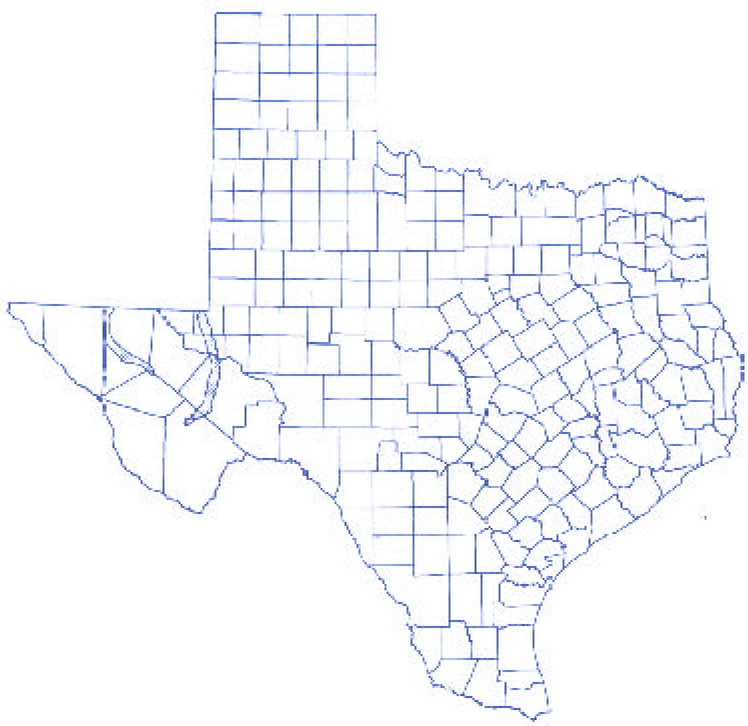
Hydrologic Atlas No. 8

Water Quality in the Capitan Reef Aquifer



by
Eric Brown
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INTRODUCTION

The Capitan Reef aquifer is located in West Texas and Southern New Mexico along the margin of the Delaware Basin. In the Permian age, the area was covered by a shallow sea and a reef formed along its edges. Over time the area experienced sedimentation followed by uplifting to form the present day configuration. The aquifer, a horseshoe-like formation 5 to 14 miles wide, extends from the Glass Mountains in Brewster County northward through Pecos, Ward, and Winkler counties, into southeastern New Mexico. The aquifer curves back south and continues through Culberson, Hudspeth, Jeff Davis, and Reeves counties. Although the two sections of the aquifer in Texas are connected, basic water-quality differences occur and a comparison between the eastern and western belt will be included in this study. The map in Figure 1 illustrates the aquifer's extent and location of sampled wells used in this atlas.

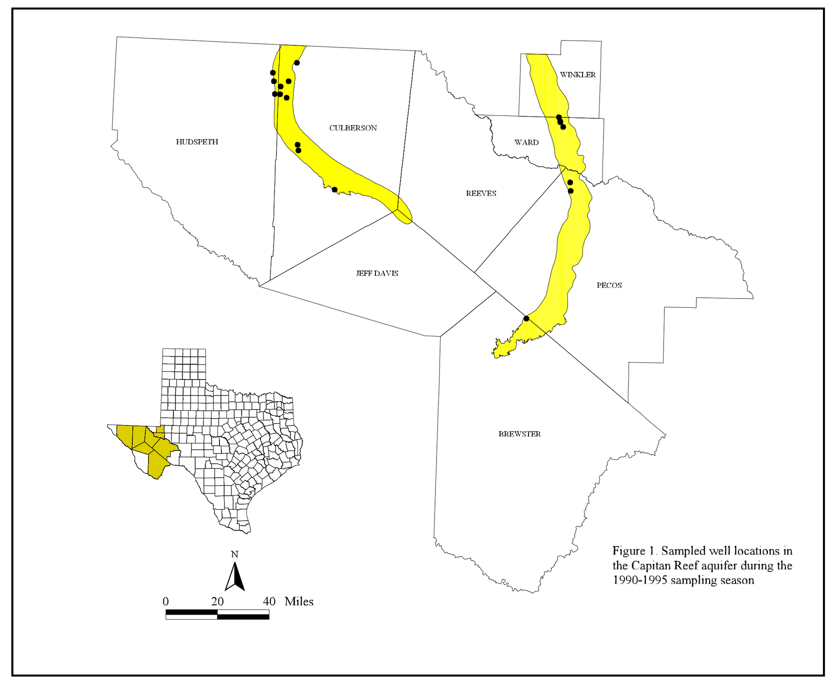

Figure 1 Sample well locations in the Capitan Reef aquifer during the 1990-1995 sampling season

The formation is composed of porous limestone and dolomite with minor amounts of sandstone and shale. It crops out extensively in the Guadalupe Mountains in Culberson and Hudspeth counties, the Apache Mountains in Culberson County, and the Glass Mountains in Brewster County. This surface topography, in relation to the aquifer's extent, is illustrated in Figure 2. White areas on the map represent the highest elevations. In Pecos, Ward, and Winkler counties the aquifer is present only in the downdip, as it is in parts of Culberson and Hudspeth counties. Although the formation is present in Jeff Davis and Reeves counties, the Texas Water Development Board (TWDB) presently has no Capitan Reef wells on record for these counties.

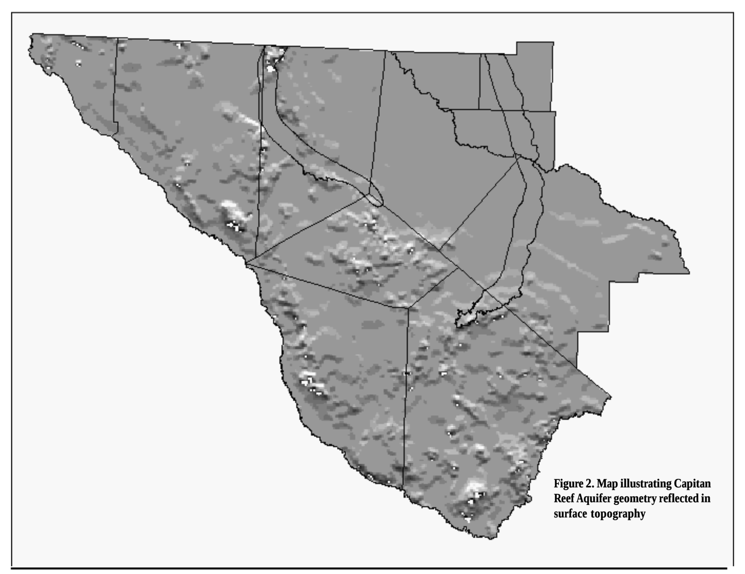

Figure 2. Map illustrating Capitan Reef Aquifer geometry reflected in surface topography

Thickness across the formation ranges from 300 to 2,000 feet. Well depths range from 14 feet to 4,500 feet, with the deepest wells located in the subsurface portions in Pecos, Ward, and Winkler counties. Small to moderate amounts of fresh to slightly saline water are available in selected areas in the Guadalupe Mountains and in the Glass Mountains. Small to large amounts of saline to brine water are available throughout most of the aquifer.

The aquifer is recharged primarily by rainfall over the Guadalupe and Glass Mountains, which ranges from 9 to 13 inches over the eight county area. Discharge occurs through springs and wells. Artesian conditions exist from Winkler through Pecos counties and in the Glass Mountains in Brewster County.

The TWDB sampled 17 Capitan Reef wells and one spring from 1990 through 1995 (12 in 1995). TWDB maintains an ongoing program to monitor the ambient water-quality in major and minor aquifers throughout the state and to determine any changes that may have occurred over time. The author sampled Capitan Reef wells in Pecos, Ward, and Winkler counties and wishes to thank the other environmental specialists who collected samples: John Asensio, Merrick Biri, Dennis Jones, Cheri Martz, and Ron Mohr. Special thanks to the landowners who permitted their wells to be sampled and geologists Phil Nordstrom and Janie Hopkins who edited the atlas. All illustrations were created with ArcView by the author, except for Figure 2, which was created by Erika Boghici.

WATER QUALITY

Most wells completed in the Capitan Reef aquifer that are in use are utilized for either livestock or industrial purposes. During the 1990-1995 sampling season, though, wells sampled covered a broader variety of uses: three domestic, three irrigation, four industrial (oil recovery), one public supply, one recreation (spring), four stock, and two unused. The two unused wells were previously irrigation wells and were sampled using the TWDB portable submersible pump rig. The Capitan Reef Formation in Ward and Winkler counties is used for the secondary recovery of oil (water-flooding); the four wells sampled in Ward and Winkler are used for this purpose. Of the 17 wells sampled, 15 appear to be completed in the subsurface portion of the aquifer. Sampled well depths range from 377 to 4,500 feet deep. One of the wells in Pecos County had reports of a ruptured casing, so there is the possibility of additional inflow from another water-bearing formation.

High yield and high use wells are preferred because they tend to provide a more representative sample, but wells of this type are not common in the study area. Regardless, environmental specialists took steps to ensure each well was producing a good sample either by making arrangements to have the well pumping on arrival, or by purging the casing and monitoring certain indicator parameters before drawing a sample. Environmental specialists take field measurements and use appropriate sampling techniques as described in the TWDB Field Manual for Ground Water Sampling (Nordstrom and Beynon, 1991) for dissolved inorganic constituents, nutrients, and, for the first time in this aquifer, radioactivity. Constituent levels as determined by the Texas Department of Health Laboratory and the Lower Colorado River Authority Environmental Laboratory are discussed, and areas in which key constituents are in excess of maximum contaminant 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		
Antimony	Sb	6 µg/l
Arsenic	As	50 µg/l
Barium	Ba	2,000 µg/l
Beryllium	Be	4 µg/l
Cadmium	Cd	5 µg/l
Chromium	Cr	100 µg/l
Fluoride	F	4.0 mg/l
Lead (EPA Lead Rule)	Pb	5 µg/l
Mercury	Hg	2 µg/l
Nickel	Ni	100 µg/l
Nitrate (as N)	NO_3 (N)	10.0 mg/l
Selenium	Se	50 µg/l
Thallium	Tl	2 µg/l
Gross Alpha	α	15 pCi/l
Gross Beta	β	50 pCi/l
Radium	Ra^{226} + Ra^{228}	5 pCi/l
Secondary Constituent Levels		
Chloride	Cl	300 mg/l
Copper	Cu	1,000 µg/l
Dissolved-Solids	TDS	1,000 mg/l
Fluoride	F	2.0 mg/l
Iron	Fe	300 µg/l
Manganese	Mn	50 µg/l
pH	pH	≥7.0
Silver	Ag	100 µg/l
Sulfate	SO_4	300 mg/l
Zinc	Zn	5,000 µg/l

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

Field Measurements

The ground water temperature of the Capitan Reef samples ranged from 17° to 33°C and averaged 26°C. Looking at the two aquifer belts separately, the temperature for the western belt averaged 20° and ranged 16° to 24° while the eastern belt averaged 31° and ranged 26° to 33°. The average pH of all Capitan Reef analyses was 7.1, with a range of 6.4 to 9.0. 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 in the water. The specific conductance for the entire aquifer ranged from 453 to 17,000 micromhos and averaged 4,194 micromhos. The eastern belt had an average specific conductance of 7,591 micromhos, and the western belt had an average of 1,552 micromhos. The average total alkalinity as determined in the field was 245 mg/l, with a range of 28 to 417 mg/l as $CaCO_3$; average bicarbonate ion concentration, calculated from mean total alkalinity, was 298 mg/l. The positive Eh average of -150.8 mV (range: -402 to +170 mV) indicates that the formation tends to have reducing conditions. Another field characteristic of the aquifer is its pungent "rotten-egg" odor, especially evident in wells in Pecos, Ward, and Winkler counties, where the author confirmed this observation first-hand.

Dissolved Inorganic Constituents

The dissolved-solids content is the main factor limiting or determining the use of ground water. These solids primarily consist of mineral constituents dissolved from the host rock, although other natural sources such as adjacent aquifers or human-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 Ground Water Protection Committee.

Class	Quality*	Examples of Use
Fresh	0 - 1,000	Drinking & all other uses
Slightly Saline	>1,000 - 3,000	Drinking if fresh unavailable; for livestock, irrigation, and industrial use
Moderately Saline	>3,000 - 10,000	Industrial, mineral extraction, oil and gas production; potential/future drinking and limited livestock watering and irrigation if fresh or slightly saline water 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 Capitan Reef aquifer. The average for each constituent represents values above detection limits and does not include values below detection levels (flagged with "<").

Constituent	Average*	Range*	# Above MCL	# Below detection level
Bicarbonate	298	22 - 509		
Calcium	336	18 - 1,020		
Chloride	881	3 - 5,877	9**	
Diss. Solids	3,059	289 -13,310	13**	
Fluoride	1.14	0.14 - 3.59	6**	
Hardness	1,335	264- 3,812		
Magnesium	120	27 - 303		
Potassium	17	<0.5 - 75		1
Silica	15	<1.0 - 28		2
Sodium	510	3.5 - 3,110		
Strontium	5.5	0.13 -18.30		
Sulfate	1,026	9 - 2,640	13**	

* Expressed in milligrams/liter ** secondary MCL

Table 3. Major anions and cations in Capitan Reef aquifer ground water.

The average dissolved-solids content of 3,059 mg/l reflects the normally saline character of Capitan Reef water. Of the 18 sites recently sampled, 13 wells had dissolved-solids levels above the secondary MCL of 1,000 mg/l. These 13 wells were located in both the eastern and western belts (Fig. 3). The wells with the highest dissolved-solids levels were all located in the deepest downdip portion of the aquifer in Pecos, Ward, and Winkler counties.

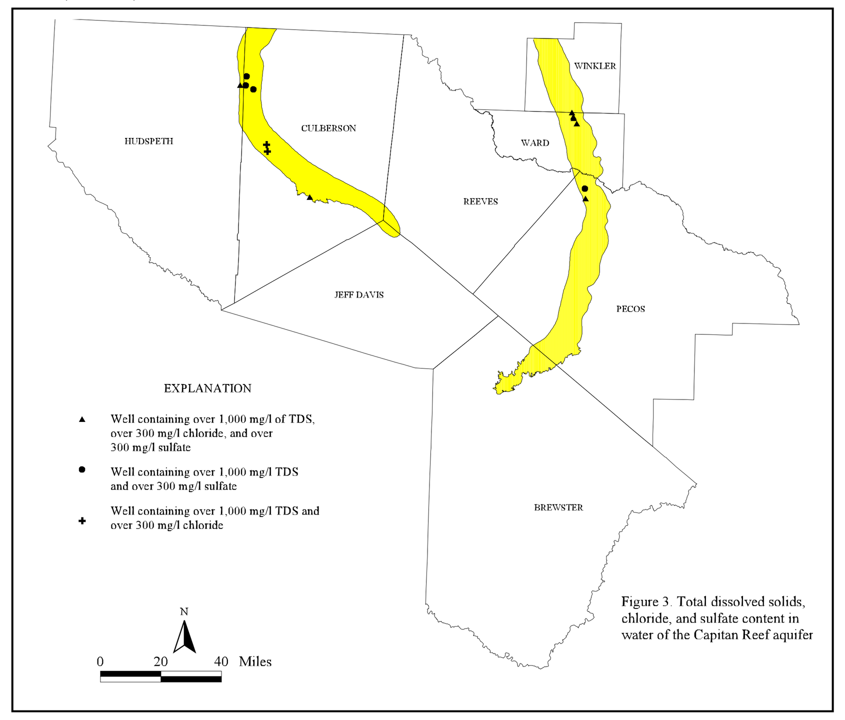

Figure 3 Total dissolved solids, chloride, and sulfate content in water of the Capitan Reef aquifer

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. Nine wells had chloride levels above the MCL of 300 mg/l (Fig. 3). A high chloride level usually coincides with high dissolved-solids content; all 9 of these wells had corresponding dissolved-solids readings over 1,000 mg/l.

Fluoride is dissolved in small amounts from most rocks and soils. In drinking water it helps to inhibit tooth decay, but high levels can cause mottling of teeth. Fluoride concentrations throughout the entire aquifer were below primary MCLs, but 6 wells exceeded secondary standards, 5 of which were in the eastern belt.

Sulfate is formed by the dissolution of sulfur from rocks and soils containing sulfur compounds such as gypsum, anhydrite, and iron sulfide. Sulfate in large amounts in combination with other ions gives drinking water a bitter taste. Thirteen of the wells recently sampled contained sulfate in excess of the secondary MCL of 300 mg/l; 11 also contained (Fig. 3) high dissolved-solids and/or chloride levels.

Table 4 lists averages and ranges of dissolved trace metal constituents in the Capitan Reef aquifer, for the most part detected in insignificant amounts. A majority of the analyses for several of the constituents were below lab detection levels. For some constituents, results below detection limits were sometimes reported in levels higher than actual maximum levels. For example, aluminum had one sample reported as < 160 µg/l, which is higher than the actual maximum level of 60 µg/L reported for another sample. These "high" below detection level results are included in the range. Four constituents-- beryllium, cadmium, lead, and thallium-- had 100% of the results below detection levels; cobalt and silver had all but one analysis below detection levels. Please note: Each average for the corresponding constituent reflects values above detection limits, that is, values that do not have a "<" sign. For all constituents, the number of samples tested for a particular constituent is in parentheses.

Constituent (No. of samples)	Average*	Range*	# Above MCL	#Below detection level
Aluminum (8)	26.7	2.1 - < 160		2
Antimony (12)	3.87	< 2.0 - 6.40	1	9
Arsenic (18)	2.10	1.7 - < 10		14
Barium (18)	27.4	< 1.0 - 111		2
Beryllium (12)	NA	< 1.0 - < 20		12
Boron (15)	418	31 - 1,720		0
Bromide (12)	3.53	< 0.10 - 20.54		1
Cadmium (18)	NA	< 0.50 - < 10		18
Chromium (15)	19.6	< 2.0 - < 64		13
Cobalt (9)	38	< 2.0 - < 64		8
Copper (17)	48.7	< 2.0 - 132		14
Iron (17)	1,308	< 6 - 7,897	5**	8
Lead (18)	NA	< 2.0 - < 50		18
Lithium (12)	164	3.6 - 380		0
Manganese (18)	72	< 2.0 - 176.7	5**	9
Mercury (9)	0.30	< 0.13 - 0.30		6
Molybdenum(12)	8.6	< 2.0 - < 40		8
Nickel (8)	14.5	4 - < 160		4
Selenium (18)	7.6	< 2.0 - < 16		15
Silver (14)	112	< 2.0 - 112	1**	13
Thallium (12)	NA	< 2.0		12
Vanadium (11)	4.13	< 2.0 - < 64		8
Zinc (17)	295	< 5 - 728		11

*Expressed in micrograms/liter (µg/l) ** Secondary MCL

Table 4. Dissolved trace metal constituents in Capitan Reef aquifer ground water.

Antimony is relatively rare in crustal rocks, occurring mostly around geothermal geysers and in some ore deposits. Its concentrations rarely exceed 3 µg/l in groundwater. Antimony was found in excess of the primary MCL, with a level of 6.40 µg/l, in a 4,500 foot well in Ward County.

Boron is a minor constituent in most natural waters. Although it has no drinking water standard, knowledge of its concentration in ground water is important because it determines the suitability of the water for irrigation. Concentrations as high as 1,000 µg/l are permissible for irrigation of boron-sensitive crops such as deciduous fruit and nut trees; as high as 2,000 µg/l for irrigation of semi-tolerant crops such as most grains, cotton, and potatoes; and as much as 3,000 µg/l for tolerant crops such as alfalfa and most root vegetables. Only 1 well, located in Ward County, contained boron in excess of 1,000 µg/l with a level of 1,720 µg/l..

Iron, dissolved from rocks and soils, occurs naturally at low levels in ground water. Higher levels can often be traced to iron casing and other equipment used in well construction, or attributed to natural causes depending on the geology of the water-bearing formations. Manganese, found naturally in ground water, and typically at low levels, can also occur naturally at high levels, often in conjunction with high iron levels. Figure 4 illustrates well locations where iron and manganese exceeded their secondary contaminant levels of 300 µg/l and 50 µg/l, respectively. Some wells exceeded only the iron secondary MCL and some only the manganese secondary MCL; these wells are marked with different symbols in Figure 4. The locations of wells with high levels are widespread, but are confined to the western belt in Culberson and Hudspeth counties. Silver is a rare element in crustal rocks. It is a non essential element and can cause skin discoloration at high levels. One well exceeded the secondary MCL of 100 µg/l. This well is located in Ward County and is 4,500 feet deep.

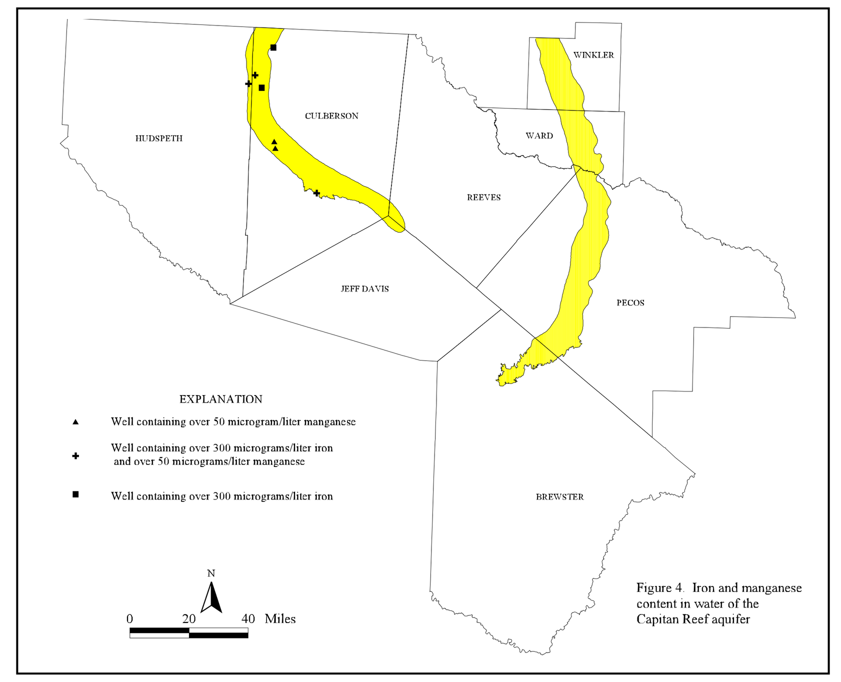

Figure 4 Iron and manganese content in water of the Capitan Reef aquifer

Nutrients

Of the four nutrients analyzed in each well, 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 commonly higher in leachates from sludge and refuse disposal and in industrial discharges. Nitrite, formed by the action of bacteria upon 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. However, in the oxidizing environments common in most aquifers, nitrites are converted into nitrates, and their values are lower. In this study, none of the wells sampled contained nutrients in excess of drinking water standards.

Constituent*	Average	Range	# Above MCL	# Below detection level
Ammonia (as N) (18)	1.26	0.01 - 7.84		4
Nitrite (as N) (11)	0.03	< 0.01 - 0.05		8
Nitrate (as N) (11)	0.58	< 0.01 - 2.21		1
Kjeldahl (18)	1.69	< 0.10 - 11.7		1

* Expressed in milligrams/liter

Table 5. Dissolved nutrients in Capitan Reef aquifer ground water.

Radioactivity

Gross alpha (α) is the total radioactivity, measured in units of picocuries per liter (pCi/l), due to alpha particle emission. Alpha-emitting isotopes in natural waters are primarily isotopes of radium^{226} and radium^{228} and usually occur in deep aquifers or in areas affected by uranium or phosphate mining. Gross beta (β) radiation is the total radioactivity due to beta particle emission. Natural β-emitting isotopes occur in the uranium and thorium disintegration series, among other natural sources. Radium is derived from igneous rocks such as granites, uranium ores, certain shales and sandstones, and volcanic rocks. The dominant radium isotopes found and detected in natural waters are radium^{226} and radium^{228}. In these analyses, seven of the samples exceeded primary MCLs for one or more type of radioactive elements. Figure 5 illustrates the location of the wells. In addition, six of these wells are located in the deepest part of the aquifer in Pecos, Ward, and Winkler counties. Note: The primary MCL for radium^{226} and radium^{228} is 5 pCi/l for the sum of both. In this study six wells exceeded this standard.

Constituent*	Average	Range	# Above MCL	# Below detection level
Gross alpha (17)	29.01	< 3.80 - 108.0	6	3
Gross beta (17)	23.45	< 4.0 - 79.0	2	3
Radium^{226} (10)	8.76	< 0.2 - 32.0	6	1
Radium^{228} (10)	5.48	< 1.0 - 8.4	2	6

* Expressed in picocuries/liter

Table 6. Radioactivity in Capitan Reef aquifer ground water.

Alpha particle radiation cannot penetrate human skin, but is very dangerous when the alpha emitting particle is ingested. Beta particle radiation can penetrate human skin. Both types of radioactivity are very harmful to tissue in internal organs, and damage depends on time and dosage of the radiation. Depending on these factors, the tissue may recover or develop cancerous cells or tumors. Radium, in excessive concentrations, can cause bone and bone marrow cancers.

Deep aquifers are known to contain natural amounts of radioactivity. The Capitan Reef geology does not lend itself to containing uranium ores, a common source of radioactivity. A possible explanation would be the migration of water from deeper formations into the Capitan Reef, causing the increased radioactivity. This is only a hypothesis and further research is needed to confirm the source of the radioactivity.

COMPARISON TO PREVIOUS WORK

A brief review of past studies show findings similar, but not as detailed, to those in this report. Richey et al. (1985) reported Capitan Reef water to be unsuitable for domestic or irrigation use, with dissolved-solids levels ranging from 550 to 2,270

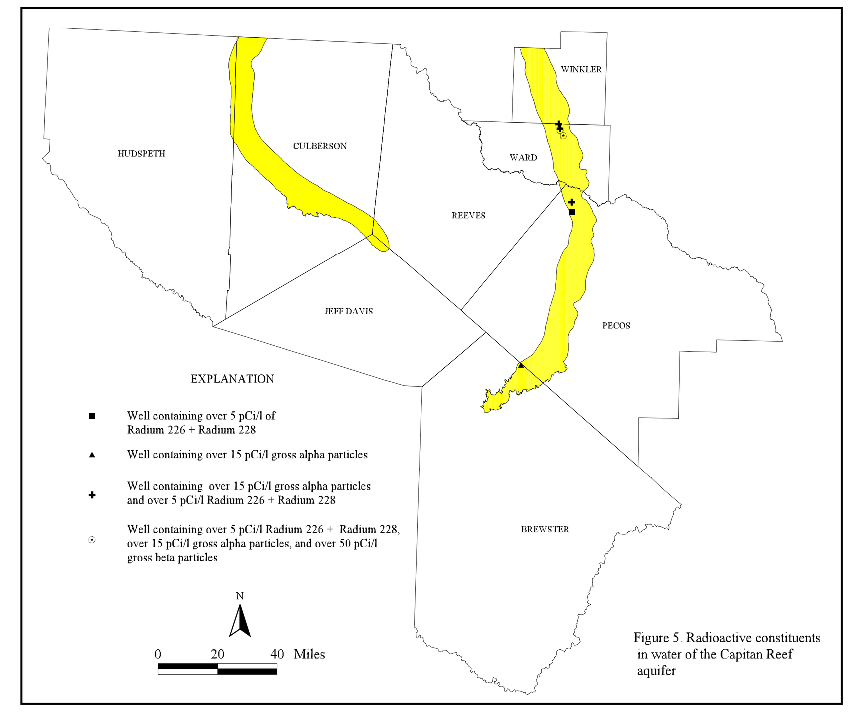

Figure 5 Radioactive constituents in water of the Capitan Reef aquifer

mg/l in Culberson County and 303 to 3,690 mg/l in Pecos County. Hiss (1975) reported that potable water was available only near Carlsbad, New Mexico and near the Glass Mountains. Large quantities of fresh to slightly saline water was reported in the Beacon Hill area of Northern Hudspeth and Culberson County and some quantities of fresh water in the Apache Mountains in Culberson County (Gates et al., 1980). Armstrong and McMillion (1961) reported that Capitan Reef water in Pecos County is unsuitable for human consumption and of doubtful quality for irrigation, although it has been used to grow cotton. They also mention the presence of H_2S gas at wells completed in the Capitan Reef. White (1971) noted that wells tapping the Capitan Reef in Ward County yielded moderately to very saline water and that it was corrosive.

Historical data taken from balanced analyses in the TWDB ground water database were examined to assess water-quality changes over time. Query language was used to calculate averages of chloride, dissolved-solids, fluoride, hardness, and sulfate during the last five decades and the present partial decade (Table 7). Because of variations in the natural water-quality of the Capitan Reef aquifer, the coverage area was divided into two main regions: eastern belt (Brewster County northward to Winkler County) and western belt (Culberson and Hudspeth County). Averages do not reflect the same sample population for each time period; although the same wells were often sampled more than one decade, few were sampled in more than one. Furthermore, the choice of decades as the time period most appropriate for the calculation of averages is arbitrary, as sampling events were not timed to correspond with any certain time period, and analyses are few and sporadic because of the lack of any widespread sampling effort until recently.

Constituent	1950 - 1959	1960 - 1969	1970 - 1979	1980 - 1989	1990 - 1995
Eastern Belt					
Chloride	550	6,812	690	626	2,123
Diss. Solids	3,694	14,937	3,676	3,435	6,762
Fluoride	--	--	3.0	2.4	2.05
Hardness	2,130	3,882	2,050	1,930	2,814
Sulfate	1,830	2,486	1,750	1,540	2,241
Western Belt					
Chloride	117	142	265	185	283
Diss. Solids	986	1,050	1,493	1,002	1,289
Fluoride	1.20	1.36	1.56	--	0.94
Hardness	634	671	823	673	625
Sulfate	423	430	615	395	453

Table 7. Comparison of averages of dissolved constituents in the Capitan Reef aquifer.

Because of the small number of samples, identifying true trends in water-quality is hampered. The table does illustrate the water-quality differences between the two sections. Any apparent trends could possibly be explained by collection, sampling, transportation, and testing methods. Before 1989, wells were sampled without specific guidelines, therefore, reliability of collection and transportation methods are questionable in some cases. In addition, sampling and testing techniques have improved over the decades, and the purpose of the TWDB monitoring program has broadened in scope to include a representative sampling of wells throughout the entire aquifer.

Another way of assessing change in water-quality over time is by examining analyses from wells sampled more than once. One well, located in Pecos County, was sampled four times between 1956 and 1995.

	Chloride	Dissolved Solids	Fluoride	Hardness	Sulfate
1956	550	3,694	---	2,130	1,830
1972	690	3,676	3.0	2,050	1,750
1989	626	3,435	2.4	1,930	1,540
1995	570	3,194	2.2	1,781	1,484

All parameters improved over the time period. A number of explanations could be discussed, but the most likely is the improvement of sampling and testing procedures.

CONCLUSIONS

The overall water-quality of the Capitan Reef aquifer is poor. Sampled well analyses contain constituents that exceed both primary and secondary standards. Concerning primary water quality standards, high levels of radioactivity are a major problem in the eastern belt; seven wells sampled in this region exceeded MCLs for one or more of the radioactive standards. High levels of radioactivity were not evident in the western belt.

Numerous samples exceeded secondary MCLs for dissolved-solids, chloride, fluoride, and sulfate. High levels of these constituents are evident in both sections of the aquifer, with especially high levels in Pecos, Ward, and Winkler counties. This is most likely due to the decreased permeability of the formation increasing the time the water has to dissolve minerals in the formation. Iron and manganese are found in excess of their secondary standards over the western extent of the aquifer.

Although the eastern belt contains the poorest water-quality, poor water-quality affects most of the aquifer, east and west. There are some exceptions, for example the well in Brewster County, several wells in Culberson and Hudspeth counties, and the spring in Culberson County, where water-quality is good enough to be used for domestic purposes. These sites are close to recharge areas and the time available for the water to dissolve minerals from the formation is limited.

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