In cooperation with the San Antonio Water System

Flow Paths in the Edwards Aquifer, Northern Medina and Northeastern Uvalde Counties, Texas, Based on Hydrologic Identification and Geochemical Characterization and Simulation

Scientific Investigations Report 2006–5200

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Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Per mil: A unit expressing the ratio of stable-isotope abundances of an element in a sample to those of a standard material. Per mil units are equivalent to parts per thousand. Stable-isotope ratios are computed as follows (Kendall and McDonnell, 1998):

$$\delta X = \{(R_{sample} - R_{standard}) / R_{standard}\} \times 1{,}000$$

where

δ is the "del" notation,

X is the heavier stable isotope, and

R is the ratio of the heavier, less abundant isotope to the lighter stable isotope in a sample or standard.

The δ values for stable-isotope ratios discussed in this report are referenced to the following standard materials:

Element	R	Standard identity and reference
hydrogen	hydrogen-2/hydrogen-1	Vienna-Standard Mean Ocean Water (Fritz and Fontes, 1980)
oxygen	oxygen-18/oxygen-16	Vienna-Standard Mean Ocean Water (Fritz and Fontes, 1980)

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Flow Paths in the Edwards Aquifer, Northern Medina and Northeastern Uvalde Counties, Texas, Based on Hydrologic Identification and Geochemical Characterization and Simulation

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Abstract

The U.S. Geological Survey, in cooperation with the San Antonio Water System, conducted a 4-year study during 2001–04 to identify major ground-water flow paths in the Edwards aquifer in northern Medina and northeastern Uvalde Counties, Texas. The study involved use of geologic structure, surface-water and ground-water data, and geochemistry to identify ground-water flow paths. Relay ramps and associated faulting in northern Medina County appear to channel ground-water flow along four distinct flow paths that move water toward the southwest. The northwestern Medina flow path is bounded on the north by the Woodard Cave fault and on the south by the Parkers Creek fault. Water moves downdip toward the southwest until the flow encounters a cross fault along Seco Creek. This barrier to flow might force part or most of the flow to the south. Departure hydrographs for two wells and discharge departure for a streamflow-gaging station provide evidence for flow in the northwestern Medina flow path. The north-central Medina flow path (northern part) is bounded by the Parkers Creek fault on the north and the Medina Lake fault on the south. The adjacent north-central Medina flow path (southern part) is bounded on the north by the Medina Lake fault and on the south by the Diversion Lake fault. The north-central Medina flow path is separated into a northern and southern part because of water-level differences. Ground water in both parts of the north-central Medina flow path moves downgradient (and down relay ramp) from eastern Medina County toward the southwest. The north-central Medina flow path is hypothesized to turn south in the vicinity of Seco Creek as it begins to be influenced by structural features. Departure hydrographs for four wells and Medina Lake and discharge departure for a streamflow-gaging station provide evidence for flow in the north-central Medina flow path. The south-central Medina flow path is bounded on the north by the Seco Creek and Diversion Lake faults and on the south by the Haby Crossing fault. Because of bounding faults oriented northeast-southwest and adjacent flow paths directed south by other geologic structures, the south-central Medina flow path follows the configuration of the adjacent flow paths—oriented initially southwest and then south. Immediately after turning south, the south-central Medina flow path turns sharply east. Departure hydrographs for four wells and discharge departure for a streamflow-gaging station provide evidence for flow in the south-central Medina flow path. Statistical correlations between water-level departures for 11 continuously monitored wells provide additional evidence for the hypothesized flow paths. Of the 55 combinations of departure-dataset pairs, the stronger correlations (those greater than .6) are all among wells in the same flow path, with one exception. Simulations of compositional differences in water chemistry along a hypothesized flow path in the Edwards aquifer and between ground-water and surface-water systems near Medina Lake were developed using the geochemical model PHREEQC. Ground-water chemistry for samples from five wells in the Edwards aquifer in the northwestern Medina flow path were used to evaluate the evolution of ground-water chemistry in the northwestern Medina flow path. Seven simulations were done for samples from pairs of these wells collected during 2001–03; three of the seven yielded plausible models. Ground-water samples from 13 wells were used to evaluate the evolution of ground-water chemistry in the north-central Medina flow path (northern and southern parts). Five of the wells in the most upgradient part of the flow path were completed in the Trinity aquifer; the remaining eight were completed in the Edwards aquifer. Nineteen simulations were done for samples from well pairs collected during 1995–2003; eight of the 19 yielded plausible models. Ground-water samples from seven wells were used to evaluate the evolution of ground-water chemistry in the south-central Medina flow path. One well was the Trinity aquifer end-member well upgradient from all flow paths, and another was a Trinity aquifer well in the most upgradient part of the flow path; all other wells were completed in the Edwards aquifer. Nine simulations were done for samples from well pairs

collected during 1996–2003; seven of the nine yielded plausible models. The plausible models demonstrate that the four hypothesized flow paths can be partially supported geochemically.

Introduction

The karstic Edwards aquifer of south-central Texas serves as the primary source of water for the city of San Antonio and adjacent areas (fig. 1). The Edwards aquifer is composed of several geologic formations (fig. 2) that consist primarily of limestone and dolostone, depending on the location and depositional province (Maclay and Small, 1984). In the recharge zone (fig. 1), rocks forming the Edwards aquifer are exposed at the land surface and receive recharge from direct infiltration of rainfall and streamflow losses. The Edwards aquifer also receives recharge from the laterally adjacent and underlying Trinity aquifer, the amount of which is small relative to the amount from other sources. Ground water moves down the formational dip from the recharge zone into the confined zone of the aquifer where it follows regional flow paths that convey water toward major natural springs (discharge points) in Comal and Hays Counties.

The study area encompasses a complex system of flow paths that developed as a result of extensional faulting. The Balcones fault zone (fig. 1) is characterized by an en-echelon network of mostly down-to-the-coast normal faults where Cretaceous strata were displaced vertically, fractured intensively, and rotated differentially within a series of southwest-to-northeast trending fault blocks (Barker and Ardis, 1996). These faults—and the secondary effects of the tectonic forces that caused them—contribute to the complexity of the diffuse and conduit ground-water flow that occurs. The Balcones faulting set the foundation for initial ground- and surface-water flow paths that since have been modified by dissolution and erosion.

Maclay and Land (1988, fig. 22, table 4) delineated and described four major flow paths (their term is flow units) in the Edwards aquifer in the San Antonio region. The flow paths originate in the recharge zone and generally convey water first to the southwest and then to the east and northeast toward major springs. Two of the four flow paths of Maclay and Land (1988) originate in the study area.

To better understand and refine ground-water flow paths in the Edwards aquifer in northern Medina and northeastern Uvalde Counties, the U.S. Geological Survey (USGS), in cooperation with the San Antonio Water System, conducted a 4-year study during 2001–04. The study involved use of geologic structure, surface-water and ground-water data, and geochemistry to indicate ground-water flow paths. For example, ground-water levels in wells that fluctuate similarly in areas bounded by faults might indicate flow paths. Geochemical characterization of ground water is important in understanding its chemical evolution along hypothesized flow paths. Simulations based on chemical and isotope data along hypothesized flow paths might be of importance in understanding areas of recharge and the degree of communication between surface-water and ground-water systems. The results of the study could be useful to water managers with responsibility for protecting sources of recharge, identifying areas with potential for recharge enhancement, and identifying areas of ground-water discharge.

Purpose and Scope

The purpose of this report is to identify major ground-water flow paths in the Edwards aquifer in northern Medina and northeastern Uvalde Counties on the basis of geologic structure and hydrologic and geochemical indicators. Knowledge of geologic structure and the work of Maclay and Land (1988) provided a beginning framework, a basis for hypothesizing flow paths. Hydrologic data were analyzed and flow paths were identified using water-level departure (from period-of-record average daily mean) hydrographs and statistical correlation of water-level departure for 11 monitoring wells in the study area. Continuous water-level data were recorded at the 11 monitoring wells during mid-March 2002–May 2004. Surface-water discharge data were obtained for three streams for the same period. Ground-water-chemistry and isotope data were obtained from samples collected at 41 wells during March 1992–August 2003. Surface-water-chemistry and isotope data were obtained from samples collected at two sites in Medina Lake during 1995–96; isotope data also were obtained for the Medina River below Medina Lake from samples collected during 1995–96. One-dimensional geochemical simulations oriented along hypothesized major flow paths provided further evidence to support the existence of the flow paths. These geochemical simulations represent the chemical evolution of ground water along the flow paths and the degree of influence of surface water on the ground-water flow system.

Structural Controls on Ground-Water Flow Paths

The Balcones fault zone is an extensional fault system that crosses Medina and Uvalde Counties from the southwest to the northeast (fig. 1). The faults are en echelon and generally downthrown to the coast with primarily normal displacement. Cross faults trend southeast to northwest. Many of the faults are not single, sharp breaks but rather shatter zones where faulting occurs over tens of feet. Examples of normal faults in the study area are the Haby Crossing and Parkers Creek faults (fig. 2). Faulting has resulted in juxtaposition of stratigraphically older rocks against younger rocks of varying lithologies. The amount of displacement along a particular fault tends to vary, and thus the effectiveness of a fault as a barrier to flow probably changes along the fault plane. Near a fault tip no barrier to flow exists; as displacement down the fault plane increases, the effectiveness of the fault as a barrier to flow increases. In the study area, rocks become progressively younger from northwest to southeast and from northeast to southwest because of faulting and extension perpendicular to faulting. Extension strongly

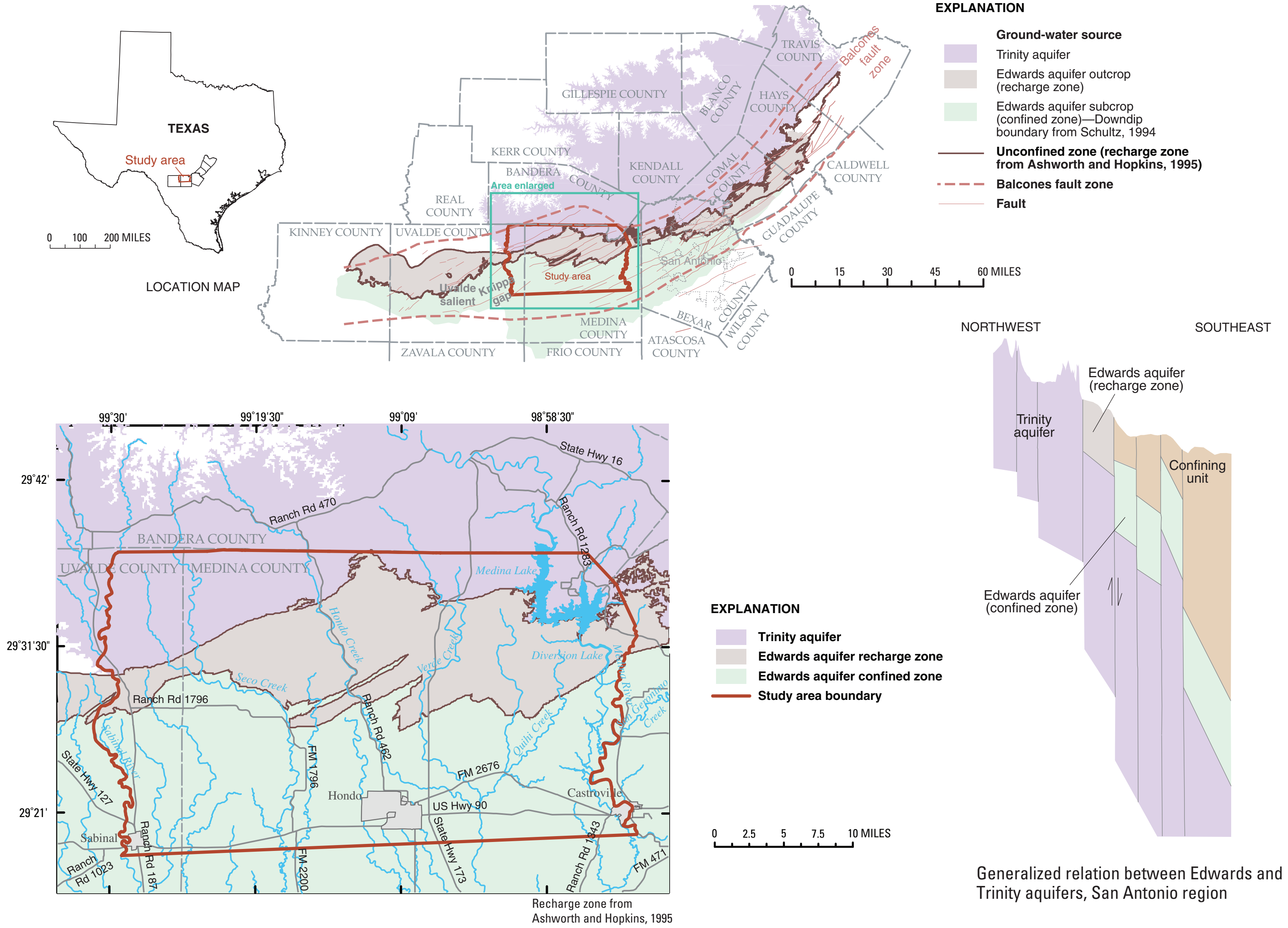


Figure 1. Location of study area and relation between Edwards and Trinity aquifers, northern Medina and northeastern Uvalde Counties, Texas.

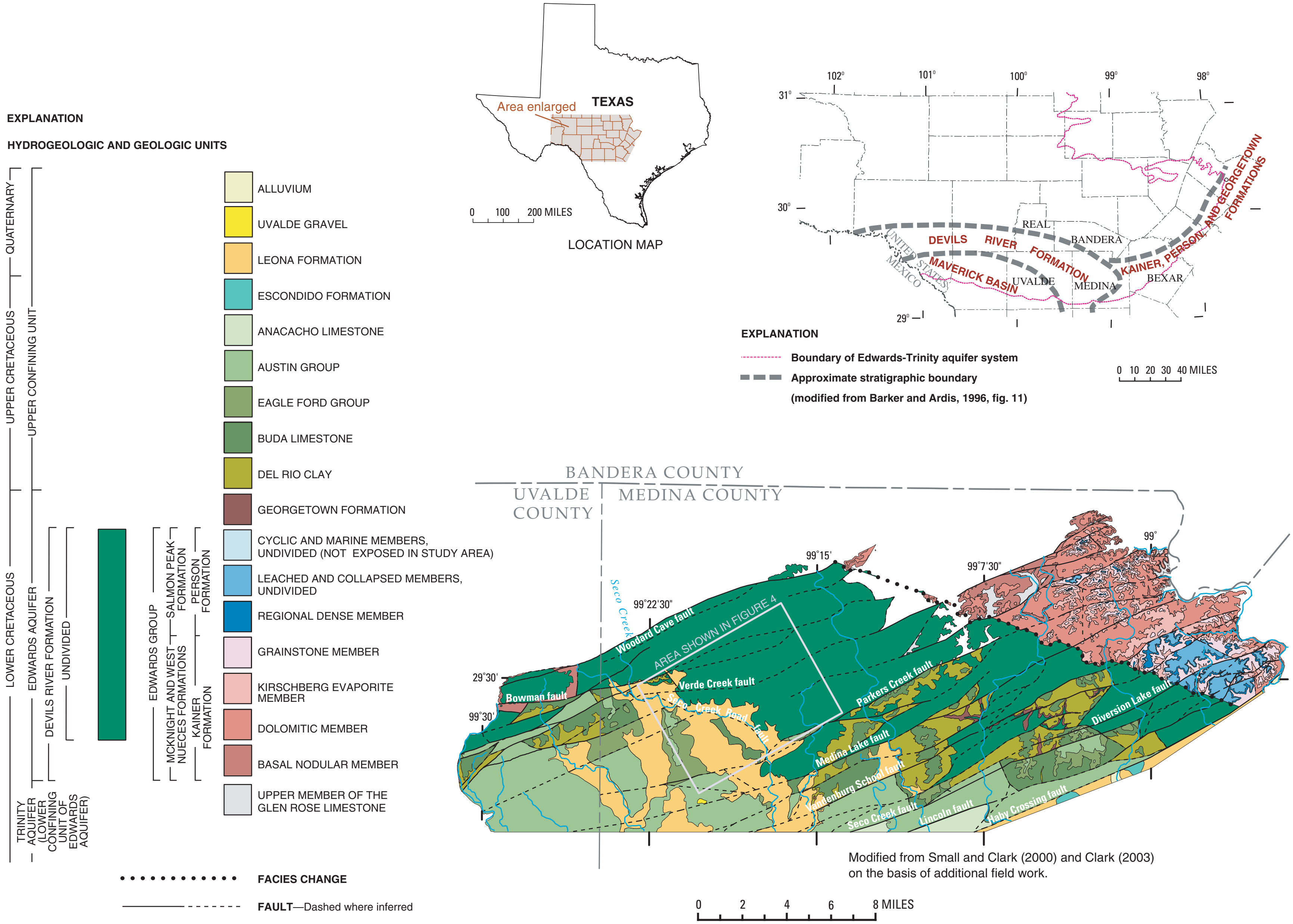


Figure 2. Surface geology and major faults in the study area, northern Medina and northeastern Uvalde Counties, Texas.

influenced the orientation of fractures, location of streams, areas of recharge, and ground-water flow paths. Fractures generally are parallel to or perpendicular to the main fault trend of the Balcones fault zone.

In this structurally complex area, the Balcones fault zone contains relay ramps that form in extensional environments to accommodate an increase in deformation. Ramp structures link the footwall of a fault segment with the hanging wall of an overlapping fault segment. The controls on surface-water drainage patterns by relay-ramp formation have been documented by Trudgill (2002) in the Canyonlands of southeastern Utah. Figure 3 shows an idealized diagram of relay-ramp development and relay-ramp structure in relation to generalized ground- and surface-water flow directions, and figure 4 shows a block model of faulting. As extension occurs and strain increases, rotation and internal fracturing occur along the relay ramp (Trudgill, 2002). Continued extension results in the formation of cross faults within the relay ramp structure. The block model in figure 4 is an example of a relay ramp breached by a cross fault along Seco Creek that downdropped confining units against the Edwards aquifer.

An example of similar controls on surface-water drainage patterns might have occurred in the evolution of the Medina River. Doyle (2003) reported that the ancestral Medina River flowed to the southwest toward the present-day city of Hondo and discharged into the ancestral Hondo Creek. Solutionally enlarged fractures and conduits might have formed parallel to the dip of the relay ramp. These same solutionally enlarged fractures and conduits might continue to move ground water to the southwest perpendicular to the present-day surface-water drainage.

Streams in the geologic past might have flowed down-dip/down structure, following the dip of relay ramps. Over geologic time, streams in the study area were intercepted by headward erosion (pirated) from the south, which caused them to change course to a more southerly direction. Present-day streams that cross the Edwards aquifer recharge zone are channelized along fractures (or faults) that are roughly perpendicular to the main fault trend. These fractures allow streams to lose much if not all of their base flow in the Edwards aquifer recharge zone. Relay ramps and associated faulting in northern Medina County appear to channel ground-water flow along four distinct flow paths that move water toward the southwest.

Acknowledgments

The authors thank personnel of the San Antonio Water System, especially Mr. John Waugh and Mr. Kirk Nixon, for obtaining easement rights for monitoring wells installed for this study and running geophysical logs of the monitoring wells. Special thanks are extended to the personnel of the Edwards Aquifer Authority (EAA) and the following property owners for access to their properties: Mr. Richard Saathoff, Mr. and Mrs. Peter Bowman, Mr. Doug Peters, Mr. and Mrs. Steven Devlin, Mr. Joe W. Rothe, Mr. Virgil Boles, and Mr. Scott Pearson.

Approach and Methods

Data Collection and Sample Analysis

Initially, pertinent historical data were compiled that included previously published reports, well locations, historical water levels, geology, hydrogeologic maps, and water-chemistry and isotope data for both ground and surface water. Data sources were the USGS, Texas Water Development Board, and EAA.

Eight Edwards aquifer monitoring wells were drilled by the USGS in northern Medina County for the study (one of which was a dry hole and thus not included in this report) (table 1). Each well was drilled to the base of the Edwards aquifer (top of the Glen Rose Limestone [fig. 2]) using primarily air rotary methods. Slotted PVC liners were placed in the holes to prevent borehole collapse and to facilitate water sampling. Water-level recorders were installed on each of the seven new wells (Medina1–Medina8 [excluding Medina6]) plus three existing wells (Hondo, Castroville, Seco); one additional well (Quihi) had a water-level recorder maintained by EAA. Continuous water-level data thus were collected from 11 wells (fig. 5; table 1) during March 14, 2002–May 31, 2004.

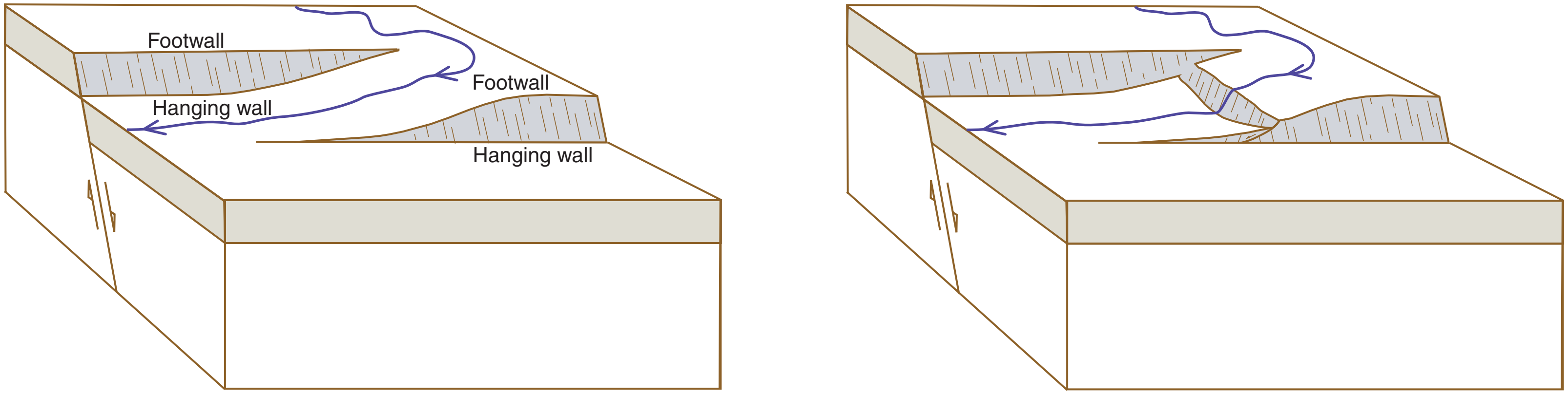
The USGS has a long-term stage-monitoring site at Medina Lake (Medina Lake near San Antonio) (fig. 5; table 1). Lake-stage data were compiled for that site for the same period as the continuous ground-water-level data, March 14, 2002–May 31, 2004. Surface-water discharge data were compiled for three existing USGS streamflow-gaging stations—Medina River at Bandera, Hondo Creek near Tarpley, and Seco Creek at Miller Ranch—also for the period concurrent with the continuous ground-water-level data.

Ground-water-chemistry and isotope data were obtained from 41 wells (fig. 6; table 1) during March 1992–August 2003. Chemistry and isotope samples were obtained from 35 wells, chemistry-only samples from two wells, and isotope-only samples from four wells) (table 1). Twenty-three wells provided historical data (1992–2001 samples from the USGS water-quality database [http://nwis.waterdata.usgs.gov/nwis/qwdata]), 11 wells provided new data (2002–03 samples collected for this study), and seven wells provided both historical and new data. Some of the historical data were collected during 1995 and 1996 and published as part of a Medina Lake area study by Lambert and others (2000).

Ground-water samples were collected from 10 wells during July 2002–February 2003 for analysis of dissolved gases (carbon dioxide, oxygen, and argon; not all detected in each sample) and sulfur hexafluoride (SF_6) concentrations. Dissolved gases and SF_6 samples were analyzed by the USGS Chlorofluorocarbon Laboratory in Reston, Va., using approved methods (U.S. Geological Survey, 2005b).

A. Stream drainage moves down the relay ramp/downgradient. Subsequently any conduit development would occur parallel to the structure.

B. Relay ramp is breached by a cross fault.



C. Down-cutting by stream and small drainages that intersect the footwall. Erosion in footwall is by solution enhancement of fractures.

D. Main stream is intercepted by headward erosion of smaller stream, which pirates the flow into a new primary drainage system. Main conduits still moving water down the relay ramp parallel to faulting and perpendicular to streams.

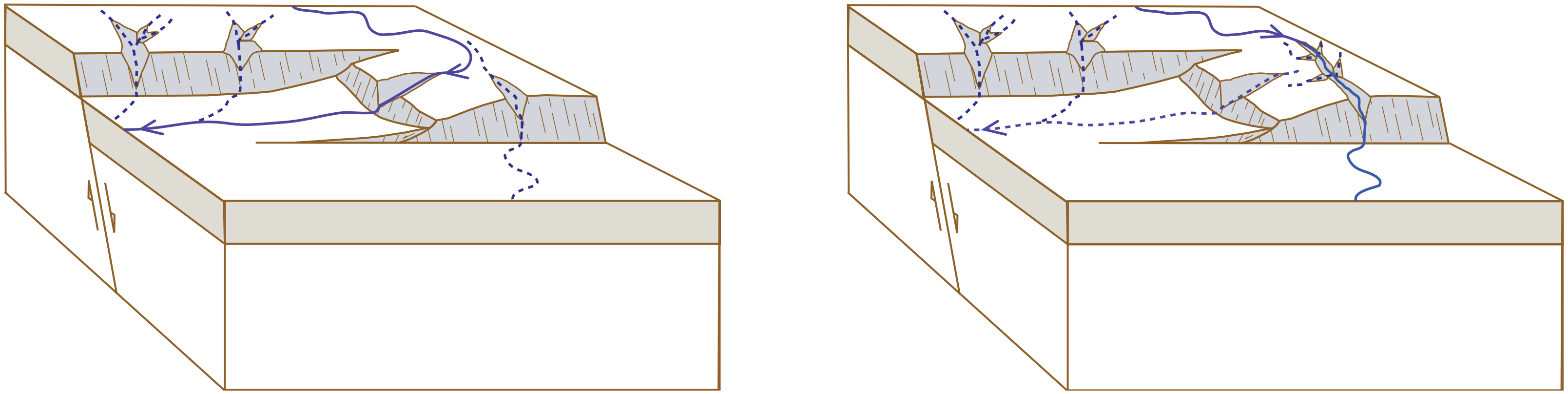


Figure 3. Relay-ramp development (modified from Trudgill, 2002).

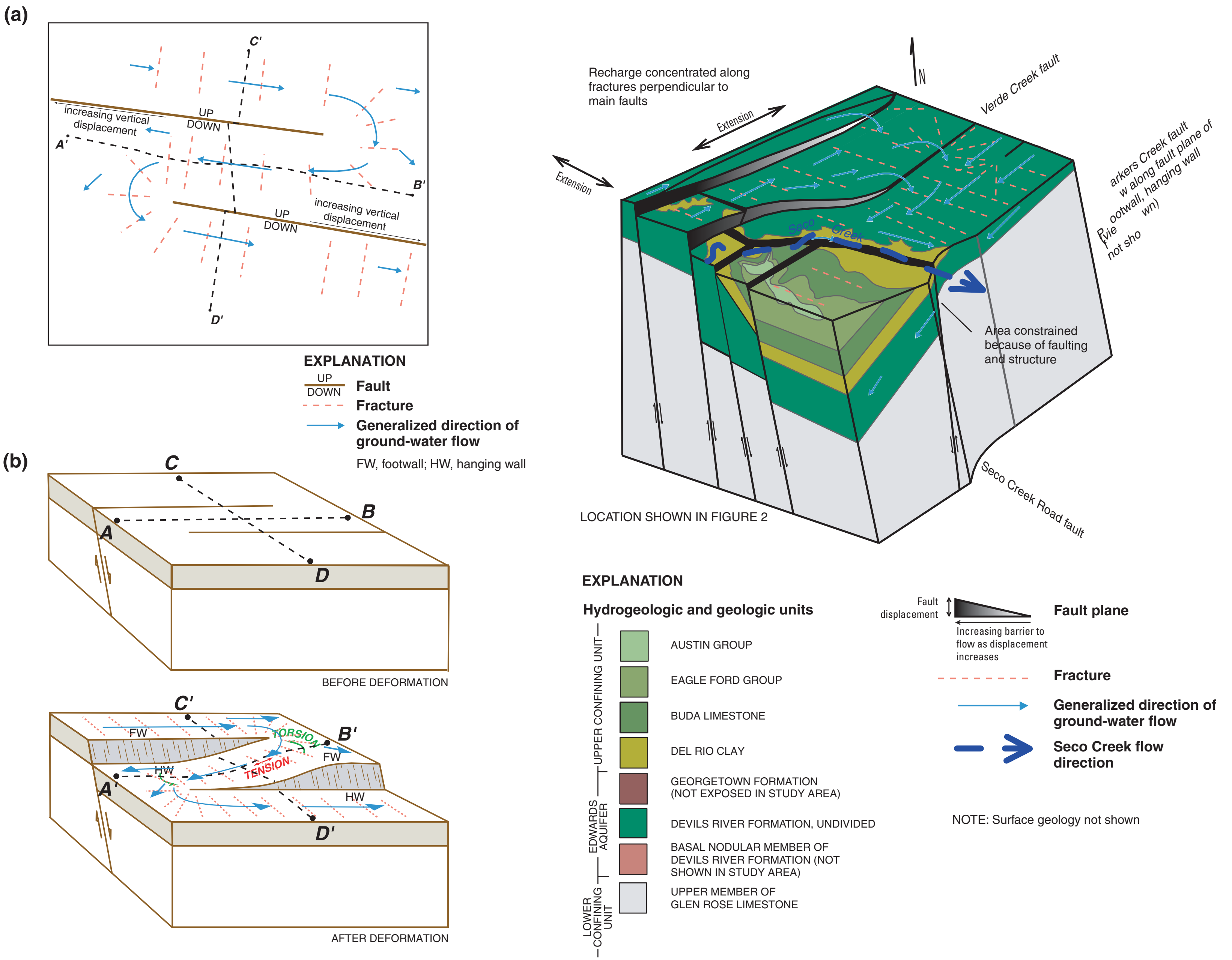
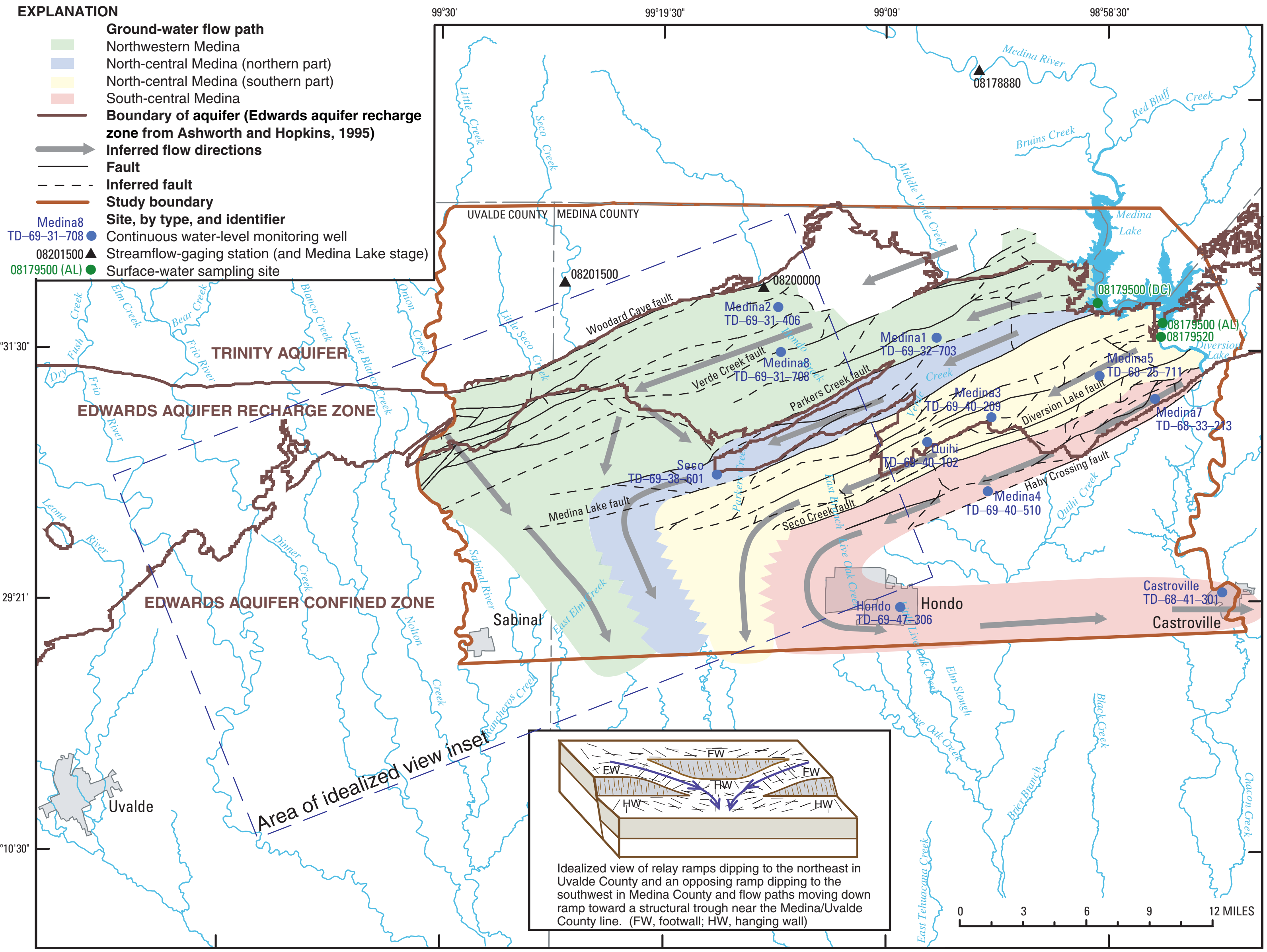


Figure 4. Idealized view of relay ramps, fractures, faults, and flow paths in the Edwards aquifer, northern Medina County, Texas.



Idealized view of relay ramps dipping to the northeast in Uvalde County and an opposing ramp dipping to the southwest in Medina County and flow paths moving down ramp toward a structural trough near the Medina/Uvalde County line. (FW, footwall; HW, hanging wall)

Figure 5. Locations of continuous water-level monitoring wells, surface-water data-collection sites, and hypothesized ground-water flow paths, northern Medina and northeastern Uvalde Counties, Texas.

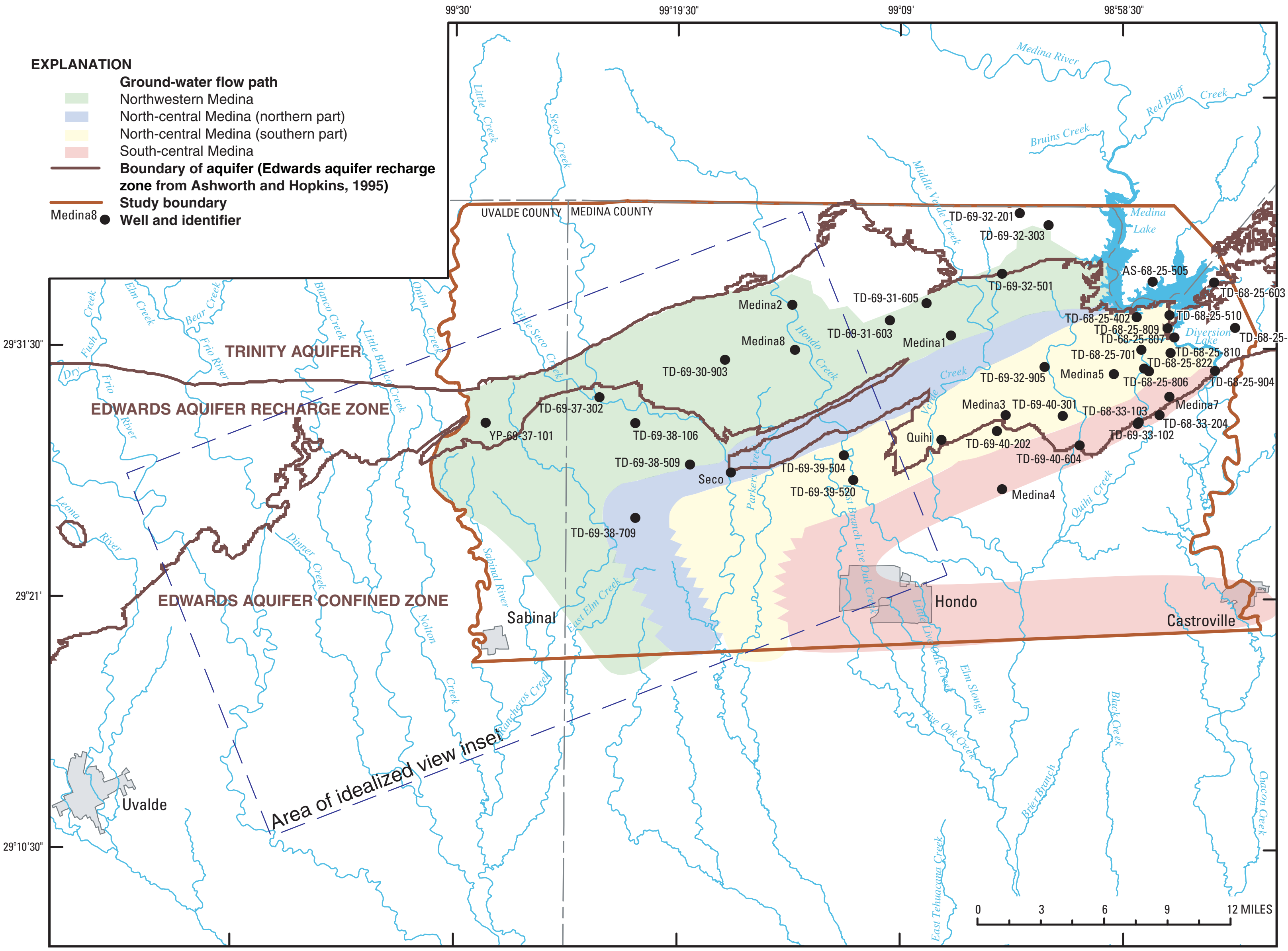


Figure 6. Locations of ground-water wells from which samples were obtained and hypothesized ground-water flow paths, northern Medina and northeastern Uvalde Counties, Texas.

Table 1. Ground-water sites (wells) and surface-water sites, northern Medina and northeastern Uvalde Counties, Texas, from which data were obtained for this report.

[Datum for open interval is land surface; USGS, U.S. Geological Survey; NA, not applicable; (s), screened with polyvinyl chloride liner; I, isotope; --, unknown; QW, water chemistry; WLC, continuous water level; XRF, X-ray fluorescence; (o), open hole; >, greater than; DIS, discharge; STAGE, water level]

USGS site number	State well number	USGS name	Aquifer	Total depth (feet)	Open interval (feet) (completion type)	Data type
Ground-water sites (wells)						
293420098552601	AS–68–25–505	NA	Trinity	334	224–334 (s)	I
293249098575101	TD–68–25–402	NA	Trinity	486	--	I, QW
293255098560401	TD–68–25–510	NA	Trinity	200	--	I, QW
293309098541901	TD–68–25–602	NA	Trinity	--	--	I, QW
293334098535401	TD–68–25–603	NA	Trinity	535	--	I
293127098573701	TD–68–25–701	NA	Edwards	615	320–400, 580–614 (s)	I, QW
[1]293026099585401	TD–68–25–711	Medina5	Edwards	380	35–370 (s)	I, QW, WLC, XRF
293033098571601	TD–68–25–806	NA	Edwards	360	200–360 (o)	I, QW
293158098560401	TD–68–25–807	NA	Trinity	252	--	I, QW
293229098553402	TD–68–25–809	NA	Trinity	>450	>450 (o)	I, QW
293119098561501	TD–68–25–810	NA	Trinity	>350	>350 (o)	I, QW
293040098572901	TD–68–25–822	NA	Edwards	380	336–380 (o)	I, QW
293034098540901	TD–68–25–904	NA	Trinity	--	--	I, QW
292820098574801	TD–68–33–102	NA	Edwards	625	10–625 (o)	I, QW
292825098574501	TD–68–33–103	NA	Edwards	350	--	I, QW
292843098564601	TD–68–33–204	NA	Edwards	360	--	I, QW
[1]292929098561801	TD–68–33–213	Medina7	Edwards	300	80–290 (s)	I, QW, WLC
292117098524701	TD–68–41–301	Castroville	Edwards	710	--	WLC
293101099171601	TD–69–30–903	NA	Edwards	440	260–440 (o)	I, QW
[1]293318099140501	TD–69–31–406	Medina2	Edwards	210	30–200 (s)	I, QW, WLC
293241099092901	TD–69–31–603	NA	Edwards	300	--	I, QW
293324099074601	TD–69–31–605	NA	Trinity	--	--	I, QW
[1]293125099135701	TD–69–31–708	Medina8	Edwards	300	80–290 (s)	I, QW, WLC
293710099032201	TD–69–32–201	NA	Trinity	180	--	I, QW
293640099020001	TD–69–32–303	NA	Trinity	660	--	I, QW
293438099041201	TD–69–32–501	NA	Trinity	--	--	I, QW
[1]293202099063501	TD–69–32–703	Medina1	Edwards	290	50–280 (s)	I, QW, WLC
293044099021101	TD–69–32–905	NA	Edwards	358	180–358 (o)	QW
292927099231101	TD–69–37–302	NA	Edwards	410	--	I, QW
292820099212801	TD–69–38–106	NA	Edwards	478	160–478 (o)	I, QW
292638099185501	TD–69–38–509	NA	Edwards	380	30–380 (s)	I, QW
292618099165901	TD–69–38–601	Seco	Edwards	538	74–538 (o)	I, QW, WLC
292423099212901	TD–69–38–709	NA	Edwards	420	--	I, QW
292704099114201	TD–69–39–504	NA	Edwards	653	84–653 (o)	I
292600099111201	TD–69–39–520	NA	Edwards	290	--	QW
292740099070201	TD–69–40–102	Quihi	Edwards	559	79–559 (o)	I, WLC[2]
292803099042601	TD–69–40–202	NA	Edwards	400	--	I, QW
[1]292843099040201	TD–69–40–209	Medina3	Edwards	550	40–520 (s)	I, QW, WLC
292841099012001	TD–69–40–301	NA	Edwards	328	--	I, QW
[1]292536099041001	TD–69–40–510	Medina4	Edwards	960	420–950 (s)	I, QW, WLC
292727099003201	TD–69–40–604	NA	Edwards	505	10–505 (o)	I, QW
293438099041201	TD–69–47–306	Hondo	Edwards	1,500	--	WLC
292821099283201	YP–69–37–101	NA	Edwards	500	--	I, QW
Surface-water sites						
08178880	NA	Medina River at Bandera	NA	NA	NA	DIS
08179500	NA	Medina Lake near San Antonio (sites AL and DC)	NA	NA	NA	STAGE, I, QW (AL and DC)
08179520	NA	Medina River below Medina Lake	NA	NA	NA	I
08200000	NA	Hondo Creek near Tarpley	NA	NA	NA	DIS
08201500	NA	Seco Creek at Miller Ranch near Utopia	NA	NA	NA	DIS

[1] Well drilled for this study.

[2] Data from Edwards Aquifer Authority.

Historical (1995–96) surface-water-chemistry and isotope data were obtained for two sites at Medina Lake (AL and DC) (fig. 5; table 1). Historical (1995–96) isotope data also were obtained for one other surface-water site, Medina River below Medina Lake (in Diversion Lake).

Water samples were collected, processed, and preserved according to analyte-specific requirements and standard USGS protocols described in Wilde and others (1999, 2003, 2004). Water-chemistry data comprised field properties, major ions, nutrients, and trace elements. Water-chemistry samples were analyzed for major ions, nutrients, and trace elements by the USGS National Water Quality Laboratory in Denver, Colo., using approved methods (U.S. Geological Survey, 2005a). Isotope data comprised naturally occurring stable isotopes of hydrogen and oxygen. The ratios of naturally occurring stable isotopes of hydrogen ($^{2}H/^{1}H$) and oxygen ($^{18}O/^{16}O$) were analyzed by the USGS Stable Isotope Laboratory in Reston, Va., using approved methods (U.S. Geological Survey, 2006). Isotopic results are reported as delta deuterium (δD) and delta 18-oxygen ($\delta^{18}O$), which represents the relative difference in parts per thousand (called per mil) between the sample isotope ratio and a known standard isotope ratio (Kendall and McDonnell, 1998).

During drilling of well Medina5, rock samples from the Edwards aquifer were collected at 10-foot depth intervals and sent for X-ray fluorescence (XRF) analysis to SGS Canada, Inc., Mineral Services. Samples from well Medina5 were selected for analysis because that well provided the most complete set of cuttings recovered during drilling.

Quality Assurance and Quality Control of Chemical Samples

Before water sampling, equipment blanks were collected to evaluate the equipment and to ensure that the procedures for cleaning the equipment did not contaminate or otherwise affect the environmental samples. Results of the equipment-blank sampling indicated that the equipment and cleaning procedures did not measurably affect the major-ion concentrations in the environmental samples that were used in the geochemical modeling.

Duplicate samples were collected from two of the 11 wells sampled for major ions and trace elements for this report and were available from the water-quality database for two other wells (table 2, at end of report). Duplicate samples for SF_6 were collected from all 10 of the wells sampled for SF_6 for this report. Duplicate samples also were available from the water-quality database from one well for one concentration pair each of δD and $\delta^{18}O$. Duplicates were used to evaluate the sampling and laboratory procedures. From the four duplicate samples for major ions, relative percent differences (RPDs) in calcium and chloride concentration pairs (constituents of interest for this report) ranged from 0 to 2.9 and 0 to 4.6, respectively. RPDs for magnesium and sodium concentration pairs were more variable and ranged from 0.11 to 7.6 and 0.52 to 21, respectively; the maximum RPDs for both constituents were from historical concentration pairs. RPDs for potassium and sulfate concentration pairs ranged from 0.99 to 4.2 and 0 to 1.2, respectively. For the 10 SF_6 concentration pairs, RPDs ranged from 0.66 to 30, with a median RPD of 7.5. For the single duplicate pair of δD concentrations, the RPD was 4.2; and for the single duplicate pair of $\delta^{18}O$ concentrations, the RPD was 0.31.

Methods of Data Analysis

Hydrologic Indicators of Ground-Water Flow Paths

Water levels relative to a land-surface or NGVD 29 datum vary over a wide range in the study area. To view water levels over time on a common scale, hydrographs of water-level departure were plotted. Water-level departure was computed by subtracting the period-of-record average daily mean from the daily mean. Plotting water-level departure allowed visual comparison between water levels at different wells, which aided in flow path identification. Although amplitude of the hydrographs varies, departure similarities in the hydrographs can indicate hydraulic connection between wells, areas of recharge, or both.

Departure hydrographs were created from the discharge and stage data from the three streamflow-gaging stations and Medina Lake, respectively, which then were compared with selected water-level departure hydrographs from wells to identify possible sources of recharge to the ground-water system. For example, a rise in measured water level (positive increase in departure) in a monitor well in the Seco Creek Basin during a period when Medina Lake is filled to capacity and no appreciable rainfall occurs could indicate a hydraulic connection along a ground-water flow path from Medina Lake to the well.

Statistical correlations between water-level departures for the 11 continuously monitored wells were done using Kendall’s tau (Helsel and Hirsch, 1995) in a statistical software package, which in this application measures the strength of the monotonic relation between two time series of water-level departures. This rank-based procedure was selected over the more commonly used Pearson’s r to measure correlation because graphs of the departure data generally show the data are not normally distributed; Pearson’s r, which measures linear correlation, requires the assumption of normally distributed data. Kendall’s tau for each of the 55 possible combinations of departure-dataset pairs was computed to indicate strongly correlated water-level pairs and thus evidence for hydraulic connection (flow paths) between wells.

Geochemical Methods to Characterize Water

XRF analysis of rock samples from well Medina5 provided bulk-rock composition, in weight-percent oxides, of major and trace elements of the aquifer. X-ray diffraction (XRD) analysis of powder rock samples also was done on these rock samples to identify the dominant mineral species. These rock analyses were conducted to augment the geochemical simulation by verifying the dominant mineral species and major elements in the Edwards aquifer in the study area.

Ages of ground water, ground-water/surface-water mixing relations, and major-ion chemistry were evaluated using geochemical data collected from selected wells and surface-water sites in the study area. Chemical and isotopic data from Medina Lake, the Medina River, and selected wells in the Edwards and Trinity aquifers were used to evaluate the geochemical and isotopic controls on ground-water composition and to assess mixing of the surface- and ground-water systems.

Dissolved gases and SF_6 were used to estimate the apparent age or year of recharge for the water in the aquifer. The technique involves comparing the SF_6 concentration in the ground water to established annual atmospheric concentrations. SF_6 occurs as a gas in the atmosphere in trace concentrations, mainly of anthropogenic origin. But SF_6 can occur naturally in some minerals, volcanic and igneous rocks, and fluids. However, caution is advised in using these apparent ages or years of recharge because the procedure does not account for mixing of older waters with younger waters. Excess air is introduced into ground water when air bubbles dissolve during a rapid rise of the water table. The addition of excess air to ground water increases the SF_6 concentration of the ground water above the air-water equilibrium concentration. If the presence of excess air is not considered in the computation of an SF_6 age, then the apparent age will be too young.

The mixing relations between ground water and surface water were quantified using $^{18}O/^{16}O$ and $^{2}H/^{1}H$. Isotopic composition of end-member waters that represented the Edwards aquifer (negligible influence of surface water) and the surface-water system (average of Medina Lake and Medina River isotope concentrations) were used in geochemical simulation to compute the percentage of surface water present in the water of a well (Hem, 1992; Gibson and others, 1993; Kendall and McDonnell, 1998; Lambert and others, 2000). A sensitivity analysis was applied to the mixing calculation method (Payne, 1983; Gibson and others, 1993; Torres and others, 2001) for ground and surface waters. The sensitivity analysis is based on the variability of the individual end-member water chemistry and the difference in the isotope concentrations between the two end-member waters (surface and ground).

Major-ion data were analyzed graphically and statistically to identify relations among constituents and differences among flow paths and ground-water/surface-water systems. Piper trilinear diagrams and Stiff diagrams were used to graphically classify the dominant water composition in the aquifers and flow paths (Piper, 1944; Stiff, 1951; Hem, 1992). Piper trilinear diagrams often are used to indicate whether particular water might be a simple mixture of other waters or whether it is affected by dissolution or precipitation of a single salt. The Stiff diagrams provide a relatively distinct shape to illustrate differences and similarities in water composition. The width of the pattern approximates the total ionic content.

Geochemical Simulation to Identify Flow Paths

Geochemical simulation is a two-phase process that first requires determination of saturation conditions in the ground water in each well to identify potential reactions that are geochemically valid (and thus plausible in the field). Second, an inverse simulation identifies changes in ground-water chemistry between two wells along a hypothesized flow path to account for the changes in aqueous ion concentrations (water composition) by moving moles of different ions from solid to liquid state (dissolve) or liquid to solid state (precipitate). The objective of inverse simulation is to find sets of minerals and gases that, when reacted in appropriate amounts, quantitatively account for the differences in composition between water samples from two wells along a flow path with the potential of surface-water interaction. Simulations of compositional differences in water chemistry along a hypothesized flow path in the Edwards aquifer and between ground-water and surface-water systems near Medina Lake were developed using the geochemical mole-balance, or inverse, model PHREEQC (Parkhurst and Appelo, 1999).

The overlying assumption in this type of simulation is that the ground-water chemistry in the downgradient well evolved from the ground-water chemistry in the upgradient well by reaction with the proposed minerals and gases or by input from the surface-water system. If this assumption is shown by simulation results to be plausible, then the existence of the hypothesized flow path is supported. Additional assumptions are that chemical reactions are controlled by thermodynamic equilibrium, the chemical composition of the ground water is nearly at steady state, and the mineralogy of the aquifer is well defined. Also, an assumption in this application was that the ground-water chemistry remained relatively stable during the periods represented by the samples and that seasonal differences were negligible. However, a lack of temporal data prevented accurate quantification of seasonal differences in water chemistry, thus the validity of this assumption is unknown. Potential reactions for geochemical modeling were identified on the basis of XRF, XRD, and existing mineralogical data. Simulated reactions include precipitation (calcite, amorphous silica), dissolution (calcite, dolomite, gypsum, halite), and ion exchange (cation, carbon dioxide). All PHREEQC simulations were constrained by holding constant the masses of sulfur, calcium, sodium, magnesium, inorganic carbon, and chloride.

The saturation index (SI) is a dimensionless measure of the departure from equilibrium of the water with respect to various mineral phases. An SI of zero indicates that the water is at equilibrium (saturated) with respect to the mineral phase. A negative SI indicates undersaturation (dissolution of the mineral is possible), and a positive SI indicates supersaturation (precipitation is possible). As the chemistry in the ground water changes from well to well, the SI changes. Model-calculated SIs were compared among various wells to show which geochemical reactions could or could not occur as water moves along a flow path between a pair of wells. For example, if a possible simulation indicates that calcite is dissolving at a particular well, but the

SI calculated for water from that well shows calcite supersaturation, then the model must be rejected.

The simulation results related the extent to which the input data (element concentrations) were adjusted by the model in a simulation. Unknowns for the simulation include the mixing fraction of each aqueous solution; the mole transfers of minerals and gases into or out of the aqueous solution; and a set of uncertainty terms that accounts for uncertainties in element concentrations as evidenced by charge (cation-anion) imbalances in the water analyses. The uncertainty terms represent uncertainties associated with analytical error and spatial or temporal variability in concentration of each element. The results included (1) the sum of residuals, which is the sum of the uncertainty of the unknowns weighted by the inverse of the uncertainty limit, which is a user-supplied estimate of uncertainty of each element that limits deviation from the chemical input data (for this application it was set to 0.10); (2) the sum of delta/uncertainty, which is the sum of the adjustments to each element concentration weighted by the inverse of the uncertainty limit; and (3) maximum fractional error in element concentration, which is the adjustment to any element or isotopic composition in any solution. If no adjustments were made, all three quantities would be zero. For a given mole-balance simulation, if no simpler inverse simulation is obtained with any proper subset of the solutions and phases of the simulation, the statement “Simulation contains minimum number of phases” is given for that simulation.

Hydrologic Identification of Ground-Water Flow Paths

Northwestern Medina Flow Path

The northwestern Medina flow path (NWMFP) is bounded on the north by the Woodard Cave fault and on the south by the Parkers Creek fault (fig. 5). The NWMFP likely receives recharge from Seco, Hondo, and Verde Creeks and from the adjacent Trinity aquifer on the basis of its proximity to the Edwards aquifer. Water moves downdip toward the southwest—primarily because of structural controls associated with a relay ramp—until the flow encounters a cross fault along Seco Creek (figs. 2, 5). The cross fault along Seco Creek probably forms a barrier or a partial barrier to flow because the fault might have offset several hundred feet of the Edwards aquifer and juxtaposed confining units against it. This barrier to flow might force part or most of the flow to the south. During times of relatively large recharge, subsurface “back-flooding” might occur, up ramp to the northeast toward Hondo Creek. Southwestern flow in the NWMFP not turned south by cross faulting near Seco Creek ultimately is turned south near the Uvalde/Medina County line by geologic structure. At the apex or culminating point of relay-ramp structures, the southwesterly subsurface flow from northwestern Medina County likely joins some southeasterly subsurface flow from northeastern Uvalde County (inset, fig. 5). Also influencing subsurface flow is a structural high in central Uvalde County, the Uvalde salient (Clark and Small, 1997; Clark, 2003), and a generally north-south trending structural trough in eastern Uvalde County, the Knippa gap (fig. 1) (Maclay and Land, 1988). The result is water being conveyed generally south to join regional southwest-to-northeast flow paths in the southern part of the Edwards aquifer.

Departure hydrographs for wells Medina2 and Medina8 and discharge departure for station Hondo Creek near Tarpley (fig. 7) provide evidence for flow in the NWMFP. The observed relation between water-level departures at Medina2 and Medina8 with discharge departure for Hondo Creek near Tarpley could indicate that ground water is moving to the southwest through Medina8 and toward Seco Creek. Medina8 showed rapid responses to recharge events (to positive increases in flow departure) occurring along Hondo Creek. Medina2, upgradient from Medina8, showed rises in water level during larger recharge events, possibly because the subsurface zone downdip was filled to capacity. Smaller recharge events along Hondo Creek caused little if any corresponding increases in water-level departure at Medina2, which could indicate that the subsurface zone downdip did not fill to capacity.

The departure hydrograph for Medina8 also indicates at least one extended period of proportionately more diffuse flow in the aquifer—water stored in fractures, bedding planes, vugs, and so forth—after recharge. A transition to more diffuse flow can be identified on the departure hydrograph by a change in recession slope to a less steep decline; for example, the period from about mid-January to about mid-February 2003.

North-Central Medina Flow Path (Northern and Southern Parts)

The north-central Medina flow path (NCMFP) is separated into a northern part (NCMFPn) and a southern part (NCMFPs) (fig. 5). The NCMFPn is bounded by the Parkers Creek fault on the north and the Medina Lake fault on the south. The adjacent NCMFPs is bounded on the north by the Medina Lake fault and on the south by the Diversion Lake fault. The NCMFP is separated into a northern and southern part because water levels at well Seco are higher than water levels at wells Medina3, Medina5, and Quihi. On average, daily mean water levels at well Seco are about 39 feet higher than daily mean water levels at well Quihi, the closest monitoring well to well Seco. This head difference is hypothesized to be the result of the Medina Lake fault acting as a barrier to hydraulic communication (connection) across the fault.

Recharge to the NCMFPn probably occurs as infiltration from Seco Creek, as underflow from the adjacent Trinity aquifer, and as leakage from Medina Lake. The NCMFPs probably receives recharge as underflow from the Trinity aquifer and by leakage from Medina Lake. Ground water in the NCMFPn and NCMFPs moves downgradient (and down relay ramp) from eastern Medina County toward the southwest. The NCMFPn

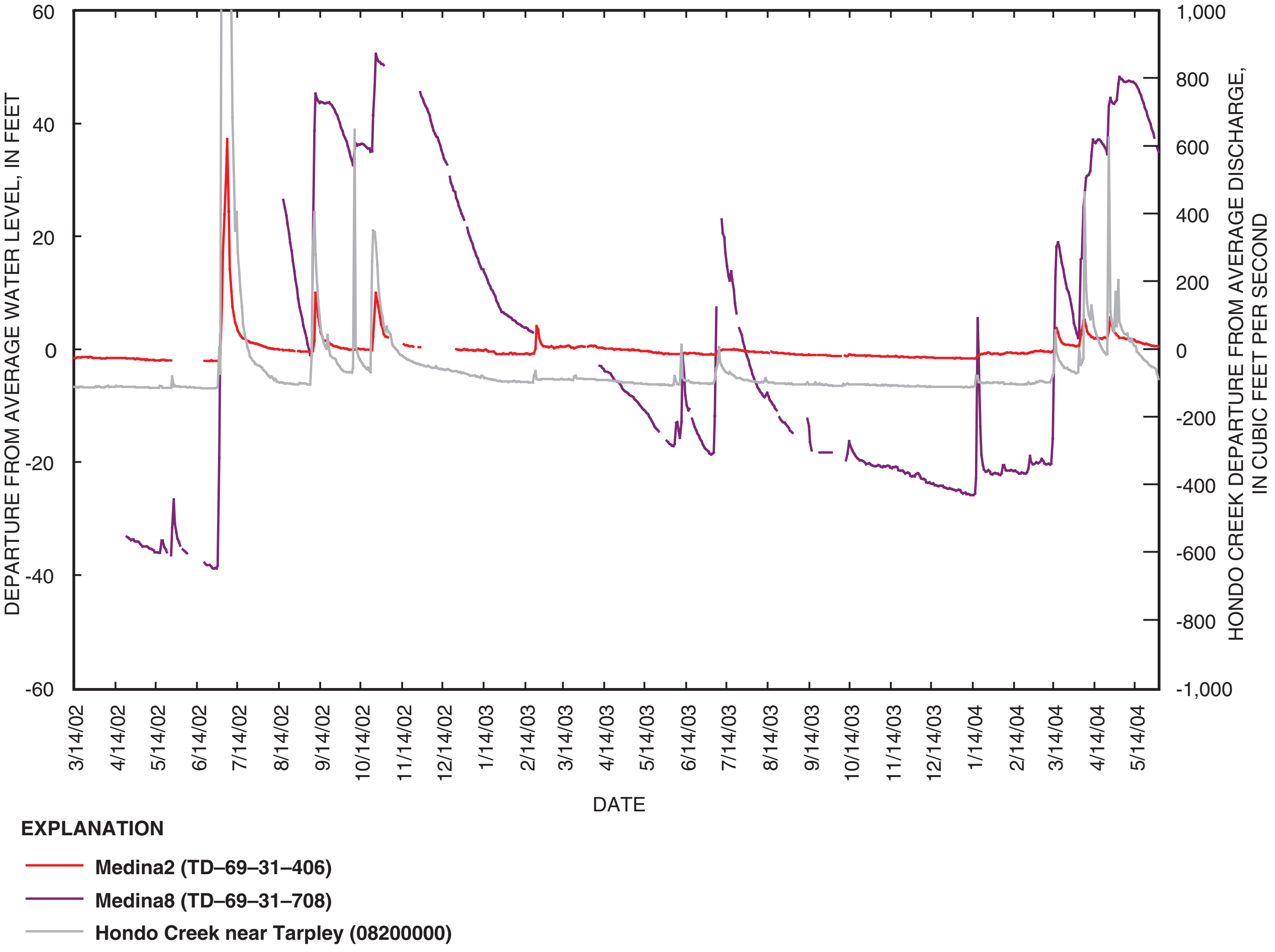


Figure 7. Hydrograph showing water-level departure for two wells in the northwestern Medina flow path, northern Medina County, Texas, and discharge departure for Hondo Creek near Tarpley, Texas, March 2002–May 2004.

and NCMFPs are hypothesized to turn south in the vicinity of Seco Creek as they begin to be influenced by the structural features that focus ground-water flow into the Knippa gap (fig. 1).

Recent studies of water-budget analyses of the Medina Lake/Diversion Lake system (Lambert and others, 2000; Slattery and Miller, 2004) indicate that the lake system leaks appreciable amounts of water to the Edwards aquifer and that the rate of leakage is related to the stage of Medina Lake. Computed rates of leakage from Medina Lake to the Edwards aquifer are about 5 to 178 acre-feet per day when Medina Lake stages range from 963 to 1,064 feet above NGVD 29 (Slattery and Miller, 2004, p. 17).

Water-level departure hydrographs for well Seco and Medina Lake and discharge departure for station Seco Creek at Miller Ranch (fig. 8), and water-level departure hydrographs for wells Medina3, Medina5, and Quihi and for Medina Lake (fig. 9) provide evidence for flow in the NCMFP. The observed relation between the well water-level departure hydrographs and the lake water-level departure hydrograph could indicate ground water is being recharged by the Medina Lake system and is moving down ramp away from Medina Lake toward the southwest. This interpretation is based on the similarity between the well water-level and lake-stage departure hydrographs. During the period July 2, 2002–April 24, 2003 (except for 1 week), the lake stage was above the spillway at the Medina Lake dam, which resulted in a relatively flat departure hydrograph for the period. During this period that the lake was at capacity, water-level departures at all four downgradient wells increased positively (water levels rose), which indicates the lake was recharging the aquifer. Comparison of water-level departure hydrographs and rainfall data from several gages in the study area during the July 2, 2002–April 24, 2003, period of rising water levels did not indicate a relation between rain events and departure-hydrograph fluctuations. In general, both the frequency and magnitude of rain events decreased during the period.

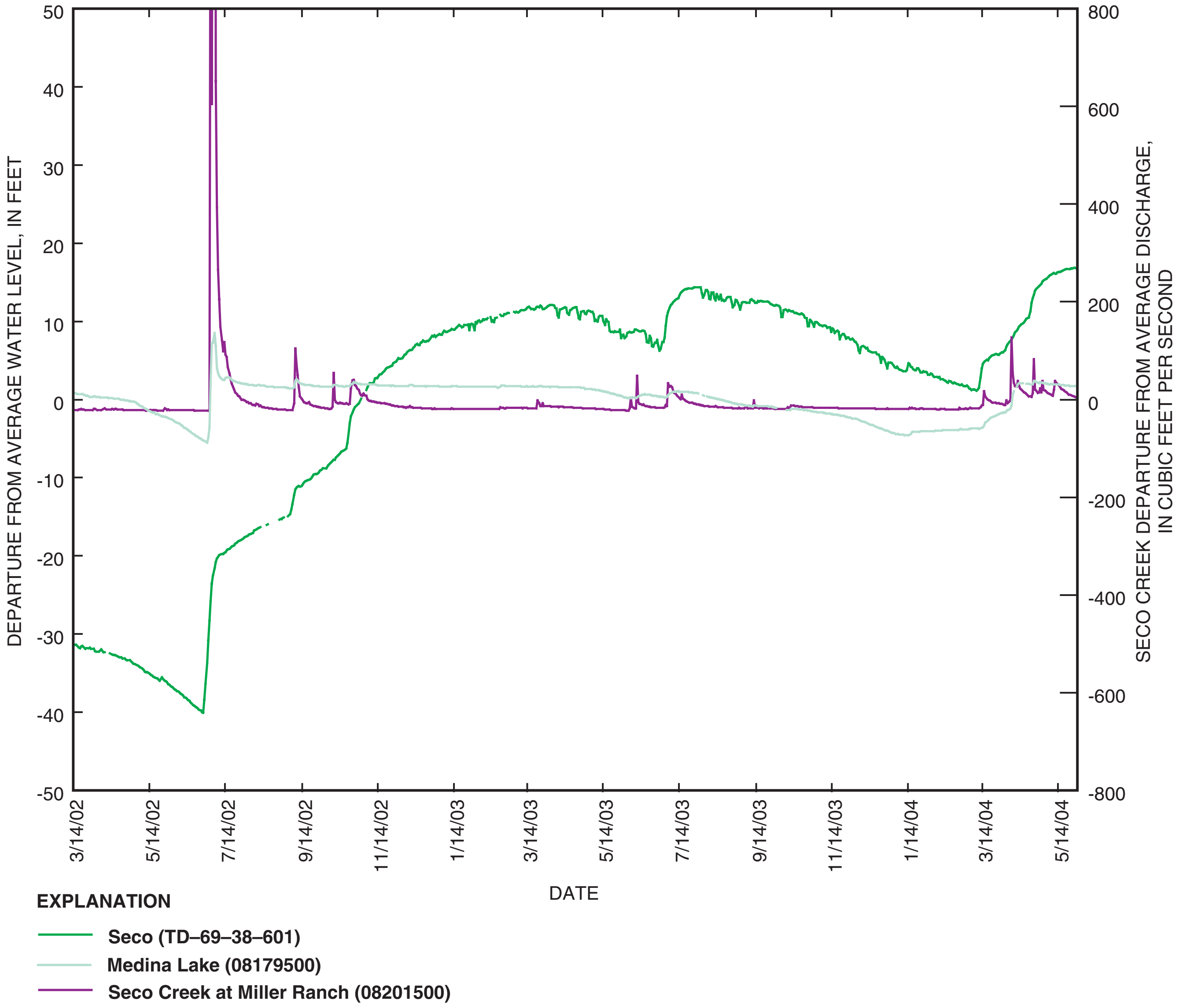


Figure 8. Hydrograph showing water-level departure for a well in the north-central Medina flow path (northern part) and for Medina Lake, northern Medina County, Texas, and discharge departure for Seco Creek at Miller Ranch, Texas, March 2002–May 2004.

South-Central Medina Flow Path

The south-central Medina flow path (SCMFP) is bounded on the north by the Seco Creek and Diversion Lake faults and on the south by the Haby Crossing fault (fig. 5). The SCMFP likely receives recharge from the Medina River and from the adjacent Trinity aquifer. Because of bounding faults oriented northeast-southwest and adjacent flow paths directed south by other geologic structures, the SCMFP follows the configuration of the adjacent flow paths—oriented initially southwest and then south. Immediately after turning south, the SCMFP turns sharply east. The SCMFP is forced east, as are all Edwards aquifer flow paths that originate in the recharge zone in and west of the study area, by the series of generally northeast-southwest trending faults that make it easier for ground water to flow toward major natural discharge points (Comal and San Marcos Springs) east of the study area than downdip to the southeast.

Departure hydrographs for wells Medina7, Castroville, Medina4, and Hondo, and discharge departure for station Medina River at Bandera (fig. 10) provide evidence for flow in the SCMFP. The similarity in configuration among the four well-departure hydrographs, which could indicate hydraulic communication, is clear; and the correspondence in dates

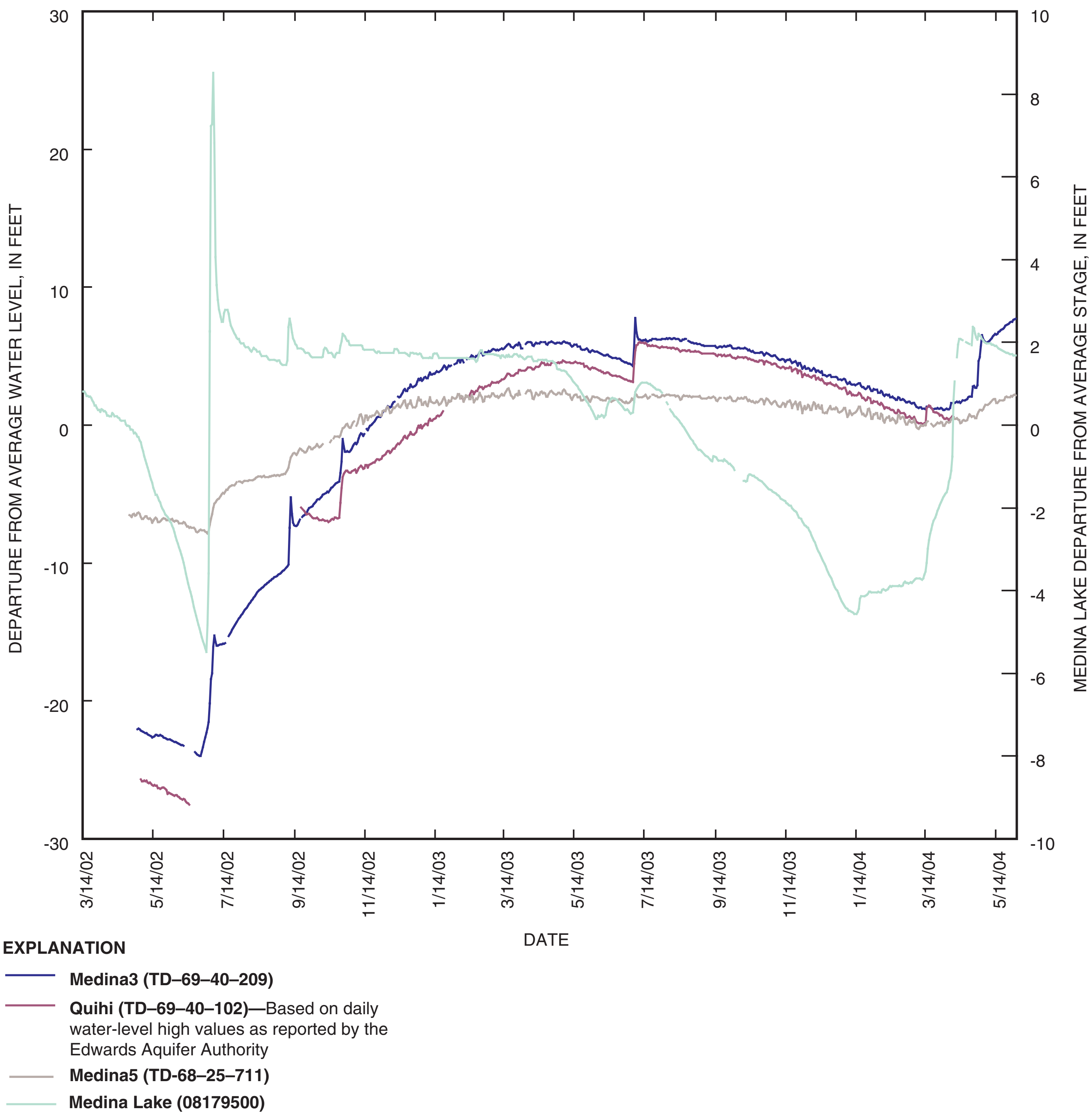


Figure 9. Hydrograph showing water-level departure for three wells in the north-central Medina flow path (southern part) and for Medina Lake, northern Medina County, Texas, March 2002–May 2004.

of positive increases in departure between ground-water levels and Medina River flow (despite the distance of the gaging station from the wells) could indicate hydraulic communication between the Medina River and the ground-water flow system. The steep negative increases in the Medina4, Hondo, and Castroville departure hydrographs (but not in the Medina7 water-level and Medina River streamflow departure hydrographs) are caused by withdrawals. The relation between the water-level departures and the flow departure could indicate hydraulic communication between the Edwards and Trinity aquifers—and thus evidence for underflow from the Trinity aquifer to the SCMFP (and other flow paths), as the Medina River at Bandera station overlies the Trinity aquifer.

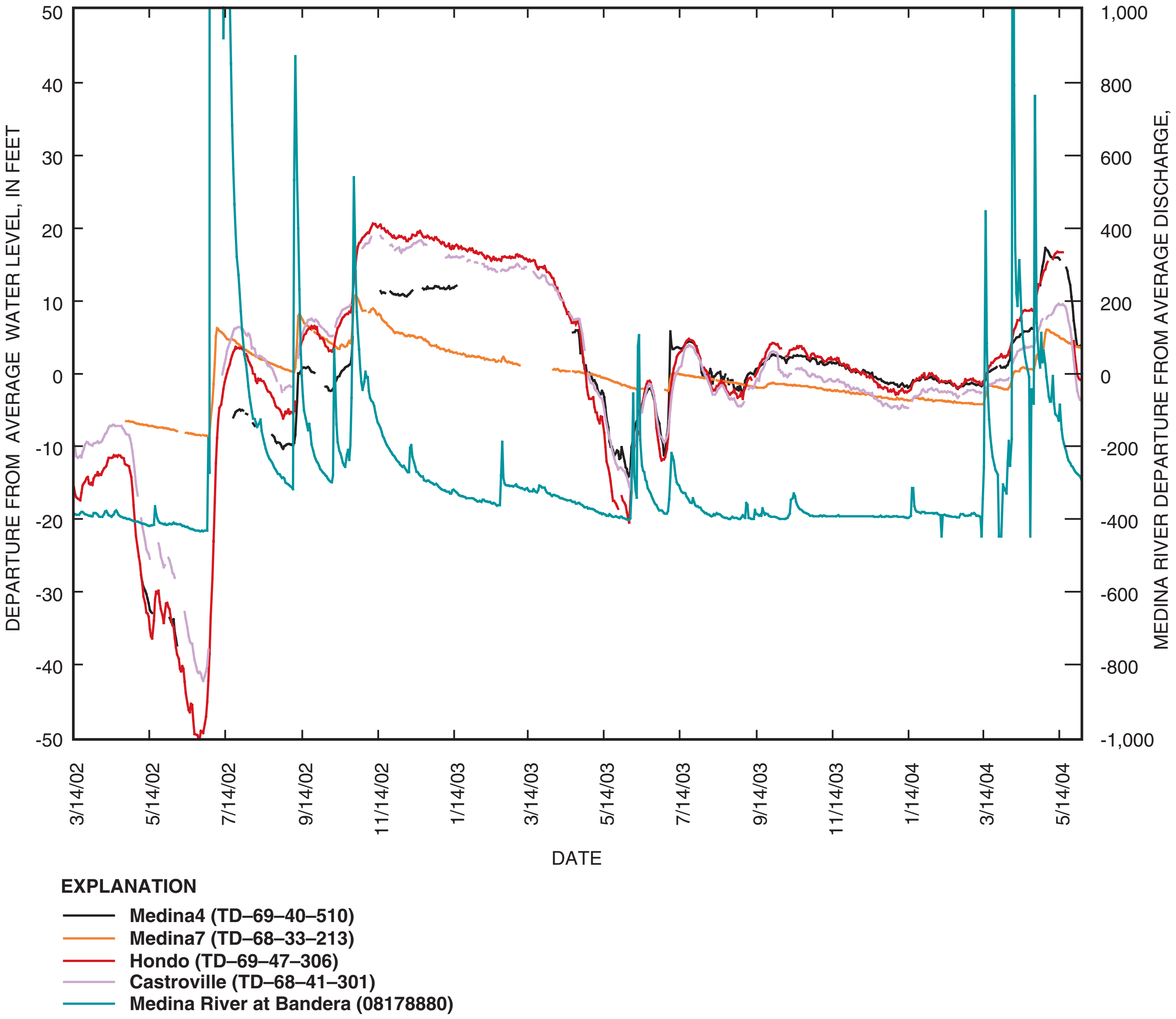


Figure 10. Hydrograph showing water-level departure for four wells in the south-central Medina flow path, northern Medina County, Texas, and discharge departure for Medina River at Bandera, Texas, March 2002–May 2004.

Correlation Between Water Levels in Wells With Continuous Record

Statistical correlations between water-level departures for the 11 continuously monitored wells provide additional evidence for the hypothesized flow paths. Figure 11 graphically summarizes the monotonic relations between each of the 55 combinations of departure-dataset pairs. The Kendall's tau correlation coefficient for each graph indicates the strength of the correlation between departure (and thus water-level) pairs—the larger the absolute value of tau within the range of -1 to +1, the stronger the correlation. The strength of each correlation is indicated by the background color of the graph. The stronger correlations (those greater than .6) are all among wells in the same flow path (fig. 12), with one exception (not shown in fig. 12): the strong correlation between departures for Medina8 (NWMFP) and Medina7 (SCMFP), for which there is no explanation. Also, there is a strong correlation between departures for Seco (NCMFPn) and those for Quihi, Medina5, and Medina3 (NCMFPs). Although it is hypothesized that the Medina Lake fault restricts hydraulic communication between the NCMFPn and NCMFPs, water levels in both parts of the NCMFP apparently are influenced by the same areas of recharge.

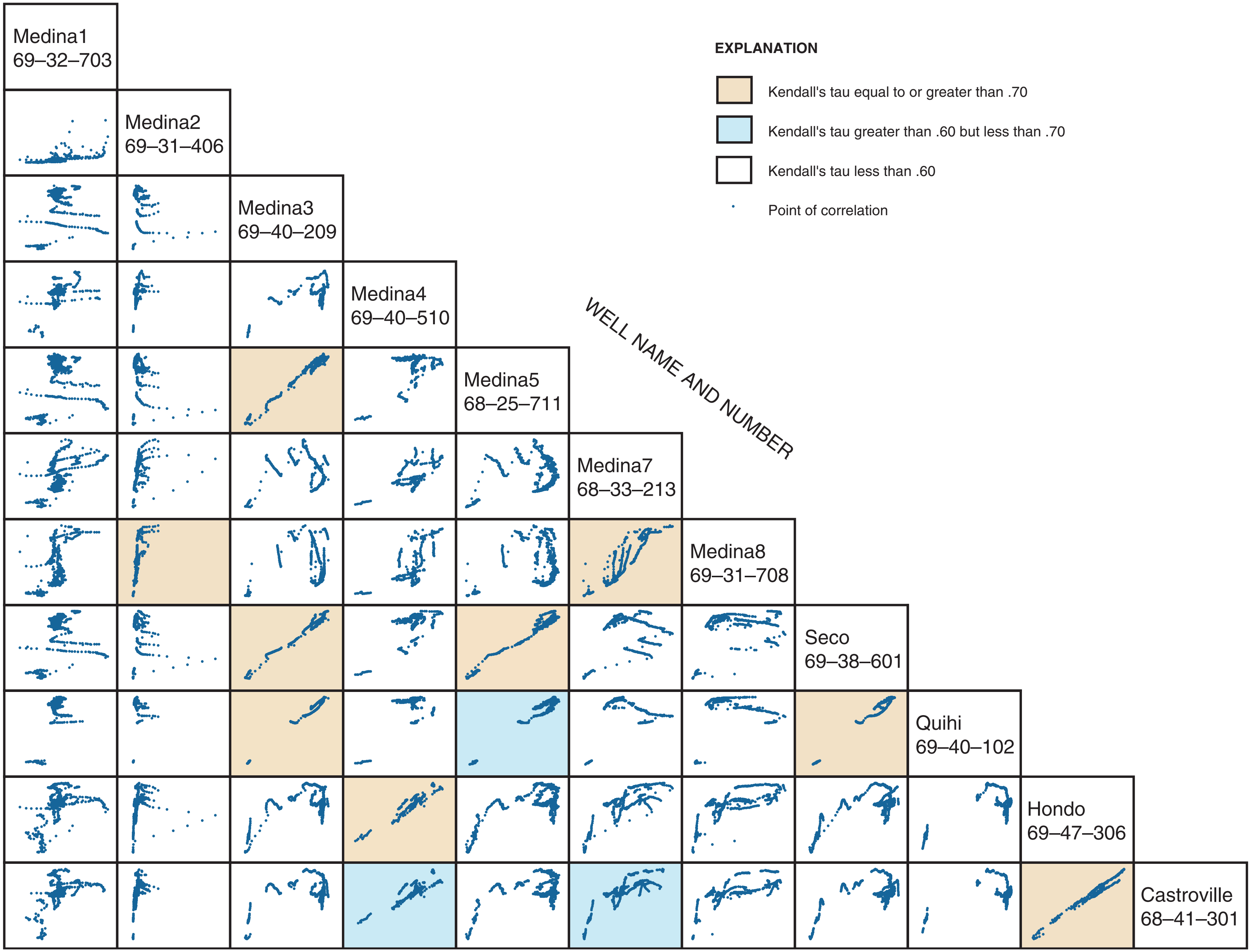


Figure 11. Correlation between water-level departures for 11 monitoring wells, northern Medina County, Texas.

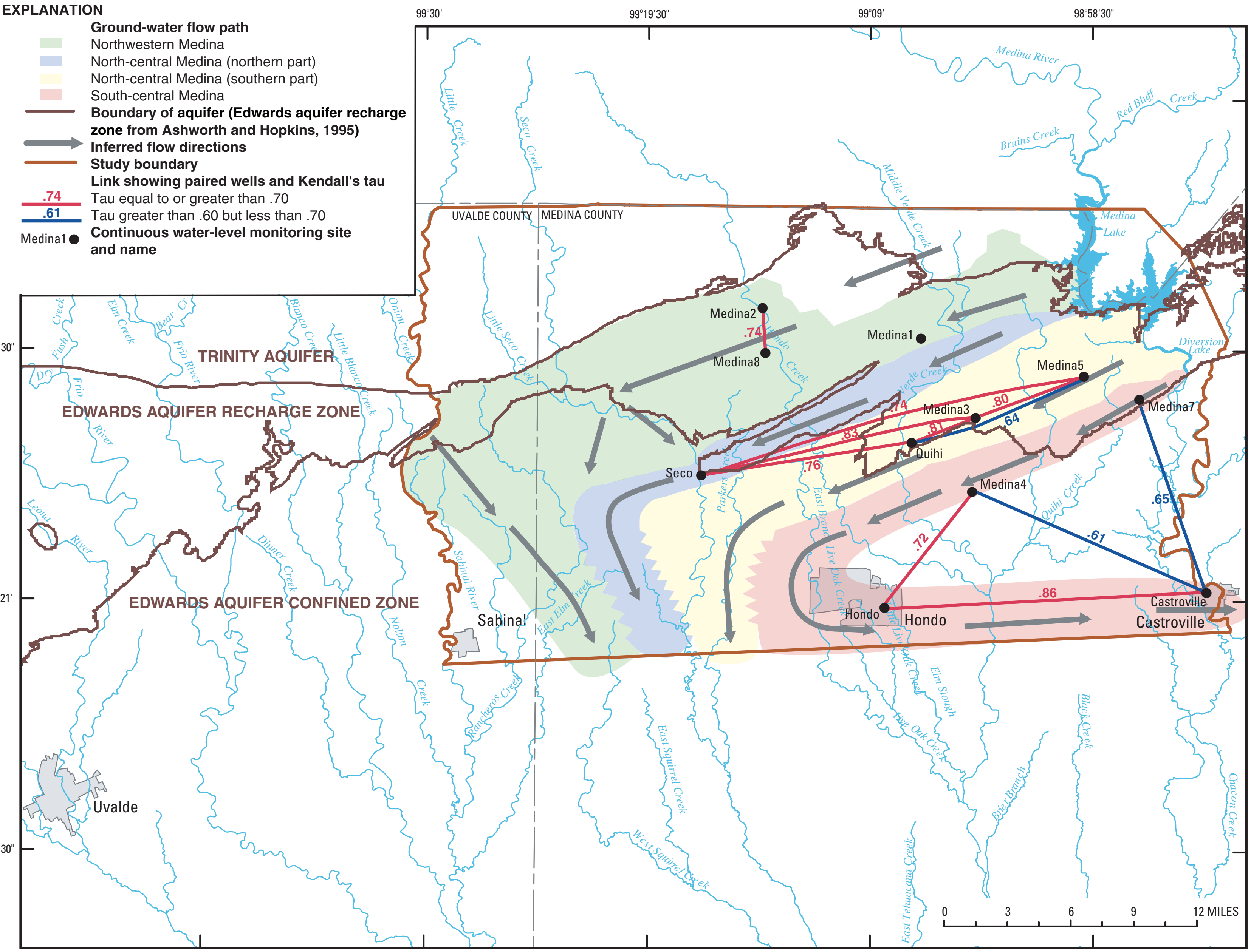


Figure 12. Water-level departure pairs from 11 monitoring wells for which Kendall's tau was greater than .60, northern Medina and northeastern Uvalde Counties, Texas.

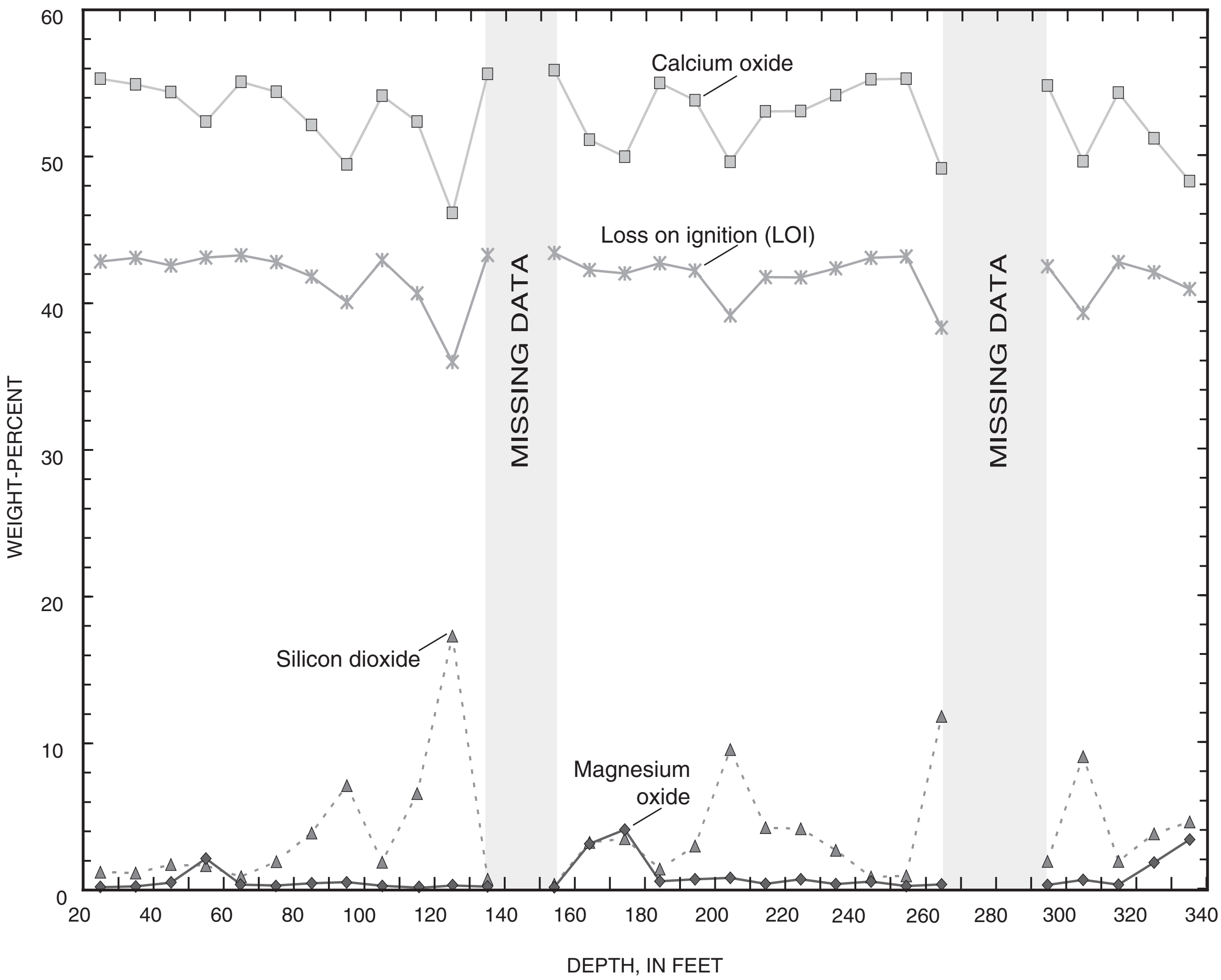


Figure 13. Variation with depth of selected bulk-rock chemistry, in weight-percent, determined by X-ray fluorescence analysis of cuttings from well Medina5 (TD–68–25–711), northern Medina County, Texas, 2002.

Geochemical Characterization

Dominant mineral phases and bulk-rock chemistry of the Edwards aquifer were evaluated using well cuttings from well Medina5. XRD analysis identified calcite as the predominant mineral at all depth intervals. No evaporite or clay minerals were identified. Bulk-rock compositions were determined from XRF analysis. The XRF results were similar to the XRD findings such that calcium, in weight-percent oxide, and loss on ignition, which usually is indicative of carbon dioxide losses from carbonates, accounted for more than 90 percent of the bulk chemistry (fig. 13). Minor silica enrichment (greater than 5-percent oxide) was identified in five 10-foot depth zones. Magnesium enrichment, which is indicative of dolomitic limestone, also was identified in three 10-foot depth zones.

Age of Ground Water

Apparent ages of ground water in the Edwards aquifer (fig. 14) ranged from 1969 in well TD–69–38–709, in the confined zone of the Edwards aquifer in the NCMFPn (fig. 6), to present day (2003) in well Medina3, in the recharge zone of the Edwards aquifer in the NCMFPs.

As would be expected in the more downgradient part of a flow path, the apparent age of water in confined-zone wells (TD–69–38–709, TD–69–38–106, and TD–69–38–509) generally was older (1969, 1975, and 1978 respectively) than water in the more upgradient parts. An exception was water in Medina4, which was relatively younger (1992) than water in other wells in the confined zone. Medina4 was the most upgradient well sampled in the SCMFP that yielded a reliable groundwater age. Greater variability in apparent age characterized water in wells in the recharge zone compared with water in the

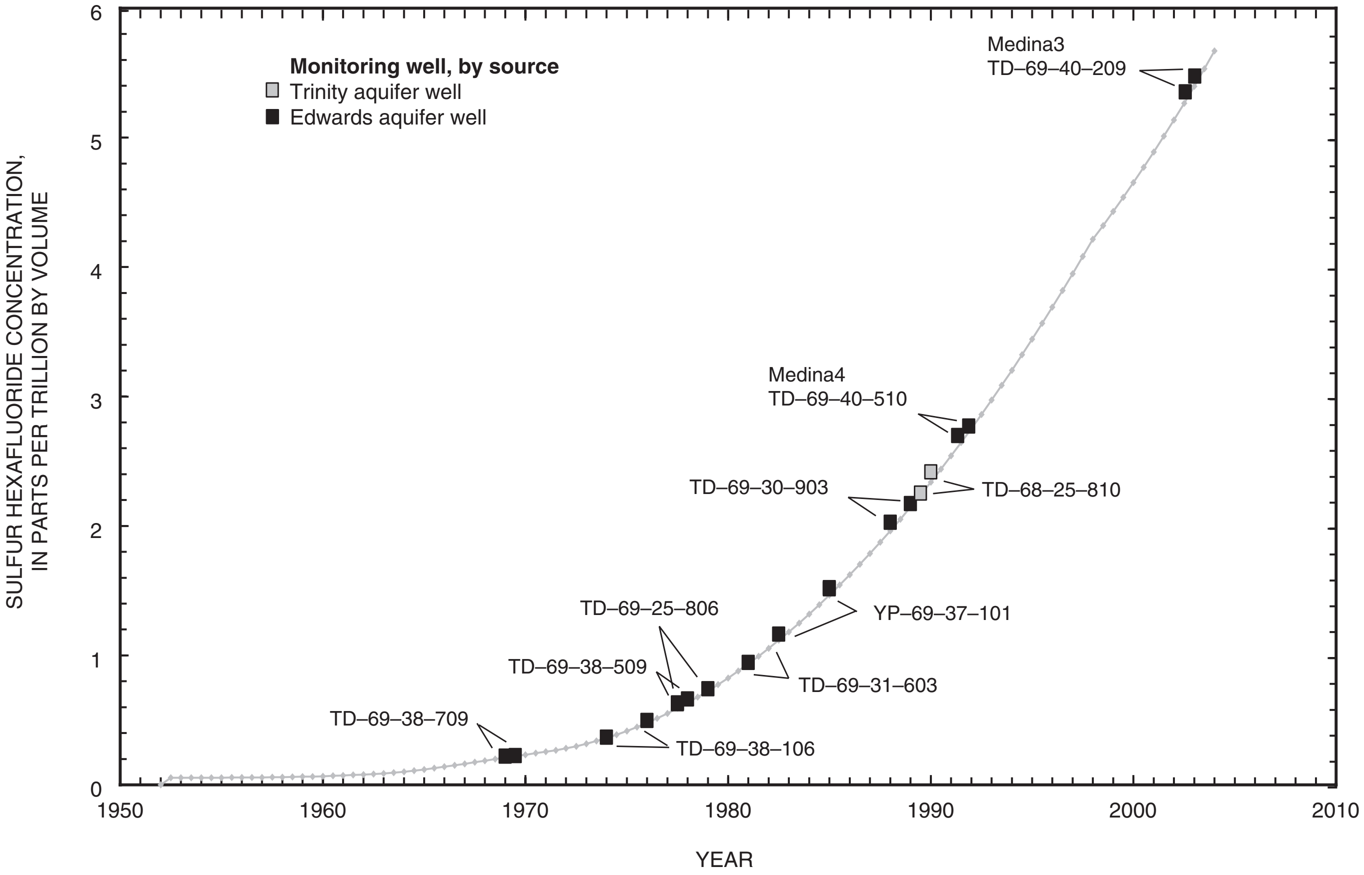


Figure 14. Apparent ages of ground water in selected wells in the Trinity and Edwards aquifers, northern Medina and northeastern Uvalde Counties, Texas, based on sulfur hexafluoride concentration (modified from Busenberg and Plummer, 2000, fig. 6A).

confined zone, probably because of more frequent mixing with rainfall and surface water. Well TD–68–25–806 yielded the oldest apparent age for ground water in the recharge zone.

Ground-Water/Surface-Water Mixing Relations

Global and local meteoric water lines (GMWL and LMWL, respectively) were graphed from the equations by Craig (1961) and Yurtsever and Gat (1981), respectively (fig. 15); δD and δ^{18}O determined from surface-water samples collected from Medina Lake and the Medina River below Medina Lake (table 2) were superimposed on the graphs. Surface-water isotope data plot below the GMWL and LMWL because of fractionation effects from evaporative processes.

Ground-water isotope data were grouped by hypothesized flow path and graphed on the same reference lines. Ground water that originated by direct recharge to the aquifer from rainfall and not influenced by surface water should have isotope ratios that plot near the meteoric water line. Isotope data from wells in the NWMFP plotted near the GMWL. Isotope data from wells in NCMFP and SCMFP produced a linear trend that extends from the surface-water data to the GMWL, which represents a gradient of mixing of the surface water with the ground water. Simple linear regression of the isotope data from this study produced a local mixing line that accounted for 96 percent of the variability ($R^2 = .958$)

Ground-water samples that represented end-member Edwards aquifer chemistry were selected from wells that had isotope ratios that plotted near the GMWL (fig. 15). Ground water from Quihi, Medina2, and TD–68–25–806 were selected, and their isotope ratios (δ^{18}O and δD, respectively) were averaged to produce the average Edwards end-member isotope composition. Isotope ratios also were averaged for samples from stations Medina Lake near San Antonio and Medina River below Medina Lake to produce the average surface-water end-member isotope compositions.

Sensitivity of end-member isotope composition to estimate the percentages of surface water in Edwards aquifer samples ranged from 10 (for δ^{18}O) to 12 percent (for δD) on the basis of seasonal or hydrologic variability in the ground-water system. The sensitivity of Trinity aquifer samples was about

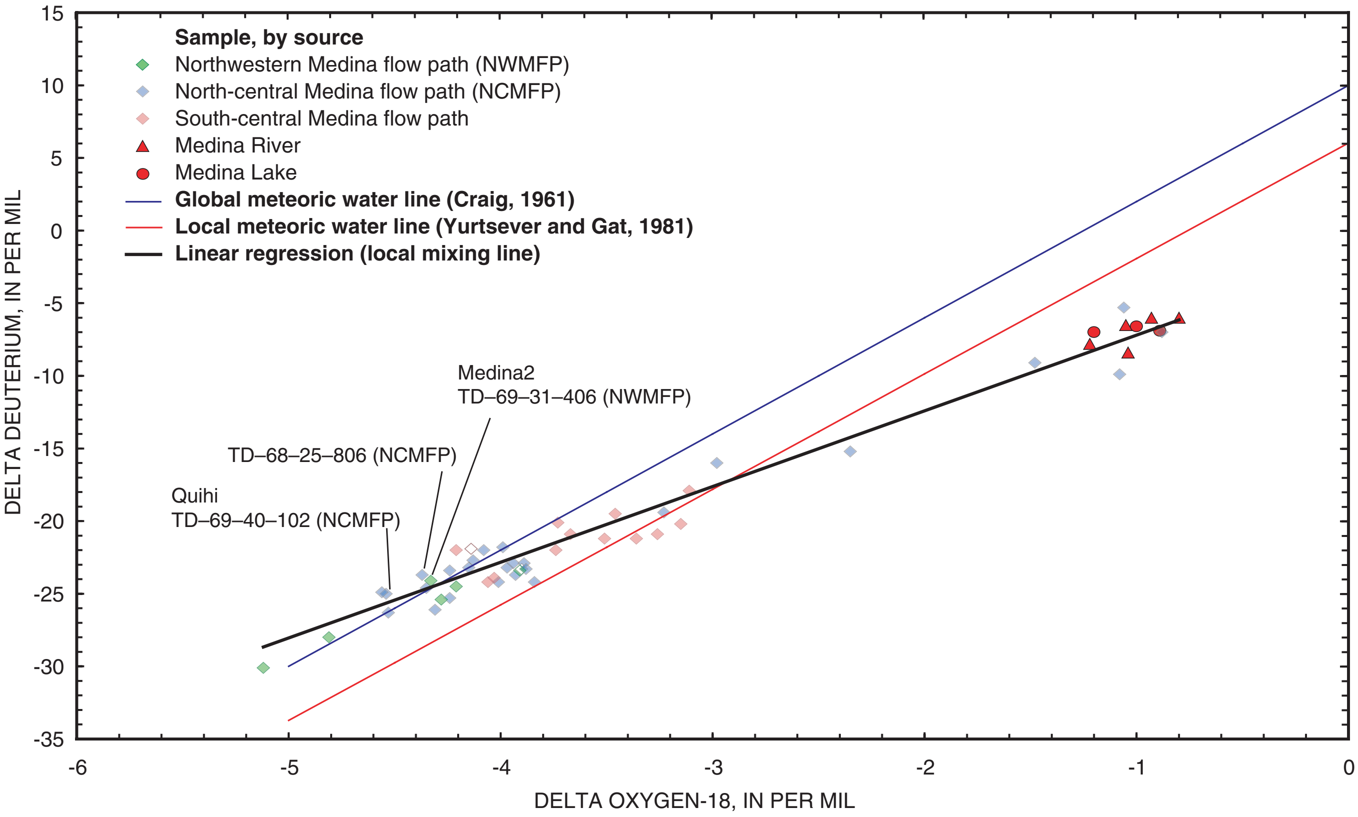


Figure 15. Relation between delta oxygen-18 and delta deuterium ratios for selected ground- and surface-water sites, northern Medina County, Texas, 1995–2003.

one-half that of Edwards aquifer samples (5 and 7 percent for $\delta^{18}O$ and δD, respectively). Therefore, all mixing computations were censored at the 10- and 12-percent levels for the Edwards aquifer samples and at the 5- and 7-percent levels for Trinity aquifer samples (table 3, at end of report).

Samples from two wells (TD–68–25–402 and TD–68–25–510) in the NCMFP and close to Medina Lake (fig. 6), were almost entirely surface water (at least 88 percent) on the basis of isotope composition (table 3). Percentages in samples from other wells ranged from less than the censored level to about 60 percent. Isotope data indicate that ground water in the SCMFP was the most influenced by surface-water recharge, possibly from the Medina River. In the NCMFP, proximity of a well to a major water body, such as Medina Lake or the Medina River, appears to be the major factor in controlling the percentage of surface water.

Major-Ion Chemistry

Analysis of major-ion chemistry indicates an appreciable difference in the basic water chemistry between the Edwards and Trinity aquifers (fig. 16; table 2) and that the Edwards aquifer receives a minimal amount of water derived from the Trinity

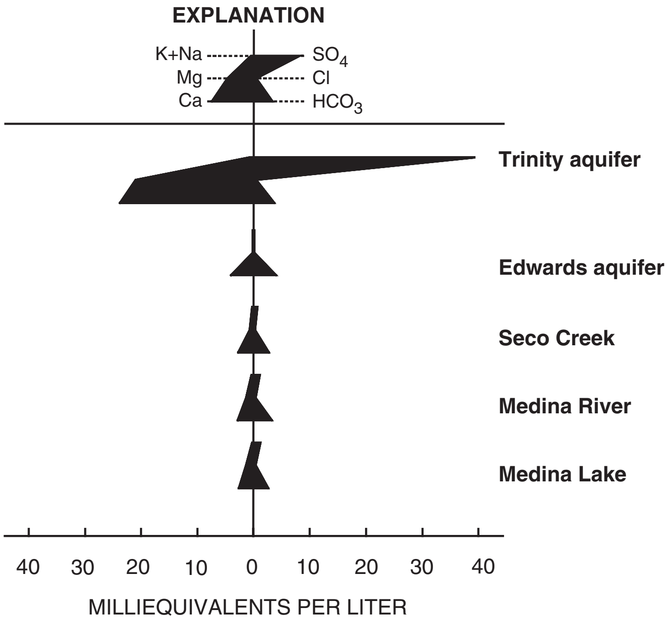


Figure 16. Stiff diagram showing the variability in composition of ground water and surface water, northern Medina County, Texas.

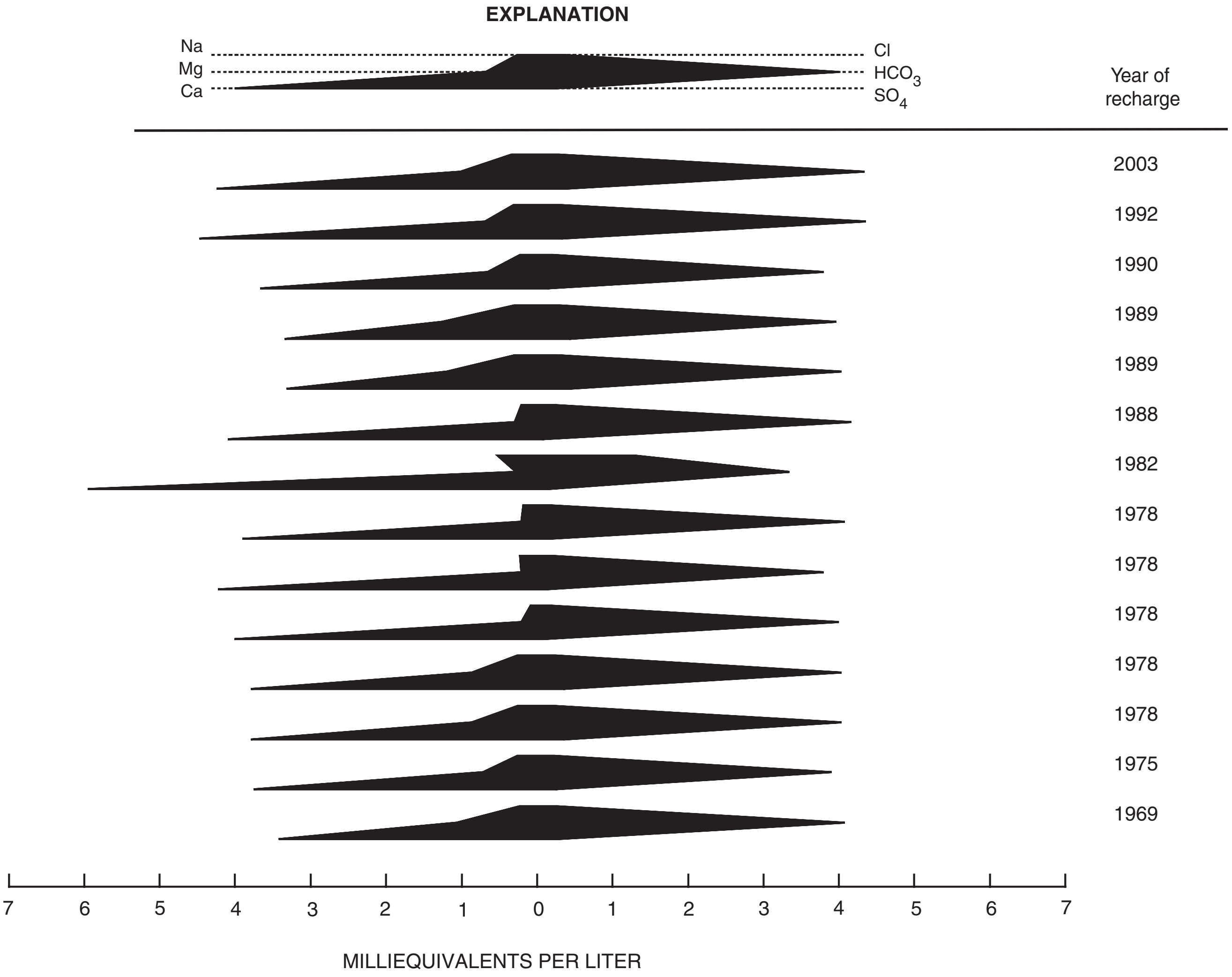
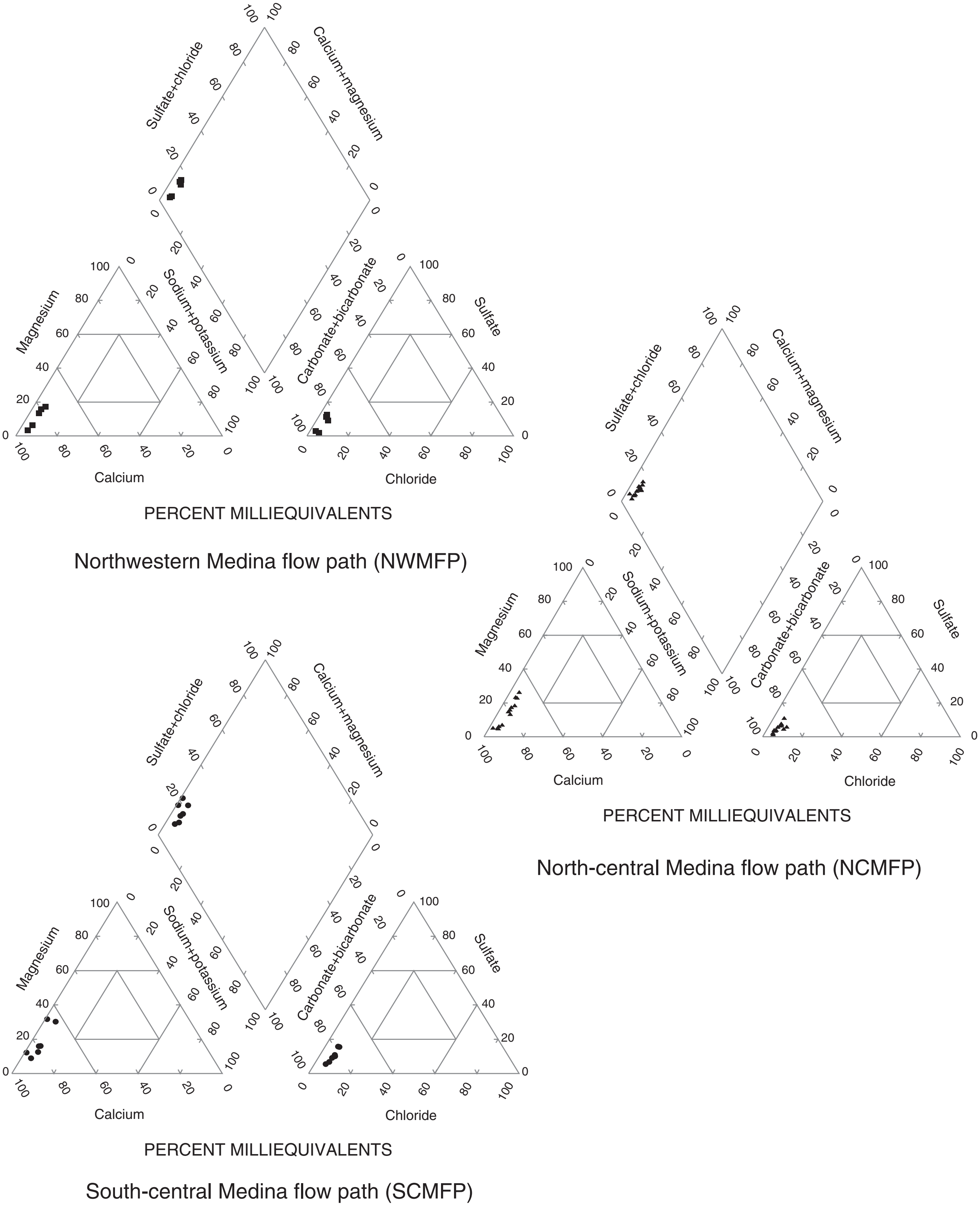


Figure 17. Stiff diagram showing the variability in composition of ground water in the Edwards aquifer, grouped by year of recharge (apparent age based on sulfur hexafluoride concentration), northern Medina and northeastern Uvalde Counties, Texas.

aquifer in the study area. Surface water from major streams and Medina Lake recharge both the Edwards and Trinity aquifers. Water chemistry indicates the amount of surface water identifiable in the ground-water system primarily is related to the proximity of the sampling point to the source of the surface water.

Relatively minor variability in major-ion chemistry was observed in water of different ages in the Edwards aquifer (fig. 17). Edwards aquifer water was of the calcium-bicarbonate type (fig. 18). Minor variability in magnesium and sulfate concentrations among samples from wells in the Edwards aquifer was indicated in NWMFP, NCMFP, and the SCMFP flow paths. Specific conductance of Edwards aquifer water in the study area ranged from 402 to 710 microsiemens per centimeter at 25 degrees Celsius, and pH ranged from 6.5 to 7.4 standard units. The temperature of Edwards aquifer water ranged from 17.5 to 30.5 degrees Celsius.

Samples from wells in the Trinity aquifer yielded ground water of a calcium-magnesium-sulfate type (fig. 16). Some minor variability in Trinity aquifer water chemistry was noted, depending on the location in the aquifer from which the sample was obtained. Specific conductance of water in the Trinity aquifer in the study area ranged from 417 to 3,160 microsiemens per centimeter at 25 degrees Celsius, and ph ranged from 6.4 to 9.4 standard units. The temperature of the Trinity aquifer water ranged from 12.5 to 24.9 degrees Celsius. The greater mineralization, as indicated by greater specific conductance in Trinity aquifer water compared with Edwards aquifer water, indicates slower ground-water movement in the Trinity aquifer than in the Edwards aquifer.



Northwestern Medina flow path (NWMFP)

North-central Medina flow path (NCMFP)

South-central Medina flow path (SCMFP)

Figure 18. Piper diagrams showing composition of ground water in the Edwards aquifer in the northwestern, north-central, and south-central Medina flow paths, northern Medina and northeastern Uvalde Counties, Texas.

Geochemical Simulation

Northwestern Medina Flow Path

Ground-water chemistry for samples from five wells in the Edwards aquifer in the NWMFP (in downgradient order, Medina1, TD–69–31–603, Medina2, Medina8, and TD–69–30–903) were used to evaluate the evolution of ground-water chemistry in the NWMFP (fig. 19; table 4, at end of report). SIs of the samples for calcite, dolomite, carbon dioxide (gas), gypsum, halite, and amorphous silica (fig. 20; table 5, at end of report) indicate that most mineral phases were near equilibrium or able to undergo dissolution. Undersaturated conditions predominated.

Seven simulations were done for samples from well pairs collected during 2001–03 (table 4); three of the seven yielded plausible models. The mole transfers of the mineral phases determined in the simulations were evaluated on the basis of plausible processes of dissolution or precipitation indicated by SIs. For example, if a simulation indicated that 1 mole of calcite needed to be precipitated to explain between-well changes in chemistry of water undersaturated with respect to calcite, then that simulation was considered not plausible.

Simulations 5, 6, and 6A used ground-water chemistry for well Medina1 from August 2003 as the initial solution with the final solutions based on ground-water chemistries from nearby wells Medina2 and Medina8. Mixing of the initial water with end-member Edwards aquifer water (TD–68–25–806, the oldest) was included in simulation 5. The most plausible model for simulation 5 required a 58-percent contribution of end-member Edwards aquifer water. Precipitation of 0.48 millimole per kilogram (mmol/kg) of calcite, degassing of 0.49 mmol/kg of carbon dioxide gas, and dissolution of minor amounts of dolomite, gypsum, halite, and silica (less than or equal to 0.027 mmol/kg) were required to produce the final solution. Mixing of the initial water with end-member Edwards aquifer water (TD–68–25–806) and surface water (average of Medina Lake and Medina River) was included in simulations 6 and 6A. Simulation 6 required a 27-percent contribution of surface water, 73-percent contribution of end-member Edwards aquifer water, and dissolution of 2.24 mmol/kg of carbon dioxide, 0.102 mmol/kg of dolomite, and minor amounts of halite and silica (less than or equal to 0.03 mmol/kg). Simulation 6a required a 33-percent contribution from surface water but no end-member Edwards aquifer water, and mole transfers similar to those in simulation 6.

The results of these simulations demonstrate that the hypothesized NWMFP described in the "Hydrogeologic Identification of Ground-Water Flow Paths" section can be partially supported geochemically; that is, plausible models—processes of dissolution or precipitation in the aquifer between some of the well pairs—were identified. Also, the results indicate a considerable contribution of ground water from the regional flow path (58 to 73 percent). Lastly, a negligible (0 percent) to appreciable (27 to 33 percent) contribution of surface water was indicated in the simulations of the NWMFP.

North-Central Medina Flow Path (Northern and Southern Parts)

Ground-water samples from 13 wells were used to evaluate the evolution of ground-water chemistry in the NCMFP (fig. 19; table 4). Five of the wells in the most upgradient part of the flow path were completed in the Trinity aquifer; the remaining eight were completed in the Edwards aquifer. SIs of samples from these wells for calcite, dolomite, carbon dioxide (gas), gypsum, halite, and amorphous silica (fig. 21; table 5) indicate, as in the NWMFP, that most mineral phases were at equilibrium or able to undergo dissolution. Undersaturated conditions predominated.

The estimated contribution of surface water in samples from NCMFP wells in the Trinity and Edwards aquifers varied over a wide range, from less than 6 to 100 percent (table 3). Samples with the largest percentage of surface water generally were from wells close to Medina Lake. No linear trend existed between the percentage of surface-water contribution and the calcite SI in ground water from the Trinity or Edwards aquifers for this flow path (fig. 22).

Nineteen simulations were done for samples from well pairs collected during 1995–2003 (table 4); eight of the 19 yielded plausible models. Initial simulations focused on the evolution of the ground-water chemistry in the most upgradient part of the NCMFP where influences from the surface-water system, specifically Medina Lake, were greatest. Trinity aquifer wells TD–68–25–402 and TD–68–25– 510 are near Medina Lake (fig. 19). Samples from these wells had isotope compositions that represented contributions of surface water from 88 to 100 percent (table 3). Simulation 1 for well TD–68–25–402 and simulation 2 for TD–68–25–510 (table 4) involved Medina Lake water as the initial solution and the ground-water chemistry from the August 1996 samples in the respective wells as the final solution. Simulations 1 and 2 required 100-percent Medina Lake water as the initial solution prior to the dissolution of about 0.3 mmol/kg of carbon dioxide, less than 0.1 mmol/kg of halite, and 0.278 mmol/kg of gypsum to reach the final-solution chemistry.

Trinity aquifer wells TD–68–25–810 and TD–68–25–809 are near Diversion Lake (fig. 19). The isotope compositions of ground water from these wells indicated a negligible (less than 6 percent) contribution of surface water in the August 1996 TD–68–25–810 sample and a 13-percent contribution in the July 1996 TD–68–25–809 sample (table 3). Simulations 3 and 4 (table 4) modeled the influence of the Edwards aquifer and the surface-water system on the ground-water chemistry of wells TD–68–25–810 and TD–68–25–809, respectively. End-member Trinity aquifer water (TD–68–25–602, upgradient from all flow paths) was the initial solution, and mixing of end-member Edwards aquifer water (TD–68–25–806) and surface water was allowed. In simulation 3, the final solution

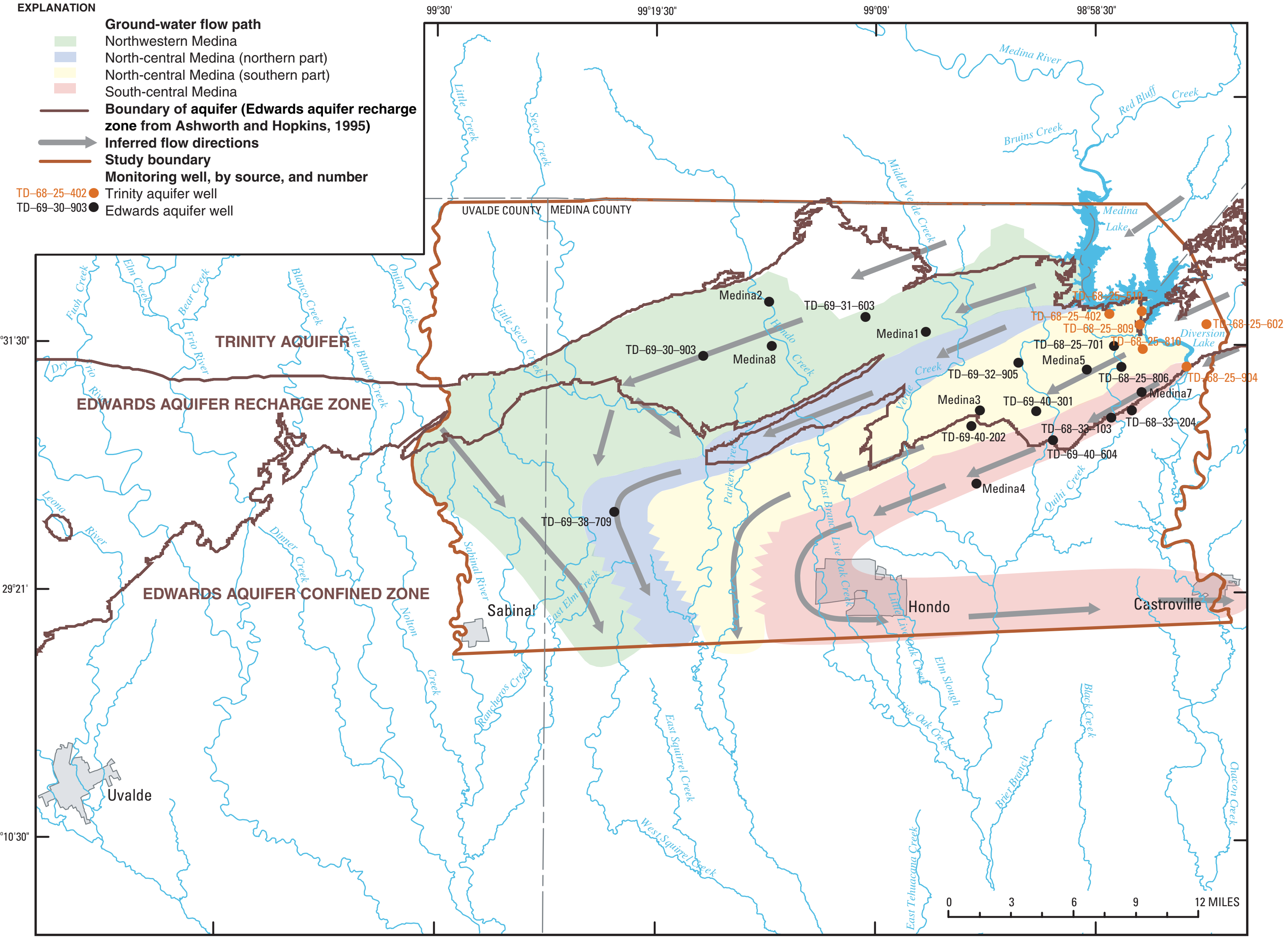
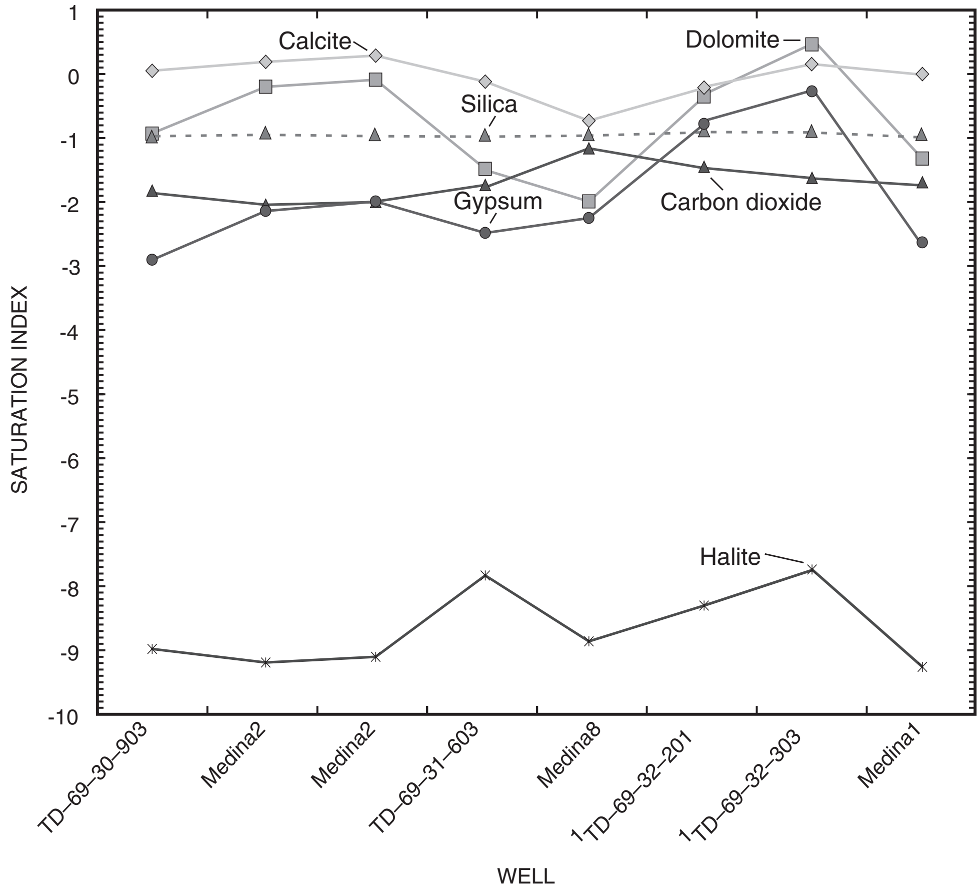


Figure 19. Wells in flow paths that yielded samples used to evaluate evolution of ground-water chemistry by simulation, northern Medina and northeastern Uvalde Counties, Texas.



[1] Probably northwestern Medina flow path

Figure 20. Saturation indexes (computed with PHREEQC) for selected mineral phases for ground water from wells in the northwestern Medina flow path, northern Medina County, Texas, 1995–2003.

was the ground water in well TD–68–25–810 for the August 1996 sample that had negligible surface-water contribution on the basis of isotope data. The most plausible model required no surface-water contribution and a 100-percent contribution from the Edwards aquifer to the initial solution. About 3 mmol/kg of carbon dioxide, 0.13 mmol/kg of dolomite, and 0.21 mmol/kg of halite were dissolved to produce the final solution. In simulation 4, the final solution was the ground water in well TD–68–25–809 for the July 1996 sample that was estimated to have a 13-percent surface-water contribution on the basis of isotope data. That simulation required a 20-percent surface-water contribution and an 80-percent contribution from the Edwards aquifer to the initial solution, which also assumed negligible Trinity aquifer water. As in simulation 3, no plausible model was identified that required a contribution from the Trinity aquifer. The evolution of ground water to the final-solution chemistry required precipitation of 2.36 mmol/kg of calcite, degassing of about 0.4 mmol/kg of carbon dioxide, and dissolution of 1.15 mmol/kg of dolomite, about 11 mmol/kg of gypsum, and 0.014 mmol/kg of halite.

Simulations 9, 11, 12, and 12A (table 4) represented the evolution of ground water from wells in the hypothesized NCMFP during December 2002–October 2003. In simulation 9, the evolution of ground water was simulated from recharge-zone well Medina5 to well Medina3, at the boundary between the recharge zone and the confined zone (fig. 19). Ground water from Medina5 (August 2003 sample) was the initial solution and had negligible (less than 11 percent) surface-water contribution on the basis of isotope data (table 3). The simulation allowed mixing of end-member Edwards aquifer water (TD–68–25–806) and surface water with the initial water. Ground water from Medina3 (August 2003 sample) represented the final solution and had an 18-percent surface-water contribution on the basis of isotope data. The PHREEQC simulation allowed carbon dioxide degassing and dissolution and dolomite, gypsum, halite, and amorphous silica dissolution only. The most plausible model required 29-percent contribution from the surface-water system and dissolution of about 1.9 mmol/kg of carbon dioxide gas, about 0.2 mmol/kg of dolomite, and less than 0.075 mmol/kg of gypsum, halite, and silica.

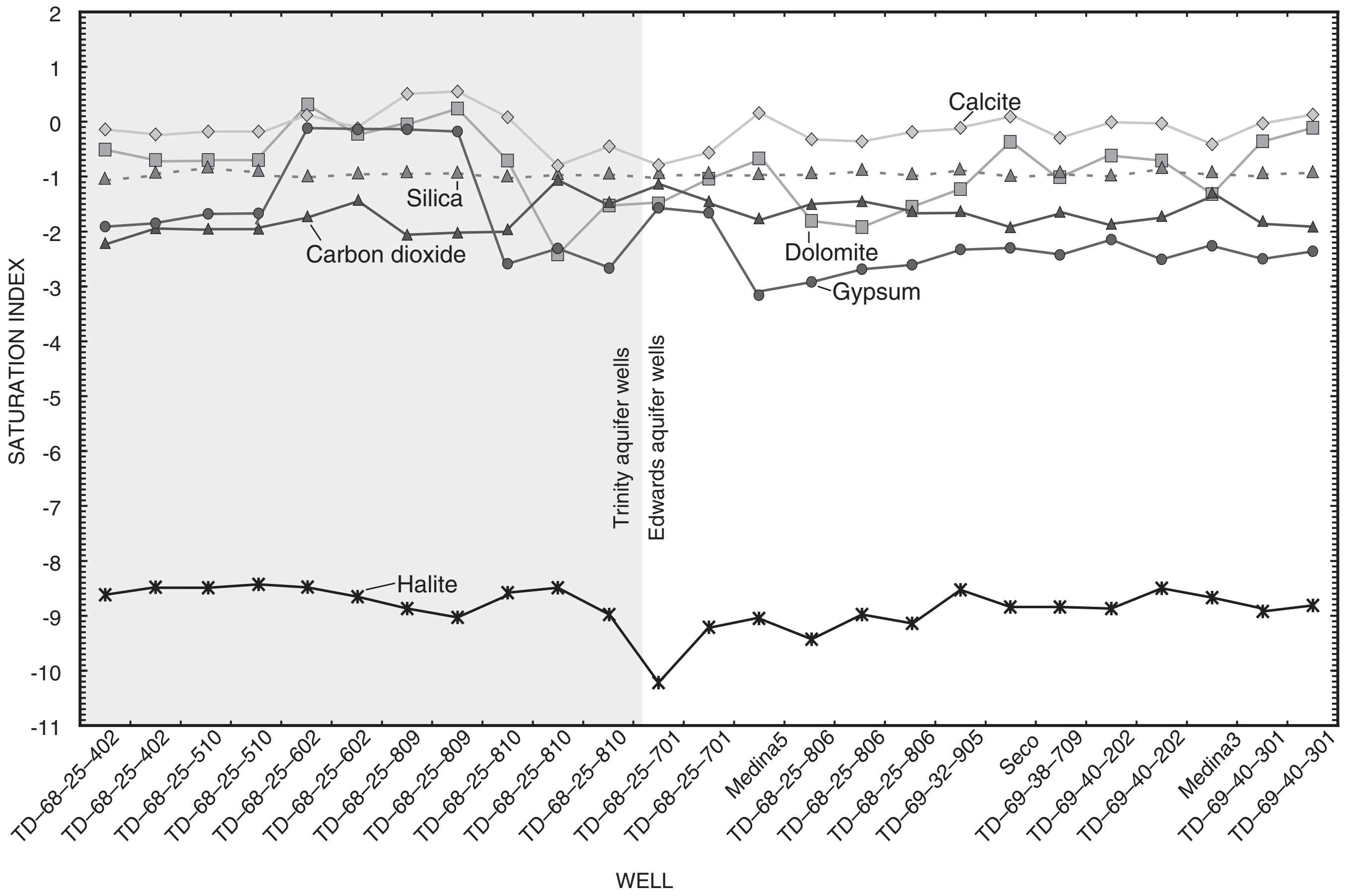


Figure 21. Saturation indexes (computed with PHREEQC) for selected mineral phases for ground water from wells in the north-central Medina flow path, northern Medina County, Texas, 1995–2003.

Simulation 11 was an attempt to reproduce the results of simulation 9 for the evolution of ground water in the NCMFP from the recharge zone to (nearly) the confined zone of the Edwards aquifer, this time using upgradient well TD–69–32–905 (October 2003 sample) and, as in simulation 9, downgradient well Medina3 (August 2003 sample). The simulation allowed carbon dioxide degassing and dissolution and dolomite, gypsum, halite, and amorphous silica dissolution only. The most plausible model for this simulation required a 23-percent surface-water contribution and dissolution of about 1.7 mmol/kg of carbon dioxide gas, about 0.25 mmol/kg of dolomite, and about 0.09 mmol/kg of halite, results similar to those of simulation 9. However, a large difference in the results of simulation 11 compared with those of simulation 9 was that 77 percent of the final solution was from end-member Edwards aquifer water (TD–68–25–806), not from the upgradient well. No plausible model was identified that allowed contribution from the upgradient well TD–69–32–905.

Simulations 12 and 12A represented the evolution of ground water in the hypothesized NCMFP from well Medina3 (August 2003 sample), which was the downgradient well in simulation 11, to the most downgradient well in the hypothesized flow path, TD–69–38–709 (fig. 19) (December 2002 sample). (Although well Medina3 is in the NCMFPs and well TD–69–38–709 is in the NCMFPn, the assumption is made for these two simulations that the NCMFP is undivided.) The sample from well TD–69–38–709 was undersaturated with respect to all mineral species and had a 14-percent surface-water contribution on the basis of isotope data (table 3). The PHREEQC software allowed mixing of end-member Edwards aquifer water (TD–68–25–806) and surface water with the initial water and calcite dissolution and precipitation, carbon dioxide degassing and dissolution, and dolomite, gypsum, halite, and amorphous silica dissolution only. Two plausible simulations were identified. Simulation 12 required a 15-percent surface-water contribution and an 85-percent contribution from end-member Edwards aquifer water for the final solution (table 4). No ground water was contributed from the initial solution (Medina3). To reach the final solution, the simulation required precipitation of 0.65 mmol/kg of calcite and the dissolution of about 0.29 mmol/kg of dolomite and about 0.05 mmol/kg of halite along the flow path. Simulation 12A

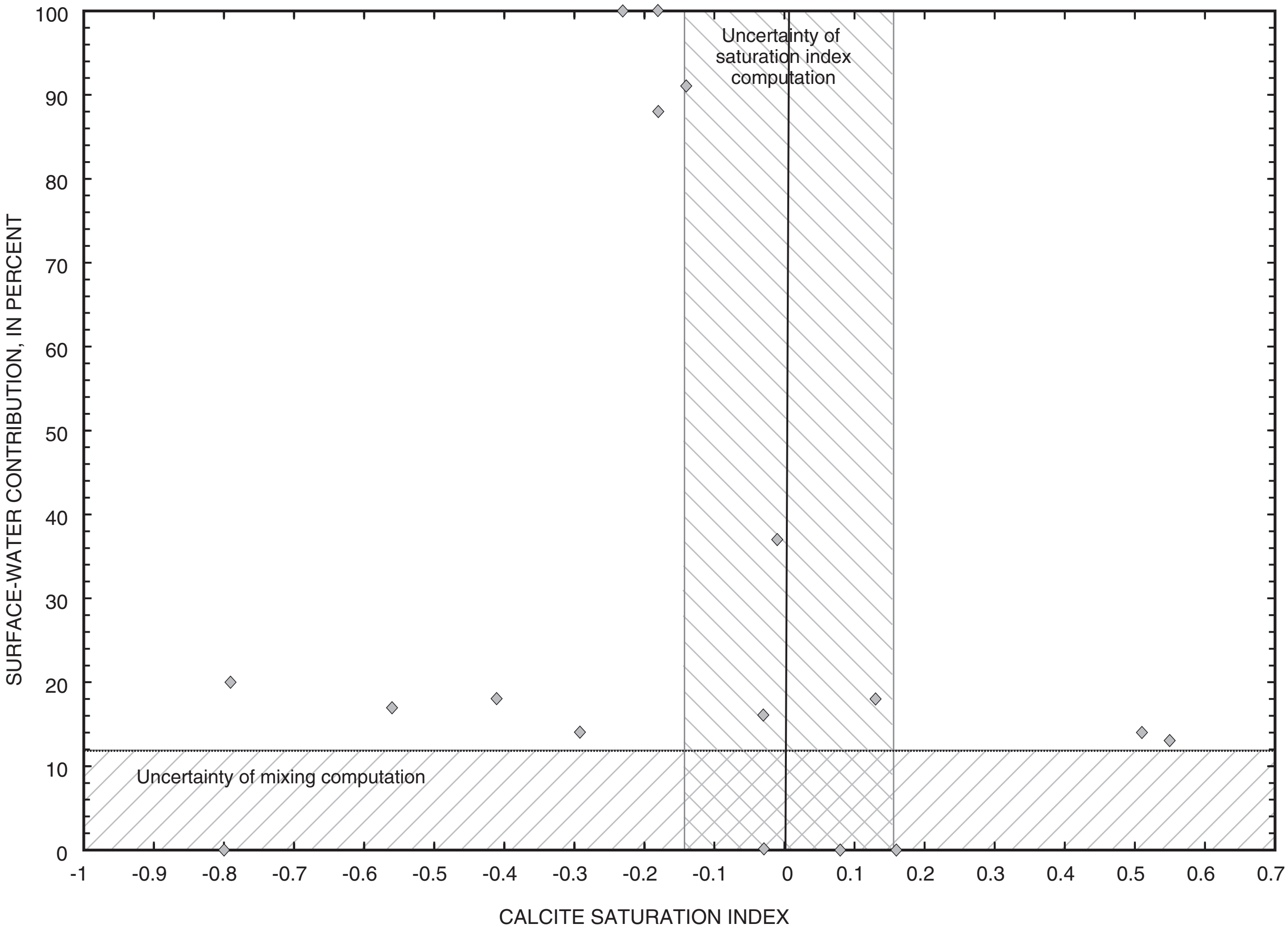


Figure 22. Relation between percentage surface-water contribution to the Trinity and Edwards aquifers and calcite saturation index, north-central Medina flow path, northern Medina County, Texas, 1995–2003.

required a 9-percent surface-water contribution and a 54-percent contribution from end-member Edwards aquifer water to reach the final solution. To reach the final solution, the model also required precipitation of about 0.58 mmol/kg of calcite, degassing of about 0.57 mmol/kg of carbon dioxide gas, and dissolution of about 0.18 mmol/kg of dolomite.

Results of these simulations demonstrate that the hypothesized NCMFP described in the “Hydrogeologic Identification of Ground-Water Flow Paths” section can be partially supported geochemically. As with simulations of NWMFP well pairs, plausible processes of dissolution or precipitation in the aquifer between some of the NCMFP well pairs were identified. However, developing plausible simulations of chemical evolution of water in wells sampled during different time periods and between wells not in the same aquifer (one in Trinity aquifer and one in Edwards aquifer) was problematic. Difficulty associated with the former issue likely arises from the assumption that seasonal differences in the ground-water chemistry are negligible. Difficulty associated with the latter issue likely arises from well construction, pump placement, depth of penetration of the borehole, position of the well along the relay ramp, and possible stratification of ground water. An example might be: Trinity aquifer water is entering the Edwards aquifer near its base; an Edwards aquifer well did not fully penetrate the aquifer and therefore Trinity aquifer water is not detected in the well, even though it is present in the Edwards aquifer at some depth below the well bore.

Surface-water contribution to the ground water was greatest in the Trinity aquifer in wells adjacent to Medina Lake. However, minor (9 to 23 percent) surface-water contributions were simulated in wells in the Edwards aquifer relatively removed from the lake, which indicates other surface-water sources (streams). The simulation results also indicate considerable contributions from regional ground-water flow.

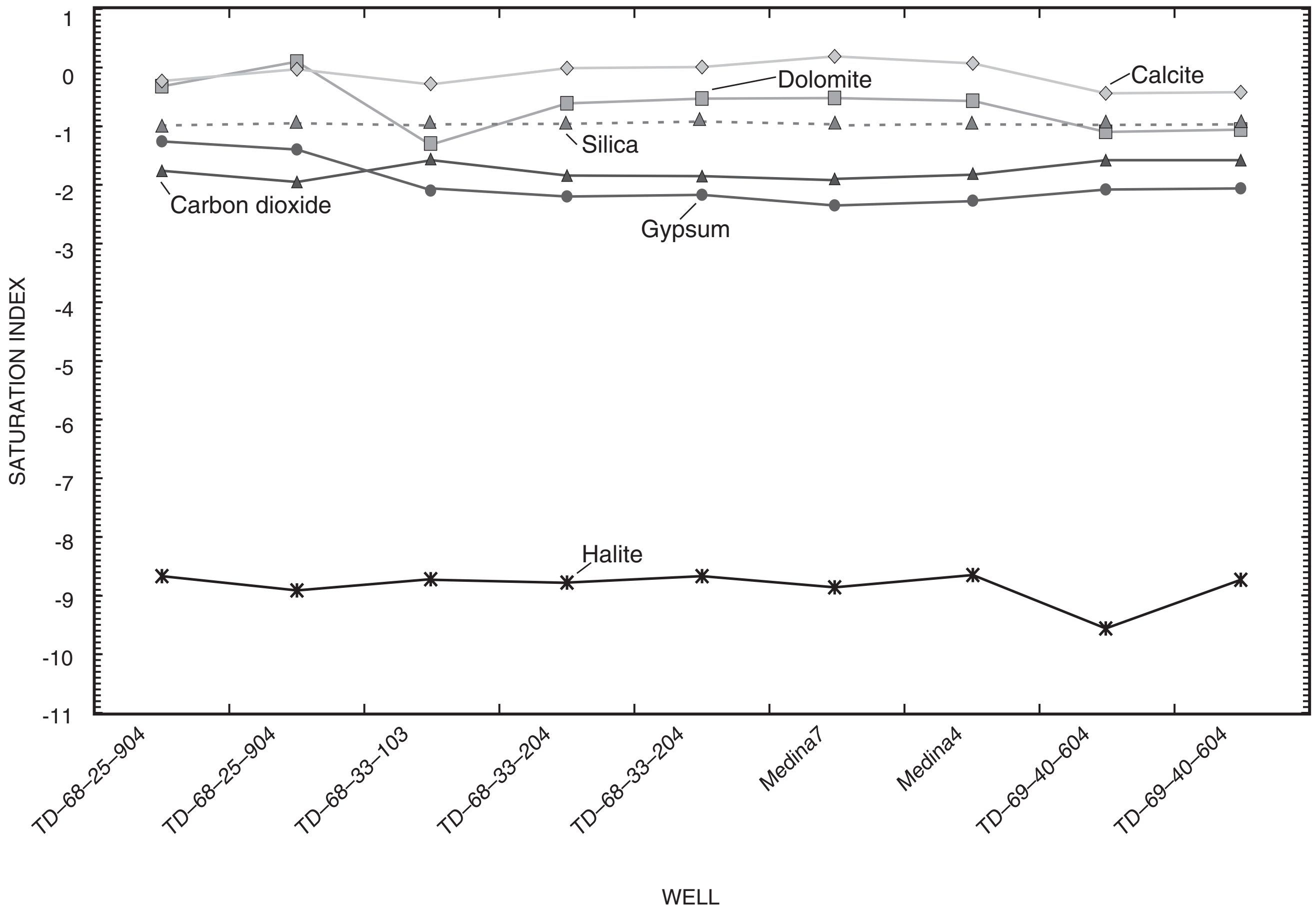


Figure 23. Saturation indexes (computed with PHREEQC) for selected mineral phases for ground water from wells in the south-central Medina flow path, northern Medina County, Texas, 1995–2003.

South-Central Medina Flow Path

Ground-water samples from seven wells were used to evaluate the evolution of ground-water chemistry in the SCMFP (fig. 19; table 4). One well was the Trinity aquifer end-member well (TD–68–25–602, upgradient from all flow paths) and another was a Trinity aquifer well in the most upgradient part of the flow path (TD–68–25–904); all other wells were completed in the Edwards aquifer. SIs of samples from these wells for calcite, dolomite, carbon dioxide (gas), gypsum, halite, and amorphous silica (figs. 21, 23; table 5) indicate, as in the other two hypothesized flow paths, that most mineral phases were at equilibrium or able to undergo dissolution. Undersaturated conditions predominated.

Ground water from all wells in the SCMFP contained an estimated contribution from the surface-water system during the period represented by the samples, which ranged from 12 to 42 percent (table 3). A linear trend existed between the percentage of surface-water contribution and the calcite SI in ground water from the Edwards aquifer for this flow path (fig. 24a). The trend implies that ground water with more than about a 30-percent surface-water contribution to the ground water tended to be undersaturated with respect to calcite and that ground water with less than about a 20-percent surface-water contribution tended to be oversaturated with respect to calcite. Although ground water in the Edwards aquifer consistently was undersaturated with respect to dolomite, as the contribution of surface water decreased, the SI tended to decrease (fig. 24b). On the basis of these trends, the mixing of surface water with ground water in the Edwards aquifer might be a more important factor than location along the flow path (residence time) for equilibrium conditions of calcite and dolomite. Mixing of two saturated waters or of saturated and oversaturated water can produce undersaturated conditions (Back, 1963; Parkhurst, 1990).

Nine simulations were done for samples from well pairs collected during 1996–2003 (table 4); seven of the nine yielded plausible models. Simulation 1 represented the evolution of the ground-water chemistry from Trinity aquifer end-member water (TD–68–25–602, upgradient from all flow paths) (July

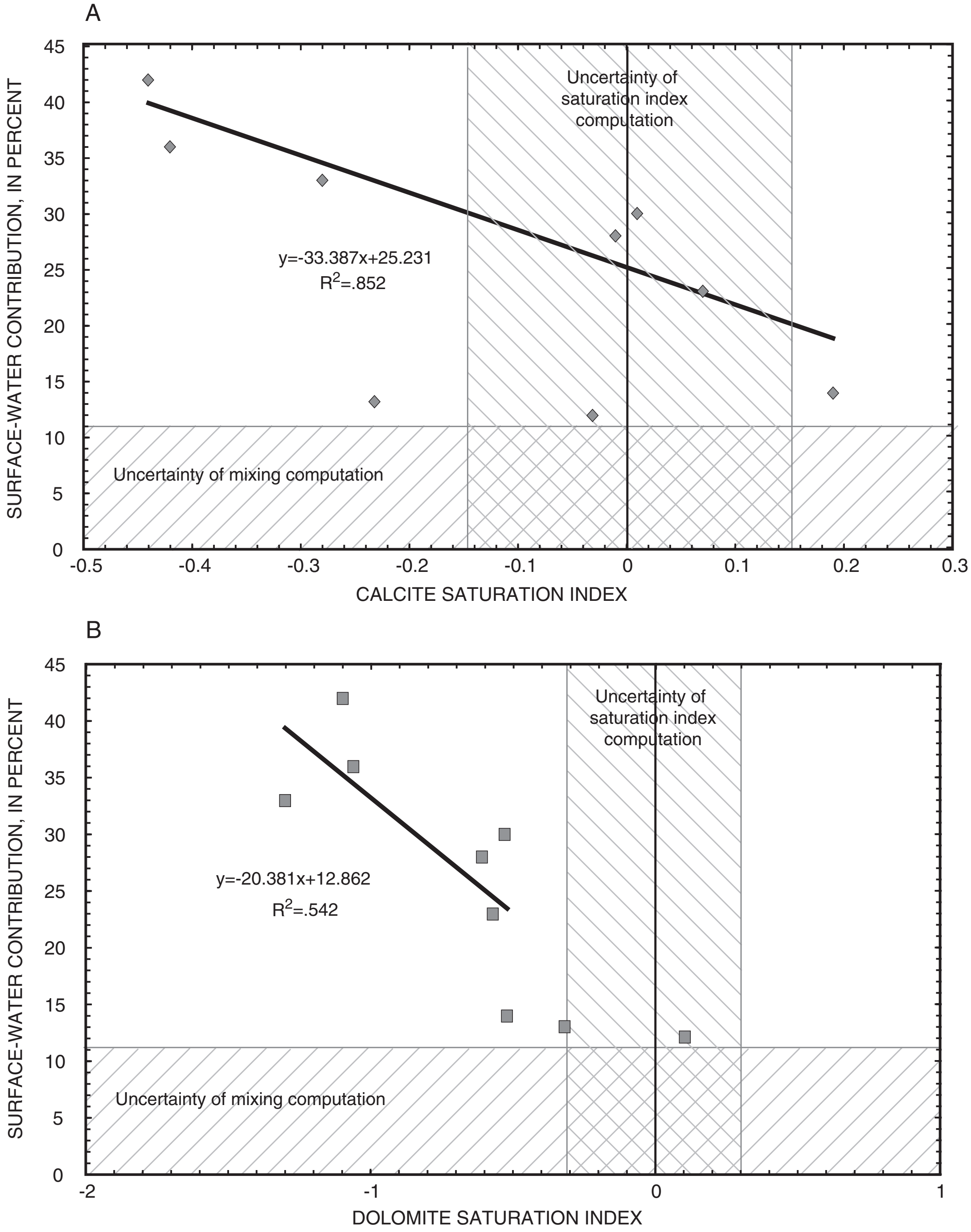


Figure 24. Relation between percentage surface-water contribution to the Trinity and Edwards aquifers, south-central Medina flow path, and (A) calcite saturation index and (B) dolomite saturation index, northern Medina County, Texas, 1995–2003.

1996 sample) to the most upgradient well in the SCMFP (TD–68–25–904) (July 1996 sample), near Diversion Lake (fig. 19). Average of δD and $\delta^{18}O$ isotope compositions in TD–68–25–904 indicated that 13 and 12 percent surface water was present in the samples collected in March and July 1996, respectively (table 3).

Simulations 2 and 2A represented the evolution of groundwater chemistry from Trinity aquifer well TD–68–25–904 (July 1996 sample), which contained an estimated 12-percent contribution from surface water, to Edwards aquifer well Medina7 (August 2003 sample), which contained an estimated 14-percent contribution from surface water (table 3). The most plausible model for simulation 2 required a 96-percent contribution from end-member Edwards aquifer water (TD–68–25–806) and only a 4-percent contribution from surface water. Only minor carbon dioxide and dolomite dissolution (0.62 and 0.10 mmol/kg, respectively) were required to equilibrate the ground-water chemistry. Also, extremely small (0.059 mmol/kg or less) amounts of gypsum and halite were dissolved. The results of simulation 2A were essentially the same (table 4).

Simulation 3 represented the evolution of ground-water chemistry from the same well as in simulation 2, TD–68–25–904 (July 1996 sample), to well TD–68–33–204 (August 1996 sample), with an estimated surface-water contribution of 30 percent (table 3). The most plausible model for simulation 3 reduced the initial-solution surface-water contribution from 30 to 10 percent and required an 83-percent contribution from end-member Edwards aquifer water, with the remaining 7 percent supplied by the upgradient Trinity aquifer well (TD–68–25–904). To equilibrate the ground-water chemistry required dissolution of 0.41 mmol/kg of carbon dioxide and 0.084 mmol/kg of dolomite along the flow path.

Simulations 4 and 4A represented the evolution of ground-water chemistry from the Edwards aquifer recharge zone (well Medina7, August 2003 sample) to the confined zone (well Medina4, August 2003 sample). Although well Medina4 was in the confined zone of the Edwards aquifer, the sample had an estimated 23-percent surface-water contribution, which was greater than the 14 percent estimated for the sample from the upgradient well (Medina7). About 0.15 mmol/kg of carbon dioxide and about 0.07 mmol/kg of halite were required to dissolve into solution. Simulation 4 required a 12-percent surface-water contribution to be mixed with the initial water from well Medina7 and no end-member Edwards aquifer water to reach a final solution at well Medina4. The results of simulation 4A were similar—a slightly smaller (7 percent) surface-water contribution and no end-member Edwards aquifer water were required.

The surface-water contribution provides an explanation for the younger apparent age (1992) of water from confined-zone well Medina4, as estimated from SF_6 concentration, than water from recharge-zone wells TD–68–25–806 (1978) and TD–68–25–810 (1990) (fig. 14). Apparently the degree of confinement associated with well Medina4, despite its location, is less than that associated with the two recharge-zone wells.

Results of these simulations demonstrate that the hypothesized SCMFP described in the “Hydrogeologic Identification of Ground-Water Flow Paths” section can be partially supported geochemically. Simulations in the SCMFP involved minimal (less than 7 percent) contribution of Trinity aquifer water to Edwards aquifer water in this flow path. Simulations produced plausible models for the regional Edwards aquifer ground water and surface water. Also, some surface-water influence was demonstrated at Medina4 in the confined zone of the Edwards aquifer.

Summary

The U.S. Geological Survey (USGS), in cooperation with the San Antonio Water System, conducted a 4-year study during 2001–04 to identify major ground-water flow paths in the Edwards aquifer in northern Medina and northeastern Uvalde Counties. The study involved use of geologic structure, surface-water and ground-water data, and geochemistry to identify ground-water flow paths. Knowledge of geologic structure and previous USGS work provided a beginning framework, a basis for hypothesizing flow paths. Hydrologic data were analyzed and flow paths identified using structural controls, water-level departure hydrographs, and statistical correlation of water-level departure for data from 11 monitoring wells in the study area. Chemical data were collected from 41 wells and two lake sites in the study area to determine chemical characteristics of ground water and surface water. One-dimensional geochemical simulations oriented along hypothesized major flow paths provided further evidence to support the existence of the flow paths. These geochemical simulations represent the chemical evolution of ground water along the flow paths and the degree of influence of surface water on the ground-water flow system. The results of the study could be useful to water managers with responsibility for protecting sources of recharge, identifying areas with potential for recharge enhancement, and identifying areas of ground-water discharge.

The Balcones fault zone is an extensional fault system that crosses Medina and Uvalde Counties from the southwest to the northeast. Extension strongly influenced the orientation of fractures, location of streams, areas of recharge, and ground-water flow paths. Fractures generally are parallel to or perpendicular to the main fault trend of the Balcones fault zone. In this structurally complex area, the fault zone contains relay ramps which form in extensional environments to accommodate an increase in deformation. Relay ramps and associated faulting in northern Medina County appear to channel ground-water flow along four distinct flow paths that move water toward the southwest.

The northwestern Medina flow path (NWMFP) is bounded on the north by the Woodard Cave fault and on the south by the Parkers Creek fault. Water moves downdip toward the southwest—primarily because of structural controls associated with a relay ramp—until the flow encounters a cross fault along Seco Creek. The cross fault along Seco Creek probably forms a barrier or a partial barrier to flow because the fault might have offset several hundred feet of the Edwards aquifer and juxtaposed confining units against it. This barrier to flow might force part or most of the flow to the south. Departure hydrographs for two wells and discharge departure for streamflow-gaging station Hondo Creek near Tarpley provide evidence for flow in the NWMFP.

The north-central Medina flow path (NCMFP) is separated into a northern and southern part because of water-level differences. The northern part of the NCMFP (NCMFPn) is bounded by the Parkers Creek fault on the north and the Medina Lake fault on the south. The adjacent southern part of the NCMFP

(NCMFPs) is bounded on the north by the Medina Lake fault and on the south by the Diversion Lake fault. Ground water in both the NCMFPn and NCMFPs moves downgradient (and down relay ramp) from eastern Medina County toward the southwest. The NCMFPn and NCMFPs are hypothesized to turn south in the vicinity of Seco Creek as they begin to be influenced by structural features. Departure hydrographs for four wells and Medina Lake and discharge departure for station Seco Creek at Miller Ranch provide evidence for flow in the NCMFPn and NCMFPs.

The south-central Medina flow path (SCMFP) is bounded on the north by the Seco Creek and Diversion Lake faults and on the south by the Haby Crossing fault. Because of bounding faults oriented northeast-southwest and adjacent flow paths directed south by other geologic structures, the SCMFP follows the configuration of the adjacent flow paths—oriented initially southwest and then south. Immediately after turning south, the SCMFP turns sharply east. Departure hydrographs for four wells and discharge departure for station Medina River at Bandera provide evidence for flow in the SCMFP.

Statistical correlations between water-level departures for the 11 continuously monitored wells provide additional evidence for the hypothesized flow paths. Of the 55 combinations of departure-dataset pairs, the stronger correlations (those greater than .6) are all among wells in the same flow path, with one exception.

Simulations of compositional differences in water chemistry along a hypothesized flow path in the Edwards aquifer and between ground-water and surface-water systems near Medina Lake were developed using the geochemical mole-balance, or inverse, model PHREEQC. The overlying assumption in this type of simulation is that the ground-water chemistry in a downgradient well evolved from the ground-water chemistry in an upgradient well by reaction with minerals and gases or by input from the surface-water system. If this assumption is shown by simulation results to be plausible, then the existence of the hypothesized flow path is supported.

Ground-water chemistry for samples from five wells in the Edwards aquifer in the NWMFP were used to evaluate the evolution of ground-water chemistry in the NWMFP. Most mineral phases were near equilibrium or able to undergo dissolution. Undersaturated conditions predominated. Seven simulations were done for samples from well pairs collected during 2001–03; three of the seven yielded plausible models. The three plausible models demonstrate that the hypothesized NWMFP can be partially supported geochemically. The simulations of the NWMFP samples indicate a considerable contribution of ground water from the regional flow path (58 to 73 percent) and a negligible (0 percent) to appreciable (27 to 33 percent) contribution of surface water.

Ground-water samples from 13 wells were used to evaluate the evolution of ground-water chemistry in the NCMFP flow path (northern and southern parts). Five of the wells in the most upgradient part of the flow path were completed in the Trinity aquifer; the remaining eight were completed in the Edwards aquifer. As in the NWMFP, most mineral phases were at equilibrium or able to undergo dissolution. Undersaturated conditions predominated. Nineteen simulations were done for samples from well pairs collected during 1995–2003; eight of the 19 yielded plausible models. The plausible models demonstrate that the hypothesized NCMFP can be partially supported geochemically. However, developing plausible simulations of chemical evolution of water in wells sampled during different time periods and between wells not in the same aquifer (one in Trinity aquifer and one in Edwards aquifer) was problematic. Surface-water contribution to the ground water was greatest in the Trinity aquifer in wells adjacent to Medina Lake. Minor (9 to 23 percent) surface-water contributions were simulated in wells in the Edwards aquifer relatively removed from the lake, which indicates other surface-water sources (streams). The simulation results also indicate considerable contributions from regional ground-water flow.

Ground-water samples from seven wells were used to evaluate the evolution of ground-water chemistry in the SCMFP. One well was the Trinity aquifer end-member well upgradient from all flow paths, and another was a Trinity aquifer well in the most upgradient part of the flow path; all other wells were completed in the Edwards aquifer. Nine simulations were done for samples from well pairs collected during 1996–2003; seven of the nine yielded plausible models. As with the other hypothesized flow paths, the plausible models demonstrate that the hypothesized SCMFP can be partially supported geochemically. Simulations in the SCMFP involved minimal (less than 7 percent) contribution of Trinity aquifer water to Edwards aquifer water in this flow path.

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Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003.

[USGS, U.S. Geological Survey; wu, water unfiltered; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; $CaCO_3$, calcium carbonate; *, sample obtained for this study; dup., duplicate; --, not analyzed or not detected; N/A, not applicable; <, less than; E, estimated; µg/L, micrograms per liter; wf, water filtered; M, presence of material verified but not quantified; pptv, parts per trillion by volume; δD, delta deuterium; per mil, parts per thousand; $\delta^{18}O$, delta oxygen-18]

State well number or USGS site number (USGS name)	Aquifer	Date	Time	Carbon dioxide, wu (mg/L)	Oxygen, dissolved (mg/L)	Dissolved oxygen, wu (mg/L)	Dissolved oxygen, (percent saturation)	pH (standard units)	Specific conductance (µS/cm)	Temperature, water (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)
Northwestern Medina flow path												
TD–69–30–903	Edwards	12/17/2002*	1145	22	7.4	6.1	75	7.2	435	23.2	220	81.9
		12/17/2002dup*	1146	--	--	--	--	--	--	--	--	--
TD–69–31–406 (Medina2)	Edwards	12/31/2001	1555	--	--	--	--	7.4	469	24.3	220	75
		07/30/2002*	1000	--	--	--	--	--	--	--	--	--
		08/15/2003*	1315	--	--	--	--	--	--	--	260	87.9
TD–69–31–603	Edwards	12/12/2001	0930	--	--	8.1	88	--	625	17.5	--	--
		11/26/2002*	1045	19	9.7	7.7	91	7	710	22	310	119
		11/26/2002dup*	1046	--	--	--	--	--	--	--	--	--
TD–69–31–605	Trinity	12/19/2001	1100	--	--	7.8	93	6.7	446	22.5	--	--
TD–69–31–708 (Medina8)	Edwards	07/30/2002*	1040	--	--	--	--	7.1	420	23	--	--
		08/21/2003*	1315	--	--	5.8	72	6.5	--	24.1	230	75
		08/21/2003dup*	1316	--	--	5.8	72	7.3	412	24.0	240	77.2
[1]TD–69–32–201	Trinity	01/31/1996	1400	--	--	--	--	7.2	1,140	12.5	670	136
		08/28/1996	1320	--	--	--	--	6.9	1,130	23	650	132
[1]TD–69–32–303	Trinity	12/11/1995	1510	--	--	--	--	9.4	2,640	19.2	1,700	369
		08/15/1996	0945	--	--	--	--	7	2,660	23.6	1,900	359
		08/15/1996dup	0946	--	--	--	--	6.2	2,660	23.6	1,700	350
TD–69–32–501	Trinity	12/11/1995	1620	--	--	--	--	9.2	2,910	17.1	2,100	512
		08/15/1996	1130	--	--	--	--	6.8	3,380	26.6	2,500	541
TD–69–32–703 (Medina1)	Edwards	07/29/2002*	1400	--	--	--	--	7.1	416	23.8	--	--
		08/13/2003*	1440	--	--	--	--	--	--	--	220	85.8
TD–69–37–302	Edwards	12/11/2001	1440	--	--	6.3	73	6.9	489	22	--	--
TD–69–38–106	Edwards	12/11/2001	1210	--	--	8	--	7	414	22.5	--	--
		01/14/2003*	1300	22	5.8	7	83	7.2	446	22.8	220	75
		01/14/2003dup*	1301	--	5.8	7	83	7.2	415	22.8	220	75
TD–69–38–509	Edwards	12/28/2001	1110	--	--	5.8	68	7.1	432	21	--	--
		11/26/2002*	1245	22	3.3	--	--	7	458	21.5	230	75.7
		11/26/2002dup*	1246	--	--	--	--	--	--	--	--	--
YP–69–37–101	Edwards	04/03/2002*	1200	--	--	--	--	6.9	450	25	230	66.3
		12/05/2002*	1250	19	7.8	6.7	79	7.1	460	22.5	230	66.8
		12/05/2002dup*	1251	--	--	--	--	--	--	--	--	--
North-central Medina flow path												
TD–68–25–402	Trinity	01/30/1996	1220	--	--	--	--	7.4	--	20.5	210	55.9
		08/08/1996	1235	--	--	--	--	7.2	454	21.8	230	62.6
TD–68–25–510	Trinity	11/29/1995	1530	--	--	--	--	7.2	495	--	260	73.3
		08/08/1996	1350	--	--	--	--	7.2	509	20.9	260	73.8
TD–68–25–701	Edwards	11/30/1995	1320	--	--	--	--	6.5	613	24.7	340	68.8
		07/29/1996	1545	--	--	--	--	6.8	608	25.5	280	58.4
TD–68–25–711 (Medina5)	Edwards	07/31/2002*	1140	--	--	--	--	7	407	24.4	--	--
		08/12/2003*	1315	--	--	5.3	74	7.2	440	30.5	220	82.4
TD–68–25–806	Edwards	12/05/1995	1220	--	--	--	--	6.9	415	22.8	210	80
		08/19/1996	1245	--	--	--	--	6.8	413	23.9	220	84.5
		12/04/2002*	1325	23	3	4.7	56	7	402	22.5	210	78
		12/04/2002dup*	1326	--	--	--	--	--	--	--	--	--
TD–68–25–807	Trinity	01/25/1996	1250	--	--	--	--	7.1	1,360	21.8	930	210
		07/09/1996	1305	--	--	--	--	7	2,160	22	1,600	359
TD–68–25–809	Trinity	12/05/1995	1515	--	--	--	--	7.3	2,060	19	1,400	536
		07/26/1996	1315	--	--	--	--	7.3	2,050	22.4	1,400	498
TD–68–25–810	Trinity	03/06/1996	1310	--	--	--	--	7.3	444	22.1	220	80.5
		08/19/1996	1545	--	--	--	--	6.4	465	22.5	230	83.7
		02/20/2003*	1220	--	--	6.1	75	6.8	417	23	220	73.2
		02/20/2003dup*	1221	--	--	--	--	--	--	--	--	--

[1] Probably northwestern Medina flow path.

Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003—Continued.

State well number or USGS site number (USGS name)	Aquifer	Date	Time	Carbon dioxide, wu (mg/L)	Oxygen, dissolved (mg/L)	Dissolved oxygen, wu (mg/L)	Dissolved oxygen, (percent saturation)	pH (standard units)	Specific conductance (μS/cm)	Temperature, water (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L)
North-central Medina flow path—Continued												
TD–68–25–822	Edwards	12/29/2001	1400	--	--	5.1	61	6.9	440	23	--	--
TD–69–32–905	Edwards	10/14/2003*	1140	--	--	--	--	--	--	--	260	97.4
TD–69–38–601 (Seco)	Edwards	03/17/1992	1340	--	--	--	--	7.3	437	22.5	230	75
		12/20/2001	1300	61	--	--	--	6.8	436	--	230	73
TD–69–38–709	Edwards	12/31/2001	1400	--	--	5.8	64	7	435	18.5	--	--
		12/12/2002*	1430	18	5.3	5.2	60	7	427	20	220	68.3
		12/12/2002dup*	1431	--	--	--	--	--	--	--	--	--
TD–69–39–504	Edwards	12/18/2001	1450	--	--	--	--	--	--	--	--	--
TD–69–39–520	Edwards	10/31/2003*	1100	--	--	--	--	--	--	--	--	--
TD–69–40–102 (Quihi)	Edwards	12/20/2001	1230	--	--	--	--	--	--	--	--	--
TD–69–40–202 (Medina3)	Edwards	03/13/1996	1145	--	--	--	--	7.2	450	23.4	240	79.4
		03/13/1996dup	1146	--	--	--	--	7.2	450	23.4	240	79.7
		08/20/1996	1320	--	--	--	--	7.1	450	25	250	87.1
TD–69–40–209	Edwards	07/29/2002*	1415	--	--	--	--	7.1	406	24.1	--	--
		07/29/2002dup*	1416	--	--	--	--	--	--	--	--	--
		08/20/2003*	1205	--	--	6.2	77	6.7	496	24.7	260	84.8
TD–69–40–301	Edwards	01/24/1996	1045	--	--	--	--	7.2	428	24.1	230	67.5
		08/21/1996	1440	--	--	--	--	7.3	415	25	250	75.7
South-central Medina flow path												
TD–68–25–904	Trinity	03/06/1996	1130	--	--	--	--	7.1	810	21.5	430	81.4
		07/26/1996	1210	--	--	--	--	7.3	779	22.9	390	73.2
TD–68–33–102	Edwards	07/30/2002*	1300	--	--	--	--	7.1	431	22.9	--	--
TD–68–33–103	Edwards	02/21/1996	1150	--	--	--	--	7	486	22.5	250	90.8
		08/06/1996	1510	--	--	--	--	7	469	22.8	250	88.3
TD–68–33–204	Edwards	12/13/1995	1250	--	--	--	--	7.2	446	22.7	230	77.7
		08/21/1996	1200	--	--	--	--	7.2	410	25.1	240	80
TD–68–33–213 (Medina7)	Edwards	07/26/2002*	1330	--	--	--	--	7.3	512	22.2	--	--
		08/11/2003*	1352	--	--	--	--	--	--	--	250	89.1
TD–69–40–510 (Medina4)	Edwards	07/29/2002*	1230	--	--	--	--	--	--	--	--	--
		07/29/2002dup*	1231	--	--	--	--	--	--	--	--	--
		08/20/2003*	1630	--	--	--	--	--	--	--	260	89.4
TD–69–40–604	Edwards	12/05/1995	1400	--	--	--	--	6.9	451	23.3	230	62.6
		08/21/1996	1150	--	--	--	--	6.9	455	23	250	66.6
Flow path unknown (well east of Medina Lake/River)												
AS–68–25–505	Trinity	12/15/1995	1100	--	--	--	--	--	--	--	--	--
		07/30/1996	1200	--	--	--	--	--	--	--	--	--
TD–68–25–602	Trinity	02/08/1996	1110	--	--	--	--	7	3,160	23.9	2,300	466
		07/30/1996	1340	--	--	--	--	6.7	3,160	24.9	2,200	491
TD–68–25–603	Trinity	02/08/1995	1200	--	--	--	--	--	--	--	--	--
		07/30/1996	1415	--	--	--	--	--	--	--	--	--
Medina Lake near San Antonio												
08179500 (AL)	N/A	05/22/1995	1020	--	--	--	--	8	403	24	190	51
		05/22/1995dup	1021	--	--	--	--	8	403	24	200	49.8
		04/02/1996	--	--	--	--	--	--	--	--	--	--
08179500 (DC)	N/A	04/02/1996	1205	--	--	--	--	8.2	420	15.5	241	52
Medina River below Medina Lake												
08179520	N/A	05/18/1995	--	--	--	--	--	--	--	--	--	--
		11/30/1995	--	--	--	--	--	--	--	--	--	--
		04/03/1996	--	--	--	--	--	--	--	--	--	--
		05/31/1996	--	--	--	--	--	--	--	--	--	--
		08/06/1996	--	--	--	--	--	--	--	--	--	--

Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003—Continued.

State well number or USGS site number (USGS name)	Magnesium (mg/L)	Potassium (mg/L)	Sodium adsorption ratio	Sodium (mg/L)	Sodium (percent)	Alkalinity (mg/L as CaCO$_3$)	Bicarbonate (mg/L)	Carbonate (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)	Residue (sum of constituents) (mg/L)	Dissolved ammonia plus organic nitrogen (mg/L)	Dissolved ammonia nitrogen (mg/L)
Northwestern Medina flow path																
TD–69–30–903	3.63	0.37	0.1	4.79	5	209	254	<1	--	8.06	<0.17	11.3	3.8	245	E0.05	<0.04
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–31–406	9	1.2	.1	4	4	196	239	--	--	6	.2	13	25	251	--	--
(Medina2)	--	--	--	--	--	190	230	--	--	--	--	--	--	--	--	--
	8.67	1.51	.1	4.67	4	217	264	--	--	6.28	<.2	12.2	31.4	--	<.10	<.04
TD–69–31–603	--	--	--	--	--	180	218	0	--	--	--	--	--	--	--	--
	3.39	.9	.3	12	8	168	204	<1	--	45.6	<.17	11.4	7.8	415	.1	<.04
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–31–605	--	--	--	--	--	242	294	0	--	--	--	--	--	--	--	--
TD–69–31–708	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(Medina8)	10.2	1.13	.2	5.75	5	187	--	--	--	8.85	.2	12.4	19	248	<.10	<.04
	10.3	1.16	.2	5.78	5	--	--	--	--	8.79	.2	12.5	18.7	--	<.10	<.04
[1]TD–69–32–201	77.1	3.98	.1	8.56	3	270	329	--	0.1	19.5	.57	13.2	335	772	.2	.177
	74.2	4.2	.2	10	3	260	317	--	<.5	21	1.3	14.1	706	1,130	<.10	<.100
[1]TD–69–32–303	235	16.6	.3	33.7	--	240	293	--	.7	25.1	5.9	13.4	1,590	2,440	--	0
	205	16.3	.35	34.5	--	250	305	--	.45	22	4.54	12.8	1,510	2,335	--	.335
	190	17.0	.3	28	--	240	--	--	--	22	3.6	11	1,500	2,280	--	--
TD–69–32–501	208	19.3	.2	17.5	2	240	--	--	.2	14	3.24	11.9	1,740	2,680	.62	.577
	282	22.2	.3	30.4	3	220	--	--	.6	22.3	7.2	14.1	2,270	3,330	.1	.16
TD–69–32–703	--	--	--	--	--	222	270	0	--	--	--	--	--	--	--	--
(Medina1)	1.86	.21	.1	4.31	4	220	269	--	--	4.69	<.2	12.2	6.8	--	<.10	<.04
TD–69–37–302	--	--	--	--	--	221	269	0	--	--	--	--	--	--	--	--
TD–69–38–106	--	--	--	--	--	197	240	0	--	--	--	--	--	--	--	--
	8.71	1.02	.2	5.96	5	196	238	<1	--	8.28	<.17	12.3	12.2	247	<.10	<.04
	8.72	1.01	.2	6.02	6	200	243	<1	--	8.67	<.17	12.3	12.3	250	<.10	<.04
TD–69–38–509	10.5	1.01	.2	5.95	5	202	246	<1	--	8.73	<.17	12	17.1	256	<.10	<.04
	--	--	--	--	--	205	250	0	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
YP–69–37–101	14.5	1.08	.2	6.83	6	202	246	0	--	9.82	.2	12.5	21.6	259	<.10	<.04
	15.3	1.1	.2	7.09	6	199	242	<1	--	10.9	.17	12.4	20.8	258	<.10	<.04
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
North-central Medina flow path																
TD–68–25–402	16.9	1.71	.2	7.72	7	140	171	--	.1	11.1	.15	9	55.4	243	.11	.074
	17.2	1.67	.3	9.4	8	160	195	--	.1	13	.2	11.6	58.9	270	<.01	<.010
TD–68–25–510	17.4	1.72	.2	8.63	7	160	195	--	.1	13.7	.17	15.2	79	308	.04	.017
	17.2	1.59	.2	9.02	7	160	195	--	.1	15	.21	13	80.8	308	.04	<.010
TD–68–25–701	39.1	2.12	0	.27	0	200	244	--	.1	8.5	.64	12.1	127	380	<.01	<.010
	31.2	1.48	.1	2.87	2	190	232	--	--	8.2	.68	12.6	112	347	<.01	<.010
TD–68–25–711	--	--	--	--	--	216	262	--	--	--	--	--	--	--	--	--
(Medina5)	3.25	.83	.1	4.39	4	214	260	0	--	7.7	<.2	13.4	2.1	242	--	--
TD–68–25–806	2.55	<1.00	.1	2.1	--	200	244	--	<.1	6.5	<.05	12	3.7	--	<.01	<.010
	2.5	<1.00	.2	5.3	--	190	232	--	<.5	7.2	<1.00	14.1	6	--	<.10	.18
	2.52	.45	.1	4.17	4	205	249	<1	--	6.26	<.17	11.7	7.7	237	<.10	<.04
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–68–25–807	97	6.94	.2	13	3	180	220	--	.1	13.4	1.05	9.7	698	1,170	<.01	1.14
	168	12.1	.2	18.3	2	180	220	--	.1	12	2.91	11.6	1,330	2,030	.39	--
TD–68–25–809	25.1	1.41	0	4.13	0	180	220	--	.1	14.2	1.63	11.6	1,120	1,830	<.01	<.010
	33.5	1.72	0	4.2	0	190	232	--	--	9.9	.29	12.5	1,070	1,750	.04	.584
TD–68–25–810	5.19	<1.00	.2	7.11	--	190	232	--	.1	13.3	.06	10.4	7.9	--	<.01	<.010
	6	<1.00	.2	7.8	--	190	232	--	<.5	15	<1.00	11.9	15	--	<.10	.17
	8.01	.38	.2	5.11	5	191	232	<1	--	7.49	.11	12.1	7.2	232	E.05	<.04
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[1] Probably northwestern Medina flow path.

Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003—Continued.

State well number or USGS site number (USGS name)	Magnesium (mg/L)	Potassium (mg/L)	Sodium adsorption ratio	Sodium (mg/L)	Sodium (percent)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L)	Carbonate (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)	Residue (sum of constituents) (mg/L)	Dissolved ammonia plus organic nitrogen (mg/L)	Dissolved ammonia nitrogen (mg/L)
North-central Medina flow path—Continued																
TD–68–25–822	--	--	--	--	--	217	264	0	--	--	--	--	--	--	--	--
TD–69–32–905	4.52	1.41	0.2	6.66	5	206	251	--	--	16.3	<0.2	13.7	12.7	--	E0.07	<0.04
TD–69–38–601	12	.8	.2	6.5	6	--	--	--	--	11	.1	11	18	257	--	--
(Seco)	10	.9	.2	5.3	5	210	256	--	--	10	.2	11	17	253	--	--
TD–69–38–709	--	--	--	--	--	198	241	0	--	--	--	--	--	--	--	--
	13	.92	.2	5.39	5	205	249	<1	--	9.75	<.17	11.5	13.6	250	<.10	<.04
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–39–504	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–39–520	--	--	--	--	--	217	265	--	--	--	--	--	--	--	E.06	<.04
TD–69–40–102 (Quihi)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–40–202	9.5	1.02	.2	5.45	5	190	232	--	0.1	9.1	.11	11.3	23.1	256	<.01	<.010
(Medina3)	9.52	<1.00	.2	6.28	--	190	--	--	.1	9.2	.11	11.2	23.1	--	<.10	--
	8.5	<1.00	.2	8.5	--	202	246	--	<.5	14	<1.00	16	9.5	--	<.10	<.100
TD–69–40–209	--	--	--	--	--	195	237	0	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	12.3	.97	.2	7.82	6	218	265	0	--	10.1	.2	13.1	17.5	292	<.10	<.04
TD–69–40–301	15.4	<1.00	.2	5.44	--	210	256	--	.1	8.2	.11	12.6	12.2	--	<.01	<.010
	14.6	<1.00	.1	5.4	--	210	256	--	<.5	10.6	<1.00	13.6	15.2	--	<.10	<.100
South-central Medina flow path																
TD–68–25–904	54.9	3.28	.2	9.19	4	200	244	--	.1	9.1	.75	11.2	263	557	.07	<.010
	50.4	2.66	.1	5.91	3	200	244	--	--	8.1	.46	12.5	198	475	.04	.12
TD–68–33–102	--	--	--	--	--	228	277	--	--	--	--	--	--	--	--	--
TD–68–33–103	5.32	--	--	--	--	210	256	--	.1	12.9	.09	12.9	17.9	--	.06	.017
	7.52	<1.00	--	<6.17	--	190	232	--	.1	11.6	.08	11.9	24	--	<.01	<.010
TD–68–33–204	9.45	<1.00	.2	5.48	--	200	244	--	.1	11.2	.08	12.1	20.9	--	<.01	<.010
	10	<1.00	.2	6.5	--	190	232	--	<.5	12.3	<1.00	14.1	22.2	--	<.10	<.100
TD–68–33–213	--	--	--	--	--	228	277	--	--	--	--	--	--	--	--	--
(Medina7)	5.56	.56	.1	5.3	4	224	273	--	--	9.58	<.2	11.4	13.3	--	--	--
TD–69–40–510	--	--	--	--	--	154	186	--	--	--	--	--	--	--	--	--
(Medina4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	8.42	1.17	.2	7.13	6	218	266	--	--	11.5	<.2	12.1	16.2	--	<.10	<.04
TD–69–40–604	17.9	<1.00	0	.99	--	180	220	--	.1	10.1	.13	11.8	34.8	--	<.01	<.010
	19.1	1.1	.2	6.1	5	180	220	--	<.5	11.3	<1.00	11.9	34.8	261	<.10	<.100
Flow path unknown (well east of Medina Lake/River)																
AS–68–25–505	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–68–25–602	275	15.6	.1	12.7	1	180	220	--	.1	12.4	5.69	10.9	2,030	2,950	.53	.687
	238	14.1	.1	10.5	1	180	220	--	--	10	4.21	12.2	1,750	2,650	.03	.666
TD–68–25–603	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medina Lake near San Antonio																
08179500 (AL)	16	1.7	.2	7.7	--	--	--	--	--	12	.2	8.1	49	--	--	.1
	17.1	1.68	.3	7.7	--	--	--	--	.1	12	.25	9	57	236	--	.01
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
08179500 (DC)	16	1.4	--	3.8	--	--	--	--	--	--	--	--	--	--	--	--
Medina River below Medina Lake																
08179520	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
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Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003—Continued.

State well number or USGS site number (USGS name)	Dissolved nitrite plus nitrate nitrogen (mg/L)	Dissolved organic nitrogen (mg/L)	Total nitrogen (mg/L)	Dissolved orthophosphate phosphorus (mg/L)	Dissolved phosphorus (mg/L)	Aluminum (μg/L)	Antimony (μg/L)	Argon (mg/L)	Arsenic (μg/L)	Barium, wf (μg/L)	Beryllium, wf (μg/L)	Cadmium, wf (μg/L)	Chromium, wf (μg/L)	Cobalt, wf (μg/L)
Northwestern Medina flow path														
TD–69–30–903	1.1	--	19.4	<0.02	<0.04	<2	<0.30	0.617	--	28	<0.06	0.51	<0.8	0.16
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–31–406	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(Medina2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1.25	--	--	<.02	<.04	M	<.30	--	--	32	<.06	<.04	<.8	.31
TD–69–31–603	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	25.8	--	23.4	<.02	<.04	23	<.30	.681	--	59	<.06	<.04	<.8	.21
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–31–605	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–31–708	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(Medina8)	.8	--	--	<.18	<.04	<2	<.30	--	--	25	<.06	<.04	<.8	.16
	.8	--	--	<.18	<.04	<2	<.30	--	--	25	<.06	<.04	<.8	.16
[1]TD–69–32–201	--	0.02	--	--	--	--	--	--	<1.0	27	<1	<1	10	M
	--	--	--	--	--	--	--	--	<5.0	28	<1	<1	40	<1
[1]TD–69–32–303	--	--	--	--	--	--	--	--	--	12	<1	<1	210	M
	--	--	--	--	--	--	--	--	<5.0	9.9	--	<1	210	M
	--	--	--	--	--	--	--	--	<1	<9	1.5	<24	<15	M
TD–69–32–501	--	.05	--	--	--	--	--	--	<1.0	5.2	<1	<1	M	M
	--	--	--	--	--	--	--	--	<5.0	2.3	<1	<1	320	M
TD–69–32–703	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(Medina1)	1.23	--	--	<.18	<.04	<2	<.30	--	--	25	<.06	<.04	<.8	.36
TD–69–37–302	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–38–106	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1.39	--	19.9	<.02	<.04	<2	<.30	.641	--	31	<.06	<.04	<.8	.14
	1.38	--	--	<.02	<.04	<2	<.30	--	--	31	<.06	<.04	<.8	.14
TD–69–38–509	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	.96	--	19.4	E.01	<.04	<2	<.30	.638	--	30	<.06	<.04	<.8	.15
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
YP–69–37–101	.97	--	--	<.02	<.06	<1	<.05	--	--	35	<.06	E.03	<.8	.17
	.99	--	23.2	E.01	<.04	<2	<.30	.707	--	34	<.06	E.03	<.8	.11
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
North-central Medina flow path														
TD–68–25–402	--	.04	--	--	--	--	--	--	<1.0	25.6	<1	<1	M	<1
	--	--	--	--	--	--	--	--	1	26.2	<1	<1	M	<1
TD–68–25–510	--	.02	--	--	--	--	--	--	2	26.6	<1	<1	10	<1
	--	--	--	--	--	--	--	--	1.7	27.5	<1	<1	M	<1
TD–68–25–701	--	--	--	--	--	--	--	--	<1.0	32.6	<1	<1	30	--
	--	--	--	--	--	--	--	--	<1.0	34.2	<1	<1	M	1.37
TD–68–25–711	--	--	--	--	--	--	--	--	--	--	--	--	--	<1
(Medina5)	--	--	--	--	--	M	<.30	--	--	28	<.06	.04	<.8	<1
TD–68–25–806	--	--	--	--	--	--	--	--	<1.0	26	<1	<1	20	<1
	--	--	--	--	--	--	--	--	<5.0	28	<1	<1	<1	<1
	.69	--	20.2	<.02	<.04	<2	<.30	.629	--	29	<.06	<.04	<.8	.15
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–68–25–807	--	--	--	--	--	--	--	--	<1.0	9.9	<1	<1	M	M
	--	--	--	--	--	--	--	--	1.3	11.2	--	<1	--	--
TD–68–25–809	--	--	--	--	--	--	--	--	<1.0	50.6	<1	<1	20	M
	--	--	--	--	--	--	--	--	<1.0	48.8	<1	<1	M	M
TD–68–25–810	--	--	--	--	--	--	<1	--	<1.1	30.8	<1	<1	M	<1
	--	--	--	--	--	--	--	--	<5.0	32	<1	<1	<1	<1
	.89	--	--	<.02	<.04	<2	<.30	--	--	27	<.06	E.02	<.8	.16
	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[1] Probably northwestern Medina flow path.

Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003—Continued.

State well number or USGS site number (USGS name)	Dissolved nitrite plus nitrate nitrogen (mg/L)	Dissolved organic nitrogen (mg/L)	Total nitrogen (mg/L)	Dissolved orthophosphate phosphorus (mg/L)	Dissolved phosphorus (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Argon (mg/L)	Arsenic (µg/L)	Barium, wf (µg/L)	Beryllium, wf (µg/L)	Cadmium, wf (µg/L)	Chromium, wf (µg/L)	Cobalt, wf (µg/L)
North-central Medina flow path—Continued														
TD–68–25–822	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–32–905	7.94	--	--	<0.02	<0.04	M	<0.20	--	--	54	<0.06	0.1	<0.8	0.21
TD–69–38–601	--	--	--	--	--	--	--	--	<1	27	--	<1.0	<1	--
(Seco)	1.4	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–38–709	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1.21	--	21.6	E.01	<.04	<2	<.30	0.663	--	49	<.06	.08	<.8	.11
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–39–504	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–39–520	5.24	--	--	<.02	<.04	--	--	--	--	--	--	--	--	--
TD–69–40–102 (Quihi)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–40–202	--	--	--	--	--	--	<1	--	<1.0	31.2	<1	<1	20	<1
(Medina3)	--	--	--	--	--	--	<1	--	<1.0	30.6	<1	<1	20	<1
	--	--	--	--	--	--	--	--	<5.0	38	<1	<1	<1	<1
TD–69–40–209	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	3.39	--	--	<.18	<.04	<2	<.30	--	--	37	<.06	<.04	<.8	.18
TD–69–40–301	--	--	--	--	--	--	--	--	<1.0	35.4	<1	<1	M	<1
	--	--	--	--	--	--	--	--	<5.0	38	<1	<1	<1	<1
South-central Medina flow path														
TD–68–25–904	--	--	--	--	--	--	<1	--	<1.0	26.9	<1	<1	M	<1
	--	--	--	--	--	--	--	--	<1.0	24.7	<1	<1	M	<1
TD–68–33–102	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–68–33–103	--	0.04	--	--	--	--	<1	--	<1.0	53.4	<1	<1	M	<1
	--	--	--	--	--	--	--	--	<1.0	37.5	<1	<1	M	<1
TD–68–33–204	--	--	--	--	--	--	--	--	1.2	32.8	<1	<1	M	<1
	--	--	--	--	--	--	--	--	<5.0	37	<1	<1	<1	<1
TD–68–33–213	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(Medina7)	--	--	--	--	--	<2	<.30	--	--	35	<.06	<.04	<.8	.34
TD–69–40–510	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(Medina4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1.5	--	--	<.18	<.04	<2	<.30	--	--	34	<.06	<.04	<.8	.18
TD–69–40–604	--	--	--	--	--	--	--	--	<1.0	27.1	<1	<1	20	<1
	--	--	--	--	--	--	--	--	<5.0	30	<1	<1	<1	<1
Flow path unknown (well east of Medina Lake/River)														
AS–68–25–505	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–68–25–602	--	--	--	--	--	--	--	--	<2.0	8.5	<2	<2	M	M
	--	--	--	--	--	--	--	--	<1.0	8.4	<1	<1	M	M
TD–68–25–603	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medina Lake near San Antonio														
08179500 (AL)	<.05	<.01	.20	--	--	--	--	--	<1	27	<.5	<8	<5	<3
	--	<.01	.29	--	--	--	<8	--	<2	24	<1	<2	<8	<8
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
08179500 (DC)	--	--	--	--	--	--	--	--	--	26	<1	<1	27	1.8
Medina River below Medina Lake														
08179520	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
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	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003—Continued.

State well number or USGS site number (USGS name)	Copper, wf (µg/L)	Iron, wf (µg/L)	Lead, wf (µg/L)	Lithium, wf (µg/L)	Manganese, wf (µg/L)	Mercury, wf (mg/L)	Molybdenum, wf (µg/L)	Nickel, wf (µg/L)	Selenium, wf (µg/L)	Silver, wf (µg/L)	Strontium, wf (µg/L)	Vanadium, wf (µg/L)	Zinc, wf (µg/L)	Sulfur hexafluoride (pptv)	δD (per mil)	$\delta^{18}O$ (per mil)	Uranium, wf (µg/L)
Northwestern Medina flow path																	
TD–69–30–903	1.2	--	4.82	--	0.2	--	0.4	2.21	--	<0.20	--	--	868	2.25	-25.4	-4.28	0.42
	--	--	--	--	--	--	--	--	--	--	--	--	--	2.03	--	--	--
TD–69–31–406	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.1	-4.33	--
(Medina2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-30.1	-5.12	--
	.8	--	<.08	--	9.4	--	1.7	5.69	--	<.20	--	--	1	--	-28	-4.81	.49
TD–69–31–603	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-23.1	-4.02	--
	1.4	--	.27	--	.4	--	<.3	3.79	--	<.20	--	--	23	.94	-26.8	-4.64	.42
	--	--	--	--	--	--	--	--	--	--	--	--	--	1.16	--	--	--
TD–69–31–605	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-25	-4.38	--
TD–69–31–708	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.5	-4.21	--
(Medina8)	.3	--	<.08	--	<.2	--	.8	2.75	--	<.20	--	--	<1	--	-23.4	-3.91	.54
	.3	--	<.8	--	<.2	--	.8	2.62	--	<.2	--	--	1.4	--	--	--	--
[1]TD–69–32–201	10	50	<1	M	20	--	4	M	--	<1	14,500	3.2	1,060	--	-27	-4.51	--
	10	170	<1	<20	10	--	4	M	--	<1	15,400	<1.0	550	--	-23.5	-4.31	--
[1]TD–69–32–303	<2	760	<1	80	50	--	<1	M	--	<1	10,900	<1	70	--	-24.7	-4.63	--
	<2	3,015	--	75	55	--	<1	M	--	<1	11,100	3.1	110	--	-27.1	-4.63	--
	--	720	<300	69	46	--	<30	<30	--	<1	9,500	<18	45	--	--	--	--
TD–69–32–501	<1	5,010	<1	80	30	--	<1	M	<5	<1	11,700	2.8	290	--	-27.8	-4.69	--
	<2	810	<1	110	10	--	<1	M	--	<1	11,600	<1.0	140	--	-24.7	-4.79	--
TD–69–32–703	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-22.2	-4.51	--
(Medina1)	.4	--	<.08	--	.8	--	.8	5.26	--	<.20	--	--	59	--	-26	-4.53	.57
TD–69–37–302	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.3	-4.52	--
TD–69–38–106	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.6	-4.27	--
	1.5	--	.17	--	<.2	--	.5	2.52	--	<.20	--	--	21	.50	-24.1	-4.33	.64
	1.6	--	.21	--	<.2	--	.6	2.52	--	<.20	--	--	21.5	.37	--	--	.64
TD–69–38–509	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.9	-4.18	--
	26	--	.83	--	.4	--	.5	3.59	--	<.20	--	--	15	.63	-22.4	-4.2	.64
	--	--	--	--	--	--	--	--	--	--	--	--	--	.66	--	--	--
YP–69–37–101	1	--	3.14	--	.1	--	.5	.72	--	<1	--	--	426	--	-24.9	-3.96	.73
	1.1	--	2.41	--	E.1	--	.5	2.45	--	<.20	--	--	482	1.51	-21.9	-3.98	.67
	--	--	--	--	--	--	--	--	--	--	--	--	--	1.52	--	--	--
North-central Medina flow path																	
TD–68–25–402	M	<5	<1	<1	<1	--	1	M	--	<1	600	4	10	--	-9.9	-1.08	--
	<1	<5	<1	M	M	--	2	M	--	<1	630	3.7	30	--	-7	-.88	--
TD–68–25–510	M	40	<1	M	10	--	2	M	<5	<1	630	5.7	230	--	-9.1	-1.48	--
	M	<5	<1	M	M	--	2	M	--	<1	570	4.3	160	--	-5.3	-1.06	--
TD–68–25–701	<1	<5	<1	10	M	--	2	M	--	<1	3,280	8.8	150	--	-21.8	-3.99	--
	<1	20	<1	10	M	--	2	M	--	<1	2,390	2.6	170	--	-23.2	-3.97	--
TD–68–25–711	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-23.1	-4.28	--
(Medina5)	.7	--	<.08	--	5.1	--	3.2	14.2	--	<.20	--	--	10	--	-24.2	-4.25	.45
TD–68–25–806	M	<5	M	<1	<1	--	<1	M	--	<1	80	7.2	2,400	--	-26.1	-4.31	--
	<2	<2	<1	<20	<1	--	<1	M	--	<1	80	2.5	660	--	-25.3	-4.24	--
	3.9	--	1.21	--	1.3	--	E.3	3.17	--	<.20	--	--	1,090	.74	-23.7	-4.37	.62
	--	--	--	--	--	--	--	--	--	--	--	--	--	.62	--	--	--
TD–68–25–807	<1	40	<1	30	M	--	1	M	--	<1	4,970	2.4	10	--	-15.2	-2.35	--
	<1	30	<1	70	M	--	--	--	--	--	7,450	--	20	--	-16	-2.98	--
TD–68–25–809	<1	1,820	<1	M	M	--	3	M	--	<1	3,590	4.8	90	--	-22.9	-3.89	--
	<1	1,380	<1	M	M	--	4	M	--	<1	3,020	1.9	70	--	-23.3	-3.9	--
TD–68–25–810	M	<5	M	<1	<1	--	<1	M	--	<1	80	3.7	240	--	-26.3	-4.53	--
	M	<5	<1	<20	<1	--	<1	M	--	<1	90	2.6	300	--	-25	-4.54	--
	.9	--	.99	--	.2	--	.8	3.46	--	<.20	--	--	285	2.17	-22.7	-4.13	.82
	--	--	--	--	--	--	--	--	--	--	--	--	--	2.42	--	--	--

[1] Probably northwestern Medina flow path.

Table 2. Selected chemical and isotope data for ground water from wells (by flow path) and surface water (by site), northern Medina and northeastern Uvalde Counties, Texas, 1992–2003—Continued.

State well number or USGS site number (USGS name)	Copper, wf (µg/L)	Iron, wf (µg/L)	Lead, wf (µg/L)	Lithium, wf (µg/L)	Manganese, wf (µg/L)	Mercury, wf (mg/L)	Molybdenum, wf (µg/L)	Nickel, wf (µg/L)	Selenium, wf (µg/L)	Silver, wf (µg/L)	Strontium, wf (µg/L)	Vanadium, wf (µg/L)	Zinc, wf (µg/L)	Sulfur hexafluoride (pptv)	δD (per mil)	$\delta^{18}O$ (per mil)	Uranium, wf (µg/L)
North-central Medina flow path—Continued																	
TD–68–25–822	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.6	-4.35	--
TD–69–32–905	8.6	--	0.98	--	0.5	--	33.3	1.75	--	<0.20	--	--	15	--	--	--	0.59
TD–69–38–601	7	29	2	--	13	--	--	--	<1	<1.0	--	--	17	--	--	--	--
(Seco)	--	20	--	--	--	--	--	--	--	--	260	--	--	--	-22	-4.08	--
TD–69–38–709	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-21.9	-4.14	--
	2.5	--	.17	--	.7	--	.5	3.28	--	<.20	--	--	90	0.22	-23.2	-4.15	.68
	--	--	--	--	--	--	--	--	--	--	--	--	--	.23	--	--	--
TD–69–39–504	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-23.4	-4.24	--
TD–69–39–520	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TD–69–40–102 (Quihi)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.9	-4.56	--
TD–69–40–202	M	<5	<1	<1	<1	--	<1	M	--	<1	250	6.6	M	--	-19.4	-3.23	--
(Medina3)	M	<5	<1	<1	<1	--	<1	M	--	<1	240	7.2	M	--	-18.6	-3.24	--
	M	<5	M	<20	<1	--	<1	M	--	<1	160	3	30	--	-24.2	-4.01	--
TD–69–40–209	--	--	--	--	--	--	--	--	--	--	--	--	--	5.5	-24.2	-3.84	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	5.3	--	--	--
	.5	--	<.08	--	E.1	--	.5	2.92	--	<.20	--	--	M	--	-22.9	-3.94	.88
TD–69–40–301	M	<5	M	<1	<1	--	<1	M	--	<1	220	4.9	310	--	-23.7	-3.93	--
	M	<5	M	<20	M	--	<1	M	--	<1	230	2.5	2,300	--	-23.3	-3.88	--
South-central Medina flow path																	
TD–68–25–904	<1	20	<1	10	10	--	4	M	--	<1	3,650	1.8	40	--	-21.9	-4.14	--
	<1	<5	<1	10	M	--	3	M	--	<1	3,180	1.3	70	--	-22	-4.21	--
TD–68–33–102	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-20.9	-3.26	--
TD–68–33–103	M	<5	<1	<1	<1	--	<1	M	--	<1	220	3.7	M	--	-20.9	-3.67	--
	M	<5	<1	<1	<1	--	<1	M	--	<1	280	4.6	M	--	-19.5	-3.46	--
TD–68–33–204	M	10	<1	M	M	--	<1	M	<5	<1	410	4.1	360	--	-21.2	-3.51	--
	<2	<5	<1	<20	M	--	<1	M	--	<1	390	2	510	--	-21.2	-3.36	--
TD–68–33–213	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-24.2	-4.06	--
(Medina7)	1.2	--	<.08	--	E.1	--	.4	3.16	--	<.20	--	--	M	--	-23.9	-4.03	.65
TD–69–40–510	--	--	--	--	--	--	--	--	--	--	--	--	--	2.8	-20.1	-3.73	--
(Medina4)	--	--	--	--	--	--	--	--	--	--	--	--	--	2.7	--	--	--
	.3	--	<.08	--	.5	--	.5	3.2	--	<.20	200	--	<1	--	-22	-3.74	.68
TD–69–40–604	M	20	<1	M	M	--	<1	M	--	<1	590	5.4	270	--	-17.9	-3.11	--
	<2	<5	<1	<20	M	--	<1	M	--	<1	560	1.4	260	--	-20.2	-3.15	--
Flow path unknown (well east of Medina Lake/River)																	
AS–68–25–505	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-16.1	-2.58	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-14.7	-2.44	--
TD–68–25–602	<2	180	<2	60	M	--	<2	M	--	<2	10,500	2.5	970	--	-26.1	-4.7	--
	<1	50	<1	M	M	--	2	M	--	<1	8,500	1.9	570	--	-25.9	-4.77	--
TD–68–25–603	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-22.3	-4.44	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-22.4	-4.25	--
Medina Lake near San Antonio																	
08179500 (AL)	<10	4	<1	5	<1	--	<10	<10	<1	1	640	<6	<3	--	--	--	--
	<6	<8	<5	<.01	<2	--	3	<20	--	<6	660	--	<5	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-6.60	-1.00	--
08179500 (DC)	1.3	<5	<1	2.3	<1	<0.2	1.6	41	--	<1	615	9.2	2	--	-7.00	-1.20	--
Medina River below Medina Lake																	
08179520	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-7.80	-1.22	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-8.40	-1.04	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-6.50	-1.05	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-6.00	-.93	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-6.00	-.80	--

Table 3. Percentage contribution of surface water to ground water at selected wells in the Trinity and Edwards aquifers, by flow path, northern Medina and northeastern Uvalde Counties, Texas, 1995–2003, based on natural isotopic compositions of oxygen and hydrogen.

[USGS, U.S. Geological Survey; δD, delta deuterium; δ^{18}O, delta oxygen-18; per mil, parts per thousand; <, censored value]

State well number (USGS name)	Aquifer	Date	δD (per mil)	δ^{18}D (per mil)	Percentage surface water (δD)	Percentage surface water (δ^{18}O)	Average percentage surface water
			Northwestern Medina flow path				
TD–69–30–903	Edwards	12/17/2002	-25.4	-4.28	<12	<10	<11
TD–69–31–406	Edwards	12/31/2001	-24.1	-4.33	12	<10	<11
(Medina2)		08/15/2003	-28.0	-4.81	<12	<10	<11
TD–69–31–708	Edwards	07/30/2002	-24.5	-4.21	<12	10	<11
(Medina8)		08/21/2003	-24.4	-3.91	15	19	17
TD–69–32–703	Edwards	07/29/2002	-22.2	-4.51	21	<10	<11
(Medina1)		08/13/2003	-26.0	-4.53	<12	<10	<11
YP–69–37–101	Edwards	04/03/2002	-24.9	-3.96	<12	17	<12
		12/05/2002	-21.9	-3.98	23	17	20
			North-central Medina flow path				
TD–68–25–402	Trinity	01/30/1996	-9.9	-1.08	84	98	91
		08/08/1996	-7.0	-.88	99	100	100
TD–68–25–510	Trinity	11/29/1995	-9.1	-1.48	89	87	88
		08/08/1996	-5.3	-1.06	100	99	100
TD–68–25–701	Edwards	11/30/1995	-21.8	-3.99	23	16	20
		07/29/1996	-23.2	-3.97	16	17	17
TD–68–25–711	Edwards	07/31/2002	-23.1	-4.28	17	<10	<14
(Medina5)		08/12/2003	-24.2	-4.25	<12	<10	<11
TD–68–25–807	Trinity	01/25/1996	-15.2	-2.35	57	63	60
		07/09/1996	-16.0	-2.98	53	45	49
TD–68–25–809	Trinity	12/05/1995	-22.9	-3.89	10	18	14
		07/26/1996	-23.3	-3.9	8	18	13
TD–68–25–810	Trinity	03/06/1996	-26.3	-4.53	-9	<5	<7
		08/19/1996	-25.0	-4.54	<7	<5	<6
TD–69–38–709	Edwards	12/12/2002	-23.2	-4.15	16	12	14
TD–69–40–202	Edwards	03/13/1996	-19.4	-3.23	36	38	37
		08/20/1996	-24.2	-4.01	<12	16	<14
TD–69–40–209	Edwards	07/29/2002	-24.2	-3.84	<12	21	<16
(Medina3)		08/20/2003	-22.9	-3.94	18	18	18
TD–69–40–301	Edwards	01/24/1996	-23.7	-3.93	14	18	16
		08/21/1996	-23.3	-3.88	16	19	18

Table 3. Percentage contribution of surface water to ground water at selected wells in the Trinity and Edwards aquifers, by flow path, northern Medina and northeastern Uvalde Counties, Texas, 1995–2003, based on natural isotopic compositions of oxygen and hydrogen—Continued.

State well number (USGS name)	Aquifer	Date	δD (per mil)	δ^{18}D (per mil)	Percentage surface water (δD)	Percentage surface water (δ^{18}O)	Average percentage surface water
South-central Medina flow path							
TD–68–25–904	Trinity	03/06/1996	-21.9	-4.14	16	11	13
		07/26/1996	-22.0	-4.21	15	9	12
TD–68–33–102	Edwards	07/30/2002	-20.9	-3.26	28	37	32
TD–68–33–103	Edwards	02/21/1996	-20.9	-3.67	28	25	27
		08/06/1996	-19.5	-3.46	35	31	33
TD–68–33–204	Edwards	12/13/1995	-21.2	-3.51	26	30	28
		08/21/1996	-21.2	-3.36	26	34	30
TD–68–33–213	Edwards	07/26/2002	-24.2	-4.06	<12	14	<13
(Medina7)		08/11/2003	-23.9	-4.03	13	15	14
TD–69–40–510	Edwards	07/29/2002	-20.1	-3.73	32	24	28
(Medina4)		08/20/2003	-22.0	-3.74	22	23	23
TD–69–40–604	Edwards	12/05/1995	-17.9	-3.11	43	41	42
		08/21/1996	-20.2	-3.15	32	40	36
Flow path unknown (well east of Medina Lake/River)							
AS–68–25–505	Trinity	12/15/1995	-16.1	-2.58	48	55	52
		07/30/1996	-14.7	-2.44	56	59	58
TD–68–25–603	Trinity	02/08/1996	-22.3	-4.44	13	<5	9
		07/30/1996	-22.4	-4.25	13	8	10

Table 4. Results of PHREEQC simulations of ground-water mixing based on initial and final water chemistry at wells, by flow path, northern Medina County, Texas.

[USGS, U.S. Geological Survey; <, less than; --, not applicable or no data; >, greater than]

Simulation number	Solutions		Percentage of surface water mixed with initial solution		Percentage of end-member Edwards aquifer water mixed with initial solution (PHREEQC)
	Initial site—State well number or USGS site number (USGS name)	Final site—State well number (USGS name)	Average computed by mixing equation	Computed by PHREEQC	
	Northwestern Medina flow path				
1	TD–69–31–708 (Medina8)	TD–69–30–903	<11	No models identified—imbalance in sulfur	--
2	TD–69–31–406 (Medina2)	TD–69–30–903	<11	No models identified—imbalance in sulfur	--
3	TD–69–32–703 (Medina1)	TD–69–30–903	<11	No models identified—imbalance in sulfur	--
4	TD–69–31–603	TD–69–31–406 (Medina2)	<11	Initial well cannot be used—cation-anion balance >17 percent off	--
5	TD–69–32–703 (Medina1)	TD–69–31–406 (Medina2)	<11	0	58
6	TD–69–32–703 (Medina1)	TD–69–31–708 (Medina8)	17	27	73
6A	TD–69–32–703 (Medina1)	TD–69–31–708 (Medina8)	17	33	0
	North-central Medina flow path				
1	Medina Lake (average of AL and DC samples)	TD–68–25–402	100	100	0
2	Medina Lake (average of AL and DC samples)	TD–68–25–510	100	100	0
3	TD–68–25–602 (Trinity end-member)	TD–68–25–810	0	0	100
4	TD–68–25–602 (Trinity end-member)	TD–68–25–809	13	20	80
5	TD–68–25–810	TD–68–25–701	17	No models identified—imbalance in sodium	--
6	TD–68–25–402	TD–68–25–701	17	No models identified—imbalance in sodium, calcium, and chloride	--
7	TD–68–25–810	TD–68–25–711 (Medina5)	<11	No models identified—imbalance in sulfur	--
8	TD–68–25–806 (Edwards end-member)	TD–68–25–711 (Medina5)	<11	No models identified—imbalance in sulfur	--
9	TD–68–25–711 (Medina5)	TD–69–40–209 (Medina3)	18	29	0
10	TD–68–25–711 (Medina5)	TD–69–32–905	--	No models identified—imbalance in chloride	--
11	TD–69–32–905	TD–69–40–209 (Medina3)	18	23	77
12	TD–69–40–209 (Medina3)	TD–69–38–709	14	15	85
12A	TD–69–40–209 (Medina3)	TD–69–38–709	14	9	54
13	TD–68–25–810	TD–68–25–806	0	No models identified—imbalance in sodium	--
14	TD–68–25–806 (Edwards end-member)	TD–68–25–810	16	No models identified—imbalance in sulfur	--
15	TD–68–25–701	TD–69–40–301	18	No models identified—imbalance in sulfur	--
16	TD–69–40–301	TD–69–40–202	13	No models identified—imbalance in sulfur	--
17	TD–69–40–202	TD–69–38–709	14	No models identified—imbalance in sodium, magnesium, chloride, sulfur	--
18	TD–69–32–905	TD–69–38–709	14	No models identified—imbalance in chloride, sodium, sulfur	--
	South-central Medina flow path				
1	TD–68–25–602 (Trinity end-member)	TD–68–25–904	13	11	81
2	TD–68–25–904	TD–68–33–213 (Medina7)	14	4	96
2A	TD–68–25–904	TD–68–33–213 (Medina7)	14	3	94
3	TD–68–25–904	TD–68–33–204	30	10	83
4	TD–68–33–213 (Medina7)	TD–69–40–510 (Medina4)	23	12	0
4A	TD–68–33–213 (Medina7)	TD–69–40–510 (Medina4)	23	7	0
5	TD–68–33–204	TD–69–40–604	36	No models identified—imbalance in magnesium and sulfur	--
6	TD–68–33–204	TD–68–33–103	33	0	44
7	TD–68–33–103	TD–69–40–604	36	No models identified—imbalance in calcium	--

Table 4. Results of PHREEQC simulations of ground-water mixing based on initial and final water chemistry at wells, by flow path, northern Medina County, Texas—Continued.

Simulation number	Mole transfer (millimoles/kilogram)						Sum of residuals	Sum of delta/ uncertainty	Minimum phases
	Calcite	Carbon dioxide gas	Dolomite	Gypsum	Halite	Silica			
				Northwestern Medina flow path					
1	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--
5	-0.480	-0.490	0.027	0.025	0.002	0.0005	0.5938	0.8232	--
6	--	2.240	.102	--	.03	.021	5.593	10.17	--
6A	--	2.33	.082	--	.026	.018	7.869	12.95	--
				North-central Medina flow path					
1	--	.291	--	--	.043	--	9.673	9.673	yes
2	--	.294	--	.278	.080	.567	5.403	5.403	--
3	--	2.97	.128	.076	.205	--	8.476	8.476	yes
4	-2.36	-.444	1.15	11.01	.014	--	6.825	12.44	--
5	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--
7	--	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--	--
9	--	1.92	.197	.001	.071	.013	7.832	12.87	--
10	--	--	--	--	--	--	--	--	--
11	--	1.744	.245	--	.087	--	7.399	12.52	yes
12	-.65	--	.286	--	.053	--	7.487	13.39	yes
12A	-.581	-.574	.176	--	--	--	8.809	18.36	--
13	--	--	--	--	--	--	--	--	--
14	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--	--
18	--	--	--	--	--	--	--	--	--
				South-central Medina flow path					
1	-2.53	-.653	1.313	.424	--	--	3.149	8.154	--
2	--	-.624	.104	.059	.033	--	7.539	15.89	--
2A	--	-.758	.049	--	.035	--	8.483	17.66	--
3	--	-.410	.084	--	--	--	9.982	22.53	yes
4	--	.147	--	--	.066	--	7.732	14.04	yes
4A	-.277	.082	--	--	.072	.014	3.067	8.274	--
5	--	--	--	--	--	--	--	--	--
6	--	--	--	.093	.030	--	10.92	16.49	yes
7	--	--	--	--	--	--	--	--	--

Table 5. Saturation indexes computed with PHREEQC for ground water from selected wells, by flow path, and Medina Lake, northern Medina and northeastern Uvalde Counties, Texas, 1995–2003.

[In milliequivalents per liter except as indicated; g, grams; --, not applicable or not determined]

State well number (USGS name)	Aquifer	Apparent age	Date	Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate	Saturation index (dimensionless)						Cation-anion balance
											Calcite	Dolomite	Carbon dioxide (g)	Gypsum	Halite	Silica	
Northwestern Medina flow path																	
TD–69–30–903	Edwards	1988	12/17/2002	4.09	0.30	0.21	0	0.23	4.16	0.08	0.05	-0.93	-1.82	-2.90	-8.98	-1.00	1.4
TD–69–31–406 (Medina2)	Edwards	--	12/31/2001	3.74	.74	.17	.03	.17	3.92	.52	.19	-.20	-2.04	-2.14	-9.19	-.95	.9
		--	08/15/2003	4.39	.71	.20	.04	.18	4.33	.65	.29	-.09	-2.00	-1.99	-9.10	-.97	1.8
		1992	08/20/2004	4.46	.69	.31	.03	.32	4.36	.34	.07	-.57	-1.81	-2.27	-8.65	-.96	4.5
TD–69–31–603	Edwards	1982	11/26/2002	5.94	.28	.52	.02	1.29	3.34	.16	-.12	-1.48	-1.73	-2.48	-7.83	-.98	17.1
TD–69–31–708 (Medina8)	Edwards	--	08/21/2003	3.74	.84	.25	.03	.25	3.74	.40	-.73	-1.99	-1.16	-2.25	-8.86	-.96	5.2
TD–69–32–201	Trinity	--	01/31/1996	6.79	6.34	.37	.10	.55	5.40	6.97	--	--	--	--	--	--	2.6
		--	08/28/1996	5.59	6.11	.43	.11	.59	5.20	14.7	-.21	-.35	-1.45	-.78	-8.30	-.90	-21.5
TD–69–32–303	Trinity	--	12/11/1995	18.4	14.4	1.54	.41	.53	5.20	29.8	--	--	--	--	--	--	-1.1
		--	08/15/1996	17.90	19.30	1.47	.42	.71	4.80	33.10	.16	.46	-1.62	-.27	-7.74	-.92	.7
TD–69–32–703 (Medina1)	Edwards	--	08/13/2003	4.28	.15	.19	.01	.13	4.41	.14	0	-1.32	-1.69	-2.63	-9.26	-.97	-.6
North-central Medina flow path																	
TD–68–25–402	Trinity	--	01/30/1996	2.80	1.39	.34	.04	.31	2.80	1.15	-.14	-.51	-2.21	-1.91	-8.62	-1.07	3.3
		--	08/08/1996	3.12	1.42	.41	.04	.37	3.20	1.23	-.23	-.70	-1.94	-1.85	-8.48	-.98	2.0
TD–68–25–510	Trinity	--	11/29/1995	3.66	1.43	.38	.04	.39	3.20	--	-.18	-.70	-1.95	-1.68	-8.49	-.85	2.6
		--	08/08/1996	3.68	1.42	.39	.04	.42	3.20	1.64	-.18	-.70	-1.95	-1.67	-8.43	-.92	2.1
TD–68–25–602	Trinity	--	02/08/1996	23.2	22.6	.55	.40	.35	3.60	42.3	.11	.31	-1.75	-.12	-8.49	-1.01	.7
		--	07/30/1996	24.5	19.6	.46	.36	.28	3.60	36.4	-.12	-.23	-1.44	-.13	-8.66	-.97	5.4
TD–68–25–701	Edwards	--	11/30/1995	3.43	3.22	.01	.05	.24	4.00	2.64	-.79	-1.49	-1.13	-1.57	-10.22	-.98	-1.2
		--	07/29/1996	2.91	2.57	.12	.04	.23	3.80	2.33	-.56	-1.04	-1.45	-1.66	-9.21	-.97	-6.0
TD–68–25–711 (Medina5)	Edwards	--	08/12/2003	4.11	.27	.19	.02	.22	4.26	.04	.16	-.67	-1.76	-3.16	-9.05	-.98	.8
TD–68–25–806	Edwards	--	12/05/1995	3.99	.21	.09	0	.18	4.00	.08	-.32	-1.81	-1.50	-2.92	-9.43	-.97	.4
		--	08/19/1996	4.22	.21	.23	0	.20	3.80	.12	-.36	-1.92	-1.45	-2.69	-8.98	-.91	6.0
		1978	12/04/2002	3.89	.21	.18	.01	.18	4.08	.16	-.19	-1.55	-1.63	-2.61	-9.14	-.98	-1.4
TD–68–25–809	Trinity	--	12/05/1995	26.7	2.07	.18	.04	.40	3.60	23.30	.51	-.05	-2.06	-.14	-8.87	-.95	3.0
		--	07/26/1996	24.9	2.76	.18	.04	.28	3.80	22.30	.55	.24	-2.02	-.18	-9.03	-.94	2.7
TD–68–25–810	Trinity	--	03/06/1996	4.02	.43	.31	0	.38	3.80	1.68	.08	-0.71	-1.96	-2.59	-8.58	-1.03	4.6
		--	08/19/1996	4.18	.49	.34	0	.42	3.80	.31	-.80	-2.42	-1.06	-2.31	-8.49	-.97	5.0
		1990	02/20/2003	3.65	.66	.22	.01	.21	3.80	.15	-.45	-1.53	-1.46	-2.67	-8.98	-.96	4.4

Table 5. Saturation indexes computed with PHREEQC for ground water from selected wells, by flow path, and Medina Lake, northern Medina and northeastern Uvalde Counties, Texas, 1995–2003—Continued.

State well number (USGS name)	Aquifer	Apparent age	Date	Saturation index (dimensionless)													Cation-anion balance
				Calcium	Magnesium	Sodium	Potassium	Chloride	Bicarbonate	Sulfate	Calcite	Dolomite	Carbon dioxide (g)	Gypsum	Halite	Silica	
				North-central Medina flow path—Continued													
TD–69–32–905	Edwards	--	10/12/2003	4.86	0.37	0.29	0.04	0.46	4.11	0.26	-0.11	-1.23	-1.63	-2.33	-8.53	-0.91	6.9
TD–69–38–601 (Seco)	Edwards	--	12/20/2001	3.74	.82	.23	.02	.28	4.20	.36	.09	-.37	-1.92	-2.30	-8.84	-1.00	-.2
TD–69–38–709	Edwards	1969	12/12/2002	3.41	1.07	.23	.02	.28	4.08	.28	-.29	-1.01	-1.64	-2.43	-8.84	-.96	1.0
TD–69–40–202	Edwards	--	03/13/1996	3.96	.78	.37	0	.39	4.04	.48	-.01	-.62	-1.86	-2.15	-8.87	-1.00	5.0
		--	08/20/1996	4.35	.70	.24	0	.23	4.20	.20	-.03	-.71	-1.72	-2.51	-8.50	-.86	7.8
TD–69–40–209 (Medina3)	Edwards	2003	08/20/2003	4.23	1.01	.34	.02	.28	4.34	.36	-.41	-1.32	-1.29	-2.26	-8.67	-.95	5.8
TD–69–40–301	Edwards	--	01/24/1996	3.37	1.27	.24	0	.23	4.20	.25	-.03	-.36	-1.81	-2.50	-8.92	-.96	2.0
		--	08/21/1996	3.78	1.20	.23	0	.30	4.20	.32	.13	-.11	-1.91	-2.36	-8.81	-.93	4.0
				South-central Medina flow path													
TD–68–25–904	Trinity	--	03/06/1996	4.06	4.52	.40	.08	.26	4.00	5.48	-.23	-.32	-1.76	-1.26	-8.67	-.99	-3.6
		--	07/26/1996	3.65	4.15	.26	.07	.23	4.00	4.12	-.03	.10	-1.95	-1.40	-8.91	-.95	-1.4
TD–68–33–103	Edwards	--	08/06/1996	4.41	.62	.26	.00	.33	3.80	.50	-.28	-1.30	-1.56	-2.10	-8.72	-.97	6.7
TD–68–33–204	Edwards	--	12/13/1995	3.88	.78	.24	.00	.32	4.00	.44	-.01	-.61	-1.84	-2.20	-8.78	-.96	1.5
		--	08/21/1996	3.99	.82	.28	.00	.35	3.80	.46	.01	-.53	-1.85	-2.17	-8.67	-.92	5.1
TD–68–33–213 (Medina7)	Edwards	--	08/11/2003	4.45	.46	.23	.01	.27	4.47	.28	.19	-.52	-1.90	-2.35	-8.86	-.99	1.3
TD–69–40–510 (Medina4)	Edwards	1992	08/02/2003	4.46	.69	.31	.03	.32	4.36	.34	.07	-.57	-1.81	-2.27	-8.65	-.96	4.5
TD–69–40–604	Edwards	--	12/05/1995	3.12	1.47	.04	.00	.28	3.60	.72	-.44	-1.10	-1.58	-2.08	-9.56	-.98	.4
		--	08/21/1996	3.32	1.57	.27	.03	.32	3.60	.72	-.42	-1.06	-1.58	-2.06	-8.73	-.97	5.6
				Medina Lake[1]													
--	--	--	--	2.71	1.37	.30	.04	.34	2.77	1.19	.21	.19	-2.33	-1.92	-8.58	-1.05	--

[1] Average of 08179500 (AL) and 08179500 (DC) samples.

Prepared by the USGS Texas Water Science Center:
8027 Exchange Drive
Austin, TX 78754–4733

Information regarding water resources in Texas is available at
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