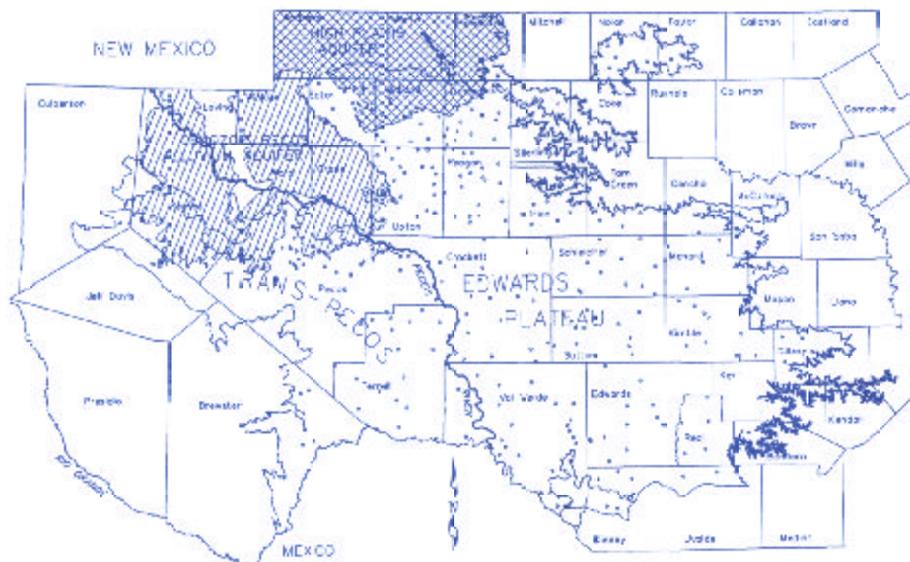# Water Quality in the Edwards-Trinity (Plateau) Aquifer, Edwards Plateau and Trans-Pecos, Texas

by
Janie Hopkins
1995

Texas Water Development Board

Hydrologic Atlas No. 3
Water Quality in the Edwards-Trinity (Plateau) Aquifer, Edwards Plateau and Trans-Pecos, Texas

by Janie Hopkins, Geologist
October 1995

INTRODUCTION

The Edwards-Trinity (Plateau) aquifer covers approximately all or parts of 36 counties in southwest Texas. More than 300 wells (Fig. 1) in the aquifer were sampled in the aquifer from 1988 to 1993 by the Texas Water Development Board (TWDB) as part of its program to monitor the ambient water quality in major and minor aquifers throughout the state and any changes that may have occurred over time. The author thanks and acknowledges the landowners who permitted the wells to be sampled; the TWDB technicians and environmental quality specialists who collected the samples: John Asensio, Merrick Biri, Dennis Jones, Ron Mohr, Robbie Ozment, Lennie Winkelman, and Eddie Zapata; geologists Phil Nordstrom and John Ashworth who edited the atlas; and proofreader Kathy Mills. TWDB interactive graphics technician Steve Gifford created the illustrations.

In recent Regional Aquifer System Analysis studies, the United States Geological Survey (USGS) considers the Edwards-Trinity in the Balcones Fault Zone subarea and the Trinity portion of the Edwards-Trinity in the Hill Country, where much of the Edwards is absent, as part of the entire aquifer system. This atlas, however, includes only the Edwards-Trinity of the Edwards Plateau and Trans-Pecos subareas (Fig. 1), identified by the TWDB as the Edwards-Trinity (Plateau) aquifer. Furthermore, these maps do not include the hydraulically connected Cenozoic Pecos Alluvium aquifer, as depicted in the northwest-southeast diagrammatic section of Figure 2 and included in the saturated thickness and historical potentiometric maps of recently published hydrologic atlases (Ardis and Barker, 1993; Bush, Ardis, and Wynn, 1993).

The Edwards-Trinity (Plateau) aquifer consists of shallow marine carbonates and fluvial sandstones deposited during the last advances of the epicontinental sea from the Gulf across Texas during the early and middle Cretaceous. Lower Trinity rocks of the Antlers Formation consist of dominantly fluvial clastic sediments in the east and fluvial-deltaic deposits in the west. These grade upward into upper Trinity, Fredericksburg, and Washita strata composed of intertidal dolomites, lagoonal and supratidal evaporites, and marine and reefal limestones and dolomites. Much of the primary porosity has been reduced by cementation. Permeability, on the other hand, has been enhanced by secondary porosity created by the selective dissolution of evaporites and other carbonate constituents. Tectonic fracturing has also increased permeability, although fracturing is greatest outside of this study area in the Balcones Fault Zone.

The ground-water potentiometric surface, for the most part, reflects the geologic structure and the regional dip of the base of the Cretaceous formations to the southeast. The direction of the flow varies in areas of artificial discharge toward pumping wells and in areas of natural discharge toward major streams and drainage courses. In the southwestern part of the plateau, ground water moves to the Rio Grande; in the north, northeast, and central part, to the Colorado River; and in the southeast, to the Nueces, San Antonio, and Guadalupe rivers. Throughout the Plateau, however, artesian conditions exist where saturated beds are overlain by strata of lower permeabilities. Uppermost saturated zones of the Edwards-Trinity are typically unconfined. Depth to the saturated zone is less than 200 feet over much of the area, and ranges from 200 to 400 feet in the south-central part of the Edwards Plateau to as much as 800 feet in the southeastern part of the Trans-Pecos area. Recharge is less than 0.5 inches/year in this relatively arid region.
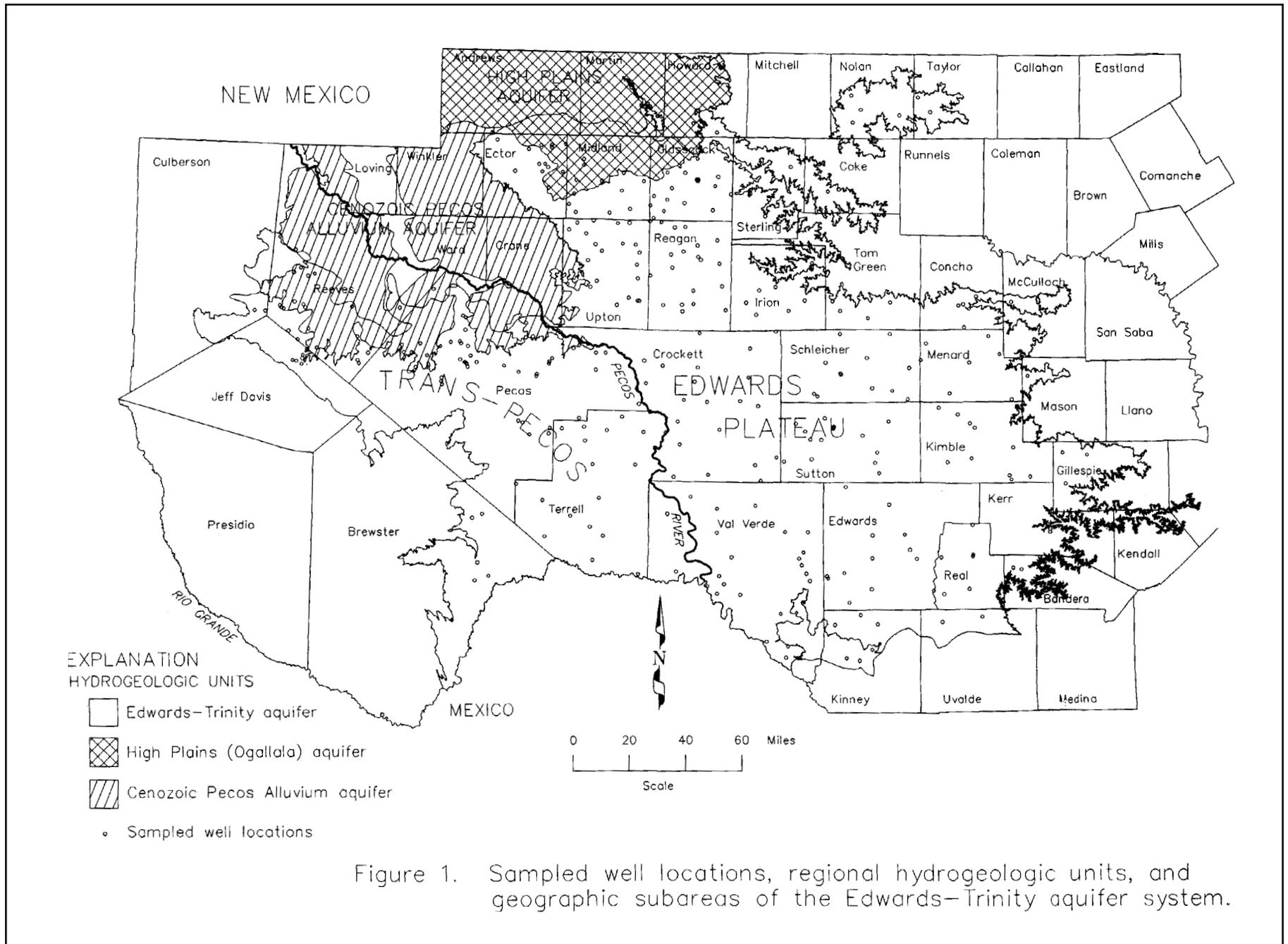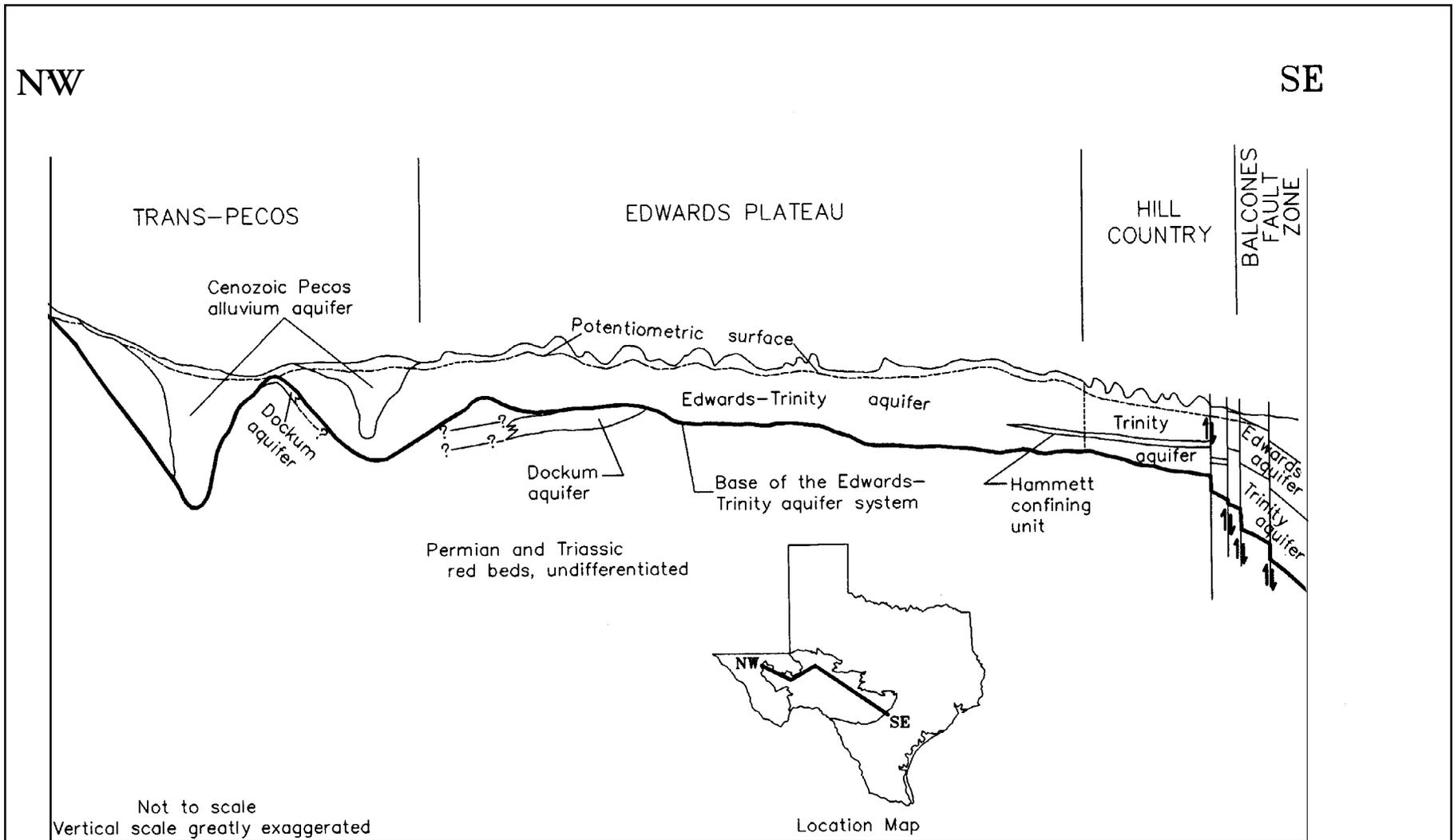
Figure 1.   Sampled well locations, regional hydrogeologic units, and geographic subareas of the Edwards–Trinity aquifer system.

NW

SE

TRANS—PECOS

EDWARDS PLATEAU

HILL
COUNTRY

BALCONES
FAULT
ZONE

Cenozoic Pecos
alluvium aquifer

Potentiometric surface

Edwards—Trinity aquifer

Dockum
aquifer

? ?
? ?
?

Dockum
aquifer

Base of the Edwards—
Trinity aquifer system

Trinity
aquifer

Hammett
confining
unit

Edwards
aquifer

Trinity
aquifer

Permian and Triassic
red beds, undifferentiated

Not to scale
Vertical scale greatly exaggerated

NW

SE

Location Map

(From: Ardis and Barker, 1993)

Figure 2. Diagrammatic hydrogeologic section through the Edwards—Trinity
aquifer system and selected contiguous hydraulically connected units.

WATER QUALITY

Samples were taken from municipal, industrial, and irrigation wells where possible. These wells, because of their constant pumping and high yield, draw water from larger areas in the aquifer, thereby ensuring a representative sample. Technicians took field measurements and used appropriate sampling techniques as described in the TWDB *Manual for Ground Water Sampling* (Nordstrom and Beynon, 1991) for dissolved inorganic constituents, nutrients, and, for the first time in this aquifer, radioactivity. Constituent ranges and averages as determined by the Texas Department of Health laboratory are discussed, and areas in which key constituents are in excess of maximum concentration levels (MCLs) are illustrated in maps where appropriate. The primary and secondary MCLs, as set by the Texas Natural Resource Conservation Commission (TNRCC), are listed in Table 1.

Constituent	Symbol	MCL
Primary Constituent Levels		
Arsenic	As	0.05 mg/l
Barium	Ba	2.0 mg/l
Cadmium	Cd	0.005 mg/l
Chromium	Cr	0. 10 mg/l
Fluoride	F	4.0 mg/l
Lead	Pb	0.015 mg/l
Mercury	Hg	0.002 mg/l
Nitrate (as N)	NO_3 (N)	10.0 mg/l
Selenium	Se	0.05 mg/l
Gross Alpha	α	15 pCi/l
Gross Beta	β	50 pCi/l
Radium	$Ra^{226} + Ra^{228}$	20 pCi/l
Secondary Constituent Levels		
Chloride	Cl	300 mg/l
Copper	Cu	1.0 mg/1
Fluoride	F	2.0 mg/l
Iron	Fe	0.3 mg/l
Manganese	Mn	0.05 mg/l
pH	pH	≥ 7.0
Silver	Ag	0. 10 mg/1
Sulfate	SO_4	300 mg/l
Dissolved Solids	TDS	1,000 mg/1
Zinc	Zn	5.0 mg/l
Radon 222	Rn^{222}	300 pCi/l

Table 1.Drinking water standards for selected inorganic constituents and radioactive species as set by the TNRCC.

FIELD MEASUREMENTS

The average ground-water temperature of the Edwards-Trinity samples was 22° C.   Twenty-two samples had a pH of less than 7.0, but the average pH of all analyses was 7.3. Secondary drinking water standards indicate that the pH should be greater than 7.0 because acidic water (less than 7.0) will act as a solvent to release metal ions to the water. The specific conductance ranged from 240 to 5,660 micromhos,

and averaged 1,051 micromhos. Although this average indicates a fairly high concentration of total dis-
solved ionized salts in the ground water, water quality is generally poor only in the west and northwest parts
of the study area. The average total alkalinity as determined in the field was 217 mg/l (range: 86 - 443
mg/l) as $CaCO_3$; average bicarbonate ion concentration, calculated from mean total alkalinity wa 264 mg/l.
Since the pH of all samples wa les than 8.3, phenol alkalinity was zero; no carbonate ions were present.
The positive Eh average of +114 mV (range: -101 to +658mV) is to be expected in oxidizing ground water
common in aquifers with good circulation rates and little organic matter.
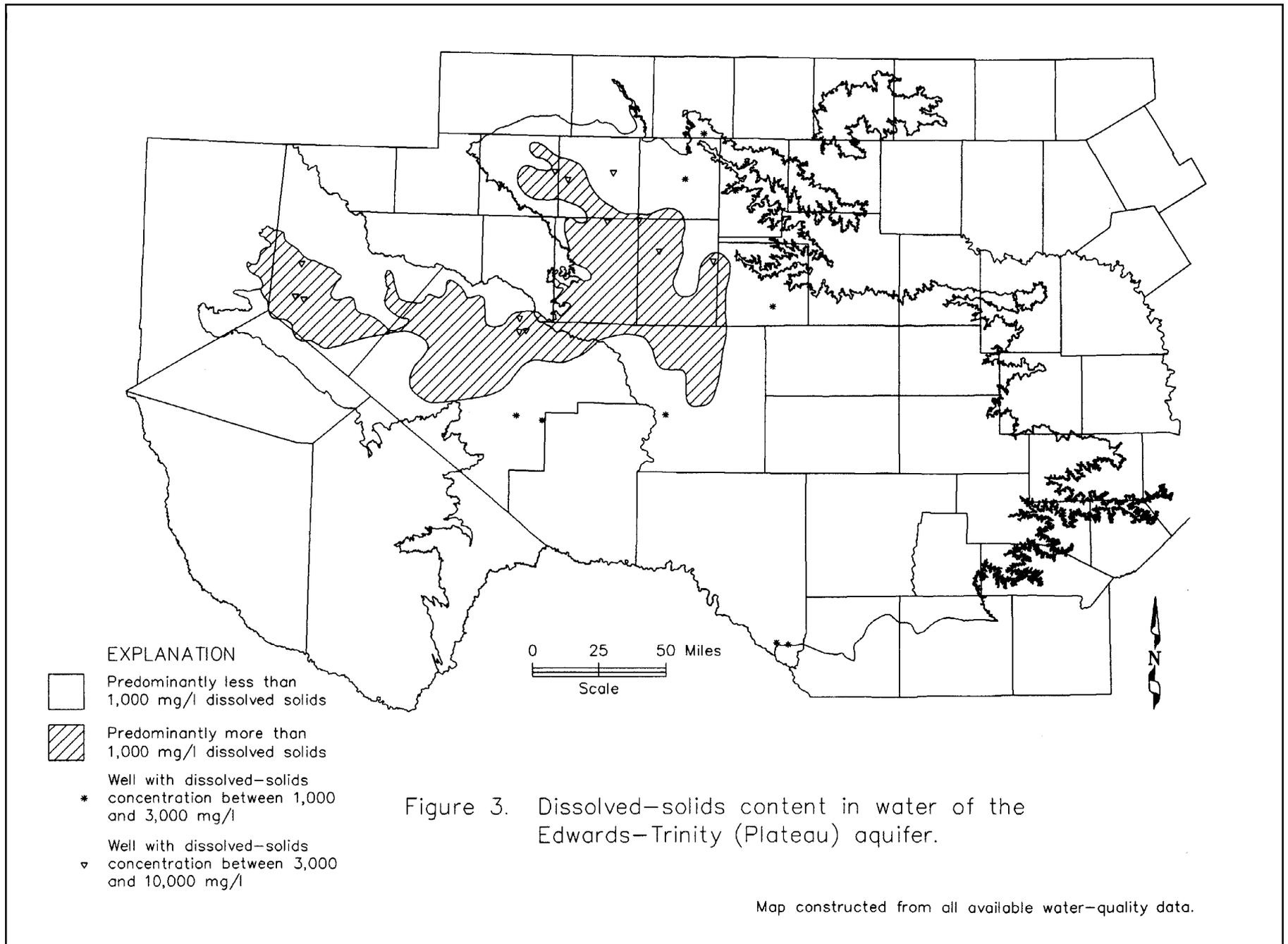
Dissolved Inorganic Constituents

The dissolved-solids content is the main factor limiting or determining the use of ground water.
These solids consist primarily of mineral constituents dissolved from the host rock, although other natural
sources, such as adjacent aquifers or man-affected sources such as oil-field brines, can also contribute certain
dissolved constituents. Table 2 describes four classes of ground water classified according to dissolved-solids
content, as defined by the Texas Groundwater Protection Committee.

Class	Quality*	Examples of Use
Fresh	0 - 1,000	Drinking and all other uses
Slightly Saline	>1,000 - 3,000	Drinking if fresh unavailable, for livestock, irriga-tion, and industrial uses
Moderately Saline	>3,000 -10,000	Industrial, mineral extraction, oil and gas produc-tion; potential/future drinking and limited livestock watering and irrigation if fresh or slightly saline is unavailable
Very Saline to Brine	>10,000	Mineral extraction, oil and gas production

* Concentration range of dissolved solids in milligrams/liter

Table 2. Ground-water classification system.

Table 3 lists average concentrations and ranges of dissolved solids and other inorganic constituents
from the Edwards-Trinity (Plateau) sampled from 1988 through 1993. The average dissolved-solids
content of 880 mg/1 reflects the influence of moderately saline waters in the northwestern and western
parts of the study area, as seen in the map in Figure 3. Here, contours indicate areas in which the predomi-
nant range of dissolved solids is greater than 1,000 mg/1 or between 3,000 and 10,000 mg/l. Wells with
dissolved-solids concentrations greater than 10,000 mg/1 assumed to be contaminated, however, were not
included in this or any other map of dissolved constituents. The majority of the 30 percent of samples
containing dissolved solids in amounts higher than the MCL are concentrated in the northwest and west,
although a few isolated cases exist outside of the contours.

EXPLANATION

Predominantly less than
1,000 mg/l dissolved solids

Predominantly more than
1,000 mg/l dissolved solids

* Well with dissolved—solids
concentration between 1,000
and 3,000 mg/l

▽ Well with dissolved—solids
concentration between 3,000
and 10,000 mg/l

0   25   50 Miles
Scale

N

Figure 3. Dissolved—solids content in water of the
Edwards—Trinity (Plateau) aquifer.

Map constructed from all available water—quality data.

Constituent	Range*		Average*	#> MCL
Silica	6.3	- 87	18	
Calcium	34	- 710	127	
Magnesium	1.3	- 265	40	
Potassium	0.5	- 55	6.4	
Sodium	1.1	- 1,515	116	
Strontium	0.1	- 19.8	2.8	
Bicarbonate	105	- 541	272	
Sulfate	1.0	- 2,066	255	27**
Chloride	5.0	- 3,452	163	15**
Fluoride	0.04	- 3.8	1.2	18**
Dissolved Solids	147	- 6,751	880	30**
Hardness	126	- 2,316	481	

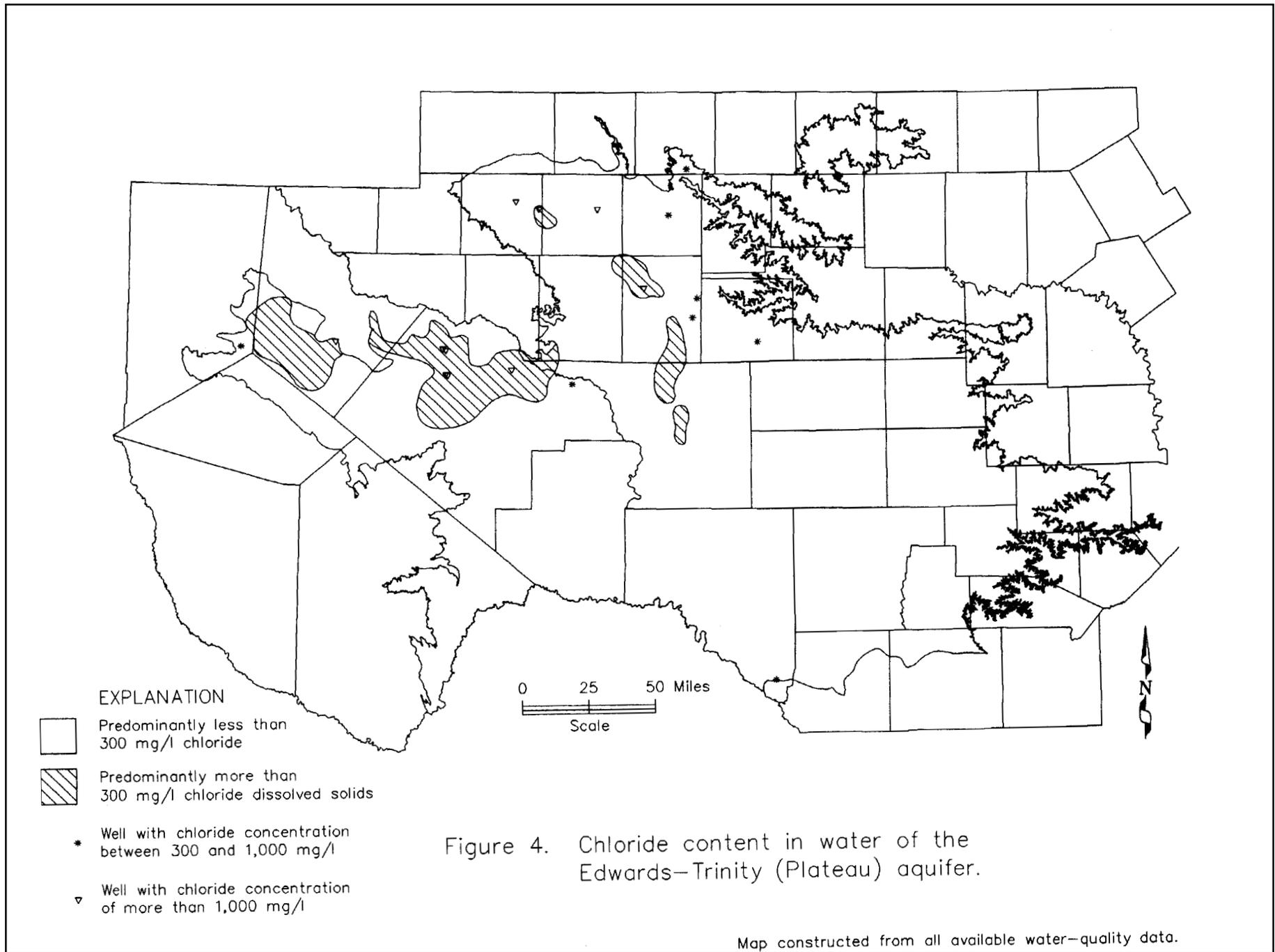*   Expressed in milligrams/liter
**   Secondary MCL
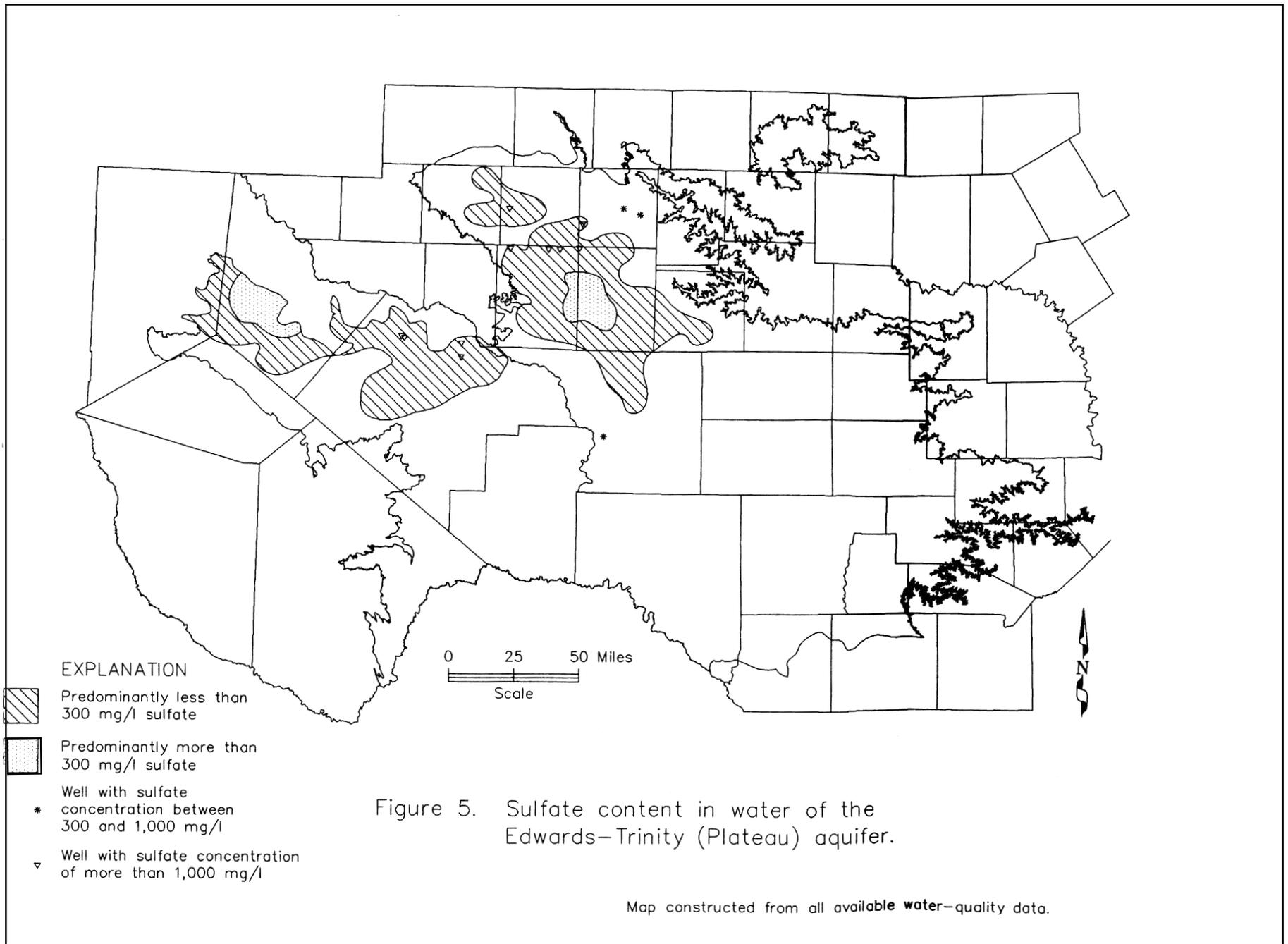***   Nitrate shown in Table 5

Table 3. Major anions*** and cations in Edwards-Trinity (Plateau) ground water.

Although historical data were considered in the construction of this map, data from the recent sampling event (1988 - 1993) were the main determinants of contour positions, particularly from wells with multiple sampling events in which recent data could more accurately delineate an increase or decrease in the amount of dissolved solids (or other constituents) over time. Furthermore, these data were collected in accordance with much better quality assurance. The maps in Figures 3 through 5 and 7 through 10 were constructed in a similar manner, using results from other sampling events dating back to the early sixties in areas where recent data were not available. The numerous points that appear outside of contoured areas indicate locations of wells with anomalously high concentrations of dissolved constituents; these are typically surrounded by wells with lower concentrations and may indicate point-source ground-water contamination. In contrast to the maps prepared with historical data, discussions of averages and ranges listed in Tables 3 through 6 only refer to data collected during the recent sampling event.

In the most thorough water-quality report to date, Bush, Ulery, and Rittmaster (1993) discuss dissolved-solids concentrations and hydrochemical facies in the Edwards-Trinity aquifer system. Their database consists of 3,571 samples (mostly taken from the TWDB database) from as many wells collected from 1936 through 1986, with almost half collected from 1966 through 1975. They determined a median dissolved-solids concentration of 379 mg/l from 2,296 water samples in the Edwards-Trinity Plateau with an interquartile range of 547 mg/l; and a median concentration of 929 mg/l from 143 samples in the Trans-Pecos, with an interquartile range of 1,626 mg/l. The median dissolved-solids concentration of the 370 samples discussed in this atlas and collected after 1987 from both the Plateau and Trans-Pecos areas is 500 mg/l, with an interquartile range of 863 mg/l, indicating a larger variability in concentration throughout the entire area.

Chloride, naturally dissolved from rocks and soils, can also be introduced into ground water by human activities, as it is present in sewage, oil-field brines, industrial brines, and seawater (a possible contaminant of fresh-water aquifers in areas of heavy pumpage). In large amounts in combination with sodium, chloride gives a salty taste to drinking water and can increase the corrosiveness of the water. The map in Figure 4 indicates areas where the chloride content is greater than the MCL of 300 mg/l. The contours in the map in Figure 4, which fall within the areas defined by the contours in the dissolved-solids map, define smaller

EXPLANATION

☐ Predominantly less than 300 mg/l chloride

▨ Predominantly more than 300 mg/l chloride dissolved solids

* Well with chloride concentration between 300 and 1,000 mg/l

▽ Well with chloride concentration of more than 1,000 mg/l

Figure 4.   Chloride content in water of the Edwards—Trinity (Plateau) aquifer.

Map constructed from all available water–quality data.

EXPLANATION

Predominantly less than
300 mg/l sulfate

Predominantly more than
300 mg/l sulfate

* Well with sulfate
concentration between
300 and 1,000 mg/l

▽ Well with sulfate concentration
of more than 1,000 mg/l

0   25   50 Miles
Scale

Figure 5.   Sulfate content in water of the
Edwards–Trinity (Plateau) aquifer.

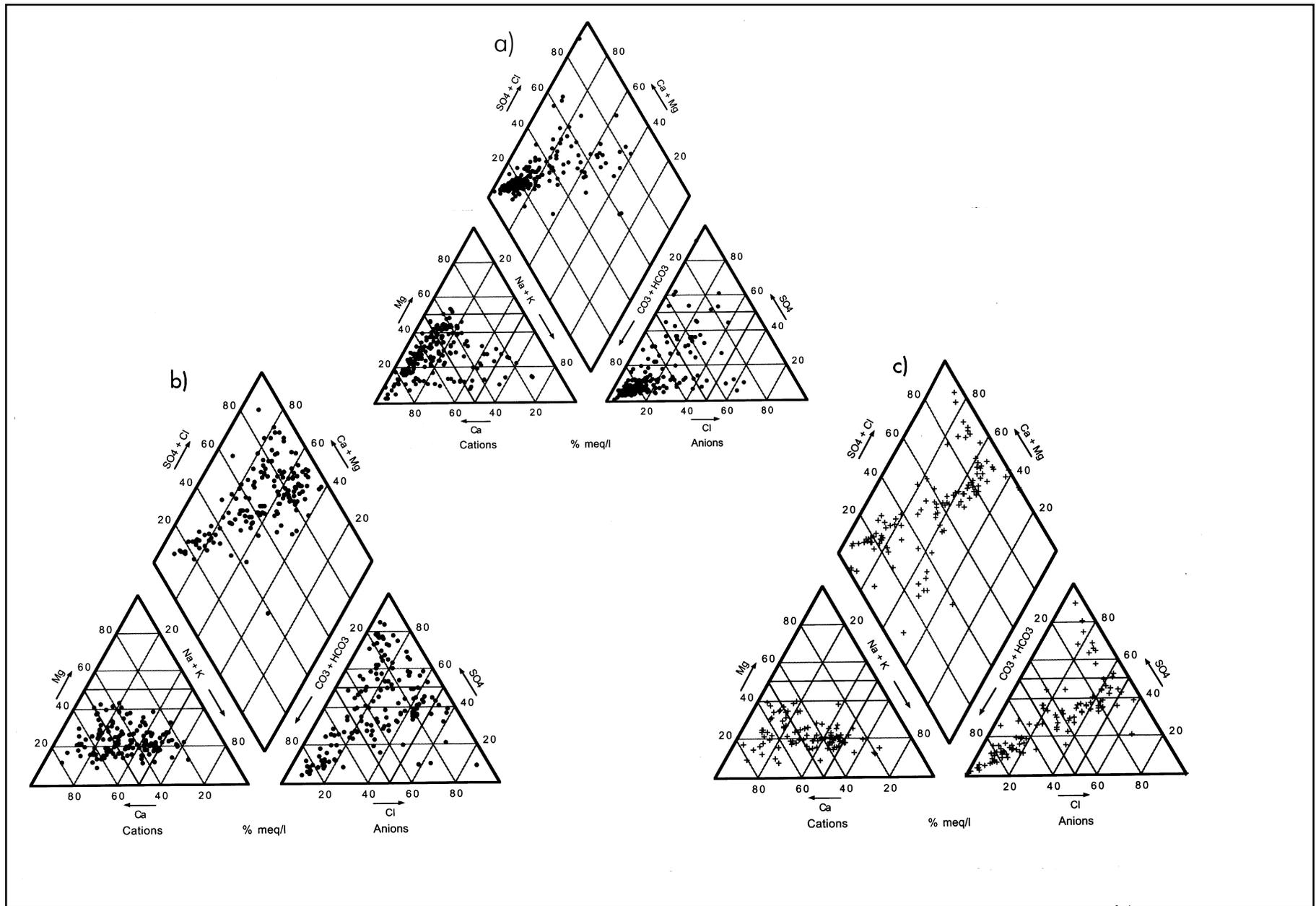Map constructed from all available water–quality data.

N

Figure 6. Trilinear diagrams of Edwards-Trinity (Plateau) ground water from wells sampled in a) Crockett, Val Verde, and eastern counties of the Edwards Plateau illustrate a dominant calcium bicarbonate facies; in b) northwestern counties of the Edwards Plateau, a larger proportion of sodium, sulfate, and some chloride ions; and in c) Trans-Pecos counties, a calcium bicarbonate to mixed cation-mixed anion hydrochemical facies.

EXPLANATION

☐ Predominantly less than
2 mg/l fluoride

▨ Predominantly more than
2 mg/l fluoride

∗ Well with fluoride concentration
of more than 2 mg/l

Figure 7.   Fluoride content in water of the
Edwards–Trinity (Plateau) aquifer.
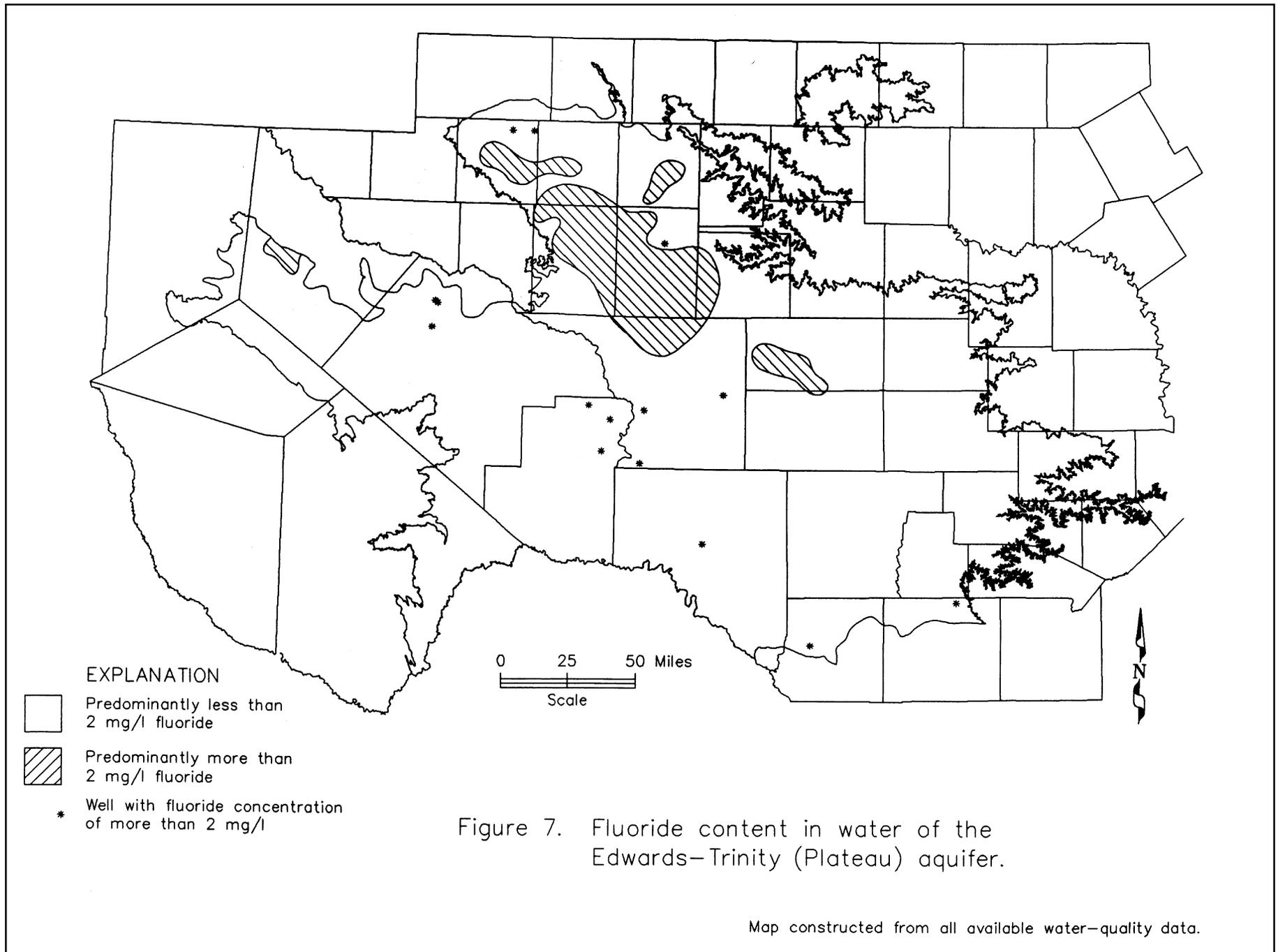
Map constructed from all available water–quality data.

areas corresponding with the smaller percentage of samples containing chloride in excess of the MCL compared to that percentage containing excess dissolved solids. Isolated occurrences of well water with chloride values greater than 300 mg/1 exist outside of these contours.

Sulfate is formed by the dissolution of sulfur from rocks and soils containing sulfur compounds such as gypsum, anhydrite, and iron sulfide. In large amounts, sulfate in combination with other ions gives a rotten-egg smell to drinking water. Figure 5 illustrates the areas in the northwest and west where 27 percent of the wells contained sulfate in excess of the secondary MCL of 300 mg/l; smaller areas contained sulfate in excess of 1,000 mg/l; and a few wells outside of the contours, as indicated with an asterisk, contained more than 300 mg/1 of sulfate.

Bush, Ulery, and Rittmaster (1993) determined that calcium bicarbonate water is the dominant hydrochemical facies in most of the Edwards Plateau and in the southern and southeastern regions of the Trans-Pecos. Seven facies in all were identified, with the northwestern part of the Plateau characterized by sulfate and some chloride water, and with the western part of the Trans-Pecos, or Toyah Basin, characterized by more saline-mixed and calcium sulfate facies. A calcium bicarbonate population is discernible in the first trilinear diagram (Fig. 6a) of recent samples from Edwards Plateau wells in eastern and southern counties, although in samples from northwestern counties (Fig. 6b), a large number of data points fall in the sodium and sulfate vicinities of the ion triangles as well. In the trilinear diagram of samples from the Trans-Pecos (Fig. 6c), a more linear configuration of points would appear to indicate either an evolution of a calcium bicarbonate water to one more dominated by sodium and mixed-anion to sulfate components, or simply the mixing of different facies altogether.

The predominant calcium bicarbonate facies can be attributed to the carbonate of the principal water-yielding zones of the aquifer, to recharge through the overlying, mostly unsaturated carbonate of the upper part of the aquifer, or to the calcite cement in the basal sandy unit of the aquifer. To determine a source for the sulfate and chloride facies, however, Bush, Ulery, and Rittmaster (1993) examined possibilities that involved contributions from (1) the underlying Dockum or other Triassic rocks, in which sulfate and chloride are the principal anions; (2) irrigation return flow; and (3) oil-field brines. Although hydraulic heads in wells open to the Dockum and adjacent rocks of Triassic age are equal to or below heads in the Edwards-Trinity, the authors hypothesize that a regional upward gradient may have existed in the past. Paleoreconstructions by Dutton and Simpkins (1986) indicate that areas to the west at altitudes above 6,000 feet may have recharged hydraulically connected Triassic rocks, causing heads considerably higher than those observed today. The second possibility was not considered an adequate source as dissolved-solids concentrations were not found to be significantly greater in areas of greater irrigation pumpage. In discussions of the third possibility, the authors acknowledge that the quality of water in individual wells has been affected by near-by brine-disposal pits and underground injection of brines. However, they contend that regional ground-water chemistry has not been affected by such brines because dissolved-solids and chloride concentrations were not found to be greater in areas with greater numbers of pre- 1970 oil and gas wells (with unlined pits).

Fluoride, formed from the leaching of fluoride-rich minerals typically associated with volcanic ash deposits, may also have been sourced from underlying and laterally adjacent Cretaceous formations as is believed to have occurred in the southern part of the Ogallala aquifer (Hopkins, 1993; Nativ, 1988). Contours on the map in Figure 7 indicate those regions in the northeast part of the study area where fluoride values are greater than secondary constituent levels of 2.0 mg/l. No samples contained fluoride in excess of the primary MCL of 4.0 mg/l.

For the most part, Edwards-Trinity ground water contained insignificant amounts of dissolved trace metal constituents (Table 4). Only iron and manganese exceeded secondary constituent levels of 0.3 mg/l to 0.05 mg/l, respectively, in small percentages. These occur naturally as iron-rich carbonates are dissolved and

are generally indicative of localized reducing conditions in the aquifer. High iron and manganese contents pose less of a health hazard and more of a nuisance due to their staining abilities and undesirable taste and odor. The map in Figure 8 illustrates specific well locations where iron and manganese exceeded secondary constituent levels.

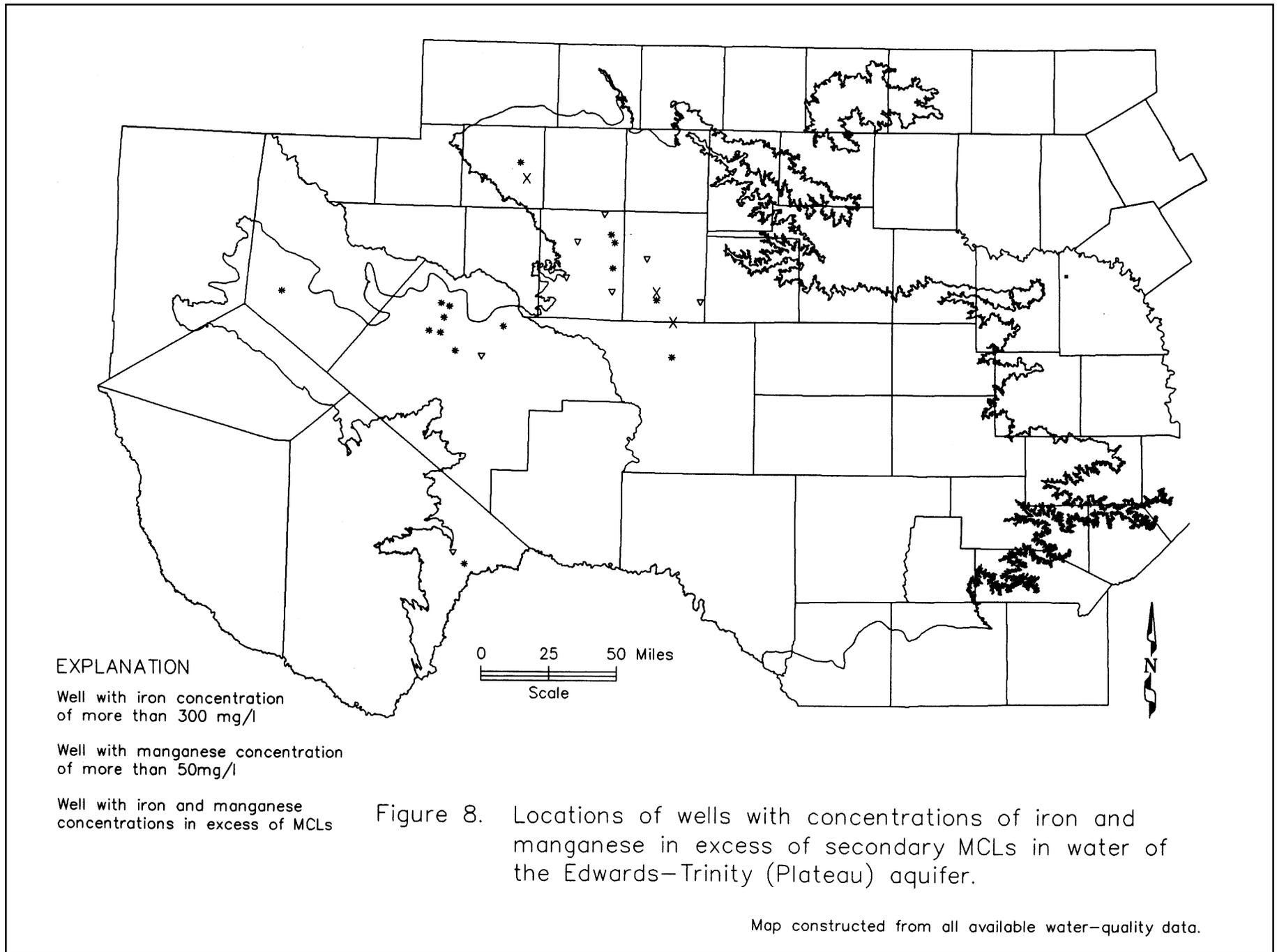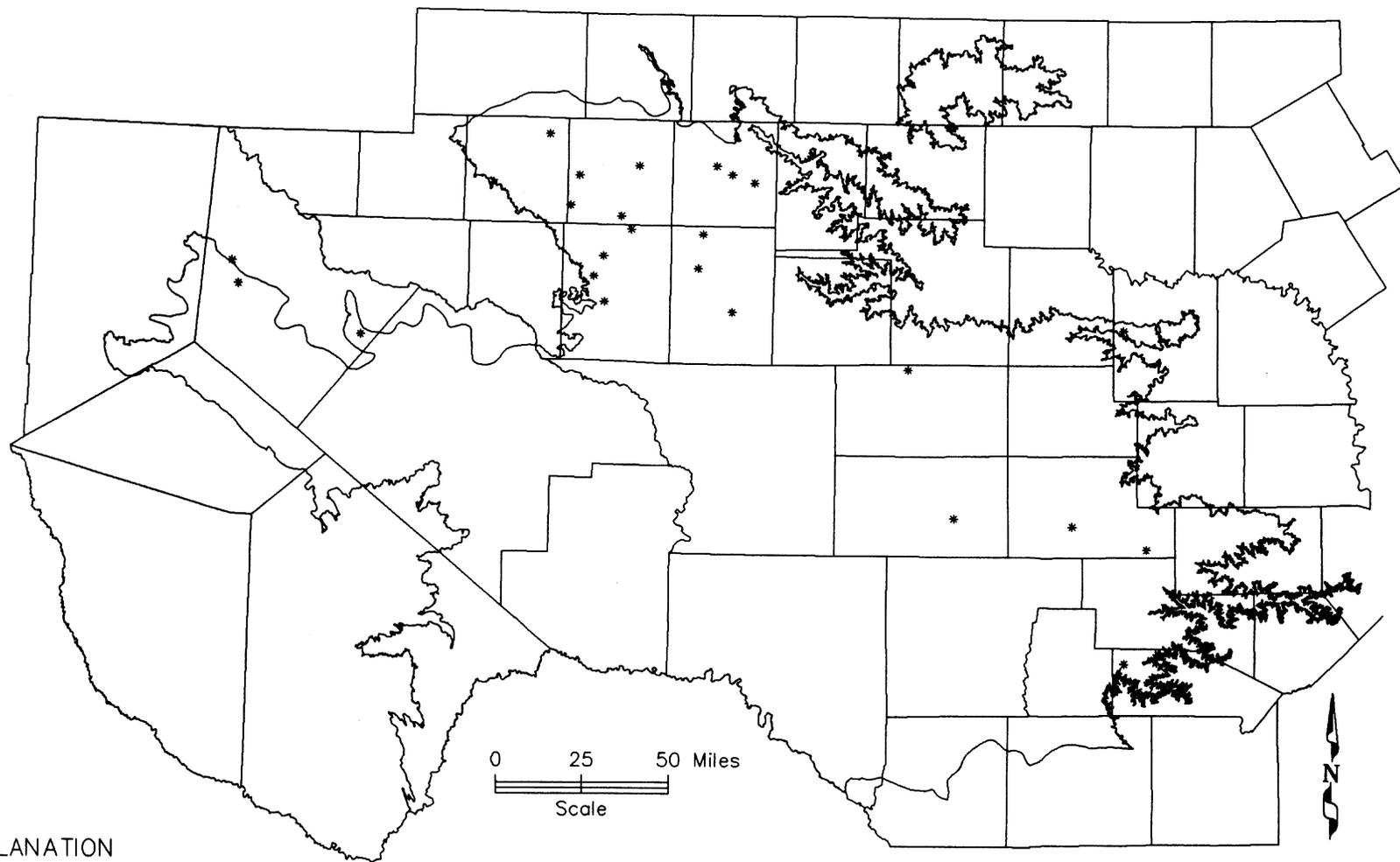| Constituent	% Above Detection	Average*	Range*			# > MCL
Arsenic	30	3.8	1	-	139	1
Barium	95	81.3	3.4	-	350	
Boron	98	385	10	-	2,140	
Cadmium	0					
Chromium	7	8.7	1	-	30	
Copper	52	16.4	1	-	3,000	1
Iron	68	115	0.19	-	7,980	22**(6%)
Lead	1					
Manganese	54	11.4	0.5	-	317	14**(4%)
Molybdenum	0					
Silver	2		1	-	40	
Vanadium	20	26.2	20	-	153	
Zinc	89	137.6	3	-	6,730	1
Aluminum	3		20	-	50	
Selenium	40	3.5	1	-	17	
Mercury	4		0.1	-	20	1

* Expressed in micrograms/liter
** Secondary MCL

Table 4. Dissolved trace metal constituents in Edwards-Trinity (Plateau) ground water.

Nutrients

Of the five nutrients analyzed in each well (ranges, averages, and percents above detection are listed in Table 5), only nitrate and nitrite have drinking water standards. Nitrate, an end product of the aerobic stabilization of nitrogen, particularly organic nitrogen, is a potential pollutant in any agricultural area; it is to be expected at high concentrations where fertilizers are used and in decayed animal and vegetable matter. Ground-water concentrations are also typically higher in leachates from sludge and refuse disposal and in industrial discharges. Averaging 18.6 mg/l as NO_3) only seven percent (or 23 samples) contained nitrate in excess of the MCL of 44.3 mg/l; wells in which nitrate exceeded the MCL are illustrated in the map in Figure 9.

Nitrite, formed by the action of bacteria on ammonia and organic nitrogen, when detected in potable water in considerable amounts, is an indication of sewage/bacterial contamination and inadequate disinfection (De Zuane, 1990). In such reducing environments, nitrite is not oxidized to nitrate. Ordinarily, however, in the oxidizing environments common in most aquifers, nitrites are converted into nitrates, and their values are lower. In this study, only two percent were above detection, and none were found to be above the MCL.

EXPLANATION

Well with iron concentration
of more than 300 mg/l

Well with manganese concentration
of more than 50mg/l

Well with iron and manganese
concentrations in excess of MCLs

0   25   50 Miles
Scale

Figure 8.   Locations of wells with concentrations of iron and
manganese in excess of secondary MCLs in water of
the Edwards—Trinity (Plateau) aquifer.

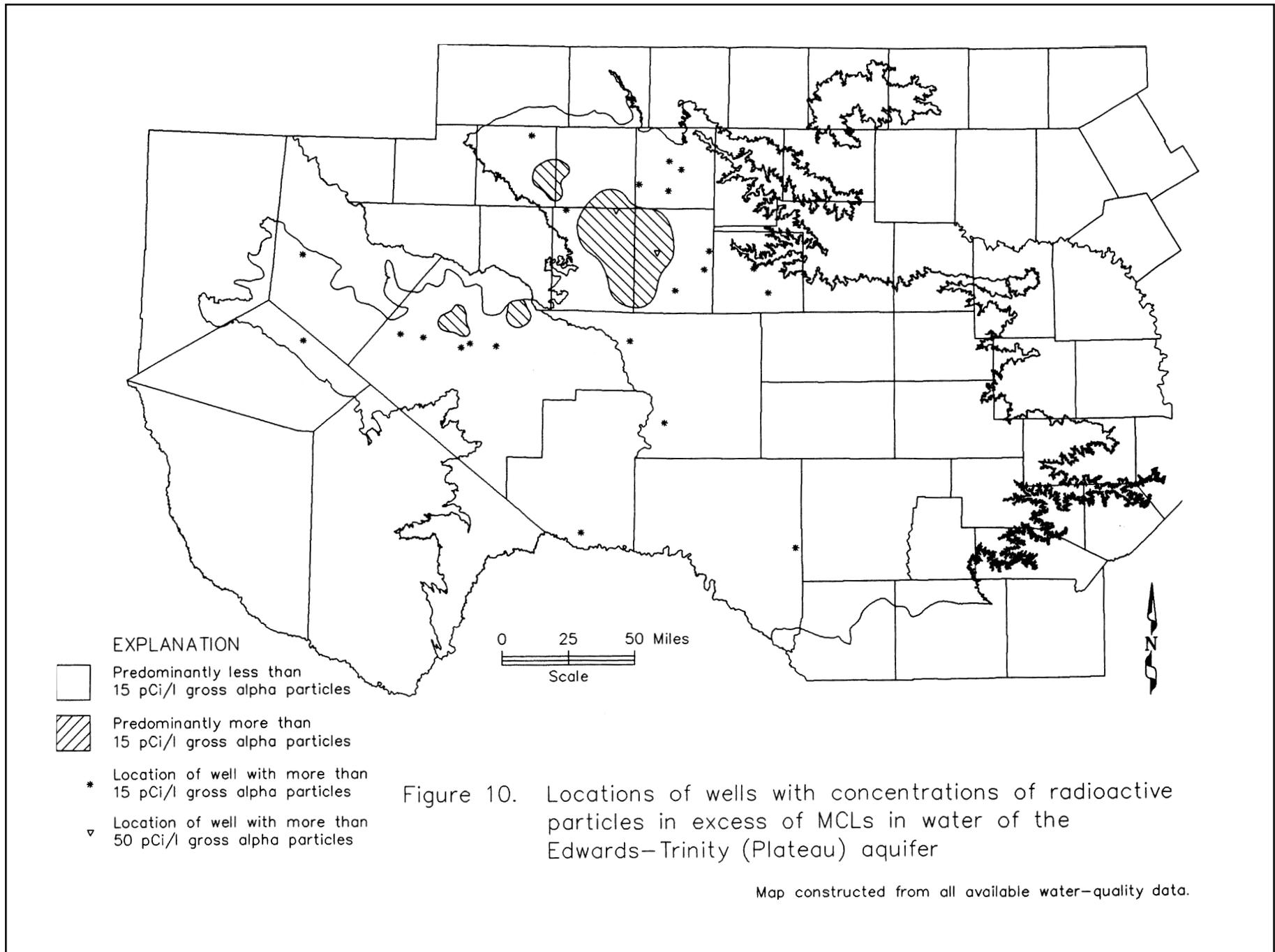Map constructed from all available water—quality data.

EXPLANATION

* Well with nitrate (NO$_3$) concentration
  of more than 44.3 mg/l

Figure 9.   Nitrate content in water of the
            Edwards–Trinity (Plateau) aquifer.

Map constructed from all available water–quality data.

EXPLANATION

☐ Predominantly less than
15 pCi/l gross alpha particles

▨ Predominantly more than
15 pCi/l gross alpha particles

∗ Location of well with more than
15 pCi/l gross alpha particles

▽ Location of well with more than
50 pCi/l gross alpha particles

0   25   50 Miles
Scale

N

Figure 10.   Locations of wells with concentrations of radioactive
particles in excess of MCLs in water of the
Edwards—Trinity (Plateau) aquifer

Map constructed from all available water-quality data.

Constituent	Average*	Range*			% Above Detection	% Above MCL
Ammonia	0.07	0.01	-	11.1	24	
Nitrite	0.01	0	-	0.28	2	
Nitrate (NO_3)	18.6	0.04	-	298	91	7
Kjeldahl	0.3	0.01	-	15.5	50	
Orthophosphate	0.01	0.01	-	0.06	18	

* Expressed in micrograms/liter

Table 5. Dissolved nutrients in Edwards-Trinity (Plateau) ground water.

Radioactivity

Gross alpha (α) radiation consists of the emissions of positively charged helium nuclei having high atomic weight. This radioactive decay is measured as gross α in units of picocuries per liter (pCi/l). Alpha-emitting isotopes in natural waters are primarily isotopes of Ra_{226} and Ra_{228}, Ra_{226} being the disintegration product of uranium (U_{238}), and Ra_{228}, the disintegration product of thorium (Th_{232}). RA_{226} decays to radon gas (Rn_{226}), which is also an α-emitter. Gross beta (β) radiation consists of the emission of high-energy *electrons and* positrons from the nucleus of atoms having high atomic weight. Natural β-emitting isotopes occur in the uranium and thoriurn disintegration series, among other natural sources.

Of the 327 samples collected that were analyzed for gross alpha, 12 percent (or 37) were found to contain gross alpha in excess of the 15 pCi/MCL, with a range of 2 to 66 and an average of 9.8 pCi/I (Table 6). Only two samples contained gross beta in excess of the 50 pCi/l MCL, with a range of 4 to 51 and an average of 9.9 pCi/l. As illustrated in the map in Figure 10, concentrations are highest in Upton, Reagan, and Pecos counties. This naturally occurring radioactivity is associated with the disintegration of uranium-bearing deposits found in the Dockum Group, immediately underlying the Edwards-Trinity in the western part of the Edwards Plateau and the Trans-Pecos. The radioactivity in the Ogallala ground water is also attributed to its association with the uranium of the Dockum (Hopkins, 1993; Cech and others, 1987; Kier and others, 1977).

Radioactive Particle	Average	Range	% Above Detection	# Above MCL	
Gross Alpha (pCi/l)	9.8	2-66	89		37
Gross Beta (pCi/1)	9.9	4-51	84		2

Table 6. Dissolved radioactive particles in Edward-Trinity (Plateau) ground water.

COMPARISON TO PREVIOUS WORK

With the exception of recent RASA publications by the USGS, few investigations have included little more than brief discussions of water quality in the Edwards-Trinity (Plateau) aquifer. Walker (1979) was the first author to compile information about the occurrence, availability, and chemical quality of ground water throughout the entire Edwards Plateau, theretofore reported on a county-by-county basis, although the study area did not extend west of the Pecos River. Walker describes water in the Antlers Formation as characteristically very hard, of the calcium bicarbonate sulfate type, and as varying greatly in amounts of dissolved solids depending upon location. He mentions that water quality in the Antlers is poorer in the

western part of the Plateau, and specifically that water with more than 1,000 mg/l dissolved solids is common in Upton, Ector, southwestern Glasscock, and northern Reagan Counties; wells in these same counties typically contained sulfate in excess of 300 mg/l, a large number of samples contained more than the recommended maximum for fluoride (2 mg/l at the time of this report); and only a few wells contained nitrate exceeding the recommended limit.

Rees and Buckner (1980) briefly discuss water quality in the Edwards-Trinity (Plateau) in the Trans-Pecos. They note that fluoride and dissolved-solids concentrations are commonly higher than recommended limits and specifically mention dissolved-solids contents in selected irrigation areas. Chloride, sulfate, and dissolved-solids concentrations are listed on their map beside each of the 113 sampled wells.

In a later report concentrating only on Midland, Glasscock, Upton, and Reagan Counties, Ashworth (1989) discusses similar water-quality problems in the Edwards-Trinity (Plateau). He ascribes excess nitrate found in a few wells to temporary pollution, and also notes that iron in half of the sampled irrigation wells was in excess of 0.3 mg/l. The high conductance range in sampled irrigation wells indicates a medium-to-very-high salinity hazard; however, even ground water with a very high salinity hazard (specific conductance up to 5,000 micromhos) and sodium absorption ratio values within the low-to-medium sodium hazard range are being used to irrigate crops under special management practices. Of the 38 samples analyzed for boron, 61 percent contained between 1.0 and 3.0 mg/l (maximum tolerable levels for different crops fall within this range), and 13 percent contained amounts in excess of 3.0 mg/l.

Ashworth points out that water quality has deteriorated over time and that areas with the poorest quality water are located over major oil fields. He discusses the potential for pollution associated with brine disposal in unlined pits before 1969; saltwater disposal in underground injection wells; improperly cased oil and gas wells; abandoned and unplugged or improperly cased oil and gas wells; and spills associated with buried pipelines. Ashworth believes that irrigation pumpage has not generally affected water quality and notes that increased levels of sulfate may be the result of mixing of water derived from Triassic (Dockum) and Permian (Rustler and Capitan) formations. As previously discussed, Bush, Ulery, and Rittmaster (1993) present convincing evidence that these underlying formations (in addition to the overlying Cenozoic Pecos Alluvium in the Toyah Basin) are the most probable sources for the sulfate and chloride facies common in the northwestern and western parts of the study area.

Historical data in the TWDB ground-water database were examined to crudely assess water-quality deterioration over time. Query language was used to calculate averages of specific constituents during two earlier sampling events - more than 4,000 analyses were averaged from 1960 to 1975 and approximately 1,000 from 1976 to 1986. Many of the same wells were sampled during each of these three periods, although this percentage was not determined. Whether the constituent concentration increased or decreased over time in wells with multiple sampling events, however, was considered during map preparation. With the exception of fluoride, all of the constituents in Table 7 have increased during the past 30 years.

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