

# **Quality of Water in the Trinity and Edwards Aquifers, South-Central Texas, 1996–98**

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Prepared as part of the  
National Water-Quality Assessment Program

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## FOREWORD

The U.S. Geological Survey (USGS) is committed to providing the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (<http://www.usgs.gov/>). Information on the quality of the Nation's water resources is critical to assuring the long-term availability of water that is safe for drinking and recreation and suitable for industry, irrigation, and habitat for fish and wildlife. Population growth and increasing demands for multiple water uses make water availability, now measured in terms of quantity *and* quality, even more essential to the long-term sustainability of our communities and ecosystems.

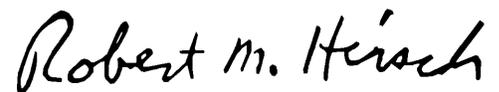
The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, and local information needs and decisions related to water-quality management and policy (<http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities.

During 1991–2001, the NAWQA Program completed interdisciplinary assessments in 51 of the Nation's major river basins and aquifer systems, referred to as Study Units (<http://water.usgs.gov/nawqa/studyu.html>). Baseline conditions were established for comparison to future assessments, and long-term monitoring was initiated in many of the basins. During the next decade, 42 of the 51 Study Units will be reassessed so that 10 years of

comparable monitoring data will be available to determine trends at many of the Nation's streams and aquifers. The next 10 years of study also will fill in critical gaps in characterizing water-quality conditions, enhance understanding of factors that affect water quality, and establish links between *sources* of contaminants, the *transport* of those contaminants through the hydrologic system, and the potential *effects* of contaminants on humans and aquatic ecosystems.

The USGS aims to disseminate credible, timely, and relevant science information to inform practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.



Robert M. Hirsch  
Associate Director for Water

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## Conversion Factors, Abbreviations, and Vertical Datum

Multiply	By	To obtain
<b>Length</b>		
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
<b>Area</b>		
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
<b>Volume</b>		
acre-foot (acre-ft)	1,233	cubic meter (m <sup>3</sup> )
<b>Flow rate</b>		
foot per day (ft/d)	0.3048	meter per day (m/d)
<b>Radioactivity</b>		
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Per mil: A unit expressing the ratio of stable-isotopic abundances of an element in a sample to those of a standard material. Per mil units are equivalent to parts per thousand. Stable-isotopic ratios are computed as follows (Gat, 1981):

$$\delta X = \left( \frac{R(\text{sample})}{R(\text{standard})} - 1 \right) \times 1,000,$$

where

X is the heavier stable isotope, and

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

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

# Quality of Water in the Trinity and Edwards Aquifers, South-Central Texas, 1996–98

By Lynne Fahlquist and Ann F. Ardis

## Abstract

During 1996–98, the U.S. Geological Survey studied surface- and ground-water quality in south-central Texas. The ground-water components included the upper and middle zones (undifferentiated) of the Trinity aquifer in the Hill Country and the unconfined part (recharge zone) and confined part (artesian zone) of the Edwards aquifer in the Balcones fault zone of the San Antonio region. The study was supplemented by information compiled from four ground-water-quality studies done during 1996–98.

Trinity aquifer waters are more mineralized and contain larger dissolved solids, sulfate, and chloride concentrations compared to Edwards aquifer waters. Greater variability in water chemistry in the Trinity aquifer likely reflects the more variable lithology of the host rock. Trace elements were widely detected, mostly at small concentrations. Median total nitrogen was larger in the Edwards aquifer than in the Trinity aquifer. Ammonia nitrogen was detected more frequently and at larger concentrations in the Trinity aquifer than in the Edwards aquifer. Although some nitrate nitrogen concentrations in the Edwards aquifer exceeded a U.S. Geological Survey national background threshold concentration, no concentrations exceeded the U.S. Environmental Protection Agency public drinking-water standard.

Synthetic organic compounds, such as pesticides and volatile organic compounds, were detected in the Edwards aquifer and less frequently in the Trinity aquifer, mostly at very small concentrations (less than 1 microgram per liter). These compounds were detected most frequently in urban unconfined Edwards aquifer samples. Atrazine and its breakdown product deethylatrazine were the most frequently detected pesticides, and trihalomethanes were the most frequently detected volatile organic compounds. Widespread detections of these compounds, although at small concentrations, indicate that anthropogenic activities affect ground-water quality.

Radon gas was detected throughout the Trinity aquifer but not throughout the Edwards aquifer. Fourteen samples from the Trinity aquifer and 10 samples from the Edwards aquifer exceeded a proposed U.S. Environmental Protection Agency public drinking-water standard. Sources of radon in the study

area might be granitic sediments underlying the Trinity aquifer and igneous intrusions in and below the Edwards aquifer.

The presence of tritium in nearly all Edwards aquifer samples indicates that some component of sampled water is young (less than about 50 years), even for long flow paths in the confined zone. About one-half of the Trinity aquifer samples contained tritium, indicating that only part of the aquifer contains young water.

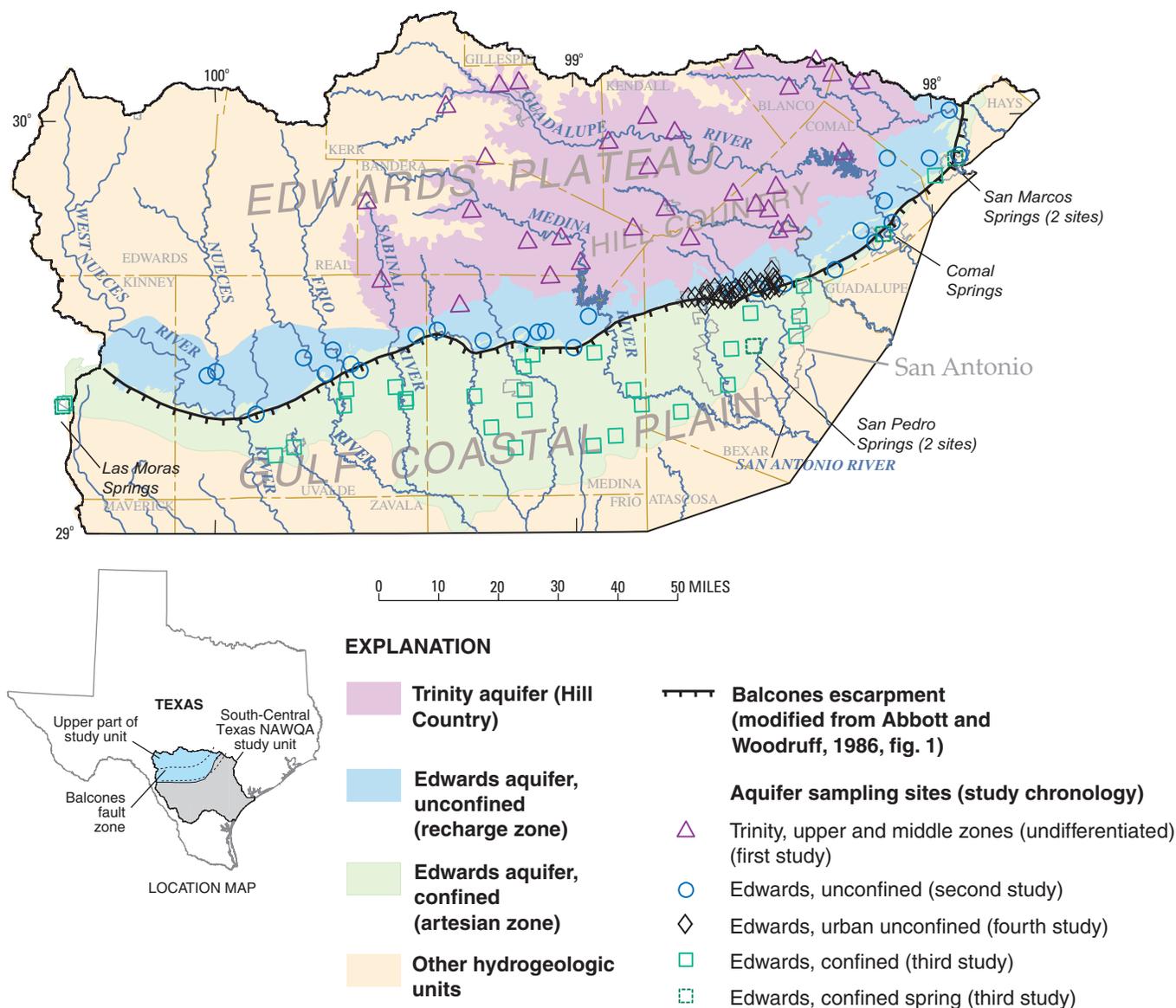
Hydrogen and oxygen isotopes of water provide indicators of recharge sources to the Trinity and Edwards aquifers. Most ground-water samples have a meteorological isotopic signature indicating recharge as direct infiltration of water with little residence time on the land surface. Isotopic data from some samples collected from the unconfined Edwards aquifer indicate the water has undergone evaporation. At the time that ground-water samples were collected (during a drought), nearby streams were the likely sources of recharge to these wells.

## Introduction

Knowledge of the quality of water resources is important to the Nation because of implications for human and aquatic health and because of costs associated with water management. In 1991, the U.S. Geological Survey (USGS) implemented the National Water-Quality Assessment (NAWQA) Program to characterize, in a nationally consistent manner, water quality of major surface- and ground-water resources of the Nation, to determine natural and human factors that affect water quality, and to define trends in water quality (Gilliom and others, 1995). One component of the NAWQA study design is to systematically assess the occurrence and distribution of natural and anthropogenic compounds in regionally important aquifers. To this end, the USGS conducted a study of surface- and ground-water quality in the upper part of the South-Central Texas NAWQA study unit during 1996–98, the results of which are presented in Bush and others (2000).

The upper part of the South-Central Texas study unit, (hereinafter, study area) which covers about 10,500 mi<sup>2</sup>, extends from the western boundary of the upper Nueces River Basin to the eastern boundary of the upper Guadalupe River

## 2 Quality of Water in the Trinity and Edwards Aquifers, South-Central Texas, 1996–98



**Figure 1.** Physiographic setting and location of wells completed in the Trinity and Edwards aquifers and Edwards aquifer springs that were sampled for water quality in south-central Texas, 1996–98.

Basin (fig. 1). Major aquifers include the Edwards and the Trinity. The Edwards aquifer, which is a fractured, karstic, carbonate aquifer, is one of the most productive aquifers in the world and is the sole source of water for the city of San Antonio. With a population of about 1.4 million, San Antonio is the eighth largest city in the United States and the second fastest growing city among those with populations greater than 1 million (U.S. Census Bureau, 2003a, b). In addition to supplying water for the increasing urban demand, the Edwards aquifer is the primary source of water for agricultural interests west of San Antonio. The much less productive Trinity aquifer is the primary source of water for the rapidly suburbanizing Hill Country.

Ground-water quality is of concern throughout the study area because ground water is the principal source of water supply. Some ground-water quality issues are: the potential for contamination of the Trinity and Edwards aquifers from urbanization, potential degradation of habitats of threatened or endangered aquatic species, and contamination of the Edwards aquifer through encroachment of saline water. Concentrations of concern for constituents such as chloride, fluoride, nitrate, sulfate, dissolved solids, and radon have been discussed previously (Bluntzer, 1992; Bush and others, 2000). In localized areas, organic constituents are of concern (for example fuel or solvent spills) (Roy Deen, Texas Commission on Environmental Quality, oral commun., 2004; Keith Muehlstein, City of San Antonio, oral commun., 1998).

## Purpose and Scope

This report provides supplemental information to Bush and others (2000) about ground-water quality of the Trinity and Edwards aquifers. The ground-water components of the study include the upper and middle zones (undifferentiated) of the Trinity aquifer in the Hill Country (eastern part of the Edwards Plateau) and the Edwards aquifer in the Balcones fault zone of the San Antonio region (fig. 1). The supplemental information was compiled from four ground-water-quality studies done in south-central Texas during 1996–98.

## Environmental Setting

The study area includes the topographically rugged and picturesque dissected part of the Edwards Plateau, the eastern part of which locally is called the “Hill Country,” and the comparatively flat Gulf Coastal Plain, which are separated by the Balcones escarpment (fig. 1). The Balcones escarpment, a surface manifestation of the Balcones fault zone, is a physiographic feature that also separates the Trinity aquifer in the Hill Country from the Edwards aquifer (figs. 1 and 2). San Antonio is the principal urban area at the southeastern margin of the study area. Agricultural lands are located mostly on the coastal plain west of San Antonio, and rangeland predominates on the plateau. Land use in the study area is characterized by 20-percent agriculture, 25-percent rangeland, 50-percent forest (juniper and oak), and less than 5-percent urban; the remainder is water, wetlands, strip mines, or barren land (Vogelmann and others, 1998).

Climate in the region is one of extremes. Drought durations of months to years are common and subsequently are followed by wet periods (Bomar, 1994). Some of the most extreme 1-day duration storms in the world have occurred along the Balcones escarpment (Slade, 1986). Storms can produce rapid runoff and recharge to the Edwards aquifer, and such storms were observed during the study period. Months-long droughts occurred during 1996 and 1998, followed by dramatic wet periods that produced floods in summer 1997 and fall 1998. In October 1998, more than 15 in. of rain fell in a 2-day period on the karstic, unconfined part of the Edwards aquifer (recharge zone), with even higher rainfall rates observed in some areas (Slade and Persky, 1999). Ground-water levels in some monitor wells rose more than 100 ft during a 2-week period in response to this storm (fig. 3). This large change illustrates a local, rapid hydrologic response in the fractured, karstic aquifer.

Precipitation provides recharge as direct infiltration to both the shallow Trinity aquifer (above the Hammett confining unit) and the Edwards aquifer (fig. 2). Springs and seeps discharge along impermeable zones of the Trinity aquifer in the deeply incised stream channels of the Edwards Plateau. These springs provide base flow to streams that flow southward and eastward from the plateau. As they flow across the highly permeable, fractured and faulted carbonate rocks of the Edwards aquifer in the Balcones fault zone, most streams lose all of their

base flow as recharge to the Edwards aquifer. A few large scenic springs, important to the local recreational economy as well as to downstream users, issue from the confined part of the Edwards aquifer. The springs of the Edwards aquifer provide unique habitat for about 90 species, about one-half of which are subterranean and include such organisms as blind shrimp, salamanders, and catfish (Bush and others, 2000). Some species have been Federally listed as endangered or threatened.

The Trinity aquifer in the Hill Country is in Lower Cretaceous rocks that consist of massive layers of limestone and dolostone interbedded with thin sand, shale, and clay layers. The unconfined part of the Trinity aquifer above the Hammett confining unit, which includes the upper and middle zones of the Trinity aquifer (Barker and Ardis, 1996), was sampled for this study. These rocks can be karstic, although they generally produce less water than the Edwards aquifer. The Trinity aquifer is the primary water resource for the Hill Country.

The Edwards aquifer in the Balcones fault zone is in Lower Cretaceous rocks (younger than those of the Trinity aquifer) that consist of relatively pure limestone. Minor amounts of marl and dolostone are present in the Edwards aquifer relative to the Trinity aquifer. The part of the Edwards aquifer downdip of the recharge zone is overlain by coastward-dipping clastic sediments, which act as confining units; thus this part of the aquifer is called the confined (or artesian) zone.

The 10-year average annual discharge (1993–2002) for the Edwards aquifer is estimated to be 414,800 acre-ft (Hamilton and others, 2002), with a regional ground-water velocity estimated by Maclay and Small (1986) to be 27 ft/d. Geary Schindel (Edwards Aquifer Authority, written commun., 2003) computed local ground-water velocities from dye-trace studies of 2,000 to 6,000 ft/d in the vicinity of Comal and San Marcos Springs, indicating that large local variations in velocities exist.

## Approach

During 1996–98, the USGS collected 125 water samples from 119 wells and six springs in south-central Texas to characterize water quality in the Trinity and Edwards aquifers. Site selection of existing wells for three studies and drilled wells for a fourth study followed protocols described by Gilliom and others (1995), Lapham and others (1995), and Squillace and Price (1996). A stratified random statistical approach (Scott, 1990) was used to select sample locations. Samples were collected using protocols developed for the USGS NAWQA program (Koterba, 1998; Koterba and others, 1995; Lapham and others, 1995). In 1996, 31 primarily domestic wells were sampled throughout the Trinity aquifer (first study), and 28 primarily domestic wells were sampled throughout the unconfined Edwards aquifer (recharge zone) (second study). In 1997, 30 primarily public-supply wells and four springs (six samples) that issue from the confined Edwards aquifer (artesian zone) were sampled (third study). The four springs sampled were Las Moras, San Pedro, Comal, and San Marcos. Existing wells and springs were sampled in these three studies to broadly char-

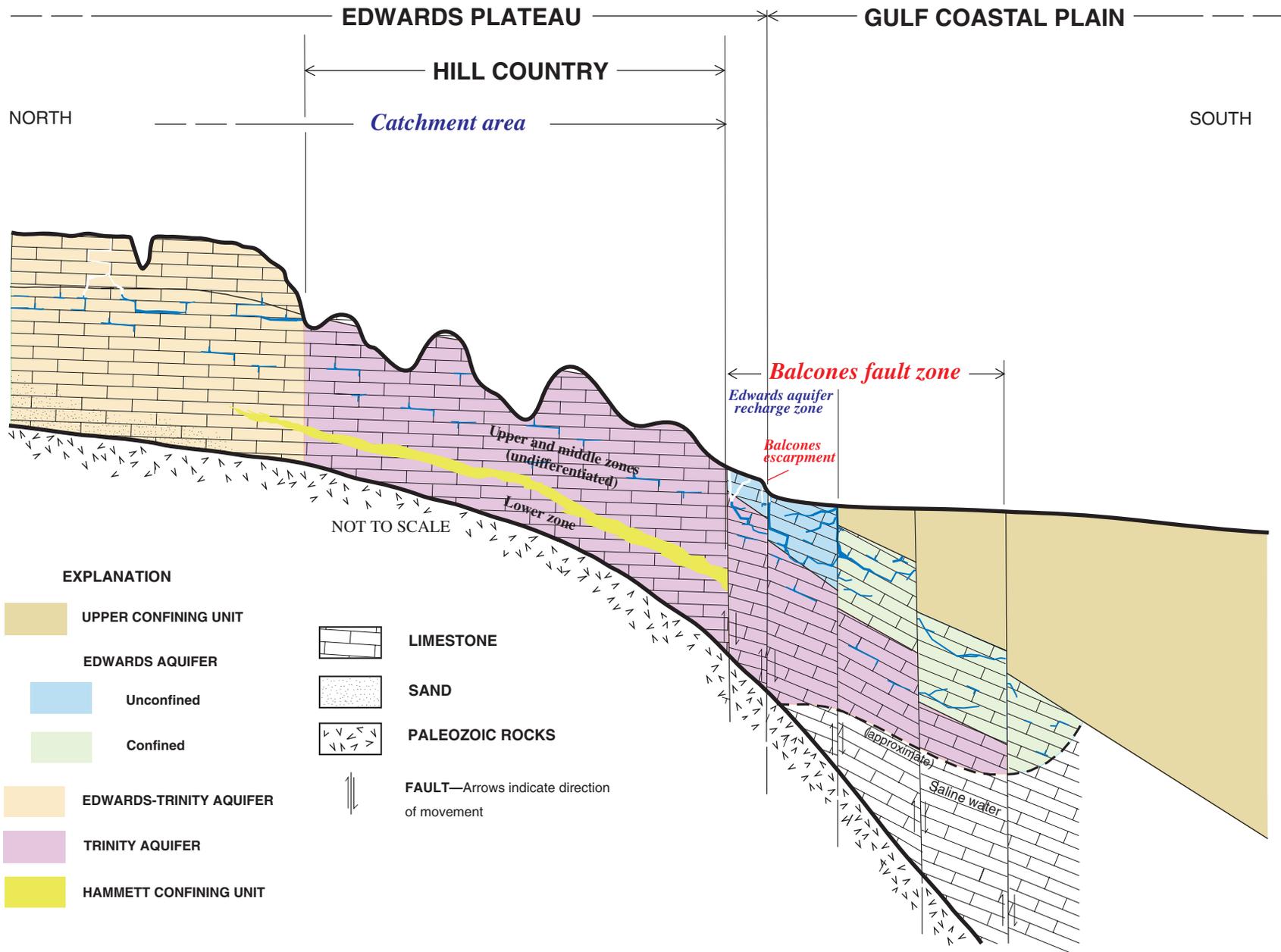


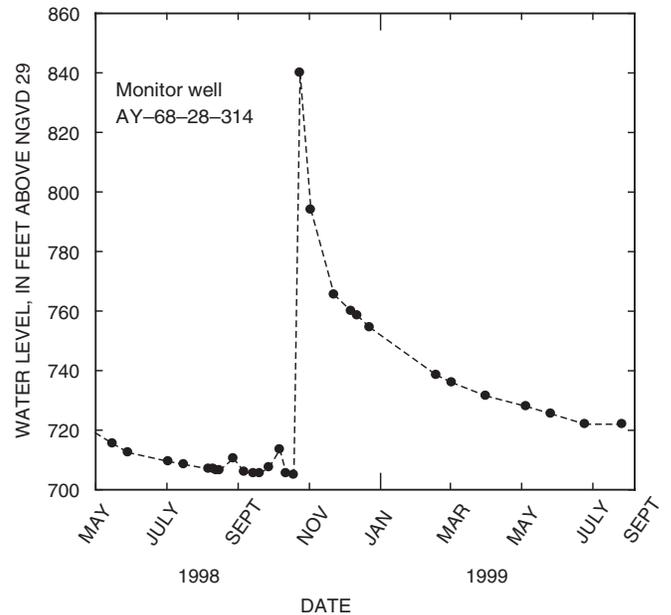
Figure 2. Generalized hydrogeologic section of the Trinity and Edwards aquifers in south-central Texas (modified from Barker and Ardis, 1996, pls. 1 and 3).

acterize existing water-quality conditions in the Trinity and Edwards aquifers. In 1998 a fourth study, in the urbanized part of the recharge zone in the San Antonio metropolitan area, was done. Thirty water-table monitor wells were installed to evaluate the effects of recent urban land use on shallow ground-water quality.

Water samples were analyzed for more than 200 constituents that include major ions, trace elements, nutrients, dissolved organic carbon, pesticide compounds, volatile organic compounds (VOCs), radon, tritium, and deuterium and oxygen isotopes. Water samples were submitted to USGS laboratories for analysis. In addition to laboratory quality control, field quality-control samples were collected in the form of replicate, organic spike, and blank samples to aid in evaluating data quality. A list of references that describes analytical methods is provided in Fahlquist (2003). Results of field quality-control samples are maintained by the USGS. For the Trinity aquifer, known well depths and depths to water from land surface ranged from 85 to 770 ft and from 31 to 447 ft, respectively. Known well depths and depths to water for the unconfined Edwards aquifer ranged from 80 to 590 ft and from 40 to 353 ft, respectively. For the urban unconfined Edwards aquifer, well depths ranged from 180 to 320 ft and depths to water ranged from 105 to 255 ft. For the confined Edwards aquifer, well depths ranged from 402 to 2,700 ft and depths to water ranged from 5 to 639 ft.

## Data Evaluation

Data in Bush and others (2000) were evaluated two ways: (1) All detections were considered regardless of laboratory method reporting level (MRL), and (2) common assessment levels were used for groups of constituents in comparisons to USGS NAWQA studies across the Nation. The MRL is the smallest measured concentration of a constituent that can be reliably reported using a given analytical method (Timme, 1995). In this report, data are evaluated with regard to MRLs for unique analytes during the data-collection period; therefore, evaluations of data in this report are different from those in Bush and others (2000). Constituents detected at or less than MRLs are treated as nondetections for this report. If multiple MRLs were used during the 1996–98 analytical period, then the highest MRL was used to evaluate measured values. In some cases, estimated values greater than MRLs are reported because of poor analytical recoveries of constituents (for example, deethylatrazine). Estimated values greater than MRLs are treated as actual values in data evaluations. Data evaluated in this report and in Bush and others (2000) are published in Gandara and others (1998) and Gandara and Barbie (1999, 2000).



**Figure 3.** Hydrograph showing change in water-level altitude after October 1998 storm in an urban unconfined Edwards aquifer monitor well.

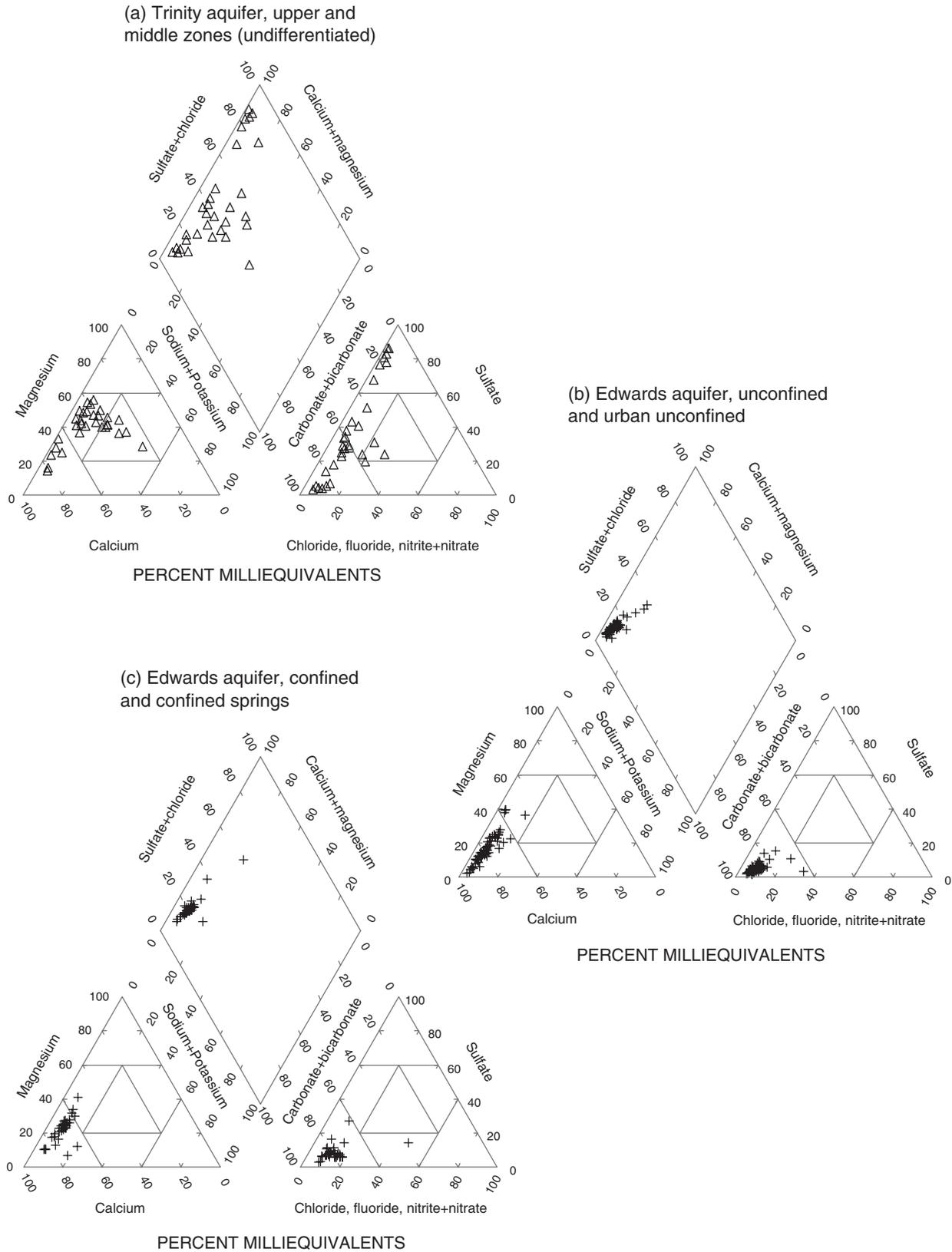
## Water Quality

### Major Ions

Although the Trinity and Edwards aquifers both are carbonate rock, differences in water chemistry are evident. Rocks of the Edwards aquifer are lithologically and chemically more uniform than the rocks of the upper and middle zones of the Trinity aquifer, and major-ion chemical data reflect these compositional differences (fig. 4). Median dissolved solids concentration for the Trinity aquifer study was 554 milligrams per liter (mg/L); medians for the Edwards unconfined study, the Edwards confined (including springs) study, and the Edwards urban unconfined study were 282, 302, and 328 mg/L, respectively.

In the Trinity aquifer, hydrochemical facies ranged from calcium-magnesium-bicarbonate-chloride-sulfate to calcium-sodium-chloride-sulfate-bicarbonate (fig. 4a). The chemistry of water in the unconfined Edwards aquifer was tightly clustered in the calcium-magnesium-bicarbonate to calcium-magnesium-bicarbonate-chloride-sulfate facies (fig. 4b). Four samples were calcium-sodium-bicarbonate-chloride-sulfate facies. Three of these samples might represent Edwards aquifer waters that have been influenced by lateral leakage of more mineralized waters from the Trinity aquifer. The fourth sample might be influenced by either Trinity aquifer water or Edwards aquifer saline water (fig. 2). Samples from the urban unconfined Edwards aquifer were calcium-magnesium-bicarbonate to calcium-magnesium-

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**Figure 4.** Trilinear diagrams showing water quality is more uniform in the Edwards aquifer than in the Trinity aquifer as indicated by relations between major cations and anions in water samples collected in south-central Texas, 1996–98, from the (a) Trinity aquifer; (b) Edwards aquifer, unconfined; and (c) Edwards aquifer, confined.

bicarbonate-chloride-sulfate facies (fig. 4b). As residence times increase in the aquifer, chemistry of these waters might become more variable as fluid moves along much longer flow paths through the deeper confined Edwards aquifer. Twenty-nine of 30 of the hydrochemical facies for Edwards confined samples (fig. 4c) were the same as Edwards unconfined samples. One sample was classified as calcium-magnesium-chloride-sulfate-bicarbonate facies. This sample might be influenced by Edwards aquifer saline water. Although the sampled springs are widely dispersed in the study area, the hydrochemical facies of the springs is the same as for the confined Edwards aquifer waters (fig. 4c).

Inorganic constituents that exceeded public drinking-water standards or guidelines include dissolved solids, sulfate, fluoride, iron, and strontium (Bush and others, 2000). Nineteen samples from the Trinity aquifer contained dissolved solids concentrations that were greater than the U.S. Environmental Protection Agency (USEPA) secondary maximum contaminant level (SMCL) of 500 mg/L (U.S. Environmental Protection Agency, 2002). Fluoride concentrations in 11 Trinity aquifer samples were greater than the SMCL of 2.0 mg/L but were not greater than the USEPA maximum contaminant level (MCL) of 4.0 mg/L. In contrast, few Edwards aquifer samples contained constituents that exceeded drinking-water standards or guidelines. In the Edwards aquifer confined samples, one dissolved solids concentration was larger than the SMCL and one fluoride concentration was equal to the SMCL. These two samples might contain freshwater that has mixed with more saline water from the deeper parts of the Edwards aquifer. These constituents, for the most part, reflect the chemistry of rock from which the water samples are in contact.

## Trace Elements

Nineteen trace elements were analyzed: aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, silver, selenium, strontium, uranium, and zinc. Most measured concentrations were low. Antimony, beryllium, cadmium, and silver were not detected in any samples. Trace elements that were detected infrequently (five or less times) in each of the studies are: arsenic, cobalt, selenium, and uranium; those detected frequently (more than five times) in all studies are: barium, chromium, nickel, strontium, and zinc. Iron, manganese, and molybdenum were detected more frequently in samples from the Trinity aquifer than in samples from the Edwards aquifer. Copper was detected in all studies except the Edwards confined study. Trace elements detected frequently (more than five times) in all studies except the Edwards urban unconfined study are aluminum, iron, lead, molybdenum, and zinc. The drilled wells in the Edwards urban unconfined study were constructed with PVC casing and contained no dedicated pumps or plumbing. The presence of these trace elements in the studies where existing wells were sampled, and not in the study where new wells were drilled, could indicate that these elements might

be derived all or in part from well construction or plumbing materials. Although some patterns of occurrence of trace elements are evident, additional data would be needed to determine whether sources are natural or anthropogenic.

Some concentrations of iron and strontium exceeded public drinking-water guidelines. Seven Trinity aquifer samples contained iron concentrations greater than the SMCL of 300 micrograms per liter ( $\mu\text{g/L}$ ), and 22 samples contained strontium concentrations larger than the USEPA lifetime health advisory (HA) of 4,000  $\mu\text{g/L}$  (U.S. Environmental Protection Agency, 2002). In contrast, three Edwards confined samples contained strontium concentrations larger than the lifetime HA.

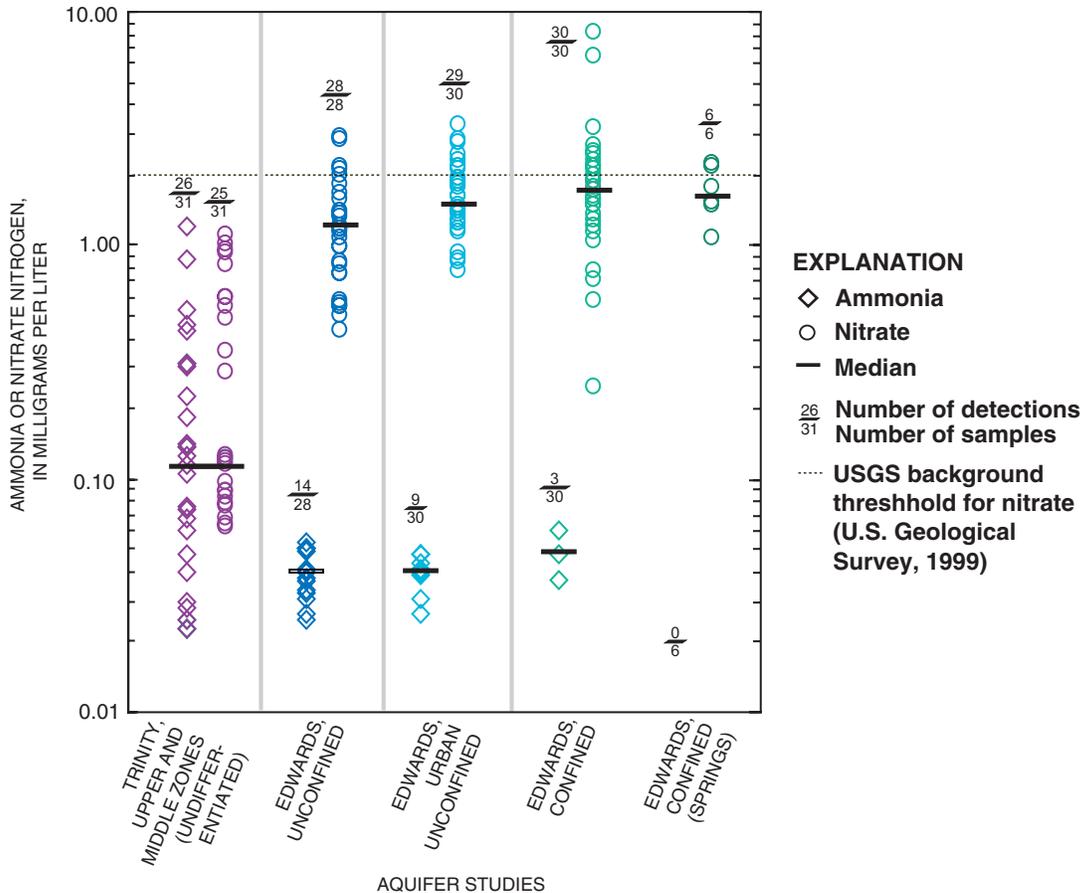
## Nutrients

Differences were observed between ammonia nitrogen and nitrate nitrogen concentrations analyzed from the four studies (fig. 5). Ammonia was detected more frequently in Trinity samples (26 detections), Edwards unconfined samples (14 detections), and Edwards urban unconfined samples (nine detections) than in the Edwards confined samples (three detections). The largest ammonia nitrogen concentrations were in Trinity samples. Possible sources of ammonia are septic waste, fertilizers, livestock, or the reduction of nitrate. For the most part, the Edwards aquifer is well oxygenated, whereas some areas of the Trinity aquifer are not. Small dissolved oxygen concentrations (less than 1 mg/L) were measured at 17 sites in the Trinity aquifer. Only four samples from the Edwards aquifer (two unconfined, two confined) contained dissolved oxygen concentrations less than 1 mg/L.

Nitrate nitrogen concentrations did not exceed the MCL of 10 mg/L (U.S. Environmental Protection Agency, 2002) in any of the studies (fig. 5). Median nitrate concentration was 0.12 mg/L for samples from the Trinity aquifer, 1.14 mg/L for the unconfined Edwards aquifer, 1.46 mg/L for the urban unconfined Edwards aquifer, and 1.73 mg/L for the confined Edwards aquifer. Nitrate concentrations ranged from 0.06 to 1.11 mg/L in samples from the Trinity aquifer and from 0.43 to 2.92 mg/L in samples from the unconfined Edwards aquifer, from 0.78 to 3.26 mg/L in samples from the urban unconfined Edwards aquifer, from 0.25 to 8.23 mg/L in Edwards confined samples, and from 1.08 to 2.22 mg/L in the confined Edwards aquifer springs. All nitrate concentrations in Trinity aquifer samples were less than the USGS-defined background threshold of 2.0 mg/L (U.S. Geological Survey, 1999). Nitrate concentrations were greater than the threshold concentration in four samples collected from the unconfined Edwards aquifer, seven samples from the urban unconfined Edwards aquifer, 10 samples from the confined Edwards aquifer, and two Edwards aquifer springs samples. Samples with nitrate concentrations greater than 2.0 mg/L might contain nitrogen derived from anthropogenic sources (for example human or industrial waste, fertilizer use, or livestock operations).

Nitrogen primarily is in the form of ammonia and nitrate in the Trinity aquifer and in the form of nitrate in the Edwards

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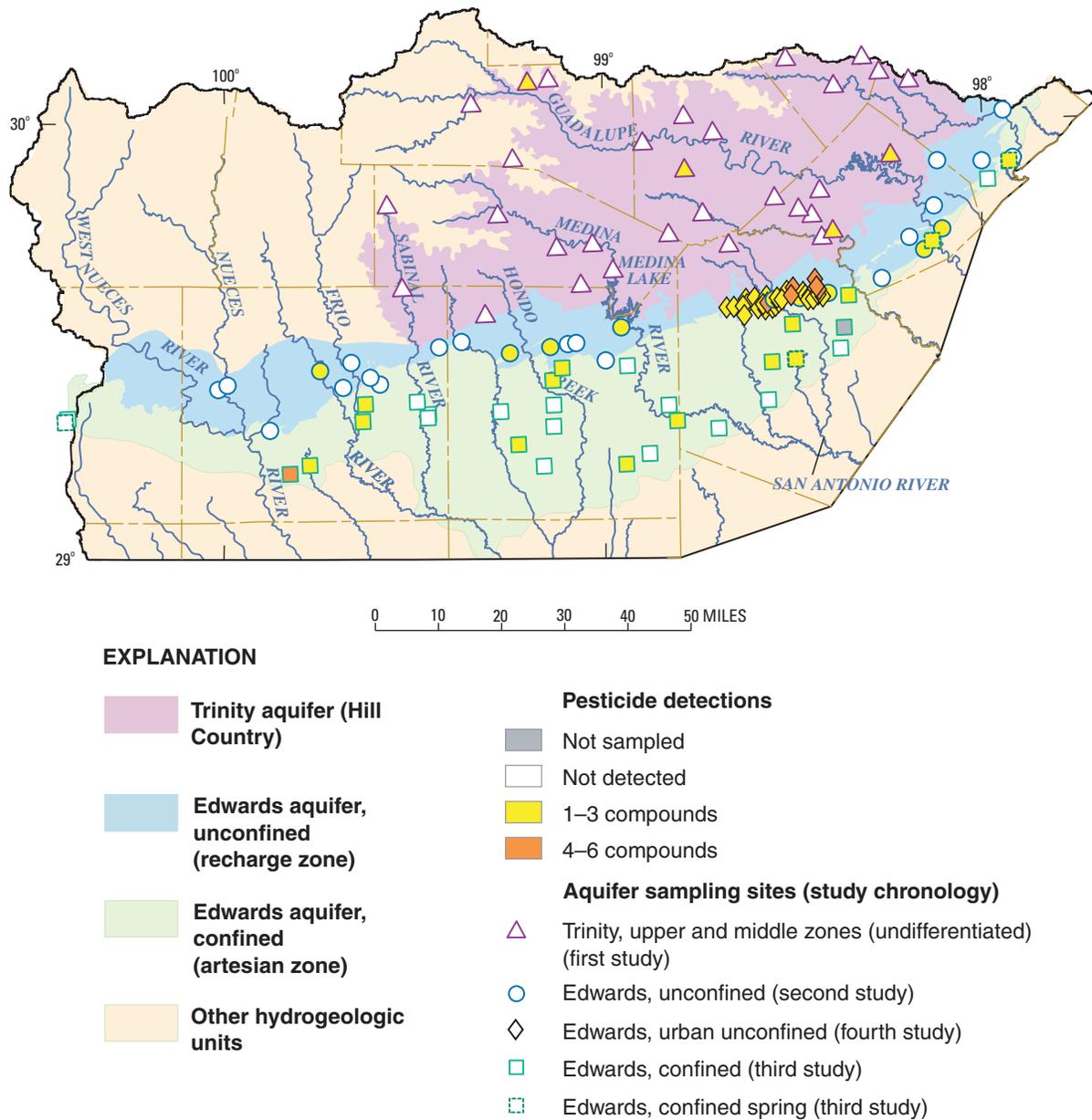
**Figure 5.** Distribution of concentrations of ammonia and nitrate nitrogen in water samples collected from wells completed in the Trinity and Edwards aquifers and Edwards aquifer springs, south-central Texas, 1996–98.

aquifer. More total nitrogen is present in the Edwards aquifer than in the Trinity aquifer. Total measured nitrogen, summed from the species analyzed (sum of ammonia plus organic nitrogen and nitrite plus nitrate nitrogen) varied between studies. Median total nitrogen concentration for samples from the Trinity aquifer was 0.42 mg/L. Medians for the Edwards aquifer studies were more than two times that of the Trinity aquifer. Median total nitrogen concentration for the unconfined Edwards aquifer study was 1.14 mg/L, whereas for the urban unconfined Edwards aquifer study the median was slightly larger at 1.62 mg/L. Median total nitrogen concentration for the confined Edwards aquifer study was 1.73 mg/L.

### Pesticides

Eighty-three pesticide compounds (pesticides and breakdown products; hereinafter called pesticides) from classes of herbicides, insecticides, and fungicides that include triazines, organophosphorus compounds, organochlorines, and carbamates, among others, were analyzed. Pesticides were detected

more frequently in samples from the Edwards aquifer than in samples from the Trinity aquifer. Few pesticides were detected in samples from the Trinity aquifer (fig. 6). However, pesticides were widely measured in samples from the Edwards aquifer, albeit at very small concentrations (less than 0.3  $\mu\text{g/L}$ ). Atrazine and its breakdown product deethylatrazine were the most frequently detected compounds in all of the studies, similar to national observations for USGS major aquifer studies across the Nation (Bush and others, 2000; U.S. Geological Survey, 1999). Atrazine was detected in three samples from the Trinity aquifer, in five samples from the unconfined Edwards aquifer, in 24 samples from the urban unconfined Edwards aquifer, and in 13 samples from the confined Edwards aquifer. Deethylatrazine was detected in five samples from the unconfined Edwards aquifer, in 29 samples from the urban unconfined Edwards aquifer, and in 14 samples from the confined Edwards aquifer. Concentrations of atrazine ranged from 0.0018 to 0.13  $\mu\text{g/L}$  and of deethylatrazine from 0.0023 to 0.033  $\mu\text{g/L}$ . Simazine was detected in six samples from the urban unconfined Edwards aquifer (0.0052 to 0.029  $\mu\text{g/L}$ ) and in one sample from the confined Edwards aquifer (0.023  $\mu\text{g/L}$ ). Diazinon was detected



**Figure 6.** Pesticide detections in water samples collected from wells completed in the Trinity and Edwards aquifers and Edwards aquifer springs, south-central Texas, 1996–98.

once in the Trinity aquifer (0.012 µg/L) and three times in the urban unconfined Edwards aquifer (0.0022 to 0.023 µg/L). Other pesticides detected one to two times during the study period include carbaryl (0.03 µg/L), diuron (0.2 µg/L), metribuzin (0.0044 µg/L), and trifluralin (0.0033 µg/L) (urban unconfined Edwards aquifer) and metolachlor (0.003 and 0.0039 µg/L) (unconfined and confined Edwards aquifer).

In the unconfined Edwards aquifer, three samples contained two pesticides and five samples contained one pesticide. Three samples contained both atrazine and deethylatrazine. In the urban unconfined Edwards aquifer, one sample contained

six pesticide compounds, four samples contained four compounds, four samples contained three compounds, 15 samples contained two compounds, and five samples contained one compound. Many of the samples that contained two compounds contained both atrazine and deethylatrazine. In the confined (including springs) Edwards aquifer, 14 samples contained one or more pesticides. One sample contained four compounds, 12 samples contained two compounds, and one sample contained one compound. Samples that contained more than one compound contained both atrazine and deethylatrazine.

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Detections of both atrazine and deethylatrazine in ground-water samples allow for the computation of the deethylatrazine to atrazine ratio (DAR; units of concentration in moles per liter). The DAR can be used as a qualitative indicator of ground-water age (Adams and Thurman, 1991; Burkart and Kolpin, 1993). Atrazine half-life in soil is about 60 days (Barbash and Resek, 1996), indicating that one-half of atrazine in soil will break down in about that time. Atrazine is converted to deethylatrazine primarily by metabolic activity in the top 3 ft of soils (Adams and Thurman, 1991). Presumably atrazine breaks down more slowly in aquifers because of comparatively little organic carbon or microbial populations in ground water. Although deethylatrazine results from breakdown of atrazine or propazine, it is presumed in these studies that atrazine is the parent compound because propazine was not detected and is not widely applied in the study area. Low DAR (less than 1) indicates that atrazine has not substantially degraded to deethylatrazine at the surface or in the soil or vadose zone, therefore suggesting rapid recharge or recharge that occurred a short distance from an atrazine source. High DAR (greater than 1) indicates slow recharge (long residence time in soil or vadose zone) or recharge that occurred long distances from sources. DARs were calculated for samples that contained atrazine, deethylatrazine, or atrazine and deethylatrazine. In the Trinity aquifer, atrazine only was detected in three samples, resulting in a DAR of zero. Low DAR could indicate that water from these wells were rapidly recharged or were located near atrazine sources. In the unconfined Edwards aquifer, seven samples contained atrazine or deethylatrazine. The DAR for three samples was less than 1. These samples with low DAR probably were from locations near recharge sources or were rapidly recharged. In the urban unconfined Edwards aquifer study, DARs were computed for 29 samples. Fourteen samples had low DARs, possibly indicating that about one-half of the samples were rapidly recharged or near sources of atrazine. DARs were computed for 14 samples in the confined Edwards aquifer. Twelve samples had high DARs possibly indicating that the samples were collected far from recharge sources or that recharge occurred slowly. DARs are mostly consistent; higher DARs are expected from samples collected from the deeper confined system.

The abundance of pesticide detections, even at very small concentrations, in the Edwards aquifer indicates that the Edwards aquifer could be susceptible to contamination from human activities. Although the Trinity aquifer is much less transmissive and samples contained far fewer pesticide detections, it also might be susceptible to contamination as suburbanization continues over the region.

### Volatile Organic Compounds

VOCs have been used for decades and are ubiquitous in the environment; they are used in commercial and industrial processes and are ingredients in products for domestic and personal use. Eighty-eight VOCs from classes of fumigants, fuels and fuel oxygenates, organic synthesis compounds, refrigerants,

solvents, and trihalomethanes (THMs), among others, were analyzed. Most VOCs were measured at small (less than 1  $\mu\text{g/L}$ ) concentrations; however, some were measured at concentrations greater than 1  $\mu\text{g/L}$ . Moran and others (2002) reported that the most commonly detected VOCs in USGS major aquifer studies across the Nation, regardless of well type, are THMs and solvents. THMs include compounds such as trichloromethane (chloroform), bromodichloromethane, chlorodibromomethane, and bromoform. Solvents include compounds such as tetrachloroethylene (PCE) and trichloroethylene (TCE). The most commonly detected compounds in rural domestic wells across the Nation are THMs and solvents, and the most commonly detected compounds in urban areas are solvents, fuel-related compounds, and THMs.

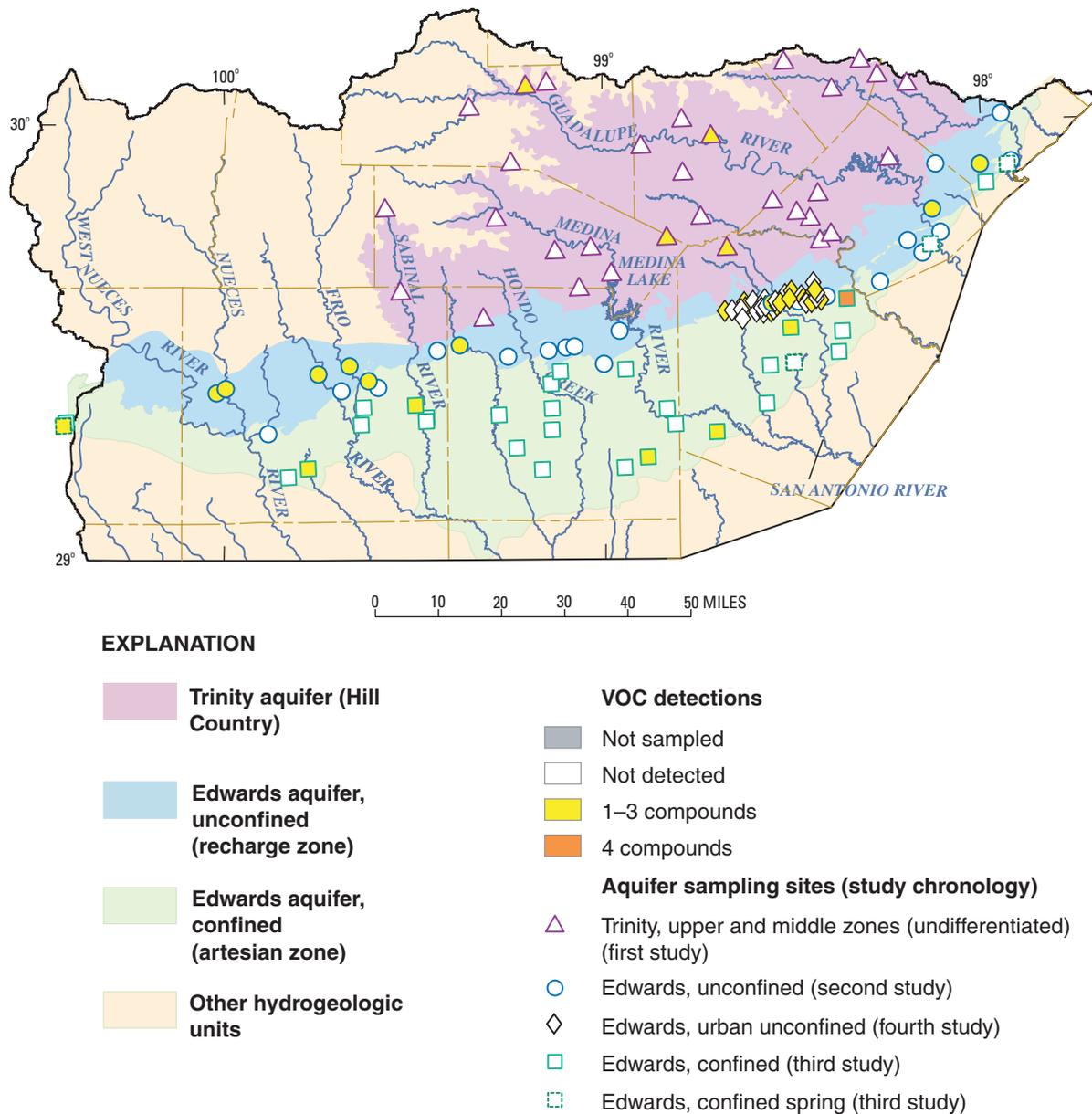
VOCs, including THMs, solvents, fuel-related compounds, and a refrigerant, were detected in samples collected from each of the studies (fig. 7). When more than one VOC was present in a sample, the VOCs usually were related (for example THMs). In most cases, the presence of VOCs in samples might be attributed to activities associated with wells (for example use of downhole pumps that contain hydrocarbons, well disinfection activities, or well construction and plumbing materials). Thus, the presence of VOCs in these ground-water samples does not necessarily indicate widespread occurrence in the aquifers.

Detections of VOCs differed among the studies. In the Trinity aquifer study, VOCs were detected in four samples. Acetone (6.4, 4.6  $\mu\text{g/L}$ ), methylethylketone (12.4, 17.6  $\mu\text{g/L}$ ), and tetrahydrofuran (42.1, 172  $\mu\text{g/L}$ ) were detected twice each. Carbon disulfide (0.27  $\mu\text{g/L}$ ) and toluene (4.4  $\mu\text{g/L}$ ) were detected once each. One sample contained three VOCs, two samples contained two VOCs, and one sample contained one VOC.

VOCs were detected in eight samples from the unconfined Edwards aquifer. THMs detected were chloroform (0.06 to 1.3  $\mu\text{g/L}$ ) in seven samples, bromodichloromethane (0.13  $\mu\text{g/L}$ ) in one sample, and chlorodibromomethane (0.06  $\mu\text{g/L}$ ) in one sample. Tetrahydrofuran (0.6  $\mu\text{g/L}$ ) was detected in one sample. One sample contained three VOCs and seven samples contained one VOC.

In the urban unconfined Edwards aquifer study, 11 samples contained VOCs. Chloroform was detected in 11 samples at concentrations ranging from 0.052 to 0.42  $\mu\text{g/L}$ . Bromodichloromethane (0.118, 0.136  $\mu\text{g/L}$ ) was detected in two samples and chlorodibromomethane (0.13  $\mu\text{g/L}$ ) was detected in one sample. One sample contained three VOCs, all of which were THMs. One sample contained two VOCs (THMs), and nine samples contained one VOC. THMs detected in urban areas are presumed to be derived from treated water used for irrigation or from septic and wastewater lines (Moran and others, 2002).

In the confined (including springs) Edwards aquifer, VOCs were detected in six samples. Bromoform (0.407 to 3.09  $\mu\text{g/L}$ ) and chlorodibromomethane (0.06 to 2.89  $\mu\text{g/L}$ ) were detected three times each. Chloroform (0.353, 0.477  $\mu\text{g/L}$ ) was detected twice. Compounds detected once were bromodichloromethane (1.23  $\mu\text{g/L}$ ), carbon disulfide (0.09  $\mu\text{g/L}$ ),



**Figure 7.** Volatile organic compound detections in water samples collected from wells completed in the Trinity and Edwards aquifers and Edwards aquifer springs, south-central Texas, 1996–98.

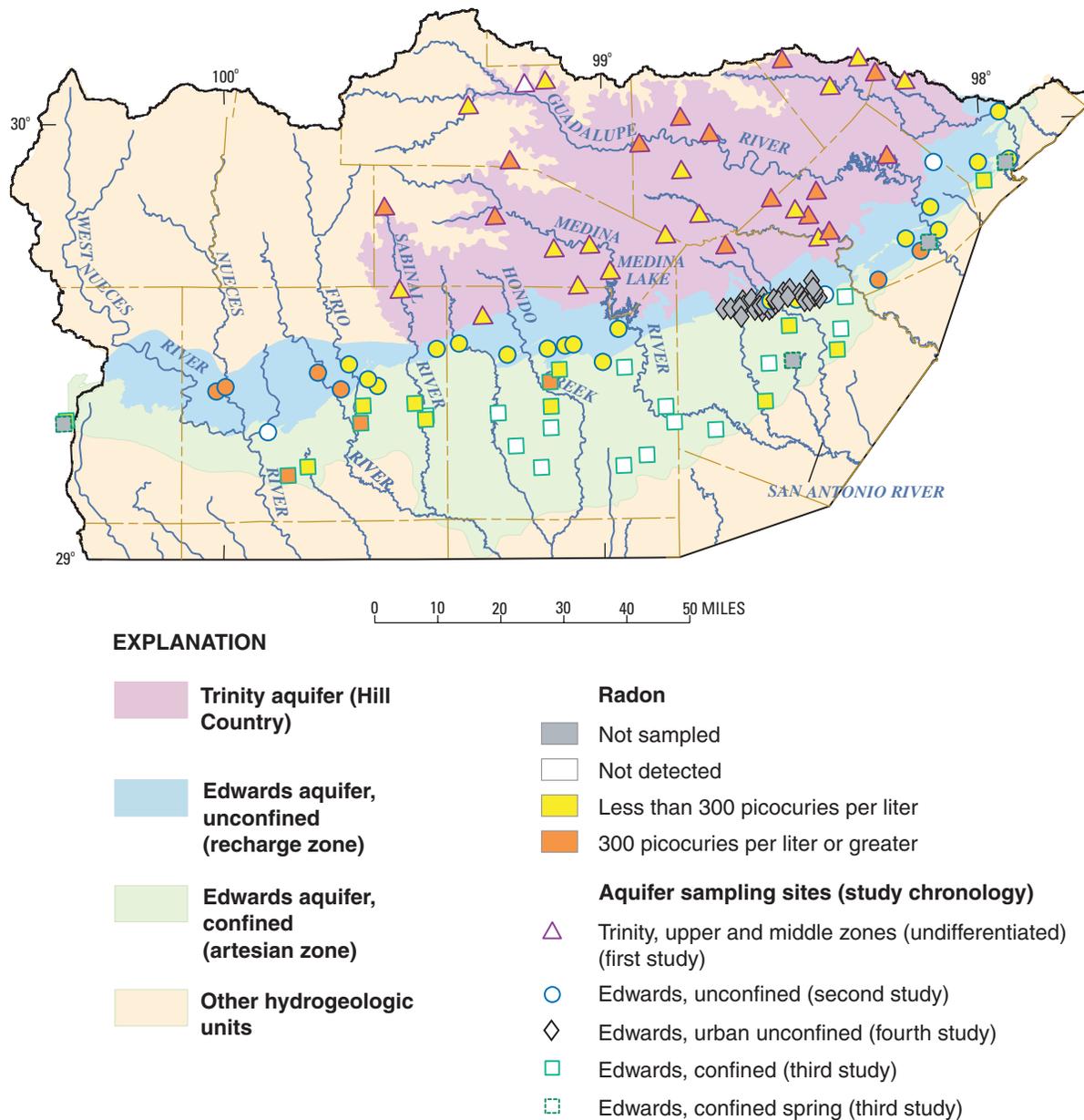
dichlorodifluoromethane (0.3 µg/L), and tetrahydrofuran (1 µg/L). One sample contained four VOCs, two samples contained two VOCs, and four samples contained one VOC.

### Radon

Radon is a radioactive gas produced by the radioactive decay of uranium in rocks. Bush and others (2000) discussed the occurrence of radon in the Trinity and Edwards aquifers relative to proposed USEPA public drinking-water standards. Radon was detected in 30 samples in the Trinity aquifer. Measured concentrations (technically, “radioactivities”) ranged

from 98 to 747 picocuries per liter (pCi/L), with a median of 295 pCi/L. Concentrations in nearly one-half (14) of the samples exceeded a proposed public drinking-water standard of 300 pCi/L for unmitigated public-supply wells (U.S. Environmental Protection Agency, 2003). The widely scattered distribution of wells with concentrations greater than 300 pCi/L is shown in figure 8. Uranium was detected at small concentrations (6 µg/L or less) in six samples in the Trinity aquifer; therefore, the carbonate rocks of the aquifer are not the likely source of radon in the aquifer. Sediments derived from the erosion of older granitic rocks underlie the Trinity aquifer sediments and are a possible source (Bush and others, 2000).

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**Figure 8.** Radon concentrations in water samples collected from wells completed in the Trinity and Edwards aquifers, south-central Texas, 1996–98.

Radon was detected in 25 samples from the unconfined Edwards aquifer and in 16 samples from the confined Edwards aquifer. Radon was not sampled in the urban unconfined Edwards aquifer study or confined Edwards aquifer springs. Concentrations from the unconfined Edwards aquifer samples ranged from 80 to 776 pCi/L, with a median of 156 pCi/L. Six samples exceeded the proposed public drinking-water standard. In the confined Edwards aquifer, concentrations ranged from 88 to 535 pCi/L, with a median of 181 pCi/L. Concentrations of four samples were greater than the proposed drinking-water standard. Uranium was not detected in the Edwards aquifer; therefore, the Edwards aquifer rocks are not the likely source

of radon. Small intrusive igneous stocks are prevalent in exposed Edwards rocks in Uvalde and Medina Counties, and igneous intrusions are known to exist at depths below the Edwards aquifer along a trend that parallels the Balcones fault zone. These igneous rocks might be a source of radon in the Edwards aquifer.

### Tritium

Tritium was analyzed in 119 samples collected in these studies to determine relative age of ground water. Tritium is a

radioactive isotope of hydrogen and exists naturally in the environment in small concentrations; however, concentrations in the atmosphere were increased during above-ground nuclear weapons tests of the 1950s and early 1960s. Since 1964, nuclear tests have been conducted underground and anthropogenic tritium no longer has been added to the atmosphere. Tritium in the atmosphere travels with precipitation that falls on the land surface. Some of this precipitation provides recharge to the Trinity and Edwards aquifers. Anthropogenically increased concentrations of tritium frequently have been used as an indicator of recently recharged ground water, although this application is waning rapidly as the radioactive tritium molecules decay through time (tritium half-life is 12.43 years). For coastal and low-latitude areas at the time of these studies, greater than 20 tritium units (TU) indicate recharge from the 1960s–70s; 10 to 20 TU indicate some fraction of water has been recharged since the 1950s; 2 to 9 TU indicate ground-water age of about less than 5 to 10 years; 0.8 to 2 TU indicate a mixture between old water (older than 1952) and young water (younger than 1952); and less than 0.8 TU indicates old water (Clark and Fritz, 1997).

Tritium previously was analyzed in Edwards aquifer samples (Pearson and others, 1975), but little is known about the occurrence of tritium in the Trinity aquifer. Tritium was detected in 17 of 30 samples collected from the Trinity aquifer. Seven samples (2.5 to 4.7 TU) were determined to have water that was young, six samples (1.2 to 1.9 TU) were determined to have a mixture of young and old water, and four samples (0.3 to 0.5 TU) were determined to have water that was old (fig. 9). Tritium was detected in 28 unconfined Edwards aquifer samples, ranging from 1.2 to 4.6 TU. Six samples indicated a mix between young and old water, and 22 samples indicated young water. In the urban unconfined Edwards aquifer, 26 of 30 wells were sampled for tritium. Tritium in 25 of the samples indicated a substantial fraction of young water (less than 5 to 10 years) and in one sample a mix of young and old water. In the confined Edwards aquifer, tritium was detected in all (30) samples, ranging from 0.3 to 4.0 TU. Twenty-six samples contained a substantial young fraction of water, three samples indicated a mix of old and young water, and one sample indicated water older than 1952. The five spring samples that were measured for tritium indicated substantial fractions of young water.

## Stable Isotopes

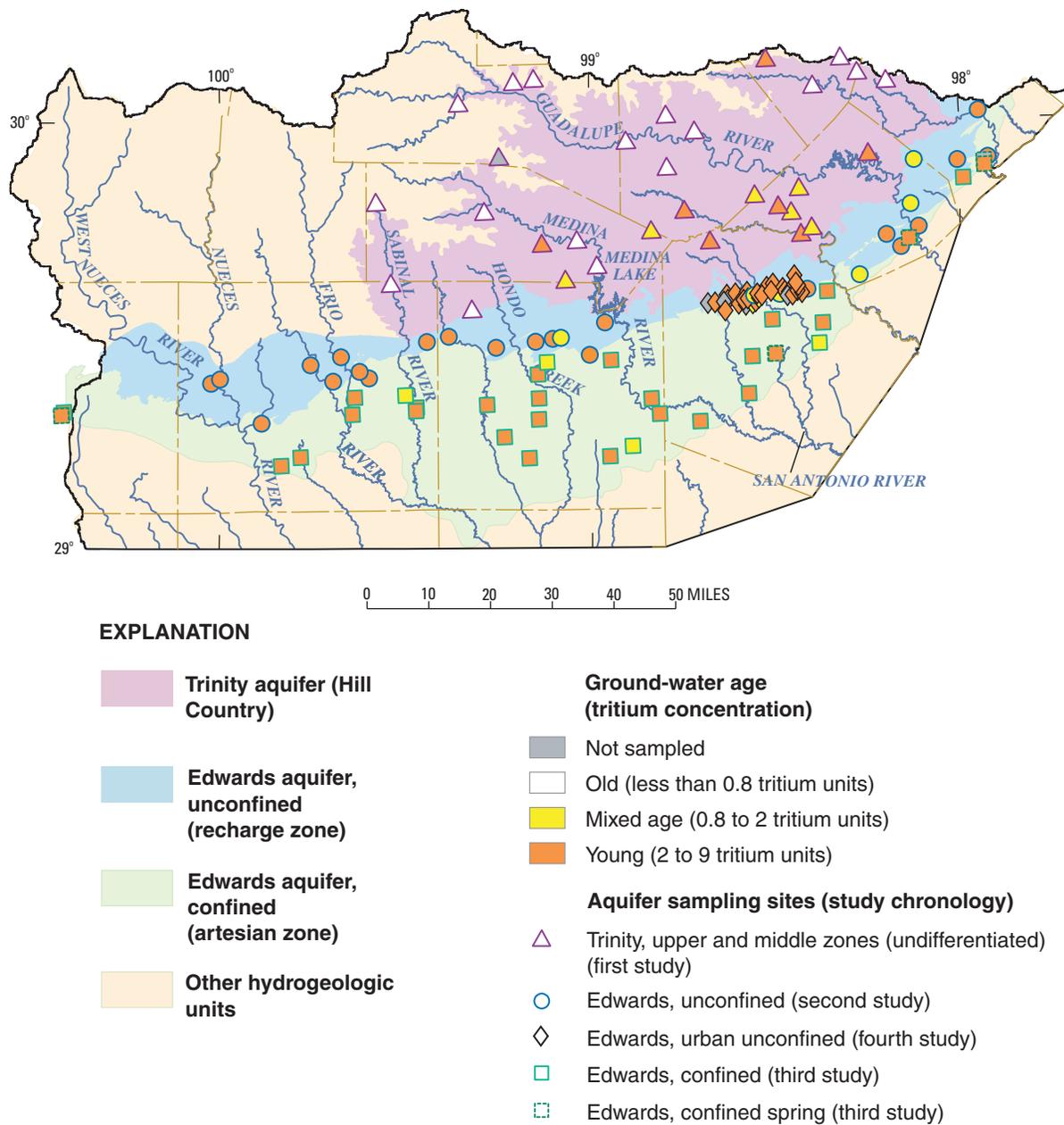
The consistent proportionality between deuterium and oxygen-18 in meteoric waters, defined by the best-fit line ( $\delta D = 8 \delta^{18}O + 10$ ) and commonly known as the Global Meteoric Water Line (GMWL; Craig, 1961), is the basis for many hydrologic applications (International Atomic Energy Agency, 2003). Oxygen and hydrogen isotopes of water can be used to assess sources and processes of recharge to ground water, thus enhancing knowledge of processes that might affect water quality. Assuming no thermal effects, evaporation and mixing are the two dominant processes that affect the stable

isotopic composition of ground water (Clark and Fritz, 1997). Figure 10 shows the relation of the ratio of deuterium to protium ( $\delta D$ , in per mil) to the ratio of oxygen-18 to oxygen-16 ( $\delta^{18}O$ , in per mil) in ground-water samples from these studies, relative to Vienna Standard Mean Ocean Water (VSMOW) isotopic standard (Baertschi, 1976; Hagemann and others, 1970). Additional isotopic data collected for other studies in the region are presented for discussion.

In figure 10, most ground-water isotopic data plot along the GMWL, illustrating that much of the water being sampled has a meteorological signature that indicates recharge entered the aquifer as direct infiltration without undergoing extensive evaporation; that is, water entered the ground-water system without much residence time on the land surface. The urban unconfined Edwards aquifer data follow the trend of the GMWL, but are shifted to the left of that trend. These data, collected from the karstic Edwards aquifer outcrop region about a month after a very large storm in the region, show a signature of that precipitation event. The urban unconfined Edwards aquifer data, in conjunction with isotopic data from grab and composite rainfall samples collected from other studies in the region, were used to compute a probable Local Meteoric Water Line (LMWL) for the study area. A few of the rainfall samples plot to the left of the LMWL and GMWL. Analytical problems probably affected these deuterium analyses and are the cause of observed shifts away from the trend lines; therefore, one of the points was not used in the determination of the LMWL. Some surface-water isotopic data from other studies were available for the study area and are presented for further understanding of recharge processes. Composite data are shown for Medina Lake (30 samples) and for streams (31 samples) in the vicinity of Medina Lake. Isotopic data from Medina Lake and area streams illustrate a characteristic trend to the right of the GMWL because of evaporative processes (Lambert and others, 2000). This shift can be used to define a local evaporation trend. A composite for a small number of samples (fig. 10, south-central surface-water composite) collected from streams (13 samples) throughout the study area also is shown. This composite does not illustrate the evaporation trend seen in the Medina Lake area surface water. For the most part, these regional surface-water samples were collected on the declining limb of storm hydrographs, indicating that samples had not undergone substantial evaporation at the time of collection. Some of the samples collected from the unconfined Edwards aquifer study plot along the evaporation trend for Medina Lake, indicating that samples underwent evaporation before becoming ground water. For the most part, these samples were collected from wells that were in proximity to streams that lose their base flow to recharge of the Edwards aquifer. Under the extended low-flow conditions (months-long drought) that occurred at the time of sampling, streams in proximity to these wells were the likely sources of water to these wells. However, under different hydrologic conditions, such as a wet or flood period, sources of recharge to the wells might be different.

Data from the Trinity aquifer samples plot along the GMWL. If the LMWL more closely approximates a local

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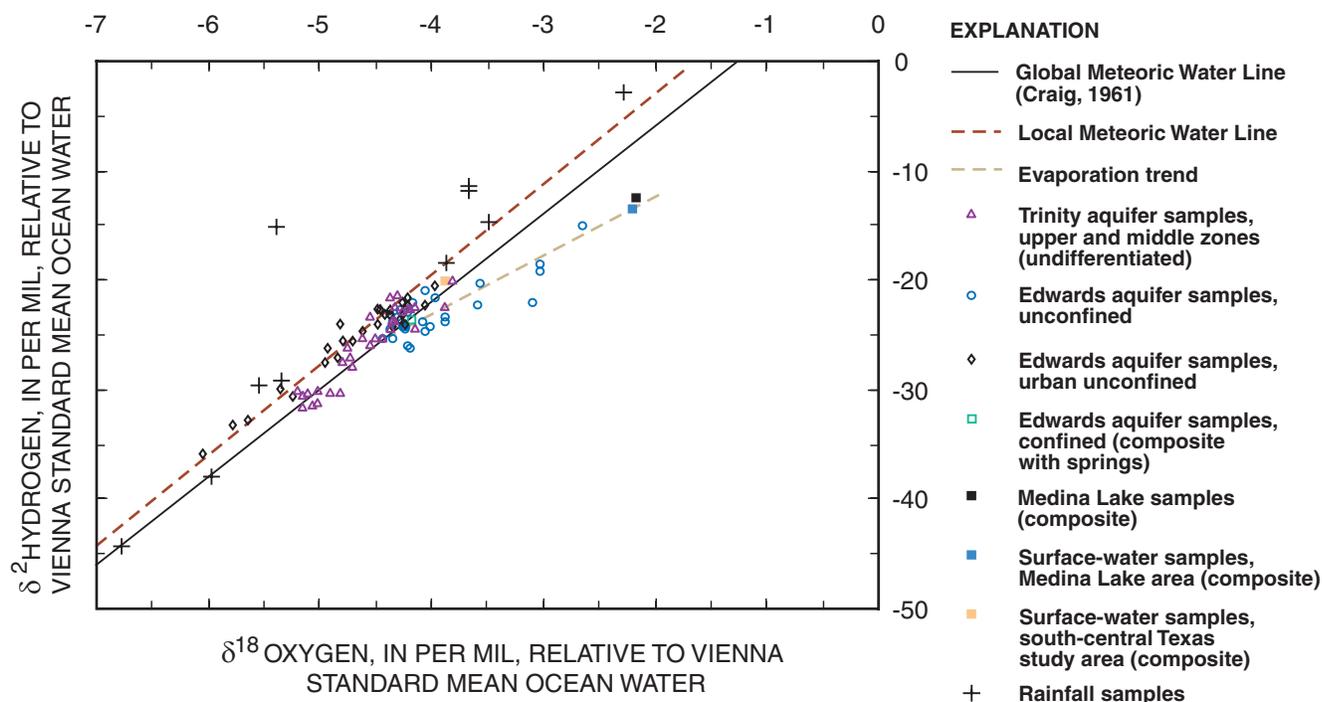


**Figure 9.** Tritium concentrations and estimated ground-water ages of water samples collected from wells completed in the Trinity and Edwards aquifers and Edwards aquifer springs, south-central Texas, 1996–98.

rainfall trend, then the Trinity aquifer data are shifted to the right toward the GMWL. Slight shifts have been observed for low-temperature ground water in extensive contact with evaporites such as gypsum (Vuataz and Goff, 1986). Gypsum is present in parts of the Trinity aquifer, and low-temperature water-rock interaction with this mineral might explain the observed shifts. Most of the data for the Trinity aquifer samples plot at the isotopically lighter (more negative) end of the GMWL. Isotopically lighter values might be caused by recharge that occurred at higher elevations or by recharge that occurred at more landward locations from coastal sources of

precipitation. Ranges of values for Trinity aquifer samples are consistent with ground-water samples derived from inland and elevated (altitude) precipitation. The presence of tritium or pesticides in almost one-half of the Trinity aquifer samples indicates that older glacial waters, which also are isotopically lighter than modern waters, probably are not a source of Trinity aquifer water.

Isotopic data from the urban unconfined Edwards aquifer study also plot toward the isotopically lighter end of the LMWL. Lawrence (1997) reported a mean  $\delta^{18}\text{O}$  value for normal summer rainfall as -2.9 per mil and an isotopically lighter



**Figure 10.** Relation between hydrogen and oxygen isotopes in water samples from wells completed in the Trinity and Edwards aquifers and Edwards aquifer springs, south-central Texas, 1996–98.

mean value of -9.4 per mil for cyclonic storms along the Texas Gulf Coast. Large tropical storms, such as that of October 1998, might explain the isotopically lighter values for the urban unconfined Edwards aquifer samples compared with the Edwards aquifer confined and unconfined samples.

Nearly all confined (including springs) Edwards aquifer data cluster tightly around the GMWL and are plotted as a composite (34 samples). These data, along with major-ion chemistry and tritium, indicate that the confined Edwards aquifer waters are chemically and isotopically homogeneous. Local effects from evaporation, mixing, or seasonal precipitation, such as those observed in the unconfined Edwards aquifer study, become masked by the overwhelming homogeneous nature of water in the large confined aquifer.

## Summary

In addition to water-quantity issues, ground-water quality is becoming an increasingly important issue as rapid growth occurs in south-central Texas. Population growth has increased the consumption of water resources as well as human activities that can affect water quality. As part of its National Water-Quality Assessment (NAWQA) Program, the U.S. Geological Survey (USGS) studied surface- and ground-water quality in the upper part of the South-Central Texas NAWQA study unit during 1996–98. This report provides supplemental information

about the ground-water quality of the upper and middle zones (undifferentiated) of the Trinity aquifer in the Hill Country and the unconfined part (recharge zone) and confined part (artesian zone) of the Edwards aquifer in the Balcones fault zone of the San Antonio region. The supplemental information was compiled from four ground-water-quality studies done during 1996–98.

The natural process of water interacting with surrounding rocks contributes to observed major-ion and trace element chemistry in the Trinity and Edwards aquifers. Trinity aquifer water is more mineralized and contains larger dissolved solids, sulfate, and chloride concentrations compared to Edwards aquifer water. Greater variability in water chemistry is observed in the Trinity aquifer, which likely reflects the more variable lithology of the host rock.

Although trace elements were widely detected and mostly at small concentrations, more data would be needed to determine whether occurrences and distributions are related to natural factors or anthropogenic activities. Strontium and iron concentrations in some samples exceeded U.S. Environmental Protection Agency (USEPA) drinking-water standards.

Median total nitrogen concentration is larger in samples from the Edwards aquifer than in samples from the Trinity aquifer. Ammonia nitrogen was detected more frequently and at larger concentrations in the Trinity aquifer than in the Edwards aquifer. Nitrate nitrogen concentrations greater than the USGS-defined background threshold of 2.0 mg/L, which indicates possible anthropogenic effects on water quality, were measured in

samples from the Edwards aquifer but not in samples from the Trinity aquifer. Nitrate concentrations did not exceed the USEPA public drinking-water standard of 10 mg/L.

Synthetic organic compounds, such as pesticides and VOCs, were detected in samples from the Trinity and Edwards aquifers but were mostly at very small concentrations (less than 1 µg/L). Although organic compounds were detected in the Trinity aquifer, the frequency of occurrence was less than in the Edwards aquifer. The most frequent detections of organic compounds were in the urban unconfined Edwards aquifer samples. Atrazine and its breakdown product deethylatrazine were the most frequently detected pesticides, and THMs were the most frequently detected VOCs. Widespread detections of these compounds, albeit at small concentrations, indicate that anthropogenic activities affect ground-water quality.

Radon gas was detected throughout the Trinity aquifer and in much of the Edwards aquifer. Fourteen samples from the Trinity aquifer and 10 samples from the Edwards aquifer exceeded a proposed USEPA public drinking-water standard of 300 pCi/L. Granitic sediments underlying the Trinity aquifer and igneous intrusions in and below the Edwards aquifer might be sources of radon in the study area.

The presence of tritium in nearly all Edwards aquifer samples indicates that some component of sampled water is young (less than about 50 years), even for long flow paths in the confined zone of the Edwards aquifer. About one-half of the Trinity aquifer samples contained tritium, indicating that only part of the aquifer studied contains young water.

Hydrogen and oxygen isotopes of water provide indicators of recharge sources to the Trinity and Edwards aquifers. Most ground-water samples have a meteorological isotopic signature indicating recharge occurred as direct infiltration of water that had little residence time on the land surface. Some samples collected from the unconfined Edwards aquifer have an isotopic signature indicating that the water has undergone evaporation. At the time that ground-water samples were collected for the study (during a drought), nearby streams were the likely sources of recharge to these wells. However, sources of recharge to the wells might be different under different hydrologic conditions.

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