Hydrologic Connection of the Edwards Aquifer between San Marcos Springs and Barton Springs, Texas

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Main Menu

Search

Author Index

Papers

Help

ABSTRACT

The Edwards Aquifer is the primary source of water for many needs in south-central Texas and is the source for several major springs. In developing a plan to manage discharge from San Marcos Springs, the concept and characteristics of a persistent hydrologic divide between the San Antonio and Barton Springs segments of the Edwards Aquifer have been questioned. To address these questions, a water-level data collection program was conducted. Water-level elevations indicate that a groundwater divide exists in the vicinity of the surface drainage divide between Onion Creek and Blanco River during wet and normal hydrologic conditions. However, data collected during the 2009 drought suggest that the groundwater divide dissipated and no longer hydrologically separated the two segments. As a result, there is potential for groundwater to flow past San Marcos Springs toward Barton Springs during major droughts. The groundwater divide appears to be influenced by recharge along Onion Creek and Blanco River, and appears to be vulnerable to extended periods of little or no recharge and pumping. The 2009 dataset shows very low gradients in the potentiometric surface between San Marco Springs and Kyle with very little variation in levels between drought and non-drought periods. From Kyle northward, the potentiometric surface slopes significantly to the north and has dramatic changes in levels between drought and non-drought periods. Structural influences or hydraulic properties inherent in the aquifer appear to change significantly in the vicinity of Kyle, and may also influence the degree of hydrologic connection between San Marcos and Barton springs.

INTRODUCTION

The Edwards Aquifer is a prolific karst aquifer and the primary source of water for municipal, industrial, domestic, irrigation, livestock, and wildlife in much of south-central Texas. It is also the source of water for several minor springs and the largest two springs in Texas, namely Comal Springs in New Braunfels and San Marcos Springs in San Marcos. These two springs are the primary sources of water in the Guadalupe and San Marcos rivers during drought conditions. In addition, the Edwards Aquifer discharges to Barton Springs in the Colorado River Basin; Barton Springs is the fourth largest spring complex in Texas.

Eight species are federally-listed as threatened or endangered at or near Comal and San Marcos Springs and additional species are proposed for listing. At Barton Springs, one species is listed as endangered and one is proposed for listing. All of them depend directly on water issuing from the Edwards Aquifer. The primary threat to these species is the loss of habitat during periods of abnormally low springflows, which are attributed to droughts and pumping. An Edwards Aquifer Recovery Implementation Program (EARIP) is being devised by a voluntary,

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multi-stakeholder group in response to the State Legislature to develop a management plan of the Edwards Aquifer to protect the federally-listed species. A federal Habitat Conservation Plan is also being developed for the endangered species at Barton Springs.

In developing a water management plan to maintain sufficient flow from San Marcos Springs during drought conditions, a question was raised on the long-standing concept of a hydrologic divide separating the San Antonio and Barton Springs segments of the Edwards Aquifer in the vicinity of Onion Creek. For hydrologic separation of the Edwards to occur, a groundwater divide (a ridge in the water table and potentiometric surface) must be sufficiently high to divert recharge and groundwater flow south of the divide to San Marcos Springs and recharge and groundwater flow north of the divide to Barton Springs. To address this question, data were collected during the severe of 2009 drought to characterize groundwater levels in a study area between San Marcos Springs and Buda, which is in the Barton Springs segment. If the 2009 data show that the groundwater divide dissipates, then pumpage in either segment could theoretically affect water levels and springflows in the other segment during drought. If the groundwater divide persists during a major drought, then one can be reasonably assured that recharge and pumpage in one segment does not significantly affect aquifer conditions in the other segment.

For regulatory purposes, the Edwards Aquifer Authority (EAA) is responsible for the San Antonio segment; and, the Barton Springs/Edwards Aquifer Conservation District (BSEACD) is responsible for the Barton Springs segment. The jurisdictional boundary between the two regulatory entities is generally along the watershed divide between Onion Creek and the Blanco River, which is also the watershed divide between the Colorado River Basin and the Guadalupe–San Antonio River Basin. Historically, it has been generally assumed that pumping in one segment does not significantly affect groundwater levels or springflow in the other segment. This assumption also applies in the calculation of recharge for the two segments. Figure 1 is a map showing the area between San Marcos Springs and Barton Springs, the Edwards Aquifer, and the regulatory boundary between the two segments.

The primary purpose of this paper is to provide an assessment of the potential for groundwater in the San Antonio segment of the Edwards Aquifer to flow past San Marcos Springs and toward the Barton Springs segment under 2009 and other recent drought and pumping conditions. The paper also places the 2009 drought in perspective with recent hydrologic conditions, estimates the magnitude of the groundwater flow passing San Marcos Springs toward Barton Springs, if any, and discusses major findings.

PREFERENTIAL GROUNDWATER FLOW ZONE BETWEEN SAN MARCOS SPRINGS AND BARTON SPRINGS

For purposes of this study, the primary hydrologic connection between San Marcos Springs and Barton Springs is believed to occur along a preferential groundwater flow zone between the two springs. The hydrologic connection between San Marcos Springs and Barton Springs under drought conditions was first discussed by Guyton and Associates (1958), and later by Senger and Kreitler (1984). A preferential groundwater flow zone near the fresh-saline water interface was proposed by Hauwert and others (2004). In this zone was delineated on the basis of geologic framework (Hanson and Small, 1995; and Small et al., 1996), hydrogeologic analyses (Baker et al., 1986; Garza, 1962), dye tracing studies (Hunt et al., 2006), groundwater modeling study (Lindgren et al., 2004; Scanlon et al., 2001), and water level data. The preferential groundwater flow zone coincides with the expected general pathway that groundwater would flow from San Marcos Springs to Barton Springs if a groundwater divide did not exist. It is shown in Figure 2 and is believed to have a relatively high transmissivity. It is located within approximately a mile (1.6 km) of the 'bad-water line',which is locally defined as a hydrochemical boundary of Edwards groundwater at a total dissolved solids concentration of 1,000 milligrams per liter (mg/L). Inspection of the distribution of hydraulic conductivity in the U.S. Geological Survey MODFLOW model of the Edwards Aquifer shows a zone of relatively high transmissivity and a conduit between San Marcos Springs and Kyle (Lindgren et al., 2004). A study by Hunt et al. (2006) shows groundwater flow paths connecting several recharge features to Barton Springs and possibly to San Marcos Springs. All major springs discharging from the Edwards (Balcones Fault Zone) Aquifer, and many large pumping centers, are in the vicinity of the 'bad-water line.' For clarification, the term 'preferential groundwater flow zone' concept in this paper represents a much broader and diffuse area of relatively high rates of groundwater flow than the concept of 'conduits' that was presented by Lindgren et al. (2004).

Main Menu
Search
Author Index
Papers
Help

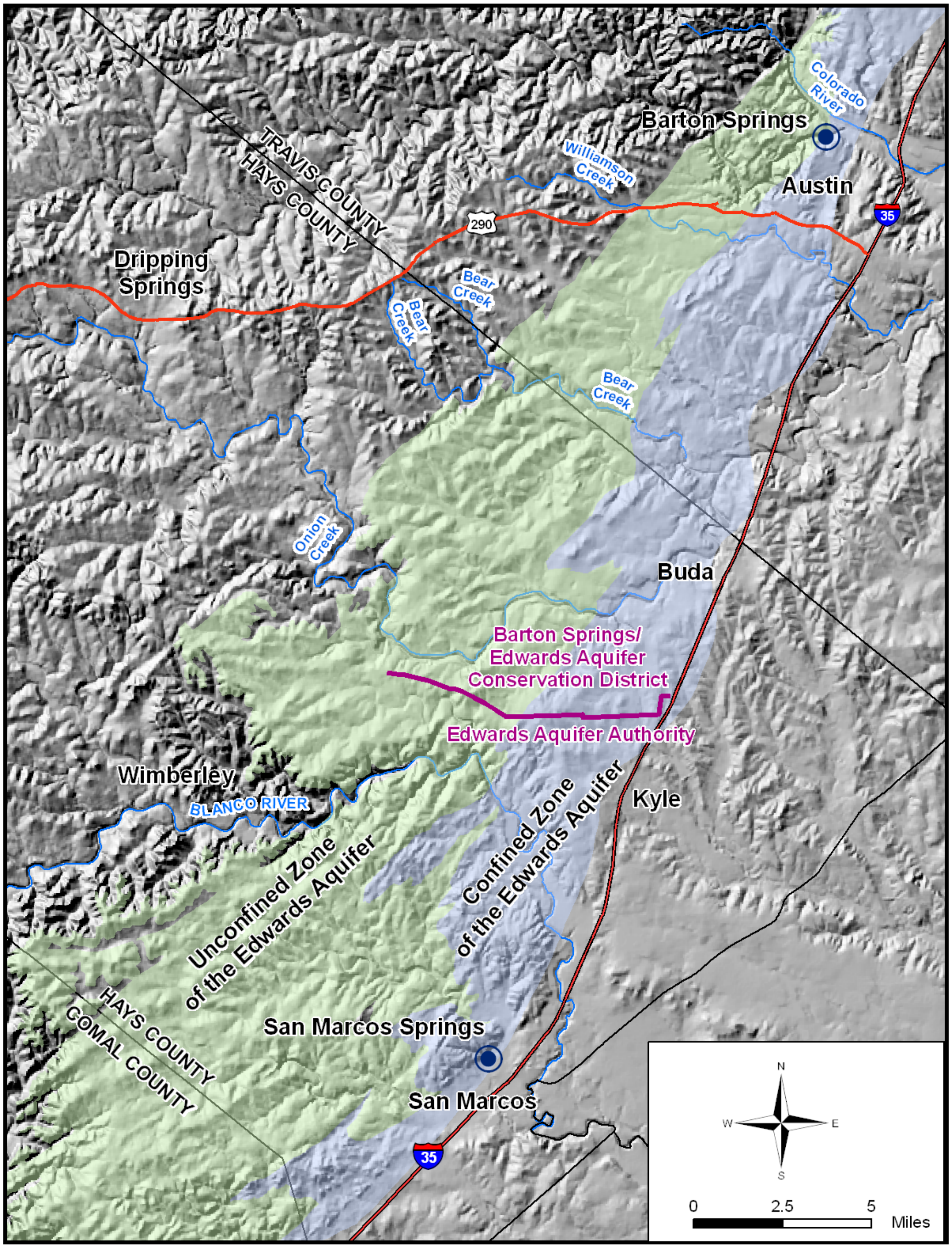

Figure 1. Location of study area, Edwards Aquifer, and Edwards Aquifer Authority, and Barton Springs/Edwards Aquifer Conservation Districts. 5 mi = ~8 km.

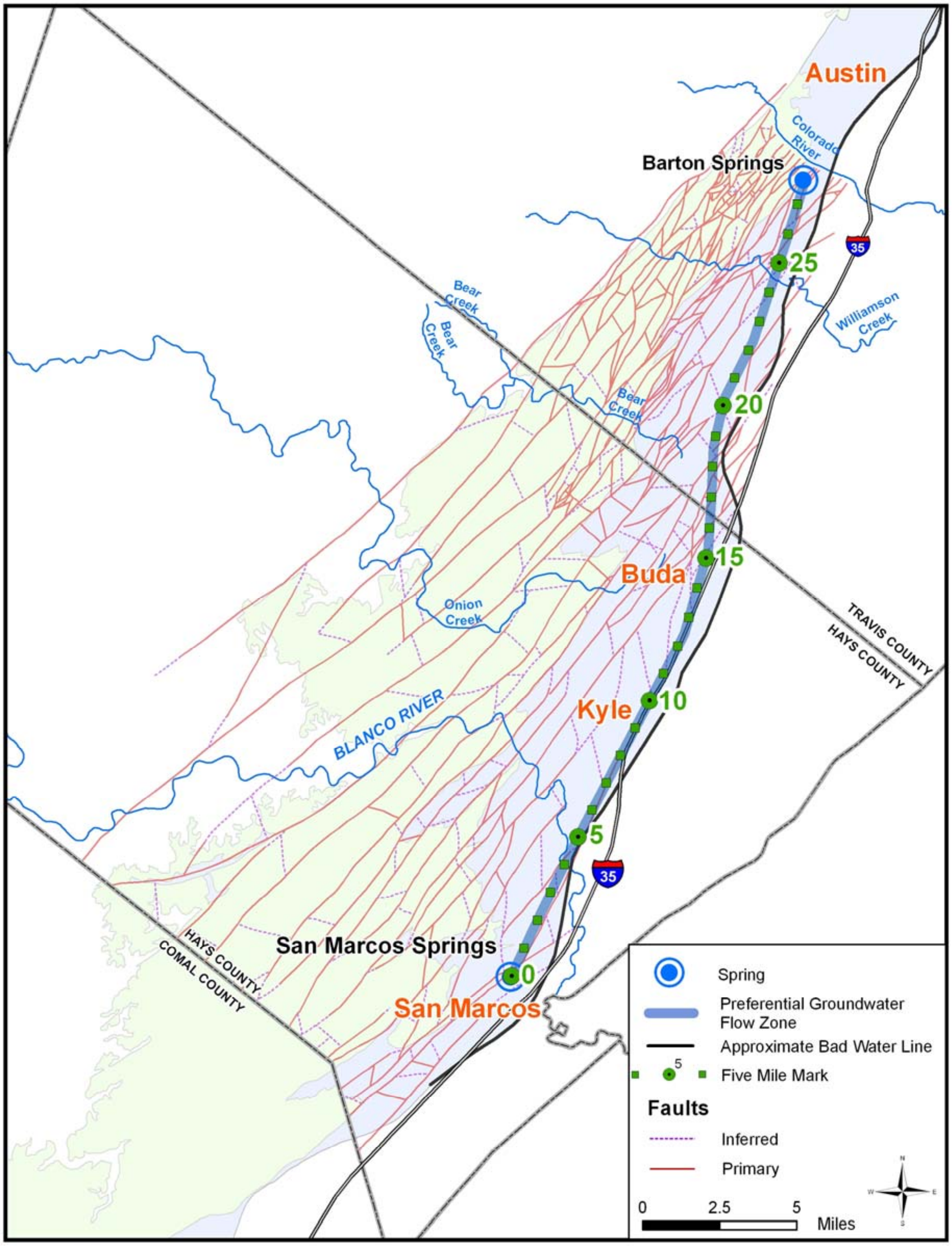

Figure 2. Location of preferential groundwater flow zone. 5 mi = ~ 8 km.

Main Menu
Search
Author Index
Papers
Help

OVERVIEW OF HYDROLOGIC CONDITIONS

1989-2009 Conditions

Springflow data for San Marcos Springs and Barton Springs were compiled from the U.S. Geological Survey database. Hydrographs of these data since 1989 are presented in Figure 3. These data show, from the perspective of springflow, that the 2009 drought had similar severity to the ones in 1989, 1996, 2000, and 2006, though the 2000 drought affected Barton Springs more severely than San Marcos Springs. In addition to dry weather conditions, the springflow also reflects the magnitude of groundwater pumping in the contributing area.

2009 Conditions

The hydrologic conditions during 2009 can be generally characterized with records from U.S. Geological Survey streamflow gaging stations: 08158827 Onion Creek at Twin Creeks Road, 08171000 Blanco River at Wimberley, and 08171300 Blanco River near Kyle. Prior to September 10, these data show that the streamflow at Onion Creek and Blanco River–Kyle was zero except for occasional runoff events. The Blanco River–Wimberley record shows a stable flow of about 12-15 cubic ft per sec (cfs) (0.34-0.42 cubic m per sec [cms]) through April, decreasing discharge until July, and about 5-6 cfs (0.14-0.17 cms) of flow in July and August. With the Blanco River–Kyle having no flow most all the time, it is generally understood that essentially all the Blanco River–Wimberley streamflow became recharge to the Edwards Aquifer.

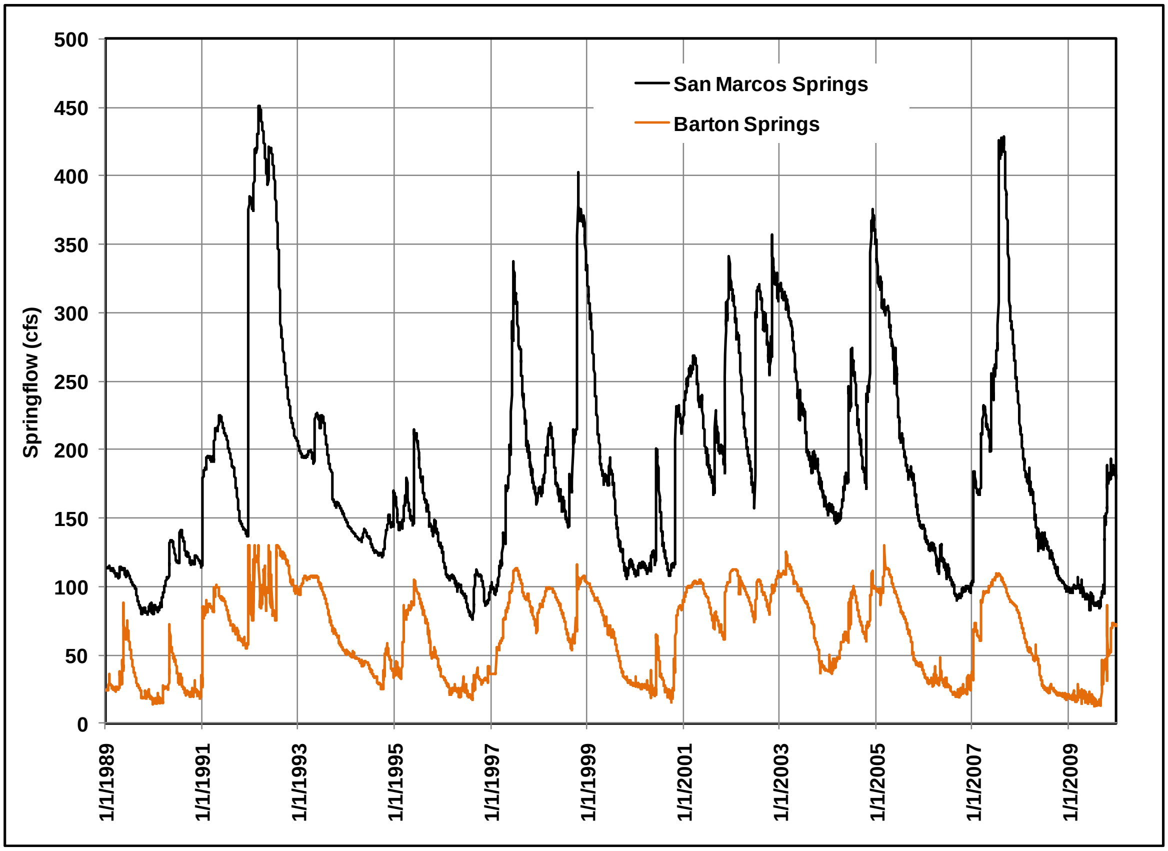

Figure 3. Discharge hydrographs of San Marcos and Barton Springs: 1989-2009. 1 cfs = 0.028 cms.

Lower Colorado River Authority's (LCRA's) Hydromet precipitation station Onion Creek at Buda was selected to provide information on rainfall during 2009 for the study area. These data are collected electronically at approximately 15-min intervals and appear to be complete for 2009. From May 25 to about September 12, the total rainfall was about 2.5 in (6.4 cm). From September 12 to the end of the year, about 20 in (51 cm) were recorded. Graphs of the monthly rainfall data are shown in Figure 4.

APPROACH

Data Collection, Compilation, and Analysis

A 2009 drought data collection program was designed and implemented in the area between San Marcos Springs and Buda. The program was planned by the Guadalupe-Blanco River Authority (GBRA), BSEACD, U.S. Geological Survey, and HDR Engineering, Inc. (HDR). Data collection was performed by the U.S. Geological Survey and BSEACD at the monitoring wells shown in Figure 5, which consisted of ten existing water wells. From late June to December 2009, water levels were measured by the U.S. Geological Survey at approximately two-week intervals. Four of the ten wells were instrumented with pressure transducers with electronic data loggers, which were programmed to provide measurements at one-hour intervals. For purposes of this study, these data are considered to be a continuous recording of water levels. Supplemental data were available from the San Antonio Water System (SAWS) and the U.S. Geological Survey for four SAWS monitor wells along a northwest-southeast transect through Kyle. Data analyses were performed by HDR and included significant consultation with GBRA, BSEACD, and U.S. Geological Survey scientists and engineers.

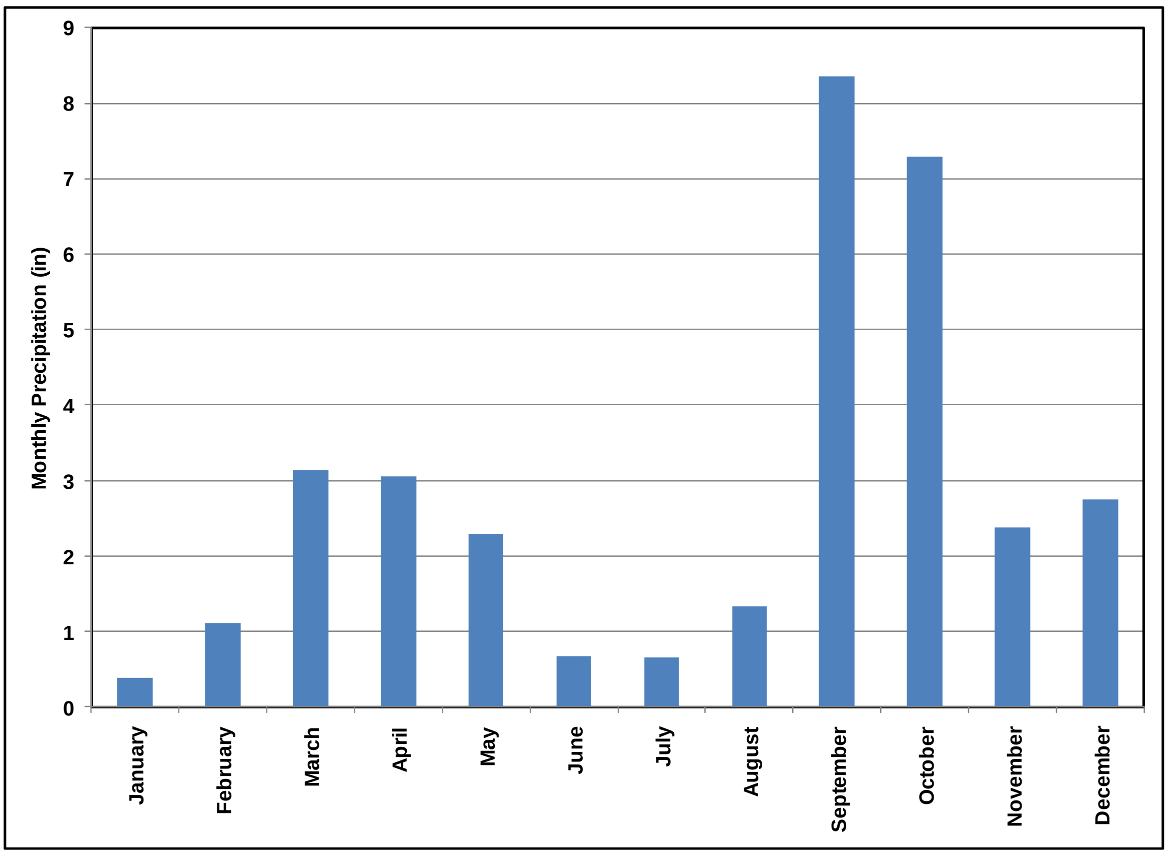

Figure 4. Monthly precipitation: 2009. 1 in = ~2.54 cm.

Other aquifer data were compiled from Texas Water Development Board (TWDB), BSEACD, EAA, and USGS databases for a hydrologic perspective on the 2009 drought. These data included groundwater levels from wells in the study area, springflow from San Marcos and Barton Springs. In addition, hydrologic conditions for 2009 were characterized with streamflow data from the Blanco River and Onion Creek and precipitation data from the Lower Colorado River Authority (LCRA) gage near Onion Creek.

Analyses of the direction of groundwater flow are based primarily on water-level profiles that were drawn along the preferential groundwater flow zone from the data collected during this study. Although the study area is an anisotropic karst system, the hydraulic gradient does provide critical information into the potential for groundwater flow, which is based on the slope of the profile (hydraulic gradient) along the preferential ground-water flow zone.

Groundwater Flow near San Marcos Springs

Lacking site-specific aquifer transmissivity data in the study area, the Edwards Aquifer–San Antonio Region Groundwater Availability Model (EA-SAR GAM) was used. This model extends from the Brackettville area to

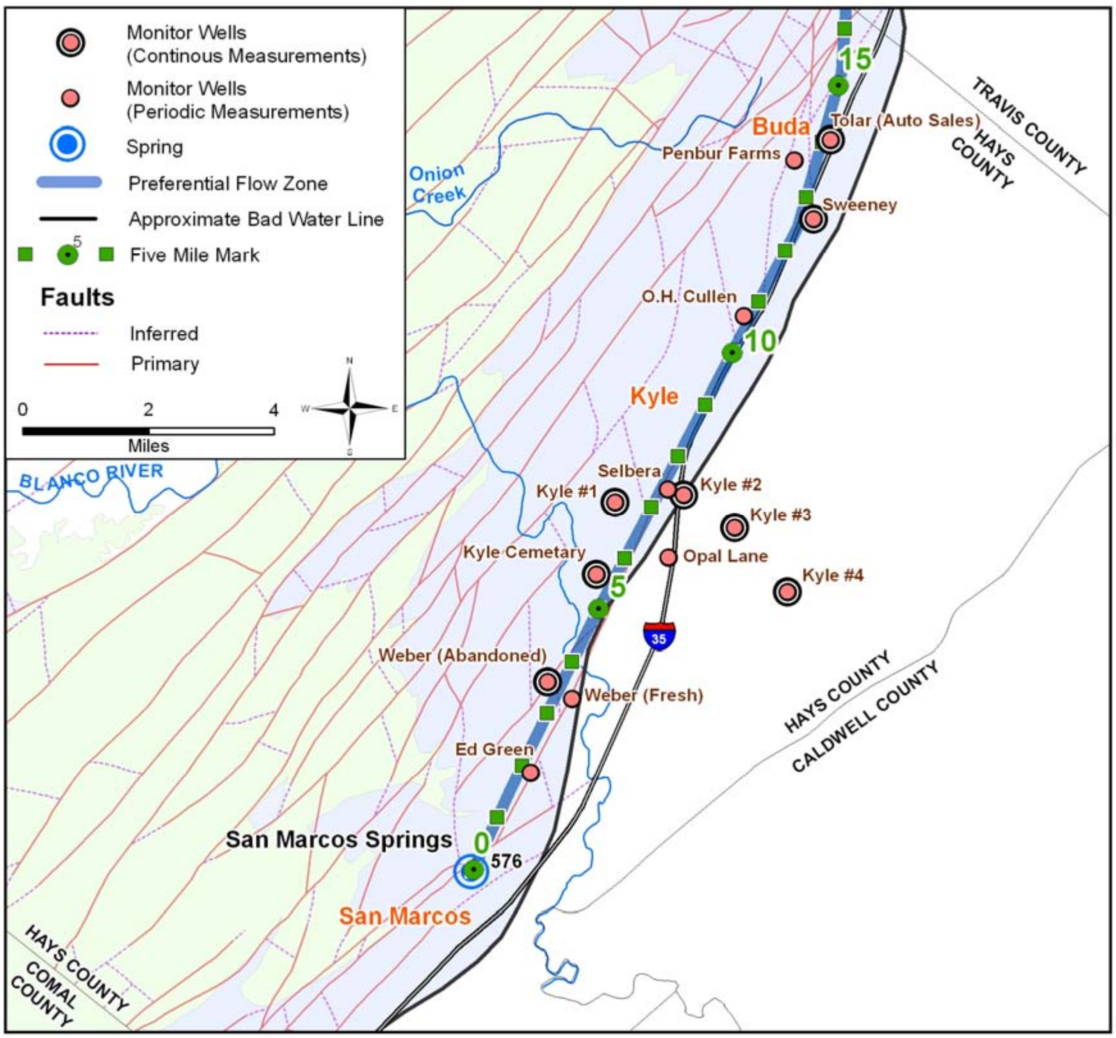

Figure 5. Location of monitor wells in 2009 study. 4 mi = ~6.4 km.

the Colorado River. A minor limitation of the model is that calibration procedures did not include the Travis County part of the model area. However, the hydrogeology in this area was represented with information from the Edwards Aquifer–Barton Springs Segment Groundwater Availability Model (EA-BS GAM) (Scanlon el at., 2001) and other sources. The rate of groundwater flow near San Marcos Springs was calculated from a simulation using the 1947-2000 calibration dataset. Calculations of the groundwater flow were made for selected months during two major droughts and two wet periods.

2009 DATA SUMMARY

Periodic Measurements

Periodic water level measurements were made in the network of ten existing monitor wells at approximately two week intervals from late June through December of 2009. The preliminary data provided by the U.S. Geological Survey were reviewed and some measurements were revised on the basis of: (1) data measurements by the pressure transducers, (2) consistency with nearby wells, and (3) hydrograph patterns. These data are summarized in Figure 6 for the monitor wells between San Marcos Springs and Kyle and in Figure 7 for wells between Kyle and Buda.

For the monitor wells between San Marcos Springs and Kyle, the maximum water level fluctuation was about 5 ft (1.5 m) and generally had a very consistent pattern among the wells. The Opal Lane well is in the saline zone of the Edwards and shows water levels to be about 4 ft (1.2 m) higher than nearby freshwater wells.

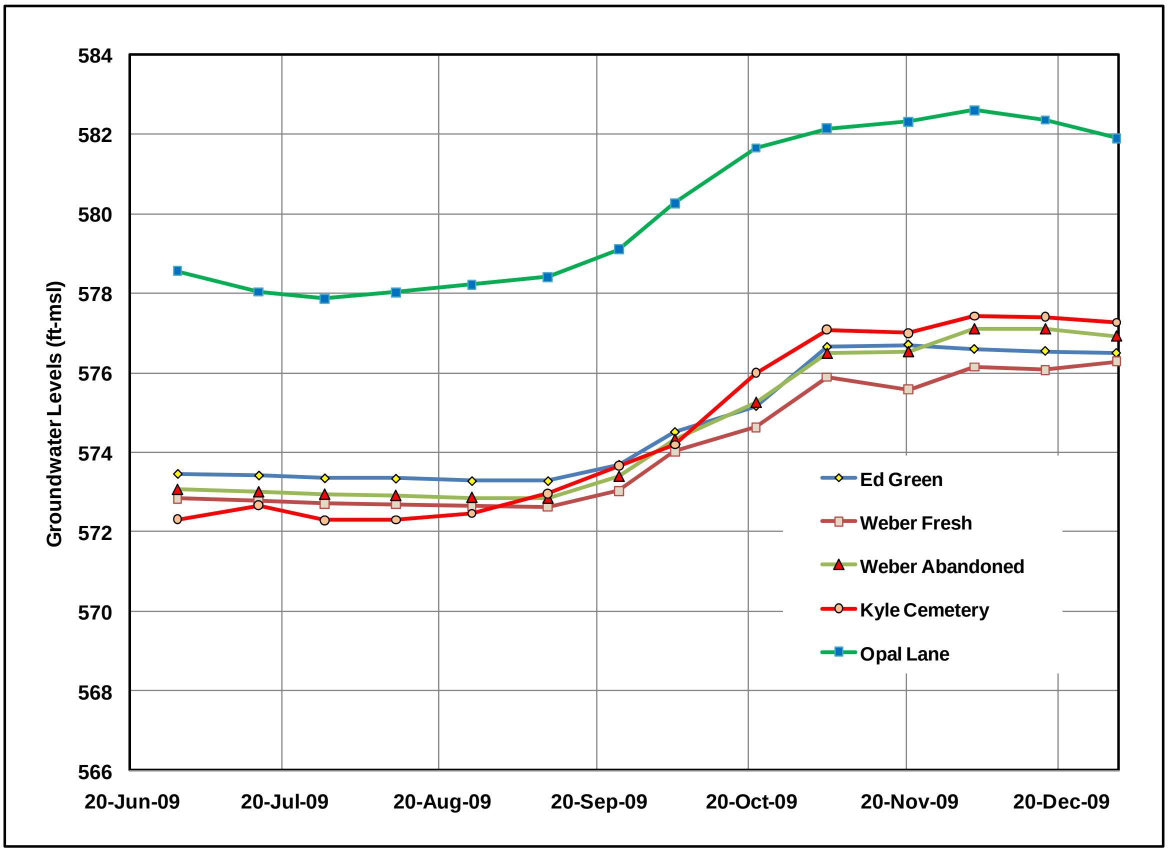

Figure 6. Groundwater level hydrographs for 2009 study monitor wells: San Marcos Springs to Kyle. 2 ft = ~0.6 m. msl, mean sea level.

Wells closer to San Marcos Springs (Ed Green, Weber Fresh, and Weber Abandoned) have smaller fluctuations than wells near Kyle (Kyle Cemetery and Opal Lane).

Data from monitor wells between Kyle and Buda show a maximum fluctuation of about 60 ft (18 m) with the lowest levels occurring in early September and the highest levels at the end of the year. The patterns are slightly erratic, which is attributed to nearby pumping wells and occasional recharge events. The Selbera well and SAWS Kyle monitor wells #1 and #2 have an unusual pattern with slightly rising groundwater levels through October and a noticeable decline by late December. Pumping records for 2009 show the City of Kyle's five public supply wells had widely varying monthly pumping rates. These data show that the well in the BSEACD has a typical demand pattern that trends from about 6,800,000 gallons (gal) (26,000,000 liters) in January to 13,200,000 gal (50,000,000 liters) in July to 6,400,000 gal (24,000,000 liters) in December. The EAA permitted wells range from 11,100,000 gal (42,000,000 liters) in January to 20,300,000 gal (77,000,000 liters) in July, abruptly decreases to 9,400,000 and 5,000,000 gal (36,000,000 and 19,000,000 liters) in August and September, respectively, and abruptly increases to 22,800,000 and 47,200,000 gal (86,000,000 and 179,000,000 liters in November and December, respectively. This unusual pumping pattern of the EAA permitted wells is believed to be the cause of the water level fluctuations in the Selbera well and SAWS Kyle wells #1 and #2 monitor wells.

Main Menu
Search
Author Index
Papers
Help

Continuous Measurements

Water level measurements were recorded at hourly intervals at the Weber Abandoned, Kyle Cemetery, Sweeney, and Tolar (Auto Sales) monitor wells by digital data loggers and pressure transducers. These results are summarized in Figure 8 and show groundwater level recoveries follow a major rainfall event on September 13

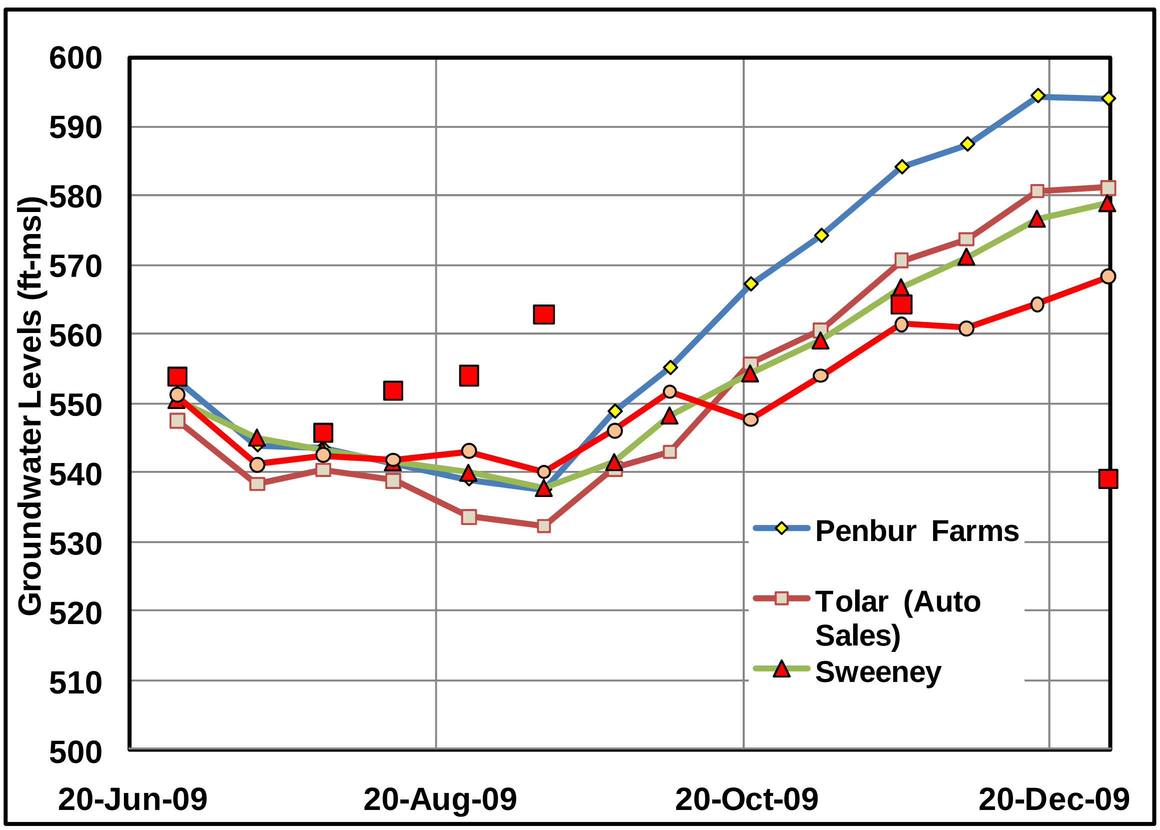

Figure 7. Groundwater level hydrographs for 2009 study monitor wells: Kyle to Buda. 10 ft = ~3 m.

and other rainfall events during the remainder of the year. The recovery continued until the end of the year for the wells near Buda, but ended in early December for the monitor wells between San Marcos Springs and Kyle.

SAWS has conducted a test drilling program and installed four monitor wells in a northwest-southeast transect through Kyle. These monitor wells are equipped with pressure transducers and data loggers. Kyle #1 monitor well is in the freshwater zone; Kyle #2 is in the transition zone between the freshwater and saline zones; and Kyle #3 and #4 are in the saline zone. Summaries of the 2009 water levels from these wells are presented in Figure 9. Monitor wells Kyle #1 and #2 have a hydrograph pattern similar to the Selbera well where recovery occurs from late July to early November and rather rapid declines occur to the end of the year. Water levels for monitor wells in the saline zone were very flat and did not track with the dominant pattern in the freshwater zone.

GROUNDWATER FLOW

February-March 2009 Conditions

A synoptic survey of groundwater levels was conducted from mid-February to mid-March 2009 by the EAA, City of Austin (COA), and BSEACD from a large network of monitoring wells. These data were collected during a relatively short time to provide a snap-shot of hydrologic conditions during a relatively short period of time. Conducting the survey in the winter minimizes the interference of pumping wells. These data were mapped in the study area and groundwater-level contours were drawn Fig. 10. In the area of key interest, these data indicate that there is a continuous declining hydraulic gradient from San Marcos Springs to Barton Springs along the preferential groundwater-flow zone.

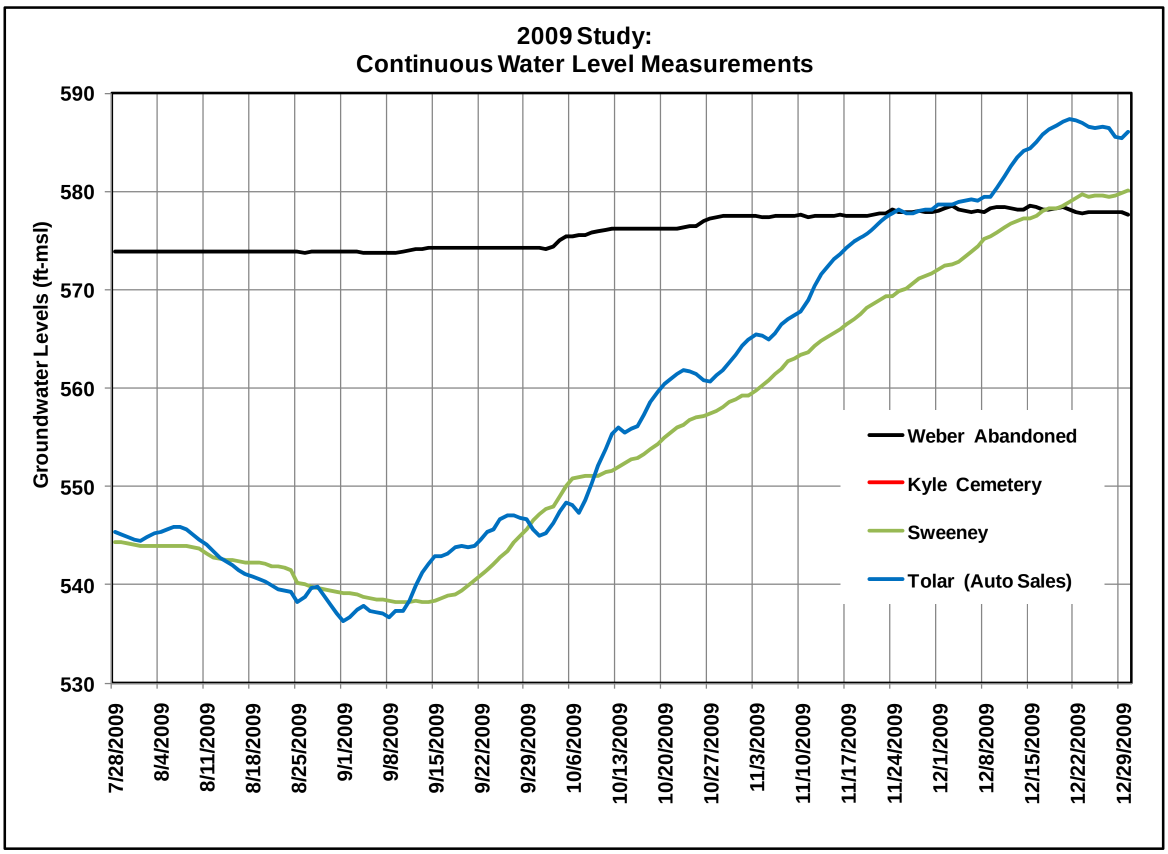

Figure 8. Groundwater level hydrographs for 2009 study monitor wells with data loggers. 10 ft = ~3 m.

The February-March 2009 synoptic water level data used in this paper were collected in a joint effort between the EAA, BSEACD and COA to evaluate groundwater conditions near the boundary between the two districts. The data were also used by the EAA to plan tracer testing projects in Hays County and to complete the San Marcos Pool report. The EAA and COA were not involved in the data interpretation or any other aspects of developing this paper.

2009 Drought and Wet Conditions

The hydrologic extremes during 2009 are considered to be August 26 data for drought conditions and December 31 data for wet conditions. The locations of the monitor wells and the groundwater levels for the selected drought and wet conditions are shown in Figures 11 and 12, respectively. Figure 13 shows a profile of the groundwater levels along the preferential flow zone for drought conditions (August 26). At this time, there was: (1) a very mild slope of the hydraulic gradient from San Marcos Springs to a few miles south of Kyle, (2) a rather steep hydraulic gradient in the vicinity of Kyle toward Barton Springs, and (3) a moderate hydraulic gradient from north of Kyle to Buda and on toward Barton Springs. Figure 14 shows the profile for wet conditions (December 31), the data show that the hydraulic gradient from San Marcos Springs to Kyle has reversed and began to slope toward San Marcos Springs. Also, a cone of depression remained in the vicinity of Kyle which caused a rather steep hydraulic gradient from Buda to Kyle. In summary, these analyses suggest that during the 2009 drought groundwater flowing from the San Antonio region has the potential to bypass San Marcos Springs and flow across the divide between the jurisdictions of EAA and BSEACD. During the 2009 wet conditions,

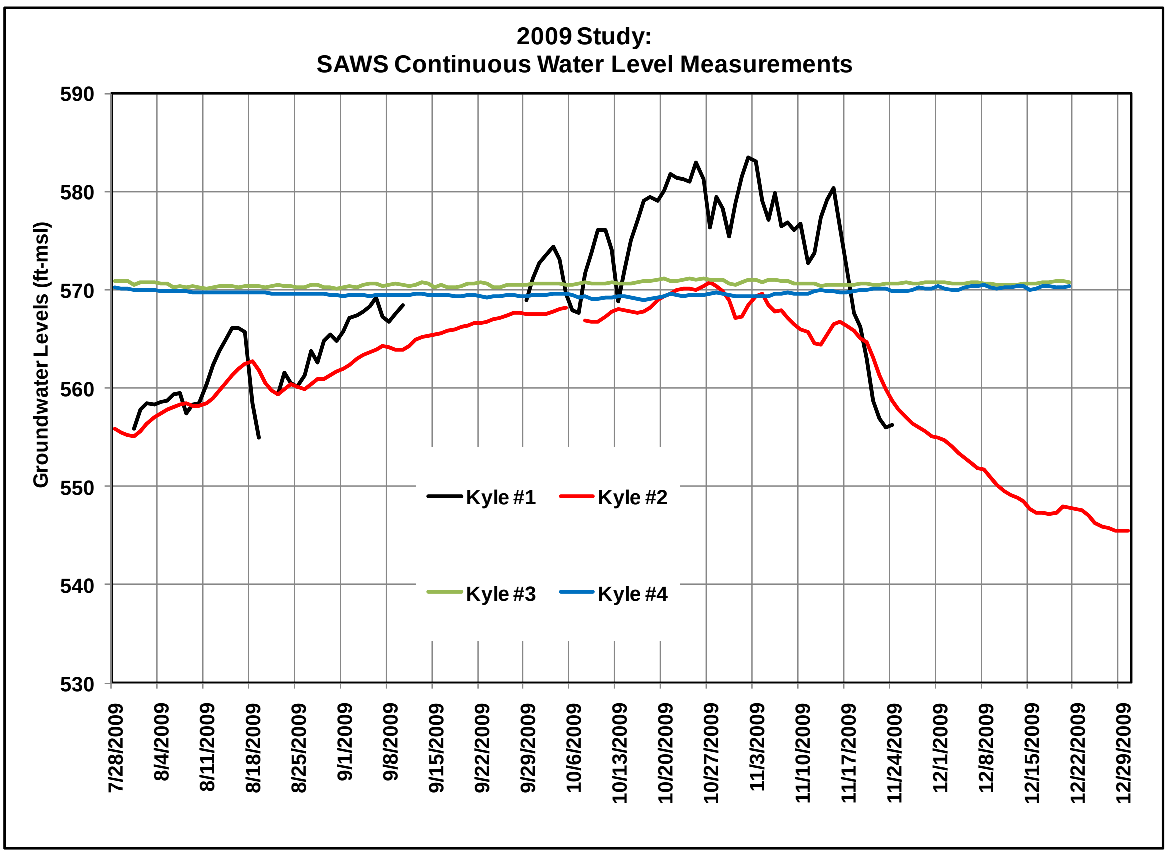

Figure 9. Groundwater level hydrographs for SAWS monitor wells along the Kyle transect. 10 ft = ~3 m.

local recharge reestablished a hydrologic divide in the vicinity of Onion Creek, which reversed the direction of groundwater flow.

Groundwater Flow Bypassing San Marcos Springs

There are not sufficient hydraulic property data on the Edwards Aquifer along the preferential groundwater flow zone to accurately calculate groundwater flow from the San Marcos Springs area to the Buda area. As an alternative, calculations of groundwater flow past San Marcos Springs were made with the EA-SAR GAM. The underflow toward or away from San Marcos Springs was calculated across a mile long transect that was drawn through a model column of cells immediately northeast of the model cell with San Marcos Springs. The flux (groundwater flow) across this transect was calculated for two major droughts and two periods of high groundwater conditions. For drought conditions, the model calculates groundwater flow bypassing San Marcos Springs and moving toward Barton Springs at rates of 3.4 and 6.1 cfs (0.10 and 0.17 cms) for August 1956 and August 1996, respectively. For wet conditions, the model shows groundwater flow across the transect from the Kyle area to San Marcos Springs at rates of 46 and 150 cfs (1.3 and 4.2 cms) for July 1992 and May 1995, respectively. Using these results as a guide, the 2009 drought underflow past San Marcos Springs is estimated at about 5 cfs (0.14 cms) during the most intense part of the drought. At that time, Barton Springs was flowing about 15 cfs (0.42 cms). This analysis does not necessarily mean that groundwater flowing past San Marcos Springs actually discharges from Barton Springs. However, much of the groundwater passing San Marcos Springs probably becomes recharge to the Barton Springs segment of the Edwards Aquifer and supports both pumpage and discharge from Barton Springs. The response time between groundwater passing San Marcos Springs and entering the Barton Springs segment from the San Antonio segment is not known. Also, the effect of groundwater flow bypassing San Marcos Springs on discharge from Barton Springs is not known.

MAJOR FINDINGS

Analyses of the water level data collected during the 2009 drought were undertaken to determine the potential for a hydrologic connection between the San Antonio and Barton Springs segments of the Edwards Aquifer. The analyses of these water level data and other available data show:

- There appears to be continuity in the direction of groundwater flow along the preferential groundwater flow zone from San Marcos Springs to Barton Springs during the 2009 drought. Thus, there is a potential for groundwater flow from San Marcos to Barton Springs during drought conditions.
- During the most intense part of the 2009 drought, the magnitude of the groundwater flow passing San Marcos Springs and flowing toward Barton Springs was estimated at about 5 cfs (0.14 cms). This rate was estimated using calibration results in the U.S. Geological Survey MODFLOW model (Lindgren et al., 2004).
- Following several major recharge events beginning in mid-September 2009, a groundwater divide was reestablished in the vicinity of Onion Creek. As a result, the direction of groundwater flow reversed and began flowing from the vicinity of Kyle to San Marcos Springs during these wetter conditions.
- Water level data in the vicinity of Buda show a maximum recovery of about 60 ft (18.3 m) by the end of 2009, but are still much lower than historic high conditions and are only slightly higher than San Marcos Springs.
- There is a major discontinuity in hydraulic gradient and water levels in the vicinity of Kyle.
- There is an area of nearly flat water levels from San Marcos Springs to near Kyle, which is consistent with the inferred zone of high transmissivity.
- In the vicinity of Kyle, substantial changes in groundwater levels during the 2009 data collection period indicate a zone of relatively low transmissivity.
- Faults do not appear to be a strong controlling factor between the zones of relatively high and low transmissivity in the vicinity of Kyle.

Main Menu
Search
Author Index
Papers
Help

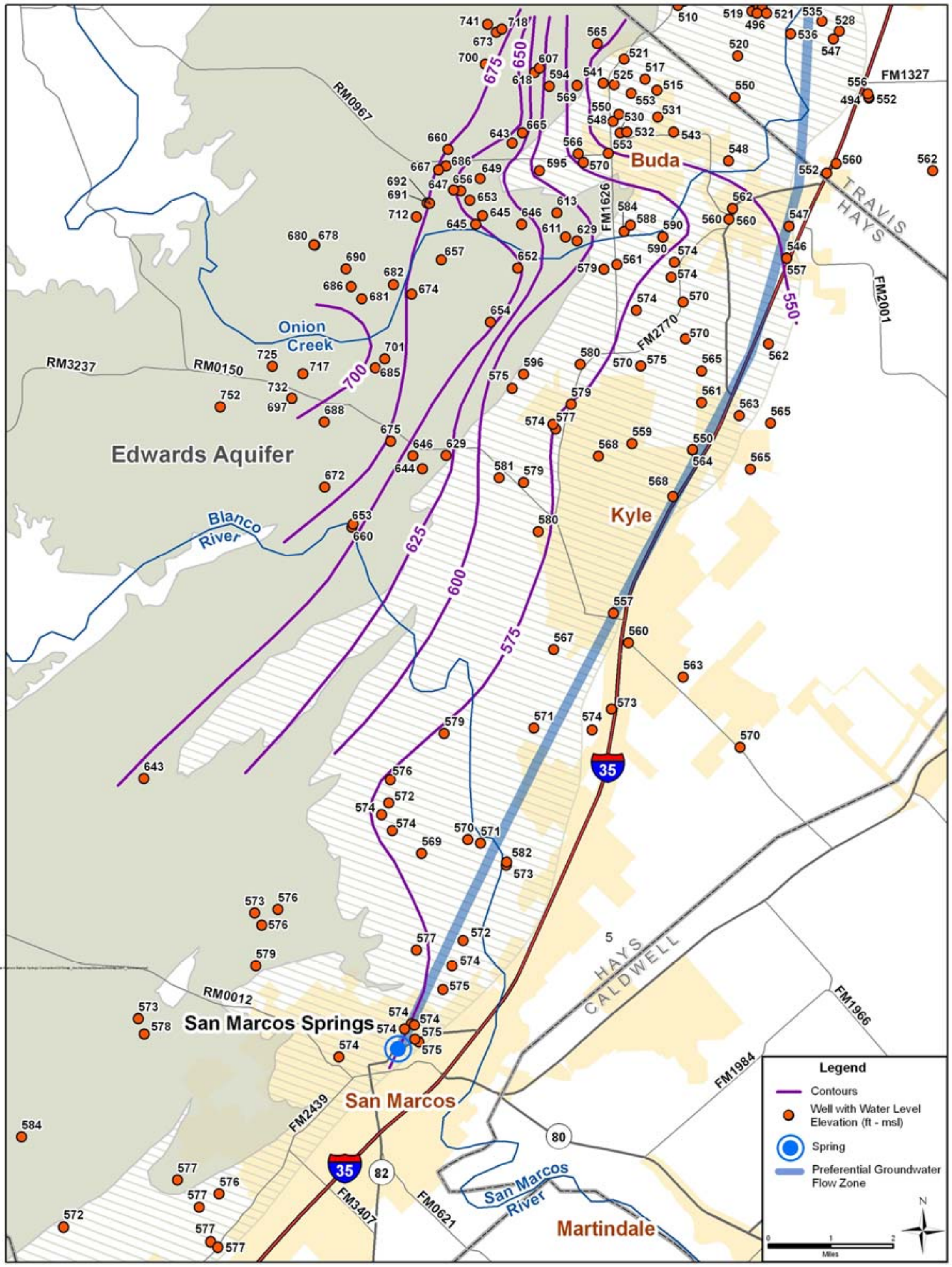

Figure 10. Groundwater level map for mid-February to mid-March 2009 from synoptic survey by EAA and BSEACD. 2 mi = ~3.2 km. 1 ft = 0.3 m.

ACKNOWLEDGMENTS

This study was planned by Dr. Todd Votteler and Tommy Hill of the Guadalupe-Blanco River Authority, Brian Hunt and Brian Smith of the Barton Springs/Edwards Aquifer Conservation District, Mike Dorsey and Marylynn Musgrove of the U. S. Geological Survey, and Larry Land of HDR Engineering, Inc. Data collection was performed primarily by the Venezia Chavez of the U. S. Geological Survey and Brian Hunt of the BSEACD. The study was greatly supported by existing data that were made available from the U. S. Geological Survey, Texas Water Development Board, Edwards Aquifer Authority, and the San Antonio Water System databases. Larry Land, P.E., prepared the initial data summaries, analyses and interpretations. This paper and the final report greatly benefitted from suggestions and review comments by all of the team members, Kirk Holland, P.G., of BSEACD, and Sam Vaugh, P.E., and Paula Jo Lemonds, P.E., P.G., of HDR.

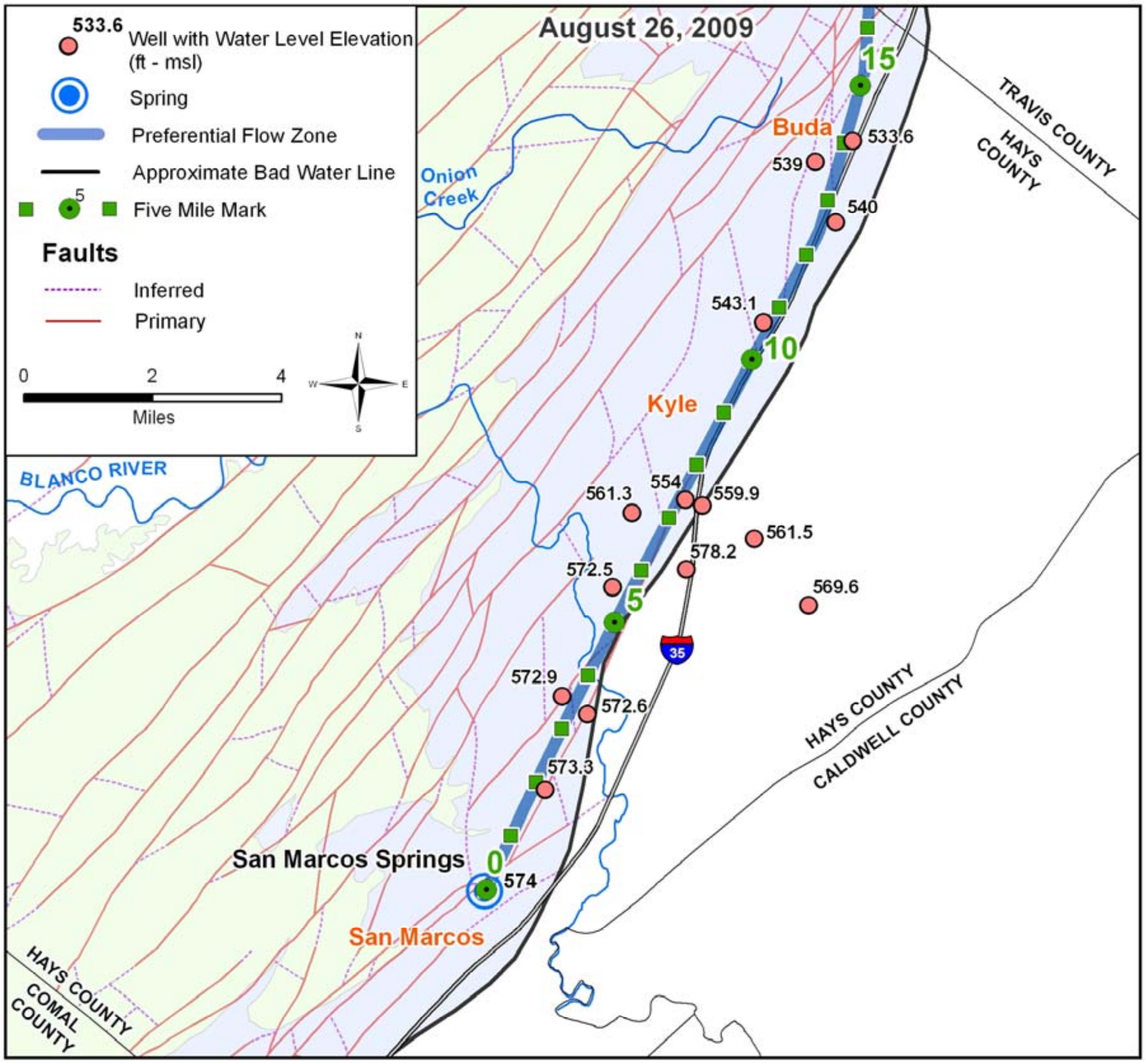

Figure 11. Groundwater levels for drought conditions: August 26, 2009. 4 mi = ~6.4 km. 1 ft = 0.3 m.

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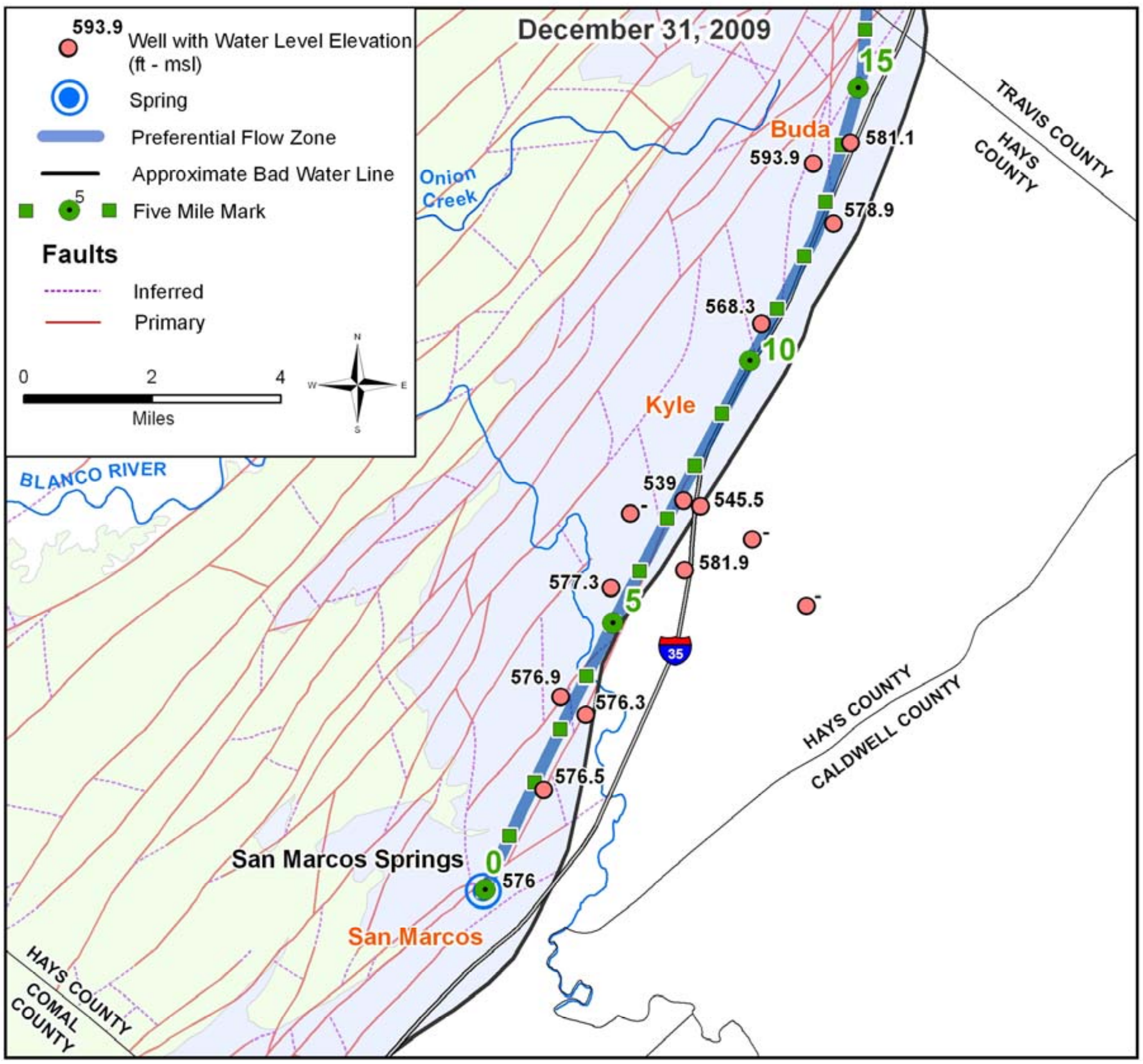

Figure 12. Groundwater levels for wet conditions: December 31, 2009. 4 mi = ~6.4 km. 1 ft = 0.3 m.

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Main Menu
Search
Author Index
Papers
Help

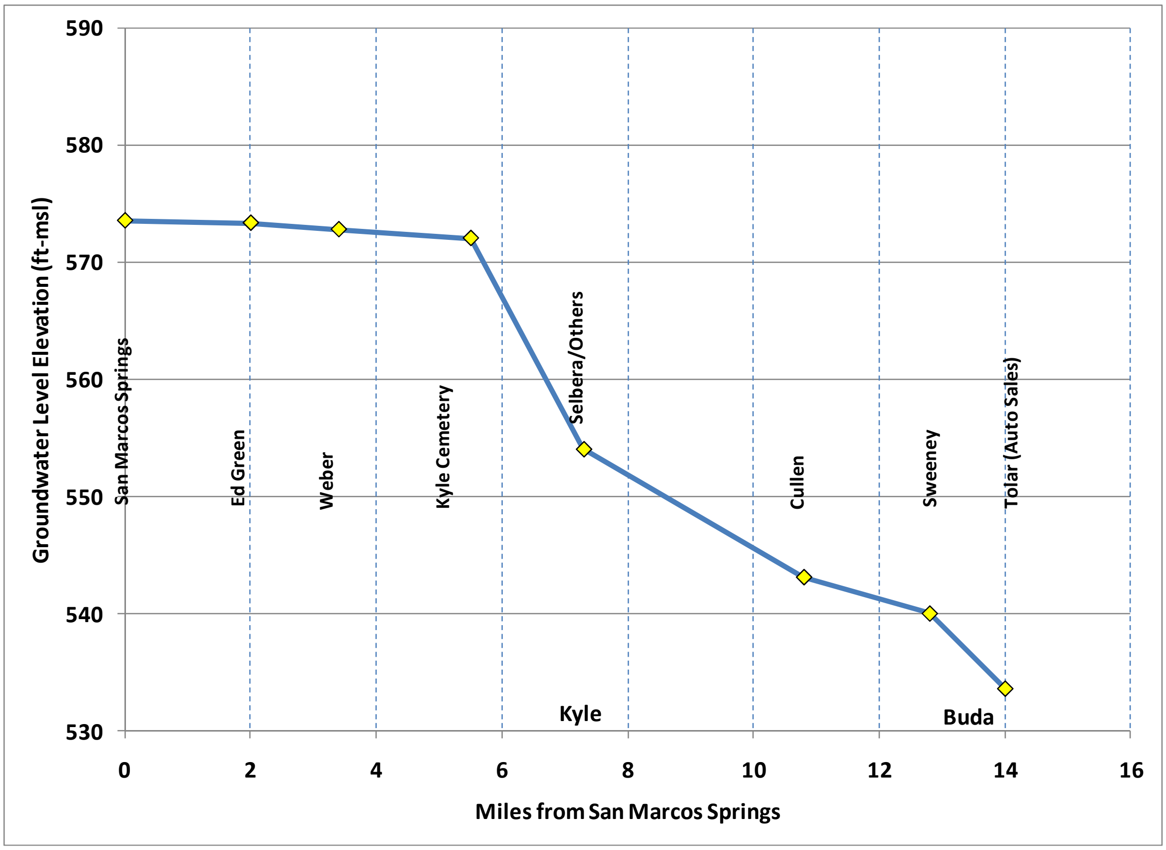

Figure 13. Groundwater level profile along preferential groundwater flow zone during drought conditions: August 26, 2009. 2 mi = ~3.2 km. 10 ft = ~3 m.

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Main Menu
Search
Author Index
Papers
Help

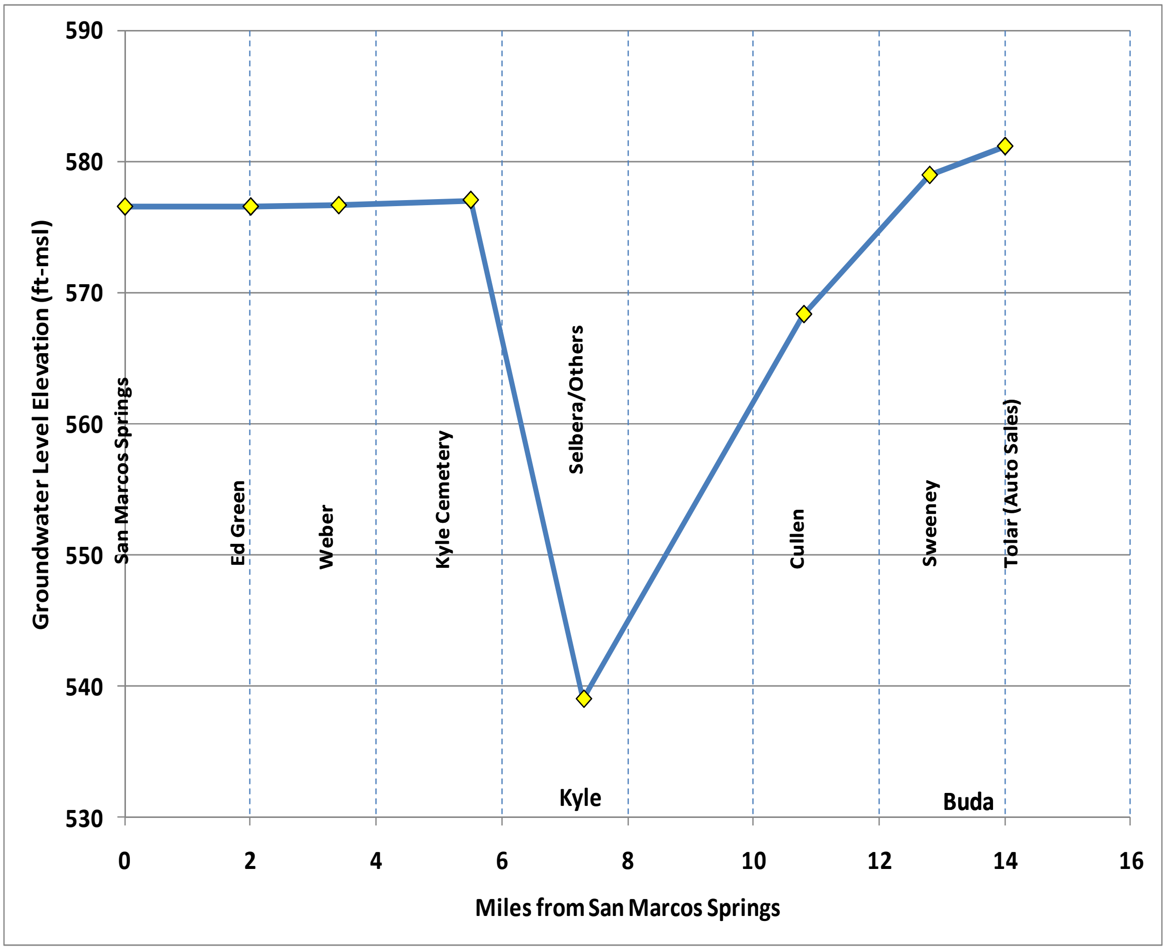

Figure 14. Groundwater level profile along preferential groundwater flow zone during wet conditions: December 31, 2009. 2 mi = ~3.2 km. 10 ft = ~3 m.

NOTES

Main Menu

Search

Author Index

Papers

Help