RELATION OF WATER CHEMISTRY OF THE EDWARDS AQUIFER TO HYDROGEOLOGY AND LAND USE, SAN ANTONIO REGION, TEXAS

By Paul M. Buszka

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4116

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Austin, Texas
1987

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

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CONTENTS

Page

ILLUSTRATIONS

TABLES

METRIC CONVERSIONS

Factors for converting inch-pound units to metric (International System) units are given in the following table:

Multiply inch-pound unit	By	To obtain metric units
acre	0.4047	hectare
degree Fahrenheit (°F)	5/9 (°F-32)	degree Celsius (°C)
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon (gal)	3.785	liter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

Water-chemistry data from the Edwards aquifer for 1976-85, consisting of nearly 1,500 chemical analyses from 280 wells and 3 springs, were used to statistically evaluate relations among ground-water chemistry, hydrogeology, and land use. Five land uses associated with sampled wells were classified on the basis of published information and field surveys. Four major subareas of the aquifer were defined to reflect the relative susceptibility of ground water to contamination originating from human activities using hydrogeologic and tritium data.

Water from an agricultural area over the unconfined zone of the aquifer had the largest median concentration of nitrite plus nitrate. Large nitrite plus nitrate concentrations were spatially associated with large tritium concentrations and nitrogen isotopic ratios characteristic of streamflow recharge. Detections of fecal-coliform bacteria were associated mainly with water from wells completed in the unconfined zone.

Most of the occurrences of tetrachloroethylene, 1,2-(trans)-dichloroethylene, trichlorofluoromethane, 1,1,1-trichloroethane, and 2,4-D in ground water were associated with wells completed in the unconfined zone of the aquifer. Fatty acids detected in water from some wells may commonly be present naturally in ground water.

The percentage of samples in which arsenic, barium, lead, and zinc were detected was similar among subareas; the samples were from the freshwater parts of the aquifer. Large lead and zinc concentrations were associated with volumes of pumpage less than 1,000 gallons.

In general, the quality of ground water in the freshwater parts of the aquifer (north of the "bad-water" line) is suitable for all uses including human consumption. Two areas that are exceptions are: (1) Northeast of Garner Field in Uvalde, Texas, where PCE (tetrachloroethylene) has been detected in ground-water samples, and (2) north-central Bexar County near the former West Avenue landfill where PCE and benzene have been detected in ground-water samples. Concentrations of these organic compounds in water from many wells in the two areas exceed the maximum contaminant level for human consumption set by the U.S. Environmental Protection Agency.

INTRODUCTION

The Edwards aquifer in the San Antonio region, which has been designated by the U.S. Environmental Protection Agency as a sole-source aquifer, supplies drinking water for more than a million residents within most of a six-county region, which includes Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties, in south-central Texas (fig. 1). The aquifer consists of a permeable, dissolution-modified limestone. The quality of water in the aquifer historically has been suitable for all uses.

Carbonate aquifers such as the Edwards are readily susceptible to ground-water contamination where the presence of pollutants coincides with the outcrop of the aquifer. The secondary, dissolution-modified permeability provides a direct conduit for contaminants to enter the aquifer. The rates of ground-water flow are so rapid and volumes of water moving through the aquifer are so great relative to clastic aquifers that processes such as mineral precipitation, biodegradation, or reversible/irreversible ion sorption are not as important in the analysis of contaminant transport as in clastic aquifers. Reeves (1976) noted a greater frequency of occurrences of fecal-coliform and fecal-streptococci bacteria, greater numbers of total-coliform bacteria, and larger concentrations of total nitrite plus nitrate and total phosphorus in water from many wells completed in and springs issuing from the unconfined zone of the Edwards aquifer as compared to water from the confined zone.

Water chemistry in the Edwards aquifer has been monitored periodically for several inorganic constituents and physical properties since the 1930's. Data for trace elements and pesticides have been reported since 1968 and for volatile organic compounds since 1982 (Reeves and Ozuna, 1985). Many of the constituents detected in water from the Edwards have been characterized by the U.S. Environmental Protection Agency (1977, 1982, 1984) as potentially harmful to human health if present in sufficient concentrations and if the water is consumed regularly.

The distribution of population over the Edwards aquifer and accompanying development of the land surface have created a variety of land uses: urban lands in and around San Antonio and smaller cities to the east and west, irrigated and dry-farmed cropland located mainly west of San Antonio, and scrub forest and rangeland typical of the northern parts of the study area. Residential and commercial development around San Antonio has progressed northward into areas that overlie either the Edwards aquifer or formations that may be hydraulically connected with the aquifer. Local planning efforts need to consider the effect of hydrogeology and land use on the chemistry of water in the aquifer system to best avoid future problems with water quality.

Purpose and Scope

The purpose of the study leading to this report was to assess the chemistry of water within the Edwards aquifer in the San Antonio region, relative to selected inorganic and organic elements and compounds, bacteria, and physical properties that may indicate present (1984-85) or potential contamination. This report presents: (1) The hydrogeologic characteristics and land-use practices that can affect ground-water chemistry; (2) the general inorganic and organic chemical character of ground water with emphasis on trace elements, pes-

page 5 follows

ticides, and volatile organic compounds; (3) the relation between ground-water flow, land use, and water chemistry; and (4) a brief description of the areas where ground-water contamination has occurred or may occur.

The scope of this report generally is limited to the freshwater part of the Edwards aquifer. The freshwater part is defined locally as that part of the aquifer where the dissolved-solids concentration of ground water is less than 1,000 mg/L (milligrams per liter). The salinewater part of the aquifer is insignificant as a source of water for human consumption. In addition, the relation between land use and water chemistry was examined only for those parts of the aquifer that are hydraulically unconfined either part or all of the time or that had relatively enriched concentrations of tritium in ground water. This latter limitation acknowledges the decreased potential effect of surficial land uses on ground-water chemistry as the thickness of confining strata and distance from recharge sources increases.

The water-chemistry assessment of the Edwards aquifer in the San Antonio region is 1 of 14 similar projects being conducted by the U.S. Geological Survey throughout the Nation. Each assessment will investigate the potential relation between land use and ground-water chemistry in a particular geographic and hydrogeologic environment that is representative of other areas in the Nation.

Description of the Study Area

The Edwards aquifer in the San Antonio region is located in the south-central and southwestern part of Texas (fig. 1). The freshwater part of the aquifer is bounded on the east by surface-water and ground-water divides in Hays County near Kyle and on the west in Kinney County near Brackettville. The northernmost outcrop of the Edwards Group (Rose, 1972) or the northern boundaries of Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties, define the northern limits of the study area. The southern boundaries of Kinney, Uvalde, and Medina Counties, the southeastern boundary of Bexar County, and a line across northern Guadalupe and Caldwell Counties define the southern boundary of the project area. These boundaries define a region about 180 mi long that varies in width from about 5 to 30 mi. The total project area is about 3,200 mi^2. About 2,000 mi^2 of the freshwater part of the aquifer are within the confined zone. The study area encompasses most of the six counties along the main body of the aquifer and parts of the two counties to the south and southeast.

The areal climate is characterized by hot summers and cool winters. The mean annual temperature is about 70 °F. Mean annual precipitation generally increases from west to east across the study area, from about 21 in. for Kinney County to about 34 in. for Hays County (Reeves and Ozuna, 1985).

Methods of Investigation

Water-chemistry data consisting of laboratory analyses of ground-water samples were compiled both from the historical Geological Survey WATSTORE database and supplemented by analyses from an additional 53 wells and 3 springs sampled during 1984 and 1985. Four major subareas were classified according to the relative susceptibility of the aquifer to contamination from surficial sources. These classifications were made by using tritium data from Pearson and others (1975) and hydrogeologic data from Maclay, Small, and Rettman (1980), and Maclay and Small (1984). Land-use data derived from a Texas Department of Water Resources (1978) study and onsite surveys by Geological Survey personnel were used to classify the major land use associated with each well. Nonparametric-statistical procedures were used to test whether land use and subarea were correlated with the distribution of selected chemical and bacteriologic constituents. The distribution of data is displayed either in tables of statistics, spatially on maps, or as boxplots. Statistical information shown on the boxplots is given as follows: Median - center bar in box; 25th and 75th percentiles - lower and upper ends of box, respectively; outliers - vertical lines on top and bottom of box extend to extreme values not designated as outliers with individual outliers shown as "x" or "0", depending on their distance from the box (Kleiner and Graedel, 1980); and the number of wells represented by each box in parentheses.

Water-Chemistry Database

Nearly 1,500 water chemistry analyses from about 280 wells and 3 springs were retrieved from the Geological Survey WATSTORE database for January 1, 1976, to March 1, 1985. These wells and springs are located principally in Uvalde, Medina, Bexar, Comal, and Hays Counties (fig. 2). They were selected for use in this study because of their verified production from the Edwards aquifer. The wells are used for public supply, irrigation, livestock, and domestic purposes. The Geological Survey sampled the wells and springs and performed the laboratory analyses. The distribution of documented well-casing depths with respect to subareas and land-use groups used in this study is shown in figure 3. These groups are defined in the following section. To supplement the limited number of organic-compound analyses available in the WATSTORE database, water samples from 53 wells and 3 springs were collected and analyzed for organic compounds during 1984. Water samples from most of the 56 locations also were analyzed for concentrations of selected major and trace elements, and nutrients. Pesticide analyses from 55 wells and 3 springs collected between 1976 and 1985 also were included in the analysis.

Available water-chemistry data from the Texas Water Development Board (previously Texas Department of Water Resources), the Texas Department of Health, the U.S. Environmental Protection Agency, and the U.S. Department of Energy, and pre-1976 data from the Geological Survey were reviewed but were not used. Data from the Texas Water Development Board generally lacked trace-element or pesticide analyses. Most of the analyses available through the Texas Department of Health were sampled from a public water-supply system at locations other than the wellhead. U.S. Department of Energy analyses of radionuclides (uranium and radium isotopes) were not included because the sample-collection technique was insufficiently documented. The STORET database from the U.S. Environmental Protection Agency for the Edwards aquifer generally was a duplication of the WATSTORE database and, therefore, was not used. Pre-1976 Geological Survey data were not included in this analysis because of the lack of compiled information on regional land use prior to that date.

page 9 follows

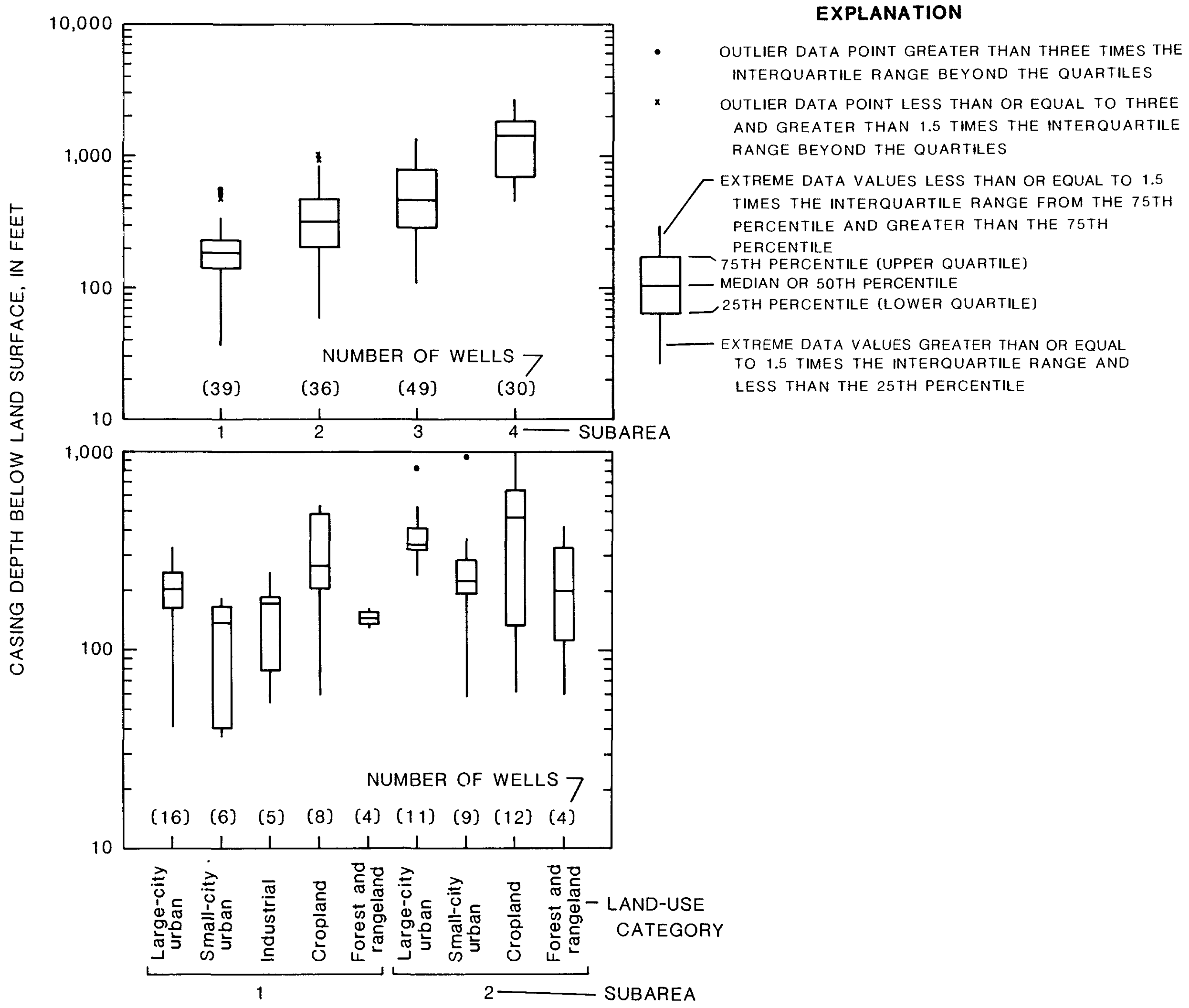


Figure 3.--Boxplots showing well-casing depths with respect to subarea for sampled wells and with respect to subareas and land use for sampled wells in subareas 1 and 2, 1976-85.

Data Analysis

The hypothesis used for study design is that the contamination of shallow ground water by human activities can be considered a function of land use, as modified by hydrogeologic conditions (Helsel and Ragone, 1984). Potential correlations between water-chemistry data, hydrogeology, and land-use data were examined statistically using nonparametric-statistical procedures. Few detailed data are available regarding which geologic members in formations of the Edwards Group (Rose, 1972) that comprise the Edwards aquifer are sampled at the wells and springs shown in figure 2. Therefore, this report describes chemical variations in ground water in two dimensions, rather than in three dimensions, during 1977 to 1985.

Nonparametric-statistical procedures used in this study were: (1) Comparisons of the ranks of data, from lowest to highest, between groups using the Kruskal-Wallis test (Bhattacharyya and Johnson, 1977) and the Tukey's HSD (honest significant difference) test (SAS Institute, Inc., 1982), and (2) contingency-table analysis that compared the frequency of occurrence of certain data values between groups. Helsel and Ragone (1984) discuss the relative merits and problems of this approach, given the types of data being examined. The statistical procedures are used to quantify the relative probability that significant differences exist among water-chemistry data grouped in different subareas or land uses. The significance level, or "alpha," of each test was selected to be 0.05 for all significance tests in this report, unless specified in the text. This significance level indicates that as many as 5 percent of all comparisons may falsely detect significant differences between groups of data.

The computer program Statistical Analysis System[1/] (SAS Institute, Inc.) was used for statistical analyses. Saturation indices were computed for water-chemistry data from this study and from analyses reported by Pearson and Rettman (1976) using WATEQ2F (J.W. Ball and D.K. Nordstrom, U.S. Geological Survey, and D.W. Zachman, Technische Braunschweig Universitaet, Braunschweig, Federal Republic of Germany, written commun., 1985), a Fortran 77 version of WATEQ2 (Ball and others, 1979).

Well-Numbering System

The well-numbering system in Texas was developed by the Texas Water Development Board for use throughout the State. Under this system, each 1-degree quadrangle is given a number consisting of two digits. These are the first two digits in the well number. Each 1-degree quadrangle is divided into sixty-four 7-1/2-minute quadrangles, which are given two-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7-1/2-minute quadrangle is divided into nine 2-1/2-minute quadrangles, which are given a single-digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2-1/2-minute quadrangle is given a two-digit number in the order in which it was inventoried, starting with 01. These are the last two digits of the well number.

[1/] Use of brand and firm trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

In addition to the seven-digit well number, a two-letter prefix is used to identify the county. The prefix for each county in the San Antonio region is as follows: AY, Bexar; DX, Comal; LR, Hays; TD, Medina; and YP, Uvalde. Each water-level observation well also is identified by a 15-digit number based on latitude and longitude and by a local number that is provided for continuity with older reports. The first 6 digits of the 15-digit number are degrees, minutes, and seconds of north latitude; the next 7 digits are degrees (including a leading 0 for those less than 100), minutes, and seconds of west longitude; and the final 2 digits are sequential numbers assigned in the order in which the wells are established in that 1-second quadrangle.

Acknowledgment

I wish to acknowledge the efforts of Paul L. Rettman, U.S. Geological Survey, San Antonio. He provided valuable assistance and advice during the sampling phase.

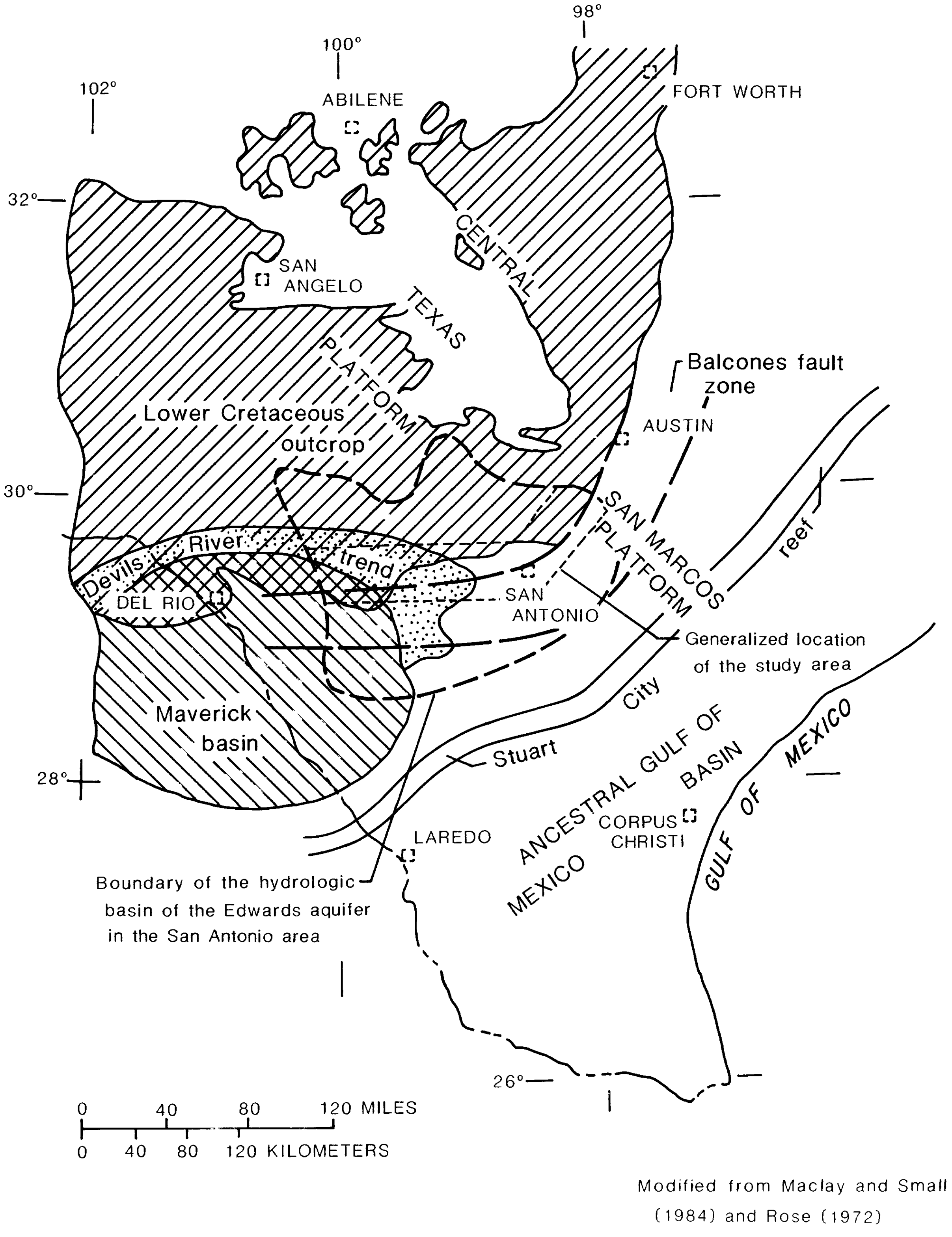
HYDROGEOLOGY OF THE EDWARDS AQUIFER

The Edwards aquifer consists of the Edwards Group of Rose (1972) and equivalent rocks or the Edwards Limestone and associated limestones of Cretaceous age (table 1, fig. 4). In the San Antonio region, the northern one-third of the Edwards aquifer is hydraulically unconfined and the southern two-thirds is confined by overlying strata. Within the unconfined zone (fig. 5), aquifer strata are either exposed or buried under several feet of moderately permeable to permeable alluvium.

The lateral boundaries of the confined zone of the aquifer, as used in this report, are: (1) The intersection of the July 1974 water level with the estimated base of the upper confining unit of the aquifer (the Del Rio Clay) on the north; (2) the ground-water divides on the east near Kyle and on the west near Brackettville; and (3) the "bad-water" line on the south. Salinewater or "bad water," for the purpose of this report, refers to ground water that has more than 1,000 mg/L dissolved solids. Lateral shifts in the northern boundary of the confined zone (fig. 5) may occur at some places within a band of several miles if water levels are substantially changed. The July 1974 water level represents a relatively high water level within the aquifer. Small or no shifts in these boundaries occur along faults with a large vertical displacement.

Rocks in the salinewater part of the aquifer generally are less transmissive than those of the freshwater part. Ground-water exchanges across the "bad-water" line and physical movement of the salinewater-freshwater interface are thought to be minor in volume because of the minimal differences between hydraulic head across the interface (Perez, 1986).

The upper, confining unit of the Edwards aquifer is the Del Rio Clay. This formation is predominantly a blue clay with a few thin beds of limestone and sand lenses. The Del Rio Clay conformably overlies the aquifer throughout the confined zone, ranging in thickness from about 30 ft in Hays County to about 120 ft in Uvalde County. The Del Rio Clay usually is considered to be almost impermeable. The lower confining unit of the aquifer is the upper part of the Glen Rose Formation. This unit generally has little permeability and is not



Modified from Maclay and Small (1984) and Rose (1972)

Figure 4.--Depositional provinces of the Edwards Limestone and equivalent rocks.

page 15 follows

Table 1.--Summary of the lithology and water-yielding characteristics of the hydrogeologic units for each of the three depositional provinces within the study area 1/

[Function: Aq, aquifer; Cu, confining unit]

MAVERICK BASIN

System	Provincial series	Group	Formation	Function	Member or informal unit	Function	Thickness (feet)	Lithology	Water-yielding characteristics and hydrostratigraphy
Quaternary and Tertiary			Alluvial fan and fluviatile terrace deposits			Aq where saturated	6-80	Gravel, sand, silt, and clay. Coarser nearer the base and toward the Balcones fault zone.	Alluvial fans extending from the Balcones fault zone. Associated fluviatile deposits. Permeable.
Cretaceous	Gulfian		Anacacho Limestone	Cu			500	Limestone and marl; contains bentonite, chalky, and massive bedded.	Little permeability.
		Austin	Undivided	Cu			600	Chalk and marl; chalk mostly microgranular calcite with bentonite seams, glauconitic.	Little to moderate permeability.
			Igneous rocks					Basalt.	Intrusive sills, lacoliths, and volcanic necks. Negligible permeability.
		Eagle Ford	Undivided	Cu			250	Shale, siltstone, and limestone; flaggy limestone beds are interbedded with carbonaceous shale.	Little permeability.
	Comanchean	Washita	Buda Limestone	Cu			100	Limestone; fine grained, bioclastic, glauconitic, hard, massive, nodular, argillaceous toward top.	Little permeability.
			Del Rio Clay	Cu			120	Clay and shale; calcareous and gypsiferous, some thin beds of siltstone.	Negligible permeability.
			Salmon Peak Formation 2/ (Edwards aquifer)	Aq			380	Limestone; upper 80 feet contains reef talus grainstone and caprinid boundstone, crossbedding of grainstone; the lower 300 feet is a uniform dense carbonate mudstone.	Deep water deposits except toward the top. Upper part is moderately permeable to permeable. Lower part is almost impermeable except where fractured.
			McKnight 2/ (unit is within the Edwards aquifer)	Cu			150	Limestone and shale; upper 55 feet is a mudstone containing thin zones of collapse breccias; middle 24 feet is shaly, lime mudstone; lower part is limestone containing collapse breccias in upper part.	Deep basinal, euxinic deposits. Little permeability.
			West Nueces 2/ (Edwards aquifer)	Cu			140	Limestone; upper 80 feet is largely a massive unit of miliolid and mollusc-bearing grainstone; lower 60 feet is a nodular, dense mudstone.	Upper part is moderately permeable. Lower part is almost impermeable.
		Trinity	Glen Rose	Cu	Upper member		1,000-1,500	Limestone, dolomite, and marl; limestone is fine grained, hard to soft, marly; dolomite is porous and finely crystallized.	Little permeability.
					Lower member			Limestone and some marl. Massive bedded.	More permeable toward base of unit.
			Pearsall	Cu			400	Sandstone, limestone, and shale.	Little permeability.
	Coahuilan		Sligo	Cu			200	Limestone and some shale.	Little to moderate permeability.
			Hosston				900	Sandstone and shale.	Little to moderate permeability.
Pre-Cretaceous								Sandstone and limestone.	Little permeability.

Table 1.--Summary of the lithology and water-yielding characteristics of the hydrogeologic units for each of the three depositional provinces within the study area 1/--Continued

DEVILS RIVER TREND

System	Provincial series	Group	Formation	Function	Member or informal unit	Function	Thickness (feet)	Lithology	Water-yielding characteristics and hydrostratigraphy
Quaternary			Alluvial and terrace deposits	Aq where saturated			0-40	Gravel, sand, and silt.	Unit occurs along stream courses of major drainage. Deposits are intermittently partly saturated. Not an important source of water.
Cretaceous	Gulfian	Austin	Undivided	Aq			200	Chalk, marl, and hard limestone; mostly a mudstone.	Little to moderate permeability.
		Eagle Ford	Undivided	Cu			250	Shale and flaggy limestone.	Little permeability.
	Comanchean	Washita	Buda Limestone	Cu			50	Limestone; dense, micritic limestone, and marly, nodular limestone.	Little permeability.
			Del Rio Clay	Cu			100	Shale and thin beds of sandy limestone.	Little permeability.
		Fredericksburg	Devils River Limestone (Edwards aquifer)	Aq			450-700	Limestone and dolomite; hard, miliolid, pellet, rudistic, shell-fragment grainstone and mudstone; locally dolomitized, brecciated; rudistids common toward the top; nodular, argillaceous limestone toward the base.	Shallow water and supratidal unit. Unit constitutes a low barrier reef that surrounded the Maverick basin on the north. Permeable and porous unit particularly in the middle and upper parts. A major aquifer.
		Trinity	Glen Rose	Cu	Upper part of Glen Rose	Cu	1,500	Limestone and marl.	Little permeability in upper part, but permeable in the lower part.
					Lower part of Glen Rose	Aq		Massive limestone.	
			Pearsall	Cu			400	Sandstone, limestone, and shale.	Little permeability.
	Coahuilan	Sligo and Hosston Formations	Cu				500-1,000	Limestone in upper part and sandstone and shale in lower part.	Variable permeability. Little permeability overall.
Paleozoic rock								Sandstone, slate, and shale.	Little permeability.

Table 1.--Summary of the lithology and water-yielding characteristics of the hydrogeologic units for each of the three depositional provinces within the study area 1/--Continued

SAN MARCOS PLATFORM IN THE BALCONES FAULT ZONE

System	Provincial series	Group	Formation	Function	Member or informal unit	Function	Thickness (feet)	Lithology	Water-yielding characteristics and hydrostratigraphy
Quaternary			Alluvium	Aq			45	Silt, sand, gravel.	Flood plain; aquifers in hydraulic connection with streams.
			Terrace deposits	Not saturated			30	Coarse gravel, sand, and silt.	High terrace bordering streams and surficial deposits on high interstream areas in Balcones fault zone.
Tertiary	Eocene	Claiborne	Reklaw	Cu			200	Sand, sandstone, and clay; lignitic, friable to indurated sandstone.	Deltaic and swamp deposits. Leaky confining unit for the Carrizo aquifer below.
			Carrizo Sand	Aq			200-800	Sandstone; medium to very coarse, friable, thick bedded, few clay beds, ferruginous.	Permeable aquifer formed by deltaic and shoreline deposits.
	Eocene and Paleocene	Wilcox and Midway		Cu		Cu	500-1,000	Clay, siltstone, and fine grained sandstone; lignitic, iron bearing.	Leaky confining bed formed by deltaic and marine shoreline.
					Wills Point	Cu	500	Clay and sand.	
Cretaceous	Gulfian	Navarro				Cu	500	Marl, clay, and sand in upper part; chalky limestone and marl in lower part.	Deeper water marine deposits. Major barrier to vertical cross-formational flow separating Cretaceous aquifer from Tertiary aquifers.
		Taylor	Pecan Gap Anacacho Limestone	Cu			300-500		
		Austin	Undivided	Aq			200-350	Chalk, marl, and hard limestone. Chalk is largely a carbonate mudstone.	Minor aquifer that is locally interconnected with the Edwards aquifer by openings along some faults.
		Eagle Ford	Undivided	Cu			50	Shale, siltstone, and limestone; flaggy limestone and shale in upper part; siltstone and very fine sandstone in lower part.	Barrier to vertical cross-formational flow.
	Comanchean	Washita	Buda Limestone and Del Rio Clay	Cu			100-200	Dense, hard, nodular limestone in the upper part and clay in lower part. Thickens to the west.	Fractured limestone in the Buda is locally water yielding and supplies small quantities of water to wells. Del Rio Clay has negligible permeability.
			Georgetown Limestone (unit is within the Edwards aquifer)	Cu			20-60	Dense, argillaceous limestone; contains pyrite.	Deep water limestone with negligible porosity and little permeability.
		Edwards Group (of Rose, 1972)	Person (Edwards aquifer)	Aq	Marine	Aq	90-150	Limestone and dolomite; honeycombed limestone interbedded with chalky, porous limestone and massive, recrystallized limestone.	Reefal limestone and carbonate deposit under normal open marine conditions. Zones with substantial porosity and permeability are laterally extensive. Karstified unit.
					Leached and collapsed members	Aq	60-90	Limestone and dolomite. Recrystallized limestone occurs predominantly in freshwater zone of Edwards aquifer. Dolomite occurs in the salinewater zone.	Tidal and supratidal deposits, conforming porous beds of collapse breccias and burrowed biomicrites. Zones of honeycombed porosity are laterally extensive
					Regional dense bed	Cu	20-30	Dense, argillaceous limestone.	Deep water limestone. Negligible permeability and porosity. Laterally extensive bed that is a barrier vertical flow in the Edwards aquifer.
			Kainer (Edwards aquifer)	Aq	Grainstone	Aq	50-60	Limestone, hard, miliolid grainstone with associated beds of marly mudstone and wackestone.	Shallow water, lagoonal sediments deposited in a moderately high energy environment. A cavernous, honeycombed layer commonly occurs near the middle of the subdivision. Interparticle porosity locally is substantial.
					Dolomitic (includes Kirschberg evaporite)	Aq	150-200	Limestone, calcified dolomite, and dolomite. Leached, evaporitic rocks with breccia toward top. Dolomite occurs principally in the salinewater zone of the aquifer.	Supratidal deposits toward top. Mostly tidal to subtidal deposits below. Porous and permeable zones formed by boxwork porosity in breccias or by burrowed zones.
					Basal nodular bed	Cu	40-70	Limestone, hard, dense, clayey; nodular, mottled, stylolitic.	Subtidal deposits. Negligible porosity and permeability.

Table 1.--Summary of the lithology and water-yielding characteristics of the hydrogeologic units for each of the three depositional provinces within the study area 1/--Continued

SAN MARCOS PLATFORM IN THE BALCONES FAULT ZONE--Continued

System	Provincial series	Group	Formation	Function	Member or informal unit	Function	Thickness (feet)	Lithology	Water-yielding characteristics and hydrostratigraphy
Cretaceous	Comanchean	Trinity	Glen Rose	Cu	Upper part of Glen Rose	Cu	300-400	Limestone, dolomite, shale and marl. Alternating beds of carbonate rocks and marl. Evaporite rocks and dolomite toward top, variable bedding.	Supratidal and shoreline deposits toward top. Tidal to subtidal deposits below. Unit has little vertical permeability but has moderate lateral permeability.
					Lower part of Glen Rose	Aq	200-250	Massive limestone with few thin beds of marl.	Marine deposits, caprinid reef zones and porous and permeable honeycomb porosity near the base.
			Pearsall (Travis Peak in outcrop)	Cu	Bexar Shale Member (of Forgotson, 1956)	Cu	300	Limestone and shale.	Shoreline deposits, relatively impermeable unit in the Balcones fault zone.
					Cow Creek Limestone Member	Aq		Limestone and dolomite. Grainstone, packstone, and coquinoid beds.	Moderately permeable unit in Comal County.
					Pine Island Shale Member	Cu		Shale and argillaceous limestone.	Little permeability.
	Coahuilan	Nuevo Leon and Durango of Mexico	Sligo and Hosston Formations	Cu			800-1,500	Limestone, shale, and sandstone.	Sandstone in lower part is moderately permeable.
Pre-Cretaceous								Slate, phylite, locally sedimentary rocks in grabens.	Basement rocks. No circulating ground water.

1/ Maclay and Small (1984).
2/ Lozo and Smith (1964).

considered to contribute to or receive major volumes of ground water from the Edwards aquifer.

The Edwards aquifer consists of stratified, fractured limestone with an average thickness of about 500 ft. The limestone contains several permeable and laterally extensive zones of porous rock at different stratigraphic positions (table 1). Steep-angle, rotated, normal faults of the Balcones fault zone are common throughout the area.

Texture and mineralogy of the rocks within the freshwater and salinewater parts of the Edwards aquifer are considerably different. These differences are the result of mineral dissolution and precipitation reactions from the diagenetic action of circulating ground water. The rocks of the freshwater part of the aquifer are largely calcitic, dense, recrystallized dolomite that contain zones of well-developed, secondary porosity (Maclay and Small, 1984). Smaller amounts of quartz, kaolinite, and unclassified, ferric oxyhydroxide minerals also are present. The rocks of the salinewater part are finely porous dolomites which are associated with gypsum, pyrite, organic matter, celestite, and some fluorite (R.K. Deike, U.S. Geological Survey, written commun., 1985). Isolated areas of restricted ground-water circulation in the freshwater part of the aquifer may contain some or all of the mineral assemblage present in the salinewater part.

The formations comprising the Edwards aquifer dip southward toward the Gulf Coastal Plain. The thickness of strata overlying the Edwards increases downdip from the confined-unconfined zone boundary. These formations historically have been assumed to protect ground water from direct contamination from the land surface. However, faulting of the strata described above has juxtaposed permeable strata within the Edwards Group (Rose, 1972) with the Austin Group, the Eagle Ford Group, undivided, the Buda Limestone, and the Del Rio Clay. The Austin Group and Buda Limestone are minor aquifers that may allow surface contamination to reach the Edwards aquifer during low water-level conditions. Faults, fractures, and joints that hydraulically connect the land surface with the aquifer also may be conduits that allow surface contaminants to move through the unsaturated zone to the aquifer.

Transmissivity and Storage Characteristics

Heretofore in this report, permeability has been used as a qualitative term because of its non-uniform distribution. Maclay and Small (1984) assigned relative values of transmissivity for rocks within the Edwards aquifer from ground-water modeling studies. These values range from less than 13,400 ft^2/d in the unconfined zone to more than 1,340,000 ft^2/d in some freshwater parts of the confined zone.

In general, the transmissivity of rocks in the unconfined zone is less than that estimated for the confined zone. Estimated values of transmissivity increase from west to east, attaining their largest values adjacent to the Comal Springs fault (fig. 6).

The distribution and continuity of permeability within the Edwards aquifer may be best understood as an interaction between layered, discontinuous, and trending heterogeneity within the formation (Maclay and Small, 1984). Layered

page 23 follows

heterogeneity is illustrated by the hydraulic separation between an upper and lower zone in some places by the McKnight Formation (Lozo and Smith, 1964) in the Maverick basin and by the regional dense member on the San Marcos platform (table 1; and Maclay and Small, 1984). Fault displacements within the aquifer (fig. 6), which juxtapose rocks of substantially different permeability, create preferential avenues of permeability and ground-water flow which generally parallel the direction of the fault or discontinuous heterogeneity. Subareal exposure and erosion of the carbonate rocks of the aquifer during the Cretaceous period produced trending heterogeneity in the form of karstic cavernous porosity. The karstic features where the Edwards Group crops out in the unconfined zone typically are the locally dominant permeability. Leaching of evaporite beds within the Edwards Group produced porous collapse breccia.

The lithologic and mineralogic composition of the Edwards aquifer affects the hydraulic characteristics of the rock matrix and the chemistry of water contained therein. The calcitic limestone in the freshwater part of the aquifer is several orders of magnitude more conductive to ground-water flow than the dolomite of the salinewater part. Vertical differences in lithology and mineralogy as documented by Maclay and Small (1984) and R.G. Deike (U.S. Geological Survey, written commun., 1985) also appear to relate to variation in hydraulic conductivity and ground-water chemistry.

Maclay and Small (1984) have estimated the storage coefficient of the confined aquifer to range from 1×10^{-5} to 1×10^{-4}. Estimates of drainable porosity of the limestone ranged from 6 to 14 percent from visual inspection and from 1.7 to 2.5 percent from neutron geophysical procedures. Estimates of regional specific yield, based on the annual water balance and changes of water levels in the aquifer, range from 1 to 4 percent. The latter range is considered to be the most representative of regional conditions.

Ground-Water Flow

The regional directions of ground-water flow within the Edwards aquifer extend from recharge areas in the unconfined zone to the confined zone and from west to east in the confined zone (fig. 6, and Maclay and others, 1985). However, this general pattern is modified by the occurrence of barrier faults within the system. For example, substantial ground-water flow within the aquifer in northeastern Medina County is diverted to the southwest by a system of southwest-trending barrier faults (Holt, 1959; Maclay and Small, 1984). Dye-tracing of ground-water-flow patterns and water levels from observation wells have supported the controlling effect of barrier faults on the direction of ground-water flow near Medina Lake (Holt, 1959; Maclay and Small, 1984). Concentrations of tritium, an environmental tracer, also support the concept of southwestward ground-water flow across this region (Pearson and others, 1975). In the confined zone of the Edwards aquifer in Bexar County, ground water generally flows in a northeast direction as the freshwater part of the aquifer narrows. During periods of high water levels, some ground water is diverted locally to San Antonio and San Pedro Springs.

Barrier faults in the aquifer in northern Bexar County direct ground water toward the northeast below both the outcrop and hydraulically connected subcrop regions. A study of trichlorofluoromethane distribution in ground water illustrated the flow of ground water parallel to a major fault north of San Antonio (Thompson and Hayes, 1979). Ground water may flow across faults in this part of northern Bexar County into the confined zone during periods when the potentiometric surface of the confined zone is lower than that of the unconfined zone (Maclay and Small, 1984). Flow patterns in the recharge areas of Comal and Hays Counties are less defined due to the karstic cavernous permeability of the Edwards aquifer in the region. The regional flow pattern in the area north of the Comal Springs fault is eastward. Near Cibolo Creek, some water may flow eastward into the confined zone in Comal County.

Ground water in the confined, freshwater part of the aquifer in Comal County flows northeastward in a narrow area between the Comal Springs fault and the "bad-water" line (fig. 6). Some movement from the unconfined to the confined zone may occur along this fault near the Bexar-Comal County boundary. Flow from the downthrown side of the Comal Springs fault (confined zone) sustains the flow of Comal Springs. Water from the unconfined zone in northwestern Comal County moves toward Hueco Springs in the area northwest of the Hueco Springs fault (fig. 6). Ground water in the unconfined zone between the Hueco and Comal Springs faults generally flows northeastward into the confined zone to discharge at San Marcos Springs. Additional discharge at San Marcos Springs originates from recharge in south-central Hays County.

Ground-water velocities have been estimated for the Edwards aquifer by a number of methods. The residence time of ground water in the confined, freshwater part of the aquifer is estimated on the basis of tritium concentrations to be greater than 20 years (Pearson and others, 1975). The distribution of a fluorocarbon compound (trichlorofluoromethane) in a plume in the confined zone of Bexar, Comal, and Hays Counties has indicated an average minimum ground-water velocity of about 14 ft/d (Thompson and Hayes, 1979). An estimate of flow velocity in the confined zone from recharge, storage, and average flow-distance estimates yielded a velocity of about 27 ft/d. Several dye-tracing attempts at wells in Bexar County using Rhodamine WT dye gave results ranging from 2 to 31 ft/d (Maclay and others, 1981).

Hydrologic Balance

Average recharge to the Edwards aquifer has been estimated for 1934-78 by Puente (1978). Recharge was estimated by the difference between measured streamflow upstream and downstream from the recharge area and inflow from interstream areas within this area. The calculated average recharge by drainage basin is shown in figure 7. Other sources of recharge--such as from unlined or cracked storm drains; irrigation of farmland and lawns in residential areas; cross-formational flow from the Glen Rose Formation, Austin Group, and Buda Limestone; and exchanges across the "bad-water" line--are included as estimates in the recharge reported for each drainage basin.

Discharge by pumpage from the aquifer has more than tripled since 1934 (Reeves and Ozuna, 1985). Water levels declined to their lowest elevations in a decade during the summer of 1984, approaching 620 ft above sea level at San Antonio. Ground-water pumpage and water use by county are illustrated in figure 8 for 1981. During 1976-81, the volume of ground water in storage fluctuated above and below average conditions for the aquifer. Dryer-than-normal conditions during 1983 and 1984 decreased both the volume of recharge to the aquifer

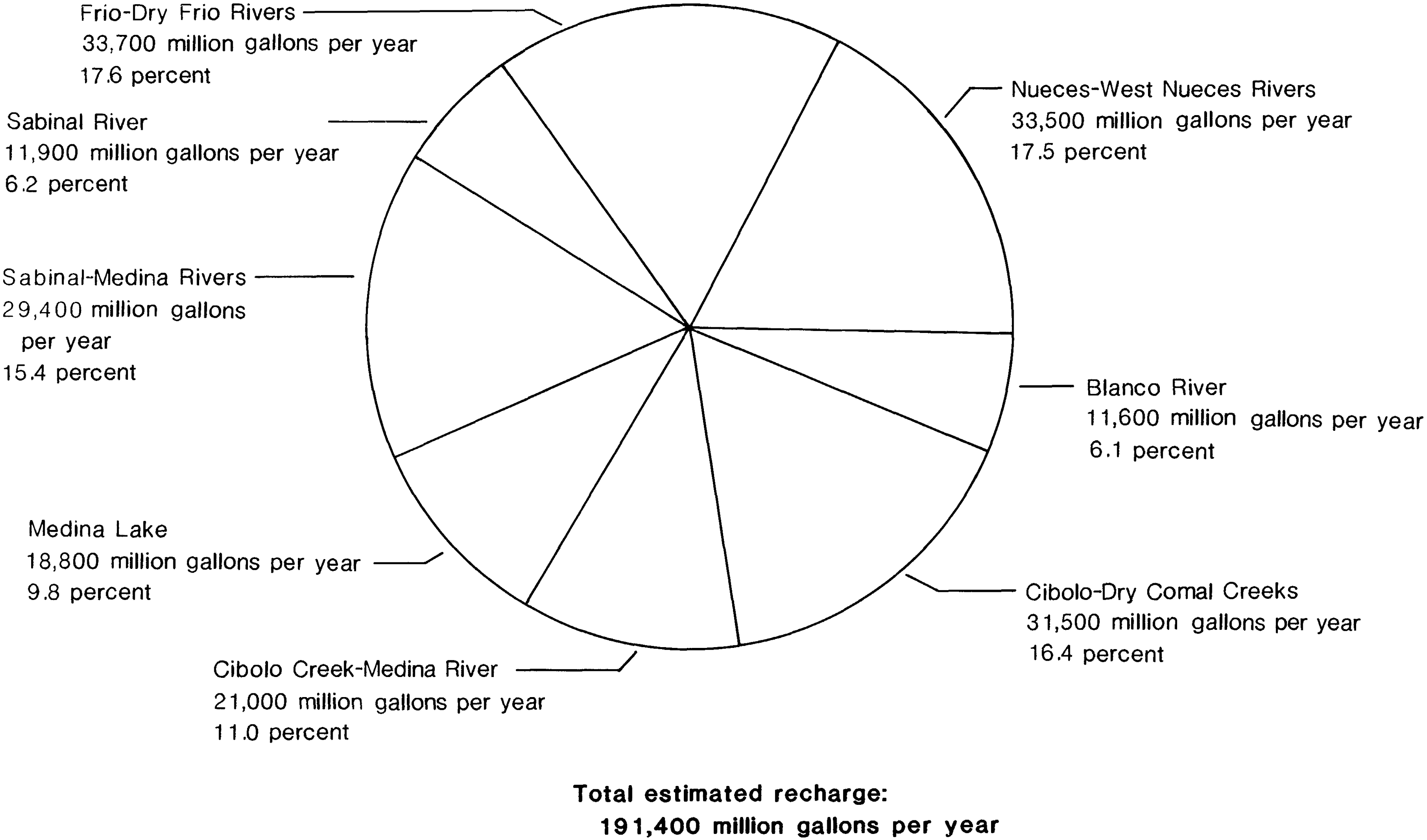


Figure 7.--Calculated annual average recharge by drainage basin, 1934-78.

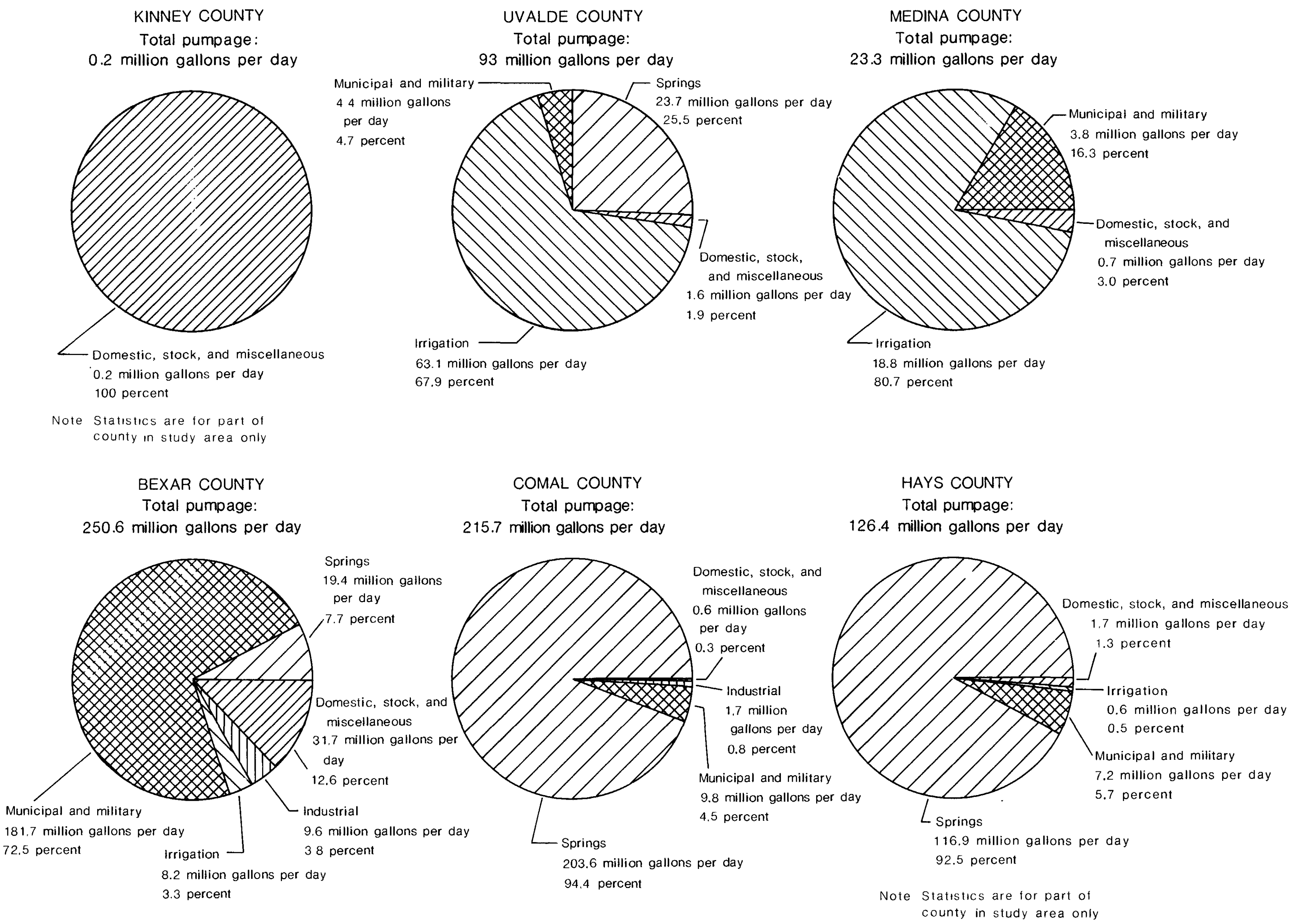


Figure 8.--Ground-water pumpage and water use by county, 1981.

and the volume of ground water in storage, causing discharge by pumpage to increase (G.B. Ozuna, U.S. Geological Survey, oral commun., 1986).

Definition of Subareas

Four major subareas of the aquifer were defined to reflect the relative susceptibility of ground water to contamination originating from human activities (fig. 2 and table 2). Geological controls on recharge and the direction of ground-water flow, as controlled by potentiometric gradient, faulting, and relative-transmissivity contrasts (Maclay, Small, and Rettman, 1980; Maclay and Small, 1984), were used to define the subareas used for statistical comparisons. The tritium concentrations in ground water sampled between 1967 and 1972 (Pearson and others, 1975) were used to qualitatively define areas of the aquifer that have received more recently recharged water. Pearson and others (1975) classify tritium concentrations greater than 20 T.U. (tritium units) as characteristic of recharge areas. The areas where tritium concentrations range from 10 to 20 T.U., from 2 to less than 10 T.U., or are less than 2 T.U. represent aggregate groups of successively older ground waters. The delineations between the four groups generally coincide with the subareas drawn using interpretations of geologic controls.

LAND USE

Land uses over the Edwards aquifer were broadly characterized within five categories using information from a Texas Department of Water Resources (1978) survey of land uses and information from well-site visits by Geological Survey personnel. These land-use categories reflect the relative variety of human activities which are characteristic of the region under study.

Large-city urban : Commercial, residential, and light industrial development associated with San Antonio and suburbs
Small-city urban : Commercial, residential, and light industrial development associated with all other cities and towns
Industrial : All industrial sites explicitly classified during Geological Survey site visit--includes rock quarries, power-generating stations, and cement plants
Cropland : Includes irrigated and dry-farmed cropland
Forest and rangeland: Includes scrub forest and grass-covered ground --generally undeveloped or used for livestock grazing

The Texas Department of Water Resources report used six categories of land use/land cover developed according to general, or Level 1 interpretation (Anderson and others, 1976) from 1973 and 1976 Landsat 1 and 2 imagery (spectral bands 4, 5, and 7 at an original scale of 1:250,000) (Texas Department of Water Resources, 1978). The Texas Department of Water Resources land use/land cover categories for the region under study were: (1) Urban or built-up land, (2) dry-farmed cropland, (3) irrigated cropland, (4) rangeland, (5) forest land, and (6) water (fig. 9). The land covered perennially by bodies of water was not considered further in this study because of the lack of associated

page 31 follows

Table 2.--Delineation and definition of subareas used for statistical analyses in this report

Subarea	Explanation
1	Most of the unconfined zone. Not defined in Kinney County and western Uvalde County. Some parts of the confined zone in Uvalde County and remaining counties. Receives direct recharge from land surface except in parts of confined zone. Measured or inferred tritium concentrations greater than 20 tritium units.
2	Confined zone near boundary between unconfined and confined zones. Not defined in Kinney County and western Uvalde County. Some parts of unconfined zone in Uvalde County and remaining counties. North and west of "bad-water" line. Receives direct recharge from land surface in unconfined zone. May receive some recharge via faults or by cross-formational flow in confined zone. Measured or inferred tritium concentrations ranging from 10 to 20 tritium units.
3	Confined zone except in Bexar County near San Antonio. Not defined in Kinney County and western Uvalde County. North and west of "bad-water" line. Receives little or no direct recharge from the land surface. Measured or inferred tritium concentrations range from 2 to less than 10 tritium units.
4	Generally limited to confined zone. Not defined in Kinney County and western Uvalde County. Includes several small areas of restricted ground-water circulation located within subareas 2 and 3. Near or south and east of "bad-water" line. Receives little or no direct recharge from the land surface. Measured or inferred tritium concentrations less than 2 tritium units.

wells open to the aquifer. The minimum mapping unit for urban or agricultural land was 10 acres. All other land uses in the study area were mapped in units no smaller than 40 acres. The total areas based on the Texas Department of Water Resources categorized land-use practices (table 3) were estimated using planimetered data from figure 9.

The land-use categories defined by the Texas Department of Water Resources were further refined by including information from site visits by Geological Survey personnel. The major land use at or upgradient from each well was first identified from the 1978 land use/land cover map. This classification was then compared with the water use/land use noted by the Geological Survey employee at the time the ground-water sample was collected. These classifications also were verified with the Survey employee who had most recently visited the site. The land-use classification used in this report and defined in table 3 is a synthesis and a simplification of the Texas Department of Water Resources land use/land cover and Geological Survey site-visit categories.

Areas categorized as urban are defined as those residential and commercial developments associated with more densely populated regions. Because the diversity of human activities and waste types commonly is greater in larger population centers, urban land use was divided into two groupings; large-city urban and small-city urban. Large-city urban land use is confined to the San Antonio metropolitan area. The smaller cities of San Marcos, New Braunfels, and Uvalde and the communities located along U.S. Highway 90 west of San Antonio were all classified as small-city urban. Of the six counties, only Bexar, Comal, Hays, and Uvalde have appreciable areas of urban land use over subarea 1 of the Edwards aquifer. Urbanized parts of the northern San Antonio metropolitan area, northern San Marcos and New Braunfels, and the Garner Field area of Uvalde overlay subarea 1. Urban development creates a greater possibility for point and non-point source contamination associated with urban development.

The land-use categories of the Texas Department of Water Resources (1978) did not differentiate industrial land use from the other types. Water-use/land-use data recorded during sampling visits by Geological Survey personnel were used to differentiate industrial land use at individual wells. The industrial land uses thus categorized include rock quarries, power-generating stations, and cement plants. The reader should note that this industrial categorization is incomplete and that many locations of small or light industry are included in the large-city urban and small-city urban categories. Light industries referred to in this discussion are chiefly manufacturing of electrical products, construction equipment, clothing, and aircraft. Present (1986) and former military bases also are included in the two urban land-use categories.

The location of landfills over the Edwards aquifer in the San Antonio region as of 1981 were located by aerial photography and aerial and ground reconnaissance (Larson and Ferguson, 1982; Alamo Area Council of Governments, 1981). Of the 186 mapped landfills, 142 are located in Bexar County. Of the 142 landfills in Bexar County, 4 are in subarea 1 and 79 are located in subareas 2, 3, and 4, and are within the study area. Throughout the six-county region, nearly all the documented landfills are associated with large-city and small-city urban land uses. Few detailed data were available from the above sources regarding the types of waste buried at these landfills.

Table 3.--Estimated land-use areas for the study area by category and county, 1977 data 1/

Land-use category for statistical analyses	Texas Department of Water Resources land use/land cover category	Area (square miles)						
		Kinney County	Uvalde County	Medina County	Bexar County	Comal County	Hays County	Total by land-use category
--	Urban or built-up land	0.5	7.0	5.6	220	24	10	267.1
Large-city urban	--	--	--	--	220	--	--	220
Small-city urban	--	.5	7.0	5.6	--	24	10	47.1
Industrial	--	(2)	(2)	(2)	(2)	(2)	(2)	(2)
--	Dry-farmed cropland	0	284	520	460	49	141	1,454
--	Irrigated cropland	0	88	84	100	0	0	272
Cropland	--	0	372	604	560	49	141	1,726
--	Rangeland	1,390	1,080	660	293	297	384	4,104
--	Forest land	7.5	130	78	170	176	113	674.5
Forest and rangeland	--	1,397.5	1,210	738	463	473	497	4,778.5
--	Water	0	0	1.7	8	16	.7	26.4

1/ Adapted from Texas Department of Water Resources (1978).

2/ Industrial land use was classified from U.S. Geological Survey site visit data. No information on the area devoted to industrial land use was available from the Texas Department of Water Resources data. The Texas Department of Water Resources category titled "Urban or built-up land" includes the areas classified as industrial land use in this report.

The remaining land within the study area is devoted to agricultural uses or is uncleared scrub forest. The predominant agricultural land use is rangeland for livestock, followed by dry-farmed cropland, and irrigated cropland. Farmed agricultural acreage, as of 1982-83, was devoted primarily to corn, hay, and sorghum (table 4). All other crops accounted for about 7 percent of the total cultivated acreage (Texas Department of Agriculture and U.S. Department of Agriculture, 1983). The crop statistics in table 4 for Hays and Kinney Counties include some areas outside the study area. Most of the rangeland in the study area can support only a low density of livestock. Therefore, the relative intensity of use of rangeland, as defined by the anticipated load of potential pollutants to the land surface, is more comparable to scrub forest than to other agricultural land uses. Therefore, forested land and rangeland are grouped together into one land use. Similarly, dry-farmed and irrigated cropland also are grouped together because they typically include cultivation of the soil and fertilizer and pesticide application.

POTENTIAL FOR GROUND-WATER CONTAMINATION

Understanding the present relation between water chemistry, hydrogeology, and land use in the aquifer is necessary to better understand the effects that future land uses may have on the aquifer. Recharge to the aquifer occurs principally within subarea 1 where water quickly infiltrates from streambeds directly into the aquifer. The dominant proportion of the contributing area for these streams is undeveloped forest and rangeland. Therefore, the potential for contaminating recharge water from existing human activity is limited. Additionally, most agricultural and urban land uses are located over the confined aquifer where recharge is limited. However, urbanization of the area north of San Antonio and in north-central Bexar County has accelerated during the 1980's. Increased storm runoff is associated with residential and commercial development. Runoff from these sources may decrease the quality of water recharging the aquifer.

A minor part of recharge to the Edwards aquifer is contributed by cross-formational flow from overlying strata such as the Austin Group, Buda Limestone, and gravel of the Pleistocene Leona Formation. Contaminant sources over these strata also may leak via cross-formational flow into the Edwards aquifer where it is unconfined. If the fluid density of the contaminant solution is sufficiently great, the potentiometric head of the contaminant may in some cases exceed the potentiometric head within the aquifer. If this happens, some parts of the confined aquifer located immediately downdip from the boundary between the unconfined and confined zones may be susceptible to entry by contaminants. Certain low molecular-weight organic compounds with small dielectric constants may induce shrinkage in slightly permeable clay strata such as the Del Rio Clay and flow of the compounds through the clay may be at rates exceeding those of normal ground-water flow (Green and others, 1981). Therefore, the part of the aquifer that is potentially susceptible to contamination includes the area downdip from the aquifer outcrop in subarea 2. Much of subarea 2 in Bexar County is urbanized. Many landfills, such as the West Avenue site in Bexar County, and potentially leaking storage tanks are present in subarea 2.

The incidence of pollution in the Edwards aquifer historically has been localized and usually limited to individual wells (Reeves, 1976). For example, the trending heterogeneity of the cavernous, karstic permeability and the

Table 4.--Crop acreage, by county, 1982 and 1983 1/

[values rounded to nearest 100 acres]

Crop	Kinney County	Uvalde County	Medina County	Bexar County	Comal County	Hays County	Total
Vegetables (1983)	200	5,100	1,100	1,100	0	0	7,500
Corn (1982)	1,600	20,000	29,700	20,700	1,400	3,400	76,800
Upland cotton (1983)	0	5,000	1,400	0	0	0	6,400
Hay (1982)	1,200	14,400	13,900	20,800	7,000	9,200	66,500
Peanuts (1982)	0	0	1,800	2,800	0	0	4,600
Sorghum (1982)	0	11,500	53,500	30,500	5,900	5,700	107,100
Soybeans (1983)	0	1,000	0	0	0	0	1,000

1/ From Texas Department of Agriculture (1983).

presence of barrier faults in subarea 1 limits the areal dispersion of many of these contamination incidents. The occurrence of pollutants from land-surface sources, septic tanks and leaking sewers, and underground storage tanks may be localized and is controlled by the incidence of fractures and improperly cased wells (Reeves, 1976). Therefore, the discussion to follow about the statistical relation between water chemistry, hydrogeology, and land use needs to be understood in the context of a heterogeneous aquifer with varying susceptibilities to contamination within each subarea.

RELATION OF WATER CHEMISTRY TO HYDROGEOLOGY AND LAND USE

Water-chemistry data were grouped by subarea and land use and statistically analyzed to examine sources of variation and potential associations with the two classificaitons. Median values were calculated for each constituent at each well, using all water-chemistry analyses for samples collected between 1976 and 1985. For each of the commonly detected inorganic parameters, the number of wells sampled, 25th percentile, median, 75th percentile, and the maximum values with respect to subarea and land use in subareas 1 and 2 are presented in tables 5 and 6. These and all other statistical analyses except the determination of maximum constituent concentrations were performed using these median values. A consequence of this approach is that a well with 1 sample is treated the same as a well with 10 samples. For trace elements, nutrient constituents, bacteria, and organic compounds, the following statistics are reported: (1) The number of median concentrations for each well that are equal to or greater than the detection limit of the constituent; (2) those median concentrations, by well, that are less than the detection limit of the constituent; (3) the median and 75th percentile of the distribution of median values greater than the detection limit; and (4) the maximum concentration of all samples for each constituent in the subarea or land-use group.

The existence of any significant differences among different subareas and land-use groups was identified using the Kruskal-Wallis test. This test compared the distribution of ranks of median concentrations for wells between selected subareas and land-use groups to determine if any of the groups was significantly different from the others. Specific, pairwise significant differences among subareas and land-use groups were determined using Tukey's HSD test. The version of the Tukey's HSD used was modified to accommodate unequal cell sizes on the ranks of median concentrations for each constituent at each well (SAS Institute, Inc., 1982). The Tukey's HSD test compared within-group variance of the ranks of constituent concentrations to calculate the minimum difference in mean rank among groups necessary to consider the groups to be significantly different. Significant differences between the mean rank from subareas or land-use groups or both may indicate differences in geochemical processes, land use, or an unidentified factor among the groups. Differences between land-use groups determined by Tukey's HSD test, though statistically significant at the 95-percent confidence level, are considered qualitative interpretations due to the small number of wells used for the testing. Data on hydrochemical facies (Maclay, Rettman, and Small, 1980) and mineral-stability relations are discussed along with the interpretations of the statistical results.

The Kruskal-Wallis and Tukey's HSD tests were applied to constituents when the percentage of median values (calculated by well) that were less than the

Table 5.--Summary statistics for selected inorganic constituents and properties in ground water by subarea, 1976-85

[mg/L, milligram per liter]

Constituent or property and statistics	Detection limit	Subarea			
		1	2	3	4
Solids, sum of constituents, dissolved (mg/L)	100.0				
Number		58	33	47	34
25th percentile		280.0	295.0	260.0	270.0
Median		290.0	320.0	300.0	385.0
75th percentile		320.0	397.0	325.0	1,662.0
Maximum		1,100.0	700.0	2,300.0	4,300.0
Tukey's HSD test		A	AB	AB	B
Hardness, total (mg/L as $CaCO_3$)	1.0				
Number		58	38	53	34
25th percentile		253.0	257.0	230.0	235.0
Median		267.0	280.0	260.0	265.0
75th percentile		290.0	303.0	287.0	960.0
Maximum		620.0	470.0	1,100.0	2,500.0
Tukey's HSD test		A	A	A	A
Hardness, noncarbonate (mg/L as $CaCO_3$)	1.0				
Number		58	33	47	33
25th percentile		18.0	19.0	20.0	34.0
Median		25.0	38.0	29.0	73.0
75th percentile		38.0	55.0	38.0	755.0
Maximum		320.0	250.0	780.0	2,200.0
Tukey's HSD test		A	A	A	B
Calcium, dissolved (mg/L as Ca)	0.1				
Number		58	38	54	34
25th percentile		82.0	73.0	65.0	66.0
Median		90.0	83.0	75.0	71.0
75th percentile		97.0	95.0	87.0	207.0
Maximum		180.0	170.0	220.0	690.0
Tukey's HSD test		A	AB	B	AB
Magnesium, dissolved (mg/L as Mg)	0.1				
Number		58	38	54	34
25th percentile		9.0	10.0	15.0	17.0
Median		12.0	15.0	16.0	22.0
75th percentile		14.0	19.0	17.0	58.0
Maximum		65.0	44.0	130.0	230.0
Tukey's HSD test		A	B	B	C
Sodium, dissolved (mg/L as Na)	0.2				
Number		58	38	54	34
25th percentile		5.0	7.0	8.0	9.0
Median		7.0	9.0	9.0	21.0
75th percentile		10.0	15.0	11.0	158.0
Maximum		170.0	58.0	370.0	480.0
Tukey's HSD test		A	B	B	C
Potassium, dissolved (mg/L as K)					
Number	0.1	58	38	54	34
25th percentile		.9	1.1	1.1	1.2
Median		1.0	1.3	1.3	2.2
75th percentile		1.3	1.5	1.5	11.0
Maximum		7.3	6.7	25.0	25.0
Tukey's HSD test		A	B	B	C

Table 5.--Summary statistics for selected inorganic constituents and properties in ground water by subarea, 1976-85--Continued

Constituent or property and statistics	Detection limit	Subarea			
		1	2	3	4
Alkalinity, titration to pH 4.5 (mg/L as $CaCO_3$)	1.0				
Number		59	38	57	40
25th percentile		226.0	210.0	204.0	190.0
Median		248.0	236.0	230.0	200.0
75th percentile		260.0	270.0	266.0	210.0
Maximum		470.0	440.0	1,280.0	370.0
Tukey's HSD test		A	A	A	B
Sulfate, dissolved (mg/L as SO_4)	0.2				
Number		59	39	60	39
25th percentile		10.0	19.0	17.0	26.0
Median		14.0	25.0	22.0	100.0
75th percentile		24.0	44.0	29.0	580.0
Maximum		270.0	310.0	890.0	2,100.0
Tukey's HSD test		A	B	B	C
Chloride, dissolved (mg/L as Cl)	0.1				
Number		59	38	61	42
25th percentile		10.0	11.0	14.0	18.0
Median		13.0	15.0	15.0	34.0
75th percentile		19.0	35.0	24.0	228.0
Maximum		260.0	150.0	740.0	1,100.0
Tukey's HSD test		A	AB	B	C
Fluoride, dissolved (mg/L as F)	0.1				
Number		57	35	52	34
25th percentile		.1	.2	.2	.4
Median		.1	.2	.2	.9
75th percentile		.2	.3	.3	2.4
Maximum		1.8	4.0	5.2	5.9
Tukey's HSD test		A	B	B	C
Bromide, dissolved (mg/L as Br)	0.1				
Number		29	11	15	1
25th percentile		.1	.1	.1	--
Median		.1	.1	.1	--
75th percentile		.2	.2	.1	--
Maximum		.5	.8	1.6	.8
Tukey's HSD test		A	A	A	A

Table 6.--Summary statistics for selected inorganic constituents and properties in ground water by land use in subareas 1 and 2, 1976-85

[mg/L, milligram per liter]

Constituent or property and statistics	Detection limit	Subarea 1					Subarea 2			
		Large-city urban	Small-city urban	Industrial	Cropland	Forest and rangeland	Large-city urban	Small-city urban	Cropland	Forest and rangeland
Solids, sum of constituents, dissolved (mg/L)	100.0									
Number		16	11	5	12	14	9	10	11	3
25th percentile		283.0	300.0	258.0	240.0	279.0	310.0	310.0	280.0	255.0
Median		290.0	330.0	285.0	268.0	305.0	350.0	320.0	305.0	270.0
75th percentile		290.0	450.0	293.0	313.0	353.0	478.0	396.0	430.0	310.0
Maximum		340.0	490.0	310.0	1,100.0	480.0	590.0	700.0	670.0	320.0
Tukey's HSD test		ABC	AB	C	BC	ABC	A	ABC	ABC	C
Hardness, total (mg/L as $CaCO_3$)	1.0									
Number		16	11	5	12	14	10	11	13	4
25th percentile		256.0	270.0	233.0	213.0	258.0	278.0	260.0	245.0	228.0
Median		260.0	300.0	255.0	240.0	280.0	300.0	285.0	265.0	258.0
75th percentile		278.0	360.0	268.0	261.0	305.0	353.0	300.0	305.0	276.0
Maximum		310.0	390.0	290.0	620.0	420.0	450.0	460.0	470.0	290.0
Tukey's HSD test		AB	A	B	B	AB	A	AB	AB	B
Hardness, noncarbonate (mg/L as $CaCO_3$)	1.0									
Number		16	11	5	12	14	9	10	11	3
25th percentile		10.0	22.0	12.0	23.0	19.0	11.0	25.0	29.0	9.0
Median		19.0	35.0	24.0	38.0	26.0	18.0	48.0	54.0	29.0
75th percentile		27.0	104.0	31.0	55.0	48.0	41.0	77.0	110.0	45.0
Maximum		51.0	150.0	48.0	320.0	150.0	250.0	240.0	160.0	67.0
Tukey's HSD test		A	A	A	A	A	A	A	A	A
Calcium, dissolved (mg/L as Ca)	0.1									
Number		16	11	5	12	14	10	11	13	4
25th percentile		83.6	85.0	76.8	64.8	85.8	84.6	67.5	72.8	59.1
Median		89.0	91.0	92.0	77.5	92.5	96.5	75.0	84.0	74.0
75th percentile		98.8	120.0	92.8	89.3	102.5	122.5	88.0	102.5	84.4
Maximum		120.0	130.0	100.0	180.0	130.0	170.0	110.0	160.0	87.0
Tukey's HSD test		ABC	AB	ABC	ABC	AB	A	BC	ABC	C
Magnesium, dissolved (mg/L as Mg)	0.1									
Number		16	11	5	12	14	10	11	13	4
25th percentile		3.8	14.0	7.7	10.1	8.3	10.6	10.0	10.5	11.1
Median		10.0	15.0	8.9	12.5	12.0	13.5	20.5	14.0	16.5
75th percentile		13.8	17.0	9.6	15.5	13.4	16.0	28.0	18.0	24.8
Maximum		28.0	21.0	13.0	65.0	24.0	17.0	44.0	20.0	28.0
Tukey's HSD test		AB	A	B	AB	AB	AB	A	AB	A
Sodium, dissolved (mg/L as Na)	0.2									
Number		16	11	5	12	14	10	11	13	4
25th percentile		5.0	7.9	5.2	7.9	5.9	9.4	6.1	7.1	5.7
Median		5.3	11.0	5.8	9.5	7.2	11.4	9.7	8.4	6.9
75th percentile		6.1	25.0	7.1	17.0	9.5	25.4	15.0	25.0	7.8
Maximum		9.0	29.0	8.1	170.0	16.0	51.0	53.0	58.0	8.4
Tukey's HSD test		C	AB	C	AB	ABC	A	AB	AB	BC
Potassium, dissolved (mg/L as K)	0.1									
Number		16	11	5	12	14	10	11	13	4
25th percentile		.7	1.2	.8	1.0	.9	1.3	1.1	1.1	1.0
Median		1.0	1.4	.9	1.0	1.1	1.5	1.4	1.3	1.1
75th percentile		1.2	1.5	.9	1.3	1.3	1.7	2.1	1.4	1.3
Maximum		2.1	2.0	1.1	7.3	3.6	2.5	6.7	1.9	1.3
Tukey's HSD test		BC	AB	C	ABC	ABC	A	AB	AB	ABC

Table 6.--Summary statistics for selected inorganic constituents and properties in ground water by land use in subareas 1 and 2, 1976-85--Continued

Constituent or property and statistics	Detection limit	Subarea 1					Subarea 2			
		Large-city urban	Small-city urban	Indus-trial	Cropland	Forest and rangeland	Large-city urban	Small-city urban	Cropland	Forest and rangeland
Alkalinity, titration to pH 4.5 (mg/L as $CaCO_3$)	1.0									
Number		16	11	5	12	15	10	12	13	3
25th percentile		241.0	250.0	206.0	192.0	246.0	240.0	210.0	204.0	190.0
Median		247.0	259.0	242.0	200.0	254.0	270.0	220.0	213.0	221.0
75th percentile		254.0	265.0	248.0	217.0	270.0	343.0	249.0	255.0	240.0
Maximum		271.0	320.0	276.0	300.0	470.0	440.0	271.0	310.0	246.0
Tukey's HSD test		ABC	AB	BDC	D	AB	A	BDC	BDC	DC
Sulfate, dissolved (mg/L as SO_4)	0.2									
Number		16	11	5	12	15	10	11	14	4
25th percentile		7.2	19.0	9.5	10.9	10.5	18.8	22.0	20.6	16.3
Median		10.5	24.0	15.0	14.0	16.0	22.0	26.0	31.0	22.3
75th percentile		13.6	44.5	19.5	21.4	45.0	28.5	79.0	50.6	38.8
Maximum		42.0	75.0	24.0	270.0	190.0	51.0	310.0	110.0	46.0
Tukey's HSD test		B	AB	AB	AB	AB	AB	A	A	AB
Chloride, dissolved (mg/L as Cl)	0.1									
Number		16	11	5	12	15	10	11	14	3
25th percentile		8.5	13.0	10.0	14.3	10.0	15.0	11.0	12.8	9.0
Median		11.0	19.0	11.5	22.0	12.0	16.3	11.5	16.0	12.5
75th percentile		12.8	72.0	12.8	47.3	18.0	26.4	34.0	47.3	14.0
Maximum		26.0	100.0	16.0	260.0	120.0	48.0	67.0	150.0	21.0
Tukey's HSD test		C	ABC	BC	A	ABC	AB	ABC	ABC	ABC
Fluoride, dissolved (mg/L as F)	0.1									
Number		16	11	5	11	14	10	10	11	4
25th percentile		.1	.2	.1	.1	.1	.2	.1	.2	.1
Median		.1	.2	.1	.1	.1	.2	.3	.2	.2
75th percentile		.2	.5	.2	.2	.2	.2	1.5	.3	.4
Maximum		.6	.9	.5	1.8	.6	.5	4.0	.7	.5
Tukey's HSD test		A	A	A	A	A	A	A	A	A
Bromide, dissolved (mg/L as Br)	0.1									
Number		12	6	5	5	6	3	6	5	2
25th percentile		.1	.1	.1	.1	.1	.1	.1	.1	.0
Median		.1	.1	.1	.1	.1	.1	.2	.1	.1
75th percentile		.1	.2	.2	.4	.2	.1	.4	.1	--
Maximum		.4	.3	.2	.4	.2	.1	.8	.1	.1
No Tukey's HSD test made		--	--	--	--	--	--	--	--	--

detection limit did not exceed 50 percent. For those constituents with smaller frequencies of detection and with occurrences that were at concentrations typically greater than twice the detection limit, a contingency-table analysis (Bhattacharyya and Johnson, 1977; Helsel and Ragone, 1984) was applied. The contingency-table analysis in this report was used to examine whether the probability of a constituent occurring at a concentration equal to or greater than the detection limit was greater in one or more of the subareas. The constituents analyzed using this procedure with respect to subarea include zinc, lead, barium, total phosphorus, total-coliform bacteria, fecal-coliform bacteria, fecal-streptococci bacteria, methylene blue active substances, methylene chloride, tetrachloroethylene, 1,1,1-trichloroethane, and the pesticide 2,4-D. Of these constituents, only zinc and lead were analyzed with respect to land use by the contingency-table procedure because of their substantial number of detectable median concentrations in one or more of the land-use groups. Differences between groups determined with the contingency-table analysis were determined at the 95-percent confidence level.

Inorganic Constituents

Summary statistics for selected inorganic constituents and the results of the Tukey's HSD test comparisons are presented with respect to subarea in table 5 and for land use in subareas 1 and 2 in table 6. The letter designation entered for each group and analysis denotes those groups that are or are not significantly different from each other as determined from the Tukey's HSD test comparisons. For example, the mean ranks of sodium concentrations for subareas 2 and 3 are not significantly different from each other (table 5). However, the mean ranks of sodium concentrations are significantly different between subareas 1 and 4 and between subareas 1 and 4 and subareas 2 and 3.

Dissolved Solids

Median dissolved-solids concentrations at each well are smallest in subarea 1 and largest in subarea 4 (fig. 10, table 5). The 25th-percentile, median, and 75th-percentile concentrations of dissolved solids in subarea 2 are larger than those in adjacent subareas 1 and 3. The median and 75th-percentile concentrations of dissolved solids in ground water are largest in the southern or downdip part of the aquifer (subarea 4), generally increasing to values that exceed 1,000 mg/L downdip from the "bad-water" line, the irregular subsurface interface between the freshwater and salinewater parts of the aquifer. The distribution of dissolved-solids concentrations for wells in subarea 1 was significantly different from those in subarea 4, though not significantly different from those in subareas 2 and 3 (table 5). The largest median concentrations of dissolved solids calculated were for the small-city urban land use in subarea 1 and for the large-city urban land use in subarea 2 (table 6). The smallest median dissolved-solids concentrations calculated were for the cropland land use in subarea 1 and the forest and rangeland land use in subarea 2.

Major Inorganic Constituents

The distributions of median concentrations of magnesium, sodium, potassium, sulfate, fluoride, and bromide are not significantly different between subareas 2 and 3. The distributions of the above constituents, with the exception of

page 45 follows

bromide, differ significantly between subareas 1, 2 and 3 grouped together, and subarea 4. This variation parallels the pattern of hydrochemical evolution from a calcium bicarbonate water type in subarea 1 and the more transmissive parts of subareas 2 and 3 to a calcium magnesium bicarbonate water type in less transmissive parts of subareas 2 and 3 to a calcium magnesium sulfate water type in the most saline parts of subarea 4 (fig. 11, and Maclay, Rettman, and Small, 1980). The larger median concentrations of sodium, chloride, and sulfate in subarea 4 with respect to subareas 1, 2, and 3 may reflect the mixing of more recently recharged, oxygenated, calcium bicarbonate water with older salinewater originating from sources further downdip in the aquifer (Pearson, 1973). Dissolution of gypsum and celestite, which has been observed in a core sample from the more saline parts of subarea 4 (R.G. Deike, U.S. Geological Survey, written commun., 1985) also may contribute to the larger sulfate concentrations in subarea 4. Ground water becomes saturated with respect to gypsum in subarea 4 with increasing distance downdip (Pearson and Rettman, 1976). Interpretation of the facies symbols in figure 11 is explained by Maclay, Rettman, and Small (1980) and by Piper (1944).

Median concentrations of calcium and alkalinity for each of the subareas decrease from subareas 1 to 4 (table 5). Ground water is saturated with respect to calcite in each of the four subareas, undersaturated with respect to dolomite and gypsum in subareas 1, 2, and 3, and saturated with respect to both dolomite and gypsum in the downdip part of subarea 4 (Pearson and Rettman, 1976). R.G. Deike (U.S. Geological Survey, written commun., 1985) documents the presence of dolomite in several members of formations in the Edwards Group (Rose, 1972) in core samples from subarea 3. Gradual dissolution of dolomite via the replacement of magnesium by calcium from ground water and dissolution of trace quantities of gypsum and celestite could explain the decrease in calcium and alkalinity from subareas 1 to 4.

The saturated state of ground water with respect to fluorite in the more saline parts of subarea 4 may similarly reflect the presence of more fluorite there relative to the freshwater parts of the aquifer. It is unlikely that fluorite is a major control on calcium concentrations in ground water. Fluorite does, however, appear to be a major contributor to fluoride concentrations in the more saline parts of subarea 4.

Significant differences using Tukey's HSD test were determined for all constituents in table 6 with respect to land use for subareas 1 and 2 except for noncarbonate hardness and fluoride. Bromide was not tested due to the small number of wells sampled for the constituent. Similar patterns in the Tukey's HSD test results for sodium and potassium indicate a potential association in the distribution with respect to land use. Median concentrations of sodium and potassium generally are larger for the small-city urban land use in subareas 1 and 2, the large-city urban land use in subarea 2, and the cropland land use in subarea 1. The smallest median concentrations of sodium and potassium were determined for the large-city urban and industrial land uses in subarea 1. The variability in sodium data, as determined by the difference between the 25th and 75th percentiles of the distribution, was largest for small-city urban land use in subarea 1 and for the cropland land use in subarea 2. Variability in potassium data generally ranged from 0.2 to 0.5 mg/L but was largest (1.0 mg/L) for the small-city urban land use in subarea 2. Interpretation of the statistical-test results are complicated by the variability of aquifer mineralogy and the lack of lithologic and mineralogic information at the wells sampled.

page 49 follows

Dissolved Oxygen and Hydrogen Sulfide

The concentrations of dissolved oxygen and hydrogen sulfide were used to qualitatively classify the redox state of water in the Edwards aquifer. Hydrogeologic environments containing appreciable concentrations of dissolved oxygen are classified as oxygenated, whereas those samples containing appreciable concentrations of hydrogen sulfide are classified as reduced. Occurrences of reduced water in oxygenated hydrogeologic environments have been used to identify plumes of contaminated ground water (Baedecker and Back, 1979). Concentrations of dissolved oxygen in ground water from subareas 1, 2, and 3 ranged from 2.2 to 6.9 mg/L (fig. 12). An anomalously small dissolved-oxygen concentration of 0.3 mg/L was measured in a sample from subarea 3 in northern San Antonio. Although this location is within 1 mi of several former city landfills, the San Antonio International Airport, and a warehouse used to store pesticides, no other dissolved species were substantially different in concentration when compared to other wells in the area. Hydrogen sulfide generally was not detected in water from wells in subareas 1, 2, and 3.

Two samples of water from subarea 4 (500 to 1,000 mg/L dissolved solids) from wells in southeastern Medina County and central Bexar County had dissolved-oxygen concentrations of <0.1 and 0.14 mg/L, and hydrogen sulfide concentrations of 12 and 0.8 mg/L, respectively. In general, water in the more salinewater parts of subarea 4 is relatively more reduced than that in the freshwater parts. Water from observation wells such as two in south-central Hays and central Bexar Counties, which contain both dissolved oxygen and hydrogen sulfide, may reflect penetration by the well of two diagenetically different environments, a gradual transition from freshwater to salinewater, or defectively cased wells. The solubility of redox-sensitive species such as dissolved iron and manganese should be increased in subarea 4 with respect to subareas 1 through 3.

Trace elements

Zinc, lead, arsenic, strontium, and lithium are the trace elements with the greatest number of median concentrations that equaled or exceeded the analytical detection limit (table 7). Selenium, barium, iron, and mercury were detected less frequently than those elements listed above and generally at concentrations equal to or less than three times the respective analytical detection limits. Other trace elements such as beryllium, cadmium, chromium, copper, manganese, silver, and vanadium either were not detected in concentrations greater than the detection limit or were detected in fewer than 10 percent of the wells sampled for trace elements.

Zinc and lead

Median concentrations of zinc in water from the Edwards aquifer typically ranged from 8 to 20 µg/L (micrograms per liter) as listed in table 7. Median concentrations of lead in ground water generally were less than 2 µg/L. The proportion of wells with water having median zinc or lead concentrations that equal or exceed the detection limits for those constituents did not vary substantially among subareas 1, 2, and 3. Results of the contingency-table analysis indicate that the occurrence of median concentrations, by well, of zinc

page 53 follows

Table 7.--Summary statistics for selected trace elements in ground water by subarea, 1976-85

[μg/L, microgram per liter; > DL, greater than detection limit; < DL, less than detection limit]

Constituent and statistics	Detection limit	Subarea			
		1	2	3	4
Arsenic (μg/L as As)	1.0				
Number detected (median > DL)		18	14	16	9
Number not detected (median < DL)		35	19	26	3
Median, detected		1.0	1.0	1.0	1.0
75th percentile, detected		1.0	1.0	1.0	1.5
Maximum, all samples		3.0	2.0	2.0	12.0
Barium (μg/L as Ba)	100.0				
Number detected (median > DL)		7	3	5	5
Number not detected (median < DL)		46	30	37	7
Median, detected		120.0	140.0	110.0	110.0
75th percentile, detected		200.0	200.0	150.0	250.0
Maximum, all samples		900.0	200.0	300.0	400.0
Iron (μg/L as Fe)	10.0				
Number detected (median > DL)		4	3	3	6
Number not detected (median < DL)		49	30	39	6
Median, detected		15.0	21.0	40.0	104.0
75th percentile, detected		19.0	50.0	50.0	320.0
Maximum, all samples		520.0	130.0	220.0	470.0
Lead (μg/L as Pb)	1.0				
Number detected (median > DL)		24	13	21	3
Number not detected (median < DL)		26	15	14	8
Median, detected		2.5	1.9	1.9	1.9
75th percentile, detected		4.0	2.5	3.5	2.5
Maximum, all samples		54.0	24.0	20.0	10.0
Lithium (μg/L as Li)	10.0				
Number detected (median > DL)		7	8	10	1
Number not detected (median < DL)		8	0	5	0
Median, detected		12.9	13.0	16.0	100.0
75th percentile, detected		19.0	15.5	18.3	--
Maximum, all samples		24.0	25.0	22.0	100.0
Mercury (μg/L as Hg)	0.1				
Number detected (median > DL)		1	4	5	5
Number not detected (median < DL)		47	22	30	6
Median, detected		.1	.3	.2	.3
75th percentile, detected		--	1.3	.3	.3
Maximum, all samples		1.0	1.7	3.6	9.6
Selenium (μg/L as Se)	1.0				
Number detected (median > DL)		6	9	7	3
Number not detected (median < DL)		45	20	29	9
Median, detected		1.0	1.0	1.0	1.0
75th percentile, detected		1.1	1.0	1.0	11.0
Maximum, all samples		6.0	2.0	3.0	11.0
Strontium (μg/L as Sr)	0.1				
Number		16	9	16	4
25th percentile		315.0	260.0	322.0	8,800.0
Median		510.0	370.0	545.0	17,000.0
75th percentile		651.0	520.0	1,240.0	23,700.0
Maximum, all samples		2,500.0	37,000.0	10,000.0	50,000.0
Tukey's HSD test		A	A	A	B
Zinc (μg/L as Zn)	3.0				
Number detected (median > DL)		37	22	28	9
Number not detected (median < DL)		13	8	12	2
Median, detected		20.0	12.3	9.0	8.0
75th percentile, detected		483.0	32.2	18.5	9.0
Maximum, all samples		2,900.0	900.0	540.0	21.0

and lead equal to or greater than the detection limit were not significantly different among all subareas. However, the median and 75th percentiles of the distribution of concentrations from each well that equaled or exceeded the detection limit were larger for zinc and lead in water from wells in subarea 1 than in water from wells in the other subareas. In general, median concentrations, by well, for zinc larger than 10 µg/L and for lead larger than 2 µg/L occur mainly in subareas 1 and 2 (figs. 13 and 14).

Zinc detections were most frequent in water from wells in the large-city urban land use in subareas 1 (87 percent) and 2 (100 percent) and least frequent in water from wells in the industrial land use in subarea 1 (two of five wells or 40 percent) as summarized in table 8. The occurrence of zinc concentrations greater than 100 µg/L in water samples from subarea 1 may be related to the volume of water pumped from the well prior to sample collection (fig. 15). A similar relation also was determined for zinc and pre-sampling pumpage for subareas 2 and 3. The use of zinc-galvanized materials in well construction commonly causes anomalously large concentrations of zinc in ground-water samples, even after the evacuation of several well-bore volumes (D.K. Nordstrom, U.S. Geological Survey, oral commun., 1985). Zinc also is used as a white-paint pigment and may be a component of some metal-plating wastes. The lack of zinc-galvanized materials or regular and long pumping of the wells yielding water with small zinc concentrations may explain some of the areal variability in zinc concentrations.

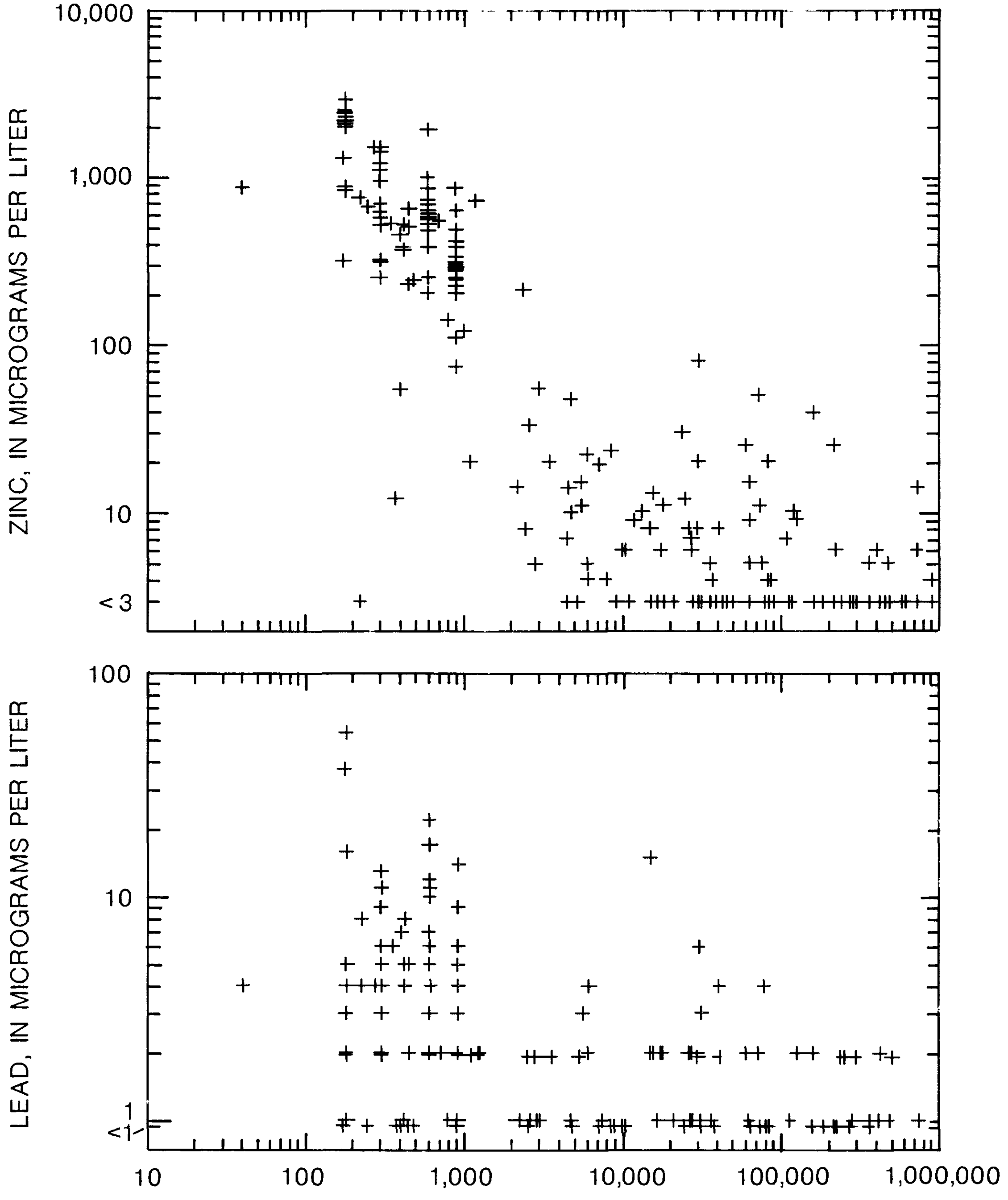
The fate of dissolved zinc in ground water is likely a function of advective-dispersive processes and to a lesser extent, ion sorption. Ground-water samples with zinc concentrations of the magnitudes reported for the freshwater parts of the aquifer are undersaturated with respect to the carbonate and hydroxide mineral phases modeled by WATEQ2F.

Concentrations of lead larger than 2 µg/L in subarea 1 are associated chiefly with samples collected after 100 to 1,000 gal of water have been pumped from a well (fig. 15). Unlike zinc, however, no relation with presampling pumpage was determined for lead in water samples collected from subareas 2 or 3. Lead was detected most frequently in water from wells associated with the large-city urban land use in subareas 1 and 2 (60 and 67 percent) and least frequently in water from wells associated with the cropland land use in subarea 1 (11 percent) as summarized in table 8.

Several wells, some of which are adjacent to losing streams in subarea 1 in Bexar and Comal Counties, historically have yielded water with lead concentrations ranging from 2 to 54 µg/L. The largest lead concentration in water from the Edwards aquifer was 54 µg/L in a sample from well AY-68-29-210 collected in August 1978 (fig. 16). A smaller area within subarea 2 in north-central Bexar County has several wells that typically yield water with lead concentrations ranging from 2 to 10 µg/L (fig. 14).

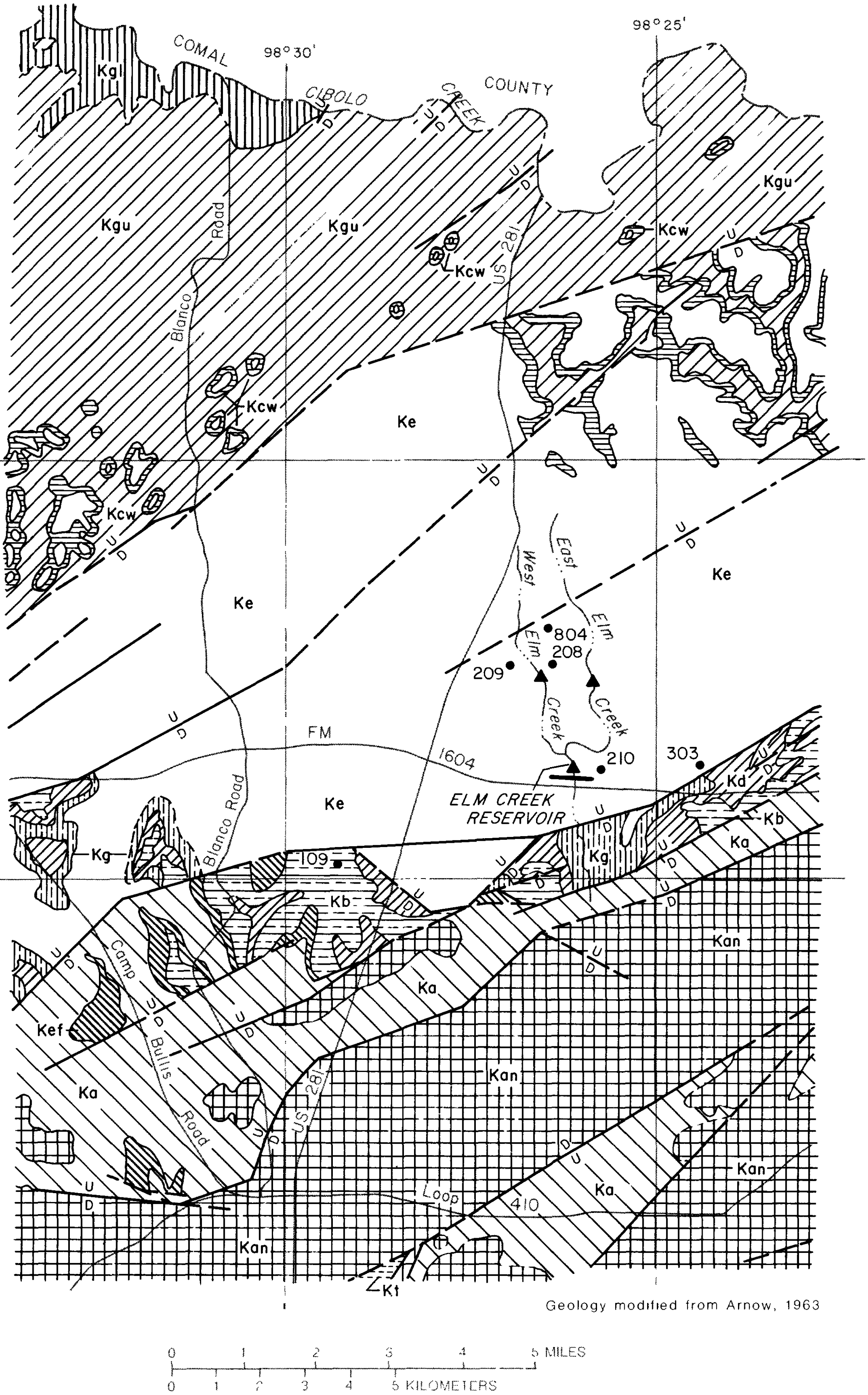
To evaluate the potential contribution of surface-water recharge to an occurrence of increased zinc and lead concentrations, plots of concentration with respect to time sampled were drawn for selected wells located near and downgradient from East and West Elm Creeks in northern Bexar County (fig. 16). The small concentrations of dissolved zinc and lead in water samples collected at gaging stations on East and West Elm Creeks and at the Elm Creek Reservoir No. 11 contrast with the larger concentrations in water samples from the adja-

page 59 follows



NOTE: "<" symbol denotes a concentration less than the analytical detection limit

Figure 15.--Relation of zinc and lead concentrations to volumes of water pumped before sample collection, subarea 1.



Geology modified from Arnow, 1963

Figure 16.--Geologic setting and location of selected wells and surface-water

EXPLANATION

CRETACEOUS	Gulfian series		Kt	TAYLOR MARL--Marl, and calcareous clay; not known to yield water
			Kan	ANACACHO LIMESTONE--Marly chalk; not known to yield water
			Ka	AUSTIN GROUP--Limestone and chalky limestone; yields small to large supplies of water of good to poor chemical quality
			Kef	EAGLE FORD GROUP--Shale and argillaceous limestone; not known to yield water
	Comanchean series	Washita group	Kb	BUDA LIMESTONE--Limestone; yields water for stock and domestic use near outcrop
			Kd	DEL RIO CLAY--Blue clay; not known to yield water
			Kg	GEORGETOWN LIMESTONE--Limestone and argillaceous limestone; part of the principal aquifer in the county
		Fredericksburg group	Ke	EDWARDS LIMESTONE--Mainly massive limestone and dolomite; part of the principal aquifer, which yields large supplies of water of good chemical quality for municipal, industrial, and irrigation use
			Kcw	COMANCHE PEAK LIMESTONE AND WALNUT CLAY--Limestone, sandy clay, and marl; limestone is part of principal aquifer in the county
		Trinity group	Kgu Kgl	GLEN ROSE FORMATION--Chalky limestone alternating with marly limestone. Upper member, Kgu; lower member, Kgl. Yields water for stock and domestic use in and near the outcrop

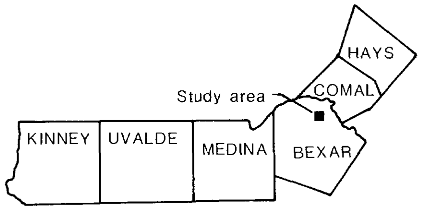
——— — — CONTACT--Dashed where approximately located

——$\overset{U}{\underset{D}{|}}$— — FAULT--U, upthrown side; D, downthrown side. Dashed where approximately located

210 ● WELL AND NUMBER

▲ LOCATION OF SURFACE WATER SAMPLING

—— DAM



LOCATION MAP

sampling sites near Elm Creek Reservoir No. 11.

Table 8.--Summary statistics for selected trace elements in ground water by land use in subareas 1 and 2, 1976-85

[µg/L, microgram per liter; > DL, greater than detection limit; < DL, less than detection limit]

Constituent and statistics	Detection limit	Subarea 1					Subarea 2			
		Large-city urban	Small-city urban	Industrial	Cropland	Forest and rangeland	Large-city urban	Small-city urban	Cropland	Forest and rangeland
Arsenic, dissolved (µg/L as As)	1.0									
Number detected (median > DL)		7	0	3	7	1	5	4	3	2
Number not detected (median < DL)		8	11	2	4	10	5	4	9	1
Median, detected		1.0	--	1.0	1.0	1.0	1.0	1.0	1.0	1.0
75th percentile, detected		1.0	--	1.0	1.0	--	1.0	1.0	1.0	1.0
Maximum, all samples		2.0	1.0	1.0	3.0	1.0	2.0	2.0	1.0	1.0
Barium, dissolved (µg/L as Ba)	100.0									
Number detected (median > DL)		0	4	2	1	0	0	1	2	0
Number not detected (median < DL)		15	7	3	10	11	10	7	10	3
Median, detected		--	115.0	290.0	200.0	--	--	140.0	170.0	--
75th percentile, detected		--	120.0	465.0	--	--	--	--	200.0	--
Maximum, all samples		400.0	300.0	900.0	300.0	200.0	100.0	200.0	200.0	48.0
Iron, dissolved (µg/L as Fe)	10.0									
Number detected (median > DL)		1	1	2	0	0	1	1	1	0
Number not detected (median < DL)		14	10	3	11	11	9	7	11	3
Median, detected		20.0	12.0	15.0	--	--	10.0	21.0	50.0	--
75th percentile, detected		--	--	15.0	--	--	--	--	--	--
Maximum, all samples		520.0	380.0	30.0	50.0	80.0	30.0	53.0	50.0	130.0
Lead, dissolved (µg/L as Pb)	1.0									
Number detected (median > DL)		9	6	3	1	5	6	3	2	2
Number not detected (median < DL)		6	4	2	8	6	3	4	8	0
Median, detected		4.0	2.0	4.0	3.0	2.0	2.0	2.0	2.0	2.0
75th percentile, detected		4.0	4.0	4.0	--	9.0	4.0	3.0	2.0	3.0
Maximum, all samples		17.0	22.0	8.0	4.0	54.0	11.0	24.0	5.0	16.0
Lithium, dissolved (µg/L as Li)	10.0									
Number detected (median > DL)		0	2	0	3	2	2	3	2	1
Number not detected (median < DL)		5	1	2	0	0	0	0	0	0
Median, detected		--	14.0	--	12.0	15.0	11.0	16.0	12.0	14.0
75th percentile, detected		--	15.0	--	24.0	19.0	13.0	25.0	13.0	--
Maximum, all samples		10.0	16.0	10.0	24.0	19.0	15.0	25.0	13.0	14.0
Mercury, dissolved (µg/L as Hg)	0.1									
Number detected (median > DL)		0	0	0	1	0	2	2	0	0
Number not detected (median < DL)		15	10	5	7	10	7	5	8	2
Median, detected		--	--	--	.1	--	.9	.2	--	--
75th percentile, detected		--	--	--	--	--	1.6	.3	--	--
Maximum, all samples		1.0	.4	.4	.3	.5	1.7	.6	.2	.2

Table 8.--Summary statistics for selected trace elements in ground water by land use in subareas 1 and 2, 1976-85--Continued

Constituent and statistics	Detection limit	Subarea 1					Subarea 2			
		Large-city urban	Small-city urban	Industrial	Cropland	Forest and rangeland	Large-city urban	Small-city urban	Cropland	Forest and rangeland
Selenium, dissolved (µg/L as Se)	1.0									
Number detected (median > DL)		1	0	0	4	1	5	2	2	0
Number not detected (median < DL)		14	10	5	6	10	5	5	8	2
Median, detected		1.0	--	--	1.0	1.0	1.0	1.0	1.0	--
75th percentile, detected		--	--	--	1.0	--	1.0	1.0	1.0	--
Maximum, all samples		6.0	1.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0
Strontium, dissolved (µg/L as Sr)	0.1									
Number		5	3	2	3	3	2	4	2	1
25th percentile		370.0	550.0	220.0	280.0	150.0	270.0	175.0	360.0	--
Median		970.0	620.0	345.0	360.0	400.0	340.0	440.0	365.0	410.0
75th percentile		1,850.0	625.0	470.0	660.0	620.0	410.0	27,907.0	370.0	--
Maximum, all samples		2,500.0	630.0	470.0	660.0	620.0	440.0	37,000.0	370.0	410.0
Zinc, dissolved (µg/L as Zn)	3.0									
Number detected (median > DL)		13	8	2	7	8	8	6	5	3
Number not detected (median < DL)		2	3	3	3	3	0	2	6	0
Median, detected		315.0	18.0	278.0	5.0	157.0	20.0	6.0	11.0	33.0
75th percentile, detected		765.0	138.0	490.0	14.0	455.0	152.0	19.0	22.0	205.0
Maximum, all samples		2,900.0	1,900.0	640.0	25.0	1,300.0	900.0	50.0	32.0	410.0

cent wells (fig. 17). The lead concentrations in water from a well next to the dam (AY-68-29-210, fig. 16) have been consistently among the largest measured in water from the aquifer since 1978. Although the relatively large zinc and lead concentrations at this location do not seem to be the result of surface-water recharge, the possibility of zinc and lead being transported into the aquifer via sorption onto bed material and suspended solids requires further study.

Some potential sources of lead in ground water may be from leaded gasoline, aerosol deposition, battery wastes, and paint pigments. Woodruff and Foley (1985) describe the natural occurrence of "amomalous concentrations of lead" in some salinewaters sampled from oil and gas wells completed in the Edwards aquifer downdip from the "bad-water" line. Lead, therefore, may be mineralogically present in isolated locations of the aquifer that had previously been associated with the upwelling of deep, basinal waters along faults or fractures. At present, the primary sources of lead detected in water samples from the freshwater part of the aquifer are unknown.

Arsenic, strontium, lithium, selenium, barium, iron, and mercury

Arsenic commonly is detected in water from the Edwards aquifer at concentrations ranging from 1 to 3 µg/L. The proportion of wells yielding water with median arsenic concentrations that equaled or exceeded the detection limit did not vary substantially between subareas 1, 2, and 3 (table 7). Detections of arsenic in water were most frequent in wells associated with the cropland land use in subarea 1 (64 percent) and least frequent in wells associated with the forest and rangeland land use in subarea 1 (9 percent) as shown in table 8. Strontium was detected in all ground-water samples analyzed for its concentration. Median strontium concentrations also did not vary substantially between subareas 1, 2, and 3 (table 7). Strontium was not sampled in a sufficient number of wells in all land-use groups to enable a meaningful comparison. Median-detected lithium and selenium concentrations did not vary substantially between subareas or land-use groups. The proportion of wells yielding water with median barium and iron concentrations that equaled or exceeded the detection limit was significantly greater in subarea 4 than in the other three subareas. Barium was detected principally in only one land-use setting, in water from those wells associated with the small-city urban land use in subarea 1 (36 percent). Neither iron nor mercury generally were detected in water from wells associated with each of the land uses in subareas 1 and 2.

Arsenic, barium, iron, and mercury are detected more frequently in subarea 4 than in the other three subareas. Strontium and barium concentrations in ground water are greater in the more saline parts of subarea 4 where dissolved-solids concentrations exceed 500 mg/L. Pearson and Rettman (1976) reported that many water samples from the Edwards aquifer with dissolved-solids concentrations exceeding 1,000 mg/L also may be slightly undersaturated to saturated with respect to celestite [$SrSO_4(s)$]. R.G. Deike (U.S. Geological Survey, written commun., 1985) reported that core samples from the salinewater part of subarea 4 and from poorly leached members of subarea 3 contained as much as 5 percent celestite and pyrite and an unquantified amount of organic carbon. Several elements such as strontium, barium, and iron were detected in milligrams per kilogram quantities in dolomite and calcite in cores collected from the freshwater and salinewater parts of the Edwards aquifer. In addition, ground water was slightly saturated with respect to barite [$BaSO_4(s)$] in water

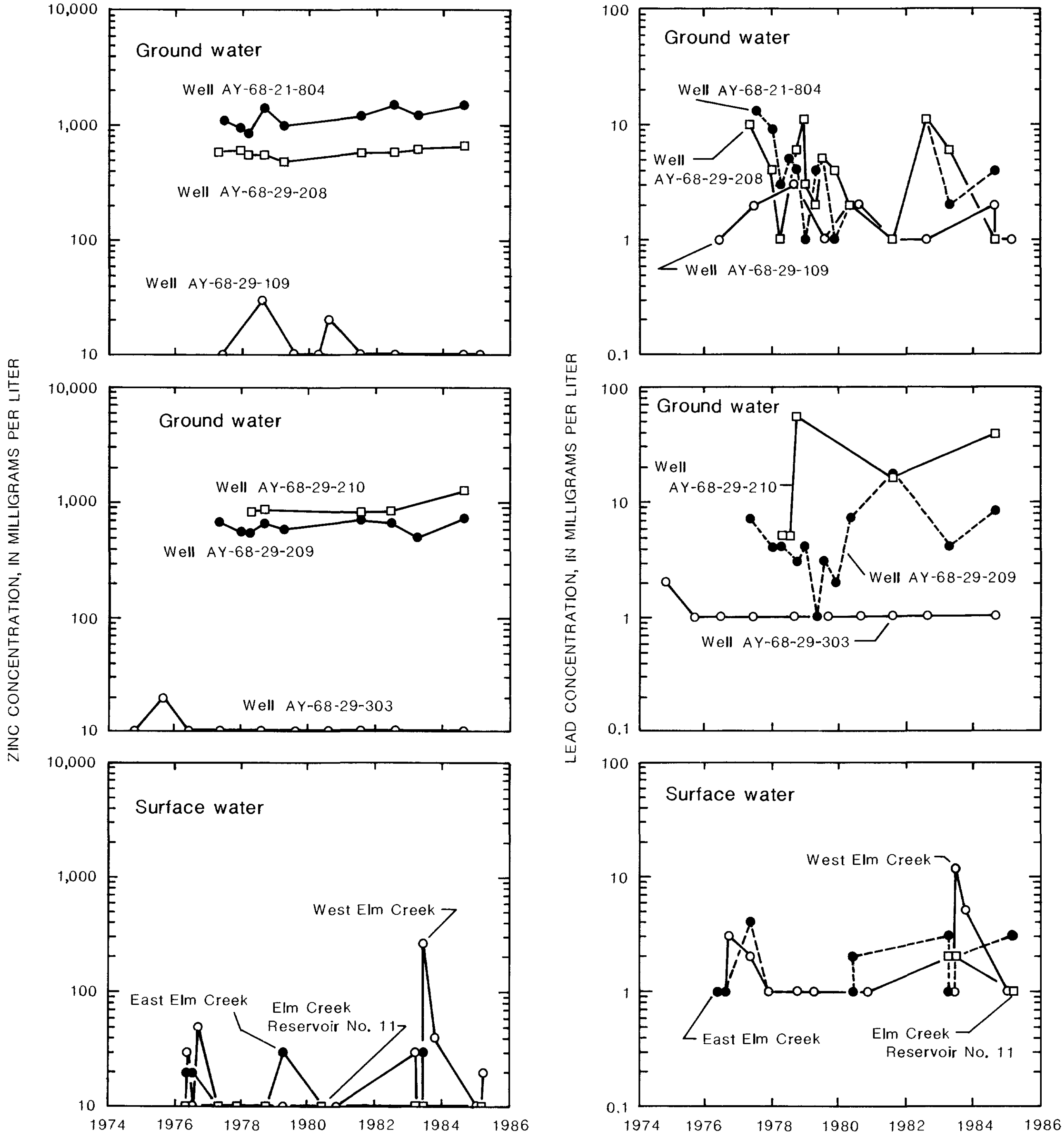


Figure 17.--Long-term of dissolved zinc and lead in ground water and surface water near Elm Creek Reservoir No. 11, 1974-85.

from two wells in southern Medina and south-central Hays Counties that are located in or within 1 mi of salinewater in subarea 4. The lack of variation in detection of these trace elements throughout subareas 1, 2, and 3 indicates a natural rather than human-induced source for arsenic, strontium, barium, and iron.

Detections of dissolved mercury in ground water may have been the result of flawed sampling procedures. Interferences with respect to mercury have been determined to result from contamination of unpreserved samples when stored with samples preserved with mercuric chloride and from the introduction of elemental mercury used for operations at surface-water streamflow-gaging stations. These sources of contamination recently have been addressed through revised sampling and handling protocols.

Maximum contaminant-level exceedances

One sample collected in 1978 from well AY-68-29-210 contained 54 µg/L dissolved lead, exceeding the maximum contaminant level of 50 µg/L (U.S. Environmental Protection Agency, 1982). Three samples from two wells in Medina County contained concentrations of cadmium and mercury larger than the maximum contaminant levels for each element. The cadmium concentration was detected in well TD-68-49-813, located on the "bad-water" line in subarea 4. The restricted flow conditions and the lack of tritium in water from this part of the aquifer indicates that the source of the cadmium is natural or an artifact of sampling, transport, or analytical procedures.

Nine samples of water from seven different wells completed in the Edwards aquifer have exceeded the secondary maximum contaminant levels (U.S. Environmental Protection Agency, 1977) for iron or manganese or both in public water supplies (fig. 18). Iron and manganese concentrations in water from subareas 1, 2, and 3 typically are less than 10 µg/L. The source of the manganese at well TD-68-49-813 probably is the mobilization of naturally-occurring manganese under the reducing conditions in the salinewater part of the aquifer. Two of the exceedances for manganese occurred at wells AY-68-28-918 and AY-68-28-920, which are located in subarea 2 within 0.25 mi of an abandoned landfill in north-central Bexar County. The maximum and secondary maximum contaminant levels for regulated elements, compounds, and chemical properties are listed in table 9.

Nutrients, Bacteria, and Selected Organic Constituents

Three constituents, nitrite plus nitrate, organic nitrogen plus ammonium, and dissolved organic carbon were detected in sufficient samples to examine their distribution with respect to subarea and land use using Tukey's HSD test analysis (tables 10 and 11). Of the three constituents, only the distribution of nitrite plus nitrate concentration was significantly different with respect to subarea. The nitrite plus nitrate analysis results in nearly all cases are composed almost entirely of nitrate. Typical nitrite concentrations were less than 0.01 mg/L. The median concentrations, by well, of nitrite plus nitrate were equal for subareas 1, 2, and 3. The 75th-percentile concentrations of this constituent decreased from subarea 1 (2.5 mg/L) to subarea 4 (1.8 mg/L). Water in subarea 4 had significantly smaller median concentrations of nitrite plus nitrate with respect to the other three subareas. The occurrence of

page 69 follows

Table 9.--Summary of regulations for selected water-quality constituents and properties for public water systems 1/

[µg/L, microgram per liter; mg/L, milligram per liter; °C, degree Celsius]

Constituent or property 2/	Primary maximum contaminant level 3/	Secondary maximum contaminant level 4/
	Inorganic chemicals and related properties	
Arsenic (As)	50 µg/L	--
Barium (Ba)	1,000 µg/L	--
Cadmium (Cd)	10 µg/L	--
Chloride (Cl)	--	250 mg/L
Chromium (Cr)	50 µg/L	--
Copper (Cu)	--	1,000 µg/L
Iron (Fe)	--	300 µg/L
Lead (Pb)	50 µg/L	--
Manganese (Mn)	--	50 µg/L
Mercury (Hg)	2 µg/L	--
Nitrate (as N)	10 mg/L	--
Selenium (Se)	10 µg/L	--
Silver (Ag)	50 µg/L	--
Sulfate (SO_4)	--	250 mg/L
Zinc (Zn)	--	5,000 µg/L
Dissolved solids	--	500 mg/L
Fluoride 5/ Average of maximum daily air temperature (°C)		
12.0 and below	2.4 mg/L	--
12.1 - 14.6	2.2 mg/L	--
14.7 - 17.6	2.0 mg/L	--
17.7 - 21.4	1.8 mg/L	--
21.5 - 26.2	1.6 mg/L	--
26.3 - 32.5	1.4 mg/L	--
pH (standard units)	--	6.5 - 8.5
	Organic chemicals	
Chlorinated hydrocarbons		
Endrin	0.2 µg/L	--
Lindane	4 µg/L	--
Methoxychlor	100 µg/L	--
Toxaphene	5 µg/L	--
Chlorophenoxys		
2,4-D	100 µg/L	--
Silvex	10 µg/L	--

1/ Public water system.--A system for the provision of piped water to the public for human consumption, if such system has at least 15 service connections or regularly serves at least 25 individuals daily at least 60 days out of the year.

2/ Constituent.--Any chemical, biological, or radiological substance or matter in water.

3/ Primary maximum contaminant level.--The maximum permissible level of a contaminant in water which is delivered to the free-flowing outlet of the ultimate user of a public water system. Maximum contaminant levels are those levels set by the U.S. Environmental Protection Agency (1976) in the National Interim Primary Drinking Water Regulations. These regulations deal with contaminants that may have a significant direct effect on the health of the consumer and are enforceable by the U.S. Environmental Protection Agency.

4/ Secondary maximum contaminant level.--The advisable maximum level of a contaminant in water which is delivered to the free-flowing outlet of the ultimate user of a public water system. Secondary maximum contaminant levels are those levels proposed by the U.S. Environmental Protection Agency (1977) in the National Secondary Drinking Water Regulations. These regulations deal with contaminants that may not have a significant direct effect on the health of the consumer, but their presence in excessive quantities may affect the esthetic qualities of the water and may discourage the use of a drinking-water supply by the public.

5/ Fluoride.--The maximum contamination level for fluoride depends on the annual average of the maximum daily air temperatures for the location in which the public water system is situated.

Table 10.--Summary statistics for selected nutrient, bacteria, and organic constituents in ground water by subarea, 1976-85

[mg/L, milligram per liter; > DL, greater than detection limit; < DL, less than detection limit; cols./100 mL, colonies per 100 milliliters]

Constituent and statistics	Detection limit	Subarea			
		1	2	3	4
Nitrogen, nitrite plus nitrate, total (mg/L as N)	0.1				
Number detected (median > DL)		42	28	27	3
Number not detected (median < DL)		0	0	2	6
Median, detected		1.7	1.7	1.7	.8
75th percentile, detected		2.5	2.4	1.9	1.8
Maximum, all samples		5.8	6.2	7.2	1.8
Tukey's HSD test		A	A	A	B
Nitrogen, organic plus ammonium, total (mg/L as N)	0.2				
Number detected (median > DL)		42	28	28	9
Number not detected (median < DL)		0	0	1	0
Median, detected		.6	.6	.6	.6
75th percentile, detected		.9	.8	.8	.9
Maximum, all samples		7.1	1.6	1.5	9.3
Tukey's HSD test		A	A	A	A
Phosphorous, total (mg/L as P)	0.01				
Number detected (median > DL)		34	23	18	7
Number not detected (median < DL)		8	5	9	1
Median, detected		.02	.01	.02	.02
75th percentile, detected		.03	.03	.03	.02
Maximum, all samples		.14	.22	.09	.08
Total-coliform bacteria, membrane filter, immediate m-endo medium (cols./100 mL)	1.0				
Number detected (median > DL)		10	0	2	0
Number not detected (median < DL)		33	21	23	4
Median, detected		10.0	--	3.0	--
75th percentile, detected		72.0	--	3.0	--
Maximum, all samples		6,300.0	3.0	110.0	1.0
Fecal-coliform bacteria, 0.7 um-mf (cols./100 mL)	1.0				
Number detected (median > DL)		5	0	0	0
Number not detected (median < DL)		35	21	24	4
Median, detected		4.0	--	--	--
75th percentile, detected		7.0	--	--	--
Maximum, all samples		47.0	3.0	24.0	1.0
Fecal-streptococci bacteria, membrane filter, kf agar (cols./100 mL)	1.0				
Number detected (median > DL)		6	1	1	1
Number not detected (median < DL)		34	20	23	3
Median, detected		8.0	2.0	3.0	23.0
75th percentile, detected		43.0	--	--	--
Maximum, all samples		200.0	160.0	150.0	44.0
Carbon, dissolved organic (mg/L as C)	0.1				
Number detected (median > DL)		53	33	42	15
Number not detected (median < DL)		2	0	0	1
Median, detected		.7	.7	.7	.6
75th percentile, detected		1.4	1.1	1.1	1.5
Maximum, all samples		16.0	59.0	35.0	13.0
Tukey's HSD test		A	A	A	A
Methylene blue active substances (mg/L)	0.01				
Number detected (median > DL)		18	8	7	0
Number not detected (median < DL)		21	9	16	1
Median, detected		.05	.075	.05	--
75th percentile, detected		.10	.10	.10	--
Maximum, all samples		1.00	.20	.20	.00

Table 11.--Summary statistics for selected nutrient, bacteria, and organic constituents in ground water by land use in subareas 1 and 2, 1976-85

[mg/L, milligram per liter; > DL, greater than detection limit; < DL, less than detection limit; cols./100 mL, colonies per 100 milliliters]

Constituent and statistics	Detection limit	Subarea 1					Subarea 2			
		Large-city urban	Small-city urban	Industrial	Cropland	Forest and rangeland	Large-city urban	Small-city urban	Cropland	Forest and rangeland
Nitrogen, nitrite plus nitrate, total (mg/L as N)	0.1									
Number detected (median > DL)		12	10	3	6	11	9	9	7	3
Number not detected (median < DL)		0	0	0	0	0	0	0	0	0
Median, detected		1.2	1.8	1.8	2.8	1.6	1.8	1.8	1.7	.8
75th percentile, detected		2.1	3.1	2.1	3.7	1.8	2.1	2.8	3.6	1.3
Maximum, all samples		5.8	4.0	2.2	3.8	3.3	3.3	6.2	3.8	1.5
Tukey's HSD test		B	AB	AB	A	AB	AB	AB	AB	B
Nitrogen, organic plus ammonium, total (mg/L as N)	0.2									
Number detected (median > DL)		12	10	3	6	11	9	9	7	3
Number not detected (median < DL)		0	0	0	0	0	0	0	0	0
Median, detected		.6	.5	.5	.8	.9	.8	.5	.6	.5
75th percentile, detected		.9	.6	.9	2.6	1.3	.9	.7	.8	.6
Maximum, all samples		1.7	4.1	1.5	7.1	3.6	1.6	1.0	1.3	1.0
Tukey's HSD test		BC	ABC	C	ABC	AB	A	ABC	ABC	AB
Phosphorus, total (mg/L as P)	0.01									
Number detected (median > DL)		12	4	3	5	10	9	6	5	3
Number not detected (median < DL)		0	6	0	1	1	0	3	2	0
Median, detected		.03	.02	.03	.02	.03	.01	.02	.04	.02
75th percentile, detected		.03	.03	.04	.02	.03	.03	.02	.08	.03
Maximum, all samples		.14	.04	.05	.13	.13	.22	.14	.15	.03
Total-coliform bacteria, membrane filter, immediate m-endo medium (cols./100 mL)	1.0									
Number detected (median > DL)		4	1	0	1	4	0	0	0	0
Number not detected (median < DL)		12	5	3	9	4	5	7	6	3
Median, detected		57.0	7.0	--	2.0	16.0	--	--	--	--
75th percentile, detected		258.0	--	--	--	53.0	--	--	--	--
Maximum, all samples		6,300.0	70.0	3,600.0	3.0	64.0	1.0	1.0	1.0	3.-
Fecal-coliform bacteria, 0.7 um-mf (cols./100 mL)	1.0									
Number detected (median > DL)		2	1	1	0	1	0	0	0	0
Number not detected (median < DL)		14	5	2	7	7	5	7	6	3
Median, detected		5.0	3.0	4.0	--	7.0	--	--	--	--
75th percentile, detected		7.0	--	--	--	--	--	--	--	--
Maximum, all samples		30.0	47.0	18.0	1.0	12.0	1.0	1.0	1.0	3.0

Table 11.--Summary statistics for selected nutrient, bacteria, and organic constituents in ground water by land use in subareas 1 and 2, 1976-85--Continued

Constituent and statistics	Detection limit	Subarea 1					Subarea 2			
		Large-city urban	Small-city urban	Industrial	Cropland	Forest and rangeland	Large-city urban	Small-city urban	Cropland	Forest and rangeland
Fecal-streptococci bacteria, membrane filter kf agar (cols./100 mL)	1.0									
Number detected (median > DL)		2	1	1	0	2	0	0	0	1
Number not detected (median < DL)		14	5	2	7	6	5	7	6	2
Median, detected		36.0	2.0	5.0	--	22.0	--	--	--	2.0
75th percentile, detected		64.0	--	--	--	36.0	--	--	--	--
Maximum, all samples		200.0	65.0	57.0	1.0	44.0	1.0	1.0	1.0	160.0
Carbon, dissolved organic (mg/L as C)	0.1									
Number detected (median > DL)		15	11	4	9	14	10	9	12	2
Number not detected (median < DL)		0	0	1	1	0	0	0	0	0
Median, detected		1.0	.6	.8	.8	.7	.8	.7	.6	1.1
75th percentile, detected		1.6	1.3	1.4	2.0	1.3	1.0	1.6	1.1	1.1
Maximum, all samples		16.0	11.0	6.7	8.4	13.0	59.0	17.0	16.0	11.0
Tukey's HSD test		A	A	A	A	A	A	A	A	A
Methylene blue active substance (mg/L)	0.01									
Number detected (median > DL)		4	2	2	2	8	0	5	2	1
Number not detected (median < DL)		12	3	3	3	0	3	2	4	0
Median, detected		.1	.1	.1	.1	.1	--	.1	.1	.1
75th percentile, detected		.1	.1	.1	.2	.2	--	.1	.1	--
Maximum, all samples		.3	.1	.2	.2	1.0	.0	.2	.1	.1

median concentrations of total phosphorus and methylene blue active substances that equal or exceed the analytical detection limit is not substantially different among the subareas.

The areal pattern of median nitrite plus nitrate concentrations in water for each well (fig. 19) generally coincides with the distribution of tritium in the aquifer as reported by Pearson and Rettman (1976) and Maclay, Rettman, and Small (1980). Areas where median nitrite plus nitrate concentrations generally are larger occur in central Uvalde County and in subareas 1 and 2 of Bexar County. These patterns of nitrite plus nitrate concentration also support the patterns of regional ground-water flow in the Edwards aquifer as shown in figure 6 and described by R.W. Maclay (U.S. Geological Survey, written commun., 1985) and of regional recharge as reported by Puente (1978).

The land use with the greatest variability in concentrations of nitrite plus nitrate is the small-city urban land use in subarea 2 (fig. 20). The least variability for nitrite plus nitrate was determined for the industrial land use in subarea 1 and for the forest and rangeland land use in subarea 2. The median concentration of nitrite plus nitrate was largest for the cropland land use in subarea 1 (2.8 mg/L) and smallest for the forest and rangeland land use in subarea 2 (0.8 mg/L). The statistically small number of wells in each of the land-use groups, however, limits the accuracy of the Tukey's HSD test and discussion of the difference in statistic magnitude. However, these interpretations indicate areas of concern for future study.

A study of the nitrogen isotopic composition of ground water concluded that the total quantity of nitrate recharging the aquifer was sufficient to explain the nitrate distribution in ground water (Kreitler and Browning, 1983). The nitrogen-15/nitrogen-14 isotopic ratios of nitrate in unconfined-zone water (1.9 to 10.0 parts per mille of nitrogen-15) and confined-zone water (3.4 to 10.0 parts per mille of nitrogen-15) are similar in range to that measured in the base flows of perennial streams (5.9 to 8.3 parts per mille of nitrogen-15). These isotopic ratios indicate the source of the nitrate in ground water to be primarily from the base flow of these perennial streams (Kreitler and Browning, 1983). The surface-water concentrations of nitrogen-15 in nitrate appear to be from the natural mineralization of organic nitrogen in soil humus. Kreitler and Browning's (1983) conclusions from nitrogen isotopic data need to be qualified because of the lack of information available about: (1) The effect of depth integration of ground water sampled from production wells on nitrate, organic nitrogen, and ammonium concentrations and on nitrogen isotopic ratios, and (2) the effect of the preservation method used after water-sample collection. The first factor could artificially dilute the contaminant concentrations that are contributed by point sources to more typical concentrations for water from the Edwards aquifer. Because the samples were preserved using a refrigeration/freezing technique, the isotopic composition of the sample may be somewhat different than that actually collected at the sample source, depending on the interval between storage and collection (Carol Kendall, U.S. Geological Survey, oral commun., 1986). The relatively rapid analysis of samples after collection indicates that the second effect is minor in importance (R.D. Reeves, U.S. Geological Survey, oral commun., 1986).

The presence of total-coliform, fecal-coliform, or fecal-streptococci bacteria in ground-water samples has been used as an indicator of possible pollution from sewage disposal (Reeves, 1976). The median concentration of

page 77 follows

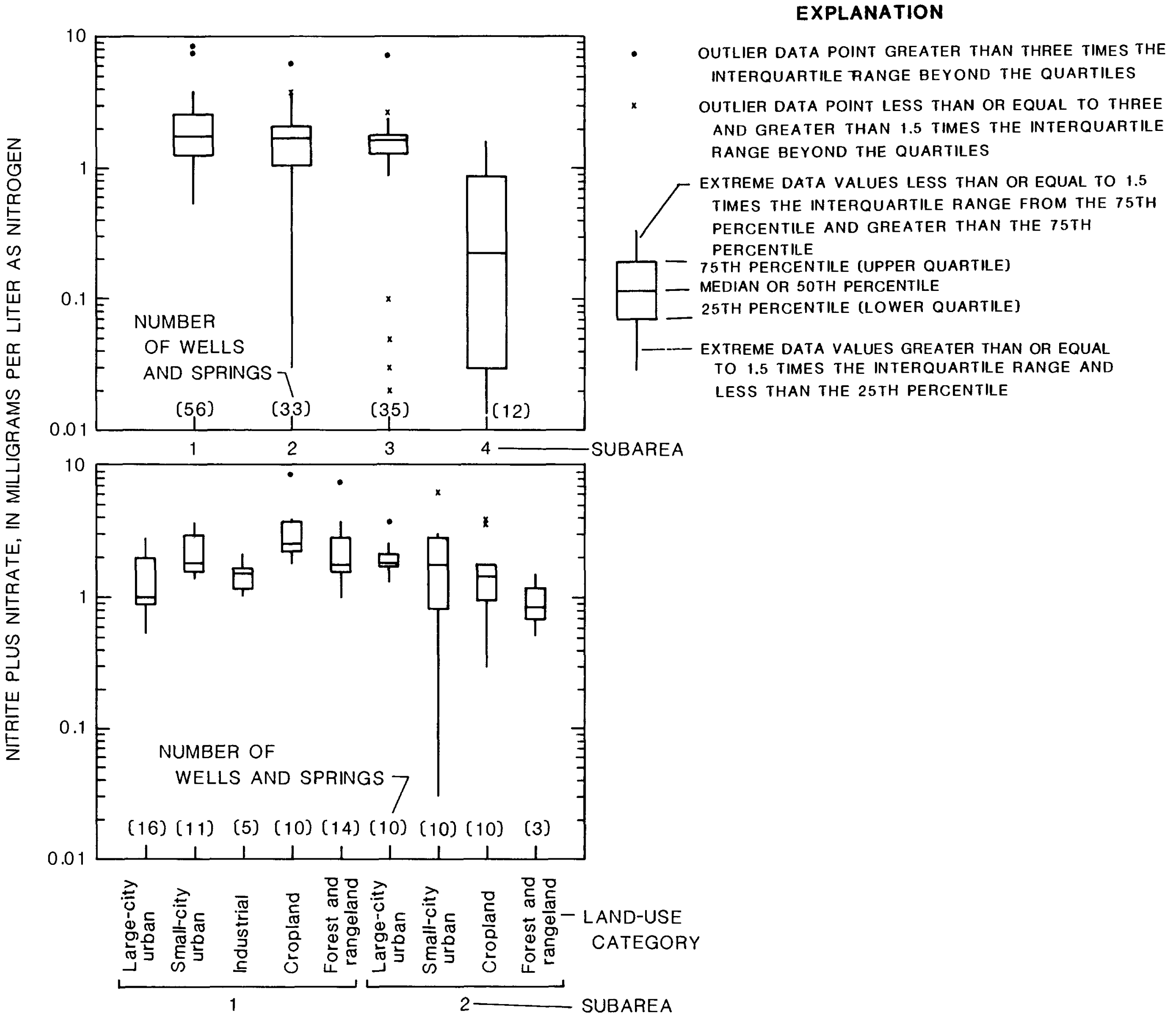


Figure 20.--Boxplots showing median concentrations of nitrite plus nitrate with respect to subareas and land use for sampled wells and springs in subareas 1 and 2.

total-coliform bacteria at sampled wells exceeded the detection limit (1 colony per 100 milliters of sample) in 30 percent of wells in subarea 1, 8 percent of wells in subarea 3, and in no wells from subareas 2 and 4. Similar statistical patterns with respect to subarea also were evident for fecal-coliform and fecal-streptoccoci bacteria. Of the three bacterial analyses, only the median concentration of total-coliform bacteria exceeding the detection limit was significantly larger in subarea 1 in comparison to the other subareas, as indicated by a contingency-table test. Reeves (1976) suggested that wells in subareas 3 and 4 with the indicator bacteria present generally have defective casing. Defectively-cased wells may allow contaminants from the land surface to enter the aquifer via the well itself or the annulus between the casing and borehole wall. Wells with at least one detection of total-coliform, fecal-coliform, or fecal-streptococci bacteria are located predominantly in subarea 1 (fig. 21).

Seventeen samples were collected from 9 wells and 2 springs in 1982 and 1983 and analyzed for their content of acid- or base-neutral-extractable nonvolatile organic compounds (fig. 22). The nine samples collected in 1982 and two of the eight samples collected in 1983 were analyzed using a gas-chromatographic scan combined with a mass-spectrometric detector (GC/MS) for compound identification. Fifty-six additional samples of ground water collected in 1984 and 1985, and the eight samples collected in 1983 were analyzed for their content of acid- or base-neutral-extractable nonvolatile organic compounds with a gas-chromatographic scan using a flame-ionization detector (GC/FID) (fig. 22).

The GC/MS analytical method was used to identify semivolatile and nonvolatile organic compounds that are extractable from water using an acid- or base-neutral extraction into methylene chloride. Compounds were identified by comparing their mass spectral patterns with those in a library of over 40,000 compounds. As applied, the method had a detection limit of 0.1 µg/L as related to an internal standard compound.

The GC/FID analytical method is used to indicate the presence of semivolatile and nonvolatile, methylene-chloride-extractable organic compounds that contain carbon-hydrogen bonding as part of their molecular structure. The method has a detection limit of 0.3 to 0.5 µg/L as related to a standard compound internal to the FID. No peaks corresponding to acid- or base-neutral-extractable nonvolatile organic compounds were identified in water samples from the aquifer using the GC/FID scan. Because there is no record of the location of the samples collected in 1983 that were analyzed by GC/FID, only the locations sampled during this study are included in figure 22.

The compounds identified by the GC/MS analysis of the ground-water samples collected in 1982 are listed in table 12. One or more of the acid-extractable compounds such as the methylesters of benzoic, butanoic, octanoic, decanoic, dodecanoic, tetradecanoic, hexadecanoic, octadecanoic, hexanoic, and nonanoic acids were detected in concentrations of between 0.1 and 1.1 µg/L at all of the wells and springs sampled except at well AY-68-28-903. Benzoic acid is a compound present in the waste of nearly all vertebrates (Merck and Company, 1983). The decanoic-acid compounds are common, nonvolatile fatty-acid components of natural water (Thurman, 1985). These fatty acids may originate from the decomposition of plant and soil organic matter, the hydrolysis of fats and triacylglycerols, or the decomposition of phytoplankton and algae. The lack of vola-

page 83 follows

Table 12.--Analyses for acid- or base-neutral-extractable organic compounds in water from selected wells and springs, 1982 1/

[µg/L, microgram per liter]

Well number	Date	Extract	Compound	Concentration (µg/L)
AY-68-27-303	June 16, 1982	Acid	Benzoic acid, methylester	0.2
			Tetradecanoic acid, methylester	.1
			Hexadecanoic acid, methylester	.4
			Octadecanoic acid, methylester	.3
			Nonanoic acid, methylester	.4
		Base-neutral	Diethyl phthalate	.2
AY-68-27-305	June 16, 1982	Acid	Benzoic acid, methylester	.4
			Butanoic acid, methylester	1.1
			Decanoic acid, methylester	.2
			Dodecanoic acid, methylester	.2
			Hexanoic acid, methylester	.3
			Nonanoic acid, methylester	.2
			Cyclohexane carboxylic acid, methylester	.8
			Benzene propanoic acid, methylester	.4
		Base-neutral	Diethyl phthalate	.9
AY-68-27-503	June 23, 1982	Acid	Hexadecanoic acid, methylester	.3
			Hexanoic acid, methylester	.2
			Butyl methyl phthalate	2.0
		Base-neutral	M-Xylene	.2
			2-Butoxy ethyl butyl phthalate	.3
			Diethyl phthalate	.9
AY-68-28-502	June 24, 1982	Acid	Hexadecanoic acid, methylester	.4
		Base-neutral	Diethyl phthalate	1.5
AY-68-28-903	June 24, 1982	Base-neutral	Tetrachloroethylene	.5
			2-Octanone	1.0
			2-Heptanol, 6-methyl	.6
			1,2,3-Propanetriol, triacetate	.3
AY-68-29-209	June 15, 1982	Acid	Benzoic acid, methylester	.4
			Dodecanoic acid, methylester	.2
			Hexadecanoic acid, methylester	.3
			Nonanoic acid, methylester	.4
		Base-neutral	2-Octanone	.5
			2-Octanol	.9
			Diethyl phthalate	2.6
AY-68-29-210	June 15, 1982	Acid	Benzoic acid, methylester	.4
			Octanoic acid, methylester	.2
			Hexadecanoic acid, methylester	.5
			Hexanoic acid, methylester	.2
		Base-neutral	Diethyl phthalate	3.4
DX-68-23-301	June 14, 1982	Acid	Benzoic acid, methylester	.3
			Octanoic acid, methylester	.2
			Hexadecanoic acid, methylester	.4
			Octadecanoic acid, methylester	.3
			Hexanoic acid, methylester	.3
			Nonanoic acid, methylester	.5
		Base-neutral	Diethyl phthalate	4.3
LR-67-01-801	June 14, 1982	Acid	Benzoic acid, methylester	.3
			Hexadecanoic acid, methylester	.5
			Octadecanoic acid, methylester	.2
			Nonanoic acid, methylester	.3
		Base-neutral	Diethyl phthalate	.6

1/ Reeves and Ozuna, 1985.

tile fatty acids in the ground-water samples suggests that the compounds formed in an oxygenated environment rather than an anaerobic environment typical of a landfill or a septic tank.

Diethyl phthalate was detected in concentrations ranging from 0.2 to 4.3 µg/L in the base-neutral extracts of seven of the eight samples analyzed in 1982. The compound is a commonly used plasticizer, indicating that well construction materials or sample contact with plastic materials may have been the source.

Volatile Organic Compounds

One hundred and seven samples of water from 78 wells completed in the Edwards aquifer were analyzed between 1982 and 1984 to determine the concentration of 27 volatile organic compounds (VOC). The types of these compounds varies from degreasers (carbon tetrachloride, trichloroethylene, and tetrachloroethylene) to solvents (benzene, chloroform, methylene chloride, and toluene) to plasticizers (vinyl chloride) to refrigerants (trichlorofluoromethane) to trihalomethane reaction products from the chlorination of drinking water supplies (bromoform, chlorobenzene, chlorodibromomethane, and chloroform). Summary statistics for those VOC that have been detected in samples from at least three wells from one or more subareas are listed with respect to subarea in table 13 and land use in table 14.

Median concentrations of tetrachloroethylene (C_2Cl_4) were equal to or greater than the detection limit (1 µg/L) in water from 17 percent of the wells sampled in subarea 1, 24 percent of the wells sampled in subarea 2, and in no wells sampled in subareas 3 and 4. A contingency-table analysis indicated a significant difference between subareas with respect to the occurrence of wells yielding water with median tetrachloroethylene concentrations equal to or greater than the detection limit. All the samples from subarea 1 in the "detected" category were associated with the small-city urban land use over an area of the aquifer adjacent to and northeast of Garner Field, a municipal airport located east of the city of Uvalde (fig. 23). Five of the six samples from subarea 2 with median concentrations of tetrachloroethylene equal to or greater than 1 µg/L are located in an area of large-city urban land use in north-central Bexar County near the abandoned West Avenue landfill (fig. 23).

Tetrachloroethylene concentrations in water from wells near Garner Field ranged from 2.9 to 13.5 µg/L. Concentrations in water from wells near the abandoned West Avenue landfill generally were smaller, ranging from 1.0 µg/L at well AY-68-28-917 on April 5, 1983, to 9.6 µg/L at well AY-68-28-918 on the same date at the West Avenue landfill property. Water sampled from other areas of the aquifer contained tetrachloroethylene in concentrations ranging from less than 1 to 1 µg/L at 10 wells distributed through Uvalde, Bexar, Comal, and Hays Counties. Occurrences of median concentrations of 1,2-(trans)-dichloroethylene ($C_2H_2Cl_2$) and trichlorofluoromethane (CCl_3F) exceeding 1 µg/L also were associated with wells adjacent to and downgradient from the West Avenue landfill.

1,1,1-trichloroethane (CH_3CCl_3) was detected in 22 ground-water samples in concentrations equal to or greater than 1.0 µg/L in 1983 and 1984. Of all wells sampled, median concentrations of 1,1,1-trichloroethane were greater than 1

page 87 follows

Table 13.--Summary statistics for selected organic compounds in ground water by subarea, 1976-85

[µg/L, microgram per liter; > DL, greater than detection limit; < DL, less than detection limit]

Constituent and statistics	Detection limit	Subarea			
		1	2	3	4
Volatile organic compounds:					
Benzene (µg/L)	1.0				
Number detected (median > DL)		2	1	4	0
Number not detected (median < DL)		22	24	22	4
Median, detected		1.0	1.0	1.4	--
75th percentile, dectected		1.0	--	1.9	--
Maximum, all samples		1.0	11.0	2.7	--
Chloroform (µg/L)	1.0				
Number detected (median > DL)		3	3	4	0
Number not detected (median < DL)		22	24	22	4
Median, detected		1.0	1.0	1.7	--
75th percentile, dectected		1.0	1.0	2.1	--
Maximum, all samples		1.0	1.0	3.2	--
1,2-(trans)-Dichloroethylene (µg/L)	1.0				
Number detected (median > DL)		0	3	0	0
Number not detected (median < DL)		23	22	26	4
Median, detected		--	2.1	--	--
75th percentile, dectected		--	2.4	--	--
Maximum, all samples		--	7.9	--	--
Methylene chloride (µg/L)	1.0				
Number detected (median > DL)		7	5	5	0
Number not detected (median < DL)		16	20	21	4
Median, detected		1.0	1.3	2.7	--
75th percentile, dectected		1.4	3.4	8.1	--
Maximum, all samples		10.0	6.3	13.0	--
Tetrachloroethylene (µg/L)	1.0				
Number detected (median > DL)		4	6	0	0
Number not detected (median < DL)		19	19	26	4
Median, detected		8.2	2.6	--	--
75th percentile, dectected		11.1	3.9	--	--
Maximum, all samples		13.5	9.6	--	--
1,1,1-Trichloroethane (µg/L)	1.0				
Number detected (median > DL)		5	5	3	0
Number not detected (median < DL)		18	20	23	4
Median, detected		1.4	2.5	1.0	--
75th percentile, dectected		1.7	3.2	1.6	--
Maximum, all samples		2.0	4.7	2.1	--
Trichlorofluoromethane (µg/L)	1.0				
Number detected (median > DL)		1	3	1	0
Number not detected (median < DL)		22	22	25	4
Median, detected		1.0	2.8	2.6	--
75th percentile, dectected		--	3.7	--	--
Maximum, all samples		1.0	5.1	2.6	--
Pesticide:					
2,4-D, total (µg/L)	0.01				
Number detected (median > DL)		5	2	0	--
Number not detected (median < DL)		33	5	10	--
Median, detected		.03	.03	--	--
75th percentile, detected		.035	.055	--	--
Maximum, all samples		.040	.110	--	--

Table 14.--Summary statistics for selected organic compounds in ground water by land use in subareas 1 and 2, 1976-85

[μg/L, microgram per liter; > DL, greater than detection limit; < DL, less than detection limit]

Constituent and statistics	Detection limit	Subarea 1					Subarea 2			
		Large-city urban	Small-city urban	Industrial	Cropland	Forest and rangeland	Large-city urban	Small-city urban	Cropland	Forest and rangeland
Volatile organic compounds:										
Benzene (μg/L)	1.0									
Number detected (median > DL)		2	0	0	0	0	1	0	0	0
Number not detected (median < DL)		4	10	1	3	4	9	7	6	2
Median, detected		1.0	--	--	--	--	11.0	--	--	--
75th percentile, detected		1.0	--	--	--	--	--	--	--	--
Maximum, all samples		1.0	1.0	1.0	1.0	1.0	11.0	1.0	1.0	1.0
Chloroform (μg/L)	1.0									
Number detected (median > DL)		1	1	1	0	0	1	1	0	1
Number not detected (median < DL)		5	10	0	3	4	10	7	6	1
Median, detected		1.0	1.0	1.0	--	--	1.0	1.0	--	1.0
75th percentile, detected		--	--	--	--	--	--	--	--	--
Maximum, all samples		1.0	1.0	1.0	--	--	1.0	1.0	--	1.0
1,2-(trans)-Dichloroethylene (μg/L)	1.0									
Number detected (median > DL)		0	0	0	0	0	3	0	0	0
Number not detected (median < DL)		6	9	1	3	4	7	7	6	2
Median, detected		--	--	--	--	--	2.1	--	--	--
75th percentile, detected		--	--	--	--	--	2.4	--	--	--
Maximum, all samples		--	--	--	--	--	7.9	--	--	--
Methylene chloride (μg/L)	1.0									
Number detected (median > DL)		4	1	1	0	1	4	0	0	1
Number not detected (median < DL)		2	8	0	3	3	6	7	6	1
Median, detected		1.0	10.0	1.0	--	1.0	1.0	--	--	1.0
75th percentile, detected		1.0	--	--	--	--	4.0	--	--	--
Maximum, all samples		1.0	10.0	1.0	1.0	1.0	6.3	--	--	1.0
Tetrachloroethene (μg/L)	1.0									
Number detected (median > DL)		0	4	0	0	0	6	0	0	0
Number not detected (median < DL)		6	5	1	3	4	4	7	6	2
Median, detected		--	8.2	--	--	--	2.6	--	--	--
75th percentile, detected		--	11.1	--	--	--	3.9	--	--	--
Maximum, all samples		1.0	13.5	--	--	--	9.6	--	--	--
1,1,1-Trichloroethane (μg/L)	1.0									
Number detected (median > DL)		3	0	1	0	1	2	1	1	1
Number not detected (median < DL)		3	9	0	3	3	8	6	5	1
Median, detected		1.0	--	2.0	--	1.0	1.0	2.0	3.0	4.0
75th percentile, detected		2.0	--	--	--	--	1.0	--	--	--
Maximum, all samples		2.0	1.0	2.0	--	1.0	2.0	4.0	4.7	4.0
Trichlorofluoromethane (μg/L)	1.0									
Number detected (median > DL)		0	0	0	1	0	3	0	0	0
Number not detected (median < DL)		6	9	1	2	4	7	7	6	2
Median, detected		--	--	--	1.0	--	2.8	--	--	--
75th percentile, detected		--	--	--	--	--	3.7	--	--	--
Maximum, all samples		--	--	--	1.0	--	5.1	--	--	--
Pesticide:										
2,4-D, total (μg/L)	0.01									
Number detected (median > DL)		0	3	0	1	1	1	0	0	1
Number not detected (median < DL)		14	6	4	4	5	0	3	1	1
Median, detected		--	.03	--	.01	.02	.02	--	--	.06
75th percentile, detected		--	.04	--	--	--	--	--	--	--
Maximum, all samples		--	.04	--	.01	.03	.04	--	--	.11

µg/L in water from 22 percent of wells sampled in subarea 1, 20 percent of wells in subarea 2, and 12 percent of wells in subarea 3. No significant difference in detection of 1,1,1-trichloroethane was determined among subareas 1-3. The large-city urban land use in subarea 1 had the greatest proportion (three of six wells or 50 percent) of median concentrations that equaled or exceeded the detection limit. The small-city urban and cropland land uses in subarea 1 had no wells yielding water containing persistent concentrations of 1,1,1-trichloroethane. The only persistent detections were at wells AY-68-28-902 (subarea 3, four samples, largest concentration--2.0 µg/L) and AY-68-37-101 (subarea 3, two samples, largest concentration--2.1 µg/L). Concentrations of the compound ranged from less than 1.0 µg/L at locations throughout the study area to 4.7 µg/L at well YP-69-45-405 in Uvalde County (subarea 2) on August 19, 1983.

Two patterns of 1,1,1-trichloroethane detection are apparent from the mapped data (fig. 23). Samples from wells AY-68-27-303, AY-68-27-504, AY-68-28-202, and AY-68-28-508 in the western part of subarea 1 in Bexar County define a group sampled in August 1983. The second pattern links wells AY-68-28-902, AY-68-28-904, AY-68-28-909, AY-68-28-920, and AY-68-37-101, also from results of August 1983 sampling. Despite the distance between wells in the two patterns, the timing of the contaminant occurrences indicates a coincidental unknown cause or causes. The similarity of the sampling dates indicates a possibility that some contamination of the samples during sampling or analysis may have occurred. No record of contamination by 1,1,1-trichloroethane exists for the laboratory blanks on the dates of sample analysis. Both patterns, however, disappeared when many of the wells were resampled in 1984.

Benzene (C_6H_6) was detected in 12 of the 107 ground-water samples submitted for VOC analysis. The analytical method used for benzene uses a Tenax exchange resin, of which one of the degradation products is benzene. Laboratory interferences for benzene in 1983 were reported to be as much as 1 µg/L. In addition, the locations of benzene detection are not persistent in time. To eliminate the potential for laboratory interference in the data, only concentrations larger than 3 µg/L were accepted as benzene occurrences in ground water. The only three samples that met that criterion were all analyzed on the same day. Therefore, benzene data is not included in this discussion because of analytical uncertainties, but summary statistics are included in tables 13 and 14.

Methylene chloride (CH_3Cl) was detected in 27 samples of ground water submitted for VOC analysis. Persistent laboratory interferences ranging from 0.2 to 0.7 µg/L were reported for methylene-chloride analyses performed in December 1983 and in January and February 1984 (S.S. Duncan, U.S. Geological Survey, oral commun., 1984). Therefore, the same 3-µg/L criteria applicable to benzene data also was used for methylene-chloride data. Eight ground-water samples contained detectable concentrations of this compound at this concentration; four samples in subarea 3 in Bexar County (wells AY-68-28-903 and AY-68-28-919), two samples in subarea 2 in Bexar County (wells AY-68-29-510 and AY-68-28-508), and two samples in subarea 3 in Comal (well DX-68-23-602) and Hays Counties (well LR-67-01-806).

Summary statistics for eight analyses of water from the wells completed in the Austin aquifer adjacent to the abandoned West Avenue landfill are listed in table 15. These analyses indicate the presence of several VOC detected in water from nearby wells completed in the Edwards aquifer at concentrations

Table 15.--Summary statistics for volatile organic compounds in water from the Austin Group at the abandoned West Avenue landfill, 1982-84

[all concentrations in micrograms per liter; <, concentration is less than detection limit]

Compound	Number of samples	Minimum	Maximum	Percentiles			
				25th	50th	75th	90th
* Benzene	8	2.0	6.6	4.5	5.0	5.9	6.6
Bromoform	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
Carbon tetrachloride	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
Chlorobenzene	8	1.4	16.0	3.9	7.5	8.9	16.0
Chlorodibromomethane	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
Chloroethane	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
2-Chloroethylvinylether	8	<1.0	3.0	<1.0	<1.0	<1.0	3.0
Chloroform	8	<1.0	1.8	<1.0	<1.0	1.0	1.8
Dichlorobromomethane	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
Dichlorodifluoromethane	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
1,1-Dichloroethane	8	<1.0	4.4	<1.0	2.5	3.8	4.4
1,2-Dichloroethane	8	<1.0	<3.0	<1.0	<1.0	1.8	<3.0
1,1-Dichloroethylene	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
1,2-(trans)-Dichloroethylene	8	5.0	110.0	25.0	28.5	34.0	110.0
1,2-Dichloropropane	8	<1.0	7.0	1.3	5.0	6.6	7.0
1,3-Dichloropropane	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
Ethylbenzene	8	<1.0	6.5	1.2	3.1	5.6	6.5
Methylbromide	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
* Methylene chloride	8	<1.0	31.0	<1.0	<1.0	6.0	31.0
1,1,2,2-Tetrachloroethane	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
Tetrachloroethylene	8	<1.0	27.0	<1.0	2.1	8.3	27.0
Toluene	8	<1.0	8.6	<1.0	1.1	2.7	8.6
1,1,1-Trichloroethane	8	<1.0	1.0	<1.0	<1.0	1.0	<3.0
1,1,2-Trichloroethane	8	<1.0	<3.0	<1.0	<1.0	<1.0	<3.0
Trichloroethylene	8	1.1	10.0	2.4	2.8	8.8	10.0
Trichlorofluoromethane	8	<1.0	5.4	<1.0	<1.0	4.2	5.4
Vinyl chloride	8	<1.0	15.0	3.6	7.0	13.7	15.0

* Reported concentration of asterisked compounds and associated statistics may have been affected by laboratory-induced interferences.

equal to or substantially in excess of those described in this section. These data indicate that the abandoned West Avenue landfill is a probable source of many of the VOC detected in water from wells located downgradient from the landfill.

The presence of many of these compounds in ground water at certain concentrations is considered to be a human health risk with persistent consumption. The U.S. Environmental Protection Agency maintains a list of "advisory opinions" regarding the relation between persistence of human consumption of a volatile organic compound and toxicity. Toxicity in these guidelines is defined as posing a carcinogenic, mutagenic, or otherwise adverse threat to human health. The health advisories are defined in terms of the duration of human exposure to the toxic threat. Recommended maximum concentration levels (RMCL) for human consumption of certain volatile organic compounds have recently been issued by the U.S. Environmental Protection Agency (1984). These RMCL are based on a "no adverse observed effect" for carcinogens and an estimate of that level for suspected carcinogens. The draft versions of the health advisory limits are listed in table 16.

No water samples from the Edwards aquifer collected during the study contained concentrations of VOC that exceed the U.S. Environmental Protection Agency's health-advisory levels. Two compounds, benzene and tetrachloroethylene, were detected at several locations in concentrations exceeding the RMCL. Benzene was detected in 12 ground-water samples from Bexar County collected during 1983 and 1984. Because of the potential laboratory interferences, the concentrations reported for benzene can be used only as a qualitative indication that benzene may have been a problem at these locations. No such interferences were discovered for tetrachlorethylene for the samples discussed herein.

Pesticides

The distribution of pesticides in the Edwards aquifer has been the subject of study since 1968. Thirteen locations (11 wells and Comal and Leona Springs) had positive detections of pesticide compounds in water between 1976 and April 1985 (fig. 24). The most commonly detected pesticide, 2,4-D, a chlorophenoxy herbicide, was detected in 15 percent of all sampled locations. Of these, 2,4-D was detected in water from 5 of 38 wells sampled (13 percent) in subarea 1, 2 of 7 wells sampled (29 percent) in subarea 2, and 1 of 10 wells and springs sampled in subarea 3. The compound was detected in water from 33 percent (three of nine wells) of the wells sampled in the small-city urban land use in subarea 1. DDE, diazinon, atrazine, endosulfan, and silvex (2,4,5-T) were detected in one sample each from water in a number of wells completed in the Edwards aquifer. No positive occurrences of any pesticide exceeded the maximum contaminant level for drinking water.

All of the pesticide occurrences were sampled from wells with depths less than 800 ft below land surface. Many of these shallow wells are not cased and grouted a sufficient depth below land surface to prevent recharge or cross-formational flow of contaminated water along the well casing or through the borehole or both into the Edwards aquifer (G.B. Ozuna, U.S. Geological Survey, oral commun., 1985).

page 95 follows

Table 16.--Draft U.S. Environmental Protection Agency advisories for exposure to volatile organic compounds in drinking water

[Only compounds that were analyzed during study are included; µg/L, microgram per liter]

Compound name	Health-advisory levels by duration of exposure (µg/L)				Recommended maximum contaminant levels 1/ (µg/L)
	1-day	10-day	Longer-term estimate		
			Duration	Concentration	
Benzene	(2)	230	(3)	70	0.0
Carbon tetrachloride	200	20	--	--	.0
Methylene chloride	13,000	1,300	3 months	150	--
Toluene	21,500	2,200	(3)	340	--
1,2-Dichloroethane	--	--	--	--	.0
1,1,1-Trichloroethane	--	--	--	--	.2
1,1-Dichloroethylene	--	--	--	--	.0
1,2-(trans)-Dichloroethylene4/	2,270	270	--	--	--
Trichloroethylene	2,000	200	(3)	75	.0
Tetrachloroethylene	2,300	175	(3)	20	.0
Vinyl chloride	--	--	--	--	.0

1/ U.S. Environmental Protection Agency, 1984.
2/ Insufficient data for calculation.
3/ Longer-term health-advisory levels apply only to contamination levels during temporary periods of exposure.
4/ The 1- and 10-day health-advisory levels for 1,2-cis-dichloroethylene are 4,000 and 400 µg/L, respectively. Some of the "cis" isomer may be included in the results of the "trans" isomer analysis.

The mix of pesticides applied to cropland in the six-county region is not documented. Information collected by the U.S. Department of Agriculture, Economic Research Service (1966, 1974, 1978; and also Ferguson and McCalla, 1981; Hanthorn and others, 1982; McCalla and others, 1982; McDowell and others, 1982; and Rich, 1982) indicates that total application of pesticides in Texas and Oklahoma such as DDT, toxaphene, parathion, and methyl parathion decreased between 1964 and 1981. Use of herbicides such as atrazine, 2,4-D, and trifluralin has increased during the same period.

The sampling dates of pesticide occurrences documented in this report coincide with the advent of their intensive use in Texas. For example, only one compound related to DDT (DDE) has been detected in the Edwards aquifer since the general use and sale of DDT was banned in 1971. An increase in 2,4-D detections from zero in 1972-76 to five during 1982-84 generally parallels the increased use of the herbicide.

SUMMARY AND CONCLUSIONS

This report describes the chemical and bacterial quality of water in the Edwards aquifer, San Antonio region, Texas, and evaluates the relation of water chemistry to hydrogeology and land use. The Edwards aquifer is the sole source of drinking water for more than 1 million residents of the region and an important source of water for irrigation and recreational uses. The freshwater part of the Edwards aquifer consists of a limestone that has been diagenetically altered by oxygenated waters thereby substantially increasing secondary permeability. Remnant, more poorly leached strata in the salinewater part of the aquifer contain more dolomite, less calcite, and more reduced and evaporitic mineral assemblages than in the freshwater part of the aquifer. Ground water generally moves from the recharge areas within the unconfined zone into the confined zone and from west to east in the confined zone through the most transmissive parts of the aquifer.

Water-chemistry data for 1976-85, consisting of nearly 1,500 chemical analyses from 280 wells and 3 springs, were obtained from the U.S. Geological Survey WATSTORE database. Four subareas were defined on the basis of ground-water-flow patterns, the tritium chemistry of ground water, and geologic information to reflect the relative susceptibility of ground water to contamination from human activities. Each of five major land uses associated with each well that has water-chemistry data was defined on the basis of a Texas Department of Water Resources (1978) study and field visits by Geological Survey personnel. Nonparametric-statistical procedures were used to determine the variation of ground-water chemistry with respect to the four subareas and the five land uses.

Results from this study indicate that the quality of water in the freshwater parts of the Edwards aquifer generally is suitable for human consumption. As expected, results indicate that the unconfined zone, represented statistically by subareas 1 and 2, is more susceptible to ground-water contamination by human activities than is the confined zone, represented statistically by subareas 3 and 4:

(1) The largest median nitrite plus nitrate concentrations (2.8 mg/L) were for the cropland land use in subarea 1. The areal pattern of nitrite plus

nitrate concentrations appears to generally parallel the paths of recharge and ground-water flow indicated by tritium data collected during 1967-72. Nitrogen isotopic ratios for nitrate indicate that recharge from streamflow may account for nearly all nitrate in ground water.

(2) Wells yielding water samples that contain bacteria (total coliform, fecal coliform, and fecal streptococci) are associated mainly with subarea 1. Those water samples obtained from subareas 2, 3, and 4 that contained bacteria generally were obtained from defective wells.

(3) Occurrences of tetrachloroethylene, 1,2-(trans)-dichloroethylene, 1,1, 1-trichloroethane, and trichlorofluoromethane in ground water are associated with point sources of contamination in subareas 1 and 2. The pesticide 2,4-D also was detected chiefly within these two subareas. The concentrations of tetrachloroethylene in an area of the aquifer east of Uvalde, Texas, and concentrations of tetrachloroethylene and benzene detected in ground water near the abandoned West Avenue landfill in north-central San Antonio exceed the U.S. Environmental Protection Agency's recommended maximum contaminant level for human consumption. Nonvolatile fatty acids detected in water from some wells in subarea 1 commonly are naturally present in water.

Nearly all of the inorganic constituents examined in this study were significantly different in concentration with respect to the five land uses. More detailed land-use and ground-water chemistry information is necessary before the differences in water chemistry may be attributed to human activities.

Most trace elements were either not detected in ground water or detected in concentrations within one order of magnitude of analytical detection limits. Zinc concentrations in ground-water samples were determined to vary inversely with the volume of water pumped from wells prior to sample collection. The presence of lead concentrations in excess of 2 µg/L in some parts of subarea 1 may be a combined function of human-induced, natural, and sampling-related causes. Cadmium, mercury, and lead were the only trace elements that exceeded the U.S. Environmental Protection Agency's maximum contaminant levels during 1976-84.

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