aquifer, Austin area, Central Texas: Bureau of Economic Geology Report of Investigations No. 141.

Senger, Rainer K., 1986, *Determinations of subsurface areas contributing water to Barton Springs*: from Austin Geological Society Guidebook 6, Hydrogeology of the Edwards Aquifer, Barton Springs Segment, Travis and Hays Counties, Texas, coordinated by C. M. Woodruff, Jr. and Raymond M. Slade.

Senger, Rainer K., Edward W. Collins, and Charles W. Kreitler, 1990, Hydrogeology of the Northern Segment of the Edwards Aquifer, Austin Region: Bureau of Economic Geology, Report of Investigations no. 192.

Slade, Raymond M. Jr., Micheal E. Dorsey, and Sheree L. Stewart, 1986, Hydrology and water quality of the Edwards Aquifer associated with Barton Springs in the Austin area, Texas: U.S.Geological Survey Water-Resources Investigations Report 86-4036.

Slade, Raymond M., Jr., Linda Ruiz and Diana Slage, 1985, Simulation of the Flow System of Barton Springs and Associated Edwards Aquifer in the Austin Area, Texas: U.S. Geological Survey Water - Resources Report 85-4299.

Smith, R. L. and J.H. Duff, 1988. *Denitrification in a sand and gravel aquifer*: Applied and Environmental Microbiology vol. 54, no. 5 pp. 1071-1078.

Stecher, Stephen L., Nancy McClintock, Mike Lyday, Fatima Paiva, Robert Heil, David Johns, and Melvin O. Hinson, 1992, Diagnostic Study of Water Quality Conditions in Town Lake, Austin, Texas: Report prepared by the City of Austin Environmental and Conservation Services Department, COA-ERM/WRE 1992-01.

Texas Groundwater Protection Committee, 1993, Joint groundwater monitoring and contamination Report 1992: Texas Natural Resource Conservation Commission SFR-1.

Tillman, David A., 1989, *Statistical analysis of water elevations and springflow for the Barton Springs Edwards Aquifer Region*: Unpublished report to the Barton Springs/Edwards Aquifer Conservation District.

Thrailkill, J., 1985, *Flow in a limestone aquifer as determined from water tracing and water levels in wells*: Journal of Hydrology, vol. 78, pp. 123-136.

Veenhuis, Jack E., and Raymond M. Slade, 1990: Relation between Urbanization and Water Quality of Streams in the Austin Area, Texas. U.S. Geological Survey Water-Resource Investigations Report 90-4107. 64 pp.

Wanielista, M.P., T.A.Tousef, and J.E. Christopher, 1980, Final Report on the Management of Runoff from Highway Bridges: Florida Department of Transportation report FL-ER-10-80, Tallahassee, Florida.

White, William, W., 1988, Geomorphology and Hydrology of Karst Terranes: Oxford University Press. 464 pp.

Woodruff, C. M., 1984, *Water budget analysis for the area contributing recharge to the Edwards Aquifer, Barton Springs Segment:* from Austin Geological Society Guidebook no. 6, Hydrogeology of the Edwards Aquifer-Barton Springs Segment, Travis and Hays County.

Woodruff, Charles W., Jr. Laura De LaGarza, and Fred R. Synder, 1989, Lineaments and the Edwards Aquifer - Barton Springs Segment, Travis and Hays County, Texas: Edwards Aquifer Research and Data Center Report of Investigations no. 89, 45 p.

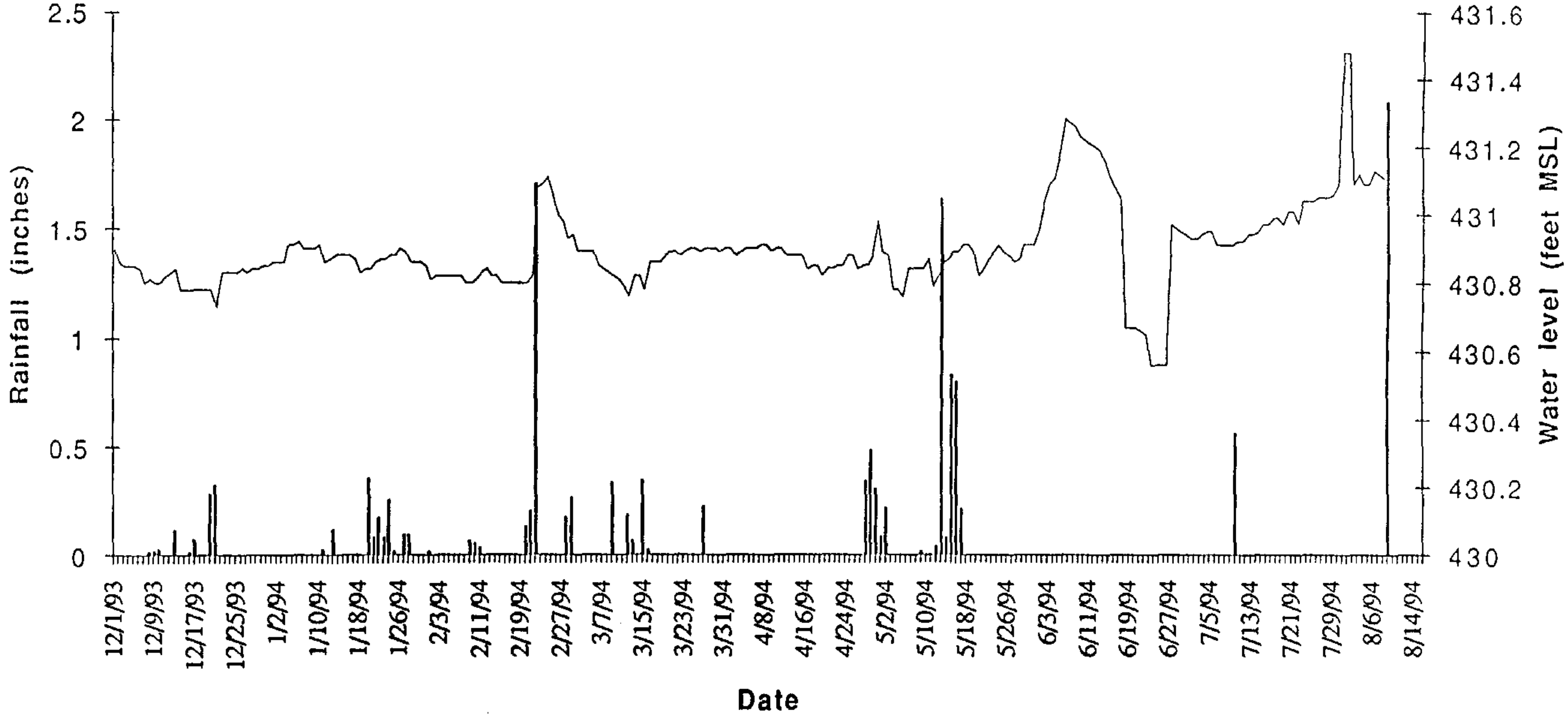
Woodruff, C. M., 1984, *Water budget analysis for the area contributing recharge to the Edwards Aquifer, Barton Springs Segment:* from Austin Geological Society Guidebook no. 6, Hydrogeology of the Edwards Aquifer-Barton Springs Segment, Travis and Hays County.

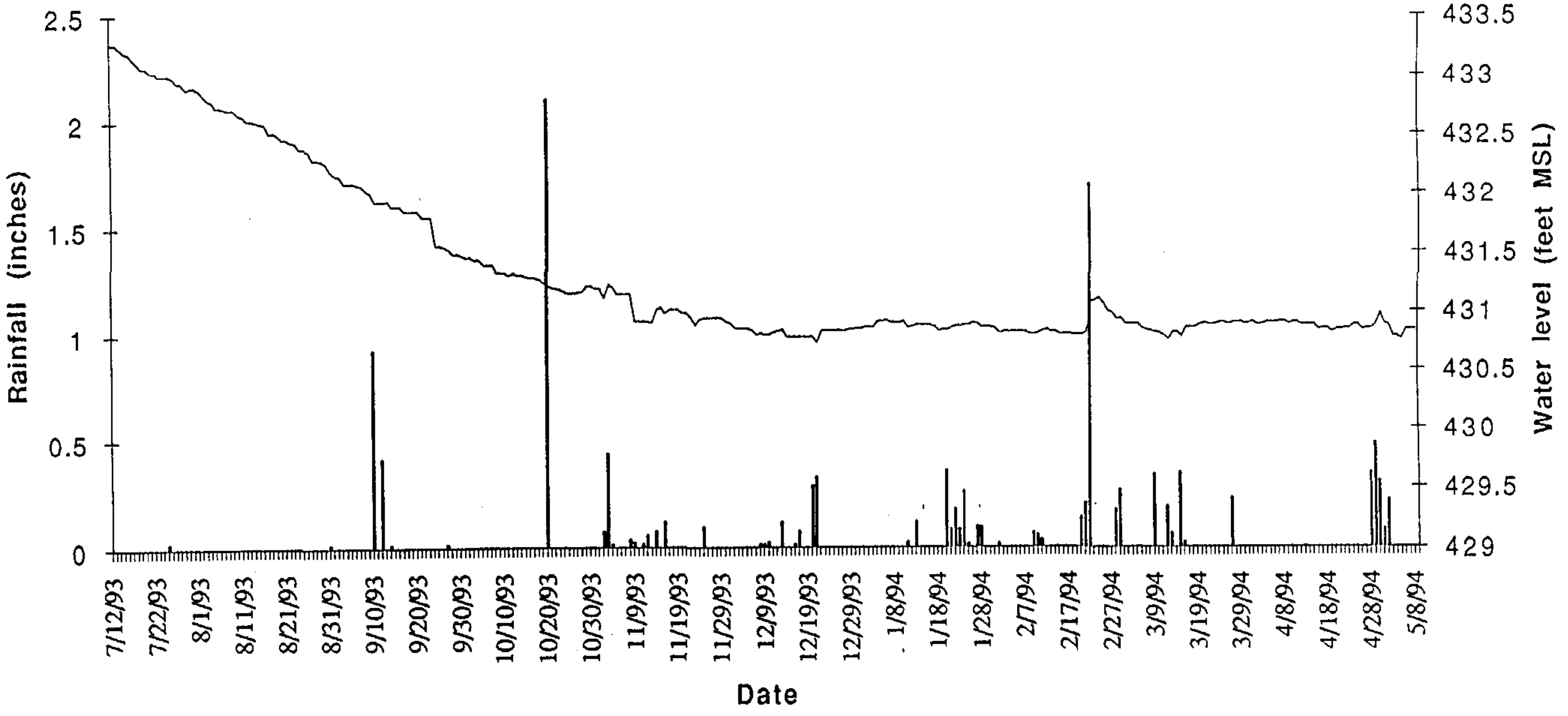
Woodruff, Charles W., Jr. Laura De LaGarza, and Fred R. Synder, 1989, Lineaments and the Edwards Aquifer - Barton Springs Segment, Travis and Hays County, Texas: Edwards Aquifer Research and Data Center Report of Investigations no. 89, 45 p.

Appendix A.
Water-Level Elevations from Individual Monitor Wells

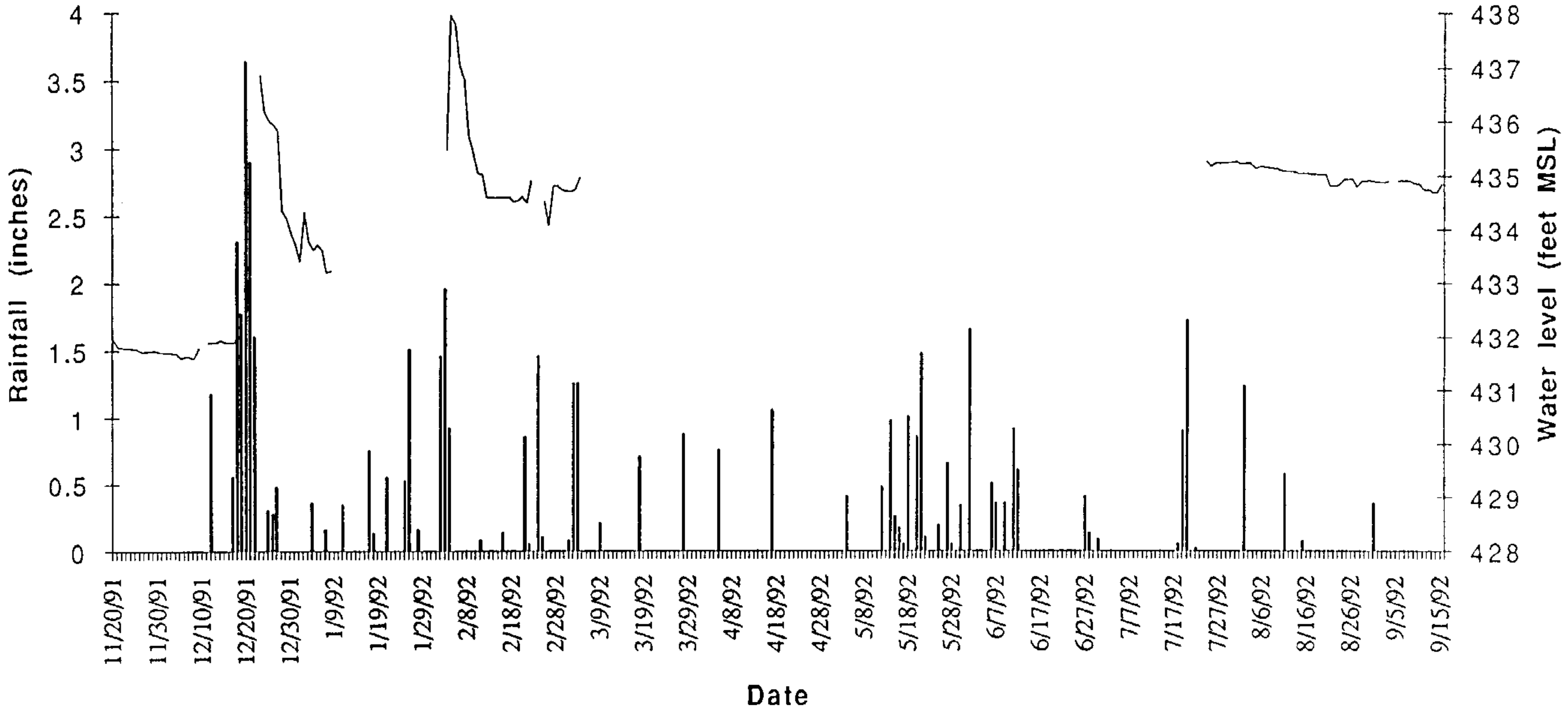
58-42-903
Barton Springs Well
Continuous Water Levels

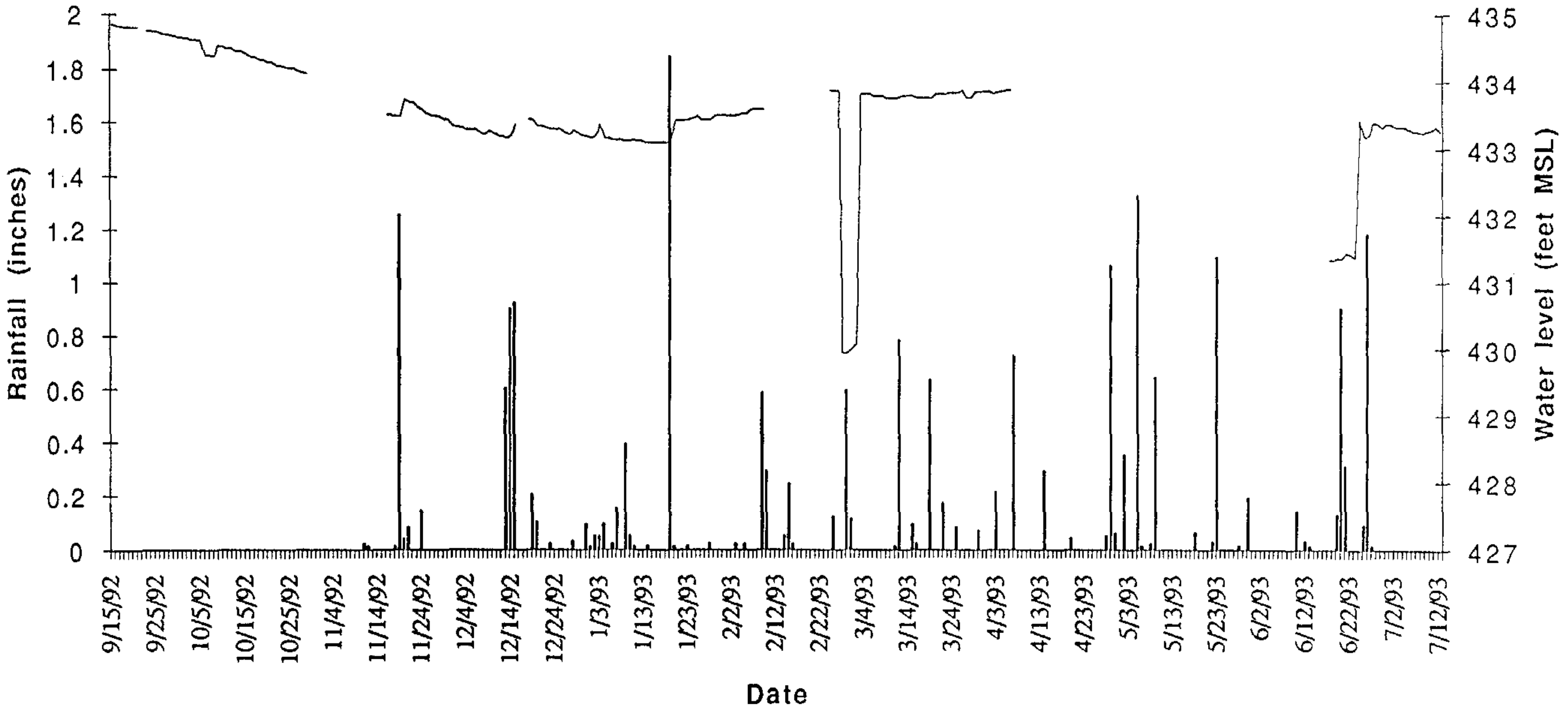
Barton Springs Well Levels and Rainfall Events - 1993 & 1994




Barton Springs Well Levels and Rainfall Events - 1993 & 1994

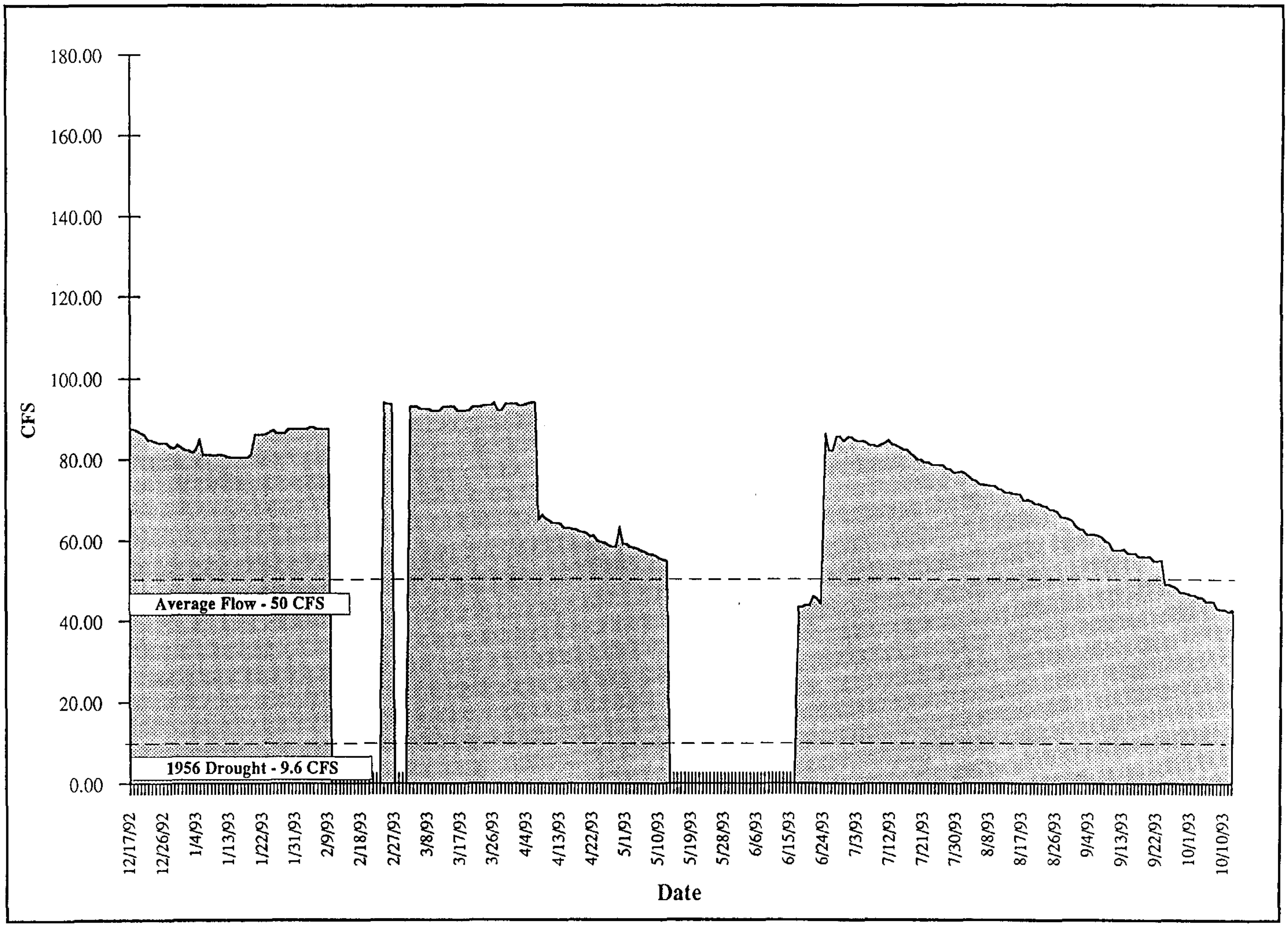
Barton Springs Well Levels and Rainfall Events - 1991 & 1992



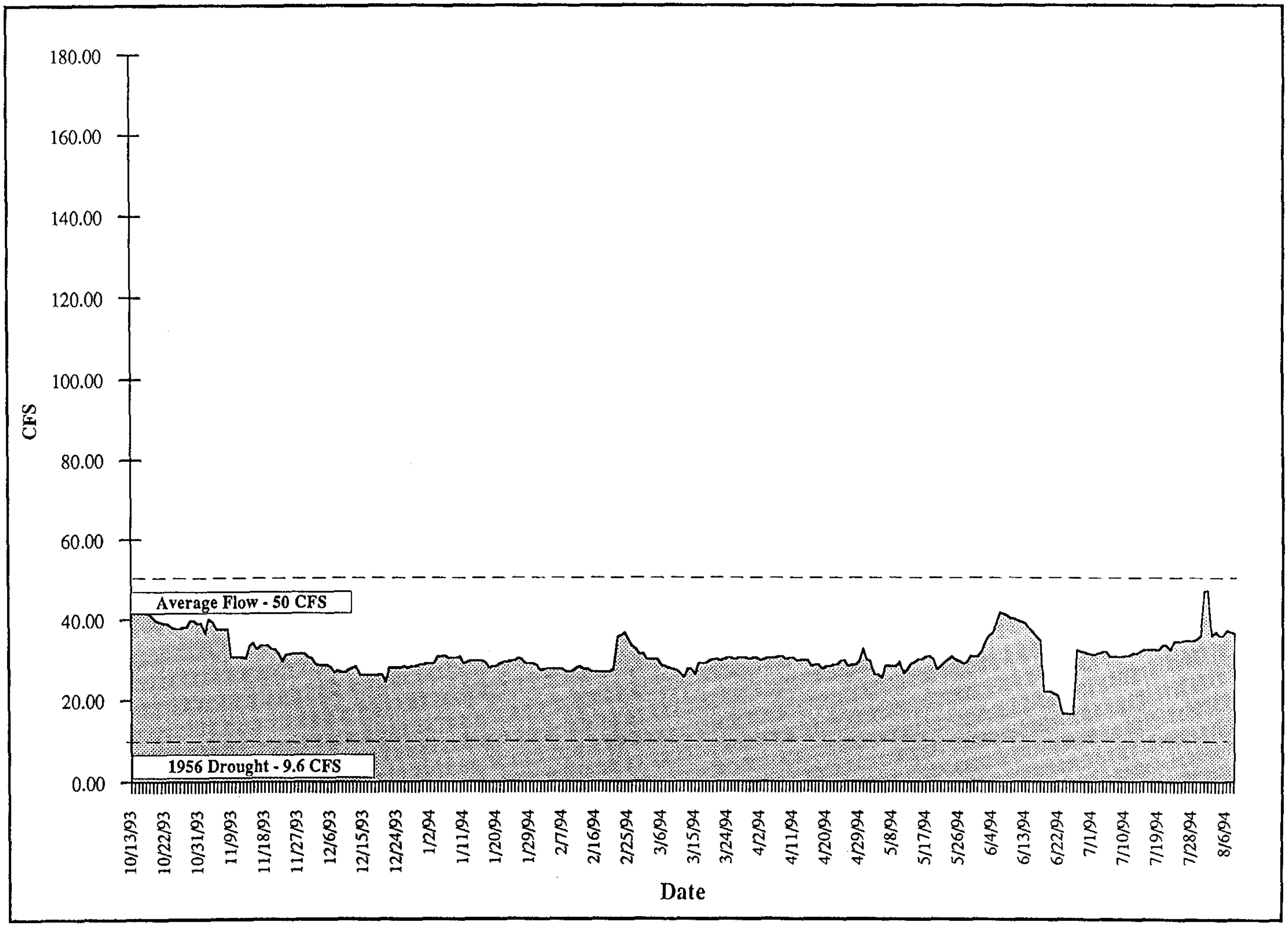

Barton Springs Well Levels and Rainfall Events - 1992 & 1993

58-42-914/ 58-42-921/ 58-42-922
Combined Flow from Barton Springs

Barton Springs Flow - Cubic Feet per Second

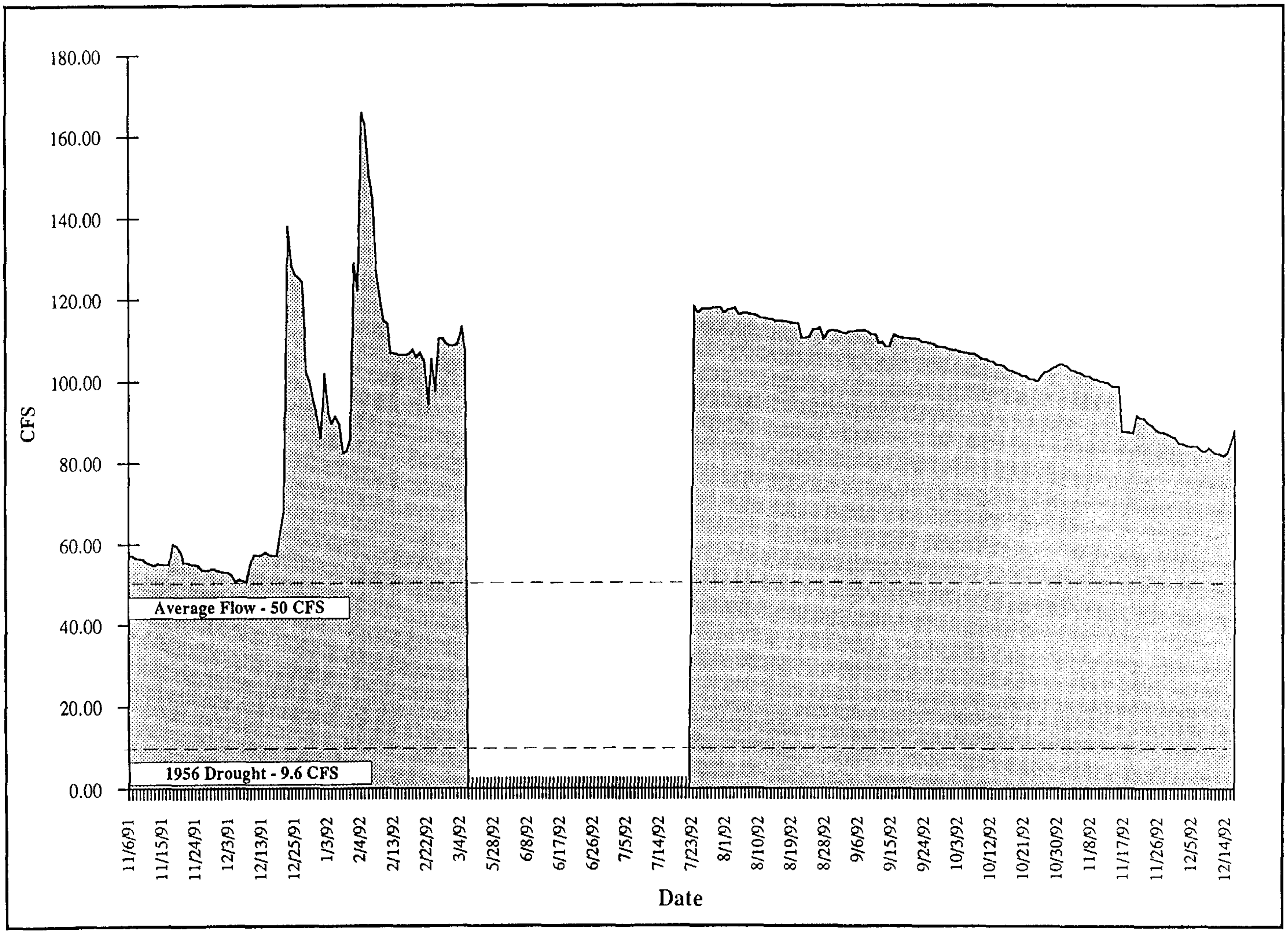


Barton Springs Flow - Cubic Feet per Second

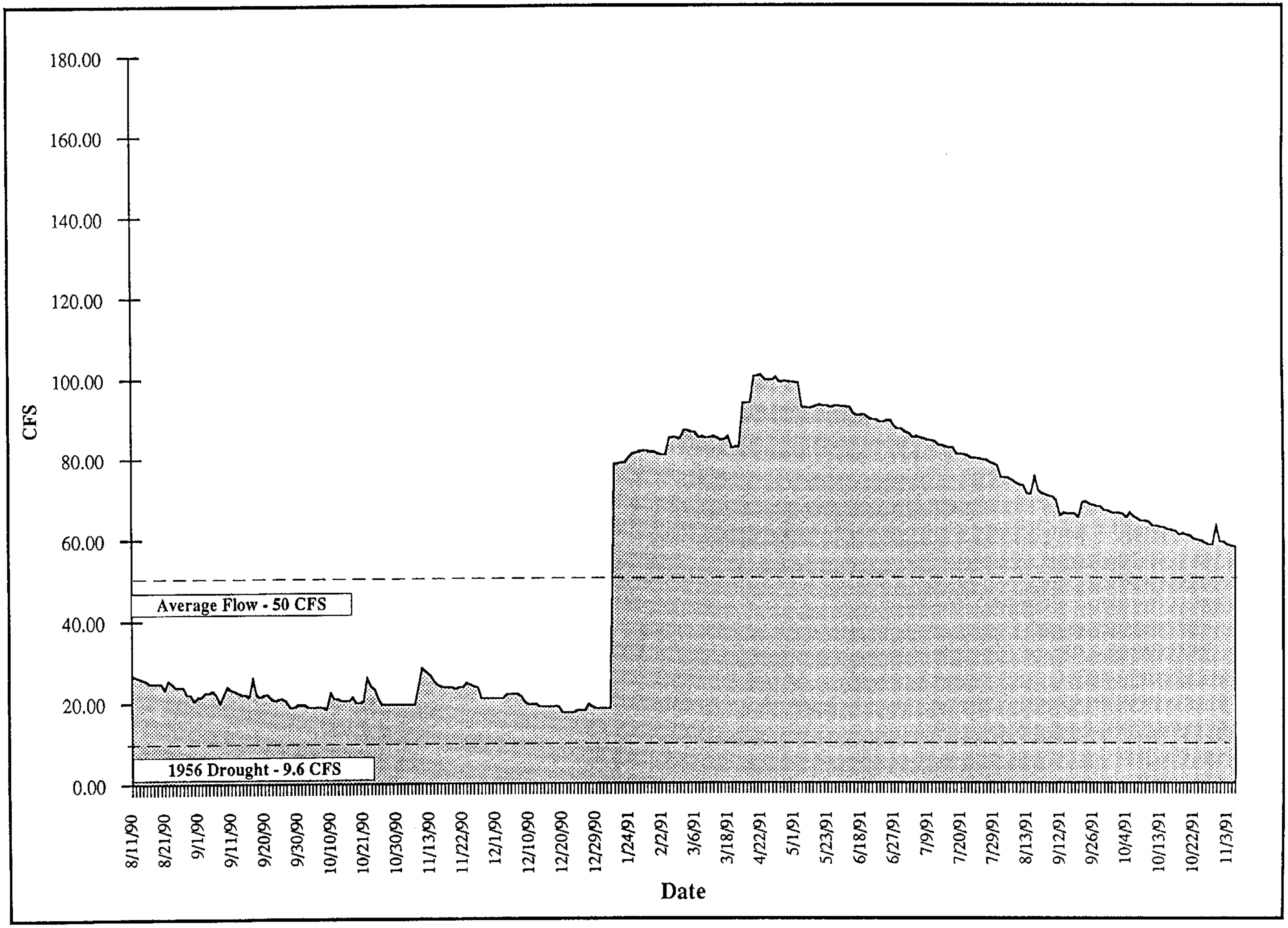


Barton Springs/Edwards Aquifer Conservation District 9/1/94

Barton Springs Flow - Cubic Feet per Second



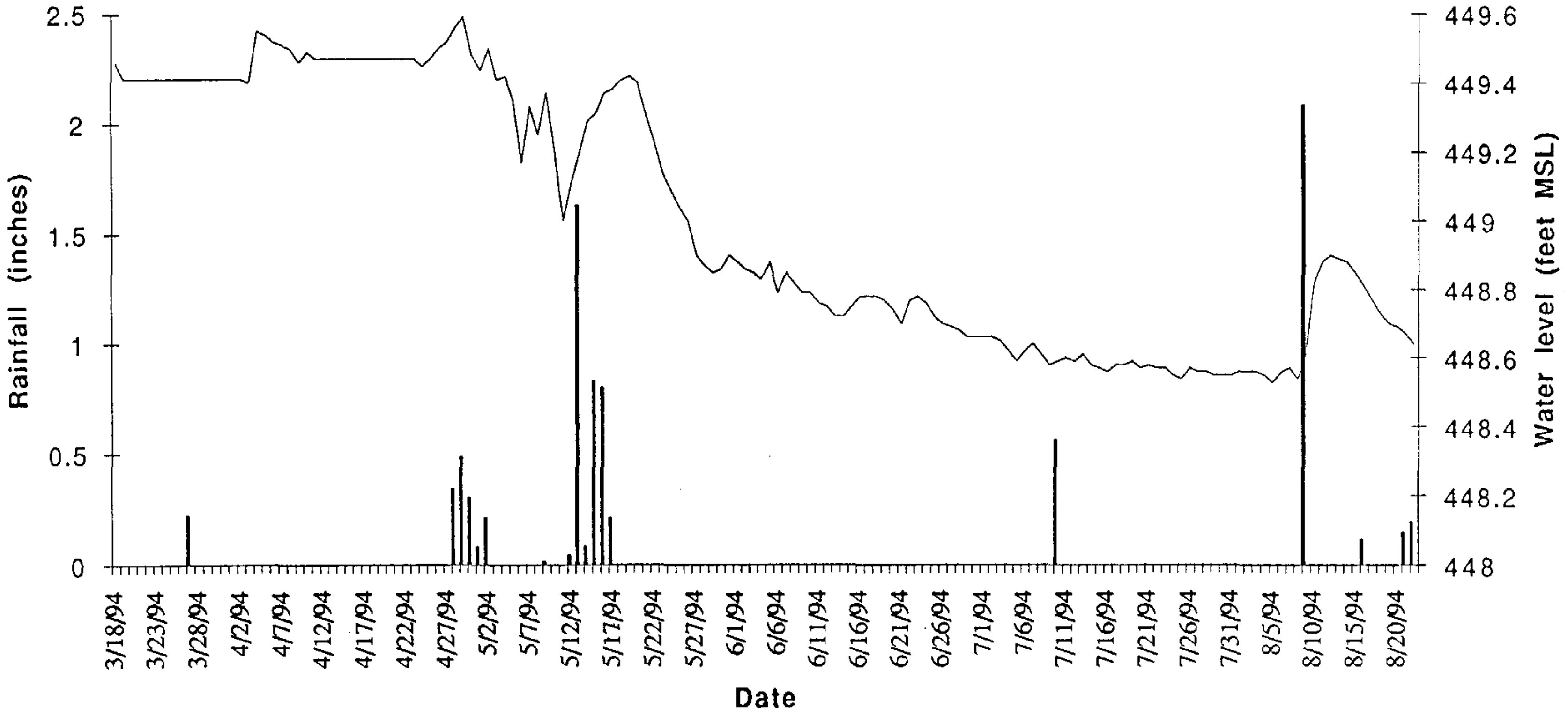
Barton Springs Flow - Cubic Feet per Second



Barton Springs/Edwards Aquifer Conservation District

9/1/94

58-42-8TW
Tom Walters Eye Care Center Well
Continuous Water Levels

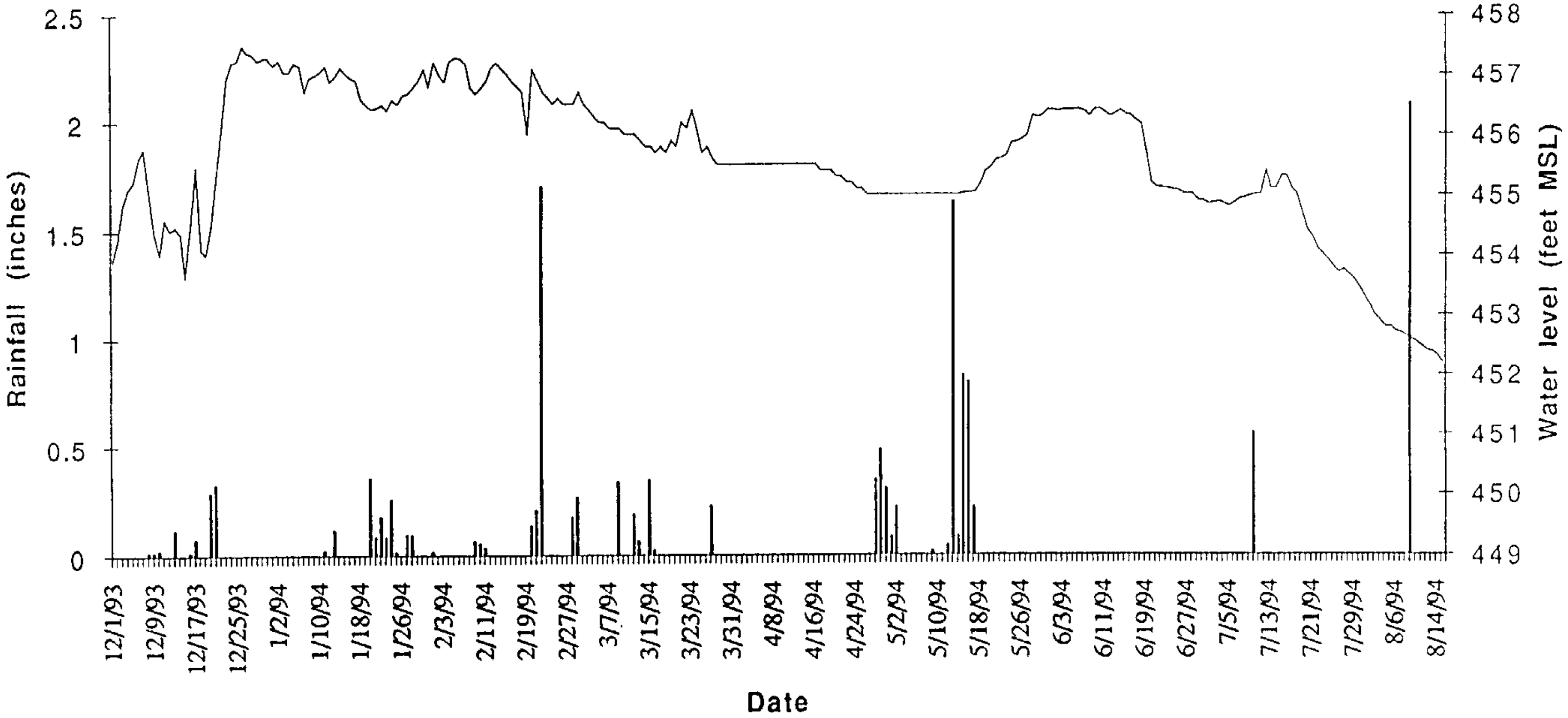


Eye Care Well Levels and Rainfall Events - 1994

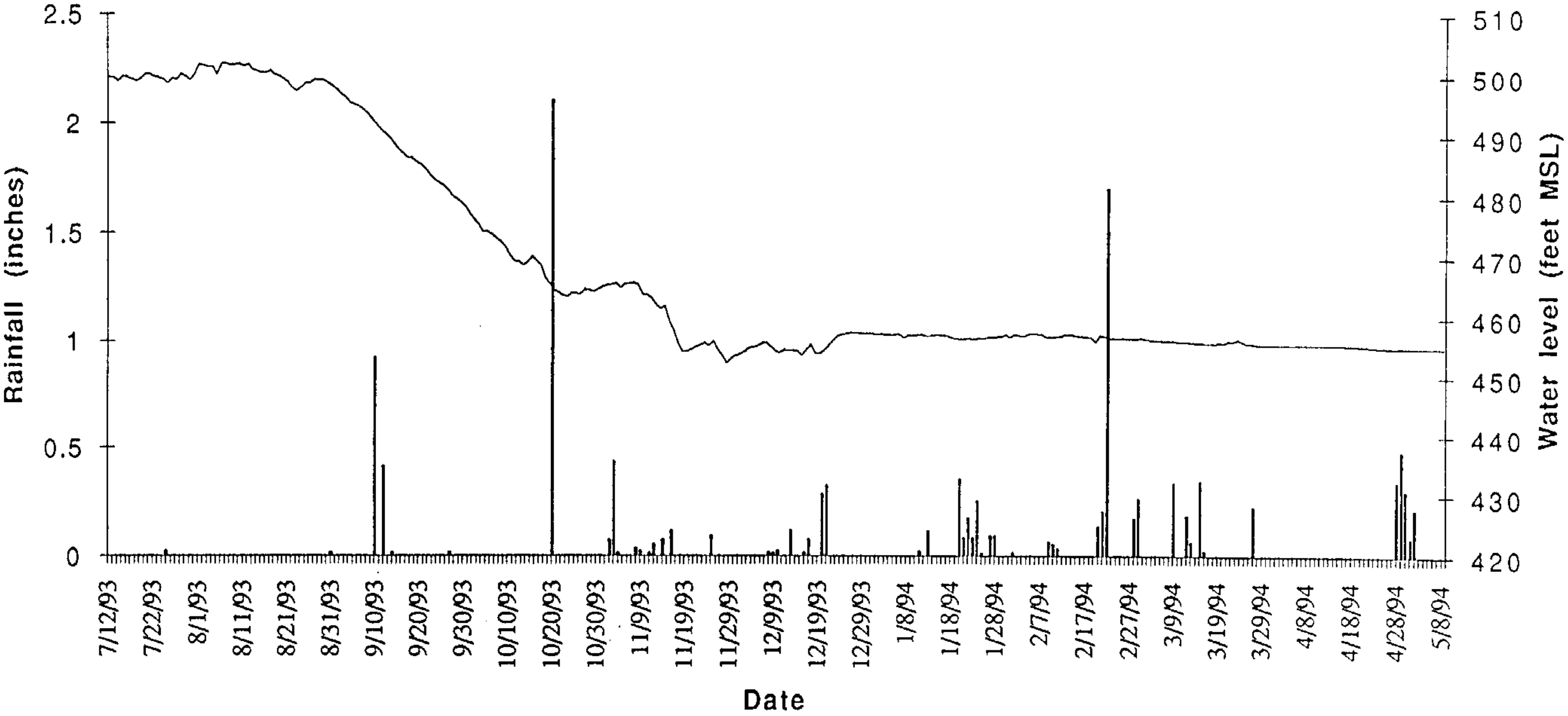
Target Well Levels and Rainfall Events - 1994

58-50-301
Lovelady Well
Continuous Water Levels

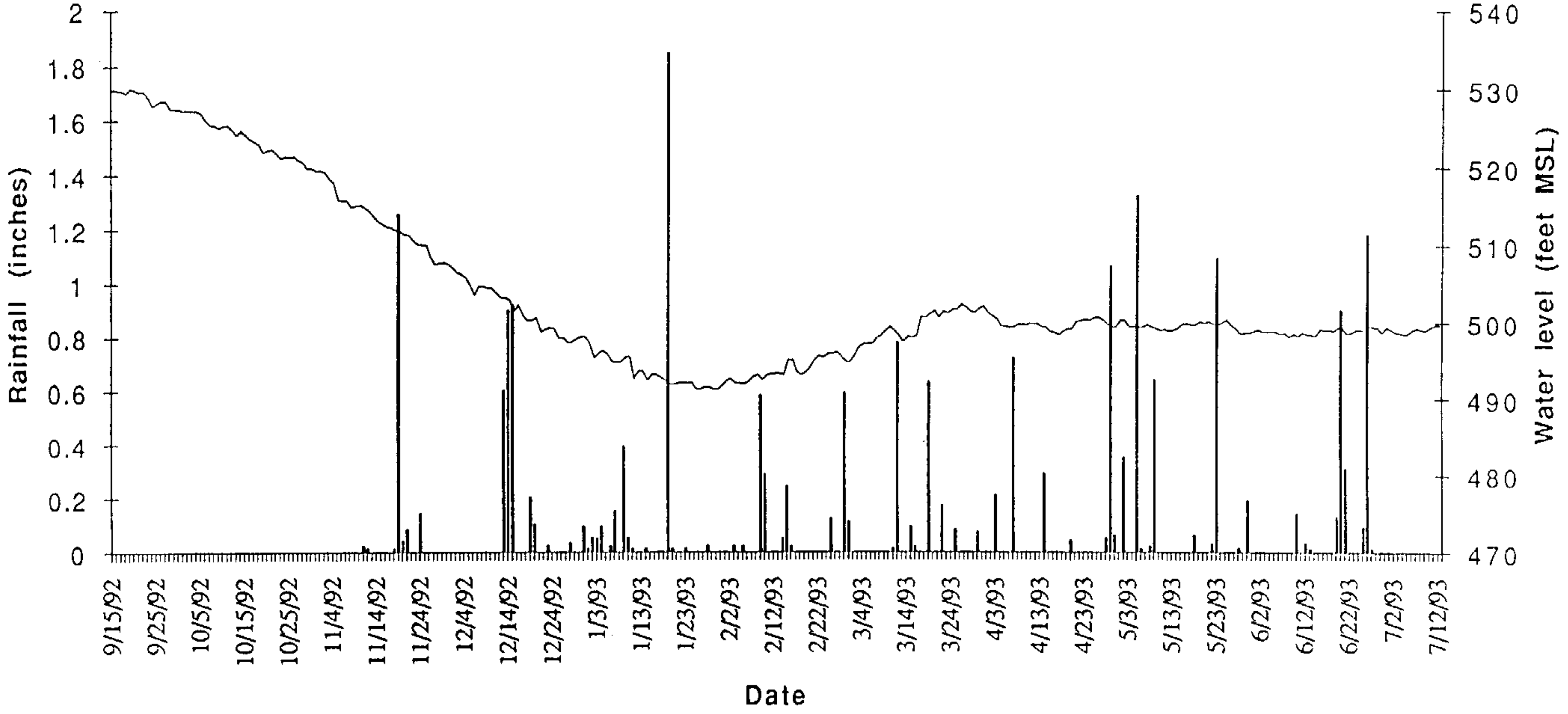
Lovelady Well Levels and Rainfall Events - 1993 & 1994



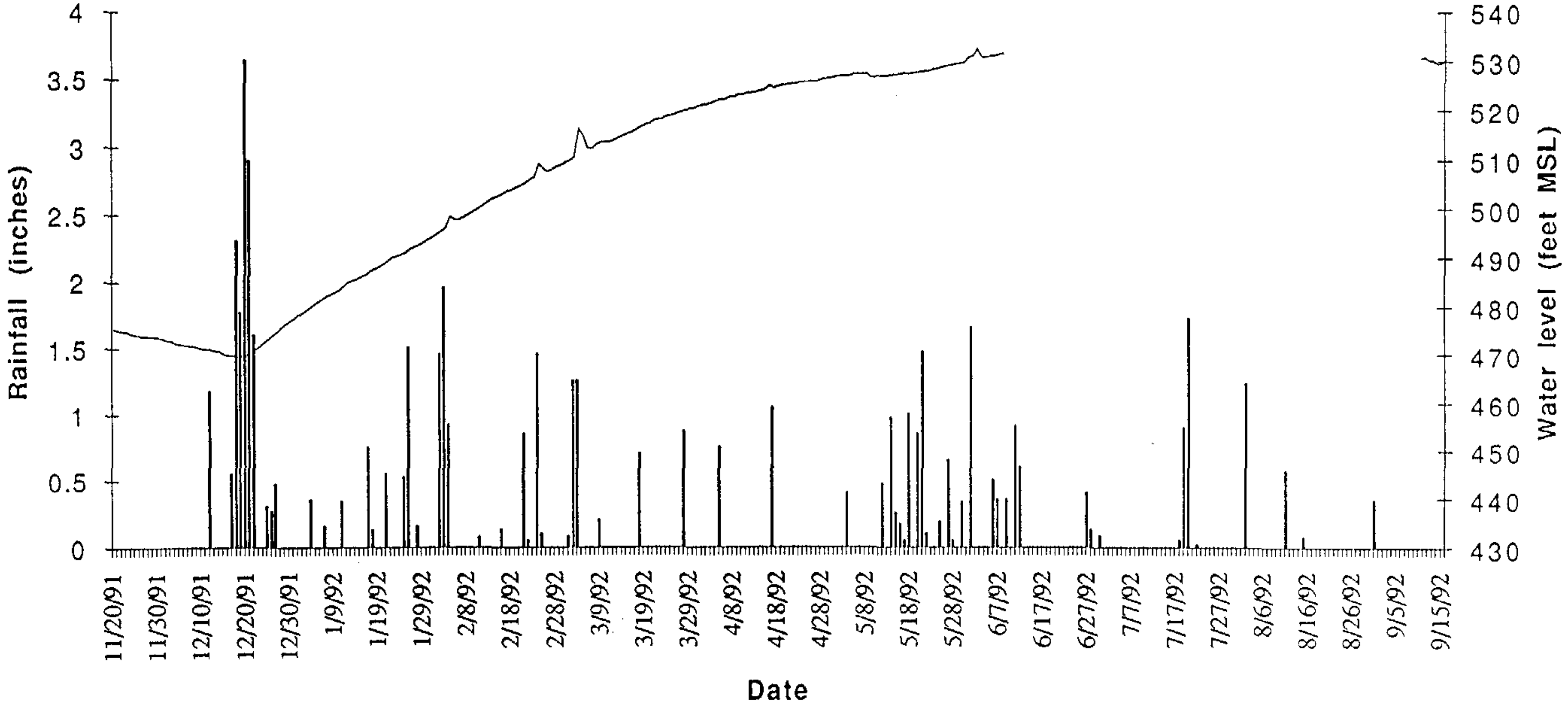
Lovelady Well Levels and Rainfall Events - 1993 & 1994



Lovelady Well Levels and Rainfall Events - 1992 & 1993



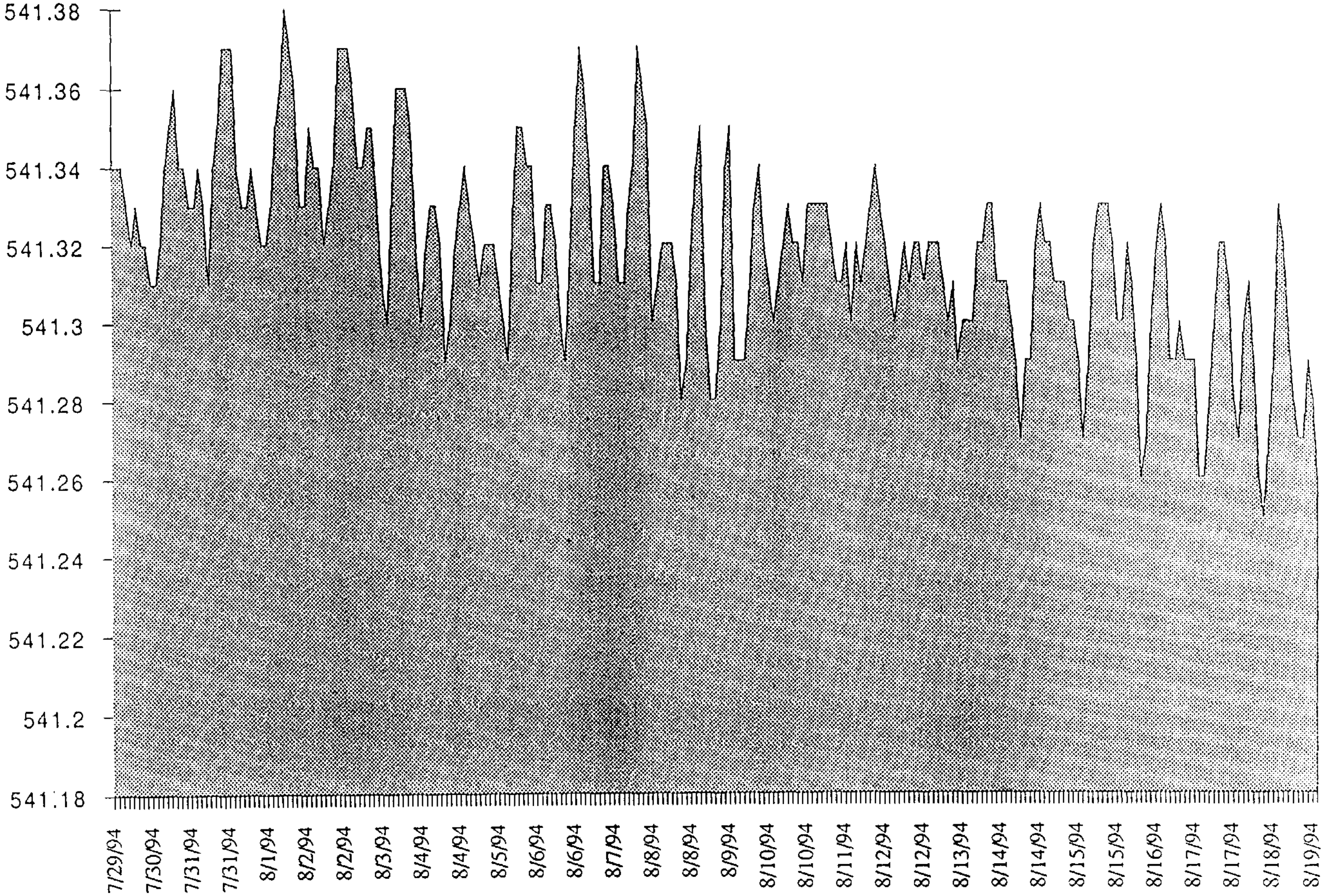
Lovelady Well Levels and Rainfall Events - 1991 & 1992



58-50-411
Circle C Well
Continuous Water Levels

Circle C Monitor Well

Brodie and Slaughter Lane

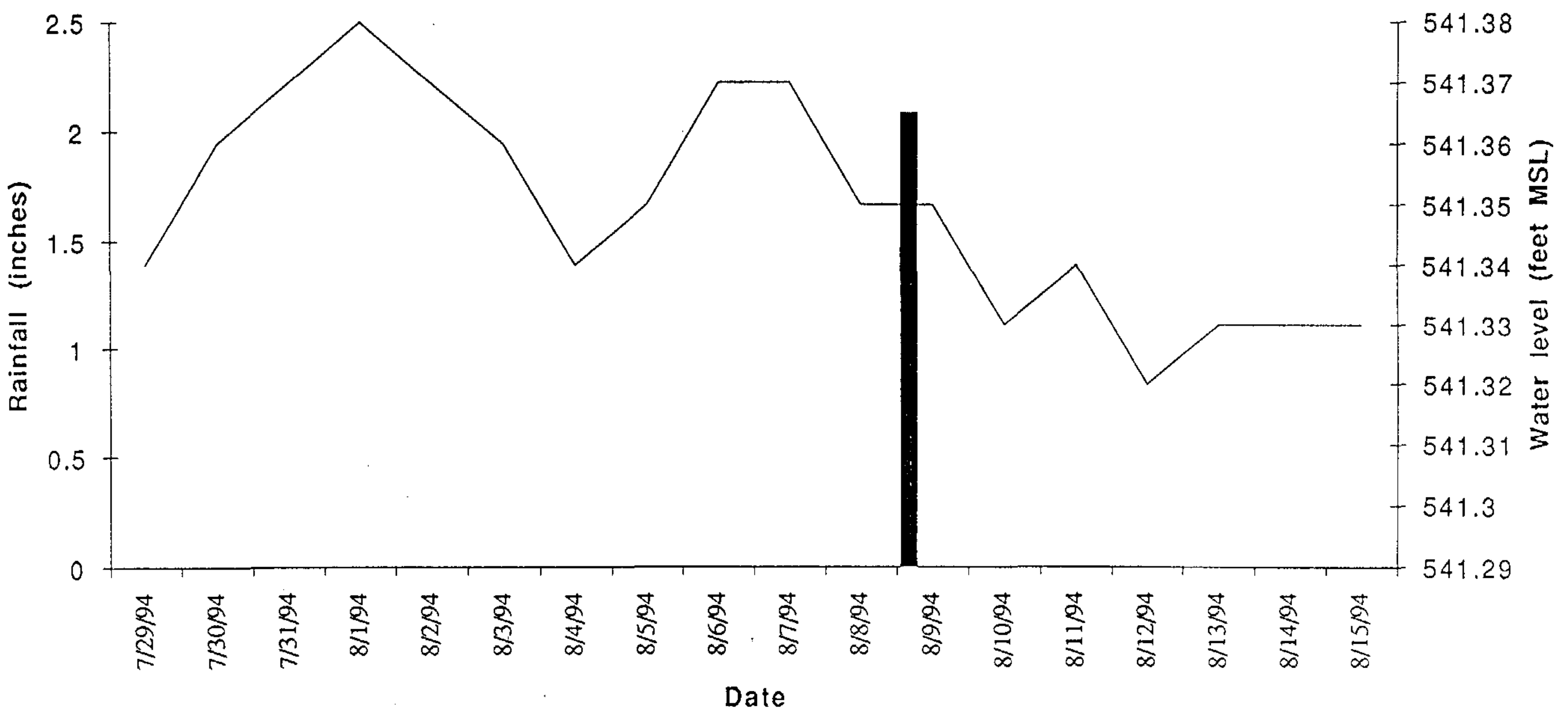


Barton Springs/Edwards Aquifer Conservation District

Well # 58-50-411

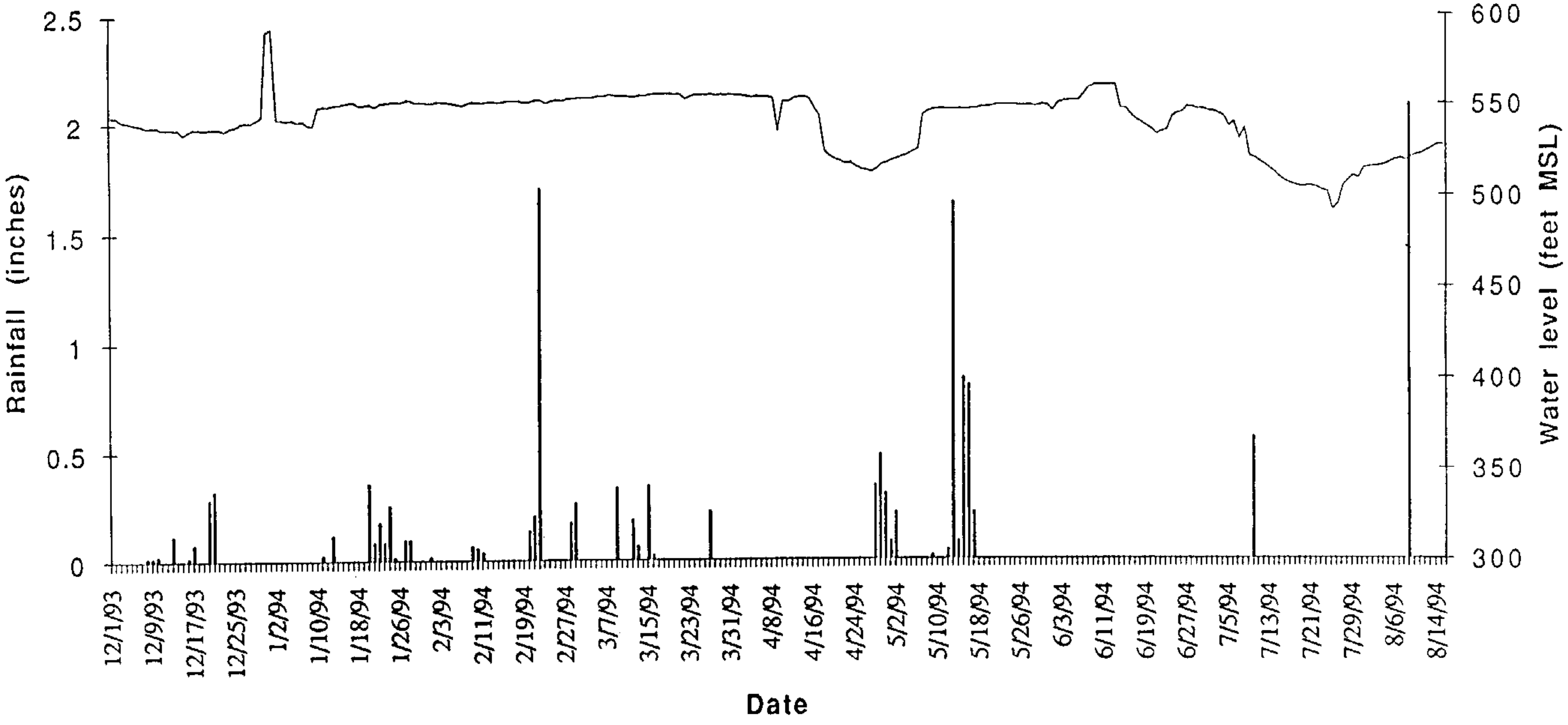
8/24/94

Circle C Well Levels and Rainfall Events - 1994

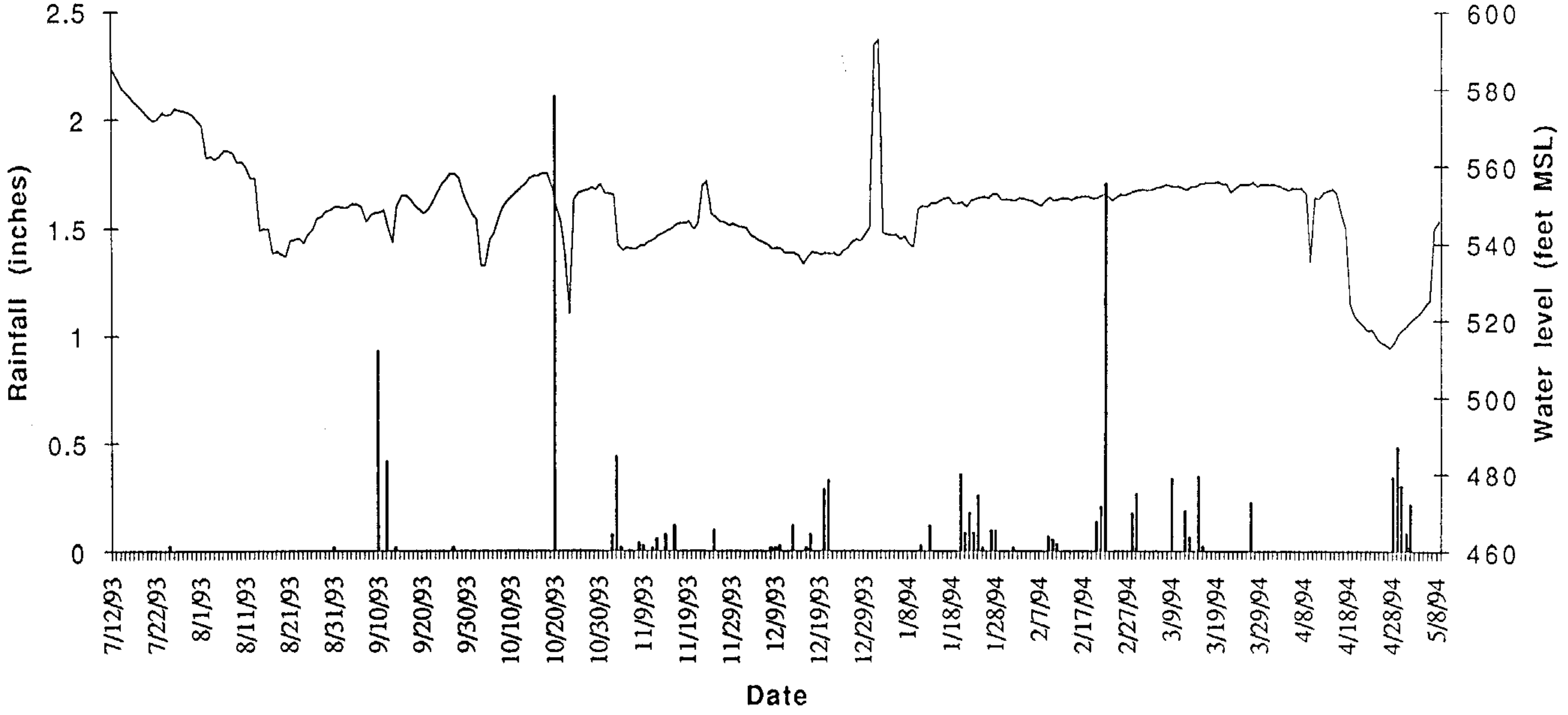


58-50-801
Dowell Well
Continuous Water Levels

Dowell Well Levels and Rainfall Events - 1993 & 1994

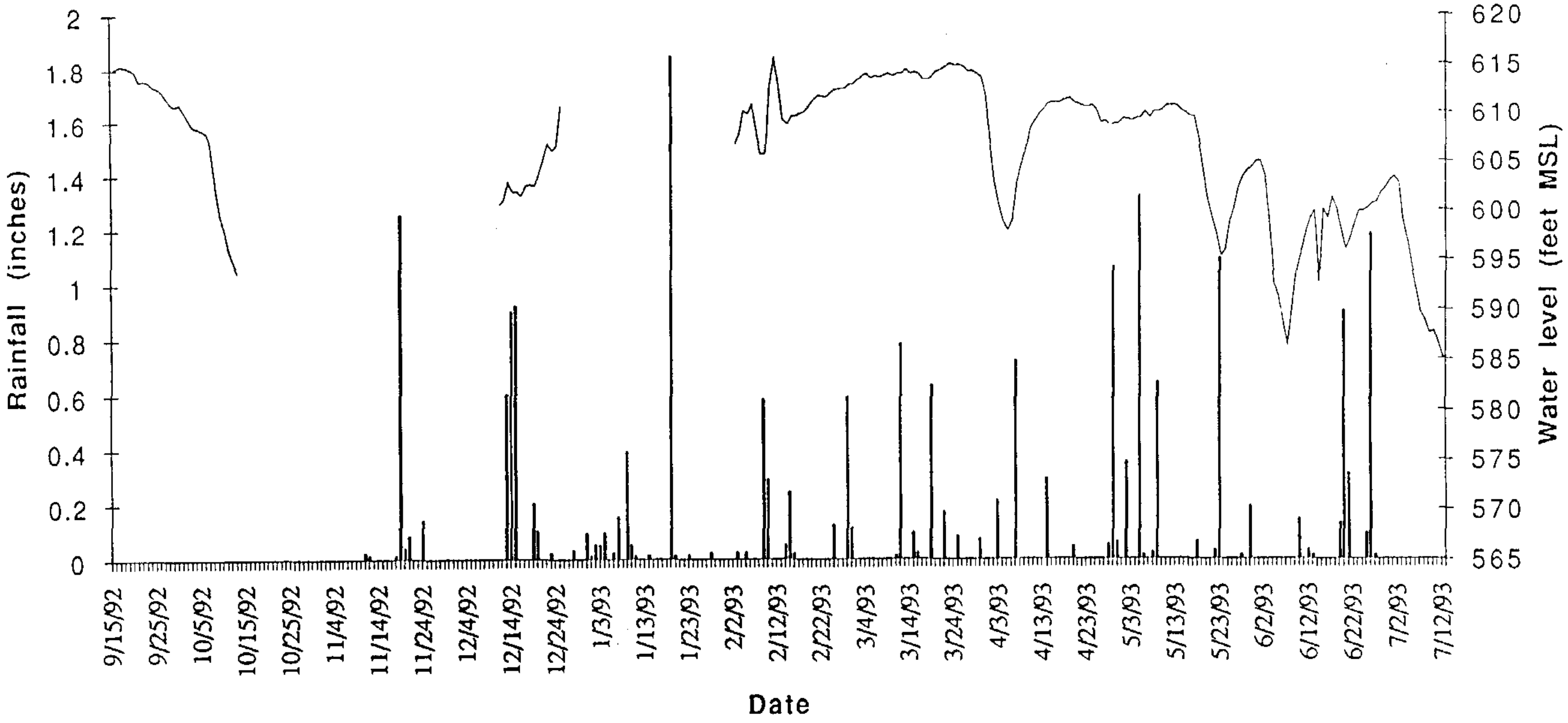


Dowell Well Levels and Rainfall Events - 1993 & 1994



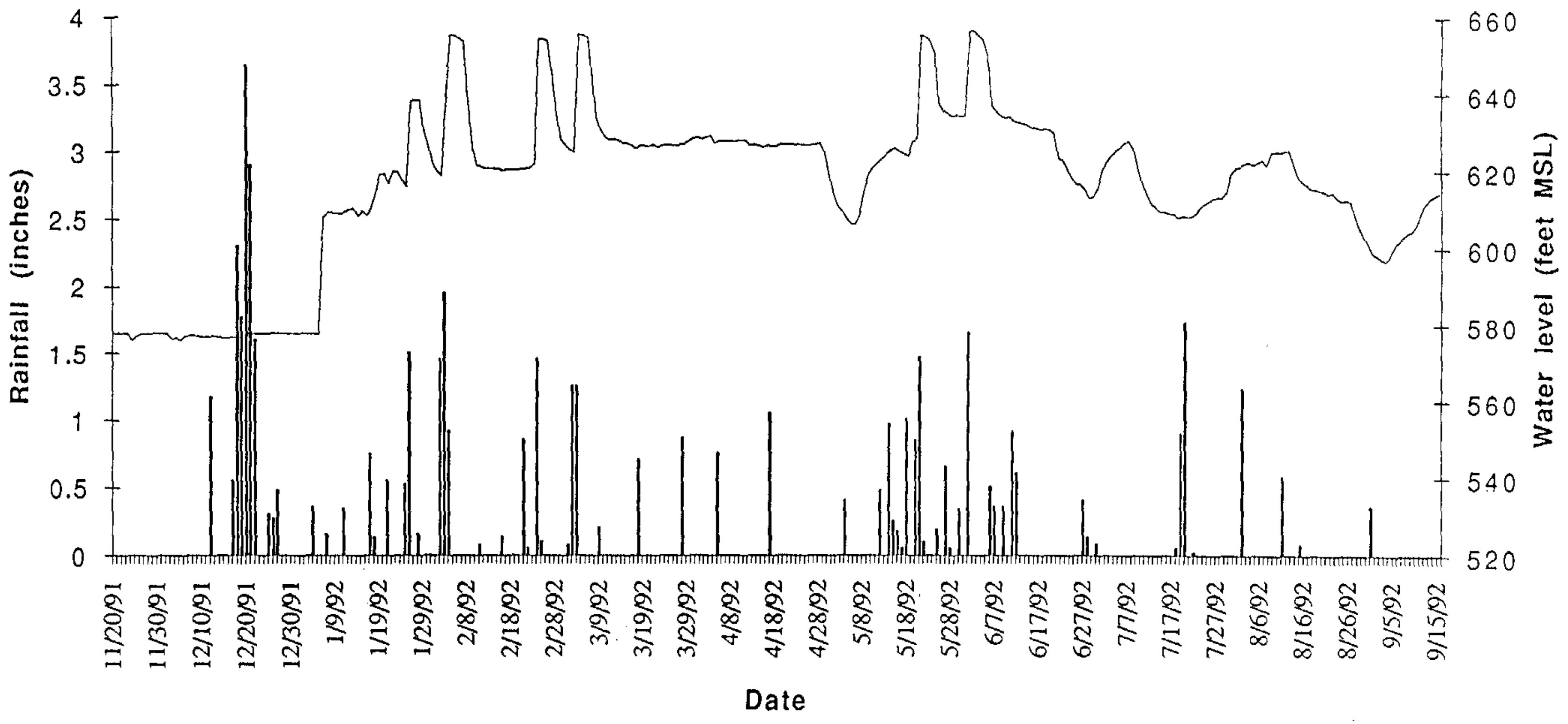
58-50-801

Dowell Well Levels and Rainfall Events - 1992 & 1993



58-50-801

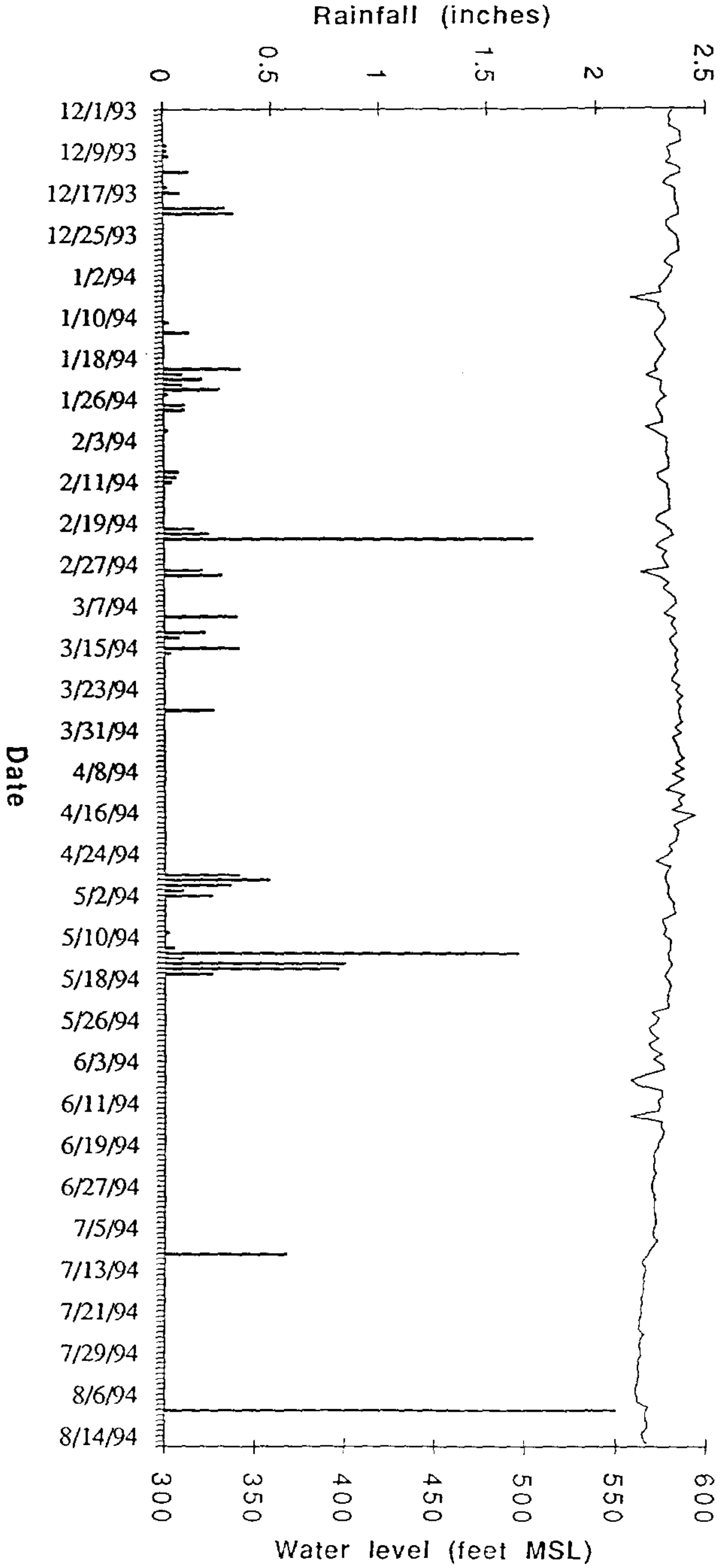
Dowell Well Levels and Rainfall Events - 1991 & 1992



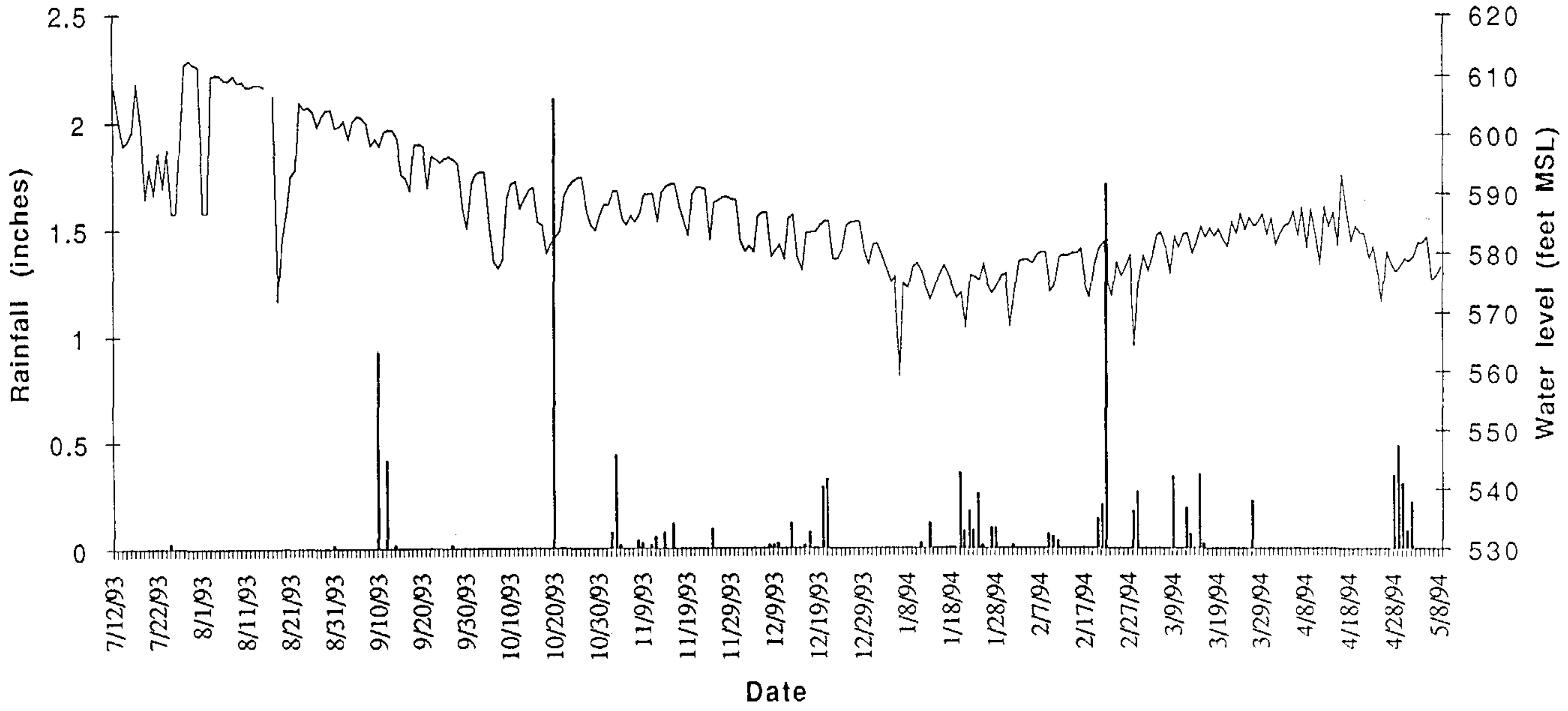
58-50-801

58-58-101
Franklin Well
Continuous Water Levels

Buda Well Levels and Rainfall Events - 1993 & 1994

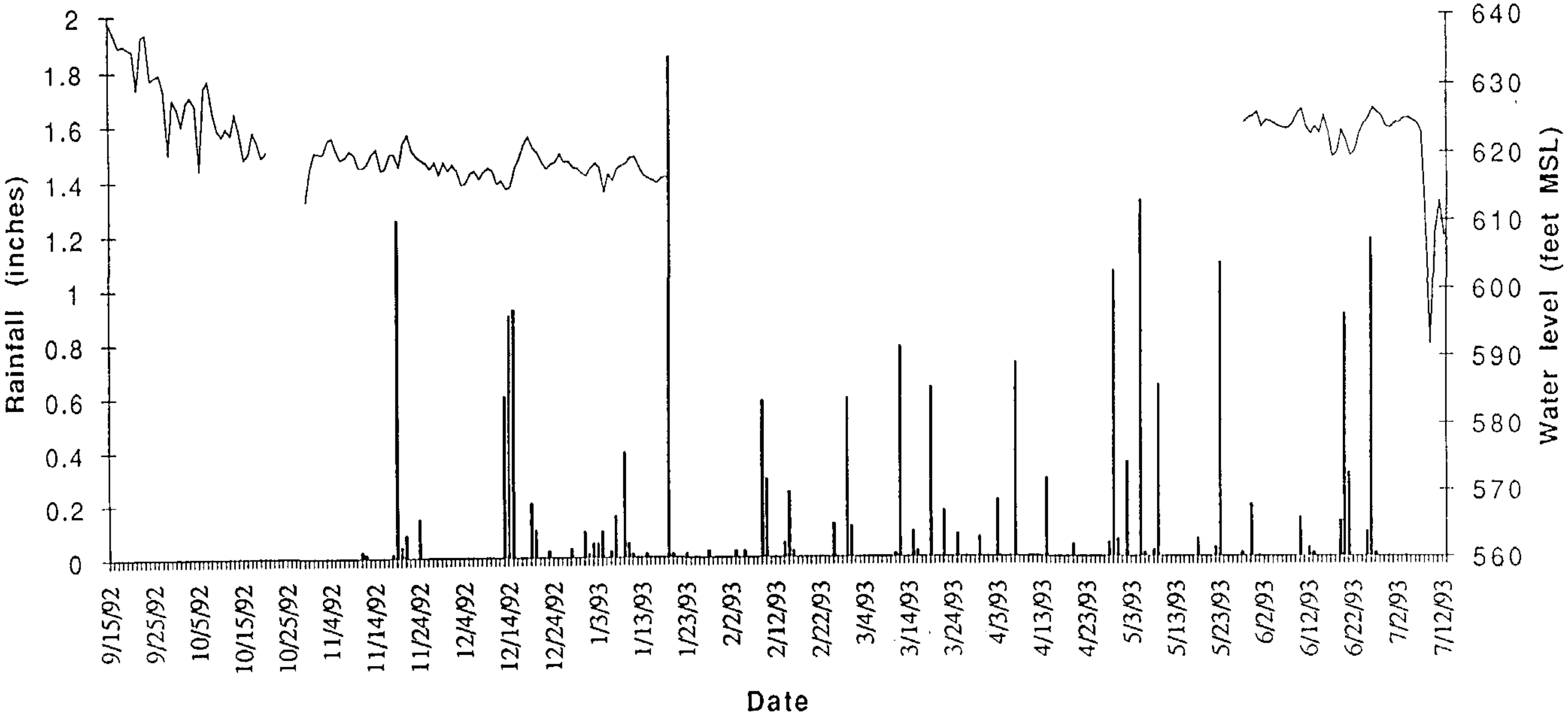


Buda Well Levels and Rainfall Events - 1993 & 1994



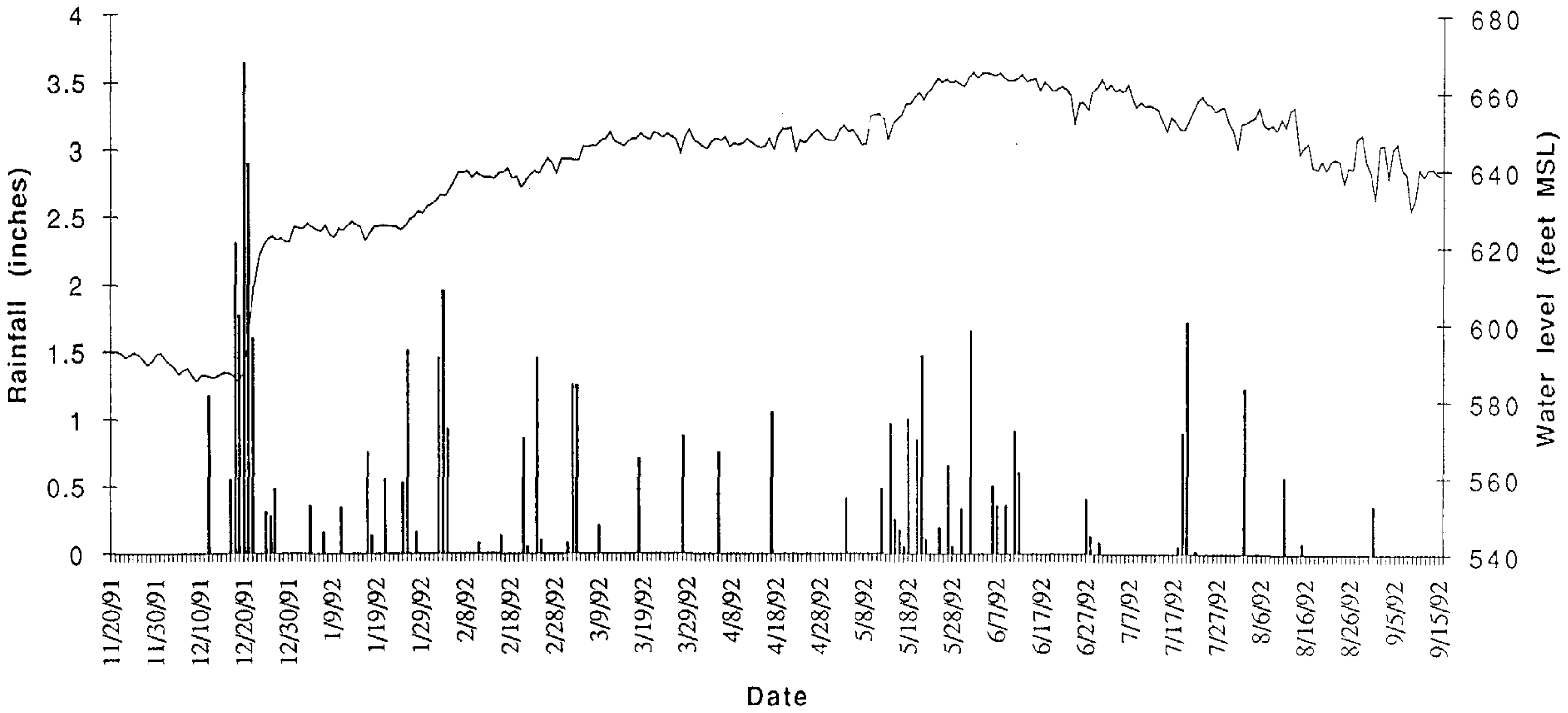
58-58-101

Buda Well Levels and Rainfall Events - 1992 & 1993



58-58-101

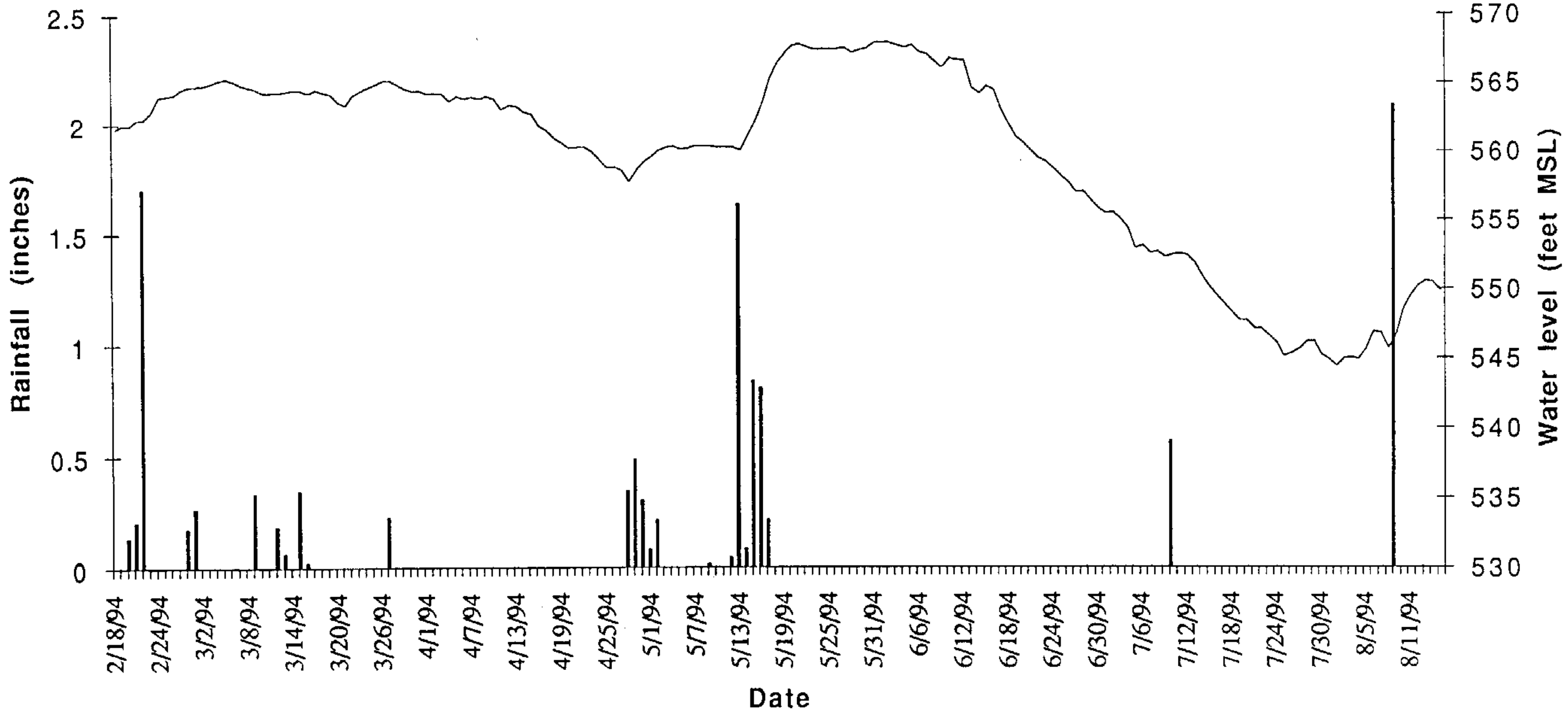
Buda Well Levels and Rainfall Events - 1991 & 1992



58-58-101

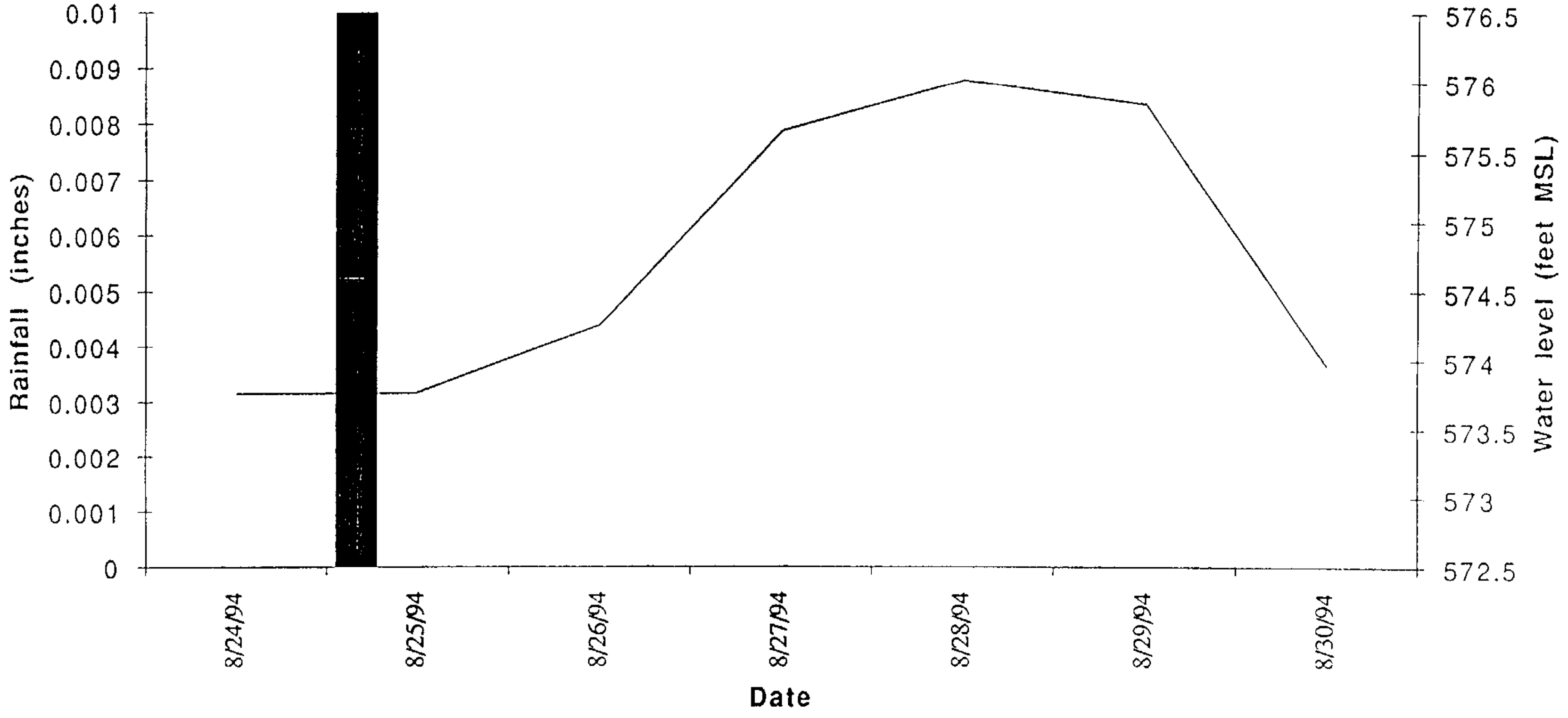
58-58-123
Porter Well
Continuous Water Levels

Porter Well Levels and Rainfall Events - 1994

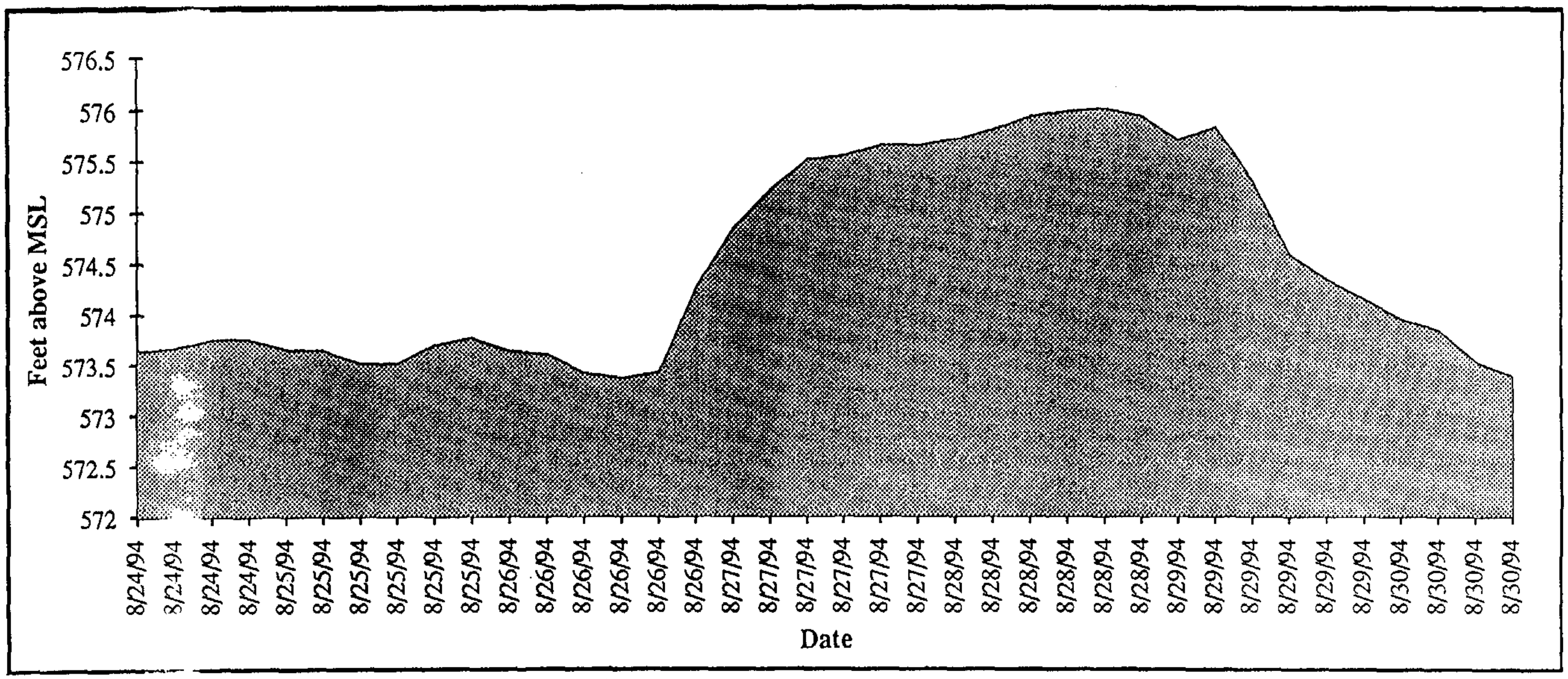


58-58-4CM
Centex Well
Continuous Water Levels

Centex Well Levels and Rainfall Events - 1994



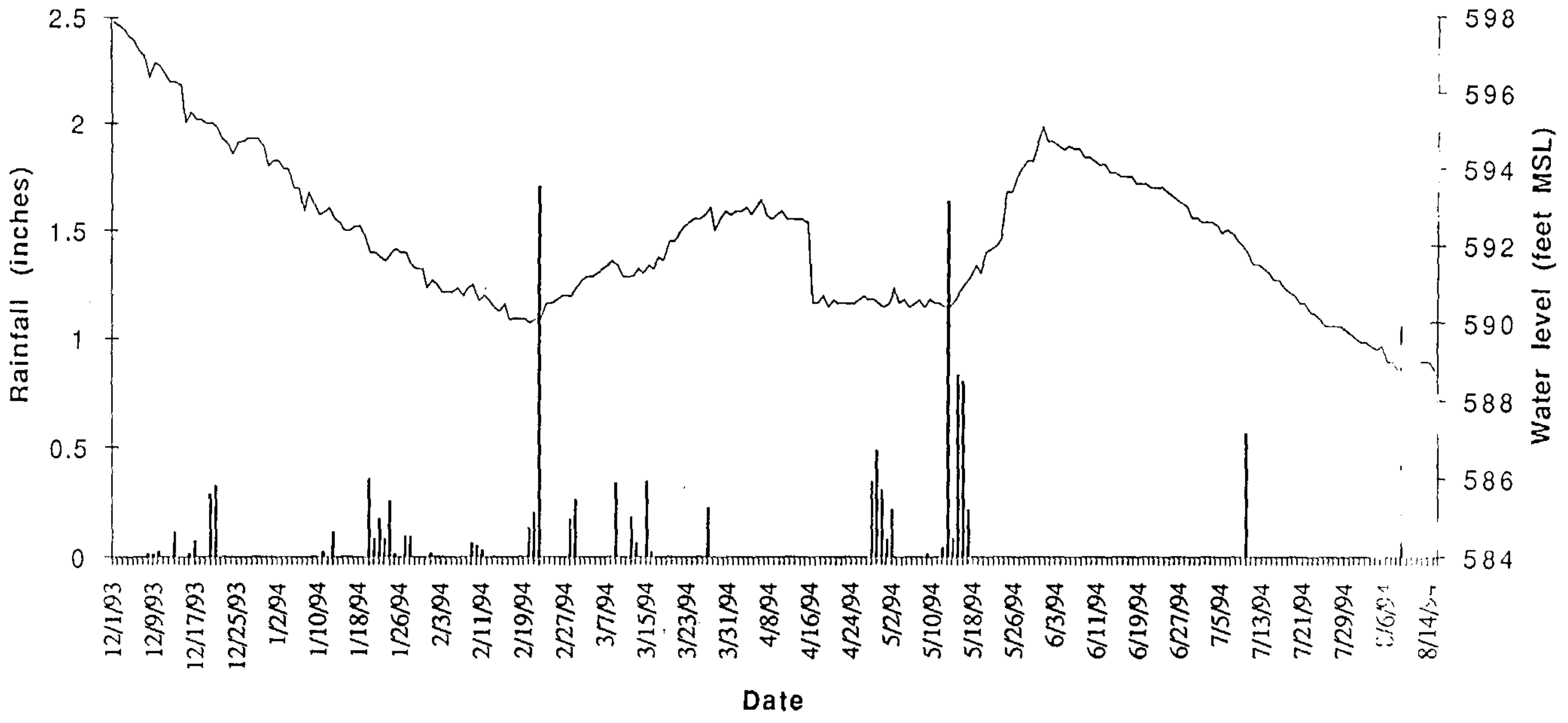
Centex Well Level



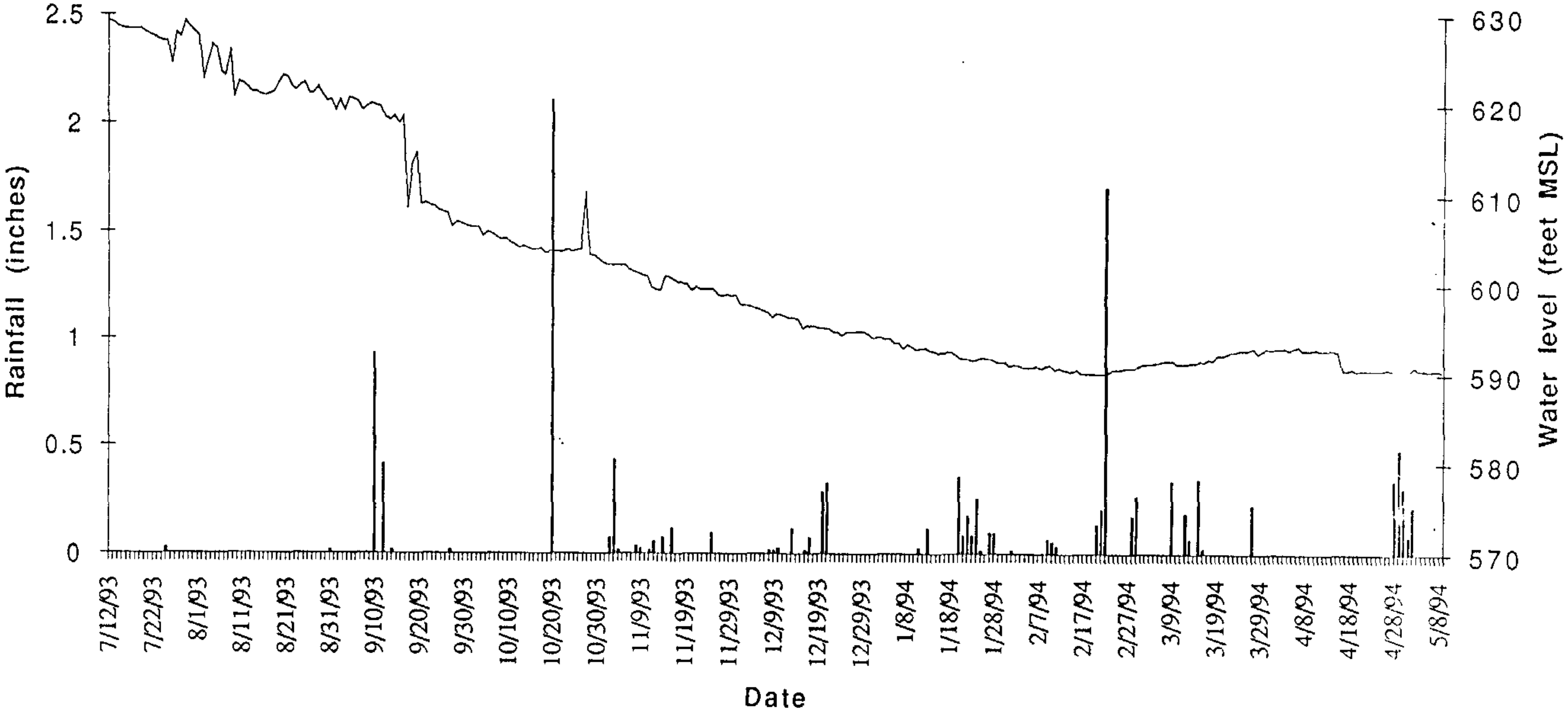
Well # 58-50-4CM

58-57-9A
Miller Well
Continuous Water Levels

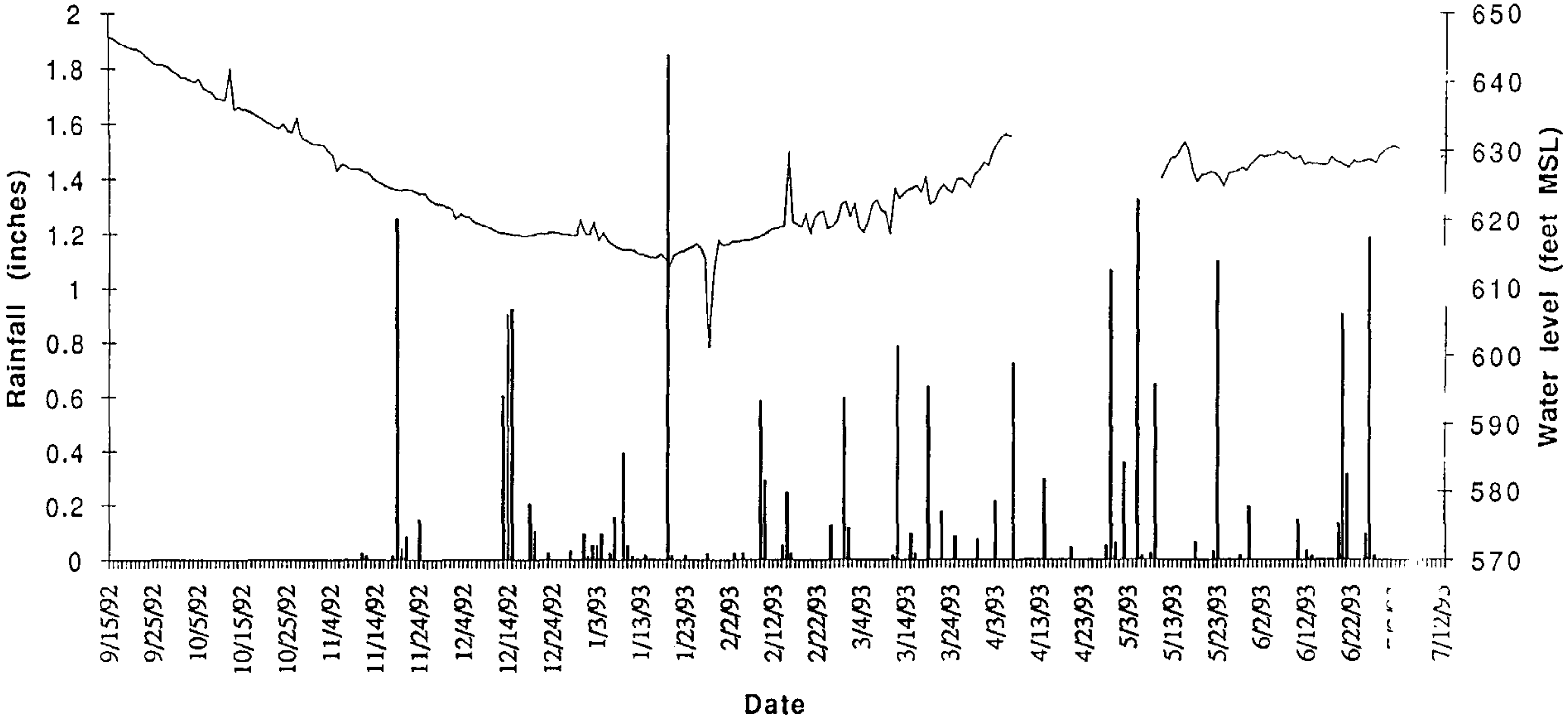
Miller Well Levels and Rainfall Events - 1993 & 1994



Miller Well Levels and Rainfall Events - 1993 & 1994

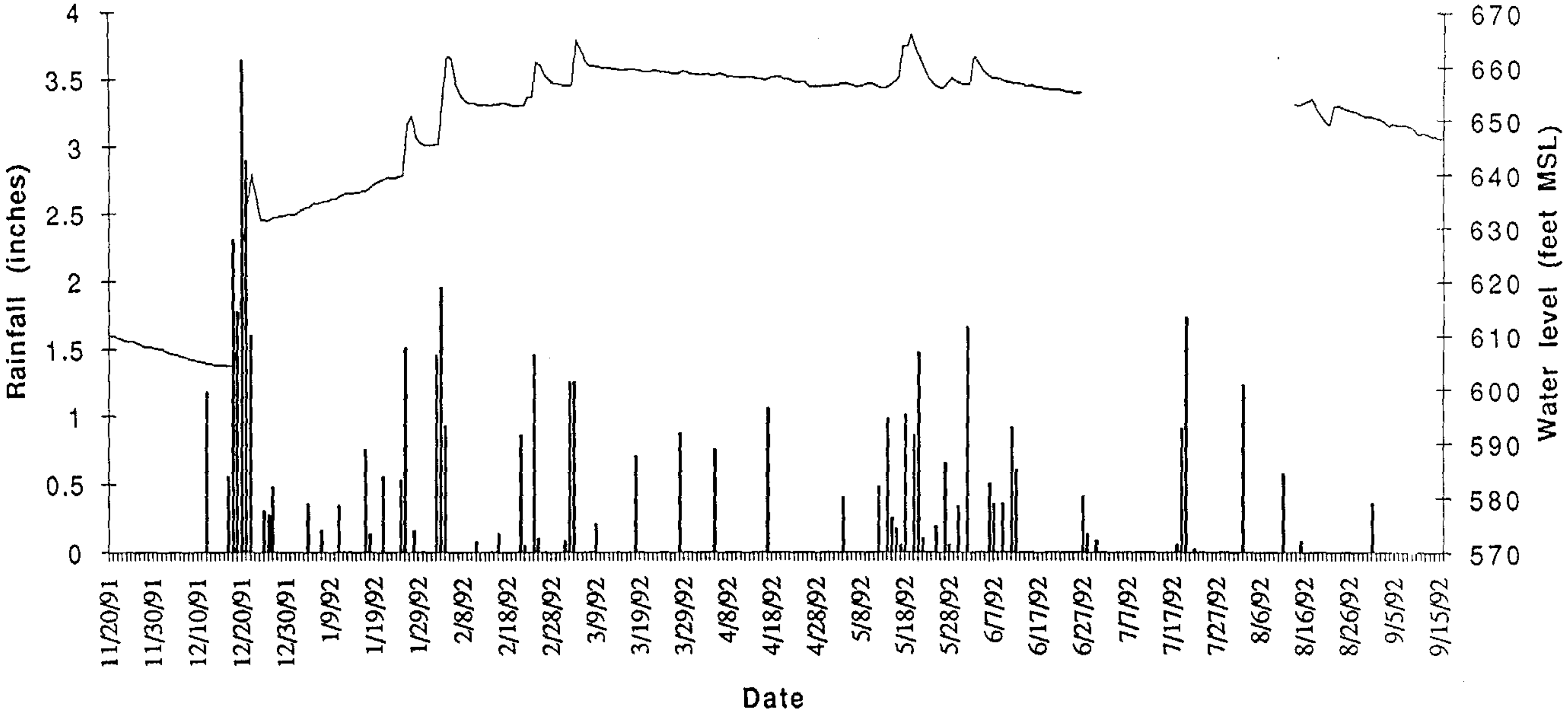


Miller Well Levels and Rainfall Events - 1992 & 1993



58-57-9A

Miller Well Levels and Rainfall Events - 1991 & 1992



Appendix B.

Water-Quality Results from 1990, 1993, and 1994 Sampling

Edwards Aquifer Water-Quality Sampling Results - May to October 1990

EAWQ Site No.	State or Temporary Well No.	Name	Date/Time Sampled (d/mo/yr hr:min)	Latitude	Longitude	Elevation (feet msl to top of casing or spring)	Well Depth (feet)	BS/EACD FIELD MEASUREMENTS				
								Depth to Water (feet from top of casing)	Temp. (°C)	pH	Conductivity (uS/cm)	Total Alkalinity CaCO3 (mg/l)
1	58-42-811	Backdoor Springs	Not Sampled	30°13'14"	97°54'11"	600	---	---	---	---	---	---
2	58-42-821	National Western Life Insurance Co.	7/16/90 14:00	30°15'38"	97°48'38"	712	460	---	22.3	7.22	528	222
3	58-42-913	Park Hills Baptist Church	7/19/90 9:30	30°16'02"	97°45'54"	532	180	---	23.7	7.11	643	291
4	58-49-708	Mike Personett	10/5/90 15:30	30°07'43"	97°58'03"	1060	310	132.5	22.4	7.01	553	326
5	58-49-7BK	Bert Kenna	Not Sampled	30°28'41"	98°05'24"	1055	480	---	---	---	---	---
6	58-49-911	Chaparral Park	6/27/90 10:30	30°07'58"	97°53'22"	834	420	---	24.7	6.83	800	288
7	58-50-223	City of Sunset Valley	6/26/90 14:30	30°13'39"	97°48' 36"	675	360	---	23.7	7.07	602	286
8	58-50-416	Linda Roudebush	8/2/90 15:30	30°10'34"	97°52'00"	775	---	---	25.3	7.09	597	
9	58-50-520	Herb Mendieta	7/18/90 15:30	30°12'26"	97°48'07"	715	---	---	24.4	7.08	559	266
10	58-50-731	Shady Hollow Estates Water Co.	7/9/90 15:15	30°08'58"	97°51'58"	740	438	---	22.8	7.08	550	271
11	58-50-733	Suburban Austin WS (Bear Creek Pk)	7/17/90 13:30	30°08'12"	97°50'43"	683	250	---	24.4	7.01	549	252
12	58-50-847	Creedmoore	6/27/90 14:00	30°07'48"	97°49'19"	625	550	---	23.9	7.11	577	255
13	58-50-852	J.D. Malone	7/3/90	30°09'42"	97°49'08"	690	425	---	24.3	7.29	643	230
14	58-50-854	St. Albans Episcopal Church	7/30/90 10:30	30°07'47"	97°47'54"	710	498	---	26.5	7.06	3160	223
15	58-50-855	Village of San Leanna	6/26/90 11:30	30°08'45"	97°49'08"	655	500	---	25	7.39	615	212
16	58-57-307	Hays C.I.S.D.(Dahlstrom)	5/10/90 14:45	30°06'01"	97°52'55"	802	470	219.66	22	7.13	510	277
17	58-57-811	Leroy Grote	9/26/90 11:20	30°02'21"	97°56'25"	890	450	300+	23.6	7.09	525	257
18	58-57-901	Hays C.I.S.D. (Hays High School)	7/9/90 11:00	30°01'56"	97°53'24"	833	575	---	23.7	7.40	506	298.2
19	58-58-114	Cimarron Park Water Company Inc.	7/12/90 14:00	30°06'57"	97°51'46"	815	490	---	22	7.44	518	249
20	58-58-202	Mystic Oak Water Co-op	7/11/90 10:15	30°07'28"	97°48'48"	650	405	---	24.6	7.27	792	224
21	58-58-219	Pool & Rogers Paving Co.	7/10/90	30°05'30"	97°49'03"	684	550	---	24.8	7.32	803	225
22	58-58-403	City of Buda	5/10/90 14:45	30°04'54"	97°50'33"	714	390	---	23	7.12	583	210
23	58-58-416	Comal Tackle Company	7/30/90 13:30	30°03'03"	97°51'32"	743	240	---	23.8	7.28	549	265
24	58-58-508	Goforth Water Supply Corp.	7/10/90	30°04'43"	97°49'51"	720	740		25.2	7.3	653	233

Edwards Aquifer Water-Quality Sampling Results - May to October 1990

State Well Number	BS/EACD LAB MEASUREMENTS (Verification Only)								LCRA Laboratory Results					
	Iron (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	Total Coliform (present/ absent)	Fecal Coliform (present/ absent)	Total Alkalinity CaCO3 (mg/l)	Bicarbonate Alkalinity HCO3 (mg/l)	Total Hardness (mg/l)	Total Dissolved Solids (mg/l)	Dissolved Aluminum (mg/l)	Dissolved Arsenic (mg/l)	Dissolved Barium (mg/l)
58-42-811	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-42-821	0.053	35.34	22.5			absent	absent	224	224	259	312	<0.01	<0.005	0.04
58-42-913	-	23.66	19.33			absent	absent	299	299	322	3.58	<0.01	<0.005	0.07
58-49-708	0	17.65	13.5	0.9	0.3	absent	absent		337	320	366	<0.01	<0.010	0.08
58-49-7BK	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-911	-	157.46	13.44			absent	absent	292	292	451	556	<0.02	<0.01	0.12
58-50-223	-	10.45	12.06			absent	absent	288	288	313	328	<0.01	<0.01	0.32
58-50-416	0.01	10.47	24.7	1.9	0.25	absent	absent	281	281	323	336	0.02	<0.005	0.07
58-50-520	-	16.85	11.34			absent	absent	269	269	282	305	<0.01	<0.005	0.14
58-50-731	0.043	17.42	11.89			absent	absent	277	277	298	312	<0.01	<0.010	0.03
58-50-733	0.048	19.33	11.53			absent	absent	268	268	277	304	<0.01	<0.005	0.04
58-50-847	-	46.14	10.51			absent	absent	240	240	273	340	<0.02	<0.01	0.12
58-50-852	-	84.37	19.73			absent	absent	222	222	279	390	<0.01	<0.010	0.05
58-50-854	-	598.7	545.2			absent	absent	228	228	738	2012	0.02	<0.005	0.05
58-50-855	-	87.27	12.68			absent	absent	224	224	284	414	<0.01	<0.01	0.07
58-57-307	0	25	12			absent	absent	262	262	303	302	0.01	<0.005	- - -
58-57-811	0.04	41	7	0.3	0.45	absent	absent		256	285	287	0.03	<0.005	0.07
58-57-901	0.046	16.07	8.35	3.48	- - -	- - -	- - -	250	250	259	276	<0.01	<0.010	0.03
58-58-114		17.42	10.78	8.00		absent	absent	258	258	276	296	0.01	<0.005	0.04
58-58-202	0.135	218.85	-			absent	absent	262	262	349	646	0.02	<0.010	0.04
58-58-219	0.423	154.95	41.67			absent	absent	228	228	277	516	0.04	<0.010	0.03
58-58-403	0	27.38	10.31			absent	absent	276	276	313	325	0.02	<0.005	- - -
58-58-416		18.42	13.63			absent	absent	270	270	293	348	<0.01	<0.005	0.06
58-58-508	0.028	118.26	10.85			absent	absent	228	228	304	444	0.02	<0.01	0.07

Edwards Aquifer Water-Quality Sampling Results - May to October 1990

State Well Number	LCRA Laboratory Results														
	Dissolved Boron (mg/l)	Dissolved Cadmium (mg/l)	Dissolved Calcium (mg/l)	Chloride (mg/l)	Dissolved Chromium (mg/l)	Dissolved Copper (mg/l)	Fluoride (mg/l)	Dissolved Iron (mg/l)	Dissolved Lead (mg/l)	Dissolved Magnesium (mg/l)	Dissolved Manganese (mg/l)	Dissolved Mercury (mg/l)	Kjeldahl Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Nitrate Nitrogen (mg/l)
58-42-811	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-42-821	0.27	<0.01	67.93	24	<0.01	<0.01	0.2	<0.01	<0.010	21.81	<0.01	<0.001	0.16	0.09	0.58
58-42-913	0.15	<0.01	95.95	21	<0.01	<0.01	0.2	<0.01	<0.01	20.09	<0.01	<0.001	0.14	0.07	1.53
58-49-708	<0.01	<0.01	74.4	13	<0.01	<0.01	0.4	<0.01	<0.01	31.76	<0.01	<0.001	0.22	0.06	0.81
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-911	0.11	<0.01	93.89	15	<0.01	0.01	0.7	<0.01	<0.01	51.38	<0.01	<0.001	0.12	0.01	0.46
58-50-223	0.08	<0.01	73.08	14	<0.01	<0.01	0.3	<0.01	<0.01	31.75	<0.01	<0.001	0.03	<0.01	2.91
58-50-416	<0.01	<0.01	71.80	24	<0.01	0.03	0.2	<0.01	<0.005	34.81	<0.01	<0.001	0.32	6.40	1.35
58-50-520	0.18	0.01	70.82	12	<0.01	<0.01	0.3	<0.01	<0.010	25.65	<0.01	<0.001	0.04	0.24	1.48
58-50-731	<0.01	<0.01	80.22	13	<0.01	<0.01	0.2	<0.01	<0.010	23.67	<0.01	<0.001	0.11	0.12	0.93
58-50-733	0.21	<0.01	72.20	13	<0.01	0.01	0.2	<0.01	<0.010	23.40	<0.01	<0.001	0.21	0.20	1.42
58-50-847	0.06	<0.01	67.77	11	<0.01	0.01	0.8	<0.01	<0.01	26.12	<0.01	<0.001	0.33	0.07	1.21
58-50-852	0.14	<0.01	56.93	20	<0.01	<0.01	2.5	<0.01	<0.010	33.11	<0.01	<0.001	0.29	0.23	0.23
58-50-854	1.38	<0.01	130.98	273	<0.01	<0.01	3.9	0.08	<0.005	99.84	<0.01	<0.001	1.36	1.19	<0.01
58-50-855	0.14	<0.01	63.22	14	<0.01	<0.01	2.1	<0.01	<0.01	30.58	<0.01	<0.001	0.03	<0.01	0.04
58-57-307	0.47	0.04	69.49	12	0.02	0.03	0.2	0.03	<0.005	24.68	0.02	<0.001	0.07	0.28	2.08
58-57-811	0.09	<0.01	58.32	9	<0.01	<0.01	0.4	<0.01	<0.005	33.83	<0.01	<0.001	0.02	<0.01	0.37
58-57-901	<0.01	<0.01	58.61	10	<0.01	<0.01	0.4	<0.01	<0.010	28.32	<0.01	<0.001	0.16	0.22	0.74
58-58-114	0.32	0.01	65.13	12	<0.01	0.02	0.4	0.01	<0.010	27.58	<0.01	<0.001	0.26	0.06	1.94
58-58-202	1.20	0.03	63.28	51	<0.01	0.02	4.0	0.01	<0.010	46.26	0.02	<0.001	0.60	0.67	0.02
58-58-219	0.37	<0.01	52.26	44	<0.01	<0.01	3.6	0.32	<0.010	35.58	<0.01	<0.001	0.52	0.62	<0.01
58-58-403	1.10	<0.01	73.05	10	<0.01	0.05	0.4	0.03	<0.005	26.34	<0.01	<0.001	0.16	0.02	1.90
58-58-416	0.14	<0.01	82.65	14	<0.01	<0.01	0.2	<0.01	<0.005	21.0	<0.01	<0.001	0.10	0.06	1.59
58-58-508	0.02	<0.01	62.75	12	<0.01	<0.01	3.2	0.29	<0.010	35.75	<0.01	<0.001	0.06	0.16	<0.01

Edwards Aquifer Water-Quality Sampling Results - May to October 1990

State Well Number	LCRA Laboratory Results													
	Nitrite Nitrogen (mg/l)	Ortho Phosphorou (mg/l)	Dissolved Potassium (mg/l)	Dissolved Selenium (mg/l)	Silica (mg/l)	Dissolved Silver (mg/l)	Dissolved Sodium (mg/l)	Dissolved Strontium (mg/l)	Sulfate (mg/l)	Dissolved Zinc (mg/l)	Suspended Solids (mg/l)	Fecal Coliform (col/100 ml)	Gross Alpha (pCi/l)	Total Organic Carbon (mg/l)
58-42-811	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-42-821	<0.01	<0.01	2.18	<0.005	8.89	<0.01	12.50	0.43	36	0.12	---	---	1.10	2
58-42-913	<0.01	<0.01	1.53	<0.005	10.0	<0.01	8.50	0.19	22	<0.01	---	---	4.9	3
58-49-708	0.02	<0.01	1.23	<0.010	12.47	<0.01	7.54	6.07	17	<0.01	---	---	11	3
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-911	0.01	<0.01	3.21	<0.01	12.94	---	7.95	8.48	163	0.02	---	---	7.3	1.7
58-50-223	<0.01	0.15	1.49	<0.01	14.39	<0.01	9.60	0.98	3	<0.01	---	---	1.2	0.8
58-50-416	<0.01	0.02	<1.00	<0.005	12.62	<0.01	8.74	0.28	10	0.03	---	---	2.2	1.3
58-50-520	<0.01	0.01	1.31	<0.005	10.0	<0.01	6.90	2.71	17	<0.01	---	---	2.9	2
58-50-731	<0.01	<0.01	1.47	<0.010	9.54	<0.01	7.16	0.47	16	0.04	---	---	1.8	2
58-50-733	<0.01	<0.01	1.90	<0.005	10.14	<0.01	7.02	1.18	18	0.01	---	---	1.4	3
58-50-847	0.01	<0.01	<1.0	<0.01	10.78	---	6.92	23.38	41	<0.01	---	---	7.3	1.7
58-50-852	0.02	0.02	2.56	<0.010	11.66		22.44	28.28	89	0.01	---	---	6.9	2
58-50-854	<0.01	0.01	17.46	<0.005		0.01	453.50	21.54	302	<0.01	---	---	---	1.3
58-50-855	<0.01	<0.01	2.08	<0.01	11.62	<0.01	10.33	41.78	93	<0.01	---	---	7.1	1.2
58-57-307	<0.01	<0.01	1.62	<0.005	10.16	---	6.88	0.25	19	0.11	---	---	2.3	0.8
58-57-811	<0.01	<0.01	4.34	<0.005	13.07	<0.01	6.25	0.81	22	<0.01	---	---	4.9	<1.0
58-57-901	<0.01	<0.01	1.93	<0.010	10.91	<0.01	5.81	2.42	15	0.02	---	---	2.9	1.9
58-58-114	<0.01	<0.01	2.59	<0.005	10.20	<0.01	6.83	0.74	20	0.01	---	---	3.2	3
58-58-202	<0.01	<0.01	9.92	<0.010	12.73	0.01	78.55	30.29	234	0.03	---	---	18.8	2
58-58-219	<0.01	<0.01	6.87	<0.005	11.46	<0.01	70.28	27.16	158	<0.01	---	---	8.4	2
58-58-403	<0.01	<0.01	<1.0	<0.005	10.70	--	6.37	11.07	24	0.01	---	---	4.5	0.9
58-58-416	<0.01	<0.01	2.48	<0.005		<0.01	8.01	0.27	18	<0.01	---	---	----	2.0
58-58-508	<0.01	<0.01	1.38	<0.005	12.42	<0.01	9.38	46.11	117	0.01	---	---	5.1	2

Edwards Aquifer Water-Quality Sampling Results - March 1993

	BS/EACD LAB MEASUREMENTS (For Verification Only)									LCRA Laboratory Results					
State Well Number	Iron (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	Total Coliform (present/ absent)	Fecal Coliform (present/ absent)		Total Alkalinity CaCO3 (mg/l)	Bicarbonate Alkalinity HCO3 (mg/l)	Total Hardness (mg/l)	Total Dissolved Solids (mg/l)	Dissolved Aluminum (mg/l)	Dissolved Arsenic (mg/l)	Dissolved Barium (mg/l)
58-42-811	-----	-----	------	------	------	present	present		267	326	408	398	0.15	<0.005	0.05
58-42-821	0.14	2	11	4.1	0.12	absent	absent		180	220	286	301	0.16	<0.005	0.03
58-42-913	0.01	1	4	1.7	0.23	absent	absent		239	291	355	373	0.21	<0.005	0.06
58-49-708	0.04	3	7	2.0	0.49	------	------		279	340	381	374	0.18	<0.005	0.08
58-49-7BK	0.02	2	10	4.3	0.32	present	absent		304	371	415	411	0.23	<0.005	0.04
---	---	---	---	---	---	---	---		---	---	---	---	---	---	---
58-50-223	0.11	8	5	2.7	0	absent	absent		246	300	344	318	0.18	<0.005	0.29
58-50-416	0.00	1	9	1.0	0.26	absent	absent		215	262	336	303	0.09	<0.005	0.04
58-50-520	0.04	0	0	0.5	0.42	present	absent		217	265	316	298	0.17	<0.005	0.10
58-50-731	0.00	27	4.00	1.80	0.009	absent	absent		225	275	305	314	0.17	<0.005	0.03
58-50-733	0.00	1	22	1.9	0.31	absent	absent		215	262	295	326	0.17	<0.005	0.03
58-50-847	---	---	---	---	---	---	---		---	---	---	---	---	---	---
58-50-852	0.01	58	8	1.0	1.60	absent	absent		186	227	287	368	0.13	<0.005	0.05
58-50-854	0.01	375	272	6.4	2.33	absent	absent		179	218	594	1560	0.24	<0.005	0.01
58-50-855	0.06	50	1	2.0	1.76	absent	absent		185	226	295	406	0.14	<0.005	0.07
58-57-307	0.02	10	8	5.5	0.23	absent	absent		211	258	320	309	0.15	<0.005	0.02
58-57-811	0.01	1	11	2.4	0.53	absent	absent		204	249	310	295	0.13	<0.005	0.06
58-57-901	0.00	1	5	0.7	0.45	absent	absent		198	242	287	265	0.13	<0.005	0.03
58-58-114	0.00	4	4	11.7	0.24	absent	absent		205	250	285	304	0.15	<0.005	0.02
58-58-202	-----	--------	------	------	------	absent	absent		184	225	346	471	0.14	<0.005	0.03
58-58-219	0.27	2	26	3.0	2.70	absent	absent		182	222	285	505	0.12	<0.005	0.03
58-58-403	0.01	5	6	1.7	0.49	absent	absent		217	265	339	328	0.15	<0.005	0.13
58-58-416	0.00	1	7	2.3	0.34	present	absent		227	278	335	333	0.17	<0.005	0.03
58-58-508	0.15	25	83	1.5	1.53	absent	absent		212	259	330	438	0.17	<0.005	0.15

N/A - Levels c

Edwards Aquifer Water-Quality Sampling Results - March 1993

EAWQ Site No.	State or Temporary Well No.	System/Well Owner Name	Date/Time Sampled (d/mo/yr hr:min)	Latitude	Longitude	Elevation (feet msl to top of casing or spring)	Well Depth (feet)	BS/EACD Field Measurements				
								Depth to Water (feet from top of casing)	Temp (°C)	pH	Conductivity (uS/cm)	Total Alkalinity CaCO3 (mg/l)
1	58-42-811	Backdoor Springs (City of Austin)	4/1/93 9:00	30°15'35"	97°49'23"	570		N/A	20.0	7.48	772	220
2	58-42-821	National Western Life Insurance Co.	3/15/93 1520	30°15'38"	97°48'38"	712	460	235.83	20.5	7.54	-----	153
3	58-42-913	Park Hills Baptist Church	3/8/93 16:00	30°16'02"	97°45'54"	540	180	N/A	20.3	7.27	641	284
4	58-49-708	Mike Personett	3/4/93 18:00	30°07'43"	97°58'00"	1060	310	114.03	20.8	7.07	1030	294
5	58-49-7BK	Bert Kenna	3/4/93 16:50	30°07'43"	97°58'03"	1055	480	98.58	21.4	7.00	710	330
6	58-49-911	Chaparral Park	not sampled	30°07'58"	97°53'22"	834	400	---	---	---	---	---
7	58-50-223	City of Sunset Valley	3/9/93 14:00	30°13'39"	97°48' 36"	675	360	---	23.5	7.16	600	288
8	58-50-416	Linda Roudebush	3/26/93 11:50	30°10'34"	97°52'00"	775	---	195.57	22.9	7.17	596	250
9	58-50-520	Herb Mendieta	3/10/93 15:00	30°12'26"	97°48'07"	715	---	182.67	22.0	7.19	850	231
10	58-50-731	Shady Hollow Estates Water Co.	3/2/93 1440	30°08'58"	97°51'35"	740	438	173.96	21.1	7.11	566	195
11	58-50-733	Suburban Austin WS (Bear Creek Pk)	3/3/93 15:40	30°08'26"	97°50'40"	683	250	---	21.5	7.18	560	220
12	58-50-847	Creedmoor-Maha WSC	not sampled	30°07'48"	97°49'19"	625	550	---	---	---	---	---
13	58-50-852	J.D. Malone	3/8/93 13:00	30°09'42"	97°49'08"	690	425	---	25.4	N/A	593	251
14	58-50-854	St. Albans Episcopal Church	3/3/93 12:00	30°07'47"	97°47'54"	710	498	---	22.9	7.33	2380	204
15	58-50-855	Village of San Leanna	3/3/93 16:50	30°08'45"	97°49'08"	655	500	---	23.8	7.41	610	167
16	58-57-307	Hays C.I.S.D.(Dahlstrom)	3/15/93 10:50	30°06'01"	97°52'55"	802	470	163.02	19.7	7.42	640	213
17	58-57-811	Leroy Grote	3/17/93 13:40	30°02'21"	97°56'25"	890	450	178.76	23.5	6.82	542	252
18	58-57-901	Hays C.I.S.D. (Hays High School)	3/15/93 12:25	30°01'56"	97°53'24"	833	575	201.34	22.1	7.47	-----	180
19	58-58-114	Cimarron Park Water Company Inc.	3/3/93 14:20	30°06'57"	97°51'46"	815	490	---	22.6	7.30	540	248
20	58-58-202	Mystic Oak Water Co-op	3/30/93 14:00	30°07'28"	97°48'48"	650	405	---	23.3	7.58	809	178
21	58-58-219	Pool & Rogers Paving Co.	3/10/93 15:00	30°05'30"	97°49'03"	684	550	64.42	23.4	7.89	800	195
22	58-58-403	City of Buda	3/26/93 13:30	30°04'54"	97°50'33"	714	390	---	23.3	7.08	590	240
23	58-58-416	Comal Tackle Company	3/23/93 14:45	30°03'03"	97°51'32"	743	240	109.00	20.9	6.81	580	240
24	58-58-508	Goforth Water Supply Corp.	3/10/93 10:00	30°04'43"	97°49'51"	720	740	94.4	23.9	6.72	659	195

Edwards Aquifer Water-Quality Sampling Results - March 1993

State Well Number			LCRA Laboratory Res									LCRA Laboratory Results			
	Dissolved Boron (mg/l)	Dissolved Cadmium (mg/l)	Dissolved Calcium (mg/l)	Chloride (mg/l)	Dissolved Chromium (mg/l)	Dissolved Copper (mg/l)	Fluoride (mg/l)	Dissolved Iron (mg/l)	Dissolved Lead (mg/l)	Dissolved Magnesium (mg/l)	Dissolved Manganese (mg/l)	Dissolved Mercury (mg/l)	Kjeldahl Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Nitrate Nitrogen (mg/l)
58-42-811	<0.01	0.02	119.70	32	<0.01	<0.01	<0.2	<0.01	<0.005	26.49	<0.01	<0.001	0.302	0.02	1.688
58-42-821	<1.00	<0.01	78.90	21	<0.01	<0.01	0:2	0.23	<0.005	21.65	<0.01	<0.001	0.111	<0.01	0.279
58-42-913	<1.00	<0.01	110.30	24	---	0.03	<0.2	<0.01	<0.005	19.27	<0.01	<0.001	<0.010	<0.01	1.649
58-49-708	<0.00	<0.01	91.71	12	<0.01	<0.01	8.0	<0.01	<0.005	36.86	<0.01	<0.001	<0.010	<0.01	1.292
58-49-7BK	0.01	<0.01	117.80	11	<0.01	0.06	0.2	<0.01	<0.005	29.42	<0.01	<0.001	0.166	<0.01	1.964
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-223	0.01	<0.01	89.99	13	<0.01	<0.01	0.3	<0.01	<0.005	28.99	<0.01	<0.001	<0.010	<0.01	3.543
58-50-416	<0.00	<0.01	79.93	28	<0.01	<0.01	0.2	<0.01	<0.005	33.12	<0.01	<0.001	<0.010	<0.01	1.148
58-50-520	0.06	<0.01	83.65	12	<0.01	<0.01	0.3	<0.01	<0.005	26.03	<0.01	<0.001	0.130	<0.01	1.570
58-50-731	0.07	<0.01	82.29	13	<0.01	<0.01	<0.2	<0.01	<0.10	24.28	<0.01	<0.001	<0.010	0.33	<0.010
58-50-733	0.02	<0.01	82.55	16	<0.01	<0.01	0.2	<0.01	<0.005	21.52	<0.01	<0.001	0.122	<0.01	3.833
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-852	0.09	<0.01	61.08	16	---	<0.01	2.1	<0.01	<0.005	32.70	<0.01	<0.001	0.126	0.07	0.340
58-50-854	1.03	<0.01	120.30	388	<0.01	---	4.4	<0.01	<0.005	71.37	<0.01	<0.001	1.340	1.43	0.132
58-50-855	0.05	<0.01	66.54	12	<0.01	<0.01	2.0	<0.01	<0.005	31.32	<0.01	<0.001	0.107	<0.01	0.326
58-57-307	<1.00	<0.01	85.36	10	<0.01	<0.01	0.3	<0.01	<0.005	25.96	<0.01	<0.001	<0.010	<0.01	1.121
58-57-811	0.01	<0.01	63.14	8	<0.01	<0.01	0.4	<0.01	<0.005	36.88	<0.01	<0.001	0.124	<0.01	0.794
58-57-901	<0.01	<0.01	64.37	9	<0.01	<0.01	0.5	<0.01	<0.005	30.66	<0.01	<0.001	<0.010	<0.01	0.403
58-58-114	0.03	<0.01	70.97	11	<0.01	<0.01	0.3	<0.01	<0.005	26.07	<0.01	<0.001	0.188	<0.01	9.498
58-58-202	0.18	<0.01	69.70	19	<0.01	<0.01	3.5	<0.01	<0.005	41.84	0.02	<0.001	0.068	0.16	---
58-58-219	0.35	<0.01	54.85	39	<0.01	<0.01	3.7	0.39	<0.005	35.88	<0.01	<0.001	0.447	0.44	0.368
58-58-403	<0.00	<0.01	89.63	10	<0.01	<0.01	0.5	<0.01	<0.005	27.95	<0.01	<0.001	0.016	0.02	1.456
58-58-416	<0.00	<0.01	96.62	12	<0.01	<0.01	0.2	<0.01	<0.005	22.70	<0.01	<0.001	0.079	<0.01	1.476
58-58-508	0.03	<0.01	77.16	11	<0.01	<0.01	1.9	<0.01	<0.005	33.36	<0.01	<0.001	0.146	0.22	0.177

:ould not be measured

N/A - Levels could not be measured

Edwards Aquifer Water-Quality Sampling Results - March 1993

State Well Number	LCRA Laboratory Results														
	Nitrite Nitrogen (mg/l)	Ortho Phosphorou (mg/l)	Dissolved Potassium (mg/l)	Dissolved Selenium (mg/l)	Silica (mg/l)	Dissolved Silver (mg/l)	Dissolved Sodium (mg/l)	Dissolved Strontium (mg/l)	Sulfate (mg/l)	Dissolved Zinc (mg/l)	Suspended Solids (mg/l)	Fecal Coliform (col/0.1 l)	Gross Alpha (pCi/l)	Total Organic Carbon (mg/l)	Total Petroleum Hydrocarb (mg/l)
58-42-811	<0.005	0.218	1.78	<0.005	15.29	<0.005	18.51	0.17	7	<0.01	5	2	7.000	1.00	<1.0
58-42-821	<0.010	<0.001	1.38	<0.005	8.78	<0.005	12.32	0.38	27	0.16	2	0	<5.000	1.00	<1.0
58-42-913	<0.010	0.011	<1.00	<0.005	9.67	<0.005	11.73	0.17	16	0.31	2	0	<5.000	1.00	<1.0
58-49-708	<0.010	0.004	1.50	<0.005	11.92	<0.005	7.25	6.66	5	<0.01	5	2	<5.000	1.00	<1.0
58-49-7BK	<0.010	0.008	<1.00	<0.005	9.97	<0.005	8.43	1.25	9	0.02	2	0	<5.000	2.00	<1.0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-223	<0.010	0.020	1.23	<0.005	14.59	<0.005	9.19	0.48	6	0.02	<1.00	0	6.000	<1.00	<1.0
58-50-416	<0.005	<0.005	1.74	<0.005	12.45	<0.005	14.28	0.39	5	<0.01	7	0	<5.000	1.00	<1.0
58-50-520	<0.010	0.012	1.26	<0.005	10.88	<0.005	7.08	2.75	11	<0.01	2	0	7.000	1.00	<1.0
58-50-731	<0.010	<0.010	<1.00	<0.005	9.87	<0.005	5.86	0.48	13	<0.01	<1.00	0	<5.000	15.00	<1.0
58-50-733	<0.010	0.014	<1.00	<0.005	10.33	<1.00	8.29	0.76	15	<0.01	11	0	<5.000	<1.00	<1.0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-852	<0.010	0.012	2.58	<0.005	11.62	<0.005	18.03	28.38	70	0.02	<1.00	0	<5.000	1.00	<1.0
58-50-854	<0.010	0.022	11.68	<0.005	14.15	<1.00	309.80	23.38	469	0.04	3	0	25.000	<1.00	<1.0
58-50-855	<0.010	0.022	1.55	<0.005	11.31	<1.00	9.90	34.77	73	<0.01	1	0	11.000	<1.00	<1.0
58-57-307	0.016	0.003	1.72	<0.005	10.27	<0.005	7.68	0.25	12	0.12	1	0	<5.000	1.00	<1.0
58-57-811	<0.005	0.013	2.57	<0.005	12.42	<0.005	6.73	1.04	19	<0.01	<1.00	0	5.000	2.00	<1.0
58-57-901	<0.010	0.004	1.34	<0.005	11.20	<0.005	5.80	3.03	10	0.03	1	0	<5.000	1.00	<1.0
58-58-114	<0.010	0.042	<1.00	<0.005	10.50	<0.005	5.79	0.68	14	<0.01	0	0	<5.000	2.00	<1.0
58-58-202	<0.005	0.010	4.82	<0.005	13.39	<0.005	21.60	34.24	106	<0.01	2	0	10.000	<1.00	<1.0
58-58-219	<0.005	0.010	6.17	<0.005	12.04	<0.005	67.14	28.18	114	<0.01	1	0	7.000	<1.00	<1.0
58-58-403	<0.005	0.007	1.72	<0.005	10.91	<0.005	6.92	11.30	16	<0.01	<1.00	0	<5.000	2.00	<1.0
58-58-416	<0.005	<0.005	1.72	<0.005	10.49	<0.005	7.55	0.24	11	<0.01	<1.00	0	6.000	2.00	<1.0
58-58-508	<0.010	0.011	1.69	<0.005	11.16	<0.005	7.15	34.47	77	<0.01	1	0	10.000	9.00	<1.0

Edwards Aquifer Water-Quality Sampling Results - March 1993

State Well Number	2,4-D (ug/l)	4,4-DDD (ug/l)	4,4-DDT (ug/l)	4,4-DDE (ug/l)	Atrazine (ug/l)	BHC-Gamma Lindane (ug/l)	Dieldrin (ug/l)	Endrin (ug/l)	Heptachlor Epoxide (ug/l)
58-42-811	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-42-821	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-42-913	<1.00	<1.00	<1.00	<1.00	---	<1.00	<1.00	<1.00	<1.00
58-49-708	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-49-7BK	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
---	---	---	---	---	---	---	---	---	---
58-50-223	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-50-416	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-50-520	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-50-731	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-50-733	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
---	---	---	---	---	---	---	---	---	---
58-50-852	<1.00	<1.00	<1.00	<1.00	---	<1.00	<1.00	<1.00	<1.00
58-50-854	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-50-855	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-57-307	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-57-811	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-57-901	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-58-114	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-58-202	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-58-219	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-58-403	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-58-416	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00
58-58-508	<1.00	<1.00	<1.00	<1.00	<0.100	<1.00	<1.00	<1.00	<1.00

N/A - Levels could not be measured

Edwards Aquifer Water-Quality Sampling Results - March 1994

								BS/EACD FIELD MEASUREMENTS					
EAWQ Well No.	State or Temporary Well no.	Name	Sample Date (day/mo/yr time)	Latitude	Longitude	Elevation (feet msl to top of casing or spring)	Well Depth (feet)	Depth to Water (feet below top of casing)	pH	Temp. (° C)	Conductivity (uS/cm)	Total Alkalinity (mg/l)	Turbidity (NTU)
25	58-42-916	Cold Springs	3/3/94 8:00	30°16'47"	97°46'47"	430	---	---	7.19	19.7	524	220	0
26	58-42-922	Old Mill Springs	3/16/94 8:00	30°15'46"	97°46'15"	440	---	---	7.24	20.5	813	210	1
26	58-42-922	Old Mill Springs	4/18/94 19:00	30°15'46"	97°46'15"	440	---	---	6.99	21.4	855	243	1
27	58-49-9EM	E.R. Manning	3/1/94 13:30	30°08'41"	97°53'13"	750	460	76.00	7.18	22.8	733	253	0
28	58-50-1CW1	New Forest Oaks, Inc	3/9/94 15:00	30°13'56"	97°51'43"	840	215	---	6.83	21.3	878	860	8
29	58-50-201	Robert Jentsch	3/3/94 13:40	30°13'08"	97°47'36"	651	290	---	7.22	22.2	529	220	0
30	58-50-2E	Leif Johnson	3/15/94 11:00	30°14'02"	97°49'19"	733	450	---	7.20	23.4	780	231	11
30	58-50-2E	Leif Johnson	4/18/94 16:00	30°14'02"	97°49'19"	733	450	---	7.36	23.3	955	---	0
31	58-50-2EM	Ed Maxey	1/3/94 10:15	30°14'19"	97°48'28"	675	---	203.70	7.38	19.3	441	160	0
32	58-50-2HB	Helen Besse	3/3/94 11:20	30°13'00"	97°49'03"	692	440	212.97	7.21	22.6	590	221	>999
33	58-50-3BL	Barton Lodge Spring	3/16/94 16:00	30°14'14"	97°47'29"	630	---	--	7.43	20.5	538	220	24
34	58-50-502	R.W. Herndon	3/15/94 9:15	30°11'13"	97°48'51"	740	300	---	7.25	21.4	567	259	0
35	58-50-511	Rodney Johnson	3/3/94 15:30	30°10'15"	97°49'31"	700	285	201.90	7.13	21.5	550	275	3
36	58-57-3BW	Becky Wyatt	3/15/94 13:45	30°06'34"	97°54'48"	820	400	120.30	7.17	22.5	557	308	20
36	58-57-3BW	Becky Wyatt	4/19/94 12:00	30°06'34"	97°54'48"	820	400	123.00	---	---	---	---	---
37	58-57-5JO	John Orr	3/9/94 12:20	30°02'49"	97°56'16"	925	450	220.00	7.61	21.3	511	195	20
	WQ Standards	(MCL unless specifie											

Edwards Aquifer Water-Quality Sampling Results - March 1994

BS/EACD LAB MEASUREMENTS (Verification Only)								LABORATORY CHEMICAL ANALYSIS							
Well no.	Iron (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	Total Coliform (present/ absent)	E. Coli (present/ absent)	Lab	Total Alkalinity CaCO3 (mg/l)	Bicarbonate Alkalinity HCO3 (mg/l)	Total Hardness (mg/l)	Dissolved Solids Residue (mg/l)	Calc. Total Dissolved Solids (mg/l)	Total Aluminum (mg/l)	Dissolved Aluminum (mg/l)
58-42-916	0.01	32	17	2.2	0.005	present	present	EARDC	208	254.8	273.2	351.6	308.9	1.23	<0.5
58-42-922	0.01	70	66.4	2.3	0.33	absent	absent	AMT	250	310	300	510	501.01	<0.10	<0.10
58-42-922	---	---	---	---	---	---	---	AMT	---	---	---	---	---	---	---
58-49-9EM	- - -	- - -	- - -	- - - -	- - -	- - -	- - -	EARDC	242	295.2	431.0	495.4	479.1	1.54	<0.5
58-50-1CW1	0.98	80	11.6	1.1	0.26	present	absent	AMT	400	490	500	620	626.37	*	<0.10
58-50-201	0.00	39	21.4	1.5	0.23	present	present	EARDC	200	243.8	299.0	343.6	322.4	*	<0.5
58-50-2E	0.03	244	13.7	1.4	1.05	absent	absent	AMT	270	320	420	560	527.33	<0.10	<0.10
58-50-2E	---	---	---	---	---	---	---	AMT	---	---	---	---	---	---	---
58-50-2EM	0.01	38	7.7	1.6	0.26	present	present	EARDC	158	192.4	233.8	228.4	264.5	1.12	<0.5
58-50-2HB	0.01	50	10.5	0.2	1.14	absent	absent	EARDC	203	248.2	304.0	364.0	494.7	6.46	<0.5
58-50-3BL	- - -	---	---	---	---	present	present	AMT	240	290	370	340	356.78	<0.10	<0.10
58-50-502	0.04	23	11.2	0.4	0.93	present	present	AMT	260	310	310	350	358.58	0.80	<0.10
58-50-511	0.00	20	12.3	2.4	0.00	absent	absent	EARDC	237	289.2	315.0	300.4	324.7	*	<0.5
58-57-3BW	0.01	3	4.2	0.6	0.30	absent	absent	AMT	300	360	390	340	383.09	<0.10	<0.10
58-57-3BW	---	---	---	---	---	---	---	AMT	---	---	---	---	---	---	---
58-57-5JO	0.06	92	9.6	0.0	0.91	present	absent	AMT	240	290	320	370	374.02	*	<0.10
WQ Standards												1000			

* Some aluminum results not reported due to possible sampling errors

Edwards Aquifer Water-Quality Sampling Results - March 1994

LABORATORY CHEMICAL ANALYSIS

Well no.	Total Arsenic (mg/l)	Dissolved Arsenic (mg/l)	Total Barium (mg/l)	Dissolved Barium (mg/l)	Boron (mg/l)	Total Cadmium (mg/l)	Dissolved Cadmium (mg/l)	Total Calcium (mg/l)	Dissolved Calcium (mg/l)	Chloride (mg/l)	Total Chromium (mg/l)	Dissolved Chromium (mg/l)	Total Copper (mg/l)
58-42-916	0.452	0.032	0.13	0.12	0.90	<0.02	<0.02	91.3	67.5	16.29	<0.02	<0.02	<0.02
58-42-922	0.0095	0.0067	<0.10	<0.10	0.16	<0.005	<0.005	87	96	67	<0.050	<0.050	0.022
58-42-922	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-9EM	•	•	0.060	0.056	0.20	<0.02	<0.02	56.3	70.0	8.50	<0.02	<0.02	0.17
58-50-1CW1	•	•	<0.10	<0.10	0.24	<0.005	<0.005	150	130	34	<0.050	<0.050	<0.020
58-50-201	•	•	0.15	0.13	0.10	<0.02	<0.02	53.3	76.7	19.29	<0.02	<0.02	<0.02
58-50-2E	<0.001	<0.001	<0.10	<0.10	0.51	<0.005	<0.005	82	81	15	<0.050	<0.050	<0.020
58-50-2E	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-2EM	<0.050	0.037	0.043	0.052	0.20	<0.02	<0.02	81.7	65.8	17.19	<0.02	<0.02	<0.02
58-50-2HB	•	•	0.17	0.085	0.90	<0.02	<0.02	1650.0	200.0	9.5	0.06	<0.02	0.12
58-50-3BL	0.037	0.0057	0.12	0.12	0.12	0.010	0.010	86	83	23	<0.050	<0.050	0.062
58-50-502	•	•	<0.10	<0.10	0.16	<0.005	<0.005	76	76	12	<0.050	<0.050	<0.020
58-50-511	•	•	0.060	0.058	0.8	<0.02	<0.02	66.3	77.5	13.025	<0.02	<0.02	<0.02
58-57-3BW	•	<0.001	<0.10	<0.10	0.12	<0.005	<0.005	77	76	9.3	<0.050	<0.050	<0.020
58-57-3BW	---	---	---	---	---	---	---	---	---	---	---	---	---
58-57-5JO	•	•	<0.10	<0.10	0.29	<0.005	<0.005	70	69	12	<0.050	<0.050	<0.020
WQ Standards	0.05 MCL	0.05 MCL	2.0 MCL	2.0 MCL		0.005 MCL	0.005 MCL			300	0.1 MCL	0.1 MCL	1.0 SCL

• Some arsenic results not reported due to possible sampling errors

Edwards Aquifer Water-Quality Sampling Results - March 1994

LABORATORY CHEMICAL ANALYSIS														
Well no.	Dissolved Copper (mg/l)	Fluoride (mg/l)	Total Iron (mg/l)	Dissolved Iron (mg/l)	Total Lead (mg/l)	Diss. Lead (mg/l)	Total Magnesium (mg/l)	Dissolved Magnesium (mg/l)	Total Manganese (mg/l)	Dissolved Manganese (mg/l)	Total Mercury (mg/l)	Dissolved Mercury (mg/l)	Ammonia Nitrogen (mg/l)	Nitrate Nitrogen (mg/l)
58-42-916	<0.02	0.203	<0.02	<0.02	0.005	<0.002	23.0	22.5	<0.02	<0.02	<0.0002	<0.0002	0.12	2.02
58-42-922	<0.020	0.39	0.081	<0.030	0.024	0.015	21	16	0.013	<0.010	<0.0002	<0.00020	0.16	2.2
58-42-922	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-9EM	<0.02	1.10	0.42	<0.02	0.036	<0.002	51.0	51.0	<0.02	<0.02	<0.0002	<0.0002	<0.10	<0.10
58-50-1CW1	<0.020	0.24	2.1	1.6	0.014	0.0097	31	27	0.43	0.39	0.00057	<0.00020	1.0	1.3
58-50-201	<0.02	0.46	<0.02	<0.02	0.006	<0.002	28.0	28.0	<0.02	<0.02	<0.0002	<0.0002	<0.10	1.25
58-50-2E	<0.020	1.3	0.25	<0.030	0.0012	0.0011	53	41	0.023	<0.010	<0.0002	<0.00020	0.33	0.94
58-50-2E	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-2EM	<0.02	0.217	0.31	<0.02	0.009	<0.002	21.0	17.5	<0.02	<0.02	<0.0002	<0.0002	0.17	0.83
58-50-2HB	<0.02	1.13	5.07	<0.02	0.009	<0.002	1130.0	41.8	<0.02	<0.02	<0.0002	<0.0002	<0.10	2.02
58-50-3BL	0.023	0.36	0.12	<0.030	0.0011	<0.001	16	14	0.032	0.012	<0.0002	<0.00020	0.30	0.33
58-50-502	<0.020	0.85	1.2	<0.03	0.0019	0.0011	30	28	0.059	0.010	<0.0002	<0.0002	0.21	0.61
58-50-511	<0.02	0.314	0.22	<0.02	0.006	<0.002	27.0	26.5	<0.02	<0.02	<0.0002	<0.0002	0.10	1.63
58-57-3BW	<0.020	0.24	0.29	<0.030	0.0015	0.0011	33	23	<0.010	<0.010	<0.0002	<0.00020	0.26	0.62
58-57-3BW	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-57-5JO	<0.020	0.56	1.1	<0.030	0.0025	<0.001	34	31	0.030	0.010	0.00037	<0.00020	0.37	0.037
WQ Standards	1.0 SCL	4.0 MCL	0.3 SCL	0.3 SCL	0.015 MCL	0.015 MCL			0.05 SCL	0.05 SCL	0.002 MCL	0.002 MCL		10.0 MCL

Edwards Aquifer Water-Quality Sampling Results - March 1994

LABORATORY CHEMICAL ANALYSIS

Well no.	Nitrate Ion (mg/l)	Kjeldahl Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)	Nitrite Ion (mg/l)	Total Phosphate (mg/l)	Ortho phosphorus (mg/l)	Total Potassium (mg/l)	Dissolved Potassium (mg/l)	Total Selenium (mg/l)	Dissolved Selenium (mg/l)	Silica (mg/l)	Total Silver (mg/l)	Dissolved Silver (mg/l)	Total Sodium (mg/l)	Dissolved Sodium (mg/l)
58-42-916	8.9	<0.10	<0.10	<0.35	<0.01	<0.01	1.15	1.10	<0.010	<0.010	15.5	<0.001	<0.001	8.00	8.50
58-42-922	9.9	0.43	0.004	0.015	0.068	<0.01	2.4	- - -	0.014	0.012	12	<0.010	<0.010	59	- - -
58-42-922	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-9EM	<0.4	<0.10	<0.10	<0.3	<0.01	<0.01	5.60	5.40	<0.010	0.010	8.0	<0.001	<0.001	4.75	5.25
58-50-1CW1	5.7	1.5	0.007	0.023	0.12	0.026	2.4	- - - -	0.012	0.0087	12	<0.010	<0.010	25	- - - - -
58-50-201	5.5	<0.10	<0.10	<0.35	<0.01	<0.01	1.50	2.25	0.0077	<0.010	8.4	<0.001	<0.001	11.00	12.75
58-50-2E	4.2	0.83	0.01	0.033	0.18	<0.01	5.9	- - -	0.026	0.0069	12	<0.010	<0.010	17	- - -
58-50-2E	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-2EM	3.7	<0.10	<0.10	<0.3	<0.01	<0.01	1.35	1.30	<0.001	<0.010	7.0	0.001	<0.001	8.50	8.50
58-50-2HB	8.9	0.57	<0.10	<0.3	0.09	<0.01	4.55	3.55	<0.010	<0.010	9.1	<0.001	<0.001	7.75	7.50
58-50-3BL	1.5	0.79	0.0018	0.006	0.030	0.024	1.5	- - -	0.032	<0.0020	11	<0.010	<0.010	18	- - -
58-50-502	2.7	0.88	0.011	0.038	0.015	<0.01	2.2	- - -	<0.002	<0.002	11	<0.010	<0.010	8.9	- - -
58-50-511	7.2	<0.10	<0.10	<0.3	<0.01	<0.01	1.25	1.15	<0.010	<0.010	7.1	0.001	<0.001	6.75	6.75
58-57-3BW	2.8	1.0	0.008	0.028	0.048	<0.01	2.2	- - -	0.0031	<0.002	13	<0.010	<0.010	5.5	- - -
58-57-3BW	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
58-57-5JO	0.16	0.70	0.00060	0.0020	0.12	<0.01	4.2	- - -	0.0056	0.0051	13	<0.010	<0.010	8.9	- - -
WQ Standards			1.0 MCL						0.05 MCL	0.05 MCL		0.05	0.05		

Edwards Aquifer Water-Quality Sampling Results - March 1994

LABORATORY CHEMICAL ANALYSIS								INDICATOR BACTERIA			RADIONUCLEIDES		
Well no.	Total Strontium (mg/l)	Dissolved Strontium (mg/l)	Sulfate (mg/l)	Total Zinc (mg/l)	Dissolved Zinc (mg/l)	Total Suspended Solids (mg/l)	Ion Balance	Total Coliform (colonies/ 100 ml)	Fecal Coliform (colonies/ 100 ml)	Fecal Strep (colonies/ 100 ml)	Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Tritium (pCi/l)
58-42-916	0.30	0.30	22.4	0.04	<0.02	0	1.01	Heavy non-coli	8	46	1.2	1.3	<0.02
58-42-922	2.6	2.4	59	0.11	0.024	1.6	1.05	0	0	1,900	3.3	2.9	<0.02
58-42-922	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-9EM	30.0	35.0	152.7	0.04	<0.02	57.15	1.040	0	- - -	- - -	2.2	5.7	<0.02
58-50-1CW1	1.1	1.1	65	0.077	0.087	5.6	1.08	0	0	0	5.4	2.6	<0.02
58-50-201	4.00	3.00	27.0	0.06	0.05	0	1.27	Heavy non-coli	1022	16	1.6	2.3	<0.02
58-50-2E	29	24	150	0.29	0.19	49	0.92	0	0	1	1.2	7.3	<0.02
58-50-2E	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-2EM	0.180	0.160	30.70	0.06	0.02	9.490	1.21	0	- - -	- - -	1.6	1.7	<0.02
58-50-2HB	14.00	16.00	71.2	0.07	<0.02	6384.4	2.31	0	0	0	3.1	4.0	<0.02
58-50-3BL	0.20	0.19	23	0.050	0.033	2.2	1.08	36	2	37	0.90	1.6	<0.02
58-50-502	0.88	0.77	22	0.12	0.070	14	1.11	540	390	0	1.9	1.5	<0.02
58-50-511	1.00	1.20	17.2	0.08	0.04	1.39	1.09	0	2	0	0.50	2.2	<0.02
58-57-3BW	2.2	2.2	19	0.073	0.038	13	1.02	34	0	0	1.5	1.1	<0.02
58-57-3BW	---	---	---	---	---	---	---	0	---	---	---	---	---
58-57-5JO	17	17	55	0.063	0.017	7.2	1.08	0	0	0	2.1	4.4	<0.02
WQ Standards			300	5.0	5.0			1	1	- -	15		

Edwards Aquifer Water-Quality Sampling Results - March 1994

	ORGANICS		PESTICIDES										
Well no.	Total Organic Carbon (mg/l)	Total Petroleum Hydrocarbons (mg/l)	4,4-DDD (ug/l)	4,4-DDT (ug/l)	4,4-DDE (ug/l)	Aldrin (ug/l)	Atrazine (ug/l)	BHC-Alpha (ug/l)	BHC-Beta (ug/l)	BHC-Gamma Lindane (ug/l)	BHC-Delta (ug/l)	Chlordane (ug/l)	Chlordane-Gamma (ug/l)
58-42-916	1.14	0.08	<0.004+	<0.003+	0.0058	<0.004	<0.053	0.0052	<0.007	0.0108	0.006	0.0096	0.0102
58-42-922	14	1.9	<0.010	<0.004	<0.004	<0.004	<5.0	<0.003	<0.006	<0.003	<0.009	<0.014	- - -
58-42-922	2.6	1.3	---	---	---	---	---	---	---	---	---	---	- - -
58-49-9EM	3.98	0.05	<0.004	0.0071	<0.008	<0.004	<0.0011	<0.002+	<0.007	<0.005+	<0.006	0.0077	<0.007
58-50-1CW1	86	11	<0.010	<0.004	<0.004	<0.004	<5.0	<0.003	<0.006	<0.003	<0.009	<0.014	- - - -
58-50-201	1.30	0.2	<0.004	<0.003	<0.008	<0.004	<0.0011	<0.002+	<0.007	<0.005+	<0.006	<0.008+	<0.007+
58-50-2E	•	•	<0.010	<0.004	<0.004	<0.004	<5.0	<0.003	<0.006	<0.003	<0.009	<0.014	---
58-50-2E	0.83	<0.03	---	---	---	---	---	---	---	---	---	---	---
58-50-2EM	1.47	0.02	<0.004	0.0061	<0.008+	<0.004	<0.053	<0.002+	0.0097	<0.005+	<0.006+	<0.008	<0.007
58-50-2HB	534.0	0.11	<0.004	<0.003	<0.008	<0.004	<0.0011	0.0086	<0.007+	0.0067	<0.006+	0.0407	<0.007+
58-50-3BL	21	0.48	<0.010	<0.004	<0.004	<0.004	<5.0	<0.003	<0.006	<0.003	<0.009	<0.014	- - -
58-50-502	19	<0.02	<0.010	<0.004	<0.004	<0.004	<5.0	<0.003	<0.006	<0.003	<0.009	<0.014	- - -
58-50-511	1.08	0.16	<0.004	<0.003	<0.008+	<0.004	<0.0011	0.0176	0.0012	<0.005+	<0.006	0.0183	0.0143
58-57-3BW	•	•	<0.010	<0.004	<0.004	<0.004	<5.0	<0.003	<0.006	<0.003	<0.009	<0.014	- - -
58-57-3BW	1.9	1.2	---	---	---	---	---	---	---	---	---	---	---
58-57-5JO	17	0.17	<0.010	<0.004	<0.004	<0.004	<5.0	<0.003	<0.006	<0.003	<0.009	<0.014	- - -
WQ Standards		0.5					3 MCL			0.2 MCL		2.0 MCL	

Note: Pesticide analyses by gas chromatograph represent maximum possible concentrations in sample, and were not verified by mass spectroscopy .

• TPH results not reported due to sampling error on 3/15/94. Wells were resampled on 4/18-19/94

+ Some level of this pesticide or herbicide may have been detected below the method-specified detection limit.

Edwards Aquifer Water-Quality Sampling Results - March 1994

	PESTICIDES										
Well no.	Dieldrin (ug/l)	Endosulfan I (ug/l)	Endosulfan II (ug/l)	Endosulfan Sulfate (ug/l)	Endrin (ug/l)	Endrin Aldehyde (ug/l)	Endrin Ketone (ug/l)	Heptachlor (ug/l)	Heptachlor Epoxide (ug/l)	Methoxychlor (ug/l)	Toxaphene (ug/l)
58-42-916	0.0006	0.0066	<0.008+	0.0165	<0.008	<0.012	0.053	0.0191	0.0248	<0.030+	---
58-42-922	<0.002	<0.014	<0.004	<0.066	<0.006	<0.023	----	<0.003	<0.083	<0.18	<0.24
58-42-922	---	---	---	---	---	---	---	---	---	---	---
58-49-9EM	<0.004+	0.0061	<0.008	<0.009	<0.008+	<0.012	<0.008	<0.006+	<0.004+	<0.030	---
58-50-1CW1	<0.002	<0.014	<0.004	<0.066	<0.006	<0.023		<0.003	<0.083	<0.18	<0.24
58-50-201	<0.004	<0.002+	<0.008	<0.009	<0.008	<0.012	1.325	0.0055	0.0107	<0.030	---
58-50-2E	<0.002	<0.014	<0.004	<0.066	<0.006	<0.023	---	<0.003	<0.083	<0.18	<0.24
58-50-2E	---	---	---	---	---	---	---	---	---	---	---
58-50-2EM	0.048	0.012	<0.008	<0.009	0.0146	0.02	<0.008	<0.006+	<0.004	<0.030+	----
58-50-2HB	<0.004	0.0351	<0.008	0.0106	<0.008+	<0.012	<0.008	<0.006+	0.0049	<0.030	---
58-50-3BL	<0.002	<0.014	<0.004	<0.066	<0.006	<0.023	----	<0.003	<0.083	<0.18	<0.24
58-50-502	<0.002	<0.014	<0.004	<0.066	<0.006	<0.023	---	<0.003	<0.083	<0.18	<0.24
58-50-511	<0.004+	0.0156	<0.008	0.013	<0.008	<0.012	0.742	<0.006+	0.022	<0.030	---
58-57-3BW	<0.002	<0.014	<0.004	<0.066	<0.006	<0.023	---	<0.003	<0.083	<0.18	<0.24
58-57-3BW	---	---	---	---	---	---	---	---	---	---	---
58-57-5JO	<0.002	<0.014	<0.004	<0.066	<0.006	<0.023	---	<0.003	<0.083	<0.18	<0.24
WQ Standards					2.0 MCL			0.4 MCL	0.2 MCL	40 MCL	3.0 MCL

Note: Pesticide analyses by gas chromatograph represent maximum possible concentrations in sample, and were not verified by mass spectroscopy.

+ Some level of this pesticide or herbicide may have been detected below the method-specified detection limit.

Edwards Aquifer Water-Quality Sampling Results - March 1994

	HERBICIDES												
Well no.	Actifluoren (ug/l)	Bentazon (ug/l)	Bromacil (ug/l)	Chloramben (ug/l)	2,4-D (ug/l)	2,4-DB (ug/l)	DCPA (ug/l)	3,6-Dichloro methoxy benzoic Acid (ug/l)	Dicamba (ug/l)	3,5-Dichloro-benzoic (ug/l)	Dichlorprop (ug/l)	Dinoseb (ug/l)	MCPA (ug/l)
58-42-916	<0.096	<0.200	1.065	<0.093	<0.200	<0.80	<0.02		<0.081	<0.061	<0.260	0.299	
58-42-922	- - -	- - - -	<5.0	- - -	<1.2	<0.91	- - -	<0.27	- - -	- - -	<0.65	- - -	<250
58-42-922	---	---	---	---	---	---	---	---	---	---	---	---	---
58-49-9EM	<0.096	<0.200	.0.527	<0.093	<0.200	<0.80	<0.02	- - -	<0.081	<0.061	<0.260	<0.190	- -
58-50-1CW1	- - -	- - -	<5.0	- - - -	<1.2	<0.91	- - -	<0.27	- - -	- - -	<0.65	- - -	<250
58-50-201	<0.096	<0.200	0.468	<0.093	0.232	<0.80	<0.02	- - -	<0.081	0.090	0.331	<0.190	- - -
58-50-2E	- - -	- - -	<5.0	- - -	<1.2	<0.91	- - - -	<0.27	- - -	- - -	<0.65	- - -	<250
58-50-2E	---	---	---	---	---	---	---	---	---	---	---	---	---
58-50-2EM	<0.096	<0.200	0.024	<0.093	- - -	<0.80	<0.02	- - -	<0.081	<0.061	<0.260	<0.190	- - - -
58-50-2HB	<0.096	<0.200	0.185	<0.093	<0.200	<0.80	<0.02	- - -	<0.081	0.118	0.283	<0.190	- - -
58-50-3BL	- - -	- - -	<5.0	- - -	<1.2	<0.91	- - -	<0.27	- - -	- - -	<0.65	- - -	<250
58-50-502	- - -	- - -	<5.0	- - -	<1.2	<0.91	- - -	<0.27	- - -	- - -	<0.65	- - -	<250
58-50-511	<0.096	<0.200	0.286	<0.093	<0.200	<0.80	. <0.02	- - -	<0.081	0.068	<0.260	<0.190	- - -
58-57-3BW	- - -	- - -	<5.0	- - -	<1.2	<0.91	- - -	<0.27	- - -	- - -	<0.65	- - -	<250
58-57-3BW	---	---	---	---	---	---	---	---	---	---	---	---	---
58-57-5JO	- - -	- - -	<5.0	- - -	<1.2	<0.91	- - -	<0.27	- - -	- - -	<0.65	- - -	<250
WQ Standards					70 MCL							7.0 MCL	

Note: Herbicide analyses were performed by gas chromatograph represent maximum possible concentrations in sample, and were not verified by mass spectroscopy. Bromacil and 4-nitrophenol concentrations were verified by mass spectroscopy. Actual concentrations are indicated.

\+ Some level of this pesticide or herbicide may have been detected below the method-specified detection limit.

Edwards Aquifer Water-Quality Sampling Results - March 1994

HERBICIDES							
Well no.	2(4-chloro-o-tolyloxy) propionic acid (ug/l)	4-nitrophenol (ug/l)	2-(1-methylpropl -4-6-dinitrophenol (ug/l)	Pentachloro phenol (ug/l)	Picloram (ug/l)	2,4,5-T (ug/l)	2,4,5-TP (ug/l)
58-42-916		0.980		<0.076	<0.140	<0.080	<0.075
58-42-922	<190	---	<0.070	---	---	<0.20	<0.17
58-42-922	---	---	---	---	---	---	---
58-49-9EM	---	0.286	---	<0.076	<0.140	<0.080	<0.075
58-50-1CW1	<190	---	<0.070	---	---	<0.20	<0.17
58-50-201	---	0.347	---	<0.076	<0.140	<0.080	<0.75
58-50-2E	<190	---	<0.070	---	---	<0.20	<0.17
58-50-2E	---	---	---	---	---	---	---
58-50-2EM	---	<0.130	---	<0.076	<0.140	<0.080	<0.075
58-50-2HB	---	0.276	----	<0.080	<0.140	<0.080	<0.075
58-50-3BL	<190	---	<0.070	---	---	<0.20	<0.17
58-50-502	<190	----	<0.070	---	---	<0.20	<0.17
58-50-511	---	0.146	---	<0.076	<0.140	<0.080	<0.075
58-57-3BW	<190	---	<0.070	---	---	<0.20	<0.17
58-57-3BW	---	---	---	---	---	---	---
58-57-5JO	<190	---	<0.070	---	---	<0.20	<0.17
WQ Standards				1.0 MCL	500 MCL		50

Note: Herbicide analyses by gas chromatograh represent maximum possible concentrations in sample, and were not verified by mass spectroscopy.

Appendix C.

District Procedures for Field Activity Preparation, Sampling, and Laboratory Analysis

BS/EACD FIELD SAMPLING PROCEDURES

I. Field Preparation

A. Calibrate the Horiba U-10 and Hach meters before each day of use. In general, use the follow standards:

Probe	Zero Standard	High Standard
pH (Horiba)	7.0	8.0
pH (Hach)	4.0	7.0
Conductivity	deionized water	500 or 1,000 uS/cm
Turbidity	deionized water	100 NTU

II. Field Sampling Steps

A. Take a static water-level measurements while the pump is off. Note that in some cases, water-level measurements cannot be taken because of the size of the access port or due to obstructions in the well. In some cases, the vent pipe may be temporarily removed, well-seal bolts can be removed, or the probe can be lowered adjacent to the pump wiring. Some water levels can be measured using a chalked steel tape. Be innovative about ways to take water level measurements, but be careful not to damage well fixtures. Make sure to maintain the probe weight on the line to prevent snagging of the e-line.

B. Determine the well depth and well-bore diameter. Both dimensions are generally documented in the well file, particularly if a drillers log is available. On open wells less than 300 feet deep, the well depth should be measured in all cases using well depth tape to verify the reported depth and determine if significant well siltation is occurring. On wells with sanitary seals, the well depth can sometimes be measured using a weighted water-level probe.

C. Locate the well spigot as close to the wellhead as possible and prior to any chlorination treatment. Note where samples were collected after chlorination. A purging hose may be used to drain water away from the wellhead and to avoid flooding the well house, although the sample should be collected directly from the spigot whenever possible. A purging hose used for formal samples should be dedicated (not previously used). The hose end should not lie on the ground, but should be attached to the side of the sample ooler in a hose clamp.

D. Read the initial meter reading prior to purging. Note that in some cases the well will already be pumping prior to the inspectors arrival. If so then document the prior pumping.

E. 1) Purge the well. Prior to collecting a *formal* groundwater sample from a well, the well bore and pressure tank must first be purged of water storage. In some cases, it may not be possible to formally purge a well because of flooding of nearby areas, or where formal samples are not required. A well should be noted as being *informally purged* or *unpurged* if: (1) changes in field parameters are not measured or documented or the pumped volume is not measured or accurately estimated; (2) either the field parameters did not stabilize or the the purge volume was not removed; or (3) the well was purged for a short time or unpurged by the sampler. Purging is unnecessary when samples are collected from springs or streams.

2) While the well is purging, calculate the purge volume required for formal sampling, if the depth to water and well depth are known. The removal of three well volumes, plus water stored in tanks and piping, is generally sufficient for sampling, although the

best way to document groundwater stabilization is through field measurements of pH, conductivity, and temperature (see 3.) Estimate the purge volume using the following formula:

Purge Volume = 3 well volumes + volume of water stored in tanks and piping

where the well volume equals:

0.04 (well-bore diam. in inches squared) (well depth - water depth in feet)

Most wells in the District have a well bore diameter of 7 or 5-5/8 inches and require about 500 to 1,000 gallons to purge three well volumes. Periodically read the meter or measure the flow from the hose using a bucket of known volume. Typically domestic wells pump at a rate of about 10 gallons/minute.

3) The well should be pumped until conductance, temperature, and pH are have stabilized. Measurements of these parameters should be made about 5 minutes apart and documented on the Water-Quality Sampling and Analysis Sheet. The parameters of pH, conductivity, and temperature should be within 0.05 pH units, 5 uS/cm, and 0.5°C, respectively, over at least three consecutive measurements to be considered stable. If possible the turbidity and dissolved oxygen should also be measured.

F. 1) Collect the sample using the proper bottle and protocol depending on the type of analysis:

Type of Sampling/Parameter	Bottle Type	Preserv./Treatment
District lab for chemical test	liter plastic	None
District lab bacteria test	100 ml bottle	Colilert broth
Diss. Metals/Hardness/Radionucl.	1 liter plastic	2 ml 50% HNO_3 (< 2pH), filter
Total Metals	1 liter plastic	2 ml 50% HNO_3 (< 2pH)
Nitrogen componds/Phosphates	250 ml plastic	0.5 ml 50% H_2SO_4 (< 2 pH)
Total Dissolved Solids	250 ml plastic	None, filter
Total Petroleum Hydrocarbons	1 liter glass	0.5 ml 50% H_2SO_4

2) Measure the field phenol and bicarbonate alkalinity. Using a graduated cylinder collect 100 ml of the sample and pour into an erlenmeyer flask. Add one package of phenolphthalein powder and swirl to mix. If the color turns pink, titrate to a colorless endpoint with the digital titrator and sulfuric acid cartridge, and note the concentration of phenol alkalinity (unless the pH of the water is much above 8.3, no phenol alkalinity will be present) Add a package of Bromcresol Green-Methyl Red Powder, swirl to mix, and titrate through a steel-blue color to a pink-colored endpoint. Around this endpoint, the pH abruptly changes as it drops below 4.8. Note this amount of bicarbonate alkalinity. Sum the phenol and bicarbonate alkalinities for the total alkalinity.

3) Sterilize the sampling spigot for bacterial sampling. After purging the well the faucet should be turned off. If the spigot is metal, it should be flamed with a propane torch to kill bacteria existing on the surface of the metal. Do not flame a plastic faucet. Once sterilized the faucet is turned on again and flushed and the sample is taken using a sterile sampling container.

G. Store the samples properly.

1) Samples will be kept on ice following collection in the field, brought to the lab as soon as possible, and analyzed within the holding time for the desired parameters. The holding time for fecal bacteria, chromium (VI), and turbidity is six, 24, and 48 hours, respectively. The holding time for metals, and most other parameters can be extended to

at least one week by cooling to 4 degrees centigrade and/or the addition of a specified preservative (See USBR, 1984, EPA Standard Methods Volume 16, Hach Manual, or TWDB Report UM-51.)

2) Samples must not be exposed to excessive heat, sunlight, oxygen or microbial organisms such as algae and bacteria.

3) Samples must be kept refrigerated until ready for analysis.

III. Laboratory Procedures

A. Laboratory Preparation and Maintenance

1) Cleaning of Labware: All labware should be thoroughly cleaned with deionized water prior to collection or testing of samples.

   a) Labware should be washed with a brush and detergent.

   b) Following washing, labware should be rinsed with water.

   c) If not used immediately, labware should be air dried following rinses.

   d) Collection containers should be rinsed before use with the sample water.

   e) Labware should be cleaned with deionized water between every constituent test.

2) Keep incubator setting at 35.5°C and on at all times.

3) Refill all squeeze-type rinse bottles with deionized water.

4) Keep laboratory countertops and equipment clean and orderly.

5) Keep blue freezer packs frozen until ready for use in the field.

6) Empty coliform test bottles, rinse, and discard as soon as practical.

B. Sample Analysis
Perform using the Hach Water Analysis Handbook or submit samples to certified laboratory for analysis.

IV. Result Documentation

Following completion of the inspection and analysis:

A. Enter results in the District water-quality database.

1) Enter the *Well Inspection* and *Water-Quality Sampling and Analysis* information on the *Water-Quality Testing Database.* Print the completed forms out on District letterhead.

2) File copies of the completed forms in the Water Well and Spring File, in the District Permittee file, and in the District activities notebook.

B. Prepare a transmittal letter to be mailed with the analytical results to the well owner.

C. Mail results to well owner.