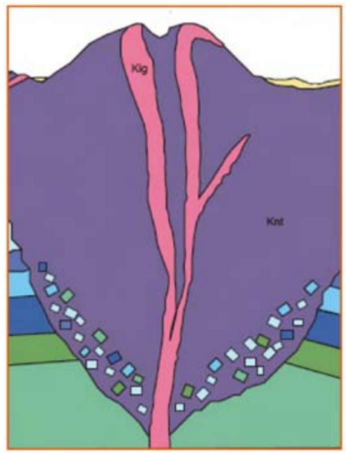
austin geological society

bulletin

volume 2

2005-2006

austin geological society



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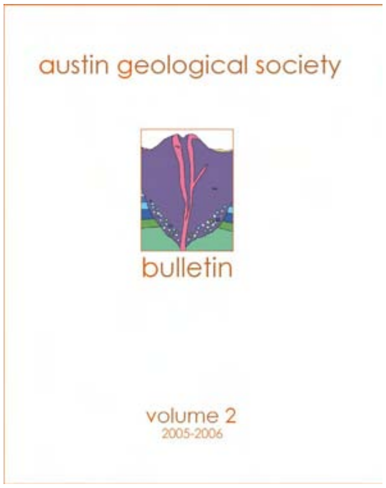


Image on preceding page: Cross-section of Pilot Knob (after Young and others, 1975).

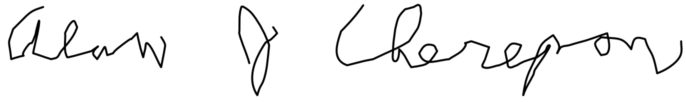
note from the president

My year as the AGS President is coming to a close as the 2nd edition of the AGS Bulletin is coming together. What began as one member's idea have become a reality and an excellent way of preserving a record of our year's activities and presentations. Other members worked with that idea to help make it a reality, and this is a good a way as any to make things happen. I applaud Robert Mace, Brian Hunt, and the others who worked hard to make this work, not just once, but repeatedly, and trust others will assist in continuing the Bulletin as the years slip past.

The field trip to the volcanic features of Austin was a somewhat similar venture this year. I suggested the idea to two of the former authors of the 1982 version of this trip. One of them, Chris Caran, agreed it was long overdue to update this trip. He, in turn, brought in Todd Housh, an Associate Scientist within the Jackson School of Geosciences, who was also interested and knowledgeable about volcanic geology. Together, through some considerable obstacles and hard work, we were able to do more than copy a previous trip, but added new stops and more detailed interpretation. Some 49 people attended, virtually filling the bus. Highlights of the trip included access to Pilot Knob, viewing what is possibly the first discernable pillow lava (or less likely a lava tube) in Williamson Creek and what may be the largest exposure of volcaniclastics material in Austin in Onion Creek.

Another person who is worthy of separate praise is the Education Chair, John Mikels. The Executive Board supported his suggestion to start an Education Committee as a mechanism to fulfill one of the primary objectives of our society. John has nearly single-handedly communicated, raised awareness, and secured help in such local educational events as the Austin Science Fair, Austin Earth Science Week, and other activities within the local schools. Others in the society have provided volunteer classes in Earth Sciences to local schools. With our President Elect, Ernie Lundelius, I have worked at getting better communication and participation with the UT geological community by holding one of our monthly meetings at UT, meeting with the UT Undergraduate Geological Society, and hosting a social gathering at Schulz's. We also need to continue to acknowledge the Bureau of Economic Geology, especially Scott Tinker and Wanda La Plante, for their continued support and efforts in allowing the AGS to hold our meetings at their facility in the Pickle Research Center. And a big thank you to Amanda Masterson for staying on and keeping the BEG publications office open for several of our meetings. We are grateful for the many ways in which the BEG gives to our professional community.

In closing, between the hard works of key individuals, good programs and field trip, and the continuing education credit requirements for our geoscientist license renewal, our membership has swelled to over 100 for the first time in a while. Which lends further credence to the adage, "the more you give, the more you receive". With these closing words, I encourage you all to give back to our profession whenever possible. Thank you all for the opportunity to work with and serve the AGS this year.



Alan Cherepon, 2005–2006 AGS President

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note from the editor

While working on the first volume of this bulletin, I kept telling myself and others that once the first volume was completed, the second volume would be as easy as finding rocks in Barton Creek. And while the overall effort on this volume has been less, it has been, in some ways, more of a struggle, primarily because of activities in my life outside of being editor of this humble bulletin. The summer started off with getting married, an event that consumed an amazing amount of time and energy requiring several months of recuperation. After that, my job at the Texas Water Development Board heated up with work on the 2007 State Water Plan and responding to various issues with drought, water production related to gas exploration in the Barnett Shale, and implementation of joint planning in groundwater management areas. And then I had to cope with mild depression after the Longhorns were driven from the national championship trail by Kansas State. Nonetheless, the bulletin beckoned (as well as the associate editors…).

An important element of getting motivated for the bulletin was the excellent papers submitted for this volume. The only alternative to finishing the bulletin was not finishing the bulletin—and that was not an option with these papers awaiting publication.

Again, I want to thank the authors that agreed to submit papers to the bulletin. I also want to thank the associate editors Brian Hunt, April Hoh, John Mikels, and Sarah Davidson; president Alan Cherepon; and Eddie Collins for guidance and assistance in assembling the bulletin. Keep the papers coming. I don't plan on getting married again (and the state water plan is not due for another five years), so next summer will be easier…

Robert E. Mace, Editor

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bulletin, volume 1, 2004-2005

mission: The mission of the *Austin Geological Society Bulletin* is to (1) summarize the previous year's activities of the Society and (2) publish technical papers, comments, and notes concerning the natural sciences of Central Texas.

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information to authors: The Editor of the *Austin Geological Society Bulletin* invites contributions relating to the natural sciences of Central Texas in the form of technical papers and discussions. If you would like to submit to the bulletin, please see the instructions to authors at the end of this document. All submissions should be sent to the editor in digital format to editor@austingeosoc.org.

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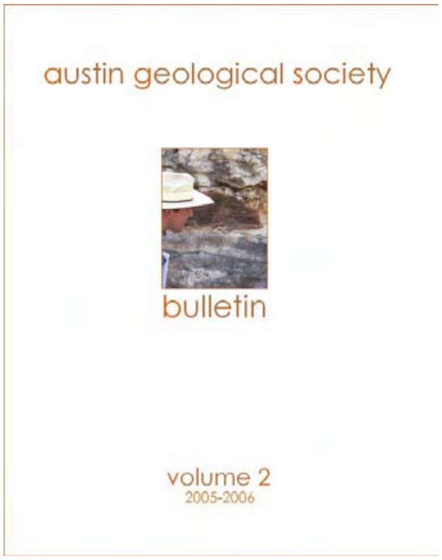

Cover photo: Reworked volcaniclastics in the McKown Formation (Brian Hunt for scale; photo by Alan Cherepon).

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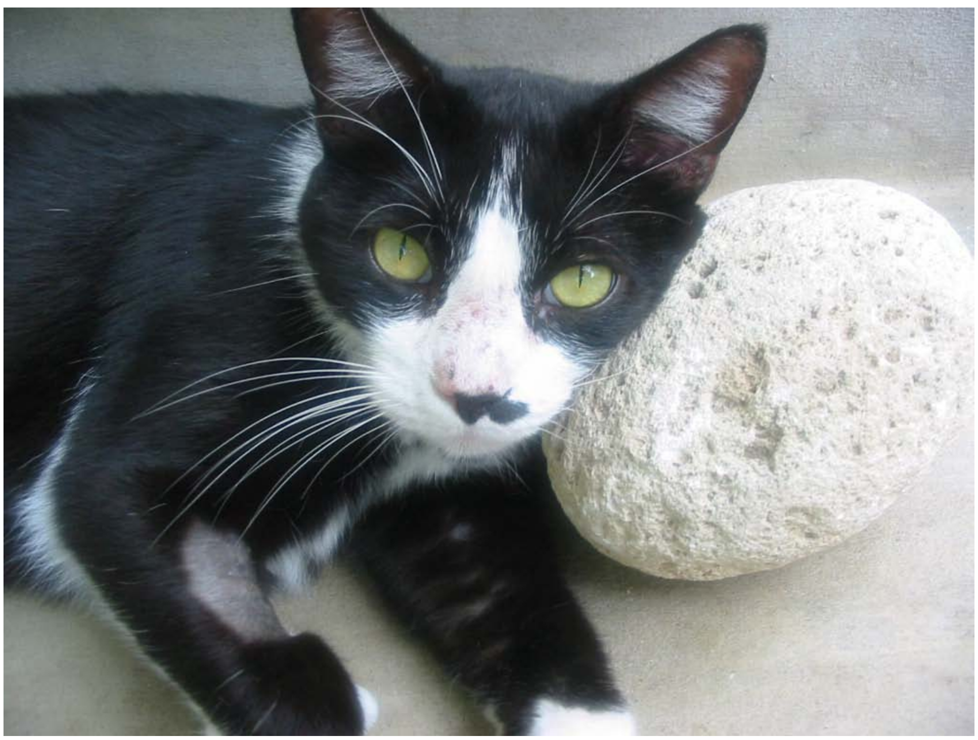

Even cats like rocks! (photo by Robert E. Mace)

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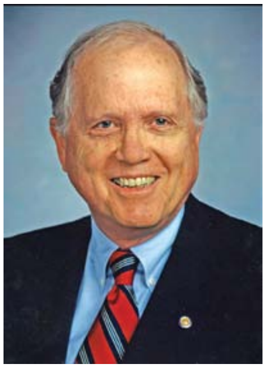
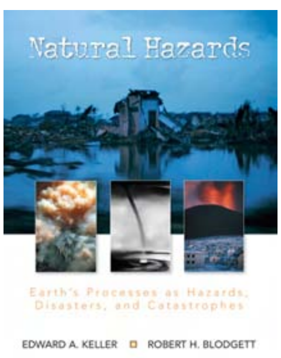


Pete Rose serves as president of the American Association of Petroleum Geologists

Our own Peter R. Rose was elected the 89th president of the American Association of Petroleum Engineers for their 2006–2007 fiscal year. The American Association of Petroleum Geologists is the world's largest professional geological society with approximately 31,000 members in 115 countries. The Association was formed in 1917. Its purpose is to foster the spirit of scientific research among its members and to advance the science of geology particularly as it relates to petroleum, natural gas, other subsurface fluids, mineral resources, and the environment. As president of the Association, Dr. Rose kept quite busy: (1) he logged 120,000 air miles, (2) he visited all six U.S. Sections and four international Regions, (3) he made more than 60 formal presentations, (4) he participated in at least 40 business meetings, and (5) he wrote an estimated 300 pages of text for Association publications. The incoming president for 2006–2007, Lee T. Billingsley, noted that "Pete Rose was a most active and engaged president. He did not shrink from any challenge. As committee members and members-at-large suggested concerns to Pete, he addressed those concerns by appointing committees, consulting the EC [Executive Committee] and, finally, gaining EC decisions. He put much heart and soul into the job to improve the organization for its members. Pete, you succeeded."



Blodgett co-authors book on natural hazards

Dr. Bob Blodgett, professor at Austin Community College and longtime member and former president of the Austin Geological Society, has co-authored a college earth science textbook with Edward Keller at the University of California at Santa Barbara. The book, entitled "Natural Hazards—Earth's Processes as Hazards, Disasters, and Catastrophes" was published by Pearson Prentice Hall in July 2005. It is primarily aimed at non-majors and is being used at over 50 colleges and universities in the United States and Canada. A short description of the book can be found on the Pearson Prentice Hall Website at: http://vig.prenhall.com/catalog/academic/product/0,1144,0130309575,00.html.

Pat Dickerson appointed to NASA Advisory Council subcommittee

Patricia Dickerson has recently been appointed to the Planetary Sciences Subcommittee of the NASA Advisory Council. The Planetary Sciences Subcommittee is one of five within the Science Committee (the others are Heliophysics, Earth Sciences, Astrophysics, Planetary Protection) of the NASA Advisory Council, which provide independent recommendations to the Agency regarding science matters. The NASA Advisory Council chair Harrison Schmitt (geologist and Apollo 17 astronaut) invited Pat to serve on the subcommittee because of her lead as the developer for field geophysical training exercises for astronauts to prepare for lunar and Martian exploration.

Flowering cactus during this year's field trip (photo by Brian Hunt)

agency news

Barton Springs/Edwards Aquifer Conservation District

In May 2005, the Barton Springs/Edwards Aquifer Conservation District and the City of Austin injected non-toxic dyes into four major sinkholes and caves that contribute recharge to the Barton Springs aquifer in order to delineate groundwater flow paths and velocities during higher-flow conditions. Dye that was injected into a cave on Onion Creek was detected in less than 2.5 days at Barton Springs and within 3 weeks at San Marcos Springs.

In November 2005 the District measured water levels in nearly 300 wells, creating a potentiometric map under below-average flow conditions. In addition, the District installed a satellite telemetry system in the Lovelady monitor well. The system was purchased from In-Situ, Inc.

In January 2006 the District installed a weather station that provides real-time weather information accessible via the Internet. The station is part of the WeatherBug® Weather Tracking Station network and is available from the KXAN-36 Television website. The station's name is "Aquifer District" in zip code 78748.

The District is currently participating with Southwest Research Institute on a new dual conductivity model that is designed to handle both matrix and conduit flow regimes. The Barton Springs Segment of the Edwards Aquifer is being used as a test case for the dual conductivity model.

The District recently completed its second year of a three-year grant from the Fish and Wildlife Service to develop a habitat conservation plan for the Barton Springs Salamander. A component of this study was an evaluation of the District's drought trigger methodology. Results of that study determined that Barton Springs and the Lovelady Well are the best triggers for drought declaration. The Board adopted the new drought trigger methodology on February 6, 2006. Ongoing activities for the habitat conservation plan include developing a water balance for various alternative management measures to be applied to a synthetic daily hydrograph of Barton Springs during critical flow periods.

For further information please contact the District at (512) 282-8441, bseacd@bseacd.org. http://www.bseacd.org/

News from the Bureau of Economic Geology:

FutureGen—The world's first near-zero-emissions energy facility

FutureGen is a one billion dollar Federal/private industry initiative sponsored by the U.S. Department of Energy to design, build, and operate a 275-megawatt energy facility that produces electricity and hydrogen from coal with near-zero emissions while, at the same time, sequestering the carbon dioxide and hydrogen produced during the process.

Preliminary technical requirements for FutureGen include:

- establishing the capacity to sequester at least 90 percent of carbon dioxide emissions from the plant;
- establishing standardized protocols for carbon dioxide measuring, monitoring, and verification; and
- proving the effectiveness, safety, and permanence of carbon dioxide sequestration.

The U.S. Department of Energy is providing $750 million for this public/private venture, and the FutureGen Industrial Alliance is providing $250 million. Once FutureGen is built, the Alliance will own and operate the facility. Results of this demonstration project will be shared among all participants, industry, and the world.

President Bush announced the FutureGen initiative in 2003. In Texas, the Governor's Clean Coal Technology Council, chaired by Railroad Commissioner Michael L. Williams, identified FutureGen as a priority in 2004 and began building a Texas response. In 2005, the Texas Legislature appropriated $2 million to develop the State's FutureGen proposal. The Bureau of Economic Geology, under the direction of State Geologist Dr. Scott W. Tinker, accepted a request by Clean Coal Technology Council Chairman Williams to manage and coordinate Texas' FutureGen proposal.

Nine Texas council of governments associations from around the state submitted proposals for the site for the FutureGen project. Governor Perry recently announced that two sites had been selected—Odessa for its expertise in commercial use of FutureGen co-products, including sequestration and transportation of carbon dioxide and use of hydrogen by the petrochemical industry, and Jewett for its abundant lignite resources.

The Texas proposal has been submitted to the U.S. Department of Energy, and the final decision on site location in the United States will be made in 2007. *– Modified from a PTTC Texas Region Newsletter Article by Scott W. Tinker, U.T. Bureau of Economic Geology, and Katie Tobin, McDonald Public Relations.*

News from the Hays Trinity Groundwater Conservation District

On October 7, 2005, the Hays Trinity Groundwater Conservation District's groundwater management plan was approved by the Texas Water Development Board. Groundwater availability numbers determined during the creation of the plan recently caused the District to implement a moratorium on permitting new wells and granting additional groundwater to existing permit holders in the Region L portion of the District. The plan states that Region L's current groundwater availability is 1,213 acre-feet per year and Region K's availability is 2,500 acre-feet per year. Withdrawal rates for Region K show there is still a small amount of surplus groundwater, but Region L is already mining the Trinity aquifer on an annual basis. The District is working with current Region L permit holders, the City of Wimberley, and the Guadalupe-Blanco River Authority to address the possibility of piping surface water to Wimberley Valley.

Al Broun, our District geologist, is working pro-bono and brings years of geologic experience to the District. He has completed three structural cross-sections and one stratigraphic cross-section. In addition Al has constructed two structural maps: one of the top of the Cow Creek Formation and the second of the top of the Lower Glen Rose Formation. To construct the cross sections and structural maps, Al correlated 40 geophysical logs throughout the District. Sixteen of those logs included detailed cuttings descriptions. The District currently monitors water levels in 24 wells, with the goal to have one in each Texas Water Development Board 2.5-minute grid. Another project is to locate all well owners, which should have operating permits, and permit them, so the District may gain a better understanding of withdrawal from the Trinity Aquifer.

News from the Lower Colorado River Authority

Over the past year, the Lower Colorado River Authority (LCRA) passed a new Highland Lakes Watershed Ordinance to protect lakes and tributaries from nonpoint-source pollution and is currently working on provisions to regulate mines and quarries in the ordinance area. LCRA participated in several geological conferences, including presentations at the Texas Water Development Board's Aquifers of the Gulf Coast conference in Corpus Christi, National Ground Water Association Groundwater Summit in San Antonio, Houston Geological Society, and the Austin Geological Society. LCRA participates in the Texas Ground Water Protection Committee. LCRA also has a staff committee that reviews all Texas Commission on Environmental Quality water quality permit applications including discharge and no-discharge wastewater permit applications. LCRA has several water/wastewater utility projects underway, including water supply well projects in some areas and surface water development projects in other areas where water quantity or quality problems exist.

LCRA is a player in regional water planning for Central Texas and worked with other stakeholders on the latest Region K water planning submittal to the Texas Water Development Board. Perhaps the most significant activity is the LCRA/SAWS Water Project, which includes a study of groundwater for agriculture in the Gulf Coastal Plains. Consultants for LCRA and San Antonio Water Systems (SAWS) are coordinating with the Texas Water Development Board and groundwater conservation districts on formulation of a new groundwater model for the central/northern Gulf Coast Aquifer. This model includes a new interpretation of stratigraphy and hydraulics for the Chicot and Evangeline aquifer units as well as shallow groundwater systems that interact with surface water resources. LCRA recently determined that the Colorado River is a gaining stream that receives flow contributions from major and minor aquifers from Austin to Bay City. The new groundwater model will also address subsidence and water quality issues associated with the LCRA/SAWS Water Project. For more information, see http://www.lcra.org/lswp/index.html.

The Texas Board of Professional Geoscientists in review

The Texas Board of Professional Geoscientists has had a very busy and productive year. The most notable actions of the Board in the last twelve months have been the development and approval or adoption of:

- firm registration rules which will be in effect beginning September 1, 2006;
- rule for a continuing education program, with full implementation starting on September 1, 2006;
- comprehensive enforcement programs;
- development and implementation of an outreach program to educate universities and county and city governments on the existence and mission of the Board; and
- operating procedures to foster more efficient Board meetings.

In addition, the Board successfully passed audits by the Office of the Comptroller and the Texas Workforce Commission and conducted two surveys of its licensees to identify how it can better carry out its mission, with consideration for the needs and advice of Texas Professional Geoscientists.

The coming year will be a maturing period for the Board with:

- review and possible redirection of the enforcement program;
- consolidation of rule development;
- designing and implementation of a more aggressive outreach program;
- development of state-wide sites for administration of the licensing examinations;
- staff consolidation to implement management changes and fiscal directives from the Office of the Governor and the Legislative Budget Board.

For more information on the programs, activities, and rules of the Texas Board of Professional Geoscientists, go to www.tbpg.state.tx.us or call (512)936-4400. – *Michael D. Hess, Executive Director*

News from the Texas Water Development Board

The Texas Water Development Board began implementation of joint planning in groundwater management areas, working closely with groundwater conservation districts across the state, including Central Texas. Board staff also worked on completing the 2007 State Water Plan, due in January 2007. To help communicate with stakeholders, the Groundwater Resources Division sends out a monthly e-letter called *The Aquifer Monitor* that presents Texas groundwater news. You can see archived versions of the newsletter here: http://www.twdb.state.tx.us/GwRD/pages/gwrdindex.html and sign up for the newsletter here: http://www.twdb.state.tx.us/GwRD/pages/gwrdsubscribe.asp.

News from the U.S. Geological Survey

One of three U.S. Geological Survey National Water-Quality Assessment Program study units in Texas includes the San Antonio Segment of the Edwards aquifer. NAWQA is expanding its study-unit support to include the Barton Springs and northern segments of the Edwards aquifer.

In 2005, the Survey drilled 32 groundwater monitor wells to provide data for study of the effects of urbanization on shallow ground-water quality of the Edwards aquifer in the recharge zone in the Austin area (northern Hays, Travis, and Williamson counties). Eleven monitor wells were drilled in the Barton Springs Segment, and twenty-one wells were drilled in the northern (north of the Colorado River) segment. The Survey collected rock samples and geophysical logs from the monitor wells, which will provide data to improve understanding of the subsurface geology of the aquifer in the region. The Survey plans to collect water quality samples from the wells in 2008. Water quality analyses will include inorganic constituents (major ions, trace elements, and nutrients), volatile organic compounds, and pesticide compounds; and possibly selected stable isotopes of water or other constituents and ground-water age-date compounds.

The U.S. Geological Survey, in cooperation with the Texas Commission on Environmental Quality, recently published a report documenting water-level altitudes collected, from March through June 2005, in the Edwards Aquifer in northern Travis, Williamson, and Bell counties. This collection effort was part of a database of 77 wells in areas with little or no historical data and was created as a part of the Commission's Source Water Assessment and Protection Program. Water-level measurements in the wells were obtained by electronic sensor, steel tape, or calibrated airline. The data will be used in studies of the hydrogeology of the Edwards aquifer in the region. The persistent URL for the report is: http://pubs.usgs.gov/ds/2005/125/

The U.S. Geological Survey is working in cooperation with the Texas Department of Transportation, Texas Tech University, Lamar University, and the University of Houston to investigate bedload transport in streams of the Edwards Plateau, central Texas. The investigation was initiated to address the considerable reconfiguration and transport of coarse bed material during high-magnitude flows and the associated structural problems and maintenance along low-water (road) crossings. Currently (2006), the Survey is characterizing watershed- and channel-scale parameters, such as channel slope and width, using remotely-sensed datasets in GIS. GIS assessments are accompanied by field work to characterize particle-size, channel geometry, and alluvial stratigraphy. The field work also functions to assess the accuracy of remotely-sensed parameters.

Chisos Mountains from a desert camp (photo by Brian Hunt)

about the technical content

The technical content in the Bulletin consists of abstracts or extended abstracts for presentations, summaries of the field trips, technical papers, and notes.

presentation

The Austin Geological Society hosts technical presentations from invited speakers concerning the natural sciences. We publish an abstract in the Society's newsletter and allow for an extended abstract in the Bulletin.

posters

The Austin Geological Society hosts a poster session each spring. Presenters can submit an abstract concerning their poster topic. This year, we received abstracts from young scientists from local schools.

field trip

The Austin Geological Society tries to have at least one field trip per year. The summary included here provides an overview of this year's trip. Interested readers are encouraged to purchase the guide book for additional information and details.

technical paper

The Bulletin accepts technical papers for publication provided that the papers meet technical and editorial requirements.

note

The Bulletin also accepts notes, which may be technical or anecdotal.

presentation

august 29, 2005, bureau of economic geology

Update on the Texas Board of Professional Geoscientists

Michael D. Hess
Executive Director, Texas Board of Professional Geoscientists

presentation

october 3, 2005, bureau of economic geology

Low Flow Gain-Loss Historical Data Analysis of the Colorado River in Texas

Geoffrey Saunders, P.G., CGWP
Lower Colorado River Authority

Most natural rivers gain or lose water as they interact with underlying groundwater aquifers. This project is designed to provide information on the gain or loss of streamflow in the Colorado River below Austin. Historical data have been reviewed and analyzed in order to provide preliminary gain-loss estimates. The period of study was October 1999 through March 2000 with emphasis on the dry month of November 1999. The Lower Colorado River was found to be a gaining stream which receives groundwater contribution from major and minor aquifers. Although there are some reaches that apparently do not contribute groundwater to the river, the net gain is approximately 200 to 235 cubic feet per second between Austin and Bay City under short-term drought conditions.

Geoff Saunders has over 25 years of experience as a consulting geologist, environmental scientist, and hydrogeologist. Saunders performed undergraduate studies in hydrogeology at Northern Arizona University and graduate studies at The University of Texas at San Antonio. He has spent most of his career in Texas and Colorado. Saunders is licensed as a Professional Geoscientist by the Texas Board of Professional Geoscientists and certified as a Ground Water Professional by the Association of Ground Water Scientists and Engineers. He is currently a Senior Hydrologist for the Lower Colorado River Authority in Austin, Texas.

Gone with the wind—The history of pumping water with windmills

Robert E. Mace, P.G., Ph.D.
Texas Water Development Board

There's something romantic about windmills—about how they reach for the sky, embrace a passing breeze, and raise cool water from the depths with a hypnotic round-and-round and up-and-down motion. Even a beheaded or damaged windmill captures the imagination—a snap shot of a ravaging storm that plowed through the plains decades ago. This seemingly simple contraption has a complicated and colorful history. The use of wind to propel boats via sails extends back four to five thousand years in early Egypt. However, the first documented wind machine—the precursor to the modern windmill—was created by Hero of Alexandria in 1 A.D. to operate an organ. Probably the first widespread effort to harness the wind on land was with the panemone, a vertically oriented windmill from Persia from about 900 to 500 A.D., used to pump and transport water.

The first documentation of windmills in Europe appeared in 1270 A.D. These windmills, called European windmills, were horizontally oriented and resemble the classic Dutch windmills of yore. Although European-style windmills were perfected over the next 500 years, they were still bulky and expensive and required constant vigilance to operate.

It wasn't until 1854 that the next great leap in windmill technology occurred: the self-regulating windmill invented by Daniel Halladay, a machinist from Connecticut. Halladay's windmill controlled, by itself, how quickly it spun. This prevented the windmill from tearing itself apart when the wind blew too hard. The Halladay windmill and the explosion of windmills it spawned are termed American-style windmills: self-regulating, smaller in scale, more affordable, and, ultimately, mass-produced. For the next 50 years after 1854, many advances were made in self regulation, self oiling, efficiency, and materials. The timing of these windmill advances was fortunate in that they coincided with the spread of railroads and barbed wire across the west (trains and cows can get mighty thirsty…). The synergy of railroad, barbed wire, and windmills amplified the applicability and spread of each technology in the west.

The spread of electric and carbon-fueled pumps and metal rationing during the world wars greatly dampened the windmill industry. Today, windmills are used where it is difficult or not economical to run power or use internal combustion engines. In its heyday, the windmill industry could count hundreds of manufacturers. Today there is only a handful. Windmills became more popular during the late 1970s and early 1980s due to increased energy costs. Given how much it costs to fill up a Ford Windstar these days, perhaps windmills will see renewed popularity in the coming years, and the metal petaled flowers of the plains will reach for the sky once again.

Robert Mace is the director of the Groundwater Resources Division at the Texas Water Development Board

presentation

december 5, 2005, bureau of economic geology

Oil and gas reserves estimating—We have met the enemy, and he is us[1]

Peter R. Rose
Rose and Associates, LLP

Whether predictions are expressed deterministically (single-number forecasts) or probabilistically (as ranges of forecasts corresponding to perceived probabilities), they are still estimates, subject to vagaries of nature, human error, and various biases. But probabilistic estimating has five important advantages:

1. forecasting accuracy can be measured;
2. use of statistics improves estimates;
3. reality checks can pre-detect errors;
4. it is faster, more efficient, avoids false precision; and
5. it promotes better communication of uncertainty to decision-makers and investors.

However, using prevailing practices that have evolved through decades of engineering practice, reinforced by U.S. Securities and Exchange Commission-approved standards, "Proved Reserves" is a deterministic number that refers to a specified volume (or more) of hydrocarbons that the estimator is "reasonably certain" will be recovered from a well, property, field, or district. Even so, it is actually a probability statement, except that no confidence-level (= probability) is specified. It is up to the individual reserves appraiser to sense his/her "reasonable certainty" and, in fact, experience indicates that individual "reasonable certainty" ranges widely. Accordingly, proved-reserves estimators cannot be accountable. Reserves estimates are also susceptible to bias because appraisers may be aware that larger proved-reserves estimates may benefit the value of their own shares, annual bonuses, repeat business, or organizational status. On the other hand, various negative career and legal consequences may ensue if the "reasonably certain" estimate turns out to be larger than the actual outcome. To say that all of this constitutes a self-made, illogical, and insupportable professional conundrum is a severe understatement!

Today, petroleum exploration and production is a divided industry: during the late 1980s and early 1990s, exploration adopted probabilistic methods as best-suited for estimating recoverable volumes of oil and natural gas from drilling prospects and plays, given discovery. But the production side generally remains stuck in the old rut of deterministic methodology, even though it is demonstrably inferior.

A simple remedy would facilitate the transition to probabilistic methods for the entire exploration and production industry: for members of all professional geotechnical and engineering societies to specify that when they use the term “proved”, they are explicitly affirming 90 percent confidence in their estimates, regardless of outmoded and illogical U.S. Securities and Exchange Commission definitions. This would immediately allow measurement and accountability, and would lead eventually to the adoption of full probabilistic methods throughout the exploration and production industry. Such assertive leadership has yet to emerge from the professional associations, however.

Ill-defined reserves standards, as well as misaligned corporate incentive schemes, organizational coercion, and motivational bias, all tend to encourage unethical behaviors in reserves estimating. Constant focus by individuals and companies on recommended practices, professional standards, and personal ethics are essential for consistent and reliable results.

[1] Walt Kelly, Pogo, circa 1970.

Peter R. Rose is a Senior Associate at Rose & Associates, LLP., and president of the American Association of Petroleum Geologists.

presentation

february 6, 2006, bureau of economic geology

Evaluation of arsenic contamination in the Southern High Plains, Texas

B.R. Scanlon, J.P. Nicot, R.C. Reedy,
J.A. Tachovsky, H.S. Nance, and R.C. Smyth
Bureau of Economic Geology, Jackson School of Geosciences,
The University of Texas at Austin

Lowering the federal standard for arsenic in drinking water from 50 to 10 micrograms per liter greatly increases the number of groundwater sites in Texas where contamination exceeds the new maximum contaminant level. The objective of this reconnaissance study was to (1) determine the distribution of arsenic in groundwater, (2) assess the potential of arsenical pesticides as a source of arsenic, and (3) evaluate geologic sources of arsenic in the Southern High Plains, Texas. Anthropogenic sources of arsenic, such as arsenical pesticides, were examined using geographical information system overlay analyses and soil sampling. Geologic sources of arsenic were evaluated using relationships between arsenic concentrations and different geologic units and relationships between arsenic concentrations and other ions, particularly oxyanions.

Groundwater arsenic contamination is widespread in Texas. Approximately 6 percent of wells exceed the maximum contaminant level of 10 ug/L. Contamination is focused in the Southern

High Plains (32% of wells exceed the maximum contaminant level) and the southwestern Gulf Coast (29% of wells exceed the maximum contaminant level). The Southern High Plains region was subdivided into two areas: a northern area characterized by low total dissolved solids (less than 500 milligrams per liter) and a southern area characterized by high total dissolved solids (greater than 500 milligrams per liter). Arsenic contamination is much greater in the southern area (51 percent of wells greater than 10 micrograms per liter; 2 percent greater than 50 micrograms per liter) than in the northern area (7 percent of wells greater than 10 micrograms per liter). Regional analyses of groundwater arsenic concentrations do not support a surficial source of arsenic contamination. Arsenic concentrations are not correlated with land use, with cotton production, with distance from cotton gins, or with nitrate concentrations. Results of drilling and sampling 18 boreholes in the Southern High Plains indicate that the distribution of arsenic is not related to the distribution of cotton production. High arsenic concentrations in a rangeland profile (peak of 77 micrograms per kilogram) indicate that background levels of water-soluble arsenic are high in soils. Arsenic levels in cultivated areas are variable. Some profiles have highest arsenic levels near the surface, which are correlated with nitrate and phosphate that may suggest a fertilizer or arsenical pesticide source. These data indicate that arsenic related to arsenical pesticides is probably restricted to the near-surface zone. Other profiles have peak concentrations in the middle of the profile or at depth. It is unlikely that arsenical pesticides associated with cotton production would have reached the water table. The unsaturated zone data indicate a widespread source of water-soluble arsenic in soils in the Southern High Plains that may contribute to groundwater arsenic contamination.

Groundwater arsenic contamination occurs in generally oxidizing conditions in the High Plains. Correlations between arsenic and other constituents (vanadium, r^2 0.65; fluoride r^2 0.30; molybdenum r^2 0.18; boron r^2 0.17; selenium r^2 0.14) suggest a geologic rather than an anthropogenic source. Arsenic concentrations are highest in the Ogallala aquifer and much lower in the Dockum aquifer. Potential sources of arsenic include volcanic ash beds in the Ogallala, black shales in the Cretaceous (Kiamichi Shale), and saline lakes. Additional studies will be required to assess geologic sources, including geophysical logging and stratified sampling.

Bridget Scanlon is a Senior Research Scientist at the Bureau of Economic Geology. Her research focuses on water resources, including water quantity and water quality issues. She has conducted extensive studies on groundwater recharge and contamination. The results of her research are published in numerous journals.

Summary of some recent studies on recharge and groundwater flow within the Barton Springs Segment of the Edwards aquifer

Nico M. Hauwert, P.G.
City of Austin and The University of Texas at Austin

A number of recent studies underway are looking at the recharge characteristics and groundwater flow path networks of the Barton Springs segment of the Edwards Aquifer.

Instantaneous creek-flow surveys point out that there are a limited number of swallets within the channel of each creek where significant recharge occurs. These swallets overlie groundwater flow paths and the amount of loss/recharge allows an estimate of the flow carried by the groundwater conduit. Creek bottom swallets tend to have larger source areas, more sustained and higher flows available for recharge than upland recharge sinkholes. However, the recharge capacity of these few creek-channel features are limited by their orifice sizes, their sensitivity to plugging by debris, and rejected recharge due to the proximity of the fluctuating water table.

Morphological features of sinkholes relate to their significance as recharge sources. Concave (bowl) cross sections are primarily shaped by recent surface dissolution while convex (underhanging) cross sections are indicators of collapse of phreatic-developed dissolution cavities. Some upland sinkholes have developed sufficiently large bowls that allows them to capture 90 percent or more of the runoff directed to them. These internal drainage basins were mapped and their catchment areas have historically made up at least 10 percent of the recharge zone of the Barton Springs segment that contributes to Barton Springs. The bowl volume of solution internal drainage basin sinkholes directly relates to its natural catchment area (as does its recharge significance), except in some instances where the bowl is inhibited by hydrostratigraphic unit or where several sinkhole clusters are complexed within the same catchment area. The bowl volume may be obscured by fill material and its natural catchment area may be dissected by drainage diversions. Upland sinkhole water balance stations, using an eddy covariance evapotranspiration tower, continuous flow measurement entering the cave drains, precipitation, and soil moisture, monitor diffuse and discrete upland recharge. Internal drainage basins appear to be relatively efficient in recharging runoff for a given amount of source area because: 1) they do not lose runoff to areas downstream of the recharge zone; 2) naturally developed channels and bowls divert runoff rapidly into the subsurface; and 3) the recharge is typically limited to intervals during and shortly after rainfall events when the humidity is near saturation and net losses to evaporation are reduced. Upland recharge areas and particularly internal drainage basins play an important role in capturing runoff from very large storms that would otherwise overwhelm creek-bottom swallets.

The pathways of preferential groundwater flow paths have been refined with further tracing and other investigations. The four major Barton Springs (Main, Eliza, Old Mill, and Upper Barton) actual represent different sources that discharge different proportions of the preferential groundwater flow paths (Cold Springs, Sunset Valley, Manchaca, and Saline-Line Flow Routes. Under high flow conditions where Barton Springs flow exceeds 100 cubic feet per second, some of the flow routes and their tributaries back up, diverting flows to other directions and rejecting much creek channel recharge.

Nico M. Hauwert, P.G., is a Hydrogeologist with the City of Austin Watershed Protection and Development Review Department and a Ph.D. Candidate with the Department of Geological Sciences, The University of Texas at Austin

presentation

may 1, 2006, bureau of economic geology

Vertebrate fossils in a Venezuelan tar seep

Christopher J. Bell, Ph.D.
The University of Texas at Austin

Recent discoveries of vertebrate fossils in an extensive tar seep (Mene de Inciarte) in western Venezuela served as a catalyst to bring together an international group of scientists and administrators to explore the potential for development of this resource. In this presentation I will provide a history of the discovery of fossils in the Menes in western Venezuela, focus on the most recent excavations and their scientific yield, and discuss plans for the future scientific development of this discovery.

Dr. Christopher J. Bell is an Associate Professor at the Department of Geological Sciences, The University of Texas at Austin. He received his B.S. in Geology from The College of William and Mary in Virginia (1988) and his M.S. in Quaternary Studies from Northern Arizona University (1990). Between completion of his M.S. and start of Ph.D., he worked as a field geologist on an archaeological poject in western North Dakota and then took a position as an Earth Sciences Collections Manager at the San Bernardino County Museum in Redlands, California. He received his Ph.D. from the University of California at Berkeley (1997) and joined the faculty in Austin in August 1997.

Geoscience outreach: Educating future citizens

Sigrid Clift

Every year, geoscientists in the Austin area volunteer many hours of their time to educate the public. They bring powerful and important messages about Earth's finite natural resources, geologic history, and geologic processes, including those that pose hazards to life, property, and the environment, to a very receptive audience. Teachers, students, and the general public want to hear about the geosciences and the contribution that our profession makes to society. Unfortunately, these are not well understood by many people in our community because geoscience education in most of our school systems is inadequate.

It is up to individual geoscientists to volunteer their time to go into the classroom or get involved in other local programs that provide educational experiences. It is critical that geoscientists actively participate in geoscience outreach so that today's student will become tomorrow's informed citizen who will have the background to make important decisions about future natural resources and the Earth's environment.

This poster provides information about how geoscientists can get involved in outreach and service to our community. The need is great and more volunteers are needed.

Sigrid Clift is at the Bureau of Economic Geology, The University of Texas at Austin

Sedimentation history and provenance analysis of a late Mesozoic rifting event at Tavan Har, East Gobi, Mongolia

Sarah C. Davidson, Cari Johnson, and Justin Gosses

The East Gobi basin in southeastern Mongolia is one of several basins in eastern China and Mongolia that was formed by intracontinental rifting during the late Mesozoic. The understanding of intracontinental deformation and basin-forming processes in the region is constrained by a lack of detailed structural, sedimentary, and paleogeographic data. This study investigated the sedimentology and provenance of pre-, syn-, and postrift sequences at Tavan Har in the northern East Gobi Basin in order to reconstruct the rifting event.

The prerift (Early to Middle Jurassic) Khamarkhoovor Formation is exposed in the southeast part of the field area, containing 10 to 15 meters of conglomerate and sandstone beds. The early synrift (Late Jurassic) Sharilyn Formation, found about 40 kilometers to the north of Tavan Har, shows thick sequences of fine-grained sandstones. The synrift (Lower Cretaceous) Tsagantsav and Hukhteg Formations are the units found most extensively at Tavan Har. Several measured sequences record basal conglomerate beds that grade into fine-grained lacustrine deposits. The postrift (Upper Cretaceous) Bayanshire Formation unconformably overlies the youngest synrift deposits and contains more mature conglomerate, along with fine-grained fluvial and lacustrine beds.

Sandstone compositions from throughout the pre- and synrift sequences are lithic-rich and are followed by more quartz-rich postrift sediments. Commonly used ternary diagrams interpret the lithic-rich samples to indicate a magmatic arc provenance. However, this provenance is understood to be a result of remnant arc sequences that make up much of the basement rock in the area rather than contemporaneous arc magmatism. The initiation of late Mesozoic rifting at Tavan Har resulted in normal faulting and further uplift of already exposed basement rock, which led to episodic, coarse, alluvial deposition. This was followed by the development of fluvial and lacustrine systems in the area. In the mid-Cretaceous, the synrift sediments were deformed by tectonic inversion of faults in response to compressional stress. More quartz-rich postrift sediments were deposited in alluvial and fluvial systems on shallower slopes.

This study shows that detailed field studies can add significantly to the understanding of late Mesozoic deformation in northern Asia. In addition, it illustrates the fact that traditional basin models—which are based on field studies done predominantly on continents composed of extensive felsic cratons—do not accurately describe basins in much of Asia, where the composition of basement rock is much more complex.

Sarah C. Davidson, Department of Geology, Beloit College, Beloit, Wisconsin (now with the Texas Water Development Board and The University of Texas at Austin); Cari Johnson, University of Utah, Department of Geology & Geophysics, Salt Lake City, Utah; Justin Gosses, Franklin and Marshall College, Lancaster, Pennsylvania (now with the University of Wisconsin, Madison)

Edwards aquifer visualization

Susan Hovorka, Reuben Reyes, John Andrews,
Jerome Bellian, and Scott Rodgers

The Witte Museum, science and history museum in San Antonio, provided an arena and raised funding for the Bureau of Economic Geology to prepare a visualization of flow processes in the Edwards aquifer as part of the Witte's 2005 special exhibit focusing on the Edwards aquifer "World of Water". The visualization became part of the permanent exhibit in 2006. Museum staff, working with a community advisory board, requested a virtual field trip through the aquifer following rainfall in the recharge zone though flowpaths within the aquifer to discharge at San Marcus Springs. In the Museum, the visualization is presented in a “cave” environment, which is a curved 3-screen, 3-projector system that surrounds the viewer and occupies one’s peripheral vision to provide an “immersive” viewpoint, as if the viewer is experiencing the trip themselves. To show at the Austin Geological Survey poster session, we have prepared a single screen version.

Key in providing public access to current research was use of high resolution three-dimensional data sets to create the visualization. Bureau staff collected ILRIS surveys of the internal surface of four Edwards’ caves. The Texas Cave Management Association, the members of the Bexar County and Travis County Grottos of the National Speleological Society, staff of the Edwards Aquifer Authority, and Texas Parks and Wildlife provided cave access and logistical support. Segments of these cave geomorphology data sets were used to create visualizations of the larger aperture vadose and phreatic flow systems of the aquifer. The visualization of smaller diameter pore systems were created from a C-T scan of a carbonate rock sample from Pipe Creek by Jim Jennings and Charlie Kerans (Reservoir Characterization Research Laboratory) and scanned by at the High-Resolution X-ray Computed Tomography Facility at the The University of Texas at Austin. To populate the aquifer with selected cave adapted species, Dean Hendrickson, Curator of Ichthyology, Texas Memorial Museum, loaned us preserved specimens of two Texas blindcats, Satan eurystoma and Trogloglanis pattersoni, which were scanned by Julian Humphries, DigiMorph.Org, at the High Resolution X-ray Computed Tomography Facility at The University of Texas at Austin. Scans were co-funded by John G. Lundberg, Department of Ichthyology, Academy of Natural Sciences. Jean Krejca (Integrative Biology, The University of Texas at Austin), Glenn Longley (Texas State University), and Gerald W. Sneegas provided movies, photographs, and consultation to create visualizations of cave adapted animals.

Data sets were subsampled, imported into 3-D Studio Max, combined with whole earth and digital elevation models, and used to create a realization of a trip from space, to central Texas, into a sinkhole, and though cavern, pore, and fracture systems of the aquifer to discharge at San Marcus Spring. Special effects were added by The University of Texas at Austin Faculty Innovation Center. The file was then rendered into a movie format. A narrative script written by Barbara Hendricks and recorded by Sandy Woods was added along with a sound file prepared by Faculty Innovation Center.

In addition, Bureau staff prepared a short movie documenting the techniques used to create the aquifer visualization to complement the visualization and document how cutting-edge science is brought to the public.

Susan Hovorka, Reuben Reyes, John Andrews, Jerome Bellian, and Scott Rodgers are staff at the Bureau of Economic Geology, The University of Texas at Austin. *The project was funded by the Witte Museum in San Antonio and includes the results of many Edwards’ researchers.*

A dynamic groundwater divide as demonstrated by dye tracing in the Barton Springs segment of the Edwards aquifer, Hays County, Texas

Brian B. Hunt, P.G., Brian A. Smith, Ph.D., P.G.,
Joseph Beery, and David Johns, P.G.

The Barton Springs/Edwards Aquifer Conservation District and the City of Austin injected non-toxic organic dyes into Cripple Crawfish Cave within Onion Creek in the Barton Springs segment of the Edwards Aquifer on August 6, 2002, and May 4, 2005. The objectives of the study were to determine time-of-travel, direction, and destination of groundwater flow and to better delineate the groundwater divide between the Barton Springs and San Antonio segments of the Edwards aquifer south of Onion Creek.

Results of the injections include documentation of a rapid groundwater flow rate of 7.4 miles per day from Cripple Crawfish Cave to Barton Springs, a straight-line distance of about 18 miles. Dye from the 2002 injection was detected only at wells and Barton Springs. Dye from the 2005 injection was detected at wells and both Barton and San Marcos Springs, although the concentrations at San Marcos were small compared to Barton Springs. The straight-line distance from Cripple Crawfish Cave to San Marcos Springs is about 11 miles. Both injections were conducted during relatively high-flow conditions in the Barton Springs segment, with Barton Springs discharging about 104 cubic feet per second. However, springflows in the San Antonio segment of the Edwards aquifer were higher during the 2002 trace than the 2005 trace. San Marcos Springs and the Blanco River were discharging 41 and 182 cubic feet per second higher, respectively, in 2002 than 2005.

These results indicate that the groundwater divide separating the Barton Springs and San Antonio segments may fluctuate according to hydraulic head conditions. Hydraulic heads in the aquifer are influenced by the amount of water recharging the major recharge features. With lower flows in the Blanco River in 2005, there would be less recharge to this part of the aquifer and therefore lower heads. With relatively higher heads near Onion Creek, dye injected into Cripple Crawfish Cave would have an increased potential to flow toward the Blanco River and San Marcos Springs. The relatively low concentrations of dye found at San Marcos Springs in 2005 and the absence of dye in 2002 indicate that the majority of flow from the Onion Creek area is toward Barton Springs. Results from the 2005 injection support 2002 data documenting groundwater flow routes occurring in the eastern and confined portion of the Barton Springs segment.

Additional traces are needed to better understand the conditions under which flow from Onion Creek to San Marcos Springs is possible.

Brian Hunt, Brian Smith, and Joseph Beery are at the Barton Springs/Edwards Aquifer Conservation District and David Johns is at the City of Austin, Watershed Protection and Development Review.

Drought trigger methodology for the Barton Springs segment of the Edwards aquifer, Travis and Hays counties, Texas

Brian B. Hunt, P.G., Brian A. Smith, Ph.D., P.G.,
and Kirk Holland, P.G.

Previous studies of the Barton Springs segment of the Edwards Aquifer have shown that, at current pumping rates and a recurrence of drought-of-record conditions, flow from Barton Springs could cease for brief periods and up to 20 percent of the water-supply wells could go dry. A drought trigger methodology was devised to improve declarations of drought and to implement mandated conservation measures by ground water users. These conservation measures are the primary means of protecting water levels and spring flow.

Three criteria were established as the basis for developing a drought trigger methodology: (1) that a drought stage declaration is triggered in sufficient time to achieve benefits of conservation measures, (2) that it be representative of aquifer-wide conditions, and (3) that it be simple to implement. Principal components of the hydrologic cycle (recharge, storage, and discharge) were evaluated along with historical data such as rainfall, stream flow, water levels, and spring flow.

The drought trigger methodology that was developed uses flow from Barton Springs and water levels in the Lovelady monitor well to determine drought status of the aquifer. Water levels in the well are indicative of the amount of water in storage. The muted response to major recharge events suggests that the well is not directly connected to the conduit system. Conversely, flow from Barton Springs responds quickly to minor and major recharge events. By using both the Lovelady well and flow from Barton Springs to signal a drought, it is likely that a serious drought can be recognized early enough that conservation measures can be implemented and continue long enough to minimize the impact of low water levels in wells on water supplies and to maintain adequate flow at Barton Springs that will be protective of the endangered salamanders at the springs.

The amount of time needed to declare a drought and to have permittees and end users take the necessary conservation measures and for the District to assess the effectiveness of the measures is estimated to be about 3 to 6 months. Considering the time frame for response to drought declaration and the amount of time for the aquifer to reach extreme drought conditions, two stages of drought were established: Alarm and Critical. Entry into drought, or Alarm Stage, is declared when the 10-day running average of flow from Barton Springs drops below 38 cubic feet per second or when the depth to water in the Lovelady monitor well is greater than 181 feet below ground surface elevation at the well. This trigger generally corresponds to levels when overflow springs within the Barton Springs complex cease flowing and precedes a prominent break in the spring-flow recession. A Critical Stage drought declaration is triggered when the 10-day running average of flow from Barton Springs drops below 20 cubic feet per second or when the depth to water in the Lovelady monitor well is greater than 192 feet below ground surface elevation at the well. Drought trigger levels were set with sufficient margins so that these measures would be taken well before aquifer conditions reach levels that would threaten the endangered salamanders at Barton Springs. To exit a drought stage, both spring flow and water level must go above their respective drought trigger values.

Brian Smith, Brian Hunt, and Kirk Holland are at the Barton Springs/Edwards Aquifer Conservation District

Sequence stratigraphic “Wheeler Diagrams” as exploration tools

Ramon H. Trevino, L. Frank Brown Jr.,
Robert G. Loucks, and Ursula Hammes

One product that resulted from our study of the sequence stratigraphy of the Corpus Christi Bay region was a time stratigraphic cross section, commonly known as a “Wheeler diagram.” The cross section portrays time on the y axis (ordinate) and distance on the x-axis (abscissa). The Corpus Christi Bay area comprises a series of growth-faulted subbasins that become younger basinward. From our research, we were able to delineate the third order (~1-3 Ma) sequences of the Frio Formation and determined that each subbasin, in large part, comprises the off-shelf portion (i.e., basin floor fan, slope fan complex and prograding wedge) of a third-order lowstand systems tract. Using available, in some cases sparse, biostratigraphic data, we were able to calibrate and correlate the sequence boundaries and maximum flooding surfaces of the local third-order sequences to global coastal onlap and global cycle charts. In a subsequent study of time equivalent sections in another part of the Gulf of Mexico basin, we used the previously-generated Frio time cross section to predict the ages of prospective Oligocene off-shelf lowstands, which had minimal paleontologic control. Using the time cross section and published maps of regional faults in conjunction with the hypothesis that significant growth faults approximate paleo shelf edges, it was possible to estimate the location, stratigraphy, and age of intraslope subbasins containing highly prospective off-shelf lowstand deposits basinward from areas of good well and biostratigraphic control. We propose that so-called “Wheeler Diagrams” in conjunction with sequence stratigraphy can be useful as predictive exploration tools.

Student science fair posters

The Austin Geological Society participated in the exhibit judging at the Austin Regional Science Festival in February 2006, specifically of the Middle and High School Earth Science and Environmental categories. Six students were given Certificates of Recognition for their projects and were invited to present their exhibits at the annual AGS poster session meeting in March. They were also invited to submit abstracts of their projects for publication in the AGS Bulletin. The students submitted the following abstracts for publication.

The perfect mud slide

Jessica Guest

The purpose of this experiment is to discover how soil content in a given soil affects the way that soil moves and reacts to moisture. Some soils are more absorbent or more plastic, depending on their content. These differences are what were observed in "The Perfect Mud Slide".

First, four soil samples were collected and a procedure that determined the content of each sample was carried out. Sample A had high silt content, a fair sand content, and small clay content. Sample B was mostly sand with a little silt and clay. Sample C was made almost entirely of silt, no sand, and a little bit of clay. Sample D had nearly all clay, no silt, and some sand.

Next, the samples were placed on a 15 degree slope individually where small amounts of moisture were added, in equal intervals. As the moisture is added the soil goes through three phases: non-plastic, plastic, and viscous. Each soil enters into the phases at different rates depending on certain characteristics.

Sample B went through the three phases the fastest because of high sand amounts. Sample C won over B barely, because of the low plasticity in silt soils, but higher absorption. Sample A required more moisture before turning viscous because it contained both silt and sand. Sample D took an extensive amount of moisture before it slide because of the high plasticity and absorption of clay soils. Thus, Sample D is "The Perfect Mud Slide".

Jessica Guest is a tenth grader at Vista Ridge High School in Cedar Park.

The secrets of Barton Springs

Holly Hummer

When I went swimming with a friend in Barton Springs, I heard a few days later that part of it was being closed off for a few days because of contamination. I’d also heard of other times this had happened, too. I wanted to relate my science project to this, so I chose to do some water sampling.

I wanted to test different areas along Barton Springs that each had different factors that could cause/reduce water contamination. When I realized it would be hard to get accurate results with a small testing strips kit, my mom and I looked in the phone book for help. We found the Barton Springs/Edwards Aquifer Conservation District, which offered to test my samples in their professional lab. So, I collected from three areas: The deep end of the Barton Springs Pool, which had no plants or animals, just humans; the area below the pool (under the dam) where dogs and people swim, which included animals, people, rocks, and insects; and Old Mill Spring (Sunken Garden), which was enclosed by a fence, so the water coming from that spring flowed out of a pipe into Barton Creek.

When I got the results back from the lab, the dog area had the most bacteria (41 colonies of e.coli and 4 colonies of other bacteria, Old Mill Spring had 4 colonies of e.coli and 1 colony of other bacteria, and the pool area only had one of each bacteria). My hypothesis that I had made was correct, and I thought the dog area would have the most bacteria because it definitely had the most animals, which is what e. coli comes from. It also had stirred up water from all the splashing and lots of plants. I hope that I can continue my project, maybe testing the sites again to get results after a period of time, and I definitely want to do more research on Barton Springs, bacteria, and why I could have gotten the results I did.

Holly Hummer is a seventh grader at Clint Small Middle School in Austin.

The solubility of sulfates in gypsum in relation to wells in the Glen Rose aquifer

Jenna Kromann

This project was conducted to determine the solubility of sulfates in gypsum in relation to the Glen Rose/Trinity Aquifer. A test was conducted on the water from the Glen Rose aquifer (with gypsum) and the Edwards aquifer (without gypsum) to verify that sulfates were contained in the ground water. Once this was verified, different gypsum materials were tested for their solubility.

Samples of gypsum sand, crystal gypsum, gypsum board (wall board), and cuttings from a well in the Glen Rose aquifer were collected. Then these sample materials were ground up to a fine powder and added to 200 milliliters of distilled water. The ground samples were then allowed to absorb/dissolve in the distilled water for 6 days, 79 days, and 91 days. Then these water samples were tested using a spectrophotometer and liquid ion chromatography.

All gypsum materials tested were soluble in water and showed a significant amount of sulfates. The sulfate concentration mean values ranged from 794 milligrams per liter to 1,514 milligrams per liter. The gypsum board soaking for 91 days had the highest sulfate concentration, which was expected because it had been soaking the longest. This also shows that when water runs slower though an aquifer over a long period of time, that it can dissolve more sulfates.

In general, the data obtained in this experiment did support the hypothesis that if there is gypsum, then there will be a higher concentration of sulfates in the ground water. The largest sulfate concentration was found in Glen Rose aquifer. The Glen Rose contained 522 milligrams per liter of sulfates to only 17 milligrams per liter in the Edwards aquifer. Overall, the findings support that gypsum significantly impacts the sulfate concentrations in the Glen Rose/Trinity aquifer.

Jenna Kromann is a tenth grader at James Bowie High School in Austin.

Lake Travis water quality study

Thomas Taylor Morris

A study of developed coves and undeveloped coves was done on Lake Travis to find out if development has a measurable impact on the water quality. The water quality of Lake Travis was excellent overall according to a study done by Lower Colorado River Authority and U.S. Geological Survey. However, a detailed study that compared developed areas of the lake to undeveloped areas has not been previously done. In this project, it was hypothesized that developed coves would have higher levels of contaminants than the undeveloped coves.

Eight samples were taken from each of the developed and undeveloped coves for a total of sixteen samples. Each sample was tested for each of the parameters as follows: nitrate/nitrite, total coliform, total aerobes, pH, and turbidity. The samples were taken to the laboratory where they were tested using U.S. Environmental Protection Agency approved analytical methods.

The results supported the hypothesis in all parameters except pH. Significantly, the developed cove showed elevated levels of coliform, in addition to higher levels of nitrate/nitrite, total aerobes and turbidity. The pH results were not significant enough to reject or confirm the hypothesis. The results indicated that, while the water is relatively clean in both coves in Lake Travis, the developed cove has measurable environmental impact due to development.

The author recommends that fertilizer should not be overused due to its impact on the environment, and that septic tanks should not be installed too close to the water.

Thomas Taylor Morris is in sixth grade at Lamar Middle School in Austin.

The study of liquefaction during an earthquake

Ian Pryor

The purpose of the experiment was to see which type of soil, loam, clay or sandy, would be the best choice to build a structure on in the occurrence of liquefaction during an earthquake.

To replicate liquefaction during an earthquake I took three cylinders and put in each one of the types of soil, sandy, loam and clay. I placed metal washers on top of the soil to represent a building or structure. The cylinders were then placed on a foot massager and vibrated to represent an earthquake. Water was slowly added as the cylinders were vibrated. I measured the change in the height of the washers after vibrating for 30 seconds. This was duplicated three times with each type of soil.

I learned that liquefaction occurs when there is groundwater less than 30 feet from the surface. During repetitive squeezing of the earth by seismic wave vibrations ground water will flow up and out causing the strength and stiffness of the soil to be reduced. This process is called liquefaction.

I discovered that clay would best withstand liquefaction because its washer dropped on average three quarters of an inch. Loam was affected the most by liquefaction because it dropped on average one and a half inches. Sand averaged one and one eighth inches. Builders could use my research to determine which soil can best be used for construction in an earthquake prone area.

Ian Pryor is a student at Canyon Ridge Middle School in Cedar Park.

Time dependent reactions in earthquakes

Jeffrey Schmidt

This experiment was conducted to test whether the speed at which stress builds up on a fault line has an effect on the power of a quake. The set up included string attached to a brick on one end and a crank on the other. In between the brick and the crank was a section of bungee cord. The bungee cord was used to simulate the elastic characteristics of fault lines, and then hooked to a spring scale that collected data. The crank was turned at different speeds and each speed was repeated 15 times. The crank was turned for a given speed and the distance the brick moved during the cycle was measured. There was no correlation between the distance moved after each run, and the speed of the cycle. A pattern did emerge which showed that the force required to move the brick fluctuated at different speeds. The range of force required went from 17 N to 20 N at the fastest cycle, and 18.5 N to 19.5 N at the slowest cycle. According to the data, speed at which stress built up had no effect on the power of a quake, but did affect the predictability of quakes. The predictability comes from the knowledge of more accurately knowing how much force is required to cause the fault to slip, and knowing the trigger of a quake would make it easier to predict.

Jeffrey Schmidt is a sophomore at Bowie High School in Austin.

field trip

Spring 2006 Field Trip

Volcanic features of the Austin area, Texas

trip coordinators:

S. Christopher Caran, Todd Housh, and Alan J. Cherepon

contributors:

Dennis Trombatore

trip summary and photos:

Alan J. Cherepon

The annual AGS field trip took place on April 1, 2006, titled “Volcanic Features of the Austin Area, Texas. This was AGS Guidebook 026. The co-authors and co-leaders included S. Christopher Caran, Todd Housh, and Alan J. Cherepon. Other contributors included Dennis Trombatore, who provided the bibliography and reference listing and considerable assistance in locating certain references and copies. The Bureau of Economic Geology provided several of the finished diagrams in the guidebook. One of the co-author’s sons also provided considerable assistance in copying, both papers and materials for the compact disk and help in measuring some of the sections. Certain stops also required access, including Bobby Schmidt for Pilot Knob, and Patricia McNiel Delgado, Director of the Cypress Ridge Home Owners Association, and the authors have Aimee Beveridge to thank for recommending the Williamson Creek exposure.

The objective of the trip was to do more than just revisit former stops from the 1981–1982 field trip. Several different stops were included in the recent trip. The interpretations at the old stops were expanded and additional details provided for each. Innovations to the guidebook included a summary diagram and table indicating where in the phase of eruption and location within the volcanic facies each stop is indicative of. In the road log, GPS latitude and longitude readings were also provided to remove any doubt of where the localities are situated and were identified on U.S. Geological Survey topographic sheets for the area. The author’s favorite innovation was the inclusion of a compact disk, which contained several very old papers on the sites, numerous diagrams, maps, and LIDAR plots of each stop area. The revised guidebook should also include digital photos of each stop. Using available technology, a far greater amount of materials can now be provided, which would previously have been unreasonable in a paper-limited guidebook.

A total of 49 people attended the trip, filling the chartered bus and keeping the cost low. A total of eight stops were planned, but only seven were actually visited due to time constraints. Highlights of the trip included access to Pilot Knob, viewing what is possibly the first discernable pillow lava (or a less likely interpretation, as a lava tube) in Williamson Creek and what may be the largest exposure of volcaniclastic material in Austin, in Onion Creek. Three separate volcanic vents were visited, which erupted during Dessau Chalk time in the Austin Chalk of the Upper Cretaceous Period. Overviews were provided by the co-leaders/authors at each stop, as well as question and answer discussions, and alternative interpretations for the more complex exposures. The weather held up (no rain), it got a little warm in the afternoon, causing us to down every one of the 150 drinks provided by the society, and requiring a pit stop to get additional drinks. Other than one injury, and a brush with a rattle snake, everyone reportedly had a great time, seeing some really complex and interesting geology.

Stop 1: Blunn Creek area, Travis High School, view of gravity slumped tuffs and limestone soft-sediment deformation.

Stop 2: St. Elmo Road railroad cut overpass; view of cross-bedded ash-ladden sandstone units of epivolcaniclastic origin. Chris Caran providing overview.

Stop 4: Upper McKinney Falls—Chris Caran providing general overview of volcanic geology of area, near the Smith Visitor Center, McKinney Falls State Park.

Stop 5: McKown Formation, reworked volcaniclastics layer being discussed by Brian Hunt and Jimmy Russell.

Stop 6: View of from a volcano—downtown Austin from Pilot Knob.

Stop 6: Small outcrop of Basanite on Pilot Knob—Todd Housh providing overview.

Stop 6: Group heading back down from Pilot Knob.

technical paper

Precambrian basement aquifer, Llano Uplift, Central Texas

Brian B. Hunt, P.G.
Barton Springs/Edwards Aquifer Conservation District

Abstract

This paper provides an overview and initial conceptual model for the Precambrian Bedrock Aquifer of the Central Texas Llano Uplift. Evaluation of well data from the Texas Water Development Board, a geographic information system, geologic mapping, and fracture-trace analysis were the primary methods used in this study. Results of the study indicate that the Precambrian basement rocks of the Llano Uplift cover approximately 1,290 square miles and provide the sole source of water for an estimated 7,200 people and 73,000 livestock supporting an estimated pumping of 3,600 acre-feet per year. The aquifer is more prolific than previously considered, as fracturing and faulting are more extensive than shown on geologic maps. The Precambrian Basement Aquifer could be considered a minor aquifer of Texas because it supplies "relatively small quantities of water in large areas of the State."

Introduction

The Llano Uplift of Central Texas is a broad structural dome exposing Precambrian granites and metamorphic rocks (basement rocks) through an erosional window of Paleozoic and Mesozoic sediments (Figure 1). Basement rocks of the Llano Uplift cover approximately 1,290 square miles and provide the sole source of water for an estimated 7,200 people and 73,000 livestock in the region. Precambrian basement rocks of the Llano Uplift are currently not listed among the minor aquifers of Texas (Ashworth and Hopkins, 1995). Although the Precambrian Basement rocks do not generally provide prolific water supplies relative to the surrounding Paleozoic and Mesozoic aquifers, they do form an aquifer that can supply modest yields of fresh water when fractured or deeply weathered.

The purpose of this paper is to provide an overview and initial conceptual model for what I am defining as the "Precambrian Basement Aquifer" of the Central Texas Llano Uplift. Few regional water-resource studies have been conducted on the Precambrian rocks of the Llano Uplift. Landers (1972) and Landers and Turk (1973) conducted reconnaissance studies in the eastern Llano County area.

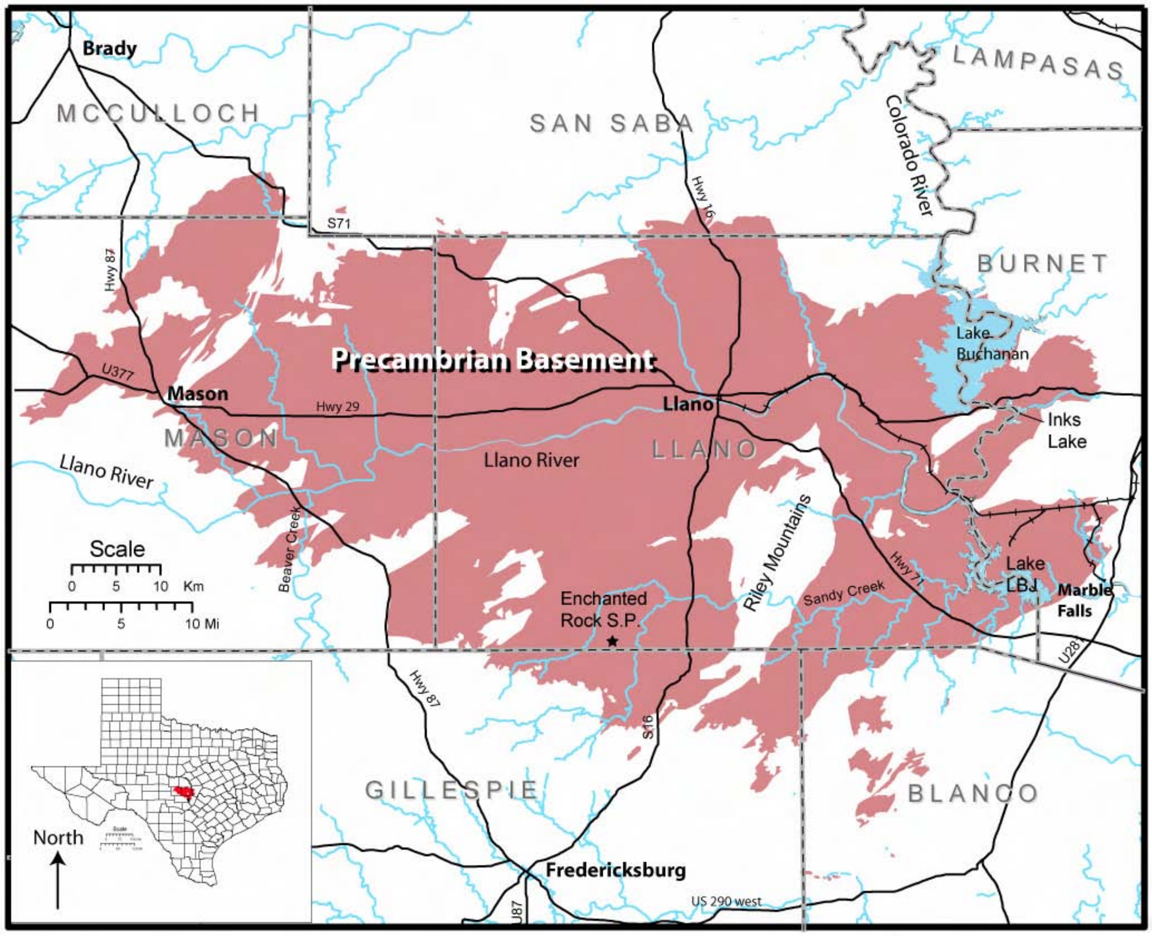


Figure 1. **Location of the study area within the Llano Uplift of central Texas. Precambrian basement covers 1,290 square miles in portions of seven counties.**

Methods used for this study include evaluation of well data compiled from the Texas Water Development Board's well database. Geographic information systems (GIS) were used for analysis and mapping. Geologic and fault mapping (1:5,000) was conducted by the author (Hunt, 2000) in a portion of the study area. Fracture-trace analysis was performed at the site scale to locate potential sites for water wells.

Results of this study indicate that an estimated 5,900 wells are completed within the aquifer pumping an estimated 3,600 acre-feet per year for domestic and livestock needs. The aquifer could meet the definition of a minor aquifer of the state as defined by Ashworth and Flores (1991) because it supplies "relatively small quantities of water in large areas of the State." Faulting and fracturing are key elements to the availability of groundwater in the Precambrian Basement Aquifer. Detailed geologic mapping has shown that faults and fractures are more prevalent than shown on published geologic maps and can be targeted for groundwater production; therefore, groundwater supplies may be greater than previously considered.

Setting

The study area is in the Llano Uplift physiographic province, also called the Central Mineral Region, or the Central Texas Uplift (Wermund, 1996). The Llano Uplift is a topographic basin floored by Precambrian metamorphic and igneous rocks and rimmed by Paleozoic and Mesozoic sedimentary rocks. The Llano Uplift lies to the northeast of the Edwards Plateau, and west of the Balcones Escarpment physiographic regions (Figure 2). Basement rocks are exposed over about 1,290 square miles (3,350 square kilometers) in an area covering seven central Texas counties. The rocks make up nearly all of Llano County and nearly one third of Mason County with smaller portions within Gillespie, Burnet, Blanco, McCulloch, and San Saba counties (Figure 1).

Despite the name "uplift" the study area is a topographic basin owing to the relatively resistant sediments that surround the igneous and metamorphic units. Sidney Paige (1912) described the Llano Uplift as *"…basin-like being etched below the Edwards Plateau and its form due to a combination of structural and erosional conditions."* Relief of the basement rocks consists of relatively flat to rolling landscape studded with rounded granite hills or domes 400 to 600 feet high (such as Enchanted Rock). Other hills consist of Paleozoic sandstone and limestone such as the Riley Mountains, which are fault-bounded grabens (Figure 1). Topography within the Llano Uplift generally slopes to the east. The range in elevation is from 800 feet along the Colorado River in the eastern study area, up to a maximum elevation of 2,000 feet.

Climate, Soil, and Vegetation

Climate of the study area is characterized as Subtropical Subhumid with hot summers and dry winters (Larkin and Bomar, 1983). The range of average annual rainfall is 26 to 30 inches per year from west to east across the study area (Figure 2**;** Daly, 1998). The topographically low core of the uplift has an effect on annual rainfall that is reflected in the 28- and 30-inch rainfall contours protruding east within the basin (Figure 2). Average gross surface water evaporation is 67 to 71 inches per year (Larkin and Bomar, 1983).

The study area is dominated by soils that formed in material weathered from granite and metamorphic units. Generally, many of the soils are moderately deep (20 to 40 inches) sandy loam soils that support grass savannahs scattered with oak trees (Goerdel, 1998). This description is similar to a vegetation map of Texas compiled by McMahan and others (1984) showing the study area as "Live Oak-Mesquite Parks." Live Oak and Mesquite are the dominant large woody species and the term "park" refers to areas where "woody plants grow as clusters or scattered individuals within continuous grass or forbs (11-70% woody canopy overall)."

Surface Water Drainage

The Llano River is a perennial river (except during extreme drought) flowing west to east through the center of the study area joining the Colorado River in the eastern Llano Uplift. Many large streams feed into the Llano River but are intermittent and generally dry or have very low flows during the summer months. However, during large rain events, rivers and creeks are prone to flash flooding. The U.S. Geological Survey and the Lower Colorado River Authority have many stream gauging stations in the Llano Uplift (Figure 3). The U.S. Geological Survey gauging station on the Llano River at Llano has measured a range of flow from 0 cubic feet per second (1952–56, 1964, 1984) to flood peaks of 88,500 cubic feet per second. Average and median flow for the period of record (1939–2004) is 380 and 157 cubic feet per second, respectively (http://waterdata.usgs.gov/tx/nwis/uv?08151500).

Surface water is the primary source of water for the small cities in Llano and Burnet counties in the eastern portion of the study area. Several of the Highland Lakes (Buchanan, Inks, and LBJ) are located along the eastern margin of the Llano Uplift and form a flood control and water supply network of reservoirs managed by the Lower Colorado River Authority.

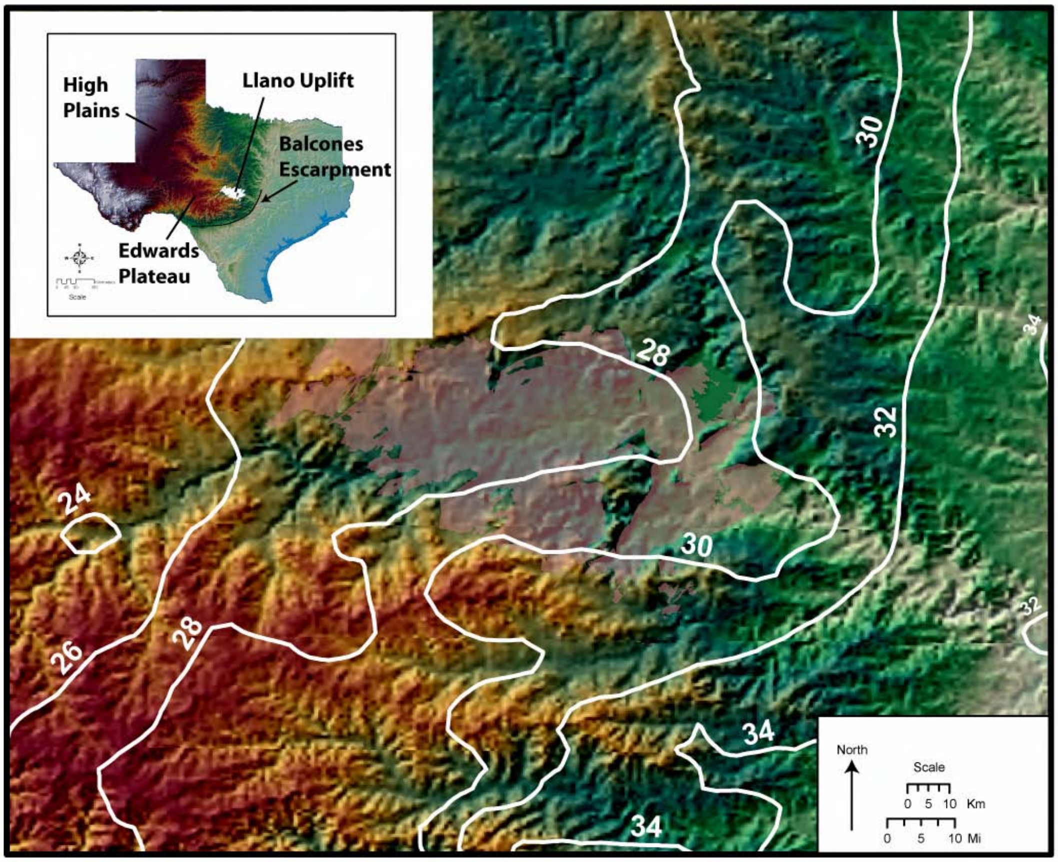


Figure 2. **(Inset map) Physiographic map of Texas showing the position of the Llano Uplift relative to other features. (Large map) Texas terrain map of Central Texas with average annual precipitation contours from 1961 to 1990 shown as white lines (from Daly, 1998). The Precambrian Bedrock Aquifer is shown in light shading. Texas terrain color ramp map was obtained from the Texas Natural Resource Information System.**

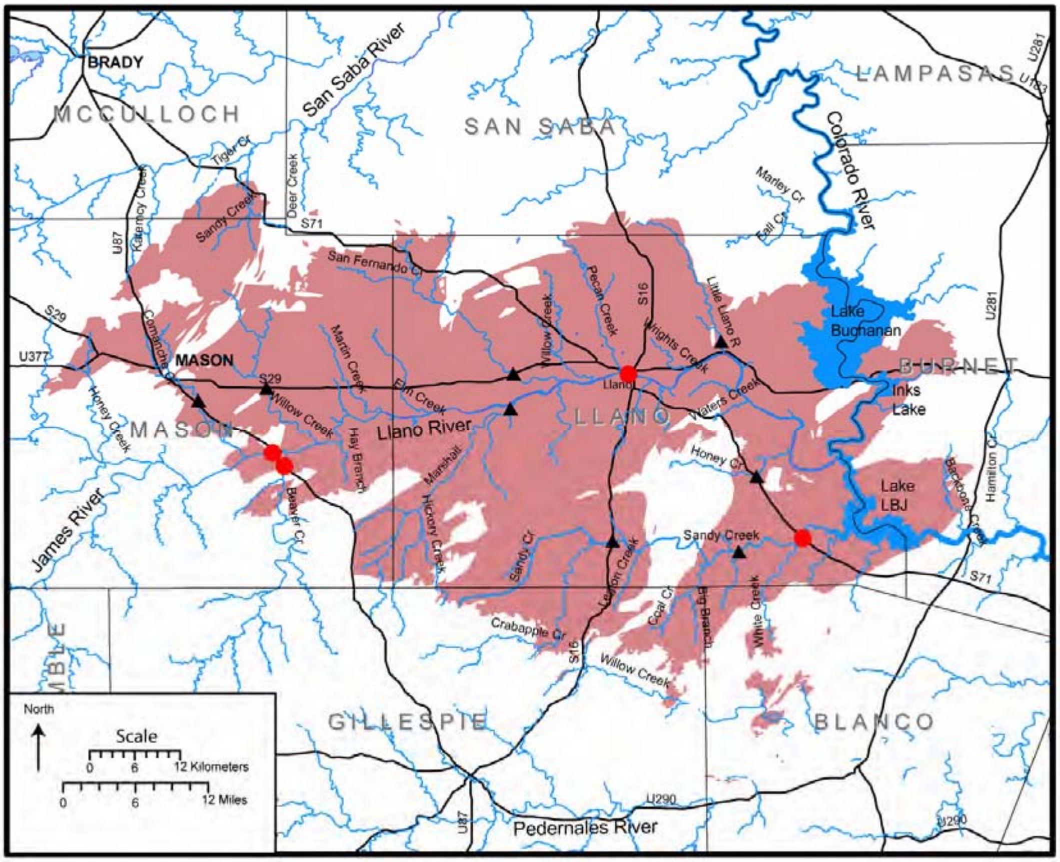


Figure 3. **Map of surface water features within the study area. Circles indicate U.S. Geological Survey stream gauging stations available on the web. Triangles indicate stream gauging stations maintained by the Lower Colorado River Authority.**

Land Use

By the 1880s windmills started to proliferate across the Edwards Plateau (Rose, 2004), allowing ranching and farming to spread throughout the region. Ranching has dominated land use to this day with about 82 percent of the study area, on average, in Llano and Mason counties used as pasture land for ranching (Goerdel, 1998; USDA, 2002; USDA 2002b). Llano and Mason counties have a total of 900 farms (ranches) within the study area with an average size of 825 acres. Livestock include cattle, goats, sheep, hogs, and horses. Cropland makes up 9 percent and 12 percent of the area for Llano and Mason counties, respectively. Cropland includes forage or hay, pecans (Llano), grapes (Llano), and peanuts (Mason) (USDA, 2002; USDA 2002b). Although croplands are present, they are generally not significant over the Precambrian Basement.

Population and Groundwater Use

A database of 230 wells was compiled for this study, but represents only a sampling (estimated less than 5 percent) of the wells completed in the Precambrian Basement aquifer (Tables 1 and

2). Domestic supply, small public water supply, and livestock supply are the two primary uses of groundwater in the study area. An attempt was made to estimate the number of domestic wells using census (2000) data for Llano and Mason counties since they contain most of the Precambrian Basement Aquifer. However, small cities in Llano County obtain their water from the Colorado River (Highland Lakes), which is reflected in low overall use of groundwater (1,800 acre-feet) representing only 27 percent of total water use in 2000. Conversely, Mason County pumps about 11,602 acre-feet per year, or 97 percent, of its water from groundwater sources in 2000 (Mace and Angle, 2004). However, these estimates, including the City of Mason and two thirds of Mason County, are primarily from Paleozoic aquifers that surround the study area. By excluding populations and households within small cities from the county totals, the number of rural households, and therefore domestic wells completed in the Precambrian Basement Aquifer, is estimated to be 4,100 (Table 3). The number of wells reasonably compares to the total estimated rural population of 7,272 that depend on the Precambrian Basement Aquifer. Livestock wells support an estimated inventory of 72,605 animals (80 percent cattle and 20 percent goats and sheep) in Mason and Llano counties (USDA, 2002; USDA 2002b). Since ranches are often quite large (see land use), they often contain several wells for livestock and domestic purposes. Accordingly, a factor of 2 was applied to the 900 ranches in Mason and Llano counties for an estimated 1,800 livestock wells. Therefore, the estimated total number of domestic and livestock wells within the Precambrian Basement Aquifer is 5,900 (Table 3). A reduction factor of two thirds was applied for Mason County estimates to account for the area of the Precambrian Basement in that county.

Table 1. Number of wells in database.*

County	Number	% of total
Llano	158	68
Mason	25	11
Burnet	20	9
Gillespie	17	7
Blanco	9	4
San Saba	1	0
McCullough	0	

*Data primarily from the Texas Water Development Board (total number of wells = 229)

Table 2. Classification of wells in database.

Classification	Number	% of total
Domestic	94	41
Public supply	54	24
Stock	34	15
Unused	32	14
Irrigation	13	6

To determine the annual pumpage from the aquifer, an estimate is needed for the amount of groundwater used for domestic and livestock purposes. Domestic use was estimated by applying the per capita 200 gallons per day (TWDB, 2002), multiplied by the average 3.2 persons per household, multiplied by the number of rural households (Table 4). Using this method the total annual domestic use equals 961 million gallons (2,949 acre-feet per year). To estimate the volume pumped for livestock, the inventory of livestock is multiplied by the reported water consumption for livestock. Using this method, the estimated annual livestock use is 226.8 million gallons (696 acre-feet per year). The total estimated annual groundwater use from the Precambrian Basement Aquifer is 1.2 billion gallons per year (3,646 acre-feet per year) (Table 4). It is noteworthy that this amount is likely a minimum volume as other counties are not accounted for in those estimates, and irrigation is also not accounted for. It is also noteworthy

Table 3. Estimated number of wells in the study area.

	2000 Census rural population	2000 Census rural households	Estimated number of domestic wells[1]	Estimated number of livestock wells[2]	Total wells
Rural Llano County:	*6,743*	*3,885*	3,885	1,384	5,269
Rural Mason County[3]:	*529*	*229*	229	416	645
Total	**7,272**	**4,114**	**4,114**	**1,800**	**5,914**

[1] Estimated from the number of rural households.
[2] Estimated from two wells for every ranch.
[3] Original value reduced by two thirds

Table 4. Estimated groundwater use in the Precambrian Basement Aquifer.

County	Estimated annual domestic use [millions gallons/yr[1,2] (acre-ft/yr)]	Estimated Annual Livestock Use [millions gallons/yr[3] (acre-ft/yr)]	Total Groundwater Use [millions gallons/yr (acre-ft/yr)]
Llano	907.5 (2,785)	149.3 (458)	131.0 (402)
Mason	53.4 (164)	77.5 (238)	1,056.8 (3,244)
Total	961.0 (2,949)	226.8 (696)	1,187.9 (3,646)

[1] 200 gallons per day per capita (TWDB, 2002)
[2] Household = 3.2 people
[3] Livestock consumption: cattle & horses = 10 gallons per day and goats and sheep = 3 gallons per day (Landefeld, and Bettinger, 2002)
Millions gallons/yr = millions of gallons per year
Acre-ft/yr = acre-feet per year

that this estimated annual volume is greater than the supplies of six other minor aquifers of Texas (TWDB, 2002).

Groundwater Management

The study area falls within Region K and Region F of the regional water planning areas. The majority of the study area lies within Region K, while the western portion of study area (Mason and McCulloch counties) lies within Region F (Figure 4). There are four groundwater conservation districts in the study area. Those districts include the Hickory Underground Water Conservation District #1 (Mason, McCulloch, and San Saba counties), Hill Country Underground Water Conservation District (Gillespie County), Blanco-Pedernales Groundwater Conservation District (Blanco County), and the Central Texas Groundwater Conservation District (Burnet County). There are no groundwater conservation districts in Llano County and portions of San Saba County.

Most studies do not consider the Precambrian Basement Aquifer a major groundwater resource (Follet, 1973; Ashworth and Hopkins, 1995). Regions K and F do not appear to explicitly account for water from the Precambrian Basement Aquifer. Accordingly, groundwater conservation districts do not appear to account for groundwater from the Precambrian Basement Aquifer in their groundwater management plans.

Geologic Setting

The Llano Uplift is a broad structural dome exposing Mesoproterozoic igneous and metamorphic rocks surrounded by an erosional window of Paleozoic and Mesozoic sedimentary rocks (Figure 5 and 6) (Barnes, 1981). The Llano Uplift was created by six broad structural arches, which intersected at the uplift (Ewing, 1991, 2004). The geologic and structural development of the Llano Uplift involves all of the major tectonic cycles to affect Texas, including two major orogenies, a great unconformity, extensional faulting, and erosion (Ewing, 1991). A geologic guidebook to the eastern Llano Uplift contains papers detailing those events (Hoh and Hunt, 2004).

The core of the Llano Uplift consists of Mesoproterozoic (1.0 to 1.3 billion years ago) igneous and metamorphic rocks (Figures 5 and 6). Metamorphic rocks cover about 60 percent of the area and consist of diverse packages of schists, gneisses, marbles, and metaigneous rocks. Polyphase folding, multiple metamorphic fabrics, boudinage, partial melting, shearing, and transposition of most rock types reveal a complex ductile deformation history of those units (Mosher, 1998). Reese and others (2000) have redefined the usage of metamorphic unit names as chronostratographic packages. Three domains, based on the chronostratographic rock packages, have been defined in the southeast uplift (Mosher, 1996, 1998; Reese and others, 2000). From structurally highest to lowest (southwest to northeast) the rock packages are as follows: the island arc Coal Creek domain (CCD); heterogeneous supracrustal, metavolcanic and metaigneous Packsaddle domain (PSD); and the supracrustal and plutonic rocks of the Valley Spring domain (VSD). Metamorphic units are intruded by 1126+5/-4 million year old to 1070±2 million year old syn- to post-tectonic granites comprising about 40 percent of the Precambrian rocks (Reed, 1999). These basement rocks record a 300 million year history of orogenic activity

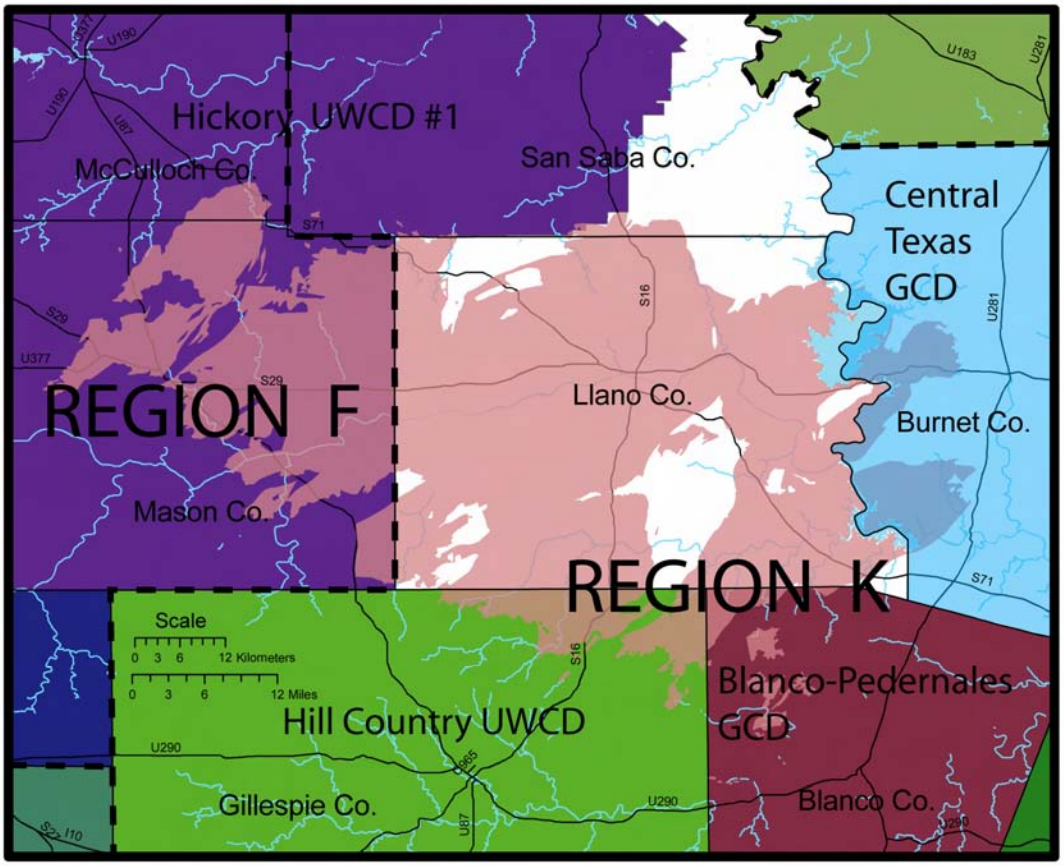


Figure 4. **Map showing boundaries of management areas and jurisdictions that overlay the Precambrian Basement Aquifer. Regional water planning areas F and K are shown as dashed boundaries. The study area contains four groundwater conservation districts. Llano County and portions of San Saba County shown in white do not have a groundwater conservation district. The study area is divided into three groundwater management areas: Blanco County is in Area 9, Burnet County is in Area 8, and the remaining counties of the study area are in Area 7. GIS data sources are from the Texas Water Development Board.**

culminating in continent-continent collision of the Mesoproterozoic Grenville orogeny and the formation of the super-continent Rodinia, (Mosher, 1998).

Following termination of Grenville orogeny, deep erosion during the next 0.6 billion years removed many kilometers of crust in the Llano Uplift region. By the mid- to late-Cambrian Period (at ~500 million years ago) the region had been reduced to a hilly area having topographic relief similar to that in the Llano Uplift today (Long, 2004).

The Paleozoic Era was dominated by marine sedimentation blanketing the igneous and metamorphic rocks with sandstones, shales, and limestones. Many of those units make up the Paleozoic aquifers that surround the Llano Uplift such as the Hickory, Marble Falls, and Ellenberger-San Saba (Preston et al., 1996).

The late Paleozoic Era was dominated by the Ouachita Orogeny related to the formation of the supercontinent Pangea. Ouachita-related, dominantly northeast-trending normal faults cut all

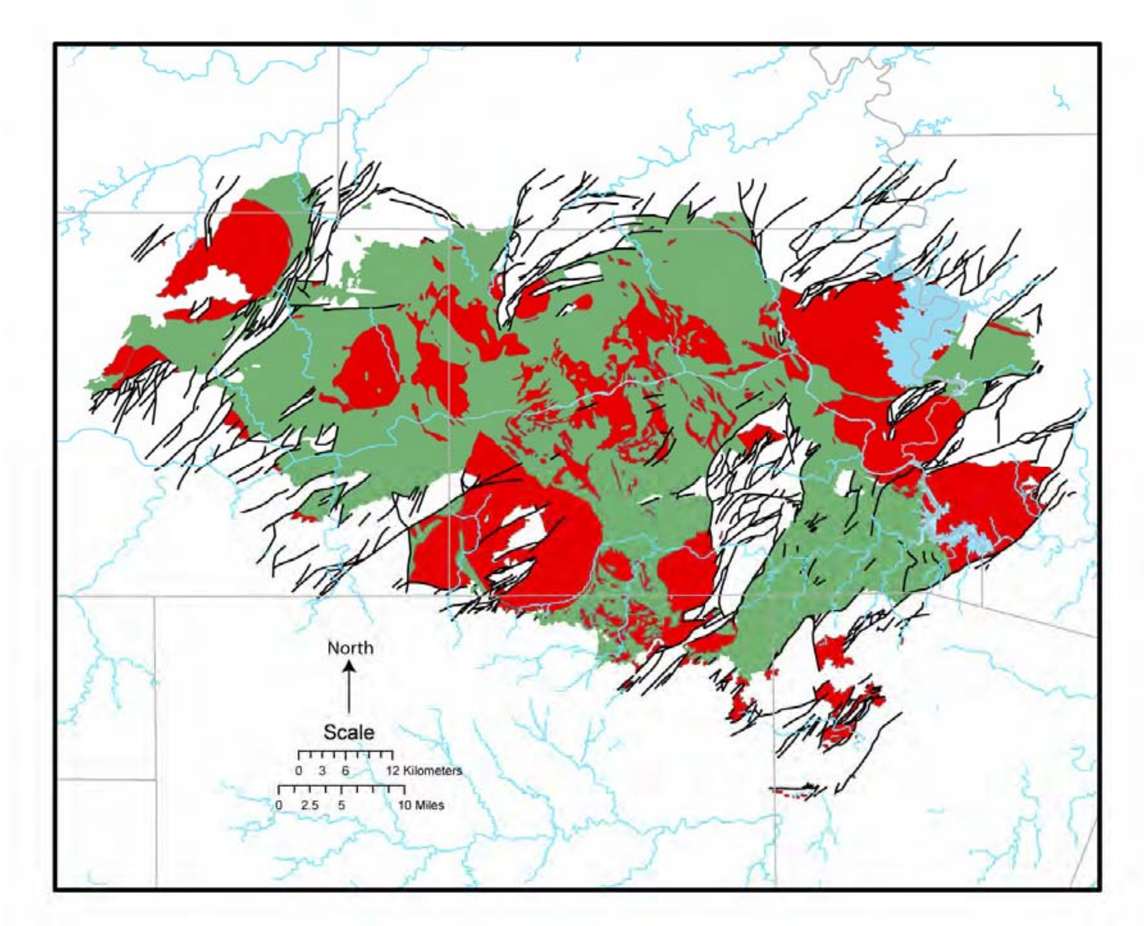


Figure 5. Simplified geologic map of the Precambrian Basement of the Llano Uplift. Granites (40 percent of total area) are shown in red and metamorphic units (60 percent of total area) are shown in green. Paleozoic-age faults are shown as black lines (geology digitized by Dr. Mark Helper [The University of Texas at Austin]; map originally from Barnes, 1981).

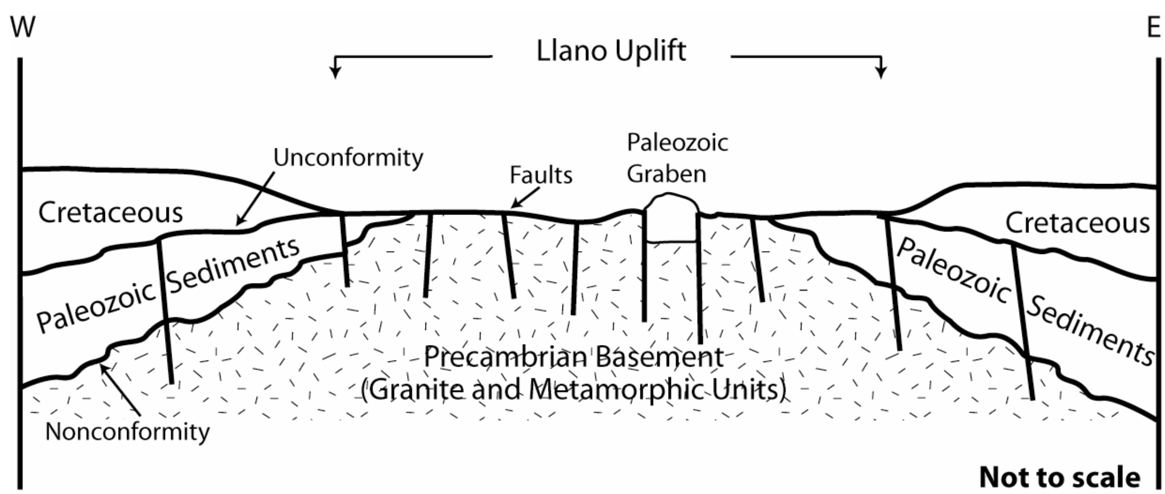


Figure 6. Schematic cross section of the Llano Uplift (modified from Preston and others, 1996).

Precambrian and Paleozoic units in the Llano Uplift. These faults are critical to the secondary porosity and permeability development of the Precambrian Basement and the formation of the aquifer and are discussed in the next section. However, until recently the origin of the pervasive extensional (normal) faults in close proximity to a convergent margin had not been fully discussed in the literature. Johnson (2004) writes "…that (normal) faulting from bending of the continental plate results from increased vertical loads near to, and parallel to, the continental margin as a consequence of thrust-induced crustal thickening and enhanced foreland sediment accumulation."

During the Mesozoic Era the Llano Uplift was a structural high and either provided detrital material or influenced deposition of many lower Cretaceous units in central Texas. Islands of Precambrian and Paleozoic-age sediments surrounded by a Cretaceous ocean provided the source for some Trinity units in Central Texas (Stricklin and others, 1971). Ultimately marine limestones blanketed most of the Llano Uplift until the seas retreated at the end of the Cretaceous.

During the Miocene (~15 million years ago), the Llano Uplift is thought to have achieved its present form. The Edwards Plateau region was uplifted and stripped of much of its sedimentary overburden. The uplifting is thought to be the result of thermal doming during the formation of the Rio Grande Rift and the Basin and Range province (Ewing, 2004).

Unconsolidated alluvial sediments and weathered granitic bedrock, also called "grus," are also significant geologic materials in the Llano Uplift.

Faulting and Fracturing

Faulting and fracturing are critical to the porosity and permeability development of the Precambrian Bedrock aquifer. Johnson (2004) has a detailed discussion of the nature and origin of the cataclastic faults and fractures in the Llano Uplift.

Paleozoic-age normal faulting crosscuts the Precambrian and Paleozoic rocks of the Llano Uplift and generally trend to the northeast, but also at nearly all other orientations (Figure 7) (Barnes, 1981). Most faults have a significant normal dip-slip component with moderate throws. Johnson (2004) notes at least nine faults have a stratigraphic throw of greater than 1,640 feet and have oblique-slip, left-lateral and right-lateral strike slip components.

Field observations within the basement rocks reveal faults that generally consist of planar features with steep dips (greater than 80 degrees) and little relief (Figure 8). Fault zones often contain gouge, sparry calcite, and, less commonly, layered sedimentary carbonate filling. Sense-of-motion indicators, such as slickensides, are not common; however, offset intrusive units locally reveal a relative sense of motion (Figure 8; Mosher, 1996; Hunt, 2000). Individual fault zones range in thickness from a few inches to greater than 15 feet. Fractures generally increase in frequency upon approaching fault zones and are useful to determine orientation and attitude of faults, as most fault planes are not exposed. Qualitative observations from well-exposed fault and fracture zones indicate there is good lateral connectedness among the fractures within individual fault zones. Locally, fractures or faults offset one another, although no chronology could be established between faults of different orientations in the field (Hunt, 2000). Johnson (2004) notes that many fractures appear to have existed prior to deposition of the Hickory Sandstone,

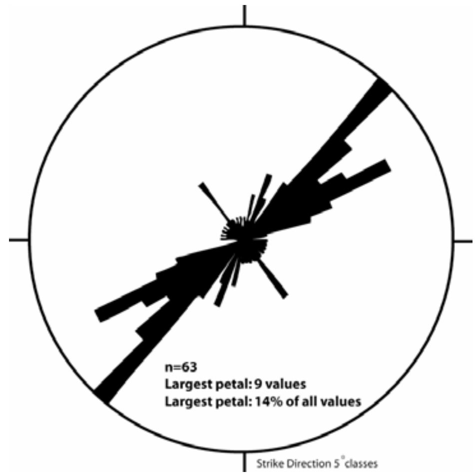


Figure 7. Rose diagram of fault trends within a 10-mile transect in the western portion of the Llano Uplift along the Llano River in Precambrian Metamorphic Units, Mason County (modified from Hunt, 2000).

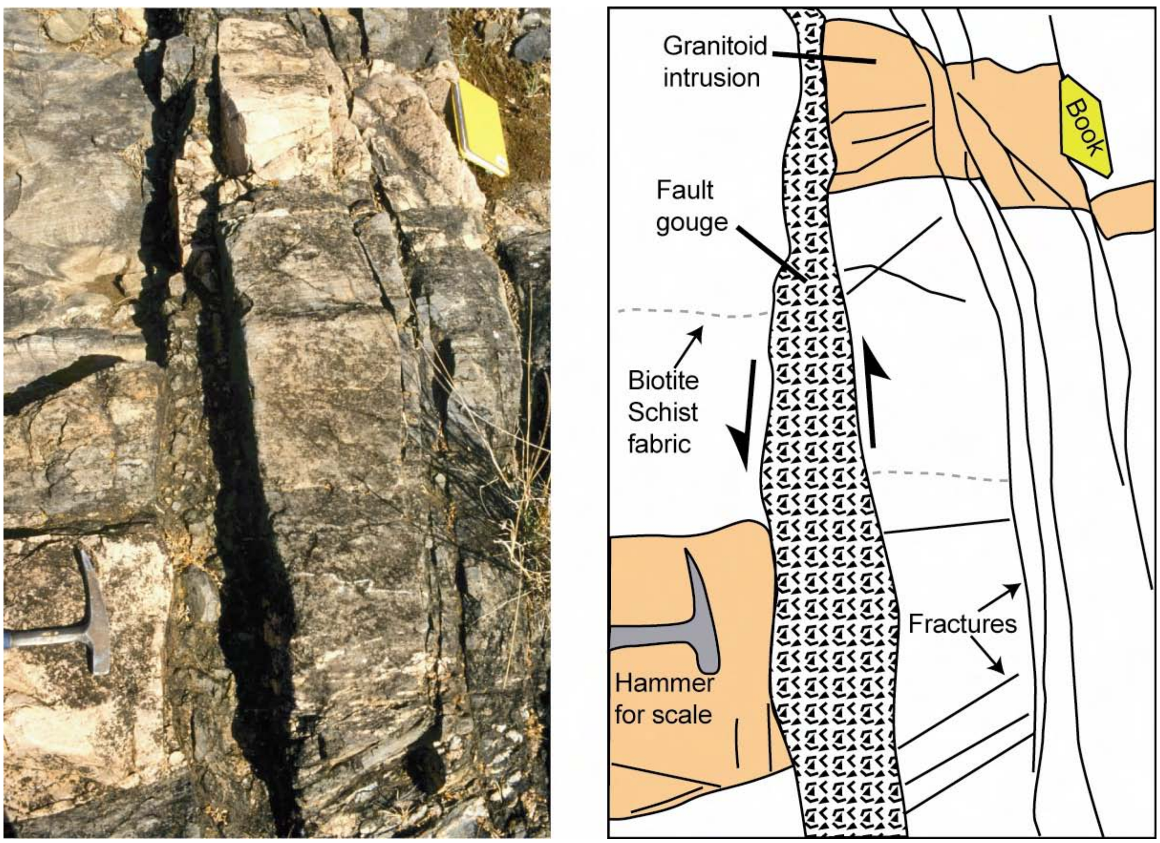


Figure 8. Photograph and sketch of a fault zone in a biotite schist within the Packsaddle Schist. The fault offsets a pink granite dike with left-lateral offset of about 3 feet (from hammer to notebook). Metamorphic fabric is normal to fault gouge. Faults correlate locally to vegetation lineaments on aerial photographs and extend more than two kilometers. The fault is not on any published maps.

the basal Paleozoic unit, making them related to some other structural occurrence (such as uplift). Additionally, Johnson (2004) notes the possibility of some Paleozoic faults resulting from reactivation of Precambrian structures.

Most faults mapped by Barnes (1981) are within the Paleozoic units of the Uplift. Hunt (2000) mapped 63 faults within a ten-mile transect of basement rocks in the western Llano Uplift (Figure 7), an area with no mapped faults at the 1:500,000 scale (Barnes, 1981). Faulting within the basement rocks is therefore much more prevalent than shown on published maps. Metamorphic basement rocks are faulted and fractured more pervasively on closely spaced, small throw faults, whereas the granitic basement deforms on widely spaced, large throw faults (Schmittle, 1987; Johnson, 2004). Thus, the fabric within the metamorphic rocks appears to have influenced the structural evolution and ultimately the hydrogeology of the study area.

An important feature of faults and fracture systems in the Llano Uplift are their prominent appearance as vegetation lineaments on aerial photos. Therefore, this characteristic can be used to help locate wells by fault-trace analysis within the Precambrian Basement rocks.

Hydrogeology

Few regional water-resource studies have been conducted on the Precambrian rocks of the Llano Uplift. A reconnaissance study by Landers (1972) and Landers and Turk (1973) looked at the occurrence and quality of groundwater in crystalline rocks of the Llano area. Follett (1973) stated that fractured Precambrian rocks provide very small to small quantities of fresh water to wells.

Precambrian Basement Aquifer

A total of 230 wells make up a database of wells from the Texas Water Development Board (Figure 9). Six aquifer units are identified by the Texas Water Development Board within the study area (Table 5). Where faulted and fractured, the Precambrian Basement rocks form an aquifer, defined here as the "Precambrian Basement Aquifer." Additionally, weathered granites, called "grus," can locally create a thick "C" soil horizon that can be a significant aquifer material. Alluvium along the Llano River and its tributaries locally provides a source of water for some wells.

Table 5. Tabulation of aquifers, wells, and springs in the Precambrian Basement.

Aquifer	TWDB code	# of wells	% of total	# of springs
Precambrian Erathem (undifferentiated)	400PCMB	86	38	4
Precambrian Granite	400GRNT	77	34	2
Valley Spring Gneiss	400VSPG	34	15	1*
Packsaddle Schist	400PCKD	21	9	1
Granite Wash	371GRNT	10	4	
Alluvium and Granite	110AGRT	1	0	

*from Brune, 1975
TWDB = Texas Water Development Board

There are eight known springs (five in Gillespie County, two in Llano County, and one in Mason County) in the Texas Water Development Board database or reports (Brune, 1975). The springs are relatively minor with reported flow of 2 to 10 gallons per minute. Most of the springs are located within contributing creeks and one within the Llano River (Figure 9). The author has observed several unmapped small springs and seeps associated with faults within the Llano River and its tributaries.

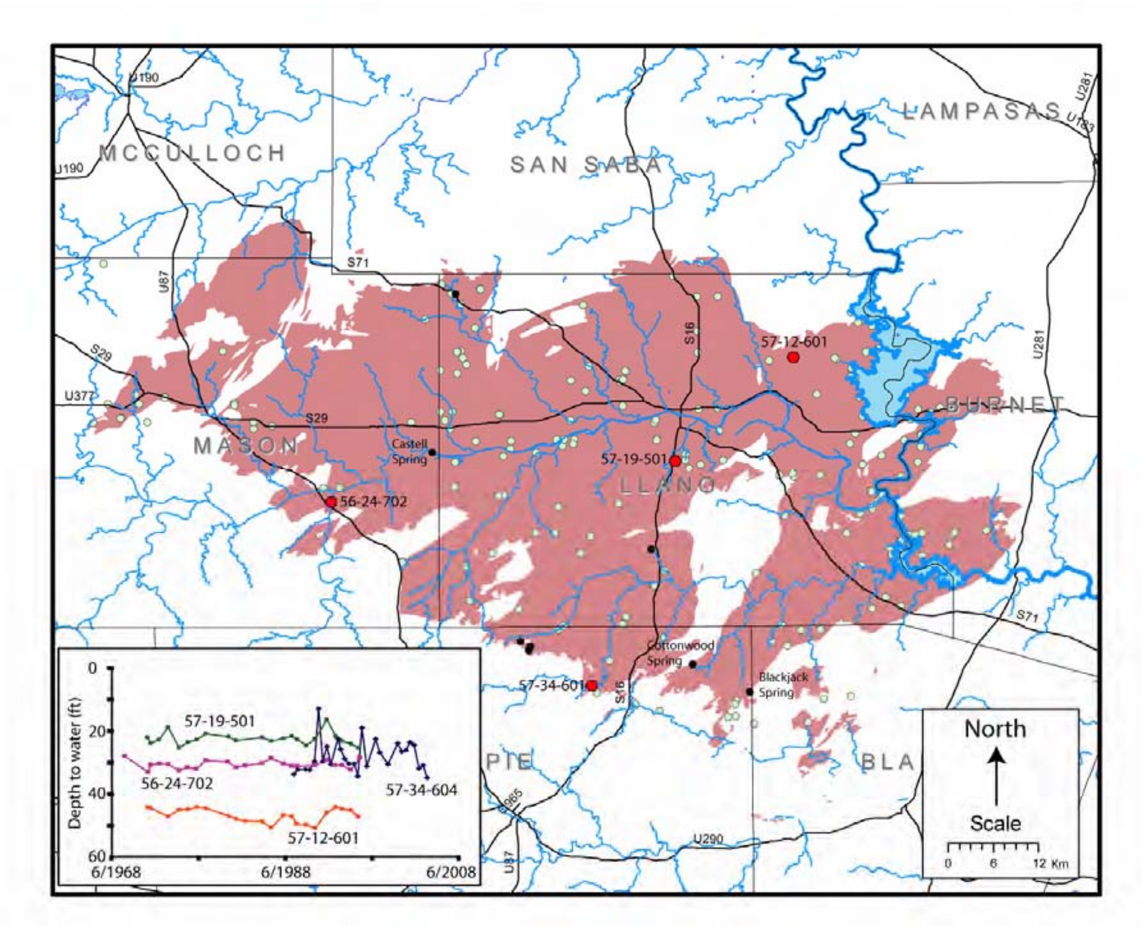


Figure 9. Locations of wells and springs of the Basement Aquifer. Wells (a total of 230) are shown as small green circles. Selected observation wells with state well numbers are shown as large red circles with their hydrographs in the inset. Springs are shown as black circles (a total of 8). Water-level and well data are from the Texas Water Development Board. Geology digitized by Dr. Mark Helper [The University of Texas at Austin]; map originally from Barnes, 1981.

Hydraulic Parameters

Plutonic and metamorphic rocks have little primary porosity ranging from 0.1 to 0.79 percent (Heath, 1983; Barker and others, 1996) and generally do not have good aquifer properties unless faulted or highly weathered. Few hydraulic parameters have been measured in the study area, so values from the literature are reported here. Hydraulic conductivity values for unfractured igneous and metamorphic rocks range from 1.0×10^{-8} to 6.0×10^{-5} feet per day (Bouwer, 1978; Domenico and Schwartz, 1990). Hydraulic conductivity of fractured and weathered igneous and metamorphic rocks range from 0.05 to 14.0 feet per day (Morris and Johnson, 1967; Bouwer, 1978).

Wells in the Precambrian Basement Aquifer have a median well yield of 12 gallons per minute (based on information from 136 wells), indicating their relatively low permeability. The range in yield is from 0.5 gallons per minute up to 200 gallons per minute (Table 6). Granitic rocks have a higher well yield than metamorphic rocks. Water well drillers also observe better yield from wells drilled within granitic basement rocks (Taylor Virdell, Virdell Drilling, personal communication, 2006). This may be due to the fact that large granite bodies can have horizontal joint systems (Morris and Johnson, 1967) or perhaps due to the larger fault and fracture zones reported to occur within granites (Schmittle, 1987) providing increased porosity and permeability. Only four specific capacity values are known for the study area (Table 6). Transmissivity values for one single-well test in the Packsaddle Schist were calculated using the Cooper-Jacob and Theis solutions and averaged 1,400 gallons per day per foot (187.6 feet squared per day).

Average well depths in the study area are 132 feet (median 100 ft; based on information from 222 wells), with no correlation between yield and depth. Yield would not be expected to correlate to depth as fracture aperture and degree of weathering is expected to decrease with depth (Landers, 1972). “Dry holes” are commonly drilled in the study area (five noted in the Texas Water Development Board database and another seven from the author’s knowledge) indicating the heterogeneous nature of the aquifer. The fractured nature of the aquifer makes the aquifer highly anisotropic.

Table 6. Summary of reported well yields.

Yield (gpm)	All	Precambrian Erathem	Granite Wash	Granite	Valley Spring Gneiss	Packsaddle Schist	Alluvium and Granite
Average	21.8	28.8	25.9	22.8	12.9	10.3	--
Median	12.0	18.0	30.0	12.0	8.0	8.0	--
Max	200.0	200.0	40.0	115.0	70.0	25.0	39.0
Min	0.5	1.5	2.5	0.5	0.5	0.8	--
n	136	49	7	48	24	15	--
Specific capacity (gpm/ft)	--	1.0	--	17.5	--	0.93	0.26

gpm = gallons per minute
Max = maximum value
Min = minimum value
n = number of well yield measurements
gpm/ft = gallons per minute per foot of drawdown

Recharge, Water Levels, and Groundwater Flow

Recharge rates and processes are not known or poorly understood for the study area. However, within the outcrop area, recharge to the Precambrian Basement Aquifer most likely occurs through the sandy loam soils and then migrates along the bedrock-soil interface before entering into faults, fractures, and weathered bedrock. Streams and rivers are often points of discharge, although they may also be areas of recharge under certain conditions.

Depth to the water table throughout the Precambrian Bedrock aquifer is shallow with a median depth to water of 23 feet (based on information from 501 wells). The water table may be a subdued reflection of the surface topography. Hydrographs from four selected historical observation wells are presented in Figure 9. Changes in water levels for these wells range from 5 to 26 feet. Wells completed within the Precambrian Bedrock Aquifer are very susceptible to dry conditions and drought suggested by the relatively shallow well depths and relatively low well yields.

Due to the heterogeneous and anisotropic nature of the aquifer, groundwater flow is likely very complicated. However, groundwater flow can generally be described as occurring along faults and fractures at relatively shallow depths. Influence of the metamorphic fabric on groundwater flow is thought to be minimal; however, the fabric appears to have indirectly influenced flow through its effect on fault and fracture development.

Water Quality

Groundwater quality is generally good with average values for water constituents generally within the U.S. Environmental Protection Agency's maximum contaminant levels and secondary standards. However, the quality can be erratic with locally high total dissolved solids, chloride, sulfate, sodium, nitrate, and some metals (Table 7). Landers (1972) reports that schists generally produce harder water with higher sulfate content than other units, although the data in Table 7 does not necessarily support that. Average values for nitrates are elevated above federal drinking water standards. Landers and Turk (1973) attribute high nitrate values to wells proximal to septic drain fields or livestock pens. This suggests that the groundwater resources may be vulnerable to contamination due to their fractured nature (transmissive) and relatively shallow water table. Samples for naturally occurring radioactive materials are generally below federal drinking water standards.

Factors Contributing to Well Yield

Locating a productive well within the Precambrian Basement Aquifer can be challenging because water-bearing fractures that generate sufficient yield can be difficult to locate due to their poor exposure. However, fracture trace analysis can identify potential areas of faulting and fracturing, and thus potential areas for high-yielding wells. In addition, other geologic and physiographic factors can be used to help evaluate and weigh, in a qualitative sense, potential well sites. Studies within similar geologic and structural settings (fractured bedrock) offer insight

Table 7. Water quality.

	Si (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Sr (mg/l)	Carb. (mg/l)	Bicarb. (mg/l)	$S0_4$ (mg/l)	Zn (mg/l)	Fe (mg/l)	Cu (mg/l)
Max	65.0	384.0	117.0	940.0	47.0	0.6	13.0	634.6	750.0	1500	102	10.6
Min	6.0	15.0	4.0	1.0	1.0	0.2	0.0	48.8	3.0	4.99	4	1.15
Avg	28	100	31	67	5	0	0	308	68	--	--	--
n	97	118	118	116	50	5	118	118	118	4	2	2
EPA Std	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*
2nd EPA Std	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*250*	*5*	*0.3*	*1.0*
TCEQ Surface Water Std	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*

	Cl (mg/l)	Fl (mg/l)	Nitrate (mg/l)	pH	TDS (mg/l)	Phen. alk. (mg/l)	Tot. alk. (mg/l)	Tot. hard. (mg/l)	Conduct. (uS/cm)	Raduim 226 (pCi/l)	Raduim 228 (pCi/l)	Alpha (pCi/L)	Beta (millirims/ yr)
Max	2240.0	9.0	915.0	8.4	3822.0	10.8	520.0	1373.0	8200.0	1.9 +/- 0.3	2.1 +/- 1.1	9.7 +/- 2.3	10 +/- 7
Min	6.0	0.1	0.0	5.6	138.0	0.0	40.0	74.0	255.0	0.2 +/- 0.1	2.1 +/- 0.5	2.5 +/- 1.4	4.4
Avg	120	1	44	7	593	0	252	377	1239	--	--	5.4	--
n	118	112	119	114	116	118	118	118	117	2	2	7	2
EPA std	*NR*	*4*	*10*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*5*	*5*	*15*	*4*
2nd EPA	*250*	*2*	*NR*	*5.6-8.5*	*500*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*
TCEQ surface water std	*NR*	*0.5*	*1*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*

Table 7. Water quality (continued).

Water quality data from Texas Water Development Board; filtered samples.

2nd EPA = secondary drinking water standard set by the U.S. Environmental Protection Agency
Avg = average value
Bicarb = bicarbonate
Carb = carbonate
Conduct. = conductivity
EPA Std = primary drinking water standard set by the U.S. Environmental Protection Agency
Max = maximum value
mg/l = milligrams per liter
millorims/yr = millirims per year
Min = minimum value
n = number of samples
NR = nor regulated
pCi/l = picocuries per liter
Phen. alk. = phenol alkalinity
TCEQ surface water std = surface water standard as set by the Texas Commission on Environmental Quality
TDS = total dissolved solids
Tot. alk. = total alkalinity
Tot. hard. = total hardness
uS/cm = microsiemanns per centimeter

into the hydrogeology of the Llano Uplift. In particular, a study by Moore and others (2002) discusses factors that contribute to well yield in a fractured bedrock aquifer of New Hampshire. Factors that can positively relate to well yields include:

- proximity to exposed fault or fracture zone,
- correlation to the strike of mapped fault or fracture zones,
- correlation to vegetation or topographic lineations,
- proximity to the intersection of lineaments or fracture zones,
- located within low slopes or swales,
- proximity to water bodies, and
- large contributing surface drainage area.

Combined, these factors can determine areas of highest probability to supply a well with sufficient yield and have been successfully applied to fieldwork by the author. The geologist must weigh the factors together to identify areas of highest potential. These positive well factors are also helpful in the understanding of the conceptual model of the aquifer.

Future Work

The amount of available water within the Precambrian Basement Aquifer is poorly understood but could be important for water resource planning. More data on the aquifer and wells are needed. In addition, detailed lineament and hydrogeologic studies could help generate better estimates of aquifer parameters, availability, groundwater flow, and recharge. Quantitative studies of well yield and positive contributing factors of yield using GIS and other statistical (multivariate) analyses are needed and could also help better define the conceptual model. Lastly, a detailed study of the fractures and faults is also needed to better understand flow in the system. Quantitative information on fractures such as lateral and vertical connectedness, density, frequency, and apertures would help characterize the system.

Conclusions

The Precambrian Basement rocks of the Llano Uplift cover approximately 1,290 square miles and provide the sole source of water for an estimated 7,200 people and 73,000 livestock with estimated pumping of 3,600 acre-feet per year. Faulting and fracturing are important elements to the availability of groundwater in the Precambrian Basement Aquifer of the Llano Uplift. Detailed geologic mapping has shown that faults and fractures are more prevalent than shown on published geologic maps and can be targeted for groundwater production; therefore, groundwater supplies may be greater than previously considered.

The Precambrian Basement Aquifer could be considered a minor aquifer of Texas because it supplies “relatively small quantities of water in large areas of the State.”

Acknowledgments

The Texas Water Development Board and the Texas Natural Resource Information System provided many geographic information system coverages and data sets used in this evaluation. Dr. Robert Reed digitized the Precambrian geology of the Llano Uplift from the Llano Geologic Atlas Sheet of Barnes (1981). Dr. Mark Helper painstakingly converted those digital data into geographic information system files, which were used in this paper. Jen Garcia (Lower Colorado River Authority) provided geographic information system coverages of surface streams in the study area. Ron Fieseler and Paul Babb (Blanco-Pedernales Groundwater Conservation District) provided well and water-quality data. Angelina Bonetti (Hickory Underground Water Conservation District #1) provided well and water quality data. The author benefited from the observations of the drillers of Virdell Drilling Inc., and discussions with Taylor Virdell. Brian A. Smith, P.G., and John Dupnik, P.G., reviewed this paper and provided helpful suggestions and comments. April Hoh and Eddie Collins provided constructive review and commentary that improved the quality of this paper. Finally, the author would like to thank Robert Mace for his formatting and editorial work.

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Biography:Brian was born in Austin, Texas, and is a fifth generation Texan and a hydrogeologist at the Barton Springs/Edwards Aquifer Conservation District in Austin. Brian earned a B.S. and M.S. from The University of Texas at Austin. Brian spends his free time in Mason County at a small cabin on the Llano River that he and his wife, Sophie, have built. The cabin is supplied by water from a well drilled into the Packsaddle Schist along a fault zone. Locating this well marked the beginning of Brian's interest into the groundwater resources of the Precambrian Basement Aquifer.

South Rim, Big Bend (photo by Brian Hunt)

Defining Groundwater Flow Characteristics in the Northern Segment of the Edwards Aquifer Based on Groundwater Chemistry

Ian C. Jones, Ph.D., P.G.
Texas Water Development Board

Abstract

Chemical and isotopic compositions along two groundwater flow paths were used to characterize groundwater flow system in the northern segment of the Edwards (Balcones Fault Zone) Aquifer. Groundwater compositions reflect geochemical processes that the groundwater encounters along a flow path, for example, interaction with aquifer rock or soil, groundwater mixing, and recharge processes. Recharge processes can be investigated by comparison of conservative constituents in both precipitation and groundwater.

Results of this study support groundwater flow model results that indicate that (1) groundwater circulation is most active in the unconfined part of the aquifer where most of the recharge occurs by infiltration through soil and intermittent streams and natural discharge occurs through perennial streams and (2) little groundwater flow enters the confined part of aquifer. The spatial distribution of groundwater flow in the aquifer produces compositional differences between groundwater in the unconfined and confined parts of the aquifer. Additionally, this study suggests that recharge to the aquifer occurs mostly during fall and winter months. This observation is based on stable hydrogen and oxygen isotopic compositions of groundwater and precipitation.

Introduction

The northern segment of the Edwards (Balcones Fault Zone) Aquifer is an important source of water for municipalities, industries, and landowners in central Texas. Of the three segments of the Edwards (Balcones Fault Zone) Aquifer, the San Antonio and Barton Springs segments have historically received greater attention due to conflicts over groundwater demand for municipal, agricultural, recreational, and ecological uses (Figure 1). The northern segment has received lower priority largely because the largest city in the region, Austin, does not rely on the northern segment for groundwater to meet its water demands. However, other smaller municipalities in the area, such as Georgetown, Pflugerville, and Round Rock, use groundwater from the Edwards (Balcones Fault Zone) Aquifer. Rapid population growth in these and adjacent municipalities is likely to be accompanied by rapid growth in demand for groundwater from the northern segment of the Edwards (Balcones Fault Zone) Aquifer. This growth necessitates our gaining a better understanding of the hydrology and potential effects of future population growth on this segment of the aquifer. This understanding can be achieved through groundwater modeling and evaluation of geochemical tracers in the groundwater.

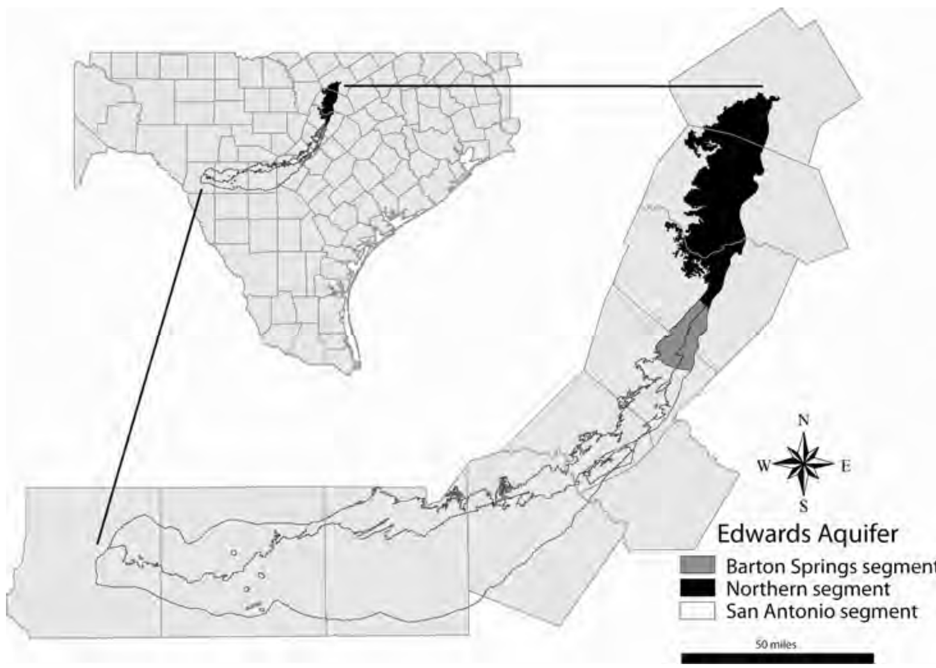

Figure 1. The Edwards (Balcones Fault Zone) Aquifer is divided into three segments: Northern, Barton Springs, and San Antonio, each separated by hydrologic divides.

Study Area

The northern segment of the Edwards (Balcones Fault Zone) Aquifer is located in central Texas (Figure 2). It is the northernmost of the three segments that make up the Edwards (Balcones Fault Zone) Aquifer, underlying parts of Bell, Travis, and Williamson counties (Figure 1). The northern segment of the Edwards (Balcones Fault Zone) Aquifer extends from the Colorado River in Travis County to the Lampasas River in southern Bell County. This segment of the Edwards (Balcones Fault Zone) Aquifer is bounded by the Colorado River to the south, the western margin of the Edwards and associated limestones outcrop to the west and north, and the easternmost extent of fresh groundwater, referred to as the bad-water line.

Central Texas has a sub-humid climate. At weather stations located within the study area, median annual precipitation ranges from 20 to 30 inches. Approximately 60 percent of annual precipitation falls in April through June and September through October (Figure 3). Some of this precipitation takes the form of severe thunderstorms. These thunderstorms frequently produce major flash floods that have the potential to generate recharge to the underlying aquifer (Senger and others, 1990). Monthly precipitation is typically lowest during July and August.

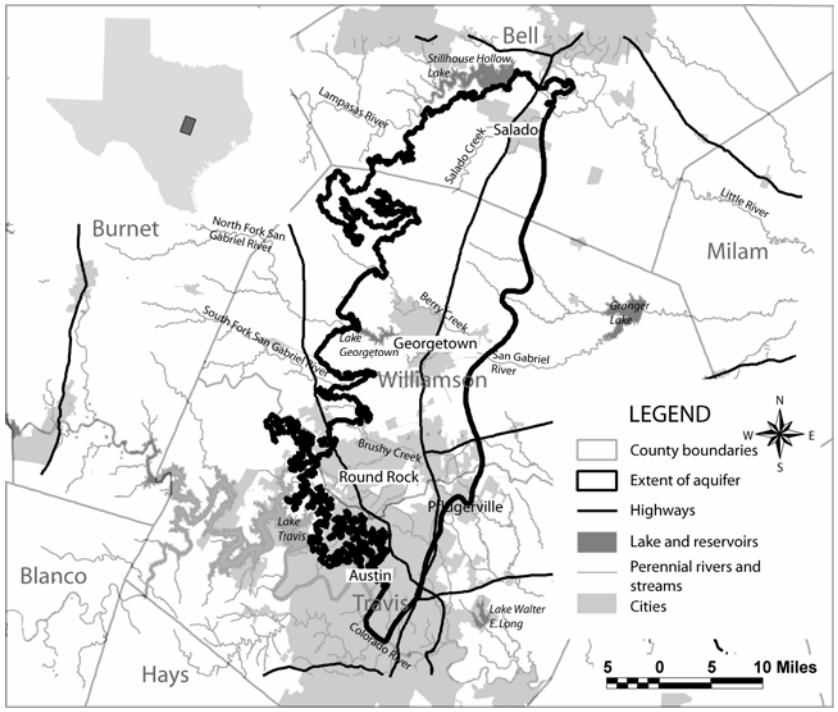

Figure 2. Location of study area.

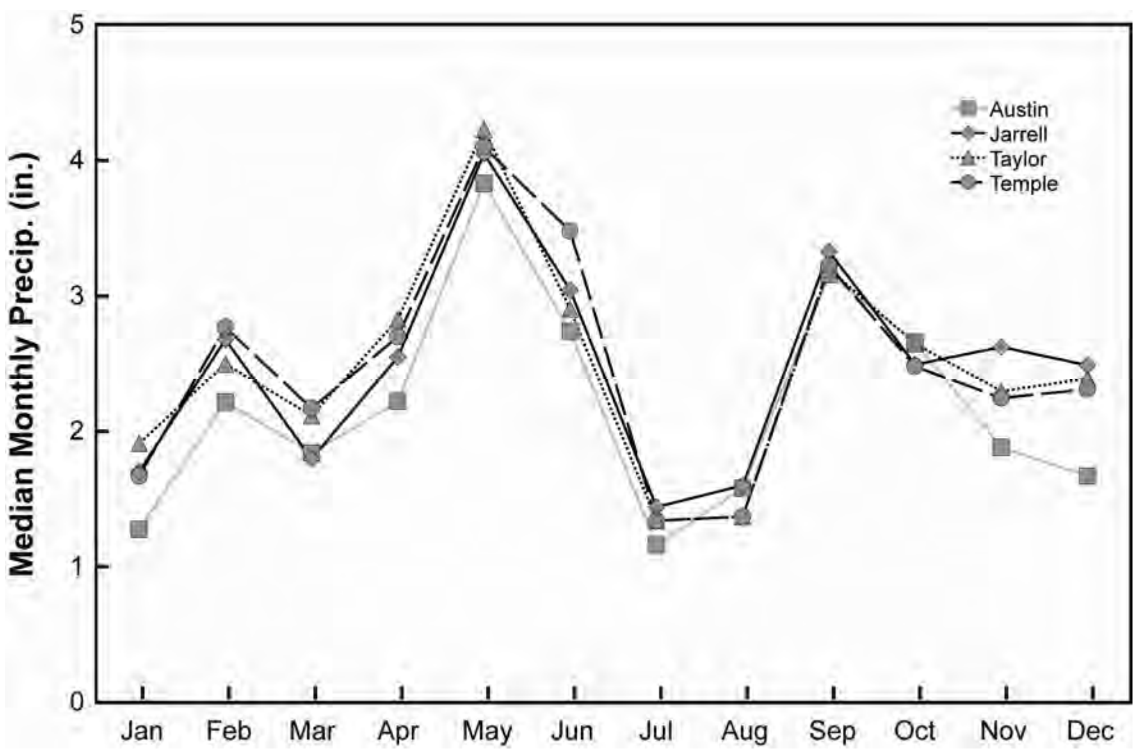

Figure 3. Median monthly precipitation at selected stations in the study area (data from National Climate Data Center).

Geology

Stratigraphic units underlying the study area range in age from the Paleozoic Ellenburger Group to Recent alluvium (Brune and Duffin, 1983). Only Cretaceous and younger rocks are exposed at the surface (Figure 4). The most important aquifer units in the study area occur in the Cretaceous Trinity, Fredericksburg, and Washita groups (Figure 4). These Cretaceous units are up to 2,000 feet thick and dip gently toward the southeast (Trippet and Garner, 1976).

The Trinity Group is divided into the Travis Peak, Glen Rose, and Paluxy formations (Figure 5; Brune and Duffin, 1983). Of these three formations, only the Glen Rose Formation occurs throughout the study area, the other two formations only occur as isolated outcrops. The Glen Rose Formation is predominantly composed of alternating layers of limestone and dolomite at the top and massive layers of limestone and dolomite at the base.

The Fredericksburg Group is divided into the Walnut Formation, Comanche Peak Limestone, and Edwards Limestone (Figure 5; Brune and Duffin, 1983). The Walnut and Comanche Peak formations are composed of fine-grained limestone and shale, occurring primarily in the subsurface in the northern part of the study area. The Edwards Limestone is composed of massive vuggy limestone with fine-grained marl at the top of the formation. This marl is very thin in the study area and tends to become thicker toward the north.

The Washita Group is divided into the Georgetown Formation, Del Rio Clay, and Buda Limestone (Figure 5; Brune and Duffin, 1983). The Georgetown Formation thins southward and is composed of fine-grained limestone that in places is hydraulically connected to the Edwards Limestone. The Del Rio Clay and Buda Limestone are composed of shale and fine-grained limestone, respectively (Brune and Duffin, 1983).

Hydrogeology

The northern segment of the Edwards (Balcones Fault Zone) Aquifer generally consists of the Comanche Peak Limestone, Edwards Limestone, and Georgetown Formation (Figures 5 and 6). These stratigraphic units constitute the upper Fredericksburg and lower Washita groups and are collectively referred to as the Edwards and associated limestones (Brune and Duffin, 1983). The aquifer overlies older Cretaceous rock of the Walnut Formation and is overlain by the Del Rio Clay (Figures 5 and 6). The Walnut Formation and Del Rio Clay are recognized as confining units (Brune and Duffin, 1983; Baker and others, 1986). The base of the aquifer is defined as the base of rocks having greater water-yielding capabilities (Baker and others, 1986). In most areas, this excludes the Walnut Formation; however, in some areas beds in the Walnut Formation are composed of potentially permeable shell beds and may thus be included in the Edwards (Balcones Fault Zone) Aquifer.

The unconfined portion of the aquifer, consisting of the outcrop of the Edwards and associated limestones, becomes narrow in the south, near the Colorado River (Figure 4). This narrowing of the outcrop occurs as a result of the combined effects of intense faulting and large topographic variations (Baker and others, 1986). Fracturing of the limestone also enhances the porosity of the limestone and plays a role in the development of karst features. Normal faulting, common in the

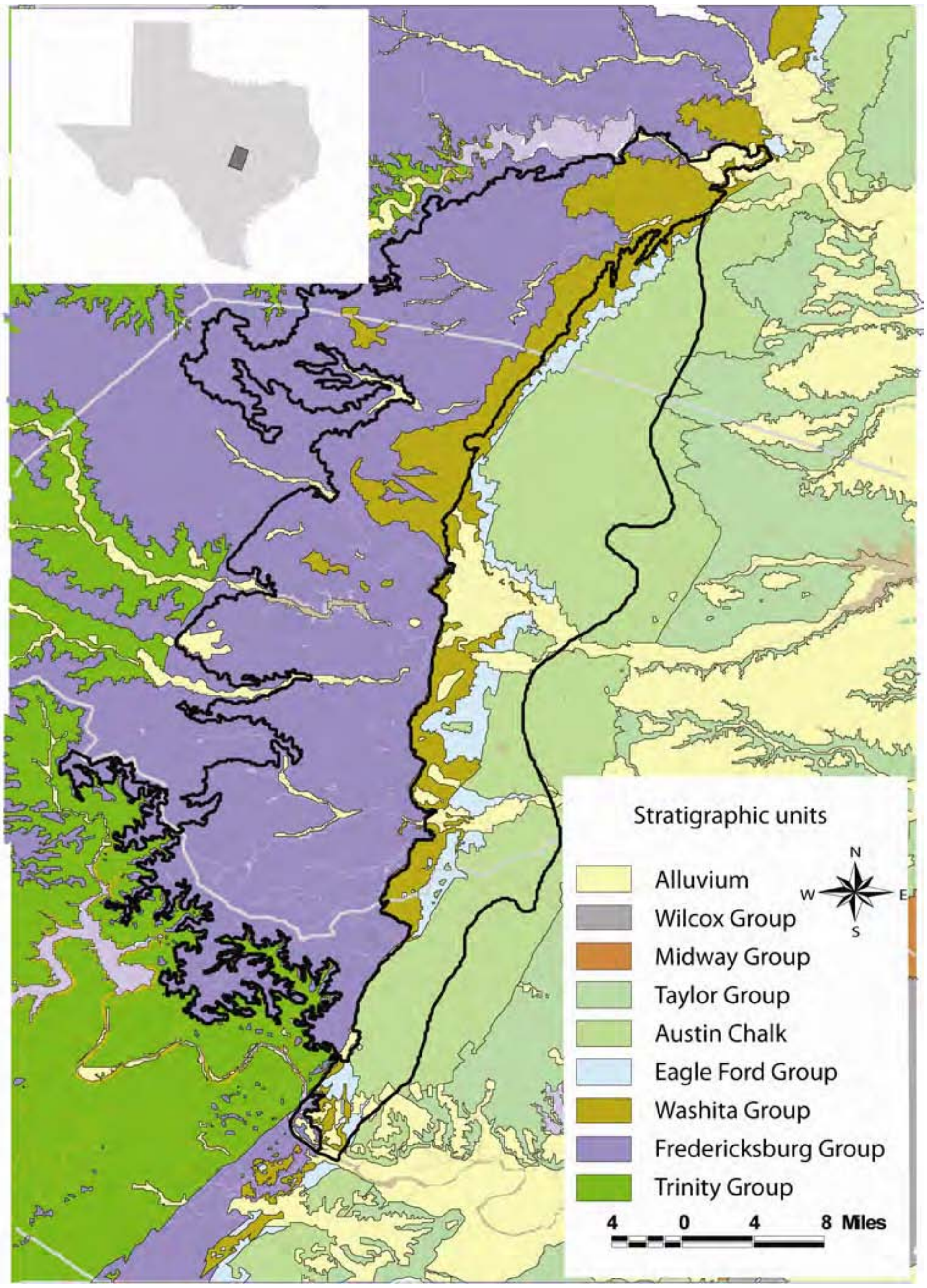

Figure 4. Surface geology in the study area (modified from Proctor and others, 1981).

Series	Group		Stratigraphic Unit	Hydrologic Unit	Maximum Thickness (feet)
Gulf	Navarro			Navarro and Taylor Group	850
	Taylor				
	Austin			Austin Chalk	450
Comanche	Eagle Ford				50
	Washita		Buda Limestone		50
			Del Rio Clay		60
			Georgetown Formation	Edwards aquifer	100
	Fredericksburg		Edwards Limestone		200
			Comanche Peak Limestone		50
			Walnut Formation		150
	Trinity		Paluxy Formation	Upper Trinity	10
		Glen Rose	Upper Member		450
			Lower Member	Middle Trinity	450
		Travis Peak	Hensell Sand Member		100
			Cow Cr. Limestone Member		100
			Hammett Shale Member		50
			Sligo Member	Lower Trinity	150
			Hosston Member		850

Figure 5. Stratigraphic and hydrostratigraphic units in the study area (modified from Brune and Duffin, 1983).

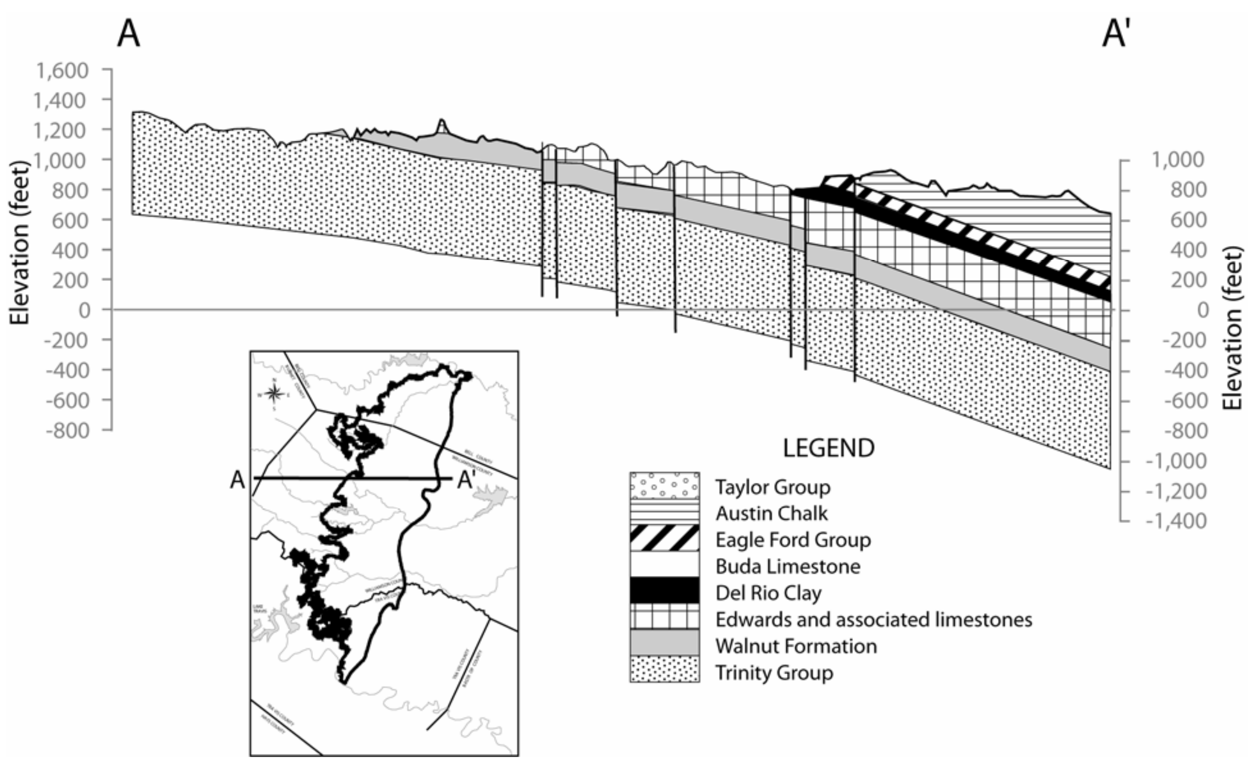

Figure 6. Geologic cross sections of the northern segment of the Edwards (Balcones Fault Zone) Aquifer (modified from Jones, 2003).

southern portion of the study area, generally decreases toward the north (Baker and others, 1986). It is associated with the Balcones Fault Zone, a zone of faults about six to eight miles wide that extends from Del Rio in south-central Texas to Dallas. This zone is characterized by major faults that strike north-south to northeast-southwest and dip 40 to 80 degrees to the east, with a net displacement of 600 to 1,000 feet (Brune and Duffin, 1983; Collins, 1987). Cross faults, sub-perpendicular to major faults, are also common (Collins, 1987). These faults influence groundwater flow in two ways: (1) faults provide preferential flow paths and (2) fault displacement in some cases produces barriers to groundwater flow (Brune and Duffin, 1983). Preferential groundwater flow along faults and joints in this aquifer often results in formation of solution cavities such as caves (Brune and Duffin, 1983).

Water Levels

In the northern segment of the Edwards (Balcones Fault Zone) Aquifer, the potentiometric surface slopes generally toward the east although adjacent to the Colorado River it slopes toward the south (Figure 7). Groundwater flow along fractures is responsible for the southward flow in the southern part of the study area, where fracturing is most intense. Senger and others (1990) suggested that some of the major faults, especially in the south, also act as hydraulic barriers, restricting west-to-east groundwater flow. In the central and northern parts of the aquifer, where faulting is less intense, the influence of fractures on regional groundwater flow is less apparent (Senger and others, 1990).

In the unconfined part of the aquifer, the water table occurs less than 100 feet below land surface and may approach land surface along incised streams (Senger and others, 1990). In the confined part of the aquifer, water levels approach or may, in some cases, exceed land surface, resulting in flowing wells. Water-level fluctuations observed in this aquifer are in response to changes in recharge and discharge rates associated with rapid recharge during wet periods (Baker and others, 1986). Adjacent to the Colorado River, water-level fluctuations are muted due to the stabilizing effect of Lake Austin and Town Lake.

Recharge

Recharge to the Edwards (Balcones Fault Zone) Aquifer takes the form of infiltration of precipitation that falls on the outcrop or infiltration of runoff derived from watershed areas upstream from the aquifer outcrop (Dahl, 1990; Slade and others, 2002). The primary mechanism for recharge to the aquifer is infiltration along intermittent streams and by infiltration of precipitation on the outcrop. The recharge zone is characterized by the occurrence of (1) numerous scattered karst features, such as dissolution-enhanced fractures, sinkholes, and caves and (2) faults and joints that intersect losing segments of perennial and intermittent streams that cross the study area. Karst features and fractures are potential recharge sites capable of transmitting large amounts of water to the aquifer following heavy rainfall events (Brune and Duffin, 1983; Kreitler and others, 1987).

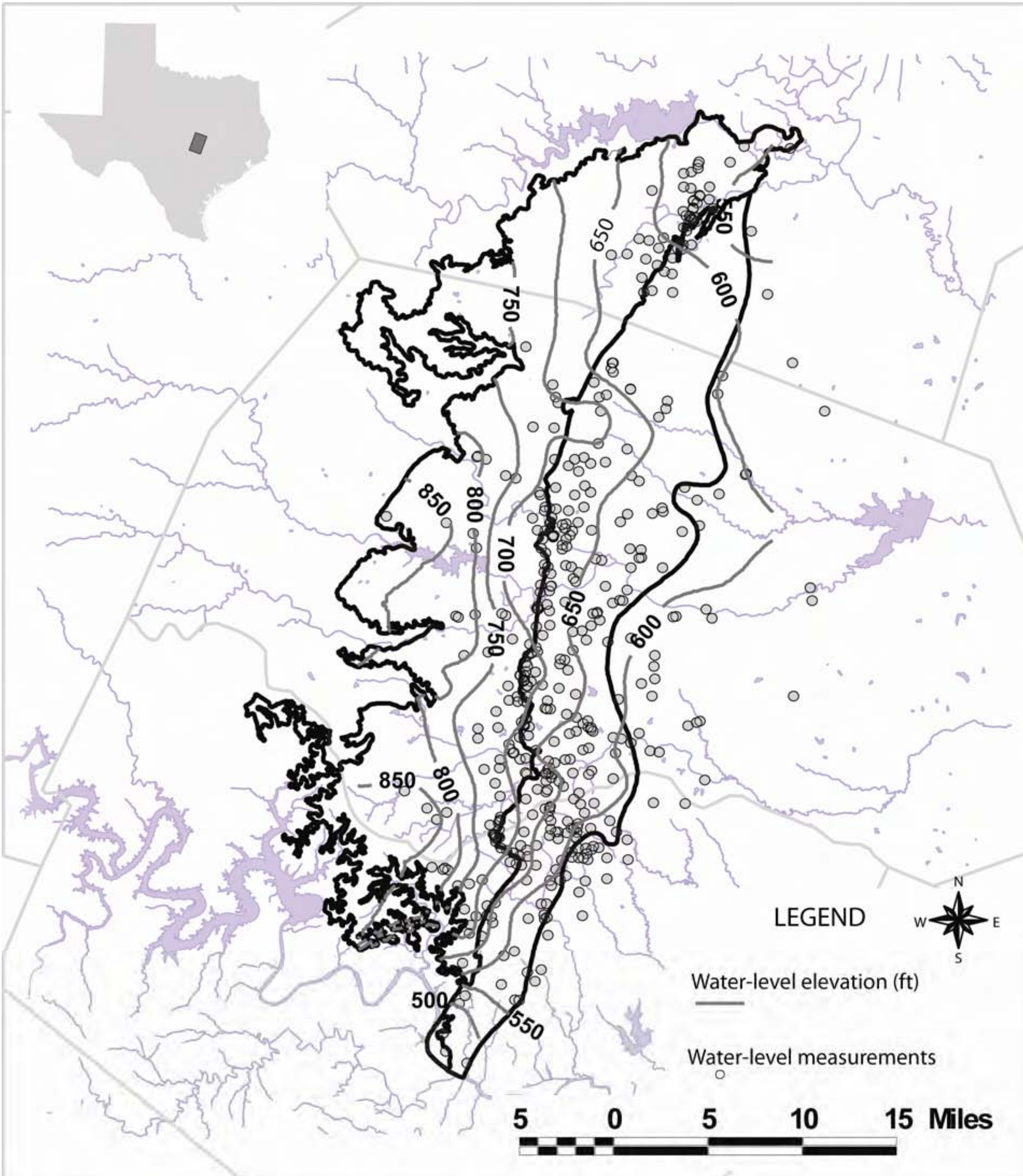

Figure 7. **Water-level elevations in the northern segment of the Edwards (Balcones Fault Zone) Aquifer for 1980.**

Discharge

The northern segment of the Edwards (Balcones Fault Zone) Aquifer is only slightly to moderately developed. Consequently, natural discharge through springs and seeps is thought to be much larger than well pumping (Duffin and Musick, 1991). TWDB pumping estimates indicate that municipal and rural domestic pumping together account for almost 90 percent of the groundwater withdrawn from the aquifer.

The Lampasas and Colorado rivers that form the northern and southern boundaries of the study area are the largest rivers in the area. Together with smaller rivers and creeks, such as Brushy Creek, Berry Creek, Salado Creek, and San Gabriel River that cross the outcrop of the aquifer, they are likely recipients of groundwater discharge as indicated by their perennial flow (Figure 2). Springs and seeps in the western part of the aquifer discharge mostly from fractures or cavities in the Edwards Limestone or along the contact between the Edwards and Comanche Peak limestones (Figure 8; Kreitler and others, 1987). In the east, major springs are associated with major faults and generally occur some distance east (down-gradient) of these faults. Faulting frequently results in the juxtaposition of relatively impermeable Del Rio Clay and Buda Limestone and Edwards aquifer rock. This juxtaposition restricts groundwater flow across faults and often results in upward flow along the fault and discharge through springs (Brune and Duffin, 1983; Land and Dorsey, 1988; Senger and others, 1990). Hence the occurrence of several major springs, for example, Mount Bonnell, Salado, San Gabriel, and Berry springs, adjacent to the boundary between unconfined and confined parts of the aquifer (Figure 8). Other major springs occurring in the study area include Childers Springs in Bell County; Deep Eddy, Mormon, Power House, and Seiders springs in Travis County; and Berry, Knight, San Gabriel, and Manske springs in Williamson County (Brune, 1975). Along the southern margin of the study area, discharge from the aquifer often takes the form of numerous small springs or seeps located along the southern margin of the Jollyville Plateau (Senger and others, 1990). Discharge in the confined part of the aquifer takes the form of cross-formational flow from the Edwards (Balcones Fault Zone) Aquifer, through the Del Rio Clay, into overlying aquifer units such as the Austin Chalk.

Precipitation over the recharge zone and the upstream contributing zone results in rapid increases in spring discharge. The lag time between precipitation events and spring response varies from almost immediate to more than one week (Brune and Duffin, 1983).

Groundwater Geochemistry

Geochemical compositions of groundwater in the Edwards (Balcones Fault Zone) Aquifer are used to define the down-dip margin of the aquifer. This boundary, referred to as the bad-water line, is defined as the easternmost extent of freshwater in the aquifer. Freshwater is defined as water with total dissolved solids less than 1,000 milligrams per liter. The bad-water line is considered as the eastern boundary of the aquifer because high groundwater salinity is often associated with restricted groundwater circulation (Ridgeway and Petrini, 1999).

Groundwater in the study area becomes progressively more saline from the outcrop recharge zone in the west to down-dip parts of the aquifer in the east (Figure 9). Total dissolved solids in groundwater varies from 200 to 400 milligrams per liter in the recharge zone and increases to

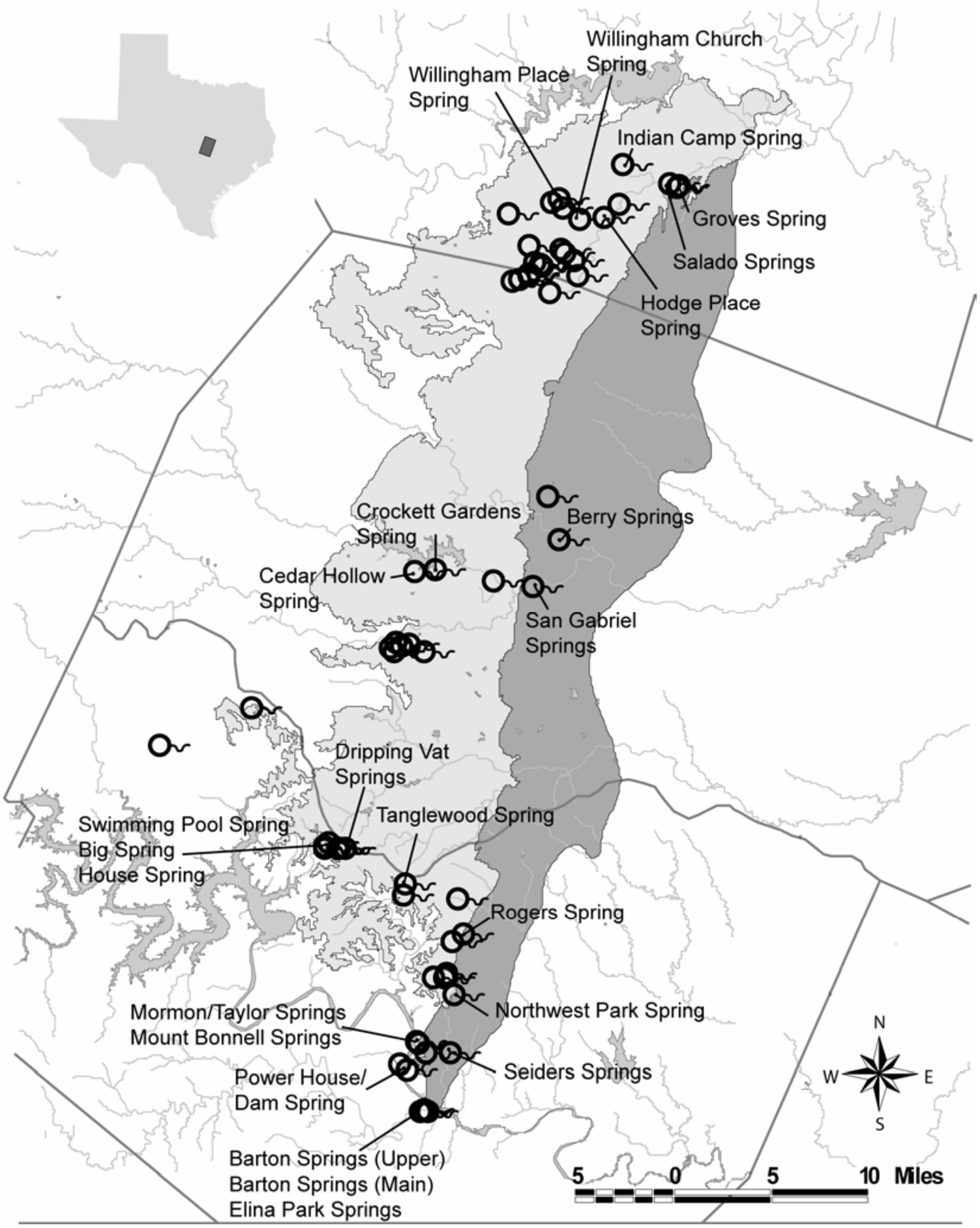

Figure 8. Location of major springs discharging from the Edwards (Balcones Fault Zone) Aquifer in the study area.

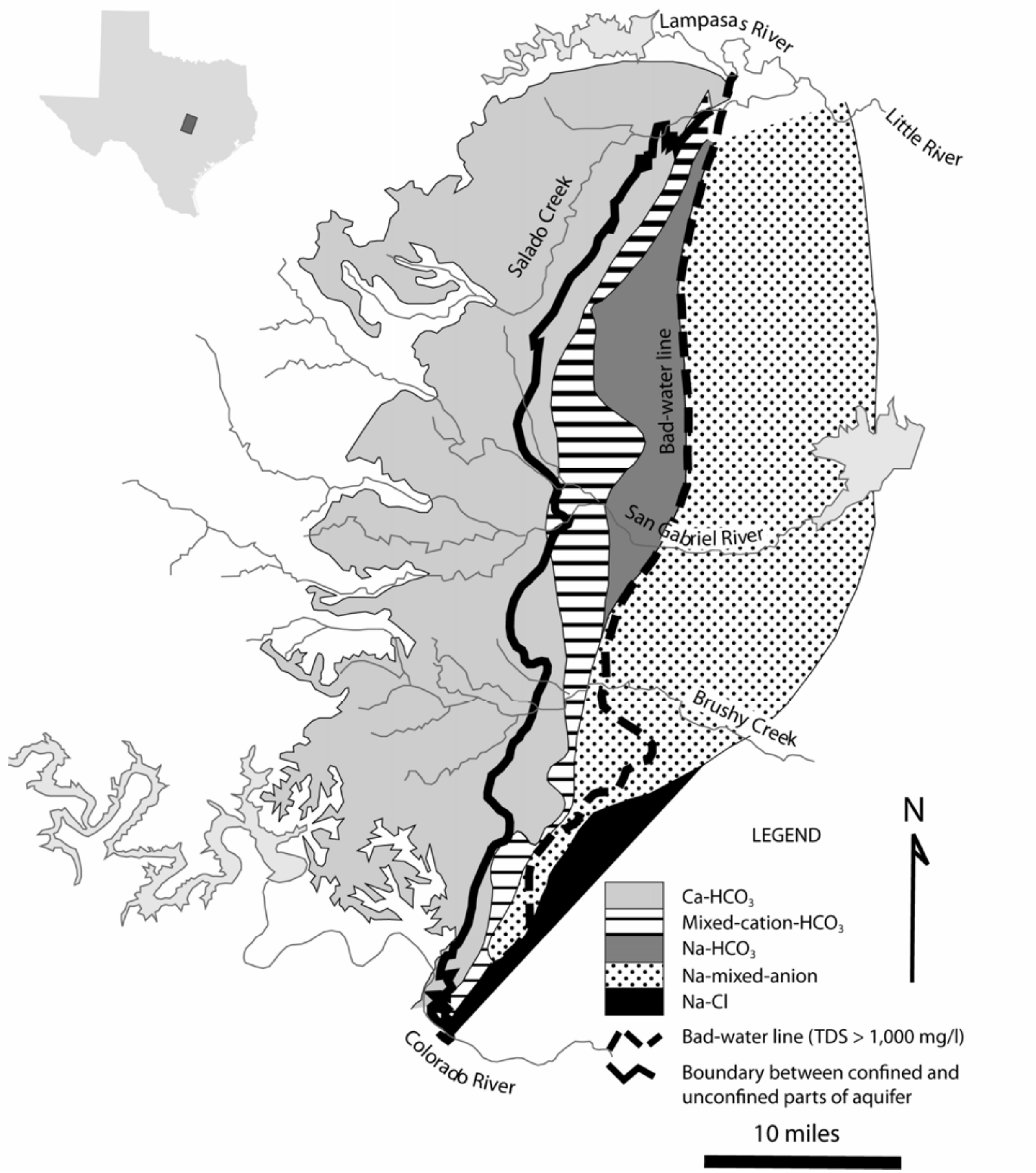

Figure 9. Variation of Edwards (Balcones Fault Zone) Aquifer groundwater chemical compositions in the study area (modified from Senger and others, 1990).

more than 3,000 milligrams per liter down-dip (Baker and others, 1986). Intense faulting in the south creates barriers to eastward groundwater flow and results in the occurrence of saline groundwater within one to two miles of the recharge zone compared to more than 10 miles further north. In addition to variations of total dissolved solids across the aquifer, groundwater geochemical compositions also vary down-dip from calcium-bicarbonate to sodium-sulfate type waters and sodium-chloride type water (Figure 9; Brune and Duffin, 1983). These hydrochemical patterns indicate hydrochemical evolution of groundwater along flow paths. In the south, where faults are more abundant, hydrochemical zones are much narrower than in the north suggesting that the large faults that disrupt fresh groundwater flow may also provide pathways for an influx of deep saline groundwater (Senger and others, 1990).

Groundwater Sampling

We collected ten water samples from springs and wells located along two groundwater flow paths in the aquifer (Figure 10). Six of the samples were collected from a groundwater flow path parallel to the San Gabriel River and the other four samples were collected along Salado Creek. The San Gabriel River and Salado Creek are major discharge zones in the central and northern parts of the study area, respectively. The San Gabriel River flow path lies parallel to the dip of the Edwards (Balcones Fault Zone) Aquifer and extends into the confined part of the aquifer, while the Salado Creek flow paths lies approximately parallel to strike and is solely within the unconfined part of the aquifer. All water samples were collected from springs except for two samples that we collected from wells located in the confined part of the aquifer. Water samples were analyzed for major elements; stable oxygen, hydrogen, and carbon isotopes; and tritium. Analytical precision, based on analyses of laboratory standards and duplicate samples is ±0.2 ‰, ±3 ‰, ±0.2 ‰, and up to 0.27 tritium units (TU) for stable oxygen, hydrogen, carbon, and tritium isotopes, respectively.

Results

Results of major element and isotopic analyses appear in Table 1. Sampling indicates generally increasing sodium, sulfate, and chloride concentrations along flow paths (Figure 11). Water samples collected from the unconfined part of the aquifer have similar major element compositions clustering close together on a Piper Diagram. The Piper Diagram indicates calcium-bicarbonate type water compositions. Water samples from wells located in the confined part of aquifer have higher sodium, sulfate, and chloride, characteristic of down-gradient groundwater compositions in the aquifer. Groundwater isotopic compositions lie mostly within narrow ranges. Stable oxygen ($\delta^{18}O_{SMOW}$) and hydrogen (δD_{SMOW}) isotopic compositions lie within the range -5.0 to -4.4 ‰ and -31 to -26 ‰, respectively (Figure 12). However, stable carbon ($\delta^{13}C_{PDB}$) and tritium compositions differ in the unconfined and confined parts of the aquifer (Figure 13). Groundwater $\delta^{13}C$ values are -12.3 to -8.7 ‰ in the unconfined part of the aquifer and -4.8 to -3.7 ‰ in the confined part of the aquifer (Figure 13). Groundwater tritium is only measurable in the unconfined part of the aquifer where concentrations range from 1.8 to 3.2 TU.

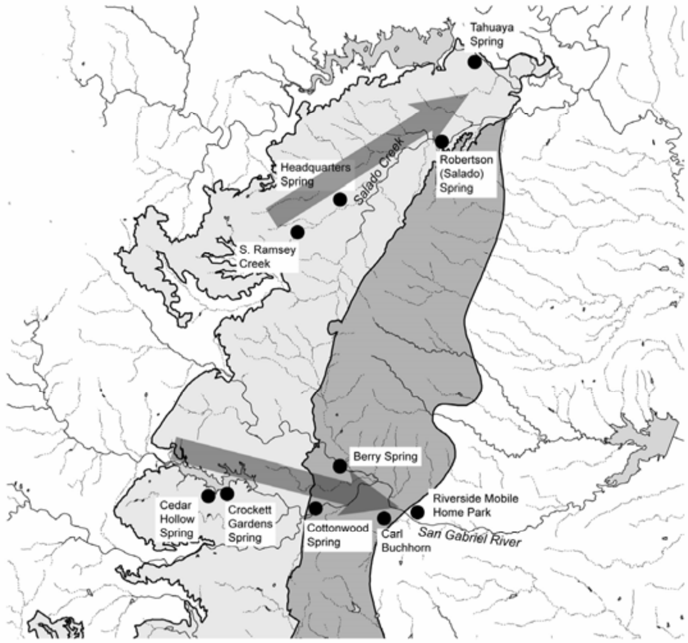

Figure 10. Sampling sites located along flow paths in the San Gabriel River and Salado Creek watersheds.

Discussion

Changes in major element and isotopic compositions along groundwater flow paths give insights into hydrologic and geochemical processes taking place in the aquifer. This information in turn can be used to determine groundwater flow characteristics of the aquifer.

The major element and isotopic compositions of groundwater samples collected in the San Gabriel River and Salado Creek watersheds indicate that compositional changes mainly occur in the down dip areas of the aquifer. Groundwater compositions are relatively uniform in the Salado Creek watershed where groundwater flows parallel to strike (Figures 11 and 13), while in the San Gabriel River watershed, groundwater displays a range of compositions. The range of major element compositions and total dissolved solids suggest mixing between fresh and saline groundwater derived from the unconfined and down-dip areas of the aquifer, respectively (Figures 11 and 13). Differences between groundwater carbon and tritium isotopic compositions in the unconfined and confined parts of the aquifer are apparent. The difference in up-dip and down-dip groundwater tritium compositions indicate different groundwater ages with young, recently recharged, groundwater occurring in the unconfined part of the aquifer and ancient groundwater in the confined part of the aquifer. Related to this, groundwater carbon isotopic compositions in the unconfined and confined parts of the aquifer indicate soil (-8 to -14 ‰) and rock (above -5 ‰) carbon sources, respectively. This is attributable to residence time in the aquifer, where recently recharged groundwater often retains a soil carbon isotopic signature while ancient groundwater adopts a rock carbon isotopic signature over time.

Table 1. **Results of major element and isotopic analyses for water samples collected from the northern segment of the Edwards (Balcones Fault Zone) Aquifer in the San Gabriel River and Salado Creek watersheds (ND indicates constituent was not detected).**

SWN:	58-18-908	58-18-907	58-19-806	58-19-609	58-20-701	58-20-805
Name	Cedar Hollow Spring	Crockett Gardens Spring	Cottonwood Spring (Middle)	Berry Spring	Carl Buchhorn	Riverside Mobile Home Park
Type	Spring	Spring	Spring	Spring	Well	Well
Date	10/31/2002	10/31/2002	10/30/2002	10/31/2002	10/30/2002	10/30/2002
pH	7.38	7.20	7.17	7.08	7.35	7.01
Temp. (°C)	20.6	21.0	21.4	20.9	24.2	25.5
Charge Balance	3%	2%	3%	3%	3%	1%
Ca (mg/l)	90.5	105	98.1	99.6	50.7	35.7
Mg (mg/l)	21.5	21.7	18.9	15.6	31.4	22.7
K (mg/l)	0.56	0.84	1.22	1.40	5.05	7.45
Na (mg/l)	7.89	29.0	12.3	11.4	73.0	189
Cl (mg/l)	13.4	33.6	19.4	17.3	41.9	97.4
NO_3-N (mg/l)	2.13	1.86	3.16	1.98	ND	ND
SO_4 (mg/l)	9.67	28.8	17.4	16.9	84.2	164
Alkalinity (mg/l)	282	320	284	280	250	285
HCO_3 (mg/l)	344	390	346	342	305	348
NO_2+NO_3-N (mg/l)	2.19	1.80	3.00	1.94	ND	ND
TDS (calc.)	490	611	517	506	591	864
Tritium (TU)	2.59	1.80	2.21	2.44	<1	<1
±	0.23	0.23	0.18	0.25		
$\delta^{13}C_{PDB}$ (‰)	-11.8	-13.3	-12.3	-12.1	-4.8	-3.7
±	0.2	0.2	0.2	0.2	0.2	0.2
$\delta^{18}O_{SMOW}$ (‰)	-5.0	-4.9	-4.7	-4.4	-4.9	-4.7
±	0.2	0.2	0.2	0.2	0.2	0.2
δD_{SMOW} (‰)	-31	-31	-29	-26	-30	-30
±	3	3	3	3	3	3

°C = degrees Celcius
mg/l = milligrams per liter
ND = not detected
SWN = state well number
TU = tritium units

Table 1. (cont.)

SWN:	58-11-202	58-03-903	58-04-501	40-60-912
Name	S. Ramsey Creek	Headquarters	Robertson (Salado) Spring	Tahuaya Spring
Type	Spring	Spring	Spring	Spring
Date	4/22/2003	4/22/2003	3/25/2003	3/25/2003
pH	7.13	7.30	7.31	7.35
Temp. (°C)	20.7	20.6	20.0	20.1
Charge Balance	1%	3%	2%	0%
Ca (mg/l)	94.9	88.6	86.8	86.0
Mg (mg/l)	12.7	11.7	12.7	14.8
K (mg/l)	0.51	0.49	1.24	1.17
Na (mg/l)	4.35	3.89	9.62	10.6
Cl (mg/l)	6.65	6.02	12.3	17.8
NO_3-N (mg/l)	1.55	4.22		
SO_4 (mg/l)	8.47	8.89	18.8	13.8
Alkalinity (mg/l)	276	246	241	261
HCO_3 (mg/l)	337	300	294	318
NO_2+NO_3-N (mg/l)	1.54	4.27	4.39	2.41
TDS (calc.)	466	424	435	463
Tritium (TU)	3.23	2.72	2.90	2.58
±	0.26	0.27	0.25	0.26
$\delta^{13}C_{PDB}$ (‰)	-10.2	-10.7	-8.7	-9.6
±	0.2	0.2	0.2	0.2
$\delta^{18}O_{SMOW}$ (‰)	-4.9	-4.9	-4.4	-4.4
±	0.2	0.2	0.2	0.2
δD_{SMOW} (‰)	-30	-31	-27	-27
±	3	3	3	3

°C = degrees Celcius
mg/l = milligrams per liter
ND = not detected
SWN = state well number
TU = tritium units

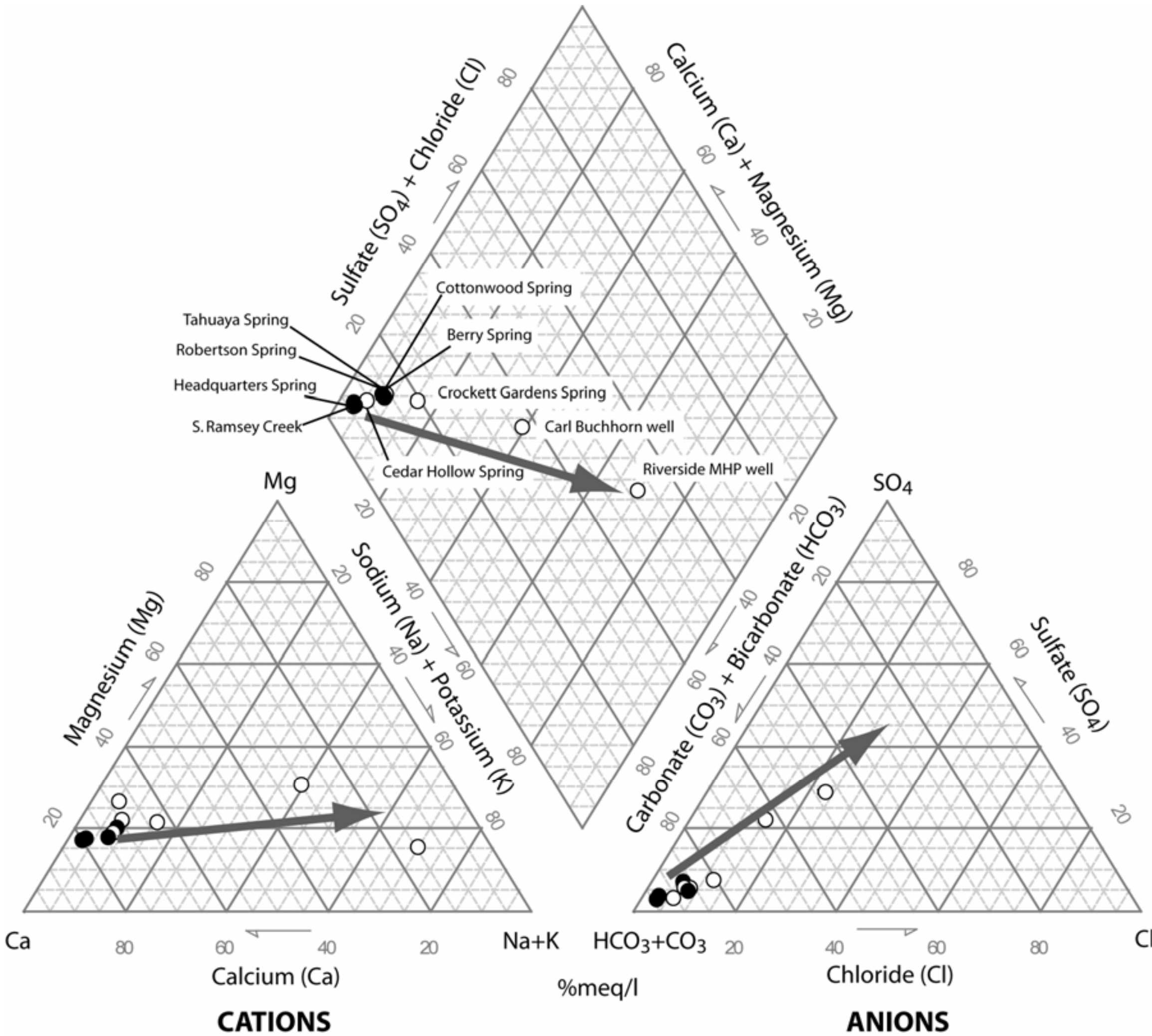

Figure 11. Piper diagram showing groundwater compositions in the San Gabriel River (white) and Salado Creek (black) watersheds. Arrows indicate geochemical evolution of the groundwater along flow paths.

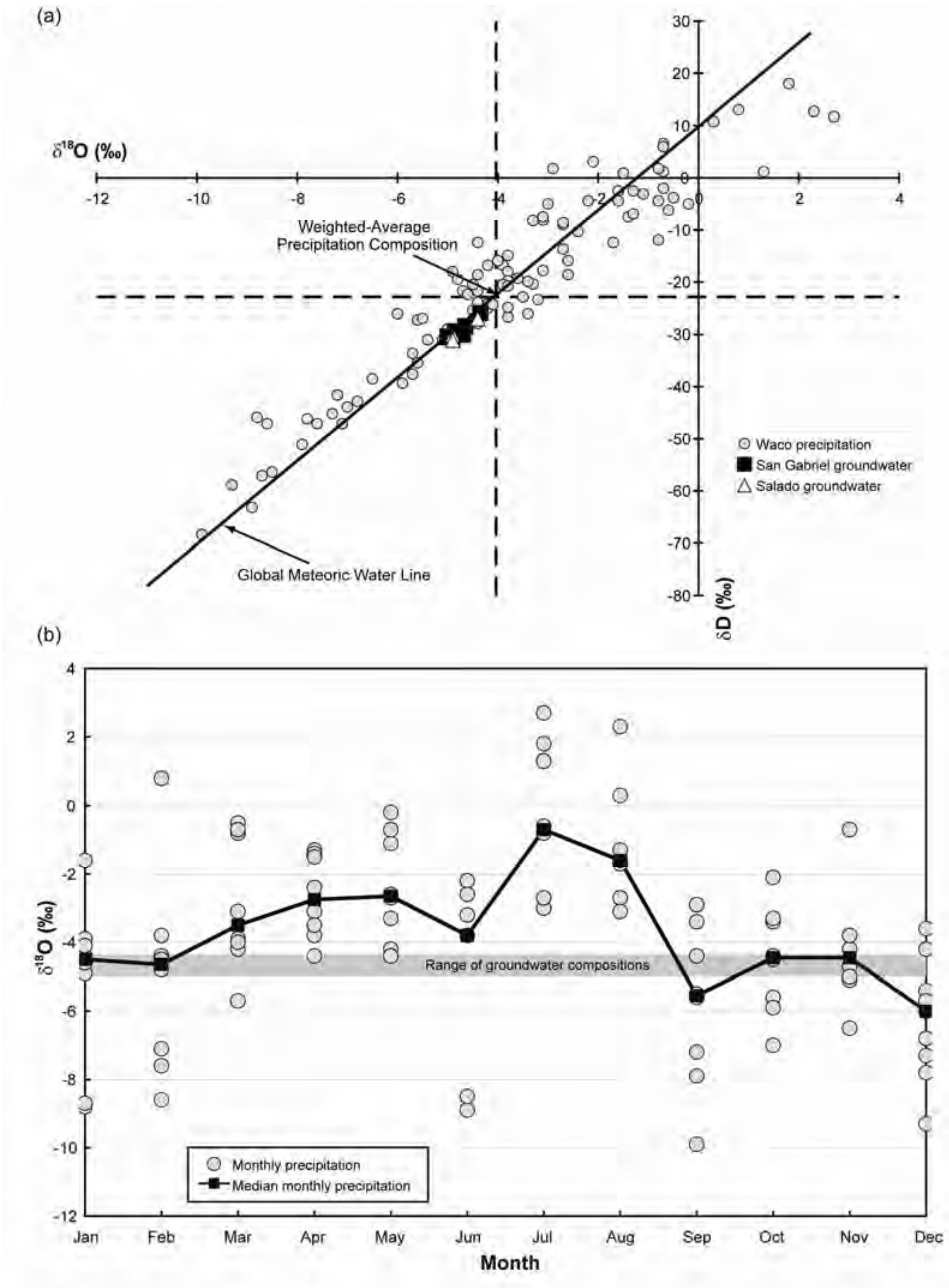

Figure 12. (a) Plot of hydrogen and oxygen isotope compositions of groundwater along with precipitation collected at Waco (precipitation data from IAEA/WMO, 2004). The dashed lines represent weight-average $\delta^{18}O$ and δD values, respectively. (b) Plot of precipitation oxygen isotopes versus time showing variation in isotopic composition during different months of the year (precipitation data from IAEA/WMO, 2004).

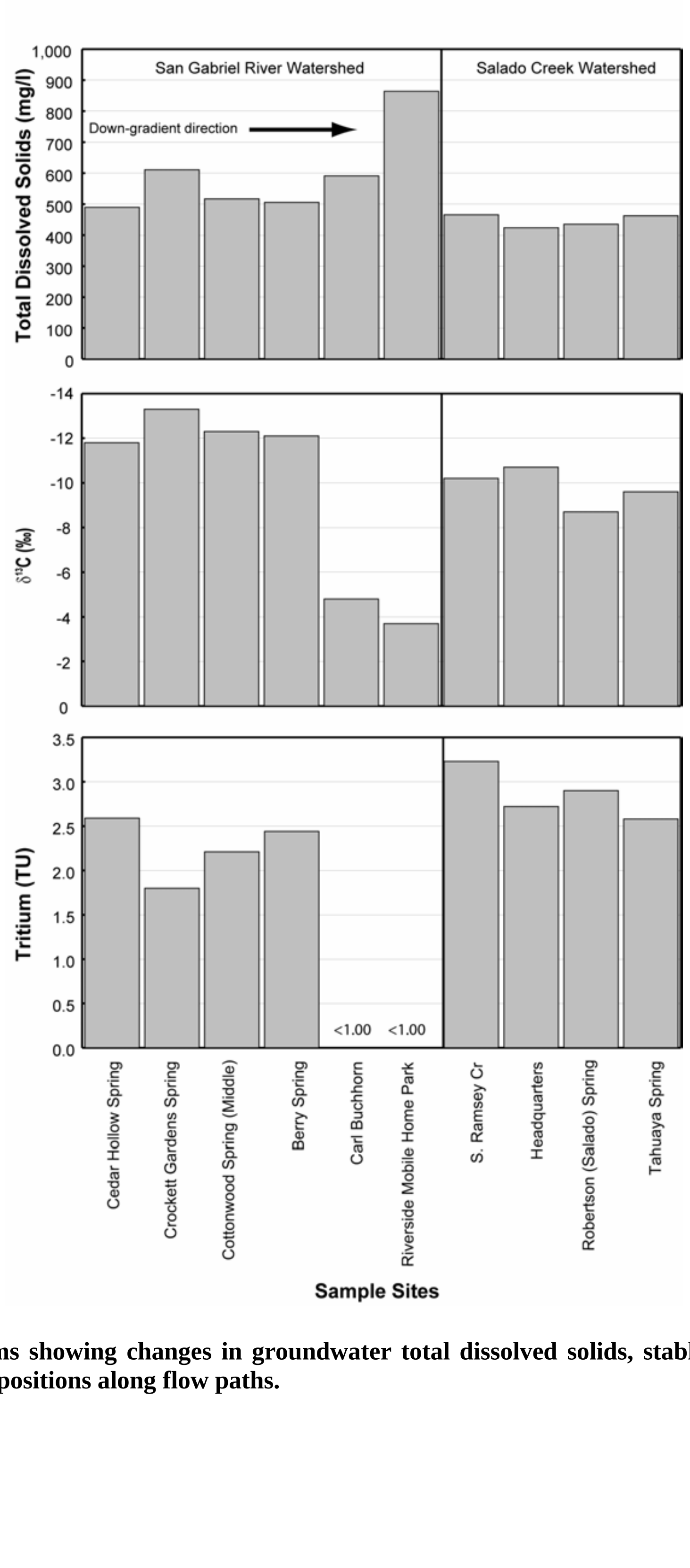

Figure 13. Bar diagrams showing changes in groundwater total dissolved solids, stable carbon isotope, and tritium compositions along flow paths.

The spatial distribution of groundwater characterized by different geochemical compositions reflects the interaction of two main flow systems in the aquifer. These flow systems involve (1) rapid circulation of fresh groundwater from the unconfined part of the aquifer and (2) a slow influx of saline groundwater from down-dip (Senger and others, 1990). The calcium-bicarbonate type water that occurs within or adjacent to the recharge zone is characterized by measurable tritium. The slowly circulating groundwater is characterized by low tritium and mixed-cation-bicarbonate, sodium-bicarbonate, and sodium-mixed-anion-type groundwater with down-dip increasing sodium and chloride concentrations (Figure 9). The contrasting low and high tritium in confined and unconfined parts of the aquifer, respectively, indicate that most groundwater circulation in the aquifer occurs in the unconfined part of the aquifer. This observation is consistent with groundwater flow modeling results which indicate that about 70 to 90 percent of groundwater circulation occurs in the unconfined part of the aquifer where recharge water is discharged as baseflow through stream beds (Jones, 2003). The boundary between low- and high-tritium groundwater coincides approximately with the bad-water line, indicating relatively little circulation of recently recharged groundwater reaching the saline parts of the aquifer. The occurrence of measurable tritium indicates young groundwater in the unconfined part of the aquifer compared to older groundwater in the confined part of the aquifer.

In addition to groundwater samples collected as part of this study, I also evaluated rainwater oxygen and hydrogen isotopic compositions from a station located in Waco, Texas, about 50 miles north of the study area. These data, from the Global Network of Isotopes in Precipitation database, were collected on a monthly basis over the period 1962 through 1986 (IAEA/WMO, 2004). The precipitation δD and $\delta^{18}O$ values lie in the range of -70 to +20 ‰ and -10 to +1 ‰, respectively. These ranges are much wider than the ranges of groundwater δD and $\delta^{18}O$ values in the study area (Figure 12). Stable isotope values of the groundwater are lower than the average precipitation value. Median monthly precipitation $\delta^{18}O$ values approach groundwater $\delta^{18}O$ values during fall and winter months rising to -4 ‰ to -2 ‰ during spring months and peaking at -2 ‰ to 0 ‰ during summer months. This suggests that the probability of recharge occurring is greatest during fall and winter months. This is surprising because highest precipitation occurs during spring months (Figure 3). However, hydrographs of streamflow in Berry Creek and Salado Creek, streams that are dominated by groundwater discharge, support the conclusion that recharge occurs primarily during fall and winter months (Figure 14). These hydrographs indicate generally rising streamflow that is attributable to recharge during fall and winter months and level or declining streamflow rates during spring and summer months.

Conclusions

1. Major element and isotopic compositions indicate young fresh groundwater in the unconfined part of northern segment of the Edwards (Balcones Fault Zone) Aquifer compared to much older groundwater in confined part of aquifer which confirm previous groundwater flow modeling results by Jones (2003) that concluded that most groundwater circulation is in the unconfined part of the aquifer with little flow entering the confined part of the aquifer.

2. Comparison of precipitation and groundwater stable hydrogen and oxygen isotopes suggests that most recharge occurs during fall and winter months.

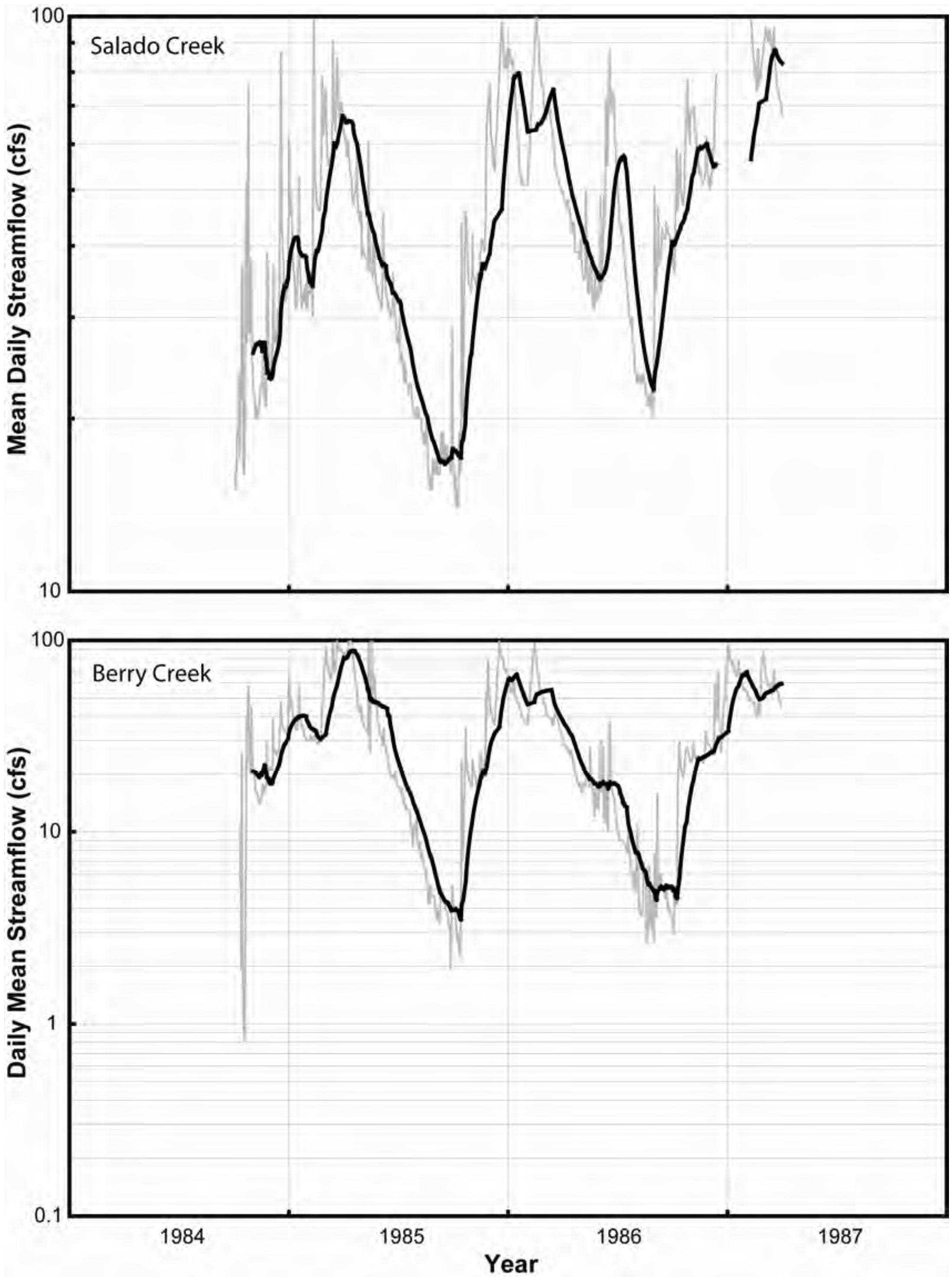

Figure 14. **Hydrographs showing mean daily streamflow in Salado and Berry creeks. The black line represents a 30-day moving average.**

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Honey Creek Cave, Glen Rose Formation (photo taken on January 21, 2006, by Kurt Menking)

note

History of water well completions and uses at the State Capitol, 1857 to 1997

Robert L. Bluntzer, C.P.G.

Introduction

The purpose of this paper is to provide a perspective on the history of water well development and use for the Texas Capitol building and grounds in Austin, Texas. Historically, eight wells have been completed and used on the Capitol grounds since 1857 when the drilling of the first well was begun. These wells include four wells used for water supply purposes and four wells used for monitoring purposes. The water supply wells include the 1859 Well, the 1874 Well, the 1889 Well, and the 1890 Well. The four monitor wells were drilled and cored and cased with steel casing in 1989 and used for measuring shallow water levels in conjunction with the possible dewatering of the Austin Chalk during the recent construction of the Capitol extension. The occurrence, availability, and quality of the ground-water resources of the Capitol grounds and adjacent area in Travis County is adequately presented for review in Brune and Duffin (1983).

Preparation of this report is based on over 40 references reviewed and researched in the Texas State Library Archives, The University of Texas' Center of American History Library, The University of Texas' Architecture Library, the U.S. Geological Survey's Water Resources Library in Austin, the library of the Bureau of Economic Geology, the State Preservation Board Library, the author's personal ground-water resources library and files, and the files of the State Preservation Board, Texas Water Development Board, and the Texas Natural Resource Conservation Commission (now the Texas Commission on Environmental Quality).

The 1859 Capitol Water Well

The first permanent State Capitol building in Austin was completed in 1852–1853 at a location between the current Capitol building which was completed in 1888 and the south entrance to the Capitol grounds at the north end of Congress Avenue (LOC on Figure 1). On August 26, 1856, the Sixth Texas Legislature appropriated $10,000 for the drilling of an artesian well and the purchase of trees and shrubbery for the Capitol grounds.

The first Capitol water well (State Well Number YE 53-43-707) which was started at a location "north" and "to the rear" of the 1852–1853 Capitol building (Well Location 1 on Figure 1) was drilled from April 1857 to July 1859 and was completed at a depth of 471 feet in the Edwards aquifer. At about 323 feet the drill struck "a vein of mineral water", and the water rose up the wellbore to within 40 feet of the surface. Once the 471-foot depth was reached the well produced

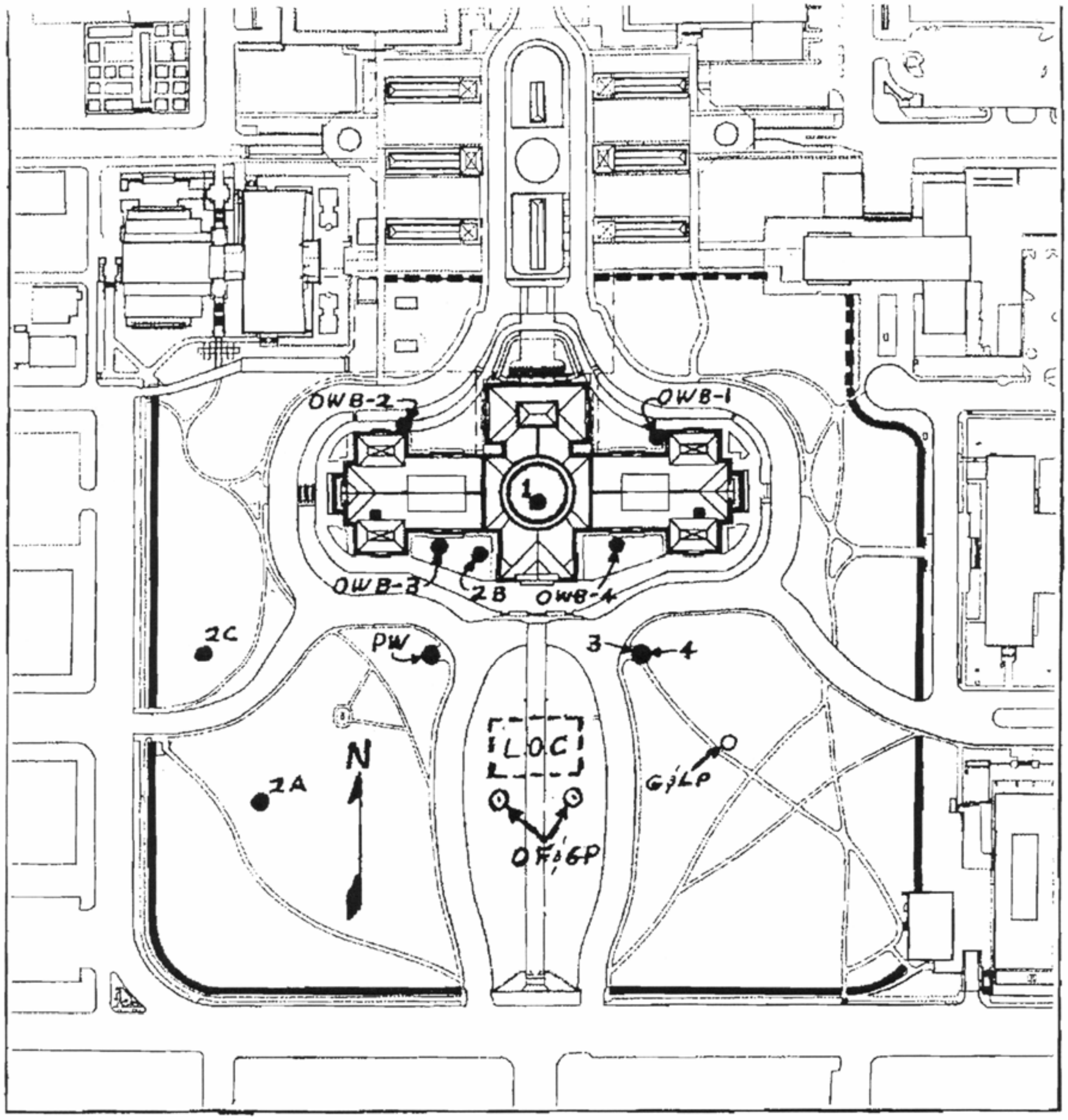


Figure 1. **Location of the Capitol buildings and wells, since 1852–1853, Austin, Texas. (LOC is the approximate location of the 1852–1853 capitol building 1; 1 is the approximate location of the 1859 Capitol Water Well [YD 58-43-707]; 2A, 2B, and 2C are the possible locations of the 1874 Capitol Water Well; 3 is the location of the 1889 Capitol Water Wel1; 4 is the location of the 1890 Capitol Water Well [YD 58-43-702]; OWB-1, OWB-2, OWB-3, and OWB-4 are the locations of the 1989 water-level observation wells; and PW is the location of the proposed artesian well by Dibrell [1900]).**

a surface flow of highly mineralized water containing abundant hydrogen sulfide. The geologic units encountered by the wellbore include from the surface to the total depth of 471 feet: the Capitol Terrace (alluvial) deposits down to 5 feet, the Austin Chalk and Eagle Ford Shale from 5 to 131 feet, the Buda Limestone from 131 to 162 feet, the Del Rio Clay from 162 to 232 feet, and the Georgetown Kiamichi and Edwards Formations from 232 to 471 feet.

The 1859 well was probably the first deep artesian well drilled in Texas and is known as the "Old State Capitol Well" and the "Austin Artesian Well". The diameter of the borehole and the contents, diameter, and amount of casing set in the borehole is unknown. However, to assure that the wellbore would not be filled with the heaving clay of the Del Rio, some type of metal casing was probably set to a depth of about 235 feet. The approximate surface elevation of the wellhead when completed in July 1859 was about 545 feet.

The 1859 Capitol well was drilled by a Mr. Peterson by first using drilling equipment driven by a horse walking in a circular path around the wellhead. Later, due to the lack of penetration of "hard rock", it was completed to a depth of 471 feet using steam-powered drilling equipment. In the early 1860s, the 1859 well was reportedly deepened to a depth of about 1,000 feet in an attempt to obtain better quality water believed to exist in the deeper "Trinity sands". The Trinity water-bearing sands were never reached.

In 1870 another deepening of the well was attempted. Apparently during this attempt a depth between 1,160 and 1,200 feet was reached when part of the drilling tools were lodged and left in the hole. The "Trinity sands" again were not reached. However, the well continued to have the surface flow of highly mineralized, "smelly" water from the Edwards aquifer.

In March 1872, Messrs. Millican and Steele attempted to remove the obstruction (lodged drilling tools) from the wellbore and planned to drill the well deeper to "obtain a good supply of water". They were unable to remove the obstruction and drill the well deeper. It may be at this time or at sometime later that the well was reported to be plugged back to the original depth of 471 feet.

Water from the well was used for medicinal purposes; that is, it was found to possess tonic and laxative properties. Early on the water was reported "to contain the following constituents named in order of their relative abundance: Chloride of Sodium, Bicarbonate of Lime, Sulphate of Lime, Sulphate of Soda, Sulphate of Alumina and Potassa, Sulphate of Magnesia, Sulphate of Iron (a trace), Sulphuretted Hydrogen". The water was reported to have "a saline taste, and is strongly impregnated with Sulphuretted Hydrogen Gas". Also, it was reported to be "too impregnated with lime to taste well" and was determined to be injurious to plants and could not be used to irrigate the Capitol grounds. A "modern", more detailed, chemical analyses of the water produced by the well was never made or reported. Other Edwards aquifer wells nearby at the Austin Public Library and The University of Texas produced water high in hydrogen sulfide gas with total dissolved solids of about 3,500 and 6,200 milligrams per liter.

The wellhead of the 1859 well apparently was sealed soon after the 1852–1853 Capitol building (LOC on Figure 1) was destroyed by fire in November 1881. It remained capped during the construction of the new Capitol building from 1882 to 1888 and never was uncapped again for further use. The capped or sealed wellhead is under the 1888 (current) Capitol building and was reported to be "located within and beneath the basement rotunda of the dome walls some distance from their foundation" (location 1 on Figure 1). It is very probable that the productivity of the 1859 Capitol Water Well was adversely affected by caving, because in 1882 the burned remains of the 1852–1853 Capitol building were “being demolished using dynamite, so preparations for the construction of the present Capitol can begin.”

In their November 1, 1886, report, the Capitol Building Commissioners suggested to the Governor, ”…and as the State has in the past spent a very large sum of money upon this well, we think the expenditure of a nominal sum now in opening it again will prove a benefit to the new capitol, for this well could supply much of the water used in the building, and more than pay for its being opened by lessening the cost to the State of procuring water from other sources.” Apparently those Commissioners were not aware of the highly mineralized water and abundant hydrogen sulfide that the well produced, the reported plugging of the well up to 471 feet, the obstruction in the wellbore which prevented previous deepening of the well, and the probable caving of the well caused by the 1882 dynamiting of the burnt remains of the 1852–1853 Capitol building.

Information for the 1859 Capitol water well is found in: Shumard (1860), Wood (1861), Texas Almanac (1865–1867), Brown (circa 1875), Myers (1881–1882), Lee and Norton (1883), Lee and McLaurin (1886), Hill and Vaughan (1898), Dibrell (1900), Hill (1901), George and others (1941), White and Livingston (1941), Arnow (1957), Connors and others (1970), Brune and Duffin (1983), Hamblett (1986), Zapalac (1994), Broussard Group/EDAW (1995), and TWDB (1997).

The 1874 Capitol Water Well

In 1874, because of the lack of water for irrigation of the Capitol grounds, the Superintendent of Public Buildings and Grounds reported that “…much labor was required in supplying the trees and plants with water; and to keep the grounds in good order generally, labor had to be employed, and paid for from private sources. The digging of a well also incurred a considerable expense; but this enterprise was deemed essential in order to test the practicability of sinking wells within the Capitol Grounds with success, as the scarcity of water is the most serious obstacle to the success of beautifying these grounds. I am able to report that at a depth of forty-five feet (blasted out of solid rock), a supply of water was found, which already has proven of great value and convenience”

The location of the well, the diameter of the wellbore, and the diameter and amount of casing (if any) placed in this well are unknown. However, it is apparent (considering the depth of 45 feet and the geologic units that occur beneath the Capitol grounds) that this well provided some unknown amount and unknown quality of ground-water from the Austin Chalk.

The 1874 well might have been located at a low place reported to be on the grounds southwest of the Capitol building. This location was reported to have a “wet weather spring” which could have been the remnant of the 1874 dug well (location 2A on Figure 1).

Also, in the mid-1930s, a subsurface vault for the State Treasury was completed just south of the southwest edge of the current Capitol building basement. A “natural spring” was reported to be under this vault that “makes the internal atmosphere (of the vault) dank.” This “spring” might be the remnant of the 1874 dug well (location 2B on Figure 1).

There have been several reports of another low place which had a pond and was located on the west edge of the Capitol grounds. This other low place, which was eventually filled-in, may have been the remnant of the 1874 dug well (See location 2C on Figure 1).

Information related to the 1874 Capitol Water Well may be found in Voigt (1874), Dibrell (1900), Jones (1980), Hamblett (1986), and Broussard Group/EDAW (1995).

The 1889 and 1890 Capitol Water Wells

Planning, Drilling, Construction, Geology, and Cost of the Wells

In the late 1880s, the Legislature apparently appropriated $10,000 to obtain a water supply for the new Capitol building (completed in 1888) and for watering the Capitol grounds. In their 1890 report, the Board for Improving the Capitol Grounds reported that options for developing an "adequate water supply" had been considered. The Board, which included Governor L.S. Ross, Attorney General J.S. Hogg, and W.M. Hardeman, Superintendent of Public Buildings and Grounds, decided that the least expensive option was to drill a deep artesian well which was expected to provide a sustained, natural flow of good quality water from the deep, Trinity water-bearing sands.

As part of the selected option, the Board had the State of Texas purchase a drilling "outfit" (rig, related equipment, and supplies) and hire a drilling crew. This was done rather than have a commercial drilling contractor drill and complete a well at what apparently was estimated to be a much higher total cost. The drilling "outfit" purchased apparently was the very first drilling rig and related equipment used by an agency of the State of Texas. Mr. Hugh McGillvray and/or the Pierce Artesian Well Company may have been the driller hired to operate the new State rig to complete the Capitol well. Mr. McGillvray was definitely reported as the driller who operated the same State drilling rig when it was used in 1895 to drill the deep artesian well at the North Austin State Hospital.

From the fall of 1889 to March 1890, two wells were drilled about seven feet apart at a location southeast of the south entrance to the Capitol building (locations 3 and 4 on Figure 1). The first well (the 1889 Capitol Water Well, location 3 on Figure 1) was drilled to 1,023 feet which was the depth where some part of the drilling tools became lodged in the borehole. During the drilling of the 8-inch diameter borehole at the 370 to 374-foot level, a "water-bearing sand" was encountered in the Edwards Limestone which had water "strongly impregnated with sulphuretted hydrogen (hydrogen sulfide gas), and had a salty taste." In December 1889, the lodged drilling tools could not be removed. An unknown amount of 6-inch diameter, metal casing was set in the wellbore. However, since the well was uncapped and used later in 1903–1904 (See discussion below), the 6-inch diameter casing may have been set to about 240 to 250 feet to keep the Del Rio Clay from. heaving and filling the borehole.

In January 1890, the drilling rig was moved about 7 feet southeast of the 1889 Well, and the drilling of a second borehole was started. On February 6, 1890, the 1,023-feet depth (total depth of the nearby 1889 Well) was reached in the second well. Drilling in the second well encountered the saline, "sulphur water" in the Edwards Limestone from 370 to 502 feet, which essentially was the same level such water was encountered in the nearby 1889 Well. Soon after the “sand” from 1,427 to 1,437 feet was penetrated by the drill bit, a “solid stream” of water began to flow out of the wellbore at the surface. On March 8, 1890, the second well (the 1890 Capitol Water Well 58-43-702) was completed at a total depth of 1,554 feet and had a natural flow at the surface of 60 gallons per minute from the Hensell Sand and Cow Creek Limestone (“first Trinity water-bearing sand”) encountered from 1,427 to 1,505 feet. The elevation of the land surface at the site of the 1890 Well is about 543 feet.

The saline, “smelly sulphur water” found in the Edwards Limestone was prevented from entering the 1890 Capitol Water Well by setting a string of 6-inch diameter metal casing in the 8-inch diameter borehole from the surface to a depth of about 525 feet. The well apparently was completed open hole from the bottom of the 6-inch casing at 525 feet to the total depth of 1,554 feet (Figure 2).

The first “modern” chemical analyses of the water from the 1890 Well was made in 1905 and resulted in total dissolved solids of about 1,460 milligrams per liter. The results of the 1905 analyses is a reliable indication that initially the saline Edwards water was successfully prevented from entering the well by the setting of the 6-inch metal casing to 525 feet. As previously stated, groundwater produced from the Edwards aquifer wells near the Capitol have total dissolved solids ranging from about 3,500 to 6,200 milligrams per liter. The 1905 analysis also indicates that the water produced by the 1890 Well is characteristic of the Trinity aquifer, represented in the wellbore by the water-bearing units of the Hensell Sand and Cow Creek Limestone, which are members of the Travis Peak Formation.

The geologic units encountered by the 1890 Capitol Water Well to the total depth of 1,554 feet are as follows: Capitol Terrace (alluvial) deposits from surface to 7 feet; Austin Chalk from 7 to 106 feet; Eagle Ford Shale from 106 to 148 feet; Buda Limestone from 148 to 180 feet; Del Rio Clay from 180 to 239 feet; Georgetown and Kiamichi Formations and Edwards Limestone from 239 to 510 feet; Walnut and Glen Rose Formations from 510 to 1,427 feet; Hensell Sand from 1,427 to 1,460 feet; Cow Creek Limestone from 1,460 to 1,507 feet; and Hammett Shale from 1,507 to 1,554 feet. The Hensell Sand, Cow Creek Limestone, and Hammett Shale are members of the Travis Peak Formation of the Trinity Group, Comanche Series, Cretaceous System. All of these geologic units and their water-bearing properties are described in Brune and Duffin (1983, Table 1, p. 14). After the 1889 and 1890 Capitol Water Wells were completed, the total cost of completing the wells was $9,702.61, which included cost of the drilling equipment, pipe, engineers’ salary, crew salaries, freight charges, telegraph charges, and coal for steam power to run the drilling “outfit”. Since the drilling rig (which cost about $4,722.76) was still on hand and of use, the net cost for the well was estimated to be about $4,979.85. The rig was used later in 1895 to complete the artesian well (State Well No. YD 58-43-401) at the North Austin State Hospital to a total depth of 1,975 feet.

History of use and nonuse of the 1889 and 1890 Capitol Wells

The slightly saline water from the 1890 Capitol Well was used in the 1890s to supply a boiler that provided steam for heating the Capitol building and for the operation of a generator for lighting the Capitol building and running hydraulic elevators. The well water was used to irrigate the grass, shrubbery, and trees on the Capitol grounds. The water was reported to be good for drinking for medicinal purposes and was reported to be “popular with invalids”. In April 1900

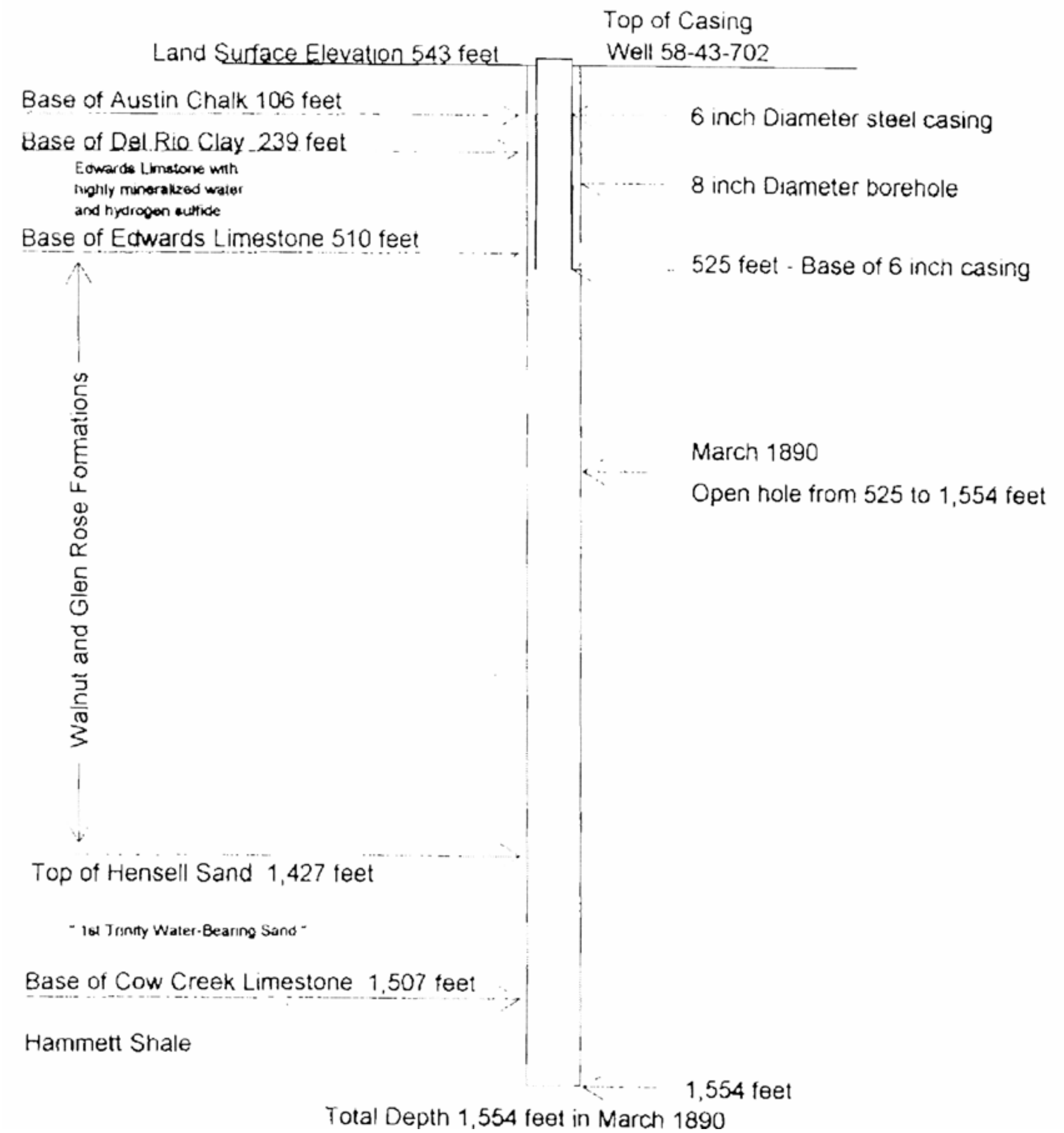


Figure 2. Diagrammatic cross section of the 1890 Capitol Water Well 58-43-702, as approximately completed in March 1890. The well flowed approximately 60 gallons per minute of water with total dissolved solids of about 1,460 milligrams per liter.

the Austin Dam on the Colorado River broke which caused considerable flooding of the city and disruption of the city's electric power and water systems. During this catastrophe, water from the well was used for drinking and other purposes by many Austinites, including the high school and the Capitol complex.

During the 1890s, the water from the 1890 Well was determined to be injurious to plant growth. The well was probably not used for any of its intended uses by 1900, because there were documentations that another, deeper artesian well should be drilled or that the Capitol building and grounds be supplied water by the City of Austin water system. Also in the early 1900s, there was an earnest judgment by the Superintendent of Public Buildings and Grounds "…for the State to build a pumping station on the banks of the Colorado river, lay a large main and supply the capitol yard with water for sprinkling purposes…" Eventually, in about 1914, an adequate network of water distribution facilities were installed, and the Capitol building and grounds were provided a reliable supply of better quality water from the city water system, which obtained water from the Colorado River.

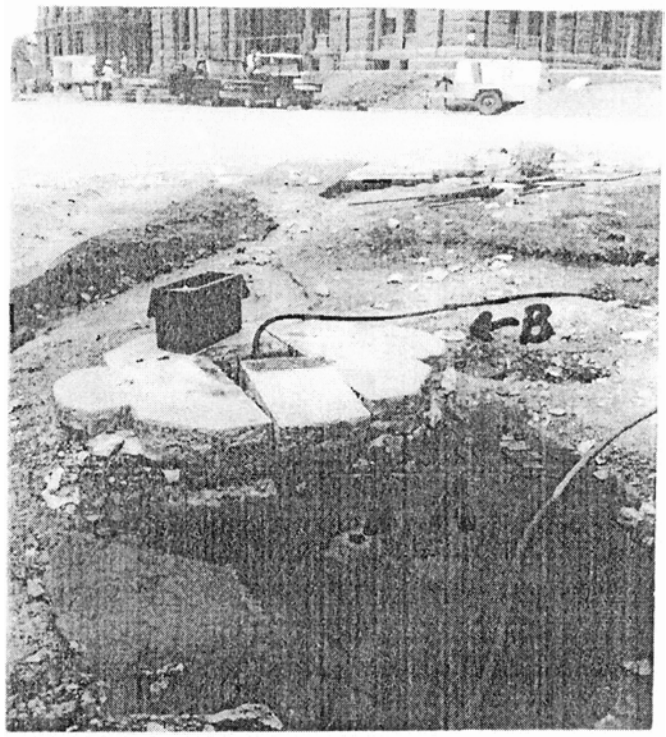
In 1903–1904, the wellhead of the 1889 Well (location 3 on Figure 1) was uncovered while installing sidewalks. The Superintendent of Public Buildings and Grounds uncapped the well and connected it to an elaborate, lighted drinking fountain which was placed west of the great walk and southwest of the south entrance to the Capitol building (location PW on Figure 1). Being Edwards water, the flow from the faucet on the fountain was cool, highly mineralized, and smelly from hydrogen sulfide. The water was reported good for medicinal purposes. In about 1907, the 1889 Well was no longer used for any purposes. In May 1996 the wellhead of the 1889 Well was again uncovered, and was found to be located about seven feet northwest of the uncovered and opened wellhead of the 1890 Well (Figures 3 through 7).

Also, in 1903–1904, the 1890 Well (location 4 on Figure 1) was refurbished with new plumbing and was connected to a new elaborate, lighted, cast iron drinking fountain which was placed at a site immediately adjacent to the wellhead. The well supplied the new fountain with warm water that had a temperature of about 93 degrees Fahrenheit, was slightly mineralized, but did not have the "rotten egg" smell associated with hydrogen sulfide.

In 1904, the 1890 Well was connected to and the water used by two ornamental fountains which had water ponds that supported goldfish (OF and GP on Figure 1). Also in the early 1900s, the 1890 Well was connected to and supplied artesian water to a grotto and lagoon which supported tropical plants in a low-lying area of the southeast Capitol grounds (just north of G and LP on Figure 1).

In the mid-1920s, the cast iron drinking fountain at the 1890 Capitol Water Well (location 4 on Figure 1) was removed due to corrosion and replaced with a granite drinking fountain. The 1890 (Trinity) Well was connected to a faucet(s) on this new granite fountain and was used by the public as a "drinking water" supply. It may be at this time that the 1889 (Edwards) Well was also connected to a faucet(s) on this new granite fountain and also used as a "drinking water" supply. However, in about May 1996 when the granite fountain was removed for restoration, there were not any pipe or pipes evident that may have been used to connect the 1889 (Edwards) Well to the nearby granite fountain. At that time there was only a system of pipes which previously were used to connect the 1890 (Trinity) Well to the granite fountain. This information is hearsay and is not based on any written documentation.

In 1978, the water from the 1890 (Trinity) Well was chemically analyzed by the Texas Department of Health (TDH). The analyses helped determine that the 1890 Well water had "four times the fluoride content allowed by the TDH for a community public water supply" and that this fluoride level may cause mottling of teeth in children 14 years of age and younger who use this water regularly." The analyses also indicated that the water was high in sulfate content and dissolved solids. The high sulfate content may cause a laxative effect if the water was consumed by humans. However, the well was determined by the TDH to be a "non-community public water supply". The results of the 1978 chemical analyses were posted at the well/fountain site, and the water from the well was allowed to be used by visitors to the granite drinking fountain.



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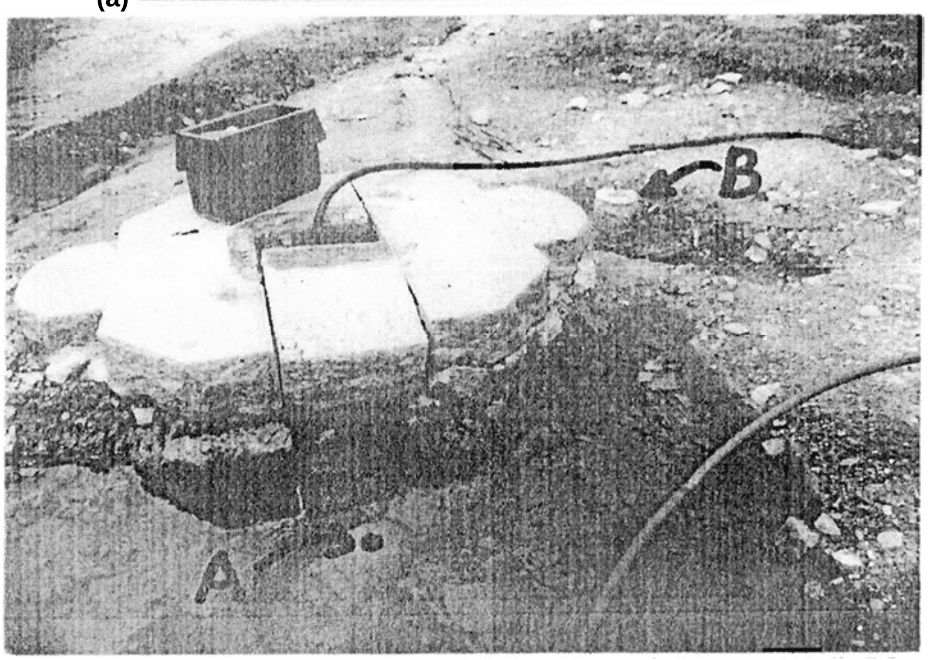


(b)

Figure 3. **Photographs (looking northwest) taken on May 27, 1996, showing the wellheads of the 1890 and 1889 Capitol. The wellheads were uncovered by the State Preservation Board's activities to restore the southeast Capitol grounds. (a) "A" is the location of the 1890 Capitol Water Well 58-43-702. "B" is the location of the 1889 Capitol Water Well. Notice the pool of water which had accumulated from the artesian flow through the opening in the 1890 Well (A). The flow was estimated to be 5 to 10 gallons per minute. Notice that the 1889 Well (B) is capped (sealed) with a plug having a 3/4-inch nipple. Notice the granite base which was used to support the granite drinking fountain installed in 1928. (b) "A" is location of the 1890 Capitol Water Well 58-43-702. "B" is the location of the 1889 Capitol Water Well.**

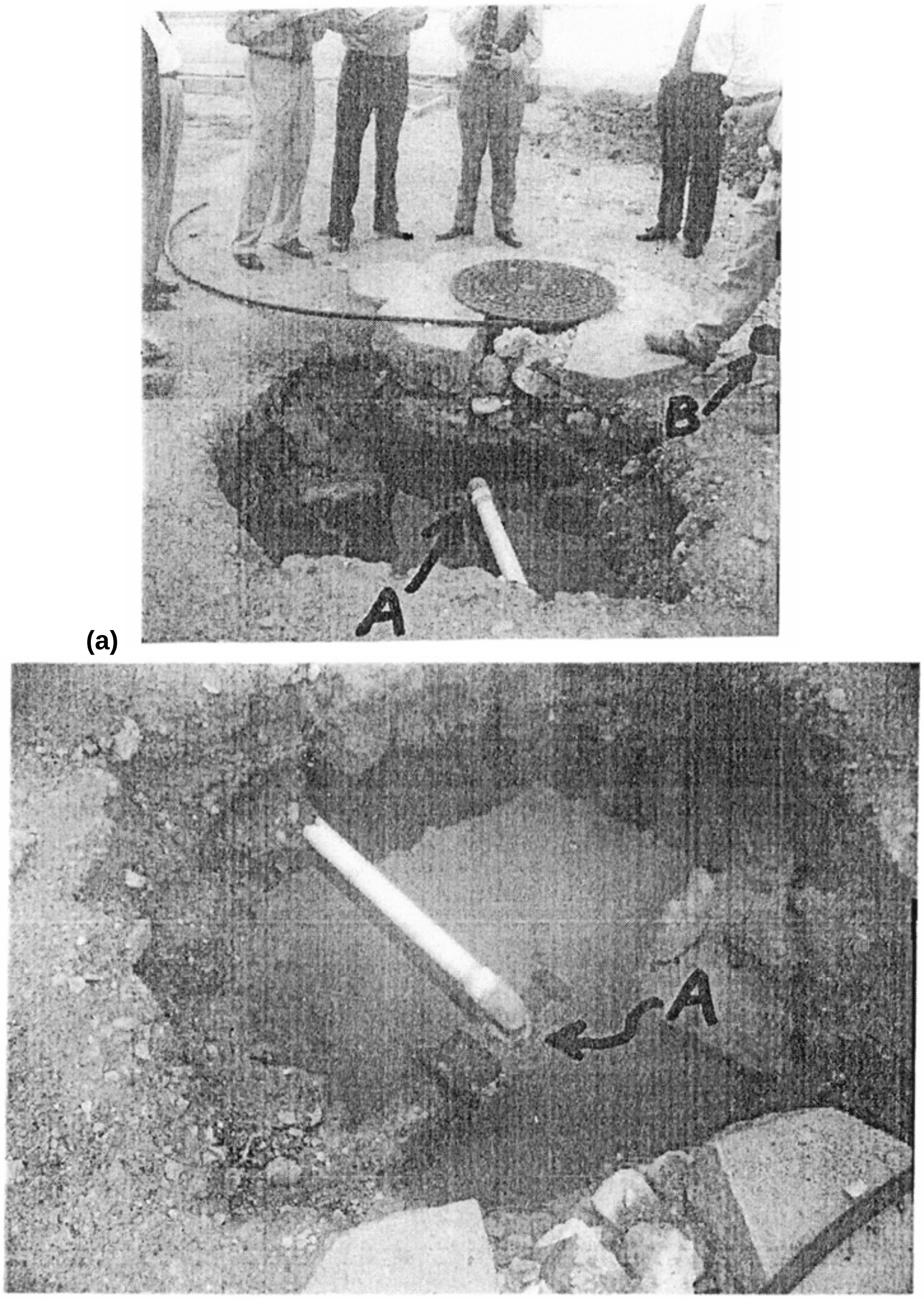
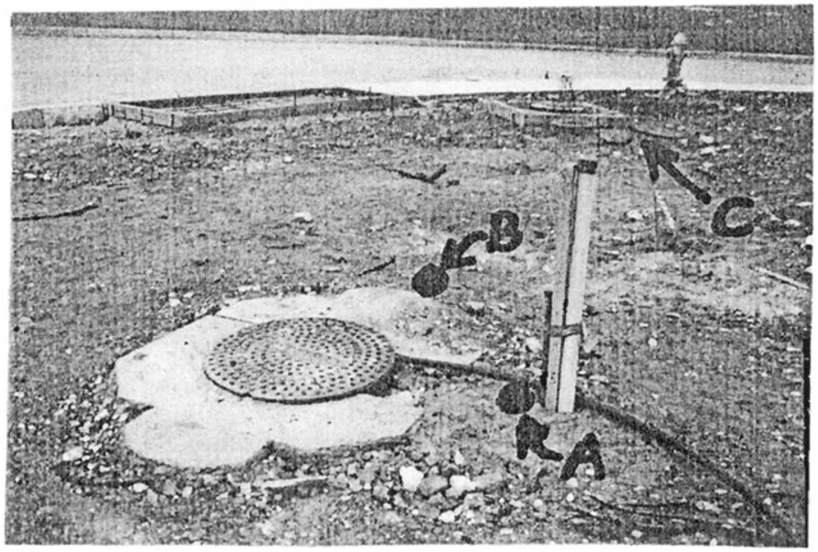


Figure 4. **Photographs Taken on September 23, 1996, Showing of the 1890 Capitol Water Well 58-43-702 and the Location of the 1 889 Capitol Water Well (Buried). (a) Looking west. "A" is the 1890 Capital Water Well 58-43-702 which has been capped and has a 20inch diameter PVC pipe which is discharging flow to a sanitary sewer to the east-northeast. The leaking wellhead has caused a pool of water around the well. Notice the granite base used to support the granite drinking fountain installed in 1928. The water outlet from the 1890 Well is under the manhole cover in the center of the granite base. Location "B" is the approximate location of the 1889 Well covered with alluvial soil and gravel. (b) "A" is the 1890 Capitol Water Well 58-43-702 which has been capped with flow diverted to a sanitary sewer to the east-northeast. Notice the pool of water caused by a small leak in the capped wellhead.**



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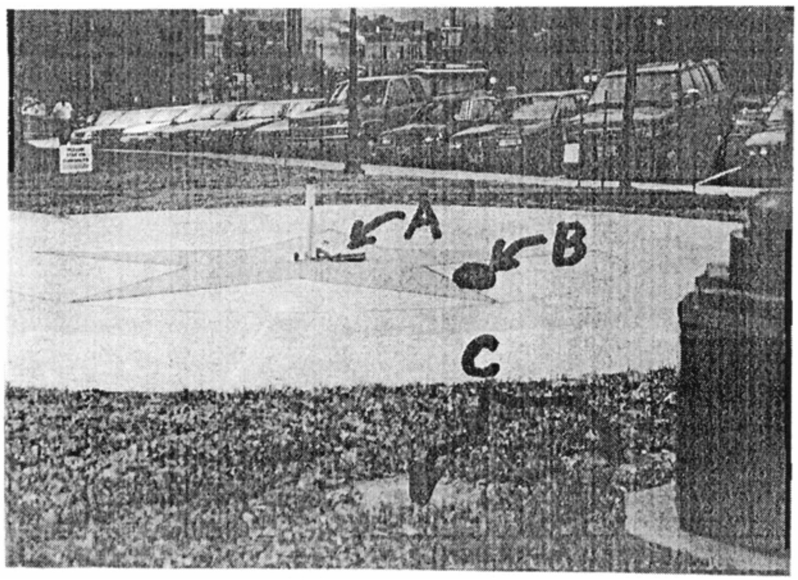
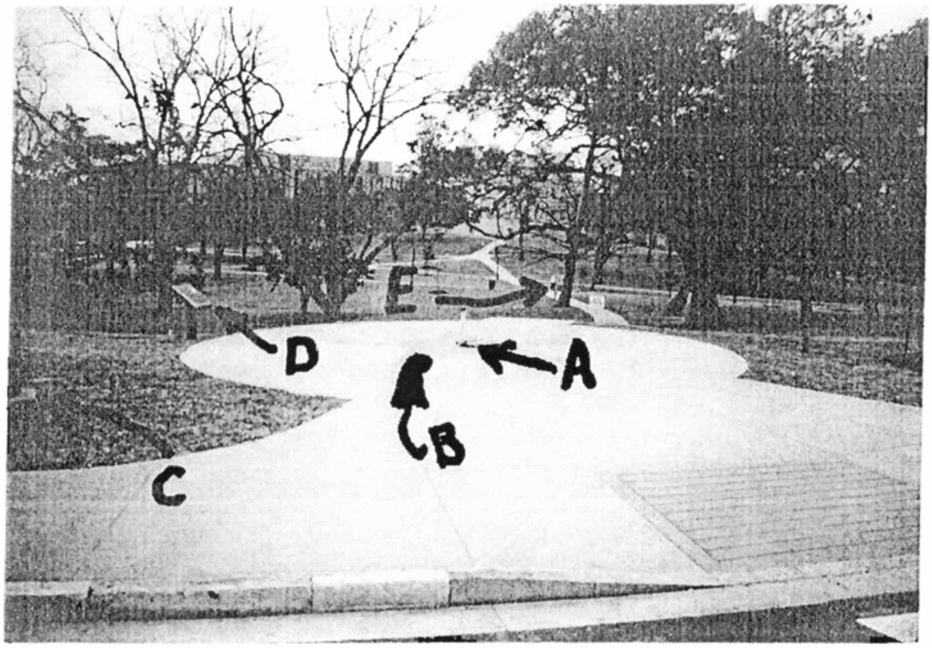


(b)

Figure 5. **Photographs taken on October 29, 1996, and January 27, 1997, of the sites of the 1890 and 1889 Capitol Water Wells. (a) October 29, 1996, photograph with "A" at location of 1890 Well 58-43-702 (pipes are city water and electrical conduits for new fountain and light); "B" at location of 1889 Well; and "C" at manhole covers with water-pressure release outlets for the 1890 Capitol Water Well. (b) January 27, 1997, photograph showing 18-foot diameter concrete base over "A" location of 1890 Well 58-43-702 under folder; and "B" approximate location of the 1889 Well. Location "C" marks the locations of manhole covers with water pressure release outlets for the 1890 Capitol Water Well.**



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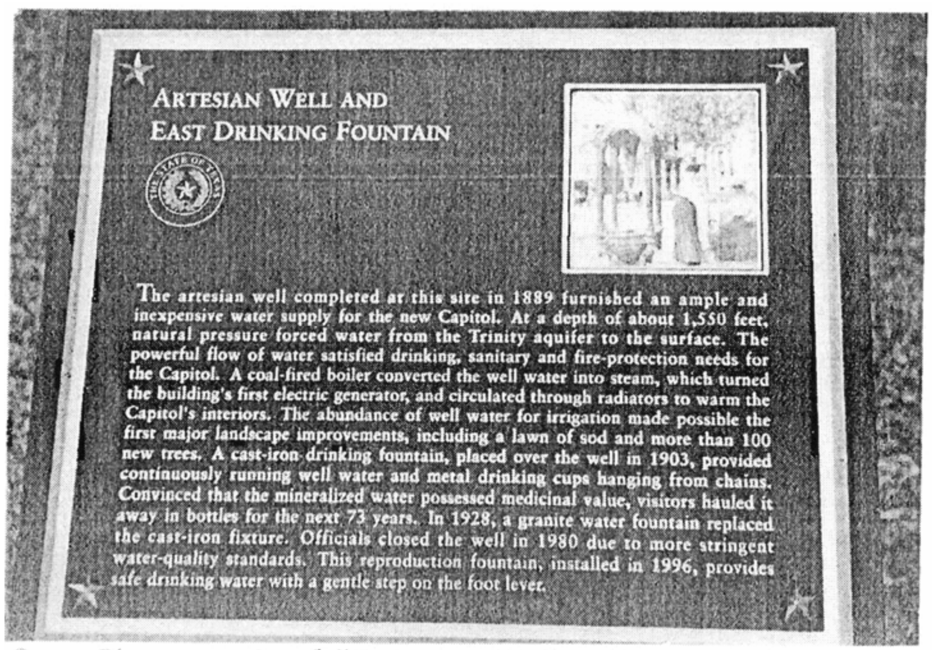
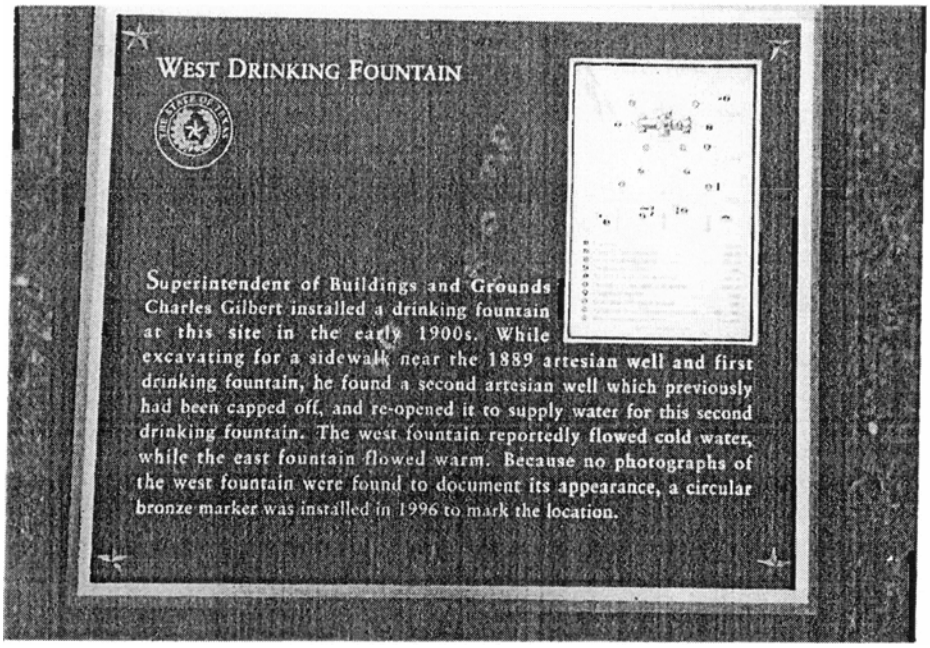


(b)

Figure 6. **Photographs taken on January 27, 1997, of the sites of the 1890 and 1889 capitol water wells and marker-plaques. (a) Photograph showing approximate locations of "A" the 1890 Well 58-43-702, "B" the 1889 Well, "C" the water-pressure release outlets from the 1890 Well 58-43-702, "D" the "Artesian Well and East Drinking Fountain" marker-plaque (See Figure 8-2), and "E" the "Grotto and Lagoon" marker-plaque (See Figure 9-2 and location "C & L P" on Figure 1). (b) Photograph of "Artesian Well and East Drinking Fountain" marker-plaque (See "D" on Figure 8-1).**



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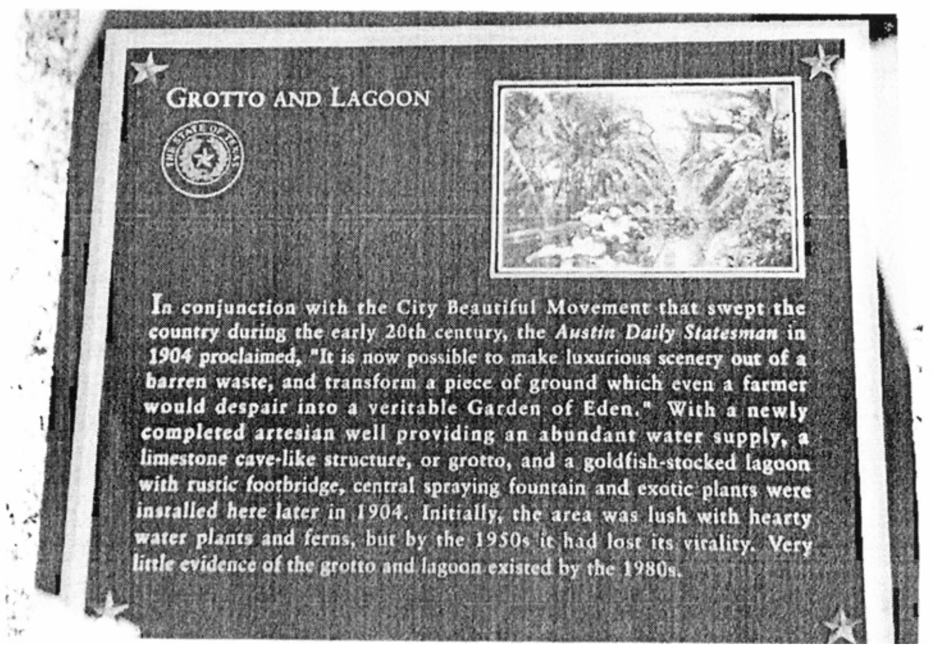

(b)

Figure 7. Photographs taken January 27 and 29, 1997, of "West Drinking Fountain" and "Grotto and Lagoon" marker-plaques. (a) Photograph taken on January 27, 1997, of the "West Drinking Fountain" marker-plaque which is at location "PW" on Figure 1. (b) Photograph taken on January 29, 1997, of the "Grotto Lagoon" marker-plaque which is "E" on Figure 8-1 and is at location P on Figure 1.

In 1980, another chemical analysis was made of the water from the 1890 Capitol Water Well. This analysis also determined that the water from the well had high concentrations of fluoride, sulfate, and total dissolved solids. Finally the well was capped and abandoned and the fountain outlets were closed. These actions were taken because the TDH required that the State agency responsible for the use and maintenance of the fountain/well be required to (1) collect and submit monthly water samples for analyses by the TDH, (2) to install and operate mechanical chlorination facilities to treat the water for drinking purposes, and (3) to post a copy of the chemical analyses of the water periodically collected from the fountain/well. Apparently, the State decided to shut-off the fountain/well, not because of the quality of the water, but because of the high cost of having to meet TDH requirements to have the water properly available for drinking by visitors to the Capitol grounds.

In May 1996, the wellheads of the 1889 and the 1890 Capitol Water Wells were uncovered by the State Preservation Board when the granite drinking fountain was removed for restoration and relocation. The fountain was removed as part of the restoration of the Capitol grounds. After restoration, the granite fountain was reinstalled near the Sam Houston State Office Building northeast of the Capitol. A replica of the cast iron, ornamental drinking fountain originally placed over and connected to the 1890 Well was installed at the site of the capped wells. This replica drinking fountain uses water from the City of Austin water system.

The uncovered 1890 Well was logged with the State logging unit in May 1996. These logs were used to determine and describe the current conditions of the well as shown in Figure 8. During this time of logging the well had a flow of water at the surface of 5 to 10 gallons per minute with a total dissolved solids content of 1,574 milligrams per liter.

The site having the uncovered wells and the foundation of the removed granite fountain (locations 3 and 4 on Figure 1) was documented in a series of photographs taken from May 1996 to January 1997 (Figures 5 through 9).

Information related to the 1889 and 1890 Capitol Water Wells can be found in Arnow (1957), Bluntzer (1996a, 1996b), Broussard Group/EDAW (1995), Brune and Duffin (1983), Connors and others (1970), Dibrell (1900), George and others (1941), Gilbert (1905, 1906), Green (circa 1988), Hamblett (1986), Hardeman (1892), Harlan (1900, 1902), Hill (1901), Hill and Vaughan (1898), Klemt and others (1976), Lower and others (1996), Phillips (1914), Ross and others (1890), Sellards (1930), TWDB (1996a, 1996b, 1997), Young (1990), and Zapalac (1994).

The 1989 capitol water-level observation wells

In June 1989, four shallow wells were completed around the Capitol building (locations OWB-1 through OWB-4 on Figure 1). These wells were drilled and cored to depths ranging from 20 to 23 feet to provide information on the subsurface geologic and hydrologic conditions at the Capitol. This information was used in the planning for a possible dewatering program during the construction of the Capitol building extension. The four wells were permanently completed with 4-inch diameter steel casing and used as water-level observation wells during the summer of 1989. Additional water-level measurements may have been taken during the construction of the Capitol extension. The wells currently exist and probably are available for future use as observation wells. Each well has a keyed locked cap which apparently can be unlocked so that

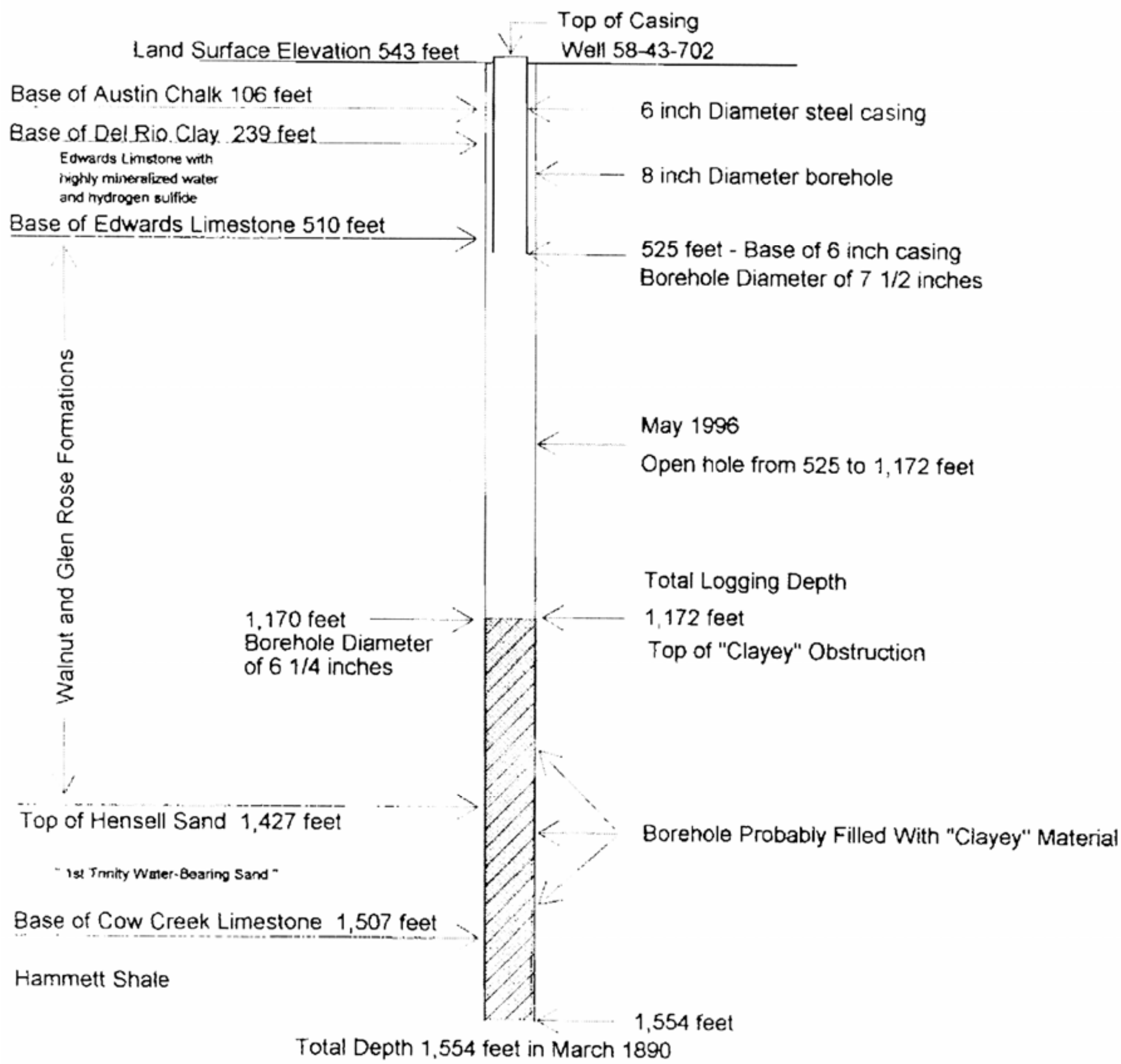

Figure 8. Diagrammatic cross-section of the 1890 Capitol Water Well 58-43-702, as determined from geophysical logs obtained in May 1996. The well flowed approximately 5 gallons per minute with total dissolved solids about 1,574 milligrams per liter.

the well can be used for future monitoring of water levels and perhaps water quality of the shallow water-bearing unit of the Austin Chalk beneath and adjacent to the Capitol building.

Proposed restoration of the 1890 Capitol Water Well

During the period from March 1890 to October 1980, water from the 1890 Capitol Water Well was used (1) as a drinking water supply for the Capitol building, (2) as a water supply for a boiler to provide steam to power an electric generator (dynamo) for lighting the Capitol building and grounds, and for radiators to heat the Capitol building, (3) as a water supply for the operation of hydraulic elevators in the Capitol building, (4) as a water supply for irrigating the grass, shrubbery, and trees on the Capitol grounds, and (5) as a water supply for drinking and ornamental fountains and a grotto and lagoon on the Capitol grounds. Groundwater data collected from the 1890 Capitol Water Well has been used in State and Federal ground-water investigations and reports to help characterize the occurrence, availability, and quality of water from the Trinity aquifer in central Texas.

The master plan for the restoration of the Capitol grounds indicates "…that the specific restoration period f or the grounds is 1888–1915 and that fundamental improvements must occur to provide a safe, functional, and appropriate setting for the Capitol…" As indicated in the previous sections addressing the 1890 Capitol Water Well and as summarized in the previous paragraph, the 1890 Capitol Water Well had a very meaningful and significant historical period of use within the 1888–1915 restoration period indicated in the master plan. Under these conditions, it is justifiable to meet the challenge and make a serious effort to restore and reuse the 1890 Capitol Well.

Therefore, the author recommends that the 1890 Capitol Water Well be restored (See Figure 9) using a well reconstruction plan and proper well rehabilitation methods and procedures to assure that the well will provide a safe and reliable supply of water from the Trinity aquifer to use for an ornamental (non-drinking) water-spraying fountain on the Capitol grounds. Also, since historical water-level and water-quality data from the well have been used to help characterize the Trinity aquifer in State and Federal ground-water investigations, the well, when restored, should be used by the appropriate State water agency as a Trinity aquifer water-level and water-quality monitoring well.

Other investigators and observers have recommended that the 1890 Capitol Well should not be restored, because (1) the well produces "smelly water" impregnated with hydrogen sulfide, (2) the flow and artesian head have deteriorated to such an extent that the well has been rendered useless for operation of a fountain and for use as a monitor well, and (3) the well very likely has unremoveable obstructions that make it impossible to restore the wellbore to the base of the water-bearing units of the Trinity aquifer. Also, doubt has been indicated that even if the well were successfully completed in the Trinity aquifer, it probably would not be an effective and useful State monitor well, because its location and subsurface position places it out of the area of concentrated development of ground water from the Trinity aquifer.

The detection of hydrogen sulfide gas from the wellhead when it was first uncovered and opened in May 1996 is accurate. Also, the deterioration of flow from the well since it was first completed, and very recently since the well was uncovered and opened, is accurate. When the wellbore was logged in May 1996, a "clayey" obstruction was encountered at 1,172 feet which made it impossible to log the well deeper. The explanation for these conditions is undoubtedly due to the deterioration of the 6-inch diameter metal casing which was installed in the well over 100 years ago.

The caliper log run in the wellbore by the Texas Water Development Board in May 1996 indicates that there are separations in the old metal casing at depths opposite the Austin Chalk, the Eagle Ford Shale, the Del Rio Clay, and the Edwards aquifer. These separations in the old casing have allowed the hydrogen sulfide gas in the Edwards aquifer to seep into the wellbore

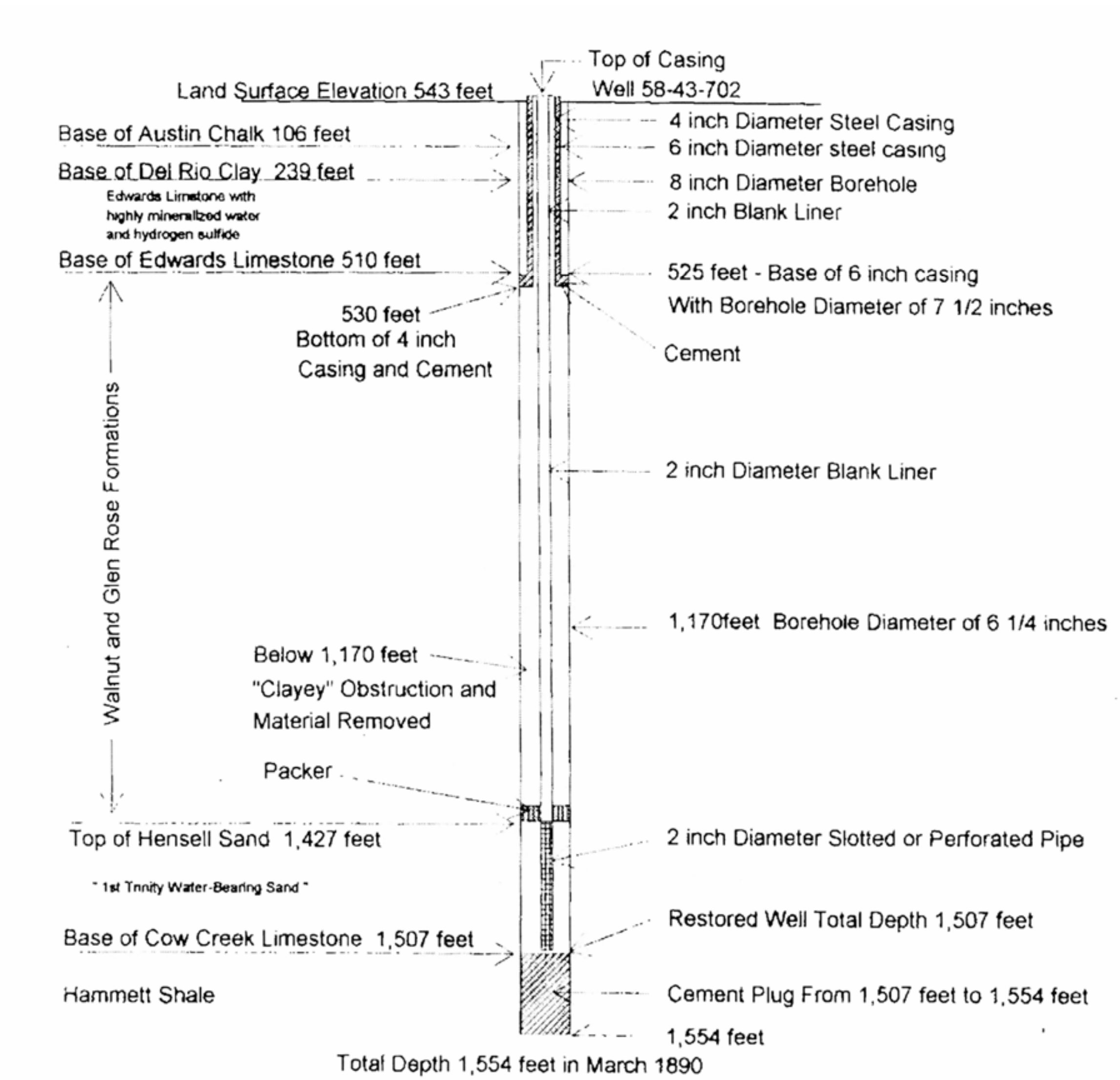

Figure 4. **Diagrammatic cross-section of the 1890 Capitol Water Well 58-43-702, after restoration. Flow expected of up to 60 gallons per minute with total dissolved solids about 1,500 milligrams per liter.**

and accumulate at the wellhead while the well is capped. Consequently, when the well was opened in May 1996, a slug of hydrogen sulfide gas was released and detected. When the author and others visited the well several times while it was open, no hydrogen sulfide gas was evident.

Since the artesian head of the Trinity aquifer is higher than the artesian head of the Edwards aquifer, part of the flow up the wellbore from the Trinity aquifer is escaping through the separations in the casing and entering the saline water-bearing units of the Edwards aquifer. This is one of the conditions causing the deterioration of flow at the wellhead of the 1890 Capitol Well.

The other cause for the deterioration of flow at the wellhead is the presence of the "clayey" obstruction found at a depth of 1,172 feet. Additional obstructions are likely to exist below 1,172 feet. The shallowest obstructions below 1,172 feet are probably caused by the Eagle Ford Shale and Del Rio Clay heaving through the separations in the old casing and falling down the wellbore. Also, the wellbore below the 1,172-foot level probably has other deeper "clayey" obstructions caused by the Hammett Shale which is known to heave up the borehole of wells with open hole completion. This condition of an obstructed borehole is shown on Figure 3. These 'clayey" obstructions have not prevented the flow of water from the Trinity aquifer at the surface and can be readily removed during the restoration of the well by the conventional rotary drilling method using the proper drilling fluid.

When the 1890 Capitol Well is restored as illustrated in Figure 9, it will make a very meaningful Trinity aquifer water-level and water-quality monitor well. The Trinity aquifer is used extensively as a domestic water supply in the rural areas on the upthrown side of the Balcones Fault Zone in northwestern Travis, Hays, and Williamson counties. The 1890 Capitol Well is located in the Balcones Fault Zone on the downthrown side of the main Mount Bonnel Fault. It is very possible that a very significant thickness of the Glen Rose Formation does not occur in the well due to a fault through the wellbore. Due to this fault and related fracturing which has been observed in the subsurface of the Capitol area, the Trinity aquifer and the Edwards aquifer in the area of the well as well as the Balcones Fault Zone in Travis and Williamson counties are probably hydrologically connected. Therefore, it is important that the restored 1890 Capitol well be used as a monitor well to detect effects of the Trinity aquifer development to the northwest and how the Balcones Fault Zone acts as a hydrologic boundary between relatively good quality Trinity groundwater to the northwest and poorer quality Trinity groundwater in the fault zone. Also the well should be used to monitor the interaction between the bad water in the Edwards aquifer and the relatively good water in the Trinity aquifer.

A diagrammatic presentation of the proposed reconstruction of the 1890 Well is provided in Figure 9. To achieve well restoration as diagramed in Figure 9, the following general methods and procedures are recommended.

- Preparation of the well site (See location 4 in Figure 1) to expose and open the wellhead (See 'A" in Figures 5 through 8), so the well can be re-logged with electric, gamma ray, and caliper logging surveys.
- Further preparation of the well site for the operation of a drilling rig over the wellhead. The drilling rig should be equipped to use the conventional mud rotary method of drilling and well workover.
- The well should be entered with appropriate rotary tools and cautiously clean-out to a depth below the base of the old metal casing. This procedure should be immediately followed by setting and cementing a string of 4-inch diameter, steel casing from surface to a depth of about 530 feet (at a point below the base of the old 6-inch diameter casing at about 525 feet). Installation and pressure cementing of the 4-inch casing will help assure that the Eagle Ford Shale and the Del Rio Clay will no longer enter the wellbore, and the wellbore can be cleaned-out further without the old casing collapsing and obstructing the wellbore. Also, the drilling operations will not lose circulation through the old separated 6-inch casing if the 4-inch casing is properly set and cemented.
- After the cementing of the 4-inch casing has set-up, enter the well with appropriate rotary drilling tools and clean-out the wellbore to its original total depth of 1,554 feet.

- Re-log the well to its total depth. A borehole deviation survey should be run in the wellbore and then followed by running appropriately scaled caliper, electric, and gamma ray logs to total depth.
- Using the hydrogeologic and borehole information provided by the logging, set a cement plug opposite the Hammett Shale estimated to occur in the well below a depth of 1,505 feet. This will permanently prevent the bentonitic clays of the Hammett Shale from heaving up the wellbore and affecting the productivity of the water-bearing units of the Hensell Sand and Cow Creek Limestone estimated to occur from 1,427 to 1,505 feet.
- Once the cement plug below 1,505 feet has set-up, install and set into the wellbore to the top of the cement plug, a 2-inch diameter perforated steel liner attached to the end of a sufficient length of blank 2-inch diameter steel liner. The top of the blank liner should be at the surface and the perforated liner should be positioned in the wellbore opposite the water-bearing units between 1,427 and 1,505 feet. Consequently, the total length of the blank and perforated liner would be about 1,505 feet. The top of the perforated, 2-inch diameter steel liner should have a downhole packer (sealer) of sufficient size to prevent ground water in the annulus above the perforated liner from entering the perforated interval opposite the Trinity water-bearing units from 1,427 to 1,505 feet.
- Once the well has been reconstructed as described above, the well should be developed to obtain a maximum flow of water at the surface. Such developed flow should approach about 60 gallons per minute (flow of the well observed in March 1890).
- A representative sample of water from the well should be collected and comprehensive chemical and radioactive analyses should be made.
- The well should then be equipped with appropriate facilities for connection to an ornamental water-spraying fountain and also have appropriate outlets for use of the well as a State monitor well for measuring the water level (head) and collecting water samples for future water-quality analyses.
- The well site should then be returned to the condition of the site before restoration of the well was started.

Acknowledgments

For help, guidance, coordination of well restoration efforts, and technical and moral support in the preparation of this report, the author would like to specially thank Ernie Baker, Peter Bluntzer, Philip Cheatham, Rick Crawford, Doug Crim, Joe Dillard, Ron Harden, Ridge Kaiser, Bill Klemt, Ann Lower, Ned Meister, Charlie Rogers, Marion Striegler, Joe Vickers, and Doug Young. Very special thanks and gratitude is extended to Representative Debra Danburg for needed leadership in getting the State to agree to cap the well for future restoration. Also, special thanks is extended to the Texas Ground Water Association, Ground Water Scientist Division and the Texas Alliance of Groundwater Districts for their written support. For her patients, moral support and at times "devils advocate" role, the author specially thanks his wife, Josephine.

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The drinking water fountain that is located over the 1890 Capital water well (photo by Robert E. Mace)

note

Historical groundwater use in Texas

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Background

Groundwater in Texas has been a source of water supply ever since the earliest inhabitants of the region camped and settled near springs. In otherwise arid parts of the state, springs provided an essential source of water. Later on, hand-drilled wells and windmills allowed early ranchers and farmers to venture from springs and streams. Since the 1940s, extensive development and use of groundwater supplies has been essential to the economic expansion, population growth, and cultural changes that the state has experienced.

Considering the importance of groundwater to the history of Texas, a general overview of total groundwater use in the state over the last 70 years is in order.

Sources of water use estimates

The Texas Water Development Board is the primary source of information on groundwater use throughout the state. In addition, the U.S. Geological Survey provides estimates of water use for all states in the United States.

The Texas Water Development Board has been collecting information on water use in Texas through its annual Water User Survey since 1937. The survey asks all Texas water suppliers about the quantity of water they supplied for themselves and for other users during the past year and the source of that water. These surveys are used to estimate the total quantity of water withdrawn from each stream and aquifer in the state for municipal and industrial users. Other methods are used to estimate agricultural use.

The U.S. Geological Survey has published water use estimates for five-year intervals since 1950. It cooperates with agencies in each state to find the most accurate information for these estimates. In 1978, the U.S. Geological Survey National Water Use Information Program was created to coordinate the work of the U.S. Geological Survey and state and local agencies (Hutson and others, 2004). The U.S. Geological Survey estimates for water use in Texas are based primarily on raw data from the Texas Water Development Board for the year prior to the year for which water use is being estimated (D. Lurry, written communication, 2005).

An overview of changes in groundwater use

Figure 1 shows total groundwater use in Texas as estimated by the Texas Water Development Board and U.S. Geological Survey reports. Economic, technological, climatic, and demographic changes throughout the state have all affected groundwater use trends over the years. However, when looking at these totals, it is important to be aware that the main use of groundwater in the state is for irrigated agriculture and that most irrigation occurs in the High Plains region of north Texas. For this reason, changes in statewide groundwater use over the last 70 years largely reflect changes in pumping for irrigation.

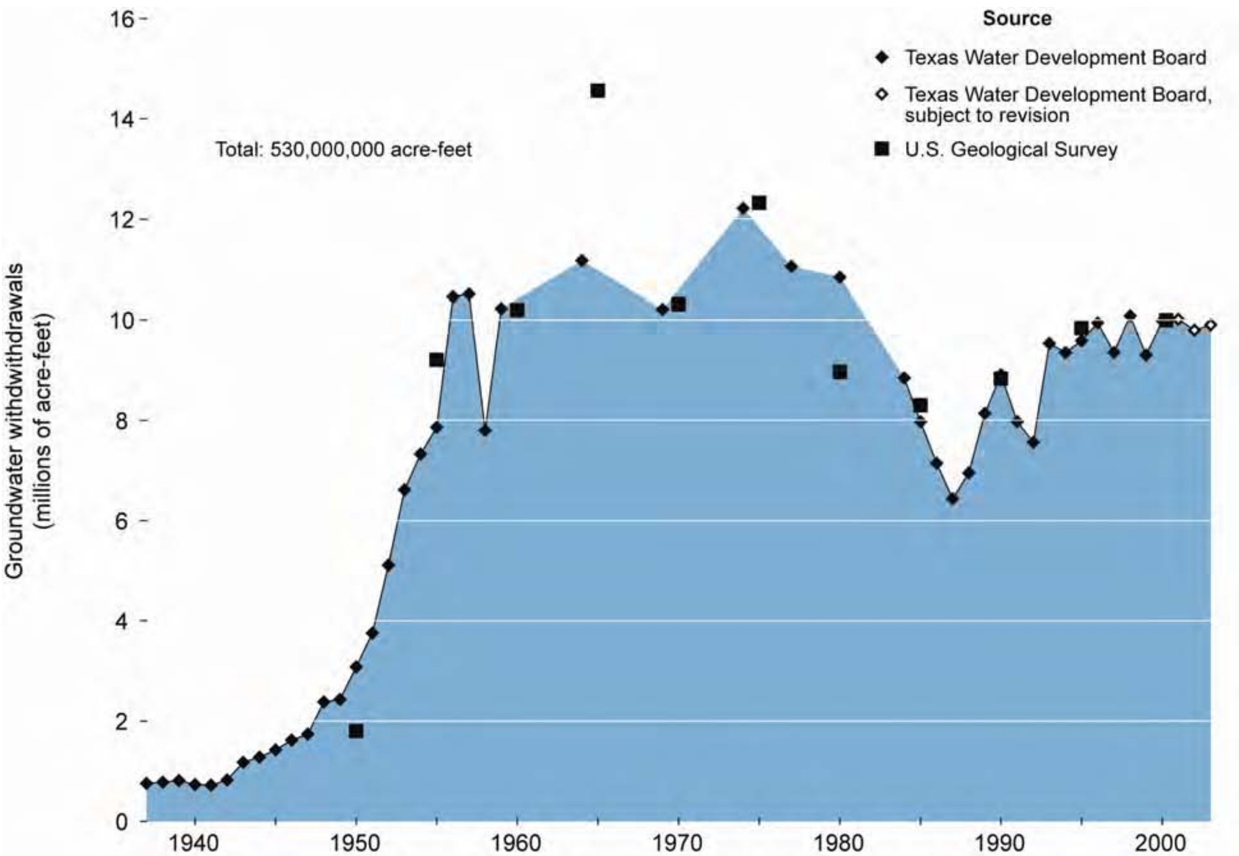

Figure 1. Total annual groundwater use in Texas, 1937–2003.

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note

Historical observations of hydrogeology in Texas— The 1850 report to the U.S. Senate by the Corps of Topographical Engineers

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Introduction

Texas has changed. As European explorers explored, settlers settled, and populations populated (and grew), Texas changed. The landscape changed with the introduction of new fauna and flora, and the hydrology changed with the landscape and with pumping and agriculture. Early explorers and survey teams saw Texas closer to its natural state, before non-Native Americans altered the landscape. Fortunately, many of these explorers and survey teams documented their observations in great detail—observations that are useful for modern studies of water resources.

In 1849, the Corps of Topographical Engineers—a group that was part of the Army but separate from the Corp of Engineers—surveyed part of Texas in search of a suitable road and railway path for commercial and military purposes between central Texas and El Paso. In addition, the California gold rush was on, with the 49ers seeking safe passage through West Texas. Sufficient water for man and beast was critical for traveling through the western part of Texas, west of the 100^{th} meridian, especially on the High Plains. Given that one could travel about 15 to 30 miles a day by horseback, frequent water stops were required. These soldiers and their parties braved rattlesnakes, drought, snow storms, blue northers, and scalpings to explore central and west Texas—and they vividly reported their observations and thoughts about their travels across Texas.

The purpose of this paper is to summarize the observations of a number of surveys across Texas made in 1849 by Lieutenant Colonel J.E. Johnston, Lieutenant W.F. Smith, Lieutenant F.T. Bryan, Lieutenant N.H. Michler, and Captain S.G. French of the Corps of Topographical Engineers. The surveys include a number of informative—and often colorful—observations concerning the landscape, rivers, and springs of Texas. Of particular interest to the hydrogeologist is the description of pre-development conditions of the rivers, springs, and landscape. These descriptions offer clues as to how the hydrologic system may have been before invasive phreatophytes and pumping changed groundwater flow and its interaction with springs, streams, and rivers. This is of interest to conservationists, biologists, historians, hydrologists, and hydrogeologists—including modelers interested in simulating predevelopment conditions of an aquifer.

To compile these observations, I read "Reports of the Secretary of War with Reconnaissances of Routes from San Antonio to El Paso" published on July 24, 1850, and delivered by the Secretary of War to the 31st Congress (Figure 1; Johnston and others, 1950) and noted any description of water, springs, and the landscape. The document also included a map of the paths followed by some of the surveys. Using historic maps by DeCordova (1849) and Grant (1885) allowed me to identify features that had different names in 1850 than at present. Brian Hunt prepared a map with most of the place names mentioned in this paper for reference (Figure 2). Finally, I summarized the hydrogeologic observations of each survey with selected quotes from the reports. To add context to these observations, I have also summarized the history of the Corps of Topographical Engineers and the corps' activities in Texas. Some of the quotations have a number of misspellings or have an archaic spelling of a word. Rather than impeder the flow of the text with numerous "sics," I have left them as is. I tried to ensure that the quotes are as accurate as possible.

The Corps of Topographical Engineers[1]

The Corps of Topographical Engineers[2] started in 1813 as part of the Corps of Engineers in anticipation of war with England. In 1838, the Corps of Topographical Engineers was separated from the Corp of Engineers as its own entity. Projects were divided between the two where the Corps of Topographical Engineers assumed the civil projects of the War Department such as river and harbor improvements. Later the topographical engineers also built lighthouses in various parts of the country and repaired roads in Washington, D.C. As their name suggests, they also collected topographical as well as geographical information of the United States.

Because they were part of the War Department, they also fought in wars, including the Mexican-American War (1846–1848), where two thirds of the engineers served. In 1863, during the Civil War, the commanders of the two corps recommended to Congress that the two corps be combined once again as the Corps of Engineers.

The Corps in Texas

Ten years after declaring independence from Mexico, Texas joined the United States in 1846. Disagreements over Texas' border immediately resulted in the Mexican-American War, the result of which fixed Texas' border at the Rio Grande. After the war ended, the United States was concerned that Mexico might attempt an invasion of Texas. Because the western part of the state, with the exception of the El Paso area, was relatively unsettled and, therefore, relatively unknown, the Corps of Topographical Engineers was ordered to map the area to find the best trails from San Antonio and other parts of Texas to El Paso. Skirmishes with Native Americans were another concern that could be better addressed with a survey of the western part of Texas. Finally, mapping trails across Texas would likely promote additional settlement, another way to tame the land, reduce the potential for a Mexican invasion, and control the Native Americans.

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[1] The information in this section is primarily from Robinson (1931).

[2] Also referred to as the Bureau of Topographical Engineers and Topographical Bureau.

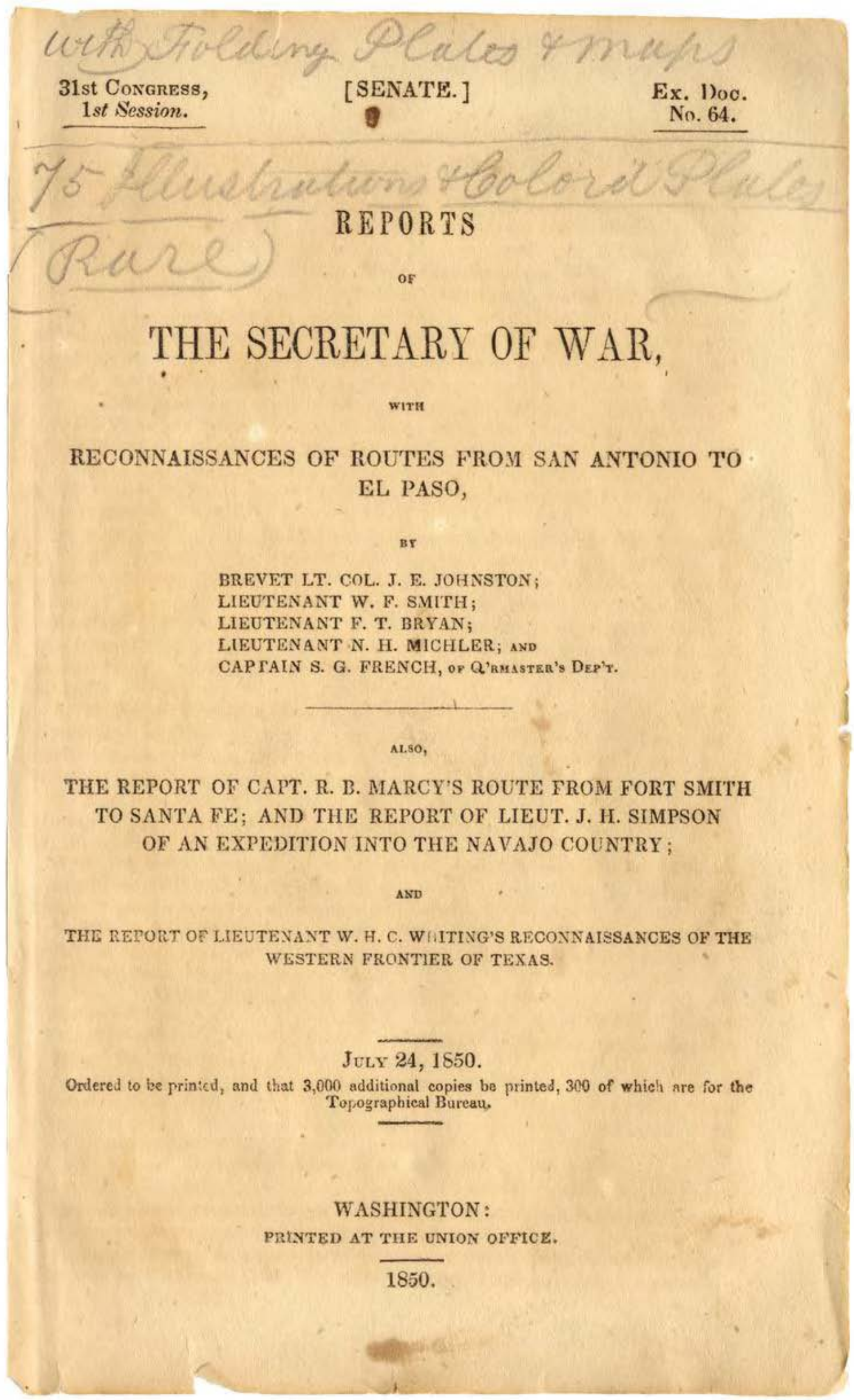

Figure 1. Title page of the report.

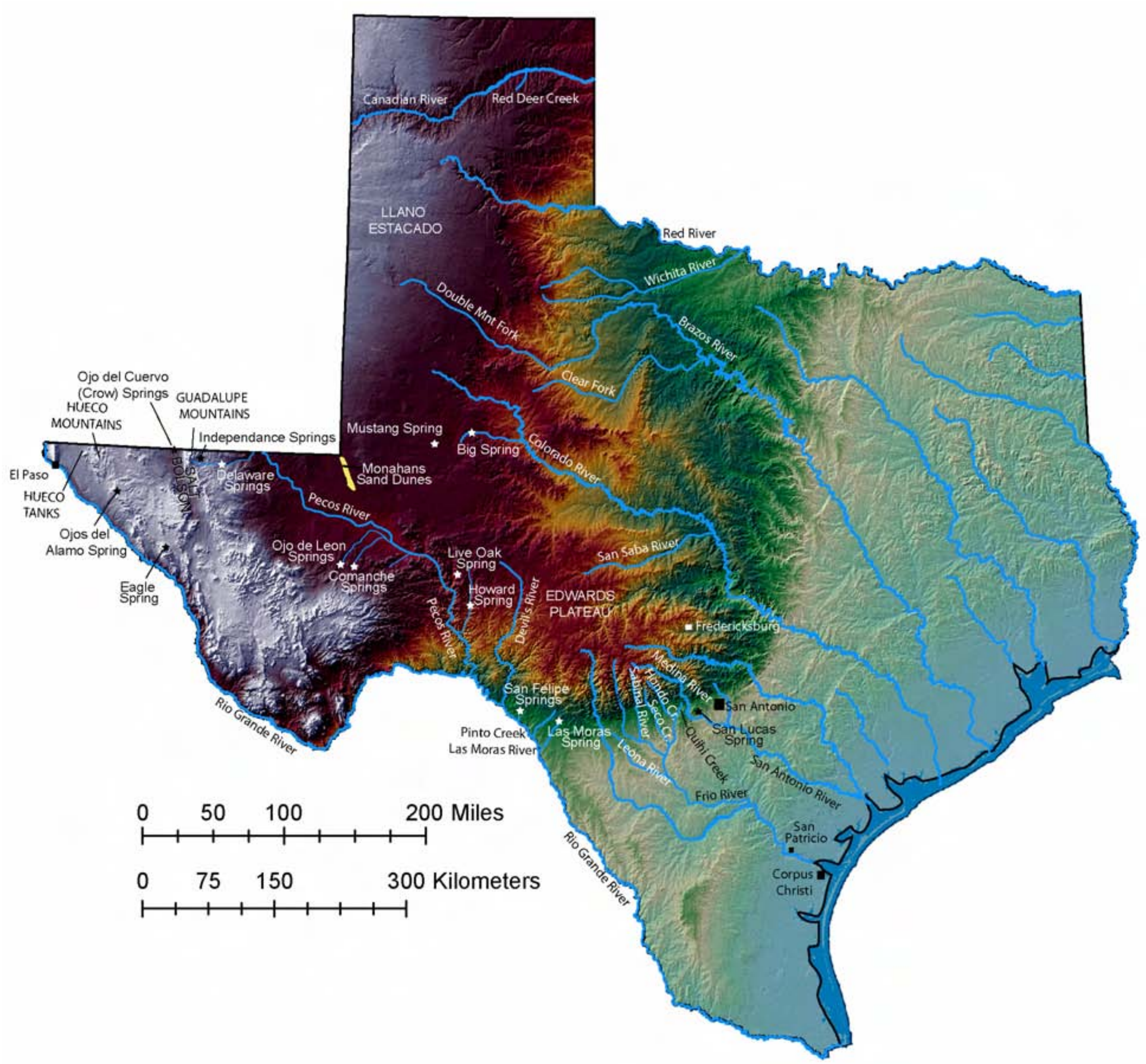

Figure 2. Place names mentioned in this paper (map by Brian Hunt).

Although the border of Texas with Mexico was settled, the western border of Texas was still under dispute.[3] Texans considered their territory to extend to the Rio Grande to the west and northwest into modern day New Mexico, Oklahoma, Kansas, Colorado, and Wyoming. Others, including the federal government and the population in modern day New Mexico, saw the border differently. After threats of military action between New Mexican and Texas and the United States and Texas, the dispute was settled by Congress in the Compromise of 1850. Under the compromise—later approved by Texas voters—Texas ceded a third of its property[4] to its current boundary in return for $10,000,000.

[3] Information in this paragraph is from TSHC (2006).
[4] Several plans were considered, including ones that would have divided Texas into two or three states.

The 1850 Report

On July 24, 1850, the Corps of Topographical Engineers printed 3,000 copies of a report to the 31st Congress titled "Reports of the Secretary of War with Reconnaissances of Routes from San Antonio to El Paso." As indicated in the cover letter from Colonel J.J. Abert, the collection of reports included the following survey reports:

- a report of a reconnaissance of a route for a road from San Antonio to El Paso by Lieutenant W.F. Smith, dated May 25, 1849;
- a report of a reconnaissance of the country between Corpus Christi and the military post on the Leona by Lieutenant N. Michler, dated July 31, 1849;
- a report of a reconnaissance of a route from San Antonio, via Fredericksburg, to El Paso, to obtain information in reference to a permanent military road from the Gulf of Mexico to El Paso by Lieutenant Frs. T. Bryan, dated December 1, 1849;
- a report of a reconnaissance of a route from the upper valley of the south branch of Red River to the Rio Pecos by Lieutenant N. Michler, dated January 28, 1850;
- a report of a reconnaissance of a route for a military road from San Antonio to El Paso by Captain S.G. French, dated December 21, 1849; and
- a report of a reconnaissance of a route from Fort Smith to Sante Fe by Captain R.B. Marcy, dated November 20, 1849.

Other reports, not discussed in this paper, involve investigating a pass through the Sacramento Mountains, a brief report from Colonel J.E. Johnston concerning the trails from San Antonio to El Paso, and a report by Lieutenant Colonel J.E. Johnston on the condition of the Colorado River and how to improve navigation on the river.

Smith's Report—San Antonio to El Paso

Second Lieutenant W.F. Smith and Lieutenant J.E. Johnston and their party traveled from San Antonio to El Paso seeking a safe route of passage. They first traveled to Fredricksburg and camped at the headwaters of the San Pedro River along the way. From Fredricksburg, they headed to the headwaters of the San Saba River before ascending to the Edwards Plateau: "[We]… travelled for about one hundred and ten miles in a direction somewhat south of west, without finding even water-holes, and being occupied three days and a night in taking that distance." This path over the plateau did not hold much promise as a viable road: "Though this country, for the distance of a hundred and twenty four miles, was such as to require no labor in advance of the wagon train, yet the great want of water caused us to consider the route as impracticable, except at the enormous expense of digging wells along it." Their path over the plateau—through modern-day Schleicher and Crockett counties—took them to the headwaters of Live Oak Creek, a tributary to the Pecos River.[5] They then traveled to Comanche Springs, known at that time by their Indian name, Ahuache Springs.

[5] The Pecos River was sometimes referred to as the Rio Puerco.

In describing a southern route from San Antonio to El Paso via the Rio Grande, Smith and Johnston visited Las Moras springs and described San Felipe springs: "To the north of the road, and a half mile distant, there is a beautiful spring of water, fifty feet in diameter at the surface, the sides of which incline towards a centre, like an inverted cone, and then, sinking in a cylindrical form to the depth of twenty eight feet, through a soil of hard clay, afford a passage for the water to rise. The water comes to the surface with slight ebullition, and flows off in a volume that would fill a cylinder two feet in diameter. This spring is the source of the San Felipe; as it flows on, the volume of its waters is increased by other large springs, on either side, until it becomes a creek, when it empties into the Rio Grande, eight miles below the crossing, some thirty feet wide and several feet deep." Traveling further west, they describe descending from probably the Delaware Mountains, finding a spring—probably from the Capitan Reef Complex aquifer—and a saline spring in the salt flats.

Michler's Report—Corpus Christi to Leona

Second Lieutenant N. Michler, Jr., and Major G. Deas reported on an excursion from Corpus Christi to a military post on the Leona River. There is not much of hydrogeologic interest reported during their trip, but they do make observations concerning the landscape. For example, they note that the prairie near San Patricio is "…is covered with fine mezquite grass, and interspersed with mezquite trees and live-oak moats." Near the confluence of Spring Creek with the Nueces River, they crossed at a ford of "…solid limestone…of sufficient breadth for several wagons abreast…" They described the flora at this ford as "[p]erfectly clear prairie, free from all lumber, bordering immediately upon the river at this point. Above and below, at a short distance from the ford, the timber in the bottom was heavy and thick, consisting of the elm, cottonwood, oak, &c., and covered with a dense growth of weeds."[6]

Michler and his party described the Leona River when they crossed it: "The Leona is a beautiful stream of excellent water—limestone. The banks are nearly upon a level with its surface. It possesses a hard gravel bottom—its width about thirty, and its depth not more three feet, and flowing with a gentle current. It is said never to rise above its present level—the stream not being of sufficient length to be affected by heavy rains. The land immediately along the river is rich, and covered with heavy timber. A few hundred yards below the ford are fine falls, arid the river not more than twelve feet in width."

Bryan's Report—San Antonio to El Paso via Fredricksburg

First Lieutenant Francis T. Bryan and Lieutenant Col. J.E. Johnston reported on their 46 day trip from San Antonio to El Paso via Fredricksburg. They mention stopping at Post Oak Springs, Pecan Spring, and Potato Spring near Kickapoo Creek. They reached the Pecos River and describe it as a "…muddy stream, of a dark red color, and, running through the plains, has very much the appearance of a canal." They crossed the Pecos River at "Horse Head Crossing," so named because of "…the number of horses' heads which lie scattered near." As they followed the Pecos River upstream, they found saline water holes and efflorescence. They approached the

[6] "&c." is an abbreviation of "et cetera"

Guadalupe Mountains and described arriving at Ojo del Cuerpo[7], a spring of brackish water smelling of sulphur in the open prairie. They stopped at the tanks of Connedos del Alamo, noting that “[w]ater issues from the rock in several places. Outside of the mountain, several wells have been dug by California parties. These wells were full when we passed. Inside the mountain, in a cavern, there is a fine large well of pure water; this is full to overflowing; the water is very cold and of good flavor.” Passing over the Hueco Mountains (spelled “Waco” in their report), they stopped at Hueco Tanks, noting that “[t]he tanks are situated in caves of large masses of granite rock. There are several of these tanks containing immense quantities of pure cold water.”

Michler’s Report—Red River to Rio Pecos

Second Lieutenant N. Michler, Jr. led an expedition from the upper valley of the south branch of the Red River (starting in Fort Washita on the Washita River in modern-day Oklahoma north of Grayson County[8]) to the Pecos River. Leaving Fort Washita on November 9, 1849, he noted that “…[t]he first two miles was through the Washita bottom; the soil rich, red clay mixed with sand, being excellent cotton land; the timber cottonwood, hickory, dogwood, elm, sycamore, and post oak.” He also noted that “[t]he water is of a bright vermilion color, and its taste brackish.” Upon reaching the Red River, Michler noted that “[t]here was some fine large and heavy timber upon the bank of the river—hackberry, mulberry, cottonwood, Spanish oak, black-jack, and willow forming the principal growth. The grazing near the river is, however, extremely bad.” He noted, in traveling west along the Red River from the confluence of the Washita River with the Red River “[t]he further west we travelled, the better grazing we found—the gramma, sedge, and buffalo grass the most abundant, but the mezquite constantly becoming more frequent.”

On the trip from the Red River to the Little and Big Wichita rivers (now referred to as the North and South Wichita rivers), Michler notes that “[n]ear the Red river the soil is slightly sandy, and you meet with some few post Oak mots. It then becomes a fine mezquite country, well timbered with mezquite, and for miles perfectly level; and even when a rolling prairie, the elevations and depressions are small. The grass at first is principally gramma, and the ordinary sedge, and their species; but then come the fine early mezquite and the winter mezquite. The whole extent was well watered by numerous branches of the two Wichitas. The country appeared to have been flooded by previous heavy rains, and numerous water holes were met at short intervals. Most of the streams possessed a slightly brackish taste: all of them were well timbered.” Of the Big Wichita River, he notes that “[t]he water is of the same color as that of Red river, and tasted very brackish and bitter; young cottonwood seems to be the only timber which grows along it. Within a few yards of its banks you find many lakes or ponds, the water of which is much more agreeable to the taste. The Indian name for this stream is "Ah he we wo nah:" translated into English, it signifies "Pond creek."”

As Michler continued south, he noted that one approaches “…the Brazos without the slightest indication of its presence. No timber along its banks as far as the eye can see: you stumble upon it without any forewarning. High bluff banks along its very edge conceal it, until you reach the top of them. Its channel is about fifty yards in width, and bounded but by a small strip of bottom

[7] Spanish for “eye of the body.” Many springs are referred to using the Spanish word “ojo.” Also referred to as Ojos del Cuervo or Ojo del Cuerbo.
[8] Cordova’s (1949) map shows the river as the “False Washita River” with Fort Washita in Oklahoma. There is a Washita River in modern-day Roberts and Hemphill counties.

land." He noted that the water of the Brazos River was brackish, although small side streams of fresh water empty into the river.

Michler's entourage continued south across the Clear Fork and Double Mountain Fork of the Brazos River. He noted that "[t]here was but little timber upon these streams upon first leaving the main fork; but the further we advanced the more we found elm being the principle growth. The whole country was well timbered with mezquite, but most of it had been killed by prairie fires." In crossing the divide between the Brazos and Colorado river basins, Michler noted that "[t]he country here undergoes a complete change. You now meet with high rolling prairies, arid, and destitute of timber, and scarcely any grass but of the most miserable kind."

Upon reaching the Colorado River, Michler's party camped at the "Big Springs of the Colorado," near modern-day Big Spring: "These springs are very large, and a considerable quantity of water is obtained from them; they cover a space of about twenty feet square, and in some places the water is fifteen feet in depth by measurement. They are walled in by a ledge of high rocks, forming a concave surface, within which the basin of the springs lies. The water is impregnated with lime, and is cool, fresh, and perfectly clear. It is carried away in a bold, running stream, which in a short distance sinks below the surface."

Traveling west from the big springs, Michler approached Mustang Springs:[9] "There was nothing to indicate their presence; a few scattering chaparral bushes were growing within half a mile of them, but in proximity to the water were no trees or bushes of any kind. A low prairie of about a hundred acres in extent, in form very nearly circular, and bounded by low bluffs, composed principally of white limestone, contains several small ponds of water, one or two pretty deep, and the rest not containing much water. The taste of the water is flat and sweet, being slightly brackish. From the number of trails leading to there, and the number of mustangs which came to water there, and the quantity of flag and other vegetable matter growing in and about them, I judge the water to be permanent. Several springs were found bubbling up in the ponds."

From Mustang Springs, Michler and crew moved on to the sand hills: "Upon reaching the sand hills, we found, for the first twelve miles, low ridges of sand, running parallel to each other, plaids of the same kind interspersed between them, with small hillocks. The sand was here of a black color. Then come the white sand hills, which are really an object of curiosity. They are a perfect miniature Alps of sand the latter perfectly white and clean: in the midst of them you see summit after summit spreading out in every direction, not a sign of vegetation upon them nothing but sand piled upon sand. They form a belt two or three miles in width, and extend many miles in a northwest direction." They also found water: "But a matter of the greatest surprise is to find large water holes among them: they are found at the base of the hills, are large, deep, and contain most excellent water, cool, clear, and pleasant. The water is permanent. A great deal of vegetable matter and young willow trees are found on their banks. This was the first water we found since leaving the Mustang spring a distance of sixty seven miles without any: during this entire distance we saw no indications of any whatever."

Finally, on December 30, 1849, Michler reached the Pecos River. He noted that "[t]he course of the stream was nearly east and west; its width was about forty feet; and, being too deep to ford, we encamped on its left bank. It answered well the description given me by others, and was truly a "rolling mass of red mud" nothing to indicate its presence but a line of high reeds growing

[9] Noted as "Mustang Fountain" on Grant's (1885) map.

upon its banks. Along its banks you find numerous lakes, the water of which is clear, but still more brackish than even that of the river." Michler followed the Pecos downstream to Horse Head Crossing and continued to San Antonio.

French's Report—San Antonio to El Paso

Captain S.G. French also made the trip from San Antonio to El Paso by way of the Rio Grande on the "southern route" and returned to San Antonio via Fredricksburg on "the northern route." He describes visits to San Lucas Springs, Las Moras Springs, San Felipe Springs, Pallas Blancas Springs, Howard's Springs, Comanche Springs, Ojo de Leon springs, Eagle Springs, Ojo de los Alamos springs, and Thorn's springs.

On his trip along the southern route to El Paso, French noted that "[t]he road from San Antonio to Castroville runs through a generally level prairie, covered with a luxuriant growth of grass; the soil is good, and country well adapted to cultivation and grazing." At the time they traveled, late in May of 1849, the Medina River flowed but Hondo, Seco, and Quihi creeks were dry. He described the Sabinal River as "…a clear, cool, delightful, running stream, with banks bordered with large trees, suitable for building purposes." He further notes that upon "[l]eaving the Sabinal [River], the country is more rolling and diversified; the growth of small mezquite bushes begins to take the place of the open prairie."

Moving farther west, French found the Frio River dry and the Leona River flowing. Of the Leona and Nueces rivers, he wrote poetically: "The Leona—a clear, cool, and beautiful stream has its source in this neighborhood, and forms, in the course of a few miles, a creek some fifty feet wide, flowing through a dense forest, on either side a quarter of a mile in width. The lands on this stream will vie in fertility with any portion of Texas; and the abundance of timber scattered over the whole extent of the Nueces adds much to its value. No part of the State offers greater inducements to the agriculturist, and as a grazing country it is unrivalled." Further on, he notes that the Nueces River flowed 40 feet wide and one and a half feet deep.

French and his party stopped in at Las Moras River, "[i]ts waters, gushing out from the springs, form at once a large creek. Trees line its banks as far as the eye can reach." He then crossed Piedra Pinta Creek, now Pinto Creek, and noted that it flowed at the time.

After crossing several more creeks, French reached San Felipe Springs. He described San Felipe Springs as "…a beautiful spring of water, fifty feet in diameter at the surface, the sides of which incline towards a centre, like an inverted cone, and then, sinking in a cylindrical form to the depth of twenty eight feet, through a soil of hard clay, afford a passage for the water to rise. The water comes to the surface with slight ebullition, and flows off in a volume that would fill a cylinder two feet in diameter. This spring is the source of the San Felipe [River]; as it flows on, the volume of its waters is increased by other large springs, on either side, until it becomes a creek, when it empties into the Rio Grande, eight miles below the crossing, some thirty feet wide and several feet deep."

French noted that beyond this point, the land changed, that San Felipe Creek represented "…the last of those small, clear streams, flowing through fertile valleys, with banks admitting every access to their waters." North of this area, moving upstream on the Rio Grande, the river was bordered by "the great table formation," the Edwards Plateau. French later refers to San Pedro

Creek as "…a stream about sixty yards wide, running over a level bed of solid limestone rock." However, he was probably referring to the modern-day Devils River.[10] Moving up onto the tablelands, French noted "…some springs sunk in the open plain at and near Pallas Blancas."[11] Returning to San Pedro Creek and following its course downstream, French noted that "…the country is a constant succession of hills on hills, destitute of grass and wood, and giving support only to the saw-leaf palmetto. It is a miserably rough, broken, and barren region, avoided alike by every living thing."

Continuing along the plateau toward the Pecos River, French and his party came upon Howard's Springs. Of Howard's Springs, French notes that "[t]he springs, from the large basin they form, afford a small stream of running water in the summer, which, after flowing a short distance, sinks into the ground." Upon reaching the Pecos River, French noted that "[t]he Pecos is a remarkable stream, narrow and deep, extremely crooked in its course, and rapid in its current. Its waters are turbid and bitter, and carry, in both mechanical mixture and chemical solution, more impurities than perhaps any other river in the south. Its banks are steep, and, in a course of two hundred and forty miles, there are but few places where an animal can approach them for water in safety. Not a tree or bush marks its course; and one may stand on its banks and not know that the stream is near. The only inhabitants of its waters are catfish; and the antelope and wolf alone visit its dreary, silent, and desolate shores. It is avoided even by the Indians."

As French moved west of the Pecos River, he noted that "…the soil becomes more and more sterile, without grass, and yielding support to nothing but dwarf bushes, Spanish bayonets, and stunted cactus." About 18 miles west of the Pecos, at Escondido Creek, he found "…water…in ponds, some of them quite deep, surrounded by a tall growth of rushes and cane. The water rises from a rocky bottom, and, as it imperceptibly glides away, gives life and freshness to the coarse grass and cane."

French then visited Comanche springs and observed that "[t]he water rises from a number of springs, and forms a stream of excellent water, perhaps twenty feet wide and two feet deep, which, after flowing some ten miles, disappears in a salt plain." He then traveled to springs at Ojo de Leon, noting that "[t]he water rises to the surface from out of springs, thirty or forty feet in diameter, that sink to a great depth, like large wells. The water runs from one spring to another, and finally, in the course of a half mile, sinks into the earth. Near the springs the ground is bare, and covered with a finely crystallized salt, which at a distance appears like snow. The odor of sulphur is perceptible about the springs."

On the 40-mile trip to Limpia Creek, French notes that one cannot count on finding water along the way. Where the road crossed Limpia Creek, the stream was flowing, although it appeared upstream of the road and disappeared a short distance downstream of the road. It had apparently been a wet summer, since he noted that "[t]he hills were here, in August, clothed in verdure as green as if it were early spring. The country is beautiful; and the mountains, covered with green grass to their summits, present a pleasing appearance."

French found little water between Limpia Creek and Eagle Springs. He found water at Smith's run, a flowing creek sourced in the mountains. He found more water at a spring 10 miles up the road. After that, it was 60 miles to Eagle Springs "…found in a ravine formed by the spurs of the

[10] There is a modern-day San Pedro Creek tributary to the Devils River.
[11] I was not able to discern the location of Pallas Blancas.

mountains." French described the springs as oozing out of the ground into numerous dug holes. From here, French's entourage traveled to El Paso which, at the time, was located on the Mexican side of the Rio Grande with only three houses on the United States side. French described the plants and agriculture in the area as well as the possibility for growth. He noted that "[t]he valley of the Rio Grande, in proper hands, is capable of supporting a large population; and…the larger portion is on the American side."

On his return trip to San Antonio, via the northern route, French first passed by Waco Tanks, now spelled Hueco Tanks, and noted that "[t]he supply of water in these tanks depends on the rains." The next water he found was at Ojo de los Alamos, which consisted of small holes dug into the side of the mountain. He noted that the holes would not supply enough water for 2,000 animals, but that more holes could be sunk. Thorn's Springs appear nine miles up the road with water "in abundance," but required the use of buckets to pull water "…from a natural well in a cave." French found water at Ojo del Cuerpo (source not described) as well as at the heads of streams sourced from the Guadalupe Mountains. Meeting the Pecos River just south of its confluence with Delaware Creek, French followed the river downstream for 175 miles. During this part of the trip, French wrote that "…few places can be found more solitary, or that present a more dreary appearance, than all this region of the Pecos. The only sign of life or moving thing is now and then a single deer, a few antelope, a flock of ducks circling over the lagoons, or a solitary crane winging his way up the course of the stream." He notes numerous salt marshes, salty quicksand—enough to mire animals, and bogs.

After this point, French concludes his report, referring the reader to the other reports that describe the trail from the Pecos River to San Antonio.

Marcy's Report—San Antonio to El Paso

Captain 5th Infantry R.B. Marcy made a survey of the Canadian River en route from Fort Smith, Arkansas, to Sante Fe, New Mexico, noting various springs on his route. His travels west carried him across the modern-day Texas Panhandle. Marcy's entourage traveled along the south side of the Canadian River. As they approach the Llano Estacado, he describes several streams of fresh water, probably Red Deer Creek and various creeks in Roberts County, features that still flow today fed by groundwater from the Ogallala Aquifer. On his trip, he vividly describes the Llano Estacado: "Leaving camp early this morning, we travelled two miles on our course, when we encountered a spur of the plain, running too far east for us to pass around under it; and finding a very easy ascent to the summit, I took the road over the plain. When we were upon the high table land, a view presented itself as boundless as the ocean. Not a tree, shrub, or any other object, either animate or inanimate, relieved the dreary monotony of the prospect; it was a vast, illimitable expanse of desert prairie the dreaded "Llano Estacado" […]; or, in other words, the great Zahara of North America. It is a region almost as vast and trackless as the ocean—a land where no man, either savage or civilized, permanently abides; it spreads forth into a treeless, desolate waste of uninhabited solitude, which always has been, and must continue, uninhabited forever; even the savages dare not venture to cross it except at two or three places, where they know water can be found. The only herbage upon these barren plains is a very short buffalo grass, and, on account of the scarcity of water, all animals appear to shun it."[12]

While in Santa Fe, Marcy decided that he wanted to cross the Llano Estacado on the way back to Fort Smith and found a Comanche that told them that it was possible to cross the Staked Plains if one followed the proper trail—a trail with water. Marcy and his party traveled down the Rio Grande to Doña Ana, about 60 miles north of El Paso, before heading east past the Organ and Sacramento mountains before cutting down to the water hole at the Hueco Mountains. Because they were traveling in an area without much water, Marcy noted how the Mexicans traveled in the area: "The manner in which the Mexican traders slake these long stages, without water (and I believe it to be the best) is, before starting, to graze their animals from morning until about 3 p.m., give them all the water they will drink, then harness and start them immediately, and drive until 4 o'clock the next morning, when they stop three hours to graze while the dew is on the grass, and drive until it becomes hot towards the middle of the day; they then make another halt until 5 o'clock in the evening, when they start again and push through to the water. In this way fifty, sixty, or seventy miles can be made with loaded mule or ox wagons in the hottest weather of the summer."

At the Hueco Mountains, Marcy stopped at what was probably Hueco Tanks, noting that they "…found a great abundance of good water in an immense tank up a ravine on the South mountain. This is a huge deep basin, scooped out of the solid rock with great symmetry and regularity, and of sufficient capacity to contain several hundred gallons of water." Moving farther east, Marcy noted that "[u]pon the east side of the "Comudas" there is an arched entrance into a large cavern which is lighted from above, and in this we found a well fifteen feet deep, filled to the top with beautifully pure water; besides this we found water sufficient for our animals in tanks on the west side of the hill."[13] Heading in the direction of the Guadalupe Mountains, Marcy visits Ojo del Cuerbo, or Crow Spring. He noted that "[t]he spring is upon the open plain, and contains a large supply of water at all seasons; and, although it is sulphurous, yet animals are very fond of it, and we found it to answer, in the absence of better, for drinking and cooking." From here, he crosses the salt lakes of the Salt Bolson.

Descending from the Guadalupe Mountains toward the Pecos River, Marcy's entourage stopped at Independence Spring where they "…found two large springs of pure cold water, which boil up from the ground and run off in a stream about the size of a barrel…" They then stopped at Ojo de San Martín at the head of Delaware Creek.[14] Marcy noted that the spring here "…bursts out of a solid limestone rock in a volume of sufficient magnitude to drive an ordinary saw-mill at the fountain-head, and is as pure, sweet water as I ever drank." He also noted that there were a number of springs in the area: "Above [Ojo de San Martin] there are several others possessing different mineral properties. One is highly charged with sulphuretted hydrogen, and tastes very much like the Kentucky "Blue Lick water." Another is decidedly chalybeate, and a, third is strongly sulphurous, leaving a thick incrustation of sulphur upon the rocks for many yards from the source. These unite in one common outlet, and the amalgamation is far from pleasant to the taste." Marcy wrote about the resort possibilities of the area: "Is it not within the scope of

[12] I took out "of New Mexico" where […] is within the quotation for clarity purposes and because I believe they were in Texas at the time, not to mention that much more of the Llano Estacado is in Texas rather than New Mexico.
[13] This could be Thorn's springs described by French.
[14] Now known as Delaware Springs; also known in the past as Head Springs, Five Springs, and La Cienega (Brune, 2002).

probabilities that these springs may be found to possess valuable medicinal properties, and that this place may yet (and at no very distant period) become, a place of fashionable resort for the "upper-ten-thousand" of New Mexico? The climate here is delightful, the atmosphere perfectly elastic and pure, and the temperature uniform and delicious; then, may not an invalid derive as much benefit at this place as at Saratoga or any other of our watering places?”

Marcy next camped along the Pecos River. He persisted in his desire to cross the Llano Estacado, but was rebuffed by his guide: “Our Comanche guide informs me this evening that I cannot, as I desired, go directly from this point to the head of the Colorado or Brazos, as no man (not even an Indian) ever undertakes to cross the "Llano Estacado" opposite here.” They continued down the Pecos River, noting that it was slightly brackish, but still usable. After crossing the river, they headed for the sand dunes in modern-day Ward County. Marcy noted that: “These hills, or mounds, present a most singular and anomalous feature in the geology of the prairies. They extend (so far as we have explored) at least fifty miles in nearly a north and south direction, and from five to ten miles east and west; they are white drift-sand thrown up with much uniformity into a multitude of conical hills, destitute of soil, trees, or herbage. In following up the trail from our road into the midst of this ocean of sand, we suddenly came upon several large, deep pools of pure water the very last place on earth where one would ever think of looking for it. We are told by our guide that water can always be found here in the dryest season, and, judging from the rushes and other water plants growing in the ponds, I have no doubt that such is the case.”

Finally, after leaving the sand dunes, Marcy got his wish to cross the Llano Estacado: “Leaving the sand this morning, we pushed out upon the high, plain of the Llano Estacado, not knowing whether we were to find water before we reached a luguna about sixty five miles distant. As our guide had passed over this portion of the road but once before, and then in a hurry, he was not very familiar with the localities. I therefore sent a party in advance to search for water, and felt some anxiety as to the result; I was relieved, however, about 11 o'clock, when a messenger returned with the cheering intelligence that the party had found a large pond of good water about sixteen miles from where we left this morning. This good news appeared to inspire our men and animals with renewed vigor. From the cheerless silence of the last two hours, the aspect of everything changed in a moment to humorous jokes and boisterous merriment. The whips were heard cracking from one end of the train to the other, and the mules appeared to move along with more ease than before.”

Marcy’s group passes several playa lakes that held water, including one he named Mustang Pond. He noted that “…it is thought there will be water at all seasons; it is about three feet deep, covers several acres of ground, and has rushes growing in it. There are also numerous trails made by mustangs leading to it, showing that it is much frequented by them; and as the horse requires water every day, he would not probably stay at a place where it could not be found at all times.” They then reached the Laguna, or Salt Lake, before reaching Big Spring: “…we reached the border of the high plain, and descended an easy slope of about fifty feet to a bench below; here we could see two low bluffs in the direction we were marching, near which our guide informed us we could find a fine spring of water. Fourteen and a half miles' travel over a beautiful road brought us to the spring, which we found flowing from a deep chasm in the limestone rocks into an immense reservoir of some fifty feet in depth.”

East of Big Spring, one of the scouts didn’t return. Marcy sent a lieutenant to find the scout. “[the] [l]ieutenant…followed the track about two miles from where he was met by the Indians, to a small branch of the Colorado, where, to his horror and astonishment, he suddenly came upon the murdered and mangled corpse of poor Lieutenant Harrison, lying down among the rocks, where they had thrown him, scalped, and stripped of all his clothing." In a brutal reminder of the challenges of exploring Texas western realms, Marcy's camp was stunned by the news: "When the melancholy news reached us that he had been murdered, there was such an expression of gloom cast over the command as I have never witnessed before. Old soldiers who had often seen their comrades falling by their sides in battle, and whose hearts, it might he supposed, were steeled against the manifestation of what some might consider weakness, were seen to turn away their faces to conceal their tears. They knew that in his death they lost a good friend." They boxed up Lieutenant Harrison to carry him back to Fort Smith.

A little farther down the trail, Marcy and his group experienced a blue norther: "We have had during last night one of the most terrific storms I have ever witnessed in the whole course of my life. The wind blew a perfect tempest from the north, and it appeared as if the whole floodgates of the heavens were suddenly opened, and the accumulated rains of a year poured out in torrents for fifteen consecutive hours upon us. The whole surface of the earth was deluged; even upon the tops of the hills there were three inches of water, and it filled every ravine and hole about us. The creek upon which we are encamped had but very little water in it last night: it is now full to the top of its banks, and would float a steamboat." From here, they cut north, to the east of the Llano Estacado, across the Colorado and the Brazos rivers, up to the Red River, and then east back to Fort Smith, Arkansas.

In all, Marcy and his group marched 2,023 miles in the course of six months. In his summary notes, he strongly recommended a railway, noting that "…the surface of the earth is so perfectly firm and smooth that it would appear to have been designed by the Great Architect of the Universe for a railroad…" once you got past the mountains. He also dreamed that the east and west coasts could be linked by railway that "…would give us a great national highway across our continent from the Atlantic to the Pacific, in a very direct line, and would enable the traveller to pass safely and comfortably over a distance in a week which before required four months of toil, hardship, and danger. It would afford our government a cheap and rapid transit for troops and munitions of war, and would enable us to communicate with our far distant territories in a few hours. These considerations, in connexion with the vast and incalculable commercial benefits that the whole civilized world would receive, would render it a monument to the genius, enterprise, and philanthropy of the American people."

Clues of Early Hydrogeologic Conditions

When these officers of the Corps of Topographic Engineers traversed Texas, they saw the hydrologic system before pumping changed it. For example, Comanche Springs, which flowed amply in the mid nineteenth century, had dried up a little more than a hundred years later due to pumping (Brune, 2002; although ample rainfall in recent years has caused the springs to flow again). The Ogallala Aquifer used to feed a number of playa lakes in the southern part of the southern High Plains as well as some springs, such as Mustang Springs (referred to as Mustang Fountain on the Grant [1885] map). However, pumping dried up the springs in the 1940s (Brune, 2002), and the water table now sits 30 to 60 feet below land surface (TWDB, 2006).

Springs sometimes unwittingly invite their demise. Because drilling a water well was expensive, people drilling for water wanted to increase their odds of a successful well as much as possible. If a spring was flowing in an area, it was a good sign that the aquifer in the area could be productive. Therefore, many early wells were drilled near springs. This happened to Big Spring, which dried up sometime after 1900 after the railroad drilled and pumped wells near the spring to supply the growing town of Big Spring (Brune, 2002). Water levels in the aquifer beneath the spring—the Trinity part of the Edwards–Trinity (Plateau) Aquifer—were about 30 feet below land surface in 1990 and were reportedly more than 150 feet below land surface in 1936 (TWDB, 2006). Comanche Springs and Ojo de Leon (also referred to as Leon Springs), both in Pecos County, also fell victim to pumping. Crow Springs, or Ojo del Cuervo (also referred to as Ojo del Cuerbo and Ojo del Cuerpo), is now dry after an irrigation well was installed near the springs in 1948 (Brune, 2002). This spring, located in the salt falts, likely issued from the Bone Spring-Victorio Peak Aquifer, where water levels are now about 20 to 60 feet below land surface. Ojo de los Alamos, also referred to as the tanks of Connedos del Alamo and Cottonwood Springs, issued from the Finlay Limestone and was flowing in 1960 but not in 1976 and later (Brune, 2002).

Las Moras and San Felipe springs, issuing from the Edwards equivalent rocks of the Edwards-Trinity (Plateau) Aquifer, continue to flow as does San Lucas Springs in Bexar County. Howard's Springs (also referred to as Howards Spring, Howard Spring, and Howard's Well) continues to flow in Crockett County. Ojo de San Martín, also referred to as Head Springs and Five Springs, and Independence Springs, in Culberson County still flow.

The observations of Ward County are interesting because they describe a number of springs in the area, even among the sand dunes. Ward County is underlain by the Pecos Valley Aquifer, an aquifer that has seen its water levels decline 50 to 100 feet in response to pumping. The pools of water noted by Captain Marcy continue to exist. Brune (2002) notes that they are fewer and shallower because of pumping of the aquifer to support oilfield operations. However, water levels in wells at the park are about 40 feet below land surface, suggesting that the ponds are not in direct contact with the Pecos Valley Aquifer and are instead fed with perched groundwater, perhaps from the dunes themselves.

Brune (2002) hypothesizes that the Pecos River in this area used to be gaining, which seems to be supported by the observations of the Corps concerning springs and swamps, especially near the river. Water levels in the underlying Pecos Valley Aquifer are currently about 50 feet below land surface near the Pecos River (TWDB, 2006). One well (46-37-401) near the river shows the decline of water levels with time where water levels were less than 2 feet below land surface in 1939 and were 20 feet below land surface by the late 1950s. The river, once a surprise on the plains, is now clearly marked with salt cedar, although there are currently efforts to eradicate this phreatophyte from the river's banks.

Conclusions

Surveys of Texas by the Corps of Topographical Engineers includes interesting and useful information about the predevelopment character of the hydrologic systems of West and Far West Texas. Because water was important to satiate the thirst of the people and animals on these surveys, water is prominently discussed. The surveys describe a number of springs, many of which have since gone dry due to pumping in subsequent years. Descriptions of the Pecos River above the Pecos Valley Aquifer strongly suggest that the aquifer used to discharge to the river as well as a collection of swamps and bogs in the area. The surveys also note the lack of vegetation along this reach of the Pecos River as well as along the upper reaches of the Brazos River, suggesting phreatophytes were less prevalent in predevelopment and pre-settlement times.

Acknowledgments

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austin geological society bulletin

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Paleozoic Buildups and Associated Facies, Llano Uplift, Central Texas by S. C. Ruppel and C. Kerans. Includes road log and articles. Guidebook 10, 1987, 33 p. **AGS 010, $10.00**

Hydrogeology of the Edwards Aquifer–Northern Balcones and Washita Prairie Segments by J. C. Yelderman, Jr., Coordinator. Includes road log and articles. Guidebook 11, 1987, 91 p. **AGS 011, $12.00**

Congress Avenue, Austin, Texas–Lessons in Economic Geology, Architecture, and History by C. M. Woodruff, Jr., Coordinator. Includes several articles and street log of Congress Avenue. Guidebook 12, 1988, 56 p. **AGS 012, $10.00**

Faults and Fractures in the Balcones Fault Zone, Austin Region, Central Texas by E. W. Collins and S. E. Laubach, Coordinators with an experimental demonstration by B. C. Vendeville and a summary of the regional fracture patterns by W. R. Muehlberger. Includes road log. Guidebook 13, 1990, reprinted 2004, 34 p. **AGS 013, $12.00**

Water Quality Issues for Barton Creek and Barton Springs by D. A. Johns, Field Trip Leader. Guidebook to field trip containing road log of eight stops, excerpts from the report of the Barton Springs Task Force to the Texas Water Commission, and five articles on Barton Creek and Barton Springs. Guidebook 14, 1991, 95 p. **AGS 014, $15.00**

Edwards Aquifer–Water Quality and Land Development in the Austin, Texas, Area by D. A. Johns and C. M. Woodruff, Jr. Includes six articles and a road log to six stops in the Austin area. Guidebook 15, 1994, 66 p. **AGS 015, $10.00**

Fractures Caused by North-South Compression, Eastern Llano Uplift, Central Texas: **A Field Guide** by David Amsbury, Russell Hickerson, and Walter Haenggi. Includes road log and details of six stops. Guidebook 16, 1991, 31 p. **AGS 016, $8.00**

Zilker Park Walking Tour Guidebook: A Recreational Visit to the Edwards Limestone by J. L. Walker and P. R. Knox. Includes the geologic setting of the Zilker Park area with a guide to Zilker Park trail (11 stops) and a guide to the Barton Creek greenbelt (8 stops). Well illustrated. Guidebook 18, 1994, 48 p. **AGS 018, $10.00**

A Look at the Hydrostratigraphic Members of the Edwards Aquifer in Travis and Hays Counties, Texas by N. M. Hauwert and J. A. Hanson, Coordinators. Seven articles and a field trip road log that represents an update of research focusing on the Barton Springs segment of the Edwards Aquifer. Guidebook 19, 1995, 81 p. **AGS 019, $15.00**

Urban Karst: Geological Excursions in Travis and Williamson Counties, Texas. C. M. Woodruff, Jr. and C. L. Sherrod. Road log for one-day field trip with seven stops. Guidebook 20, 1996, 73 p. **AGS 020, $16.00**

The Hill Country Appellation: A Geologic Tour of Selected Vineyards and Wineries of Central Texas by C. M. Woodruff, Jr., P. R. Rose, and J. W. Sansom, Jr. Guidebook 18, 1998, 56 p. **AGS GB018, $10.00**

Rocks, Resources, and Recollections: A Geologic Tour of the "Forty Acres:" The University of Texas at Austin Campus by C. W. Woodruff, Jr., and B. L. Kirkland, coordinators. Guidebook 19, 1999, 62 p. **AGS GB019, $12.00**

Geology and Historical Mining, Llano Uplift Region, Central Texas by Chris Caran, Mark Helper, and Richard Kyle, Leaders. Guidebook 20, 2000, 111 p. **AGS GB020, $15.00**

Austin, Texas, and Beyond?Geology and Environment: A Field Excursion in Memory of L. Edwin Garner by C. M. Woodruff, Jr., and E. W. Collins, Trip Coordinators. Guidebook 21, 2001, 120 p. **AGS GB021, $15.00**

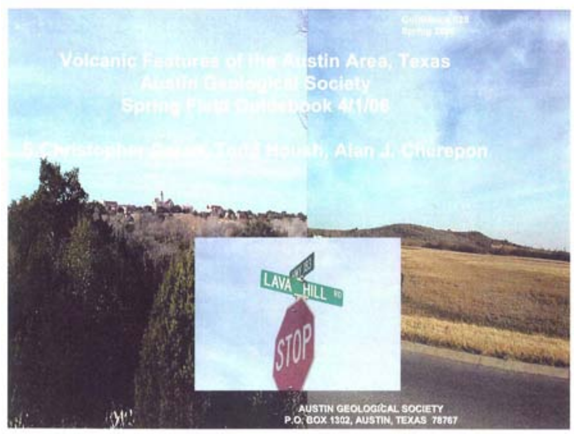
Time, Land, and Barton Creek—An Excursion to Shield Ranch, Travis and Hays Counties, Texas by C. M. Woodruff and Edward W. Collins, Trip Coordinators. Guidebook 22, 2003, 71 p. **AGS GB022, $13.00**

Lignite, Clay, and Water: The Wilcox Group in Central Texas by Robert E. Mace and Berney Williams, Trip Coordinators. Guidebook 23, 2004, 96 p. **AGS GB023, $10.00**

Tectonic History of Southern Laurentia: A Look at Mesoproterozoic, Late-Paleozoic, and Cenozoic Structures in Central Texas by April Hoh and Brian Hunt, Trip Coordinators. Guidebook 24, 2004, 90 p. **AGS GB 24, $18.00**

Geology, Frontier History, and Selected Wineries of the Hill Country Appellation, Central Texas by P. R. Rose and C. M. Woodruff, Jr. Guidebook 25, 2005, 109 p. **AGS GB 25, $15.00**

Volcanic Features of the Austin Area, Texas, by S. C. Caran, Todd Housh, and A. J. Cherepon. Guidebook 26, 110 p., 1 CD, Spring 2006. **AGS GB 26, $25.00**



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Austin Geological Society Membership Application:

Please enroll me in the Austin Geological Society as (check one): *Date:* ____________________

- O Renewal Active Member ($20 dues/year)
- O Renewal Student Member ($5 dues/year)
- O New Active Member ($20 prior to November, $15 Nov.-Jan., $10 Feb.-April, $5 May-July)
- O New Student Member ($5 prior to November, $3.75 Nov.-Jan., $2.50 Feb.-April, $1.25 May-July)

• *Name*: ____

Renewing Members:

- O Check here if your previous year membership information in AGS files is current. If your information is current, you do not need to fill out the rest of the form.

New Members or Renewing Members With Changes:

• *Telephone*: (Office)____________________(Home)____________________

• *Mailing Address*:

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City:____________________ Zip: ____________________

• *Email Address*: ____

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• *Background:*

Employer: ____

College Education (degree and field, year, school):____________________

____

Present Focus*:* ____

Disciplines of Interest: ____

Mail this form and payment to:
Treasurer, Austin Geological Society, P.O. Box 1302, Austin, TX 78767-1302

We invite you to become a member of the Austin Geological Society and share in our programs. Your membership will bring you:

- notice of AGS meetings with speakers.
- notice of AGS field trips to sites of geological interest.
- social gatherings of geological professionals in the Austin area.
- a monthly newsletter to keep you informed of Society and regional news of interest to geologists.
- the opportunity to become acquainted with other geologists in the Austin area.

The requirements for membership are:

- To be eligible for Active Membership, an applicant shall have a degree in geology from a recognized college or university, or the equivalent experience, or have been actively engaged in the application of geology or related scientific or professional work for a minimum of two years.
- Consideration of Honorary Membership shall be based on continued dedication and service to the Austin Geological Society. Honorary members shall be selected by the Executive Board. Any Active Member may submit the name of an individual to the Executive Board for consideration as an Honorary Member.
- Any person who is a student in good standing, studying for a degree in geology or related science, is eligible for Student Membership. Student Members shall not be eligible to vote or hold elective office.

constitution

AUSTIN GEOLOGICAL SOCIETY

CONSTITUTION

Approved October 7, 1965
Revised December 21, 1990
Revised August 14, 1995
Revised May 1, 2000

ARTICLE I

Name and Objectives

Section 1. This organization shall be named "Austin Geological Society."

Section 2. The objectives of the Society are:

(1) to stimulate interest in and promote advancement of geology;
(2) to facilitate discussion and dissemination of geologic information;
(3) to encourage social and professional cooperation among geologists and associated scientists;
(4) to maintain a high professional standing among the members; and
(5) to enhance public understanding of the professional activities of the members.

ARTICLE II

Membership

Section 1. The members of the Society shall consist of persons concerned with the science and practice of geology.

Section 2. Various classifications of memberships and qualifications thereof shall be established by the Bylaws of the Society.

ARTICLE III

Government

The government of the Society shall be vested in five (5) elected officers and an Executive Board. The composition of this government, the manner of selection, the terms of office, the specific duties, responsibilities, and other matters relevant to such bodies and officers shall be as provided in the Bylaws of the Society. Any responsibility and authority of government of the Society not otherwise specified in these governing documents shall be reserved for the Executive Board.

ARTICLE IV

Amendments

Amendments to this Constitution may be proposed at any time by petition signed by at least 20 percent of the Active Members or by the Executive Board. Adoption of such amendments shall be by ballot in which approval is given by at least three-fourth of the total number of Active Members. There shall be an intervening Regular Meeting before the balloting and subsequent to the submission of the amendment.

ARTICLE V

Dissolution of Society

In the event it should be deemed advisable to dissolve the Society, all assets at the time of dissolution shall be donated to a worthy geologic cause, as selected by the Executive Board.

ARTICLE VI

Bylaws

The Bylaws, consisting of six (6) articles as appended hereto, are adopted and may be amended, enlarged, or reduced as provided in the Bylaws.

bylaws

AUSTIN GEOLOGICAL SOCIETY

BYLAWS

ARTICLE I

Membership

Section 1. The membership of this organization shall be made up of Active, Honorary, and Student Members.

(1) To be eligible for Active Membership, an applicant shall have a degree in geology from a recognized college or university, or the equivalent experience, or have been actively engaged in the application of geology or related scientific or professional work for a minimum of two (2) years.

(2) Consideration for Honorary Membership shall be based on continued dedication and service to the Austin Geological Society. Honorary members shall be selected by the Executive Board. Any Active Member may submit the name of an individual to the Executive Board for consideration as an Honorary Member.

(3) Any person who is a student in good standing, studying for a degree in geology or related science, is eligible for Student Membership. Student Members shall not be eligible to vote or hold elective office.

Section 2. Any member who is in arrears of dues or legally incurred indebtedness to the Society shall be suspended from the Society. The Executive Board shall restore former membership status to any such suspended member when the indebtedness has been liquidated.

Section 3. All Active, Honorary, and Student Members shall be guided by the highest standards of business ethics, personal honor, and professional conduct. Any member who, after proper investigation by the Executive Board, is found guilty of violating any of these standards of conduct may be admonished, suspended, allowed to resign, or expelled from membership at the discretion of the Executive Board.

Section 4. Applicants for membership shall submit an application and dues to the Treasurer. Membership applications shall include the following information:

(1) Professional affiliation,

(2) Education, and

(3) A statement of how the prospective member qualifies for membership.

New members shall be announced in the next newsletter and introduced to the Society at the next meeting.

ARTICLE II

Dues and Special Assessments

Section 1. The annual dues for Active Members and Student Members of the Society shall be established at the beginning of each administrative year by the Executive Board. Dues shall be payable on or before November 1 each year. No dues shall be required of Honorary Members.

Section 2. Dues for new members who join the Society after the beginning of the administrative year shall be prorated according to the quarter of the administrative year.

Section 3. Members who are in arrears for dues and/or special assessments for a period of three (3) months shall be deemed suspended and may be dropped from the rolls at the discretion of the Executive Board. Such former members may be reinstated by the Executive Board upon payment of dues and/or special assessments in arrears plus a reinstatement fee of 25 percent of the amount owed.

ARTICLE III

Officers

Section 1. The officers of this organization shall be the President, President-Elect, Vice-President, Secretary, and Treasurer. The tenure of these officers shall be one (1) administrative year.

Section 2. The duties of the President shall be to preside at all meetings, call Special Meetings, appoint such committees as are not provided for in the Bylaws, and, jointly with the Secretary and Treasurer, sign all written contracts and other obligations of the Society. The President shall assume the duties of Chairperson of the Executive Board and supervise the business of the Society. The President shall also be responsible for making arrangements for a meeting place for Regular Meetings and providing for an annual audit of financial records.

Section 3. The duties of the President-Elect shall be to participate in Executive Board meetings and serve as understudy to the President. The President-Elect will assume the office of the President the following year. The President-Elect shall also serve as Chairperson of the Election Committee.

Section 4. The duties of the Vice-President shall be to assume the office of president when a vacancy for any cause occurs and assume the duties of the President during the absence or disability of the President. In addition, the Vice-President shall serve as Chairperson of the Technical Program Committee.

Section 5. The duties of the Secretary shall be to keep the Minutes of all meetings, to attend to all correspondence and press notices, to receive and be custodian of all documents and papers of the Society, and to notify all Executive Board members of each Executive Board Meeting. The Secretary shall also serve as Chairperson of the Newsletter Committee. The Secretary, jointly with the President and Treasurer, shall sign all written contracts and other obligations of the Society and shall assume the duties of the President in the absence of the President and Vice-President.

Section 6. The duties of the Treasurer shall be to receive and disburse all funds as authorized by the Society, to keep accurate accounts thereof, and to submit annually a report of the

Treasurer's records for auditing. The Treasurer shall be present or delegate a substitute to be present at each Regular Meeting to collect monies and membership applications. The Treasurer, jointly with the President and Secretary, shall sign all written contracts and other obligations of the Society, and shall assume the duties of the President in the absence of the President, Vice-President, and Secretary.

Section 7. The Executive Board shall consist of the President, President-Elect, Vice-President, Treasurer, and the last available past President. The Executive Board's duties shall be to appoint officers to fill vacancies occurring during the administrative year, except the office of President to which the Vice-President shall succeed; and to have general supervision of the organization.

Section 8. The election of officers shall be held at the Annual Meeting. Nominations shall be made by the Election Committee consisting of the President-Elect and at least two members appointed by the President-Elect. This Committee shall nominate two or more candidates for each elective office to be announced in the Society Newsletter prior to the Annual Meeting. At the Annual Meeting, additional nominations may be made from the floor following the report of the Election Committee. The Election Committee shall be responsible for preparation, distribution, and collection of the ballots at the Annual Meeting, and the tabulation of the results of said balloting. The committee shall present the results of the balloting to the President of the Society during the Annual Meeting so that the newly elected officers may be presented to the Society. Voting shall be by secret ballot. Ballots shall be distributed during registration at the Annual Meeting and shall be returned to the Election Committee upon completion. If none of the candidates for a particular office obtains a majority of the votes cast, the candidate with the least number of votes shall be eliminated and a second ballot taken. If there is a tie between two candidates, a second ballot shall be taken at the Annual Meeting. If, after the second ballot, there is still a tie, the winner shall be decided by the flip of a coin.

ARTICLE IV

Standing Committees

Section 1. There shall be the following Standing Committees within the Society:

- Publications Committee,
- Technical Program Committee,
- Newsletter Committee,
- Field Trip Committee,
- Membership Committee,
- Web Committee,
- Election Committee, and
- Awards Committee.

The President shall appoint a Chairperson to those committees not already chaired by an officer. These appointments shall be for one administrative year. The Chairperson of a Standing Committee may, in turn, appoint any additional members in good standing with the Society to his or her committee.

In addition to the aforesaid standing committees, there is the Nominating Committee, as previously set forth in Article III, Section 8, of the Bylaws. The President may appoint any special committees as the Executive Board may authorize.

Any Committee Chairperson or member may be removed and replaced by a new appointee upon majority action of the Executive Board.

Section 2. The purpose of the Publications Committee is to oversee the sale of Society publications and assist in the publication of any other manuscripts or documents the Executive Board may authorize.

Section 3. The function of the Technical Program Committee is to provide a program for the Regular Meetings of the Society and to make necessary arrangements for that program.

Section 4. The function of the Newsletter Committee shall be to prepare and mail a newsletter to serve as an announcement of Society Meetings.

Section 5. The purpose of the Field Trip Committee shall be to organize the Society field trips on a suggested schedule of one in the fall and one in the spring.

Section 6. The Membership Committee shall encourage membership, assist the Treasurer and Newsletter Chairperson, maintain a list of active members, and prepare the Society Directory.

Section 7 The Web Committee shall be responsible for the design and upkeep of the Society Web page.

Section 8. The Awards/Scholarship Committee shall nominate and recommend award and scholarship candidates to the Executive Board.

ARTICLE V

Meetings

Section 1. The meetings of the Society shall be of three classes: Regular, Executive Board, and Annual.

Section 2. The Society shall hold at least one Regular Meeting each month from August through April except that, by vote of the Executive Board, additional Regular Meetings may be held or Regular Meetings may be discontinued for a period not to exceed three months. The appropriate time and place for Regular Meetings shall be selected by the President or a delegated Committee.

Section 3. Executive Board Meetings shall be held at such times and places and for such purposes as the Executive Board deems necessary and as announced by the President.

Section 4. The Annual Meeting shall be held during the month of May at a place and time designated by the Executive Board. The purpose of this meeting will be to complete the business of the administrative year and shall include the following order of business:

(1) Report of the Executive Board, the President, the Treasurer, and the Standing Committees. Standing Committees may be considered with the report from the President.
(2) Old or unfinished business.
(3) New business.
(4) Election of new officers.

(5) Program.
(6) Presentation of new officers.

Section 5. The administrative year shall be from August 1 of one year to July 31 of the following year.

ARTICLE VI

Awards

Section 1. The Awards Committee shall submit recommendations to the Executive Board for the Public Service Award, the Distinguished Service Award, and for scholarships to be awarded by the Society.

Section 2. The Public Service Award shall be given to recognize contribution of members to the Society to public affairs and to encourage geologists to take a more active part in such affairs. The recipient shall be a member of the Society, but may be in any class of membership. This award may be given without regard to previous awards. Granting the award in any year shall be discretionary.

Section 3. The Distinguished Service Award shall be given to members who have distinguished themselves in singular and beneficial long-term service to the Society. The emphasis shall be on long-term and, at the same time, meaningful service to the Society. The term singular does not necessarily mean without precedence, but rather that the activity be specific as distinguished from general service. More than one member of the Society may be considered in any one year for the award, but Honorary Members should generally be excluded.

Section 4. Scholarships shall be awarded from an endowed scholarship fund. The Executive Board shall select scholarship recipients from candidates recommended by the Awards Committee. Granting scholarships in any year shall be discretionary.

ARTICLE VII

Amendment to Bylaws

Amendments to the Bylaws shall be made by vote of three-fourths of the Active Members present at any Regular Meeting, provided that due notice of the proposed amendment has been submitted to the members of the Society at least two weeks in advance of the date on which the ballot is taken, and provided a quorum (twenty-five percent of the Active Membership) is present at said meeting.