

Chapter 15

Hydrogeology of the Rustler Aquifer, Trans-Pecos Texas

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Introduction

The Rustler aquifer is one of the less-studied aquifers in Texas, and this paper is an attempt to review and summarize all available hydrogeologic information on this aquifer. The Rustler Formation consists of up to 500 ft of carbonate and evaporite strata of Permian age deposited in the Delaware Basin of West Texas. The formation yields moderate to large quantities of fresh to brackish groundwater, primarily from solution openings in its upper section. Recharge takes place by cross-formational flow from deeper aquifers and percolation of surface water through the formation outcrop. Discharge is predominantly to pumping wells and by flow into overlying aquifers. Geochemical data indicate the main processes impacting the groundwater chemical composition are the dissolution of calcite, dolomite, gypsum, and halite and cation exchange.

Regional Geologic Setting

The Rustler Formation underlies the Delaware Basin in West Texas and Southeastern New Mexico and is the youngest unit of the Late Permian Ochoan Series. The formation outcrops in a north-to-south-trending belt in the Rustler Hills of Culberson and Reeves Counties and the contiguous plains to the east, where it unconformably overlies the Salado Formation. The 250- to 670-ft-thick Rustler strata extend downdip toward the center of the Delaware Basin. In outcrop they consist of dolomite, dolomitic limestone, limestone breccia, gypsum, and mudstone, with minor siltstone and sandstone near the base (Hentz and others, 1989). Six subsurface formation members have been identified in the Rustler Hills area (table 15-1).

The Rustler Formation becomes thinner (40–200 ft) and conformably overlies the Salado Formation toward the eastern margin of the Delaware Basin and across the Central Basin Platform and Val Verde Basin (fig. 15-1). Hentz and others (1989) recognized three distinct subsurface members in Pecos County (table 15-2).

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Table 15-1: Subsurface stratigraphy of the Rustler Formation in Culberson and western Reeves Counties (from Hentz and others, 1989).

Division	Thickness Range (ft)	Lithology
Forty-niner Member (Vine, 1963)	70–90	Two beds of white to gray massive and nodular anhydrite and gypsum separated by a thin gray to red gypsiferous mudstone or siltstone bed
Magenta Member (Adams, 1944)	20–28	Interbedded gray dolomite and gray gypsiferous dolomite
Tamarisk Member (Vine, 1963)	105–125	Two beds of white to gray massive and nodular anhydrite and gypsum separated by a gray gypsiferous mudstone bed
Culebra Member (Adams, 1944)	50–55	Grey laminated dolomite, locally brecciated
Lower gypsum and mudstone member	35–50	Gray and tan mudstone and gypsum interspersed with thin gypsiferous dolomite beds
Siltstone member	95–145	Gray and locally red dolomitic siltstone and mudstone in the lower part; gray dolomite at top

Table 15-2: Subsurface stratigraphy of the Rustler Formation in Pecos County (descriptions from Hentz and others, 1989).

Division	Thickness Range (ft)	Lithology
Upper Member	10–55	Gray dolomite, locally calcareous and oolitic. Vuggy porosity.
Middle Member	40–65	Calcareous siltstone, sandstone, red and gray shale, with interspersed anhydrite, gypsum, and shale, locally massive anhydrite and gypsum, and sandy dolomite.
Lower Member	10–50	Brownish-gray dolomite, locally calcareous, argillaceous, oolitic, or sandy. Vuggy porosity common.

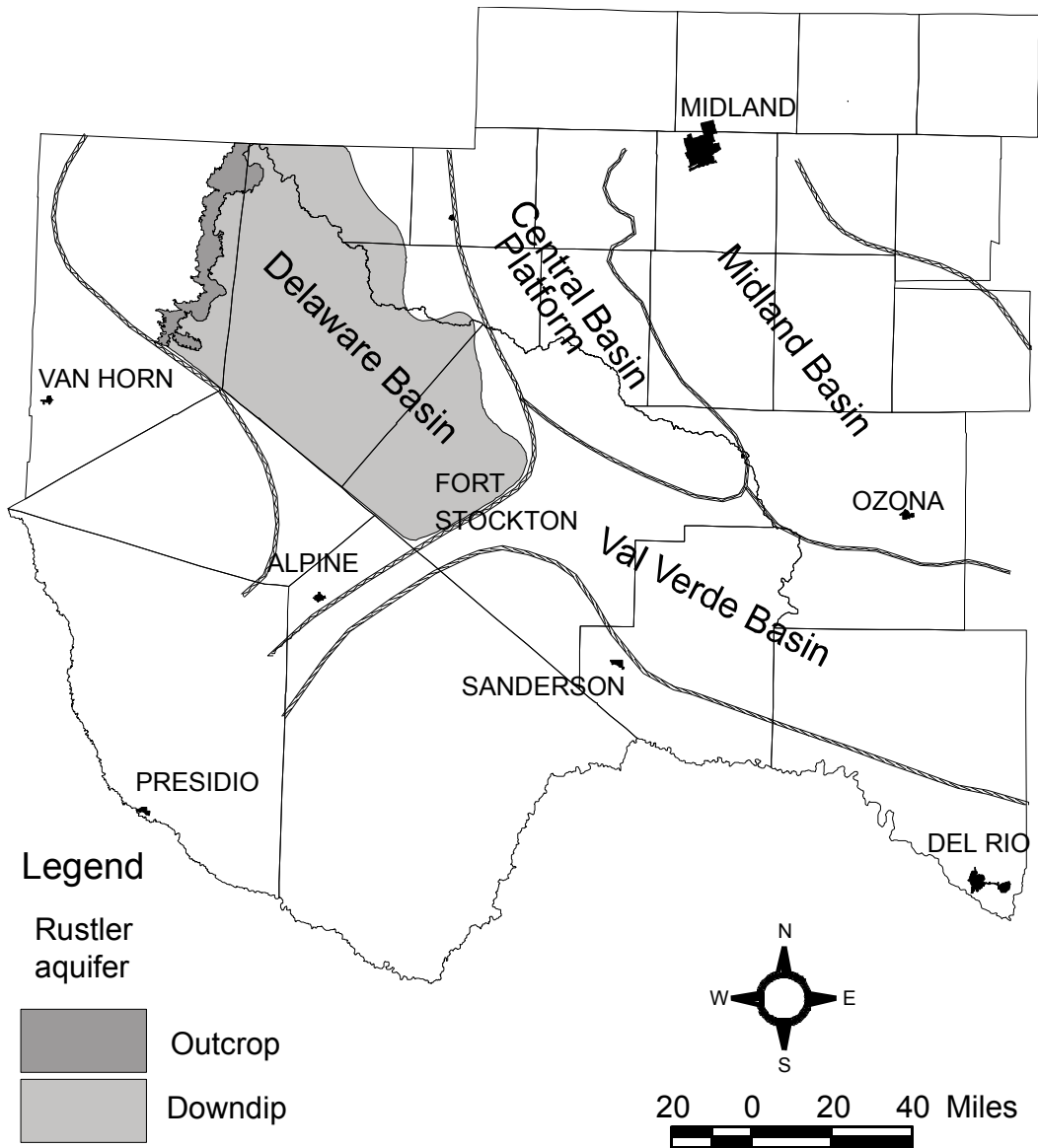


Figure 15-1: Regional Permian structure (modified from Small and Ozuna, 1993).

Structure

The most prominent structural features in the Rustler region are the Delaware Basin, the Central Basin Platform, and the Val Verde Basin (fig. 15-1). The structure of the Rustler rocks in the study area closely reflects the structure of the older Permian strata. Generally Rustler beds dip away eastward along a wide, irregular monocline. Late Tertiary tectonic activity in the Basin and Range area left northeast-trending fault patterns that are visible today throughout the Trans-Pecos gypsum plain. An important effect of Tertiary faulting

and eastward tilting of the Delaware Basin was the commencement of dissolution of Ochoan evaporites. This process caused the Permian beds to collapse and form a network of deep troughs and depressions throughout West Texas. Salt solution troughs have been mapped directly above the Capitan Reef on the eastern edge of the Delaware Basin, as well as under the west-central Delaware Basin (Hiss, 1976). Triassic, Cretaceous, Tertiary, and Quaternary rock and sediments gradually filled the troughs and underwent subsidence, faulting, and folding. Today they form prolific aquifers.

Structure for the top of the Rustler Formation (fig. 15-2) reveals several solution troughs resulting from the union of many lens-shaped subsurface depressions. The Balmorhea-Pecos-Loving Trough (Hiss, 1976) originates near Balmorhea and extends northward to Pecos and on into Eddy County, New Mexico. The Belding-San Simon Trough (Hiss, 1976) follows the Capitan Reef trend from Belding in Pecos County, Texas, to the San Simon swale in Lea County, New Mexico.

Aquifer Delineation

In Texas, the Rustler aquifer underlies an area of approximately 480 mi² encompassing most of Reeves County and parts of Culberson, Pecos, Loving, and Ward Counties (fig. 15-3). The southwestern Rustler aquifer boundary was arbitrarily traced along the Jeff Davis-Reeves-Pecos County line because of lack of well coverage in that area. Although the Rustler Formation is present in Brewster and Jeff Davis Counties, no Rustler water-well data are currently available for these counties. The 5,000-mg/L total dissolved solids (TDS) isoline was designated as the downdip limit of the aquifer to the northeast and southeast (fig. 15-3).

Aquifer Properties

Pump-test data for the Rustler aquifer were not available at the time this paper was written. Aquifer permeability is thought to be low except where porosity has been enhanced by carbonate and evaporite dissolution (Muller and Price, 1979). Reported well yields vary from 7 gallons per minute (gpm) to 4,400 gpm. Prior to 1955, when well acidizing became common in the area, few wells could produce from the Rustler in Reeves County (Ogilbee and others, 1962). The acidizing practice “almost eliminated dry holes” (Ogilbee and others, 1962) and resulted in temporarily increased yields of up to 1,000 gpm.

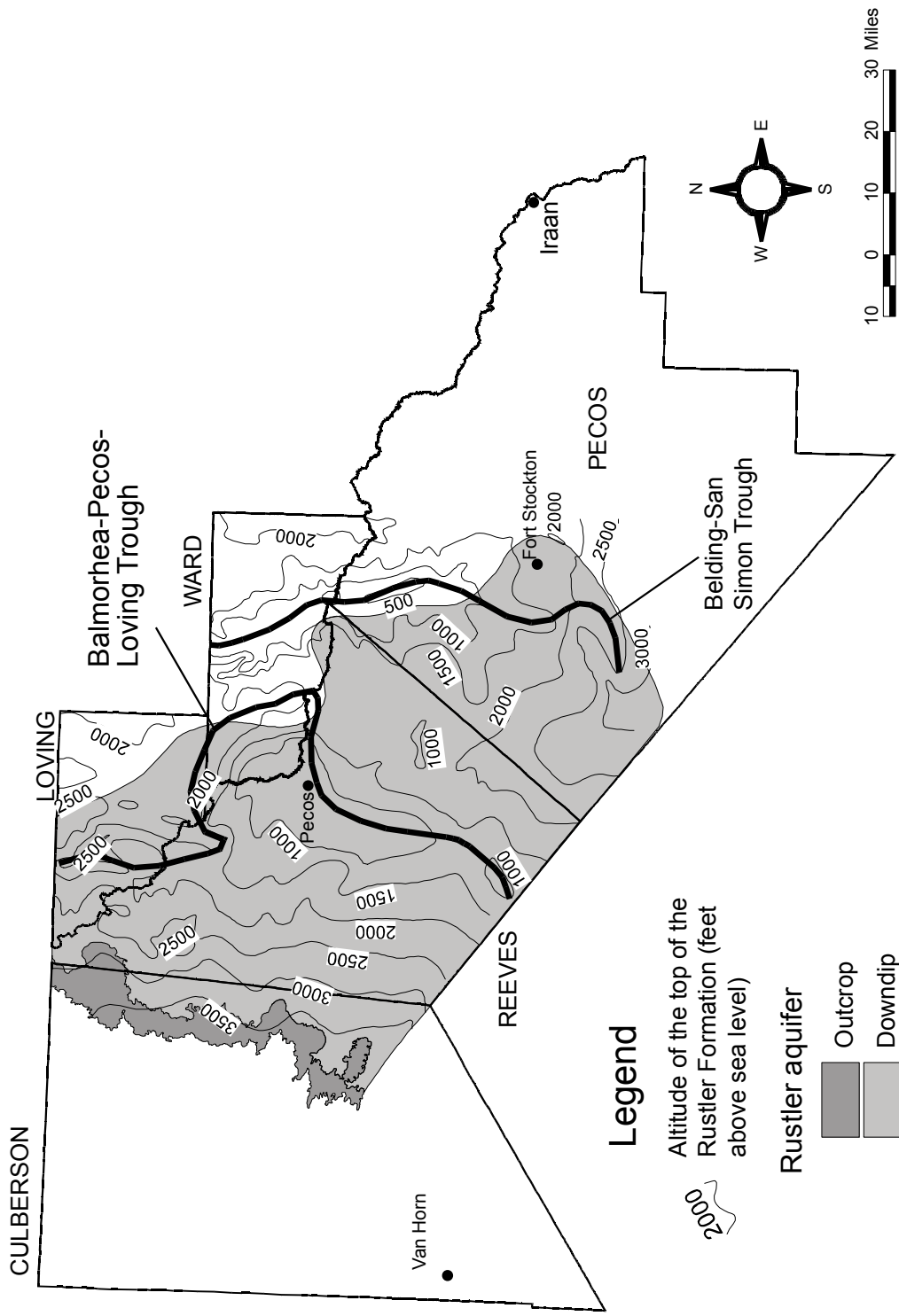


Figure 15-2. Structure map at the top of the Rustler Formation. Contours and modified trough locations from Hiss (1976).

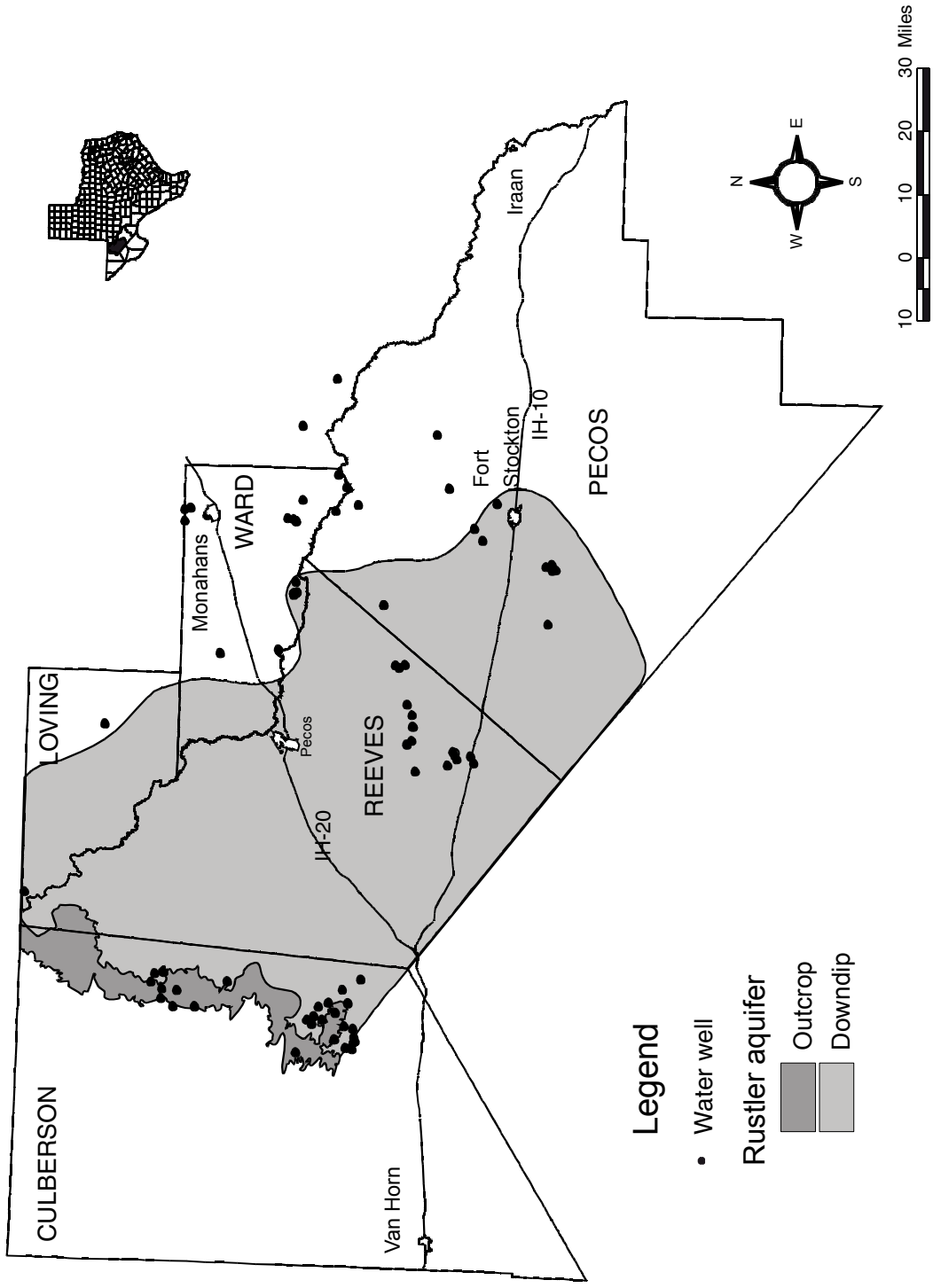


Figure 15-3. Location map and available Rustler wells. Map includes wells outside the aquifer limits. Data from TWDB.

The most productive interval of the Rustler Formation is the Upper Member (table 15-2), which, during the 1950's, was supplying 500 to 1,000 gpm to 30 irrigation wells in Reeves County (Ogilbee and others, 1962). A well drawing 4,400 gpm was drilled in 1964 near Belding in Pecos County. Many of the wells in the Rustler flowed when drilled, and some are still flowing today, albeit at greatly reduced rates. For example, well 46-40-801 was flowing 0.25 gpm in 1995, down from 900 gpm when drilled in 1932. This flow diminution is probably due to a lowering of the water levels in parts of the aquifer. Well-construction problems, such as ruptured casings and caving of the formation below the casing, could also explain the reduction in flow (Armstrong and McMillion, 1961).

Potentiometry

Water-level data from for the Rustler aquifer are very sparse. Historically no more than 13 wells have been measured throughout the aquifer in any given year. The areal distribution of the wells with water-level measurements made it impossible to contour an aquiferwide potentiometric surface map. From the outcrop of the Rustler aquifer in southeastern Culberson County, groundwater moved generally to the east-northeast toward the Reeves County line in 1988 (fig. 15-4). The average hydraulic gradient in the area was 0.015. Hydraulic heads in the outcrop ranged from 3,255 to 3,368 ft. A large data gap spans the area between the Culberson-Reeves County line and the Pecos meridian. In western Pecos County and southeastern Reeves County groundwater moved toward the north-northwest, with an average hydraulic gradient of 0.004. Hydraulic heads in this area ranged from 3,058 ft in the Belding area southwest of Fort Stockton to 2,612 ft near the Pecos-Reeves County line.

A water-level measurement from a Crane County well was used to constrain the downdip water-level configuration. Boghici (1997) delineated flow directions on the basis of earlier hydraulic heads outside the formal limits of the aquifer. The flowlines (fig. 15-5) show a centripetal pattern that converges under an area north of Fort Stockton. Trends in the potentiometric surface suggest the presence of a high-permeability area funneling groundwater flow in eastern Reeves County. In 1988, depths to groundwater in the Rustler outcrop were between 50 and 150 ft. The water levels were deeper in southeastern Reeves County, where they ranged from 130 to over 250 ft. Groundwater was 134 and 139 ft deep in two wells owned by the Belding Farms in Pecos County.

Time-series hydrographs of selected wells in the study area (fig. 15-6) illustrate long-term temporal fluctuations in aquifer storage. Depletion of storage due to pumping has occurred in Pecos County wells 51-16-608 and 51-16-609 from the mid-1960's through late 1970's. Declines in water levels of up to 100 ft have been recorded during this period.

Beginning in the 1980's, reductions in groundwater withdrawals resulted in water-level recovery to levels above those encountered when these wells were drilled. The cessation of irrigation pumping in Reeves County well 46-60-902 has resulted in water levels rising 170 ft from 1960 to 1968.

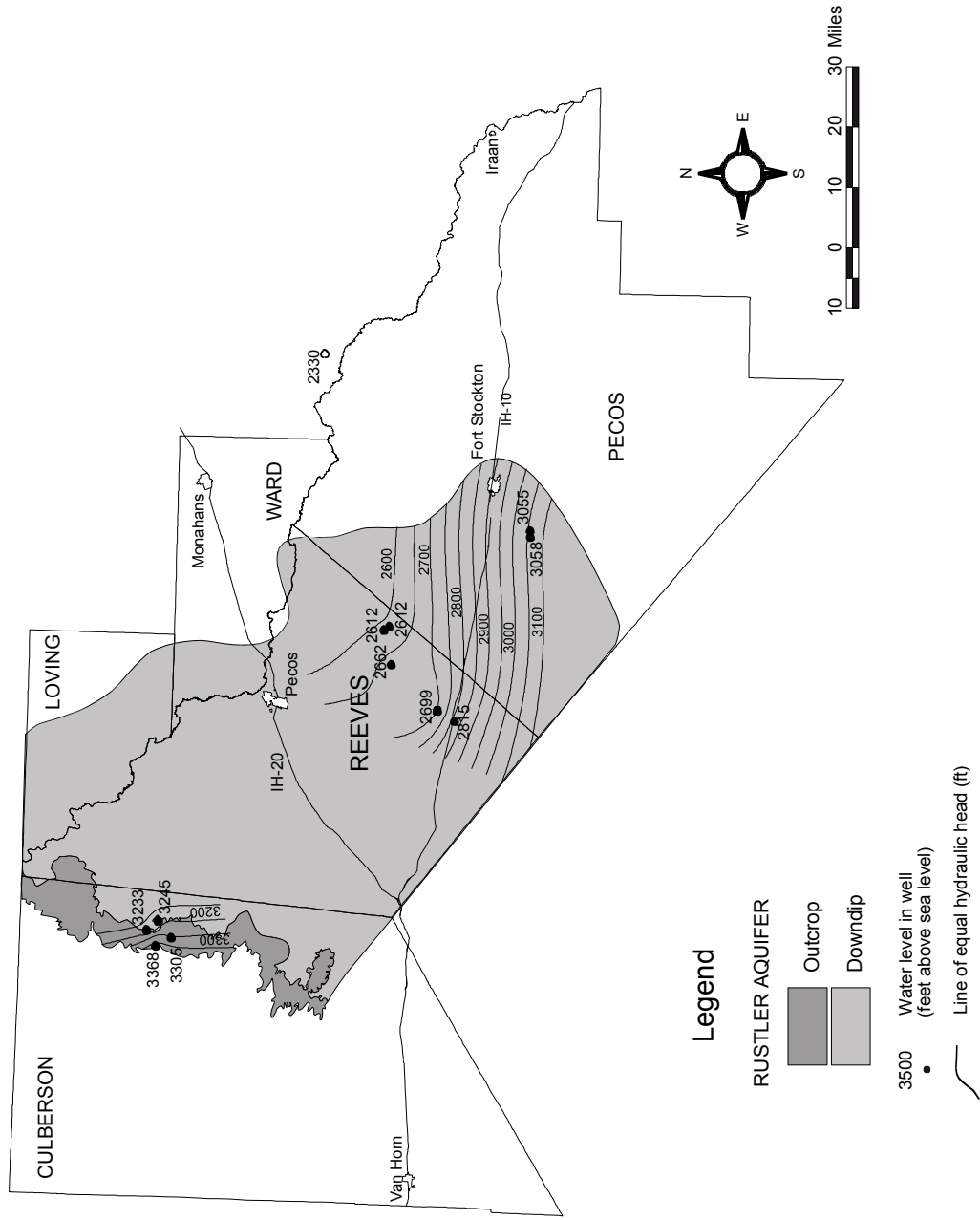


Figure 15-4. Potentiometric surface map for Rustler aquifer, 1988. Data from TWDB.

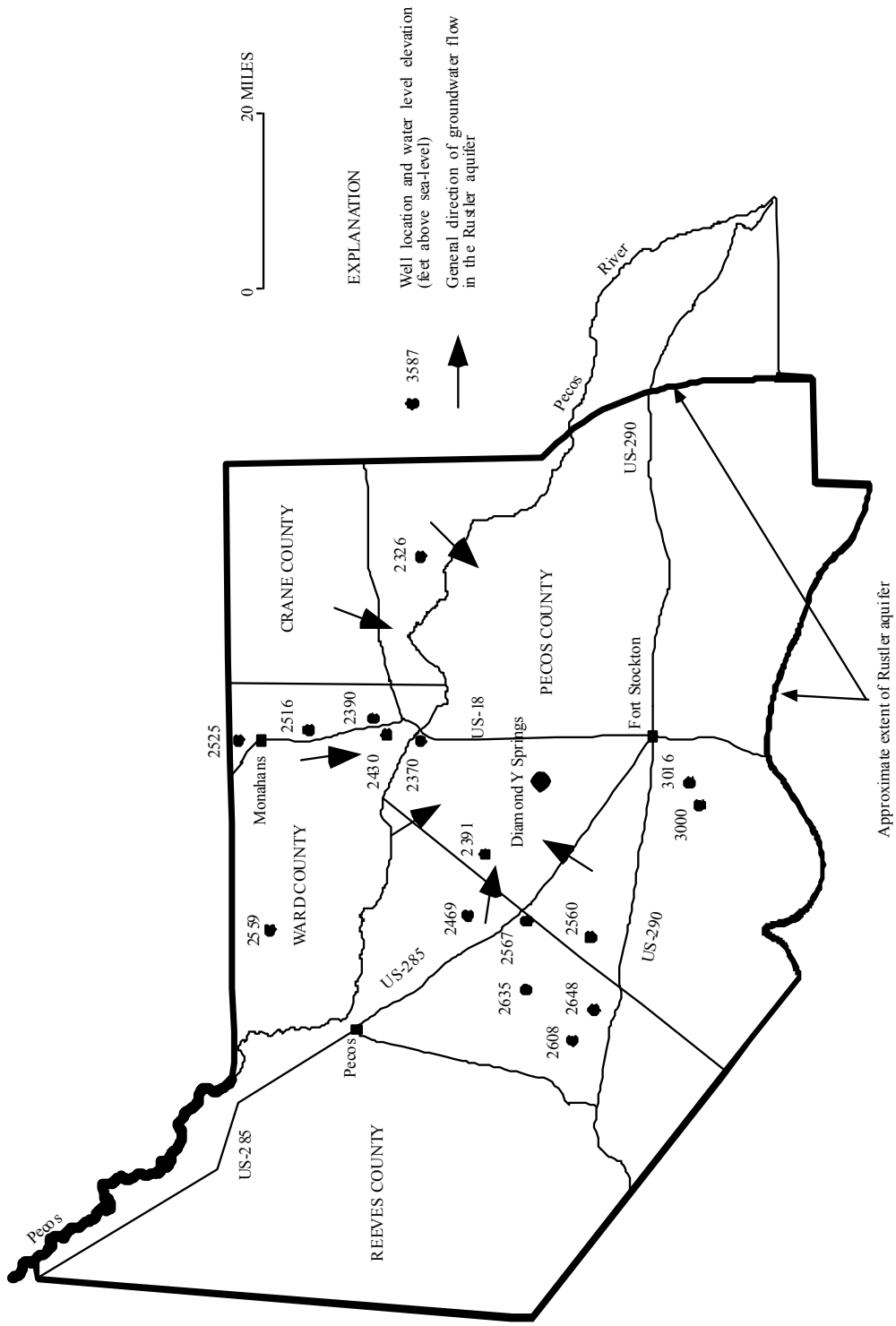


Figure 15-5. Selected wells, water levels and inferred flow directions in the Rustler aquifer. Data from Richey (1987).

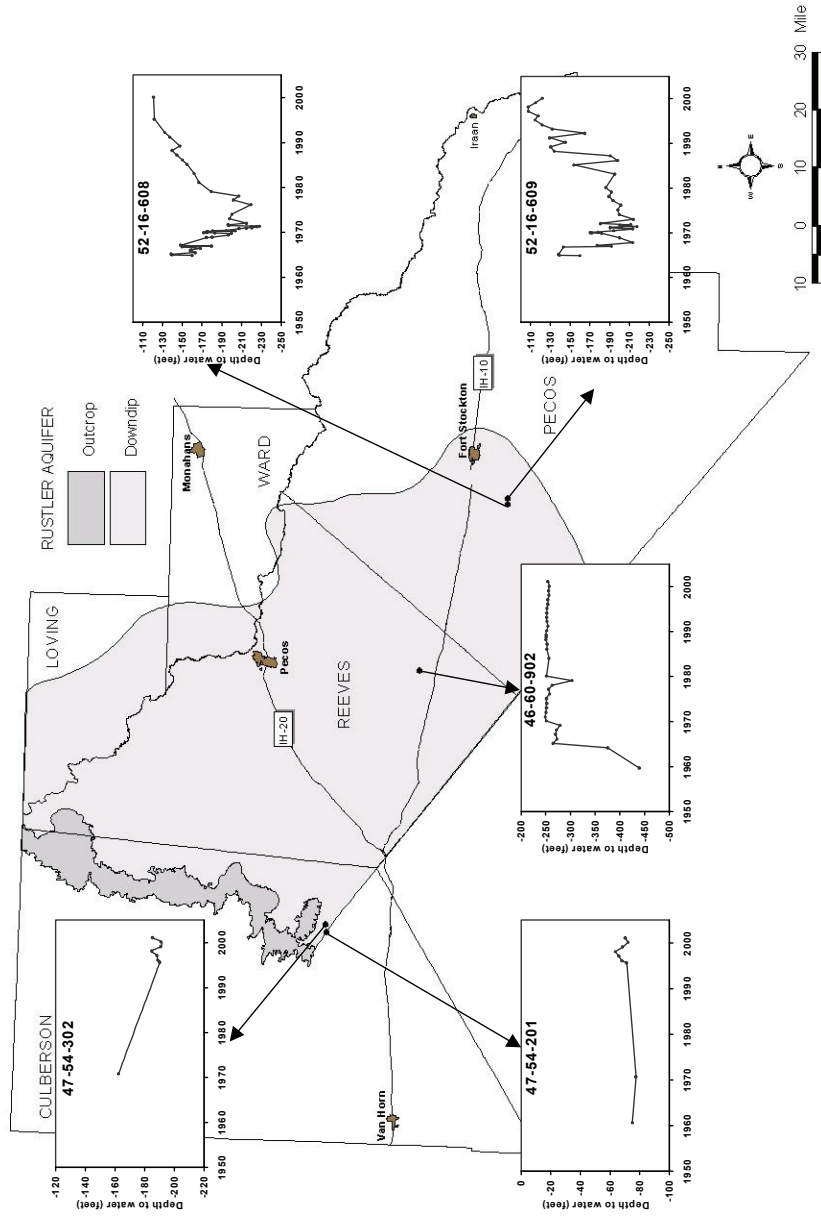


Figure 15-6. Hydrographs for selected wells in the Rustler aquifer. Data from TWDB.

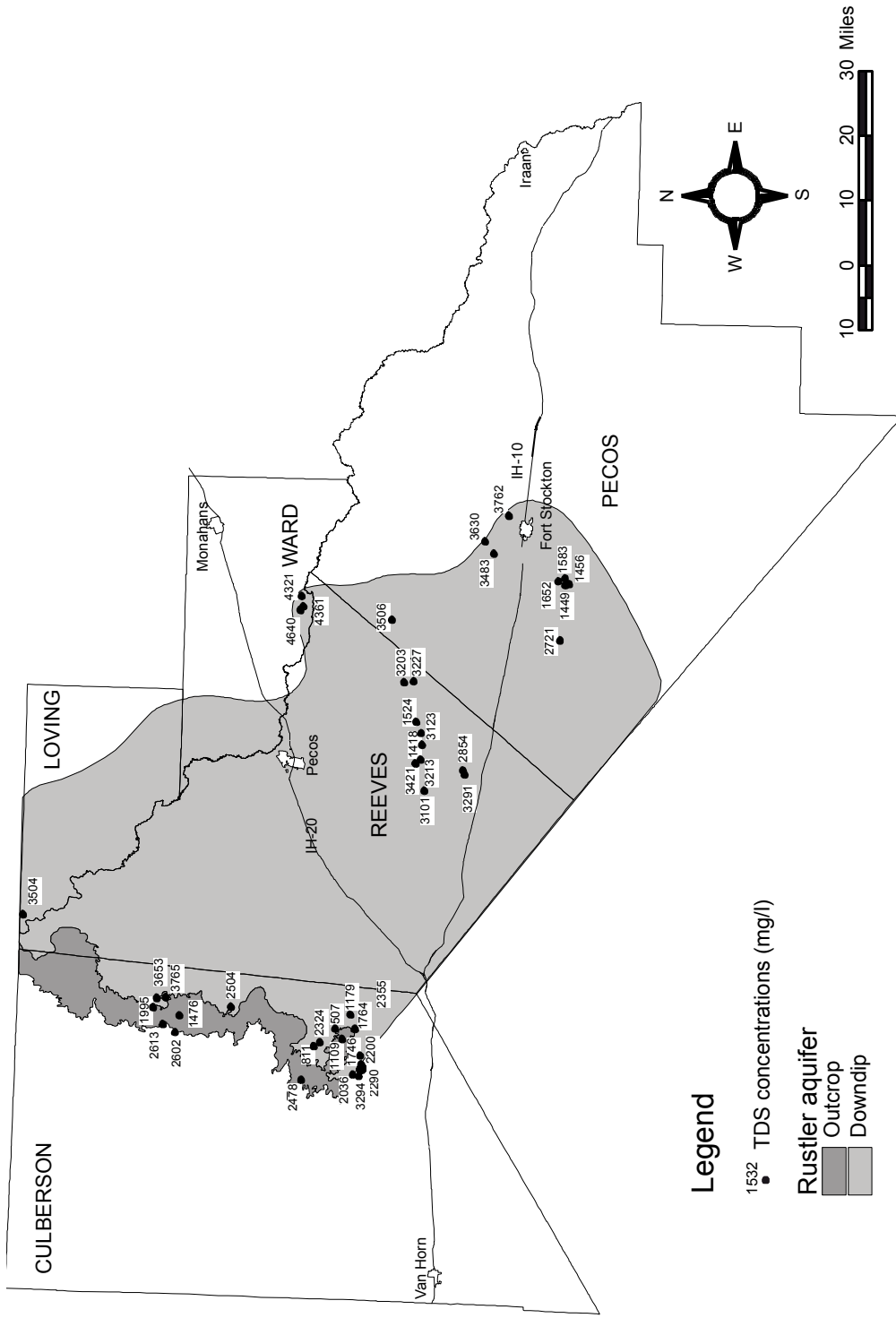


Figure 15-7. Salinity distribution in Rustler aquifer. Data from TWDB.

Table 15-3. Isotope composition in Rustler groundwater samples, Pecos County

State Well Number	Date Sampled	Tritium (TU)	pmC ¹
53-01-203	Aug. 1996	0.00	N/A
53-01-203	Aug. 2000	0.00	5.25
52-16-613	Aug. 2000	0.06	13.91

¹ Percent Modern Carbon

The two stock wells in southeastern Culberson County shown on figure 15-6 are completed in different intervals of the Rustler aquifer. Pre-1995 data are sporadic at best but seem to show a trend of storage depletion for well 47-54-302 and relatively steady-state conditions for well 47-54-201. The post-1995 portions of the hydrographs show similar trends in both wells and indicate possible hydraulic communication between them.

The fluctuations shown by the hydrographs most likely reflect long-term variations in water-use patterns. Armstrong and McMillion (1961) estimated that some 7,500 acre-ft of Rustler water was pumped in 1958 from Pecos County, mainly for irrigation. From 1980 to 1993, the average groundwater pumpage stood at 354 acre-ft/yr (TWDB Water Use Survey). The aquiferwide water use increased to over 1,550 acre-ft/yr from 1994 through 1997 (TWDB Water Use Survey). The resumption of irrigation pumpage of the Rustler in Pecos County accounts for this escalation. Despite the rise in withdrawal rates, water levels in wells 52-16-608 and 52-16-609 continued to recover from 1994 through 2001 (fig. 15-6).

Recharge, Discharge, and Water Availability

Ogilbee and others (1962) stated that recharge to the Rustler aquifer occurs by precipitation and infiltration of streams in its Rustler Hills outcrop, as well as by cross-formational flow. The Tessey Formation, an equivalent to the Rustler Formation that crops out in the Glass Mountains of Pecos and Brewster Counties, is also thought to contribute recharge to the Rustler aquifer.

Boghici (1997) looked at the tritium and ¹⁴C composition of groundwater from two Rustler wells in Pecos County. Tritium and ¹⁴C are radioisotopes used to determine the age of water (table 15-3). The samples are virtually devoid of tritium and exhibit low radiocarbon activities, which is typical for older waters in slow-moving flow systems and not for permeable aquifers with short groundwater residence times, as the Rustler aquifer is purported to be. Water temperature at the time of sampling ranged from 28° to 31° Celsius, 3° to 7° warmer than the rest of the wells in the Rustler aquifer. These findings imply that, at least in Pecos County, very little recharge is by percolation of recent rainfall and stream seepage, but most of it may be contributed by cross-formational flow

of old water from deeper formations. Recharge by rainfall could also be impeded by the high potential evapotranspiration in the area, which is about nine times higher than the precipitation rate (Armstrong and McMillion, 1961). Veni (1991) suggested that shallow groundwater north of Fort Stockton may be in part derived from the underlying Capitan Limestone of the Permian Delaware Mountain Group. Low tritium activities in the Capitan groundwater (Boghici, 1997) support Veni's assertion and may point to it as potential source of the flow in the Rustler.

Groundwater discharges from the Rustler aquifer primarily through well withdrawals as springs and seeps (for example, at Diamond Y and Rustler Hills) and as cross-formational flow into the overlying Edwards-Trinity aquifer. Results of numerical groundwater flow modeling in Pecos County by Boghici (1997) indicate that 260 acre-ft/yr of water from the Rustler aquifer may be discharged through the Diamond Y fault system, and some 3,800 acre-ft of water per year may be upwelling into the overlying Cretaceous strata in the Belding area. Locally, where the water table is shallow, some discharge may take place by evapotranspiration. The Texas Water Plan (1997) estimates that approximately 4,000 acre-ft of Rustler water should be available for use every year without using water from storage.

Groundwater Geochemistry

The salinity distribution for waters of the Rustler aquifer is shown in figure 15-7, which was built using data from 40 samples collected by TWDB between 1956 and 2000. All but two groundwater samples are brackish, with total dissolved solids (TDS) concentrations ranging between 507 and 4,640 mg/L. There is no clear pattern in salinity variations along the presumed direction of groundwater flow. Fresher waters have been found in some downdip wells, more so than in the outcrop.

Groundwater in the study area is predominantly of the Ca-Mg-SO₄ facies (fig. 15-8), reflecting the prevailing dolomitic-gypsiferous nature of the Rustler Formation. Several downdip samples (shown as triangles in fig. 15-8) are more dilute (1,500–1,700 mg/L TDS) and show distinctly different compositions of a Na-Cl-SO₄ type. These samples are from areas underlain by the Belding-San Simon Trough (Hiss, 1976). The dissolution-induced thinning of the Rustler and extensive deep faulting in this locale could provide an opportunity for Na-Cl water from the underlying Ochoan section to up well and mix with the sulfate-rich Rustler aquifer. Mineral saturation indices computed by the geochemical modeling program PHREEQC (Parkhurst, 1995) show that groundwater from the Rustler aquifer is undersaturated with respect to calcite and dolomite and at equilibrium with gypsum.

The aquifer mineralogy, mineral equilibria, and chemical composition suggest that carbonate and gypsum dissolution may be the main processes affecting the groundwater chemistry of the Rustler aquifer.

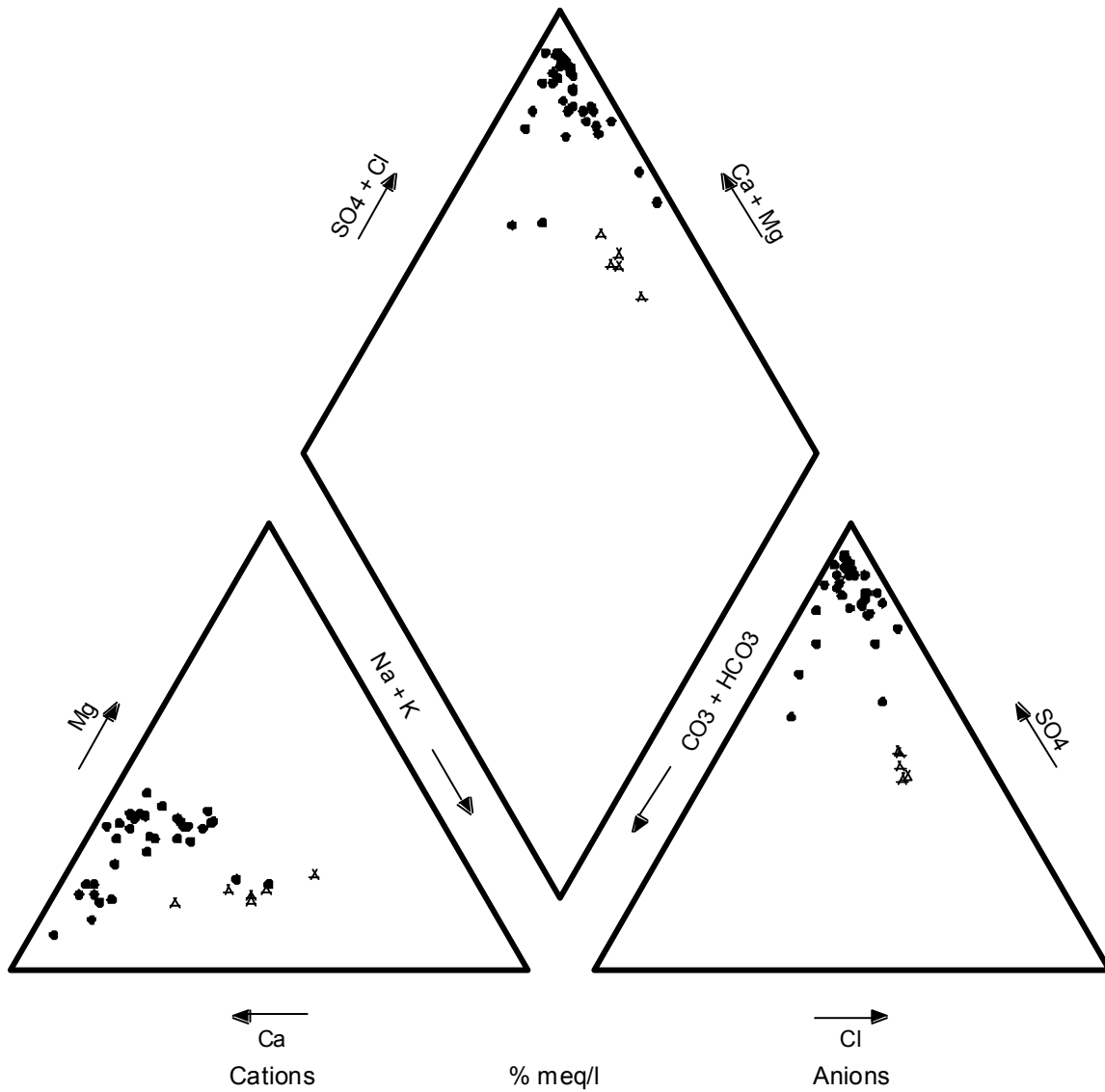


Figure 15-8. Piper plot showing Rustler groundwater composition. Data from TWDB.

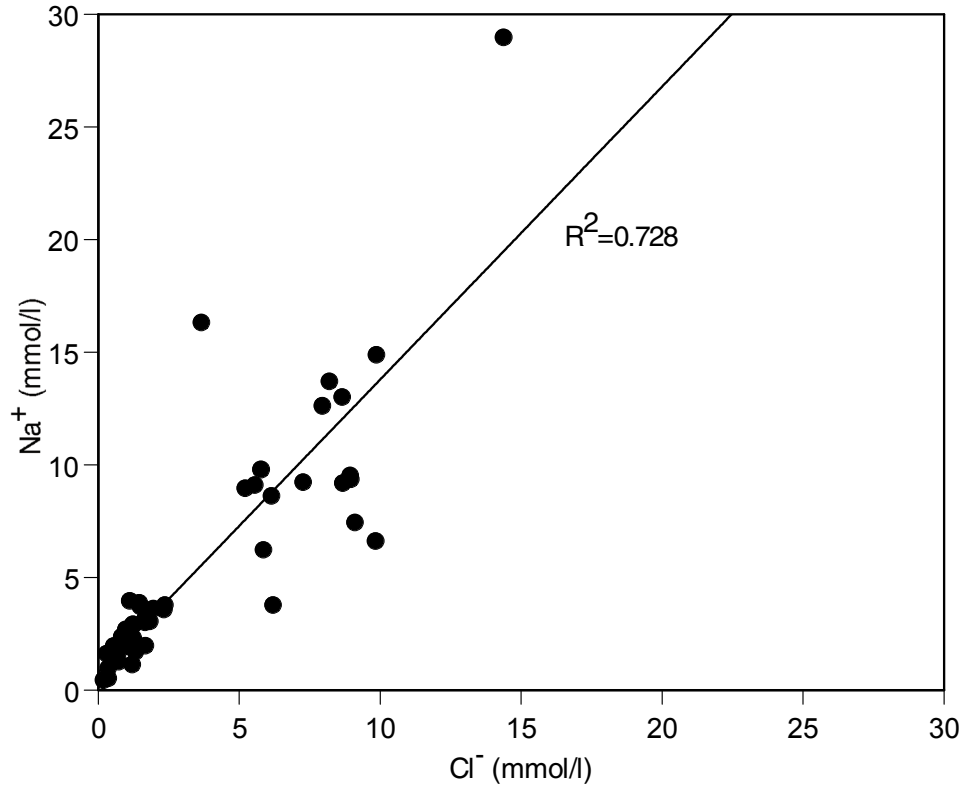
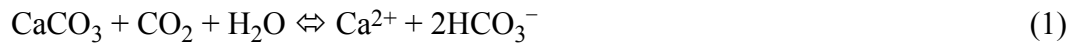


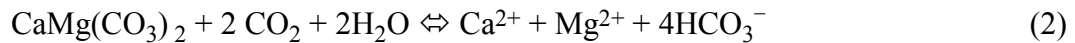
Figure 15-9. Plot of Na⁺ versus Cl⁻.

Following are the governing equations for prominent mineral dissolution and precipitation reactions occurring in aqueous systems:

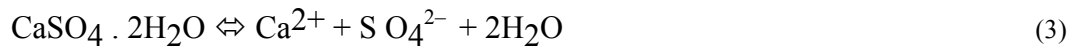
Calcite dissolution and precipitation:



Dolomite dissolution:



Gypsum dissolution:



Halite dissolution:



Ion exchange:



A plot of sodium against chloride (fig. 15-9) is roughly linear, with a slope of 1.3 and an intercept near origin, indicating that some sodium and chloride may come from halite. The predominance of sodium over chloride indicates a source of sodium beyond halite dissolution.

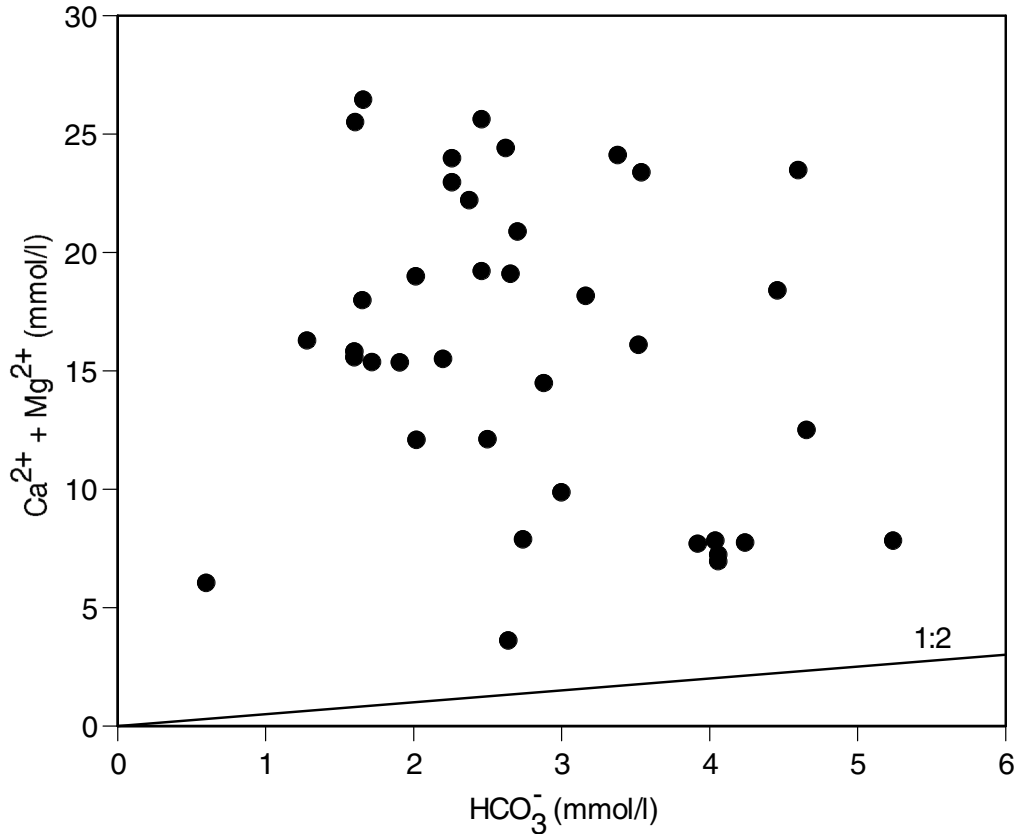


Figure 15-10. Plot of $\text{Ca}^{2+} + \text{Mg}^{2+}$ versus HCO_3^- .

Figure 15-10 shows the relationship between the concentration of calcium and magnesium versus bicarbonate. If all calcium and magnesium were derived from calcite and dolomite dissolution, then data would plot along a line with a slope of 1:2, as stated by equation 1. All points in this figure are above the 1:2 line, indicating an additional source of calcium and magnesium.

Additional calcium can be found in abundance in the gypsum-bearing Rustler Formation. To account for the calcium derived from gypsum dissolution, calcium and magnesium molar concentrations are summed up and plotted against the sum of sulfate and half of bicarbonate concentration (fig. 15-11). The major-ion water chemistry suggests that the calcium, magnesium, sulfate, and bicarbonate present in the water are the result of a simple dissolution of the available dolomite or magnesium-calcite, along with gypsum or anhydrite. In an ideal case, such dissolution reactions would result in these samples plotting on a straight line through the origin with a slope of one. The Rustler waters plot along an obvious line with a slope of 0.875 (fig. 15-11), a good coefficient of correlation ($R^2=0.974$), and an intercept near zero. The slope of the trend line suggests that there is a partial loss of calcium plus magnesium relative to the amount of bicarbonate and sulfate present. This is consistent with a partial cation exchange where some of the calcium plus magnesium is lost from the water and sodium is gained. This interpretation explains why most of the water samples have a higher ionic concentration of sodium than chloride (fig. 15-9), which indicates that there is a source of sodium beyond halite dissolution.

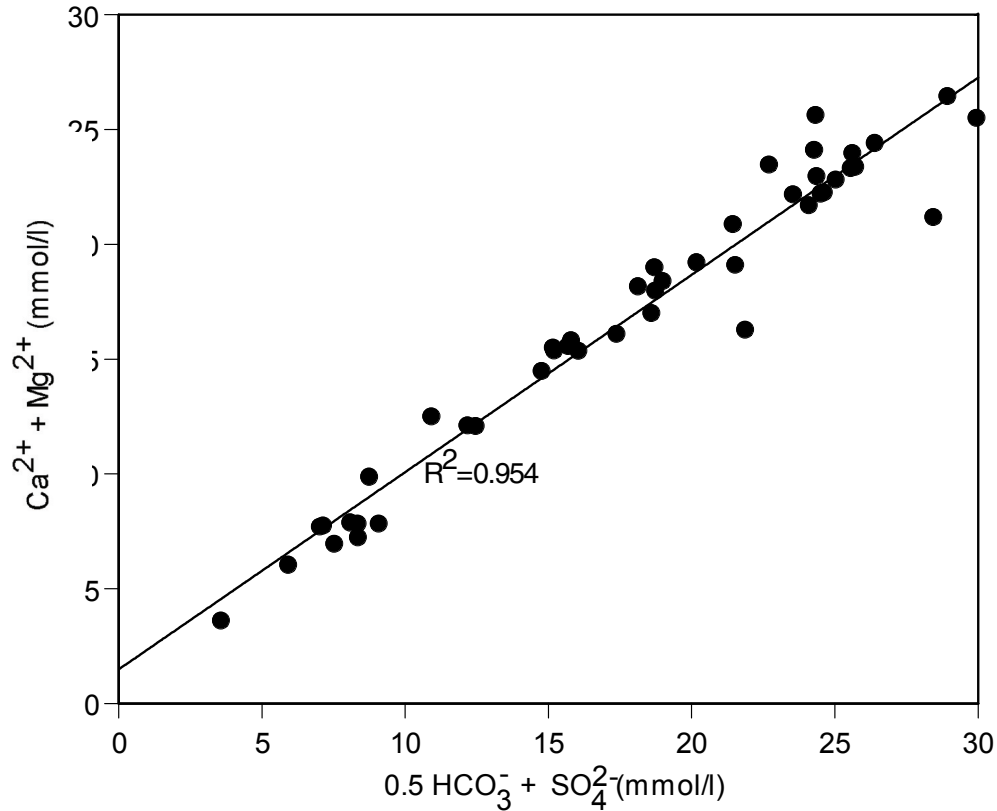


Figure 15-11. Plot of $\text{Ca}^{2+} + \text{Mg}^{2+}$ versus $\text{SO}_4^{2-} + 1/2 \text{HCO}_3^-$.

To test the ion exchange hypothesis, the concentration of $(\text{Na}^+ - \text{Cl}^-)$ is plotted against $(\text{Ca}^{2+} + \text{Mg}^{2+} - \text{SO}_4^{2-} - 1/2 \text{HCO}_3^-)$. The quantity $(\text{Na}^+ - \text{Cl}^-)$ represents excess sodium, that is, sodium coming from sources other than halite dissolution, assuming that all chloride is derived from halite. The quantity $(\text{Ca}^{2+} + \text{Mg}^{2+} - \text{SO}_4^{2-} - 1/2 \text{HCO}_3^-)$ represents the calcium and/or magnesium coming from sources other than gypsum and carbonate dissolution. These two quantities represent the maximum amount of sodium and calcium plus magnesium available for ion-exchange processes.

The samples plot near a line with a slope of 2:1 (fig. 15-12), suggesting that some cation-exchange reactions are taking place where the aquifer media permit it. Waters undergoing exchange of calcium and magnesium for bound sodium on clays will gradually become of sodium-sulfate type. The fact that calcium is still the dominant cation in most of these samples indicates that exchange reactions have not yet occurred extensively. However, a close examination of these data shows that the cation exchange is somewhat more involved than this. There is more magnesium in the water than can be accounted for by

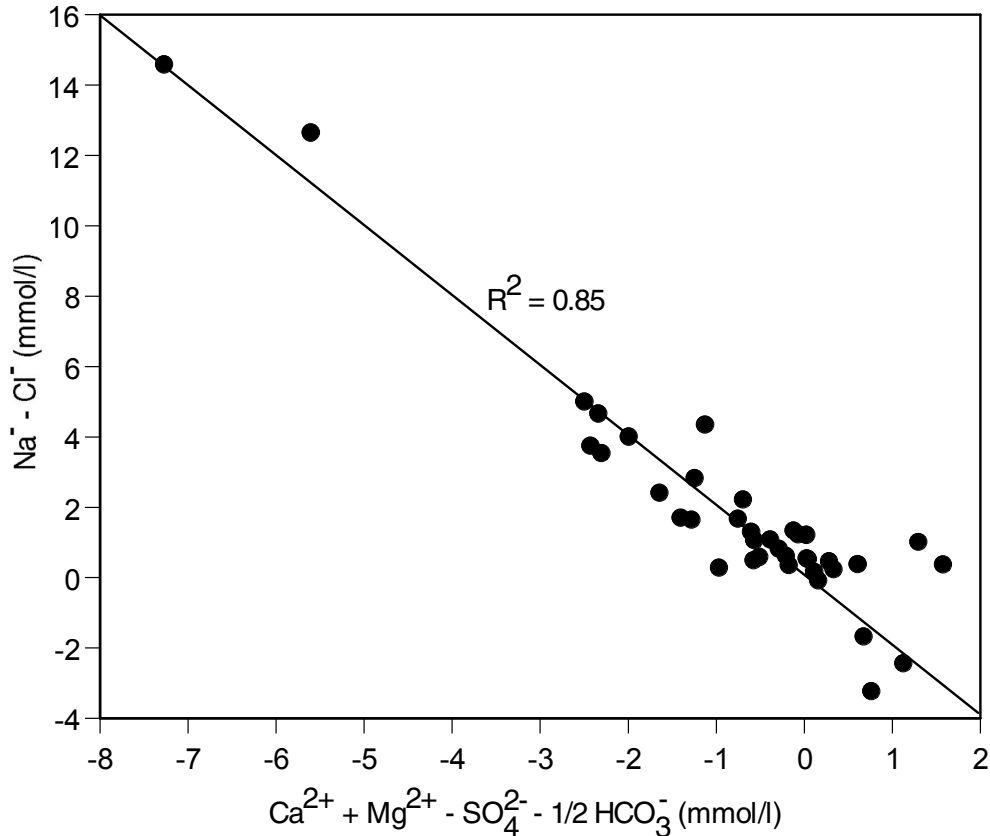


Figure 15-12. Plot of $\text{Na}^+ - \text{Cl}^-$ versus $\text{Ca}^{2+} + \text{Mg}^{2+} - \text{SO}_4^{2-} - 1/2 \text{HCO}_3^-$.

the dissolution of dolomite. It is thought that these data also represent a significant amount of ionic exchange where calcium is lost and magnesium is gained.

More than half of the data points in figure 15-12 represent wells located in the Rustler outcrop in Culberson County. For ion exchange to take place it is necessary that, in addition to having a suitable clay medium, enough time be allowed for the reaction to proceed. This observation, coupled with the high salinities observed in outcrop samples, seems to indicate slow groundwater recharge rates and longer groundwater residence times in this recharge area.

Summary

The Rustler aquifer of Trans-Pecos Texas is in the carbonates and evaporites of the Rustler Formation, of Late Permian age. The aquifer yields brackish water to irrigation and stock wells. Most of the water production comes from fractures and solution openings in the formation Upper Member. Recharge to the Rustler aquifer is by precipitation on its outcrop in Culberson County and by cross-formational flow from deeper aquifers. Geochemical and isotopic data indicate that parts of the aquifer contain

old water, and modern recharge events may be less common than previously thought. Discharge from the Rustler takes place mainly through wells, by seeps and springs, and by leakage into the overlying strata. Rustler water quality is variable and ranges from fresh to brackish. The geochemical data for this aquifer fit a carbonate, gypsum, and halite dissolution and base-exchange model fairly well.

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