Groundwater-Level Monitoring Program: Example from the Barton Springs Segment of the Edwards Aquifer, Central Texas

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ABSTRACT

Groundwater-levels are the most critical information collected about an aquifer indicating its hydrologic character and stresses. Water-level data are increasingly used by agencies to calibrate groundwater models and to design, implement, and monitor the effectiveness of groundwater management and conservation efforts. However, water-level data are often limited in frequency and geographic distribution for meaningful analyses. This paper presents an example of the Barton Springs Edwards Aquifer Conservation District (District) program to systematically collect continuous, accurate water-level data at relatively low cost and effort. The District operates a network of 19 absolute pressure transducers collecting data from wells within the Edwards and Trinity Aquifers. Absolute pressure transducers are relatively low-cost as they avoid the need for a vented cable from the probe to the surface, and have internal data loggers and power supply. The raw data is corrected for barometric effects using techniques and procedures developed at the District and the probe manufacturer. The District's water level network is a crucial component of the District's aquifer science and management program.

INTRODUCTION

Groundwater is an important resource for Texans and constituted nearly 60% of all water used by Texans in 1999 (TWDB, 2002). National trends in groundwater use have increased by 9% from 1995 to 2000 (Hutson et al., 2004).

The Edwards Aquifer in central and south-central Texas is the sole-source of water for millions of people. The Barton Springs segment of the Edwards Aquifer (Barton Springs aquifer) is a portion of this prolific karst aquifer on which approximately 50,000 people depend on as their sole source of drinking water. Permitted pumpage volume at the District has increased about 30% from 2000 to 2004. The aquifer is an important groundwater resource for industrial, recreational, and ecological needs. The principal natural discharge of the aquifer occurs primarily at Barton Springs, habitat for the federally-listed endangered Barton Springs salamander.

Groundwater levels provide critical information about the hydrologic relationships of recharge and discharge to storage within an aquifer, and the direction of groundwater flow. Long-term, systematic measurements of water-level data are essential to develop groundwater models and to design, implement, and monitor the effectiveness of groundwater management programs (Taylor and Alley, 2001). Fortunately, agencies have been measuring water levels in the Barton Springs aquifer for many years, including the United States Geological Survey (USGS), Texas Water Development Board (TWDB), and the District.

Statutory mandate requires the District to conserve, protect, and enhance the groundwater resources of the Barton Springs aquifer. As part of the District's role of managing groundwater, the District has established a water-level monitoring program.

This paper presents the essential components of the District's current water-level monitoring program and some examples of how the water-level data are used. The purpose of this paper is to give an example of an effective, accurate, reliable, and cost-effective program that may help other agencies establish a rigorous and systematic water-level program.

SETTING

The District is located within portions of Travis and Hays Counties in central Texas. The Barton Springs aquifer is located along the Balcones Fault Zone and is generally bounded to the north by the Colorado River, to the south by the city of Kyle, to the east by Interstate 35, and to the west by FM 1826 (Figure 1). The Trinity Aquifer is located below the Edwards Aquifer and to the west of the Balcones Fault Zone (the Contributing Zone in Figure 1).

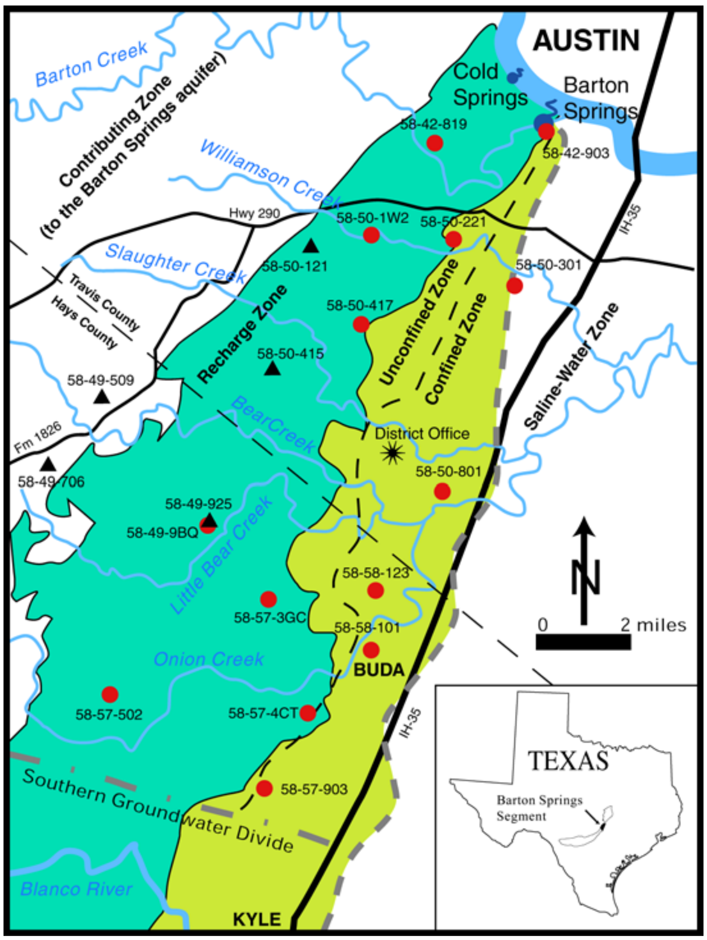


Figure 1: Location map of the study area showing hydrologic zone of the Barton Springs aquifer and monitor well locations with state well numbers. Circles indicate wells completed in the Edwards Aquifer, triangles indicate wells completed in the Middle Trinity Aquifer.

Barton Springs Aquifer

The Edwards Aquifer is a prolific karst aquifer composed of the Cretaceous-age Edwards Group (Kainer and Person Formations) and the Georgetown Formation (Rose 1972, Small et al., 1996). The aerial extent of the Barton Springs aquifer is about 155 square miles. Approximately 80 percent of the aquifer is unconfined with the remainder confined (Slade et al., 1985).

The Edwards Aquifer is geologically and hydraulically heterogeneous and anisotropic, which strongly influences groundwater flow and storage (Slade et al., 1985; Maclay and Small, 1986; Hovorka et al., 1998). Water levels and spring discharges are very dynamic and can fluctuate dramatically due to both short and long-term stresses such as pumping and recharge. Karst aquifers, such as the Barton Springs aquifer, are often described as triple porosity (and permeability) systems consisting of matrix, fracture, and conduit porosity (Ford and Williams, 1992; Quinlan et al., 1996; Palmer et al., 1999). Most of the storage of water in the Edwards Aquifer is within the matrix porosity (Hovorka et al., 1998); therefore volumetrically, flow through the aquifer is dominantly diffuse and fracture flow. However, groundwater dye tracing studies have demonstrated that significant components of groundwater flow are very rapid and influenced by conduits (Hauwert et al., 2002).

Trinity Aquifer

The Trinity Aquifer is also an important groundwater resource for central Texas and is composed of Cretaceous-age limestone and sandstone units. In the Balcones Fault Zone the Trinity Aquifer is both adjacent (to the west) and beneath the Edwards Aquifer. Previous hydrologic studies of groundwater resources acknowledge a hydraulic connection between the Trinity and Edwards Aquifers (Slade et al., 1986; Mace et al., 2000). However, the extent of that hydraulic connection, and therefore the inter-aquifer flow of water, is poorly understood. Current numerical modeling for the Barton Springs Aquifer (Scanlon et al., 2001) does not account directly for flow between the Edwards and Trinity Aquifers. Characterizing the hydraulic connection is important for predictions of groundwater availability in both aquifers and for springflow at Barton Springs. Additionally, significant inflow from the Trinity Aquifer could have impacts on the water quality of the Edwards Aquifer and its springs. Accordingly, continuous long-term water-level data will be critical to understanding the Trinity and Edwards hydraulic connection and therefore groundwater availability for the region.

MATERIALS AND METHODS: ESSENTIAL COMPONENTS OF THE WATER-LEVEL PROGRAM

Wells and Equipment

Monitor well selections were determined considering several criteria including: spatial distribution, available historic data, locations of major pumping centers, Edwards or Trinity Aquifer, confined and unconfined conditions, flow paths, well head protection, and longevity of access to the well. The District has 19 wells that contain equipment to measure water levels (Figure 1). Five wells are used to determine drought status of the Barton Springs aquifer by the District.

Figure 2. *Stefani Campbell down-loads data from the Insitu miniTroll probe onto the laptop at the Sunset Valley (58-50-417) well.*

Methods for continuous water-level measurements consist of the combined use of instantaneous e-line measurements (for the observed water level) in conjunction with an absolute pressure transducer for each well (Figure 2). The probes are In-Situ Inc. MiniTroll, 100 psi-rated, and can measure fluctuations of water levels up to 231 feet. A single absolute pressure transducer records barometric pressure changes at the District office and is used to compensate for barometric effects on the raw absolute pressure data collected at all 19 wells (discussed below). Total cost for each monitor well is about $1,000.00 ($800 probe and $200 for stainless steel wire [$0.30/ft] and other hardware items). Additional one-time equipment costs include an eline, laptop computer, and computer-probe cable.

Data Collection Frequency

Water levels and spring discharges in the Barton Springs aquifer are very dynamic and can fluctuate dramatically due to both short- and long-term trends and stresses such as pumping and climatic conditions. Therefore, only long-term and systematic collection of water-level data offers the greatest likelihood that all scales of these trends will be observed. Greater than ten years of continuous data collection is needed to observe a range of water levels and trends (Taylor and Alley, 2001).

Several of the District monitor wells have up to 10 years of historic data. In general, the frequency of data collection depends upon the purpose, variability of fluctuations, and resolution needed to fully characterize the hydrogeologic behavior of the aquifer. Due to the dynamic nature of the Edwards aquifer, and the objectives and standard operating procedures developed by the District, data is collected every 10 minutes within each well. The In-Situ MiniTroll probe can store up to 220,000 readings and internal lithium AA-batteries can last more than a year. The collection of such high-frequency data allows for short-term trends such as recharge and pumping to be observed, and allows the ability to filter out any "noise" from short-term influences such as pumping. However, only the daily minimum 'depth to water' is stored within the Districts database.

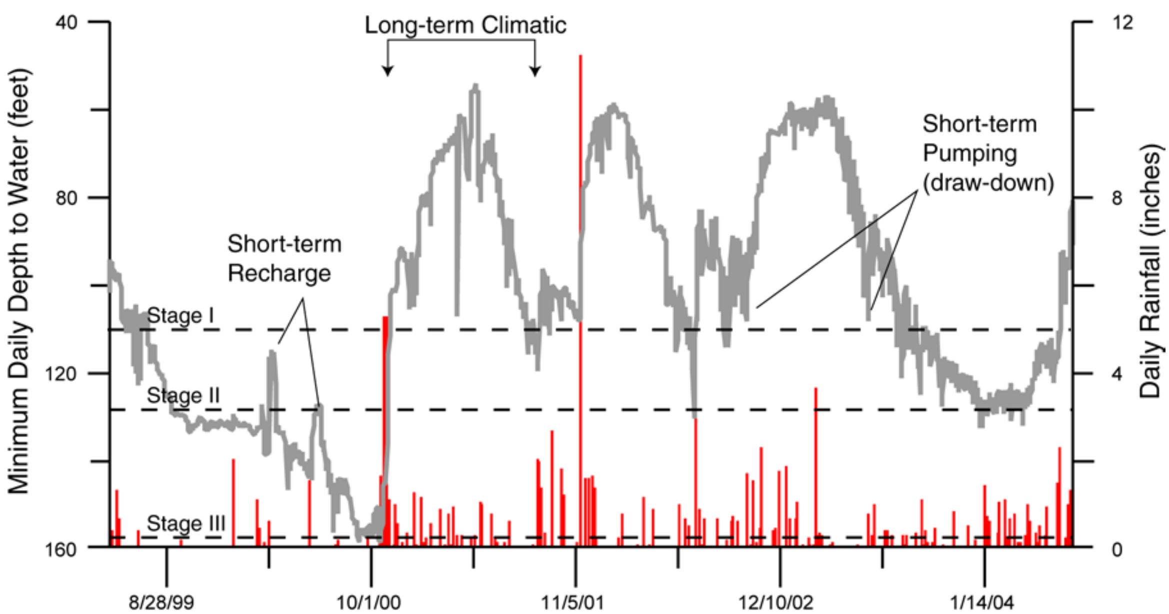


__Figure 3__: Hydrograph of the Buda monitor well illustrating the long-term and short-term fluctuations in water levels as a result of a change in storage due to climatic, recharge, and pumping influences. Bar graph indicates daily rainfall. This well is used for drought declaration and its respective triggers (Stages I-III) correspond to the historic median, lower quartile, and historic low water level, respectively.

Field Procedures

Methods for collecting continuous water-level data consist of the combined use of instantaneous measurements with an e-line in conjunction with continuous water-level changes measured with an absolute pressure transducer and datalogger.

Probes are suspended on stainless steel wire, instead of costly vented cables and can fit within ¾ inch diameter pvc pipe. This requires that the probe be physically removed from the well each time to download data. The probe is programmed to measure *changes* in absolute pressure (in feet). The data represents changes in pressure from the combined effects of the column of water above the probe and barometric (atmospheric) pressure. The next section discusses how to remove the barometric pressure effects form the data.

After the probe is deployed in the well, the 'depth to water' is measured with an e-line at the exact time the probe is scheduled to begin recording data. The depth to water is measured from a designated measuring point on each well (usually the top of casing) to the nearest 0.01 ft and recorded in a field book. Additionally, the date, time, personnel, and any comments for the measurement are recorded (such as, "recovering water level").

To extract the raw data the probe is physically pulled from the well, connected by a short cable to a laptop computer, and the data is downloaded onto a laptop computer (Figure 2).

Data Processing and Procedures

Absolute pressure transducers record *changes* in pressure from the time the probe was deployed. The changes are due to the combined effects of the water above the probe and barometric pressure. Barometric pressure changes can produce "false" water-level changes up to 1.5 ft over a period of a year. In order to obtain changes in water levels only, barometric effects are subtracted from the data collected at each well. A probe at the District office continuously measures barometric pressure changes (also recorded in units of feet). The corrected water-level data are then combined with the 'depth to water' measurement taken manually with the eline at the start of the test to produce a 'depth to water' data set (Table 1).

***Table 1**: Example spreadsheet of data processing procedures.*

Raw data from well			Raw barometric data "zeroed" to start date & time of well data		Calculation		
Raw data Date & Time	**Elapsed Time (Seconds)**	**Relative WL Change (Ft)**	**Baro. data Date & Time**	**Baro. Change (ft)**	**Corrected Relative WL Change (C-E)**	**Measured Water Depth @ T=0**	**Corrected Water Depth (G-F)**
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
10/27/03 14:35	0	0	10/27/03 14:35	0	0	-120.75	-120.75
10/27/03 14:45	600	2.081	10/27/03 14:45	-0.001	2.082	-120.75	-122.832
10/27/03 14:55	1200	4.171	10/27/03 14:55	0.008	4.163	-120.75	-124.913
10/27/03 15:05	1800	6.093	10/27/03 15:05	0.012	6.081	-120.75	-126.831

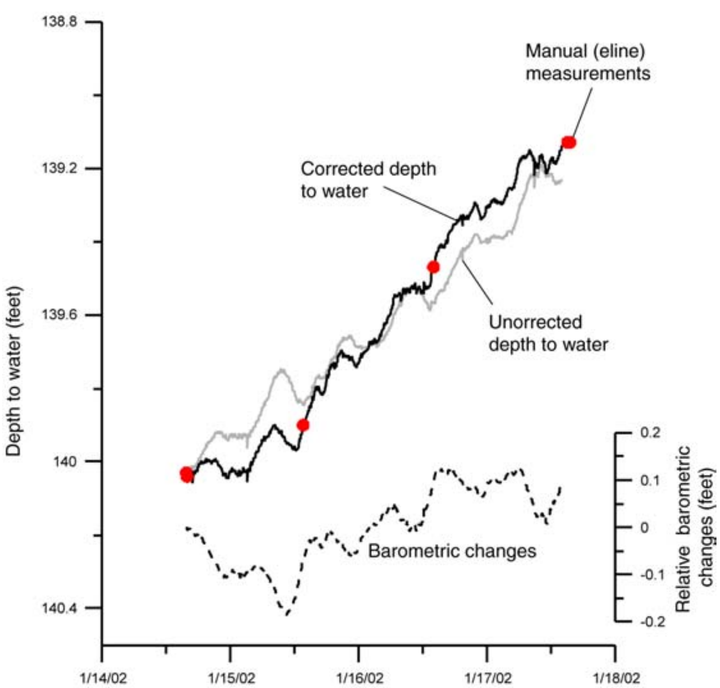


***Figure 4**: Hydrograph of water levels and relative barometric changes for the same time period. The graph illustrates the results of barometric corrections to absolute water-level data*

Quality Assurance and Control

Manufacturer reported performance accuracy for the 100-psi In-Situ Mini-Troll is 0.18 ft. Uncorrected data has an additional uncertainty, depending on the pressure changes that occur while the probe is deployed, though range from 0.01 up to 0.5 feet on average for a deployment of a few months (Figure 4).

Procedures for operating the absolute pressure transducer require that relative water-level changes be collected relative to a manual measurement (e-line). Manual measurements at the beginning of each deployment of the probe allow verification of the continuous data collected by the probes. Accordingly, any errors resulting from the barometric effects are not compounded over time, but are effectively "reset" each time data are collected.

Data Reporting and Archiving

The District has developed software (using Microsoft excel) to automate the process of barometric corrections and selection of the daily minimum, maximum, and average depth to water for input into a database. Furthermore, the District has developed a continuous water-level database (Microsoft Access), which is automatically updated from the data processing software and has graphing capability. Figure 3 is an example of the graph generated from the database for a drought trigger well.

SOURCES OF WATER-LEVEL FLUCTUATIONS

Water-level fluctuations represent changes in storage within the aquifer and are caused by hydrologic stresses that include long-term and short-term cycles described below.

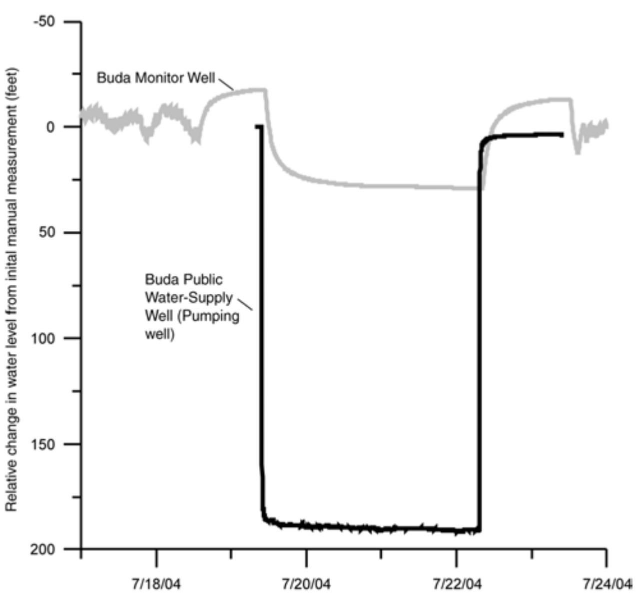
***Table 2**: Sources of water-level fluctuations*

Fluctuation Source	Approximate magnitude of fluctuation	Comment
Long-term Climatic (Months)	up to 100 ft (confined) up to 70 ft (unconfined)	
Pumping (daily)	up to 50 ft (confined)	From nearby large-capacity wells
Recharge (daily)	up to 15 ft (confined) up to 10 ft (unconfined)	Rainfall, losing streams
Barometric (daily)	up to 0.1 ft	Daily, confined conditions
Tidal (daily)	0.01 ft?	Needs further study

Long-term Climatic Variations and Drought Declaration

Long-term fluctuations in water levels represent changes in storage from recharge and discharge (spring flow and pumping). Fluctuations from drought-of-record conditions to high-flow conditions are up to greater than 75 and 100 feet in the unconfined and confined portion of the aquifer, respectively (Table 2).

The District uses 5 wells, each with its own drought trigger elevation, to determine drought status. The drought trigger elevations are based upon 50 years of water levels collected prior to 1989 by the TWDB, USGS, and the City of Austin. When at least 2 of the 5 drought trigger wells enter their respective drought declaration level for more than two weeks, the District's Board of Directors can vote to officially declare the stage of drought. Each drought stage requires conservation measures by the groundwater users of 10%, 20%, and 30% for drought stages I, II, and III, respectively (Figure 3).



Long-term water-level data is critical for calibration of numerical groundwater models. Continuous water-level data for the Barton Springs aquifer were used to develop the TWDB's Groundwater Availability Model (Scanlon et al., 2001). Continuous water-level data throughout the anisotropic and heterogeneous Barton Springs aquifer, and the Trinity Aquifer, will undoubtedly improve the accuracy and application of future generations of numerical models.

Pumping

Large-scale pumping produces visible short-term impacts to water levels as shown in Figure 3. Daily fluctuations in pumping are observed in many of the District's wells and can cause fluctuations of water levels of up to 50 feet (Table 2). Long-term effects of pumping on the aquifer under drought conditions are not as obvious and have been evaluated with a numerical groundwater model (Scanlon et al, 2001). Simulated drawdown from pumping in the southeastern portion of the aquifer due to pumping at a rate of 7,240 acre-ft/yr is up to 150 ft below drought-of-record water levels (Smith and Hunt, 2004).

Continuous monitor-well data are also used to for calculating aquifer parameters from pumping tests and to help establish pre- and post- aquifer testing trends. Periodically probes are temporarily moved to measure the effects of pumping tests on water levels near the pumping well (Figure 5).

Recharge

The Barton Springs aquifer has a very dynamic and heterogeneous response to recharge throughout the aquifer. Continuous water-level data allow scientists to better characterize aquifer response to recharge.

For example, a comparison of water-level data collected from the Wentzel quarry lake and a nearby Edwards well demonstrate the hydraulic connection of the quarry lake to the aquifer by its response to recharge (Figure 6). Accordingly, the data suggests a strong hydraulic connection and that the quarry lake reflects water-table (groundwater) conditions of the Edwards aquifer.

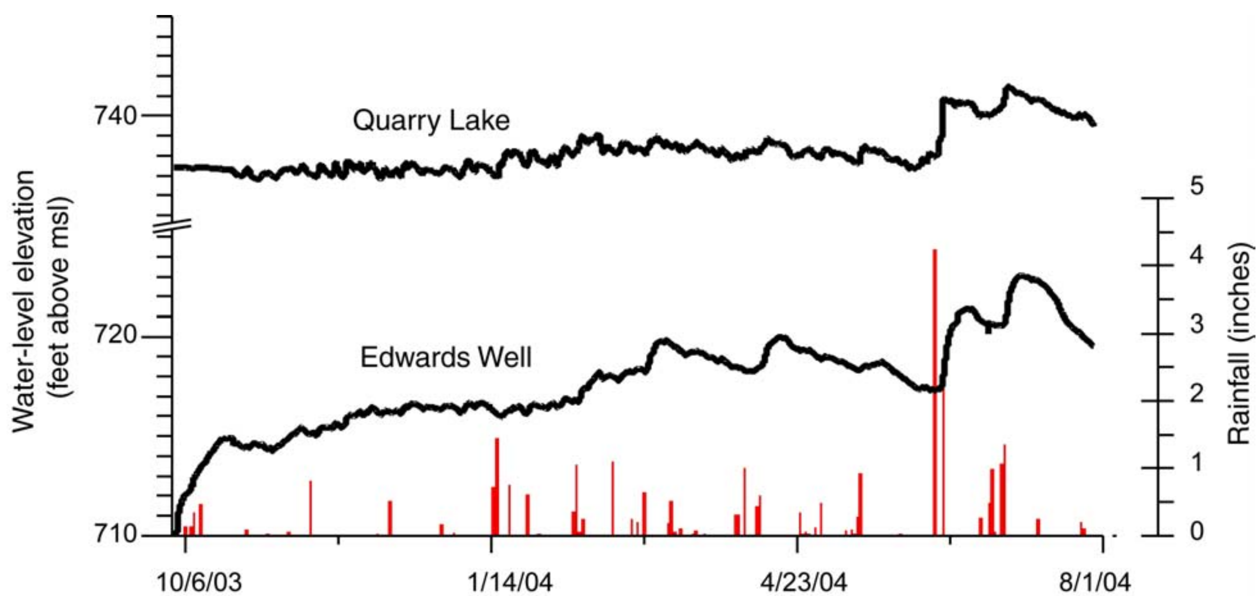


Figure 6: Hydrograph of perennial quarry lake and nearby monitor well completed in the Edwards Aquifer.

A Note About Barometric Effects

Barometric pressure acts upon the aquifer rock matrix, and water levels within a well. Water levels have an inverse relationship to barometric pressure changes and are most commonly observed in confined aquifers because of the hydraulic gradient between the well and the surrounding aquifer (Figure 4). Whereas barometric responses are not commonly observed in wells completed within unconfined aquifers because pressures are evenly distributed between water levels within a wells and the water table (Domenico and Schwartz, 1990). In areas where hydraulic gradients are low (1 foot per mile), the addition of barometric head to the elevation head increases the accuracy of data, which could result in better-inferred direction of groundwater flow.

The barometric efficiency of a confined well (58-57-903) in the Barton Springs aquifer, determined from a 2-day period, is 0.67, indicating a good relationship between water-level and barometric changes.

After correction of the false water-level fluctuations from barometric changes (due to the absolute, non-vented nature of the probe), actual water-level fluctuations of up to 0.1 feet can be attributed to changes in barometric pressure in the confined portion of the aquifer (Table 2, Figure 4). Because of the relatively high hydraulic gradients within the Barton Springs aquifer (from 6 to 100 ft per mile), no corrections for actual water-level fluctuations due to barometric effects are made to data from confined wells.

Potentiometric Maps

A potentiometric map is an imaginary surface defined by contouring locations of equal water-level elevations (head) in a well. Potentiometric maps represent a “snap shot” of regional water levels and the general direction for groundwater flow from higher to lower elevations. Aquifer characteristics, such as zones of high permeability, influence water levels and the potentiometric contours and can be a source of critical information.

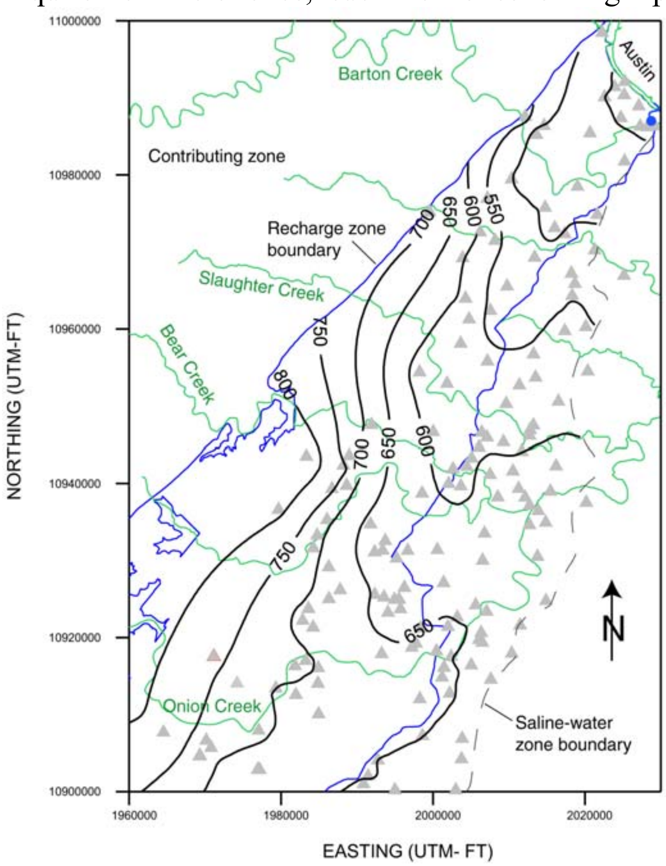


Figure 7: Potentiometric surface map of the Barton Springs aquifer during high flow conditions (February 2002). Note: gray triangles are data locations (n=175), and contours are in feet above mean sea level.

The District periodically creates potentiometric maps during different hydrologic conditions to better understand regional groundwater flow. Figure 7 illustrates a potentiometric map with water-level measurements from about 175 wells, which reveals the anisotropic nature of flow in the Barton Springs aquifer. Flow is generally west to east in the western portion of the aquifer and then flows to the northeast towards Barton Springs in the central and eastern portions of the aquifer. Troughs in the potentiometric surface represent paths of preferential flow (high permeability), verified by dye tracing (Hauwert et al., 2002). Mounds in the potentiometric surface, like that shown by the 650-ft contour line along Onion Creek, can indicate places of active recharge. Antioch Cave, the largest-capacity recharge feature in the study area is located along Onion Creek in the area of the mound. Potentiometric maps from other periods indicate regional “cones of depression” from areas with numerous large-capacity pumping wells.

CONCLUSIONS

- Absolute pressure transducers are relatively low-cost and the data is easily corrected for barometric effects using techniques and procedures developed at the District and the probe manufacturer.
- Continuous water-level data are critical to understanding the short- and long-term trends and stresses in an aquifer.
- The District's water-level program is a crucial component of the District's aquifer science and management programs.

Acknowledgements

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