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Updated Evaluation of Groundwater Resources in Parts of Trans-Pecos, Texas

By
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ABSTRACT

The updated evaluation of groundwater resources of a part of Trans-Pecos region of West Texas includes all or portions of Loving, Pecos, Reeves, Ward, and Winkler Counties. This report is in response to Senate Bill 1, passed in 1997 by the 75th Texas Legislature. The bill calls for the identification of areas in the State experiencing or expected to experience critical groundwater problems within the immediately following 25-year period.

The study area climate is arid, with large variations in daily temperature, low precipitation, and high evaporation rates. Water needs in the region are supplied mainly from the Cenozoic Pecos Alluvium aquifer and from the Pecos River. Other aquifers such as the Edwards-Trinity (Plateau) provide lesser amounts of water to the study area. The Cenozoic Pecos Alluvium consists of up to 1,500-feet thick alluvial material such as sand, silt, gravel, clay, and caliche.

Between 1988 and 1998, water levels continued to decline in the areas of intense groundwater pumpage, such as southeast Reeves County, northwest Pecos County, and central Ward County. Elsewhere, groundwater withdrawals less than the effective recharge have resulted in stationary or rising water levels.

The groundwater quality in the Cenozoic Pecos Alluvium aquifer between 1989 and 1995 can be described as static and unchanging. With few exceptions, the total dissolved solids (TDS) levels in wells did not fluctuate by more than 10 percent of the 1989 value. The larger increases in major ion concentrations are associated with areas of active pumpage such as Coyanosa in Pecos County and Wickett in Ward County.

In 1995, approximately 181,400 acre-feet of surface water and groundwater were used to meet the needs of the study area, a 28 percent increase compared with the 1985 use. The total groundwater pumpage had a 94 percent (170,491 acre-feet) share in the area water use, up from 90 percent (128,171 acre-feet) in 1985. The remainder was supplied from surface water sources. Based on current demand projections, the annual water requirement area-wide is estimated to decrease to approximately 129,000 acre-feet by the year 2030. Groundwater is expected to account for approximately 86 percent of the total water use. By the year 2030, the Cenozoic Pecos Alluvium aquifer within the study area is projected to have approximately 6.5 million acre-feet of usable-quality groundwater remaining in storage.

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INTRODUCTION

This report is an update to the Texas Water Development Board's (TWDB) Report 317, *Evaluation of Groundwater Resources in Parts of Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas* by J. B. Ashworth, published in January of 1990. TWDB Report 317 was prepared in response to the 1985 passage of House Bill 2 by the 69th Texas Legislature. This legislation, in part, focused on addressing areas of the state where groundwater quantity and quality were deteriorating.

Purpose

This report is in response to Senate Bill 1 (SB-1), passed in 1997 by the 75th Texas Legislature. This act calls for the identification of areas of the State experiencing or expected to experience water problems within the immediately following 25-year period, including shortages of surface water or groundwater, land subsidence resulting from groundwater withdrawal, and contamination of groundwater supplies.

This study addresses the physical and chemical changes that occurred in the region's water supplies between 1988 and 1998. A description of historical water use, future demands, and availability is also included.

Location

The study area is located in the northern part of the Trans-Pecos region of West Texas, and is defined by the areal extent of the Cenozoic Pecos Alluvium in parts of Loving, Pecos, Reeves, Ward, and Winkler Counties (Figure 1).

Climate and Precipitation

The climate of the study area is arid, characterized by low precipitation, high evaporation rates, and large variations in daily temperature. Most of the rainfall in the region occurs from May through September and is strongly correlated with elevation (Schuster, 1997). The average annual rainfall rate ranges from 9.5 in/year at Toyah (elevation 2,916 ft) to 13.3 in/year at Balmorhea (elevation 3,205 ft). Pan evaporation data collected at Balmorhea between 1940 and 1990 indicate evaporation rates of up to 115.7 in/year, more than five times the local annual rainfall rate. The high evaporation rate is likely to preclude much of the rainwater falling on the alluvium from reaching the aquifer (LaFave, 1987).

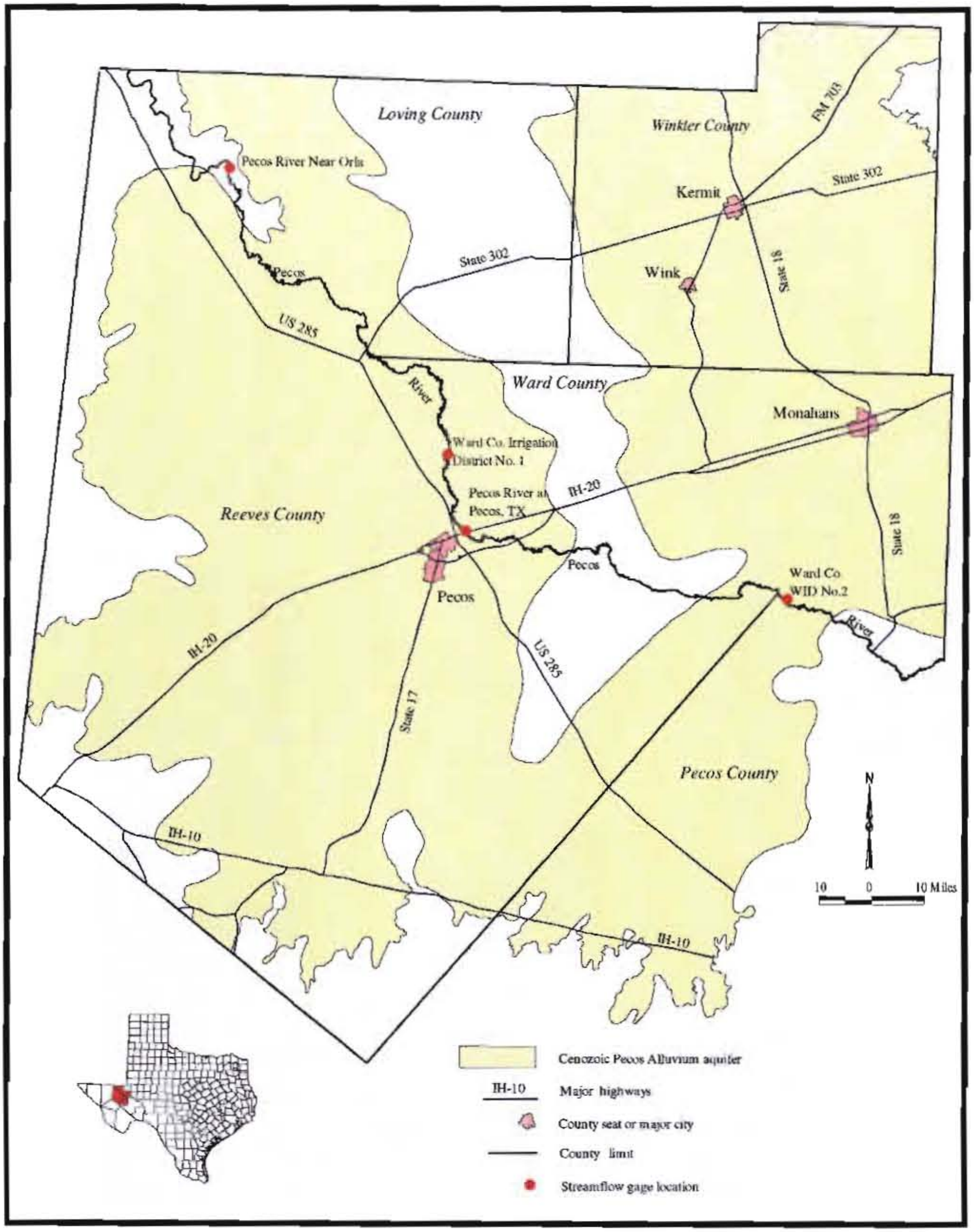

Figure 1. Location of study area

On the other hand, precipitation falling on the fractured volcanics of the Davis Mountains runs off into the local creeks and likely infiltrates the alluvium (Schuster, 1997).

HYDROGEOLOGY

The Cenozoic Pecos Alluvium aquifer consists of up to a 1,500-feet thick section of alluvial material including sand, silt, gravel, clay, and caliche. This aquifer is the principal source of water for irrigation in Reeves and Pecos Counties, and for industrial and public supply uses elsewhere in the study area. For a detailed description of the local and regional geologic and hydrogeologic setting the reader is referred to the TWDB Report 317 (Ashworth, 1990).

Potentiometric Surface Map and Water Levels

Water levels in 87 wells were measured between January 1997 and February 1998. Figure 2 shows the updated potentiometric surface map of the Cenozoic Pecos Alluvium aquifer built using those data. Groundwater in the alluvial sediments moves toward the Pecos River except in areas where cones of depression have developed as a result of pumping activities. Such practices have caused water level drops in excess of 200 feet between the 1940s and late 1970s. A comparison between this map and the 1989 water level elevation map (Ashworth, 1990, p. 17) shows only minor changes in the potentiometric surface configuration. The updated potentiometric map exhibits two major cones of depression located under (1) the irrigated areas along State Highway 17 in Reeves County, and (2) the Coyanosa irrigation area in Pecos and Reeves Counties. To a lesser extent, groundwater flow is being diverted toward the public supply and industrial pumping centers southwest of Monahans in Ward County.

Water level elevations range from more than 3,000 ft in western Reeves County and northeastern Winkler County to less than 2,300 ft in the center of the Coyanosa cone of depression. Hydraulic gradients range from 0.003 in areas with no groundwater development in Winkler and Loving Counties to 0.007 under the irrigated areas in Pecos and Reeves Counties.

Depths to groundwater in the Pecos River Valley are between 10 and 20 ft. The water table deepens to approximately 50 ft away from the river in wells in Winkler, Loving, and Ward Counties. Groundwater is as deep as 300 ft in parts of the irrigation districts in Pecos and Reeves Counties. Perched aquifers have also been encountered in the area south of the City of Pecos (Ogilbee et al., 1962).

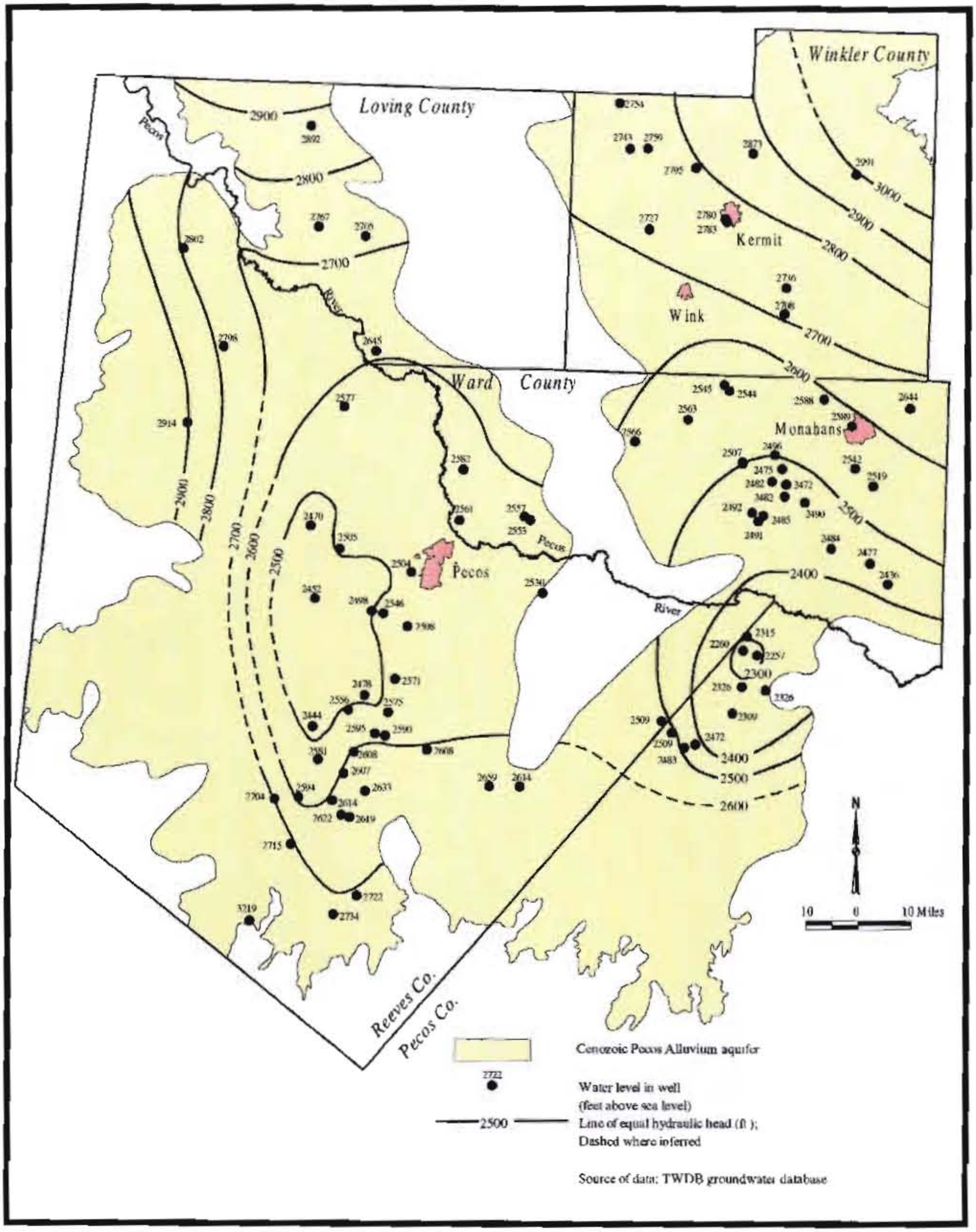

Figure 2. Potentiometric surface map, 1998

Water-level changes in the Cenozoic Pecos Alluvium aquifer between 1989 and 1998 are depicted in figure 3. Many wells located west of the city of Pecos have recorded water-level rises up to 30 ft, while wells located south and southeast of the city of Pecos have experienced water-level declines as great as 40 ft between 1988 and 1998. Wells in Loving and northeastern Winkler County show nearly static or slightly rising (up to 10 ft) water levels between 1989 and 1998, continuing a long-term trend of increasing storage due to the absence of groundwater mining. Southwest of Monahans in Ward County, water levels dropped by an average of 5 ft. The largest changes in water levels between 1989 and 1998 occurred along the Reeves/Pecos county line, where local water-level declines up to 40 ft have been reported.

Time series hydrographs of selected wells in the study area (Figure 4) illustrate long-term temporal water-level fluctuations and explain changes in the potentiometric surface map. Depletion of aquifer storage due to groundwater pumping historically occurred in most of Reeves County and northwest Pecos County between the 1940s and the early 1980s. Beginning in the 1980s, reductions in groundwater withdrawals resulted in water-level recovery over much of the area west of the City of Pecos. This recovery can be observed in the hydrographs for wells 46-35-501, 46-44-501, 46-59-105, and 52-03-302 in figure 4. The area southeast the City of Pecos, however, experienced a decline in water levels (see figure 3). The water level in well 46-54-701, for instance, recorded a 40-foot drop, as irrigation started in 1990 on previously uncultivated land (figure 4). Hydrographs for selected wells in Loving and Winkler Counties are characteristic of areas with little or no groundwater development, as denoted by relatively stable water levels over time. Wells 46-07-901, 45-01-901, and 46-24-301 in Figure 4 demonstrate a slight rise in water levels over time, therefore indicating addition of water to storage. Finally, the area in Ward County southwest of Monahans experienced a slight depletion of water from storage, as indicated by the downward-trending hydrograph for well 45-33-501.

The historical water use data (Table 4, page 20) are consistent with the changes in water levels shown in Figure 3: the areas of focused groundwater pumpage are experiencing the largest declines in water levels (southeast Reeves County, northwest Pecos County, and central Ward County). Elsewhere, especially toward the edges of the basin in Loving and Ward Counties, groundwater withdrawals in amounts less than the effective recharge have resulted in stationary or raising water levels. The aquifer storage is still intact or is even being increased in these areas (see Figure 4).

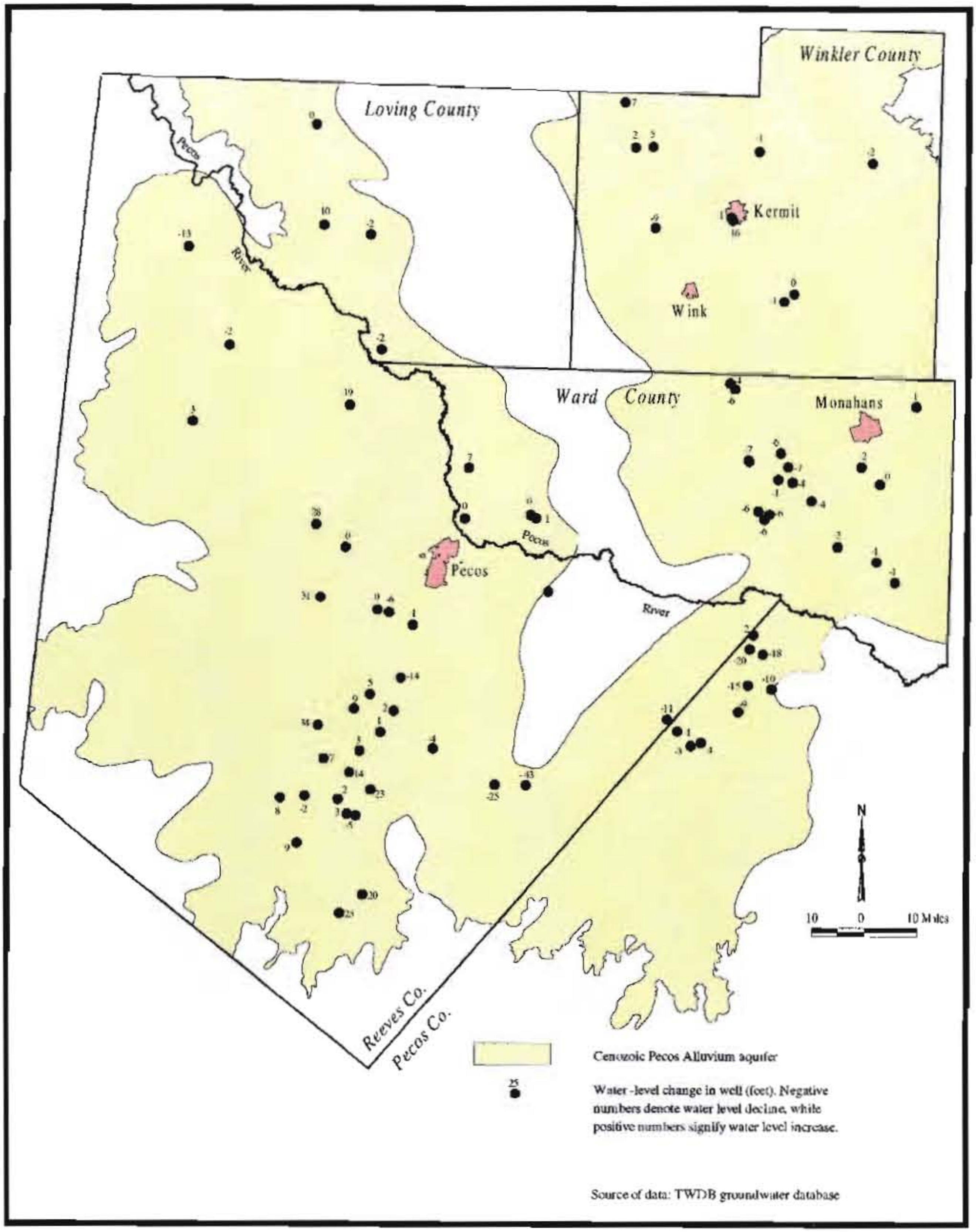

Figure 3. Approximate water-level change from 1989 to 1998

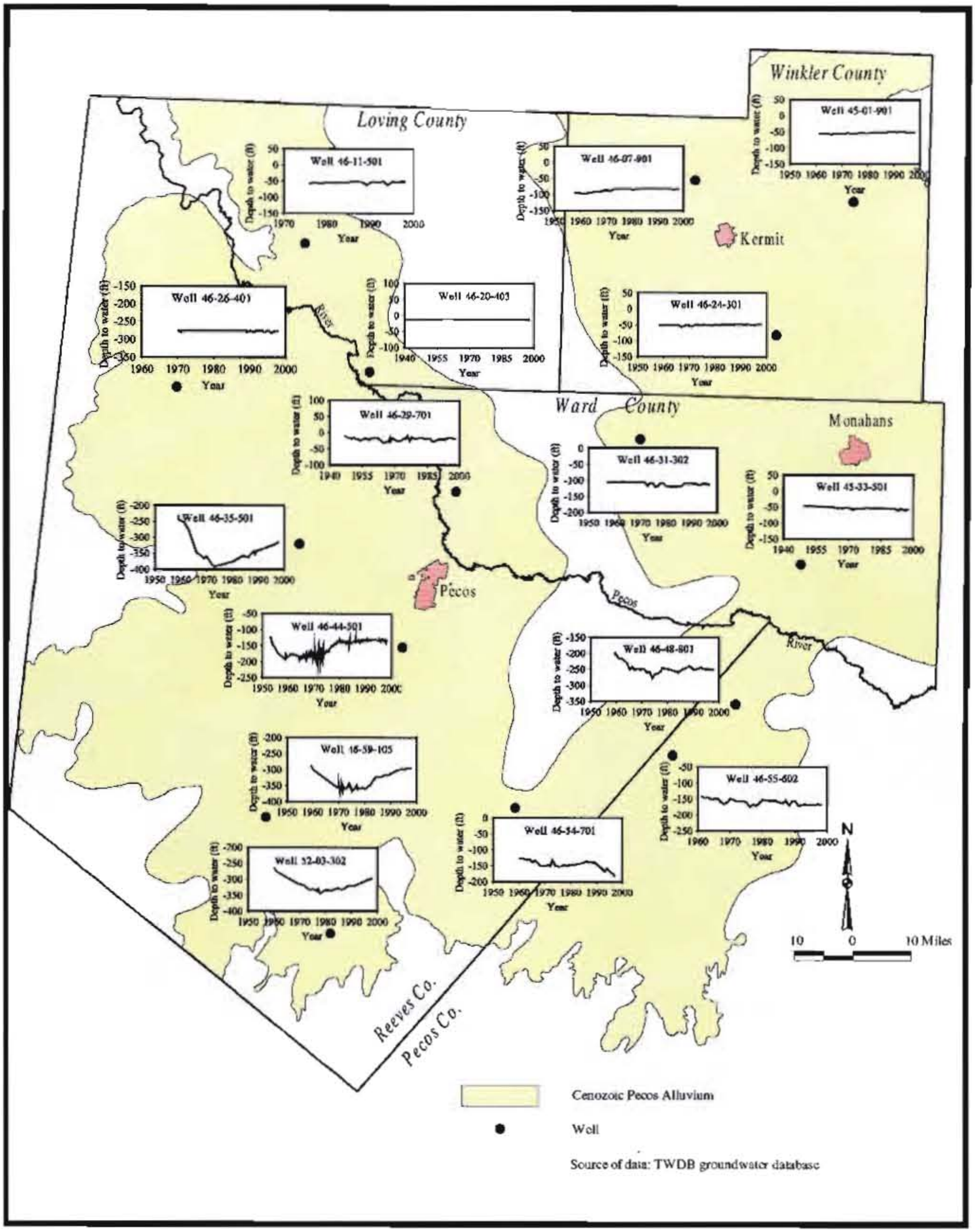

Figure 4. Hydrographs for selected wells

Groundwater Quality

The general quality of the Cenozoic Pecos Alluvium aquifer is shown on the regional Stiff map (Figure 5), which was built using data collected by TWDB in 1995. The majority of the samples collected from wells in Reeves, Loving, and western Ward Counties had total dissolved solids (TDS) concentrations greater than 1,000 mg/L, with most samples ranging from 1,000 to 3,000 mg/L. Several locations have recorded TDS concentrations up to 9,000 mg/L, such as wells 46-37-301, 46-36-908, and 46-43-603, located in and around the City of Pecos. Groundwater in Winkler, eastern Ward, and northwest Pecos Counties was generally of better quality, as shown by the samples with TDS values of less than 1,000 mg/L. Groundwater samples with salinity of 1,000 to 3,000 mg/L were collected in southern Ward County. Several wells in northwest Pecos County had TDS concentrations in the 4,000-mg/L range.

Three general water types could be identified based on their distinct hydrochemical signatures:

(1) a Na-Ca-Cl-SO_4 type in high-TDS (greater than 3,000 mg/L TDS) wells throughout Loving and Reeves Counties and along the Pecos River;
(2) a Na-Cl type observed in several saline (1,000 to 3,000 mg/L TDS) samples in Winkler and Ward Counties; and,
(3) a Ca-HCO_3 type with a minor SO_4 component, observed in several fresh water (less than 1,000 mg/L TDS) wells in Winkler, Ward, and Pecos Counties.

Samples from 89 wells within the study area were analyzed in 1995 for major and minor ions, trace elements, and radionuclides. Of these, twenty-one exceeded the maximum contaminant levels (MCLs) set by the U.S. Environmental Protection Agency's "National Primary and Secondary Drinking Water Regulations" (1998) for at least one constituent (see Table 1 below).

Well no.	County	Constituent	Measured Value	MCL
4541902	Pecos	Alpha	17 pCi/L	15 pCi/L
4648505	Pecos	Mn	149 mg/L	0.05 mg/L
4609901	Reeves	Alpha	29 pCi/L	15 pCi/L
4609901	Reeves	Beta	127 pCi/L	50 pCi/L
4609901	Reeves	Cd	23 mg/L	0.005 mg/L
4609901	Reeves	Mn	65 mg/L	0.05 mg/L
4609901	Reeves	Se	301 mg/L	0.05 mg/L
4610701	Reeves	Cd	14 mg/L	0.005 mg/L
4610701	Reeves	Fe	2300 mg/L	0.3 mg/L
4610701	Reeves	Mn	96 mg/L	0.05 mg/L

Table 1. Groundwater samples exceeding the Maximum Contaminant Levels for trace elements and radionuclides

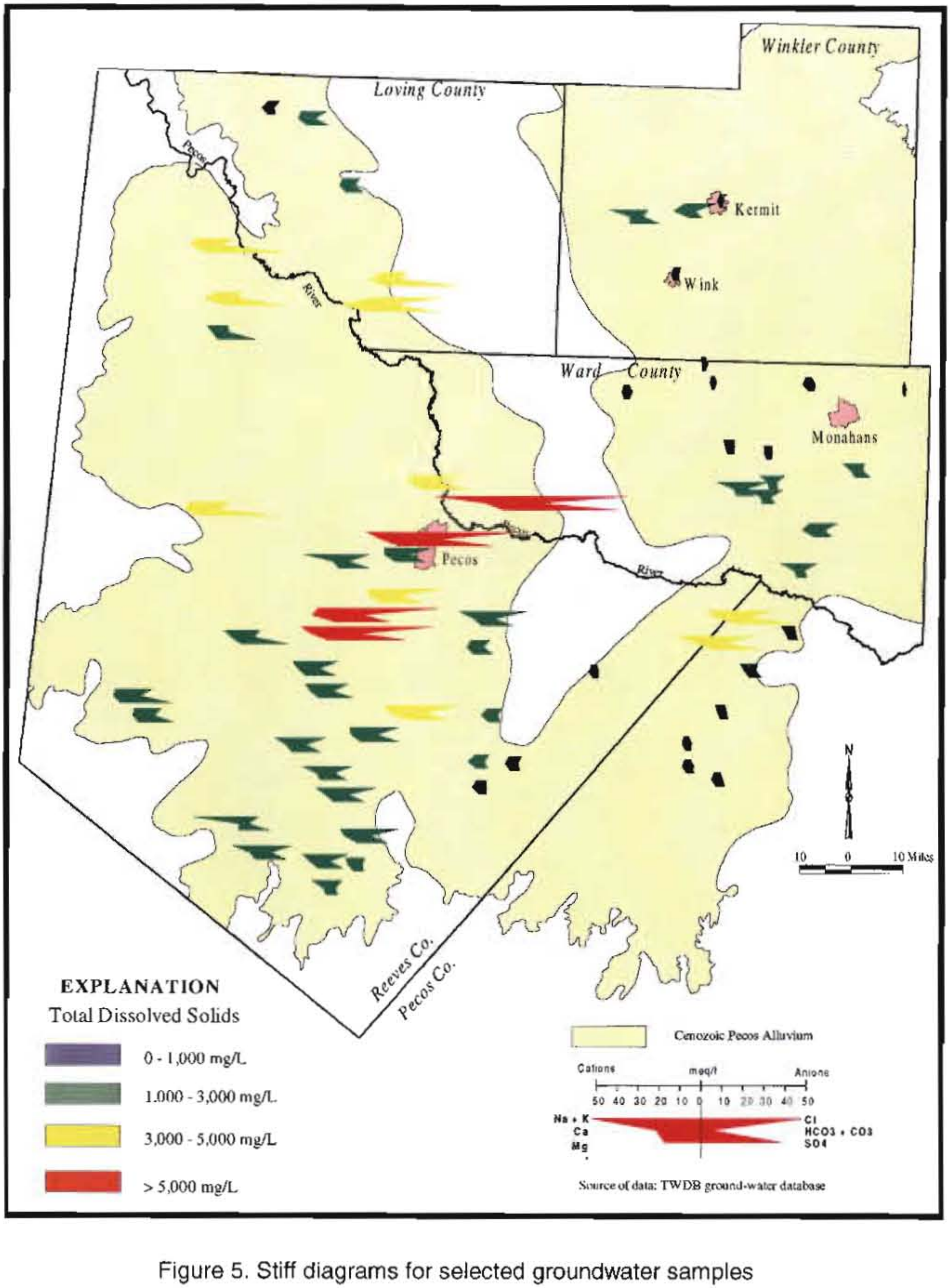

Figure 5. Stiff diagrams for selected groundwater samples

Well no.	County	Constituent	Measured Value	MCL
4618801	Reeves	Mn	51 mg/L	0.05 mg/L
4627303	Reeves	Fe	1270 mg/L	0.3 mg/L
4634401	Reeves	Fe	693 mg/L	0.3 mg/L
4634401	Reeves	Mn	162 mg/L	0.05 mg/L
4636908	Reeves	Alpha	34p Ci/L	15 pCi/L
4642913	Reeves	Fe	1200 mg/L	0.3 mg/L
4642913	Reeves	Mn	119 mg/L	0.05 mg/L
4643603	Reeves	Alpha	18 pCi/L	15 pCi/L
4644705	Reeves	Alpha	20 pCi/L	15 pCi/L
4644705	Reeves	Pb	20 mg/L	15 mg/L
4644706	Reeves	Alpha	32 pCi/L	15 pCi/L
4645601	Reeves	Fe	789 mg/L	0.3 mg/L
4652608	Reeves	Alpha	21 pCi/L	15 pCi/L
4652608	Reeves	Fe	1618 mg/L	0.3 mg/L
4652709	Reeves	Alpha	16 mg/L	15 pCi/L
4653802	Reeves	Pb	18 mg/L	15 mg/L
4654401	Reeves	Alpha	15 pCi/L	15 pCi/L
5203117	Reeves	Alpha	17 pCi/L	15 pCi/L
4615402	Winkler	Fe	321 mg/L	0.3 mg/L
4615924	Winkler	Mn	141 mg/L	0.05 mg/L
4616102	Winkler	Mn	55mg/L	0.05 mg/L

Table 1. Groundwater samples exceeding the Maximum Contaminant Levels for trace elements and radionuclides (continued)

The concentrations of iron in seven samples, manganese in eight samples, selenium in one sample, and cadmium in two samples were found to be above the MCLs for these constituents. Two samples collected in Reeves County displayed lead concentrations higher than the 1994 EPA action level (15 μg/L). Ten samples, all collected in Reeves County, showed gross alpha activities above the EPA-set MCL of 15 pCi/L. Similarly, one sample in Reeves County exceeded the 50 pCi/L MCL for beta activity.

Alpha- and Beta-emitting substances in natural water are mainly isotopes of radium and radon (Hem, 1985), elements that are commonly found in volcanic rocks. Such outcrops can be encountered in southern Reeves County.

Sulfate and chloride are the dominant ions in the study area. In 1995, forty-six samples exceeded EPA's secondary standards for these constituents (see Figure 6). In forty-one of those samples, concentrations of both chloride and sulfate were above the 250 mg/L limit recommended for drinking water. Eighty-five wells were analyzed for nitrate. Figure 7 depicts six wells with nitrate levels (expressed as NO_3) ranging from 54 to 269 mg/L, thus surpassing the 44.3 mg/L MCL.

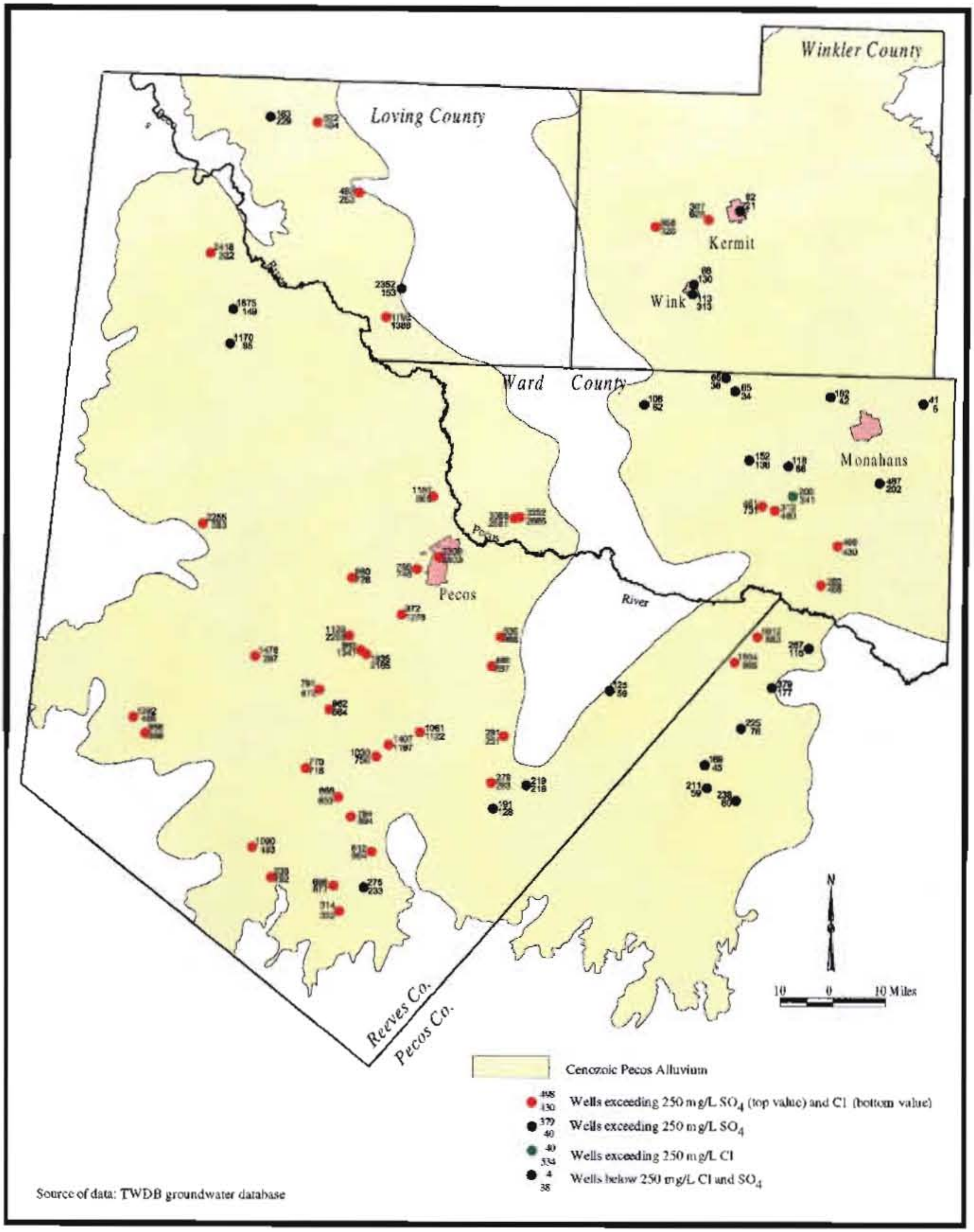

Figure 6. Sulfate and chloride concentrations in groundwater, 1995

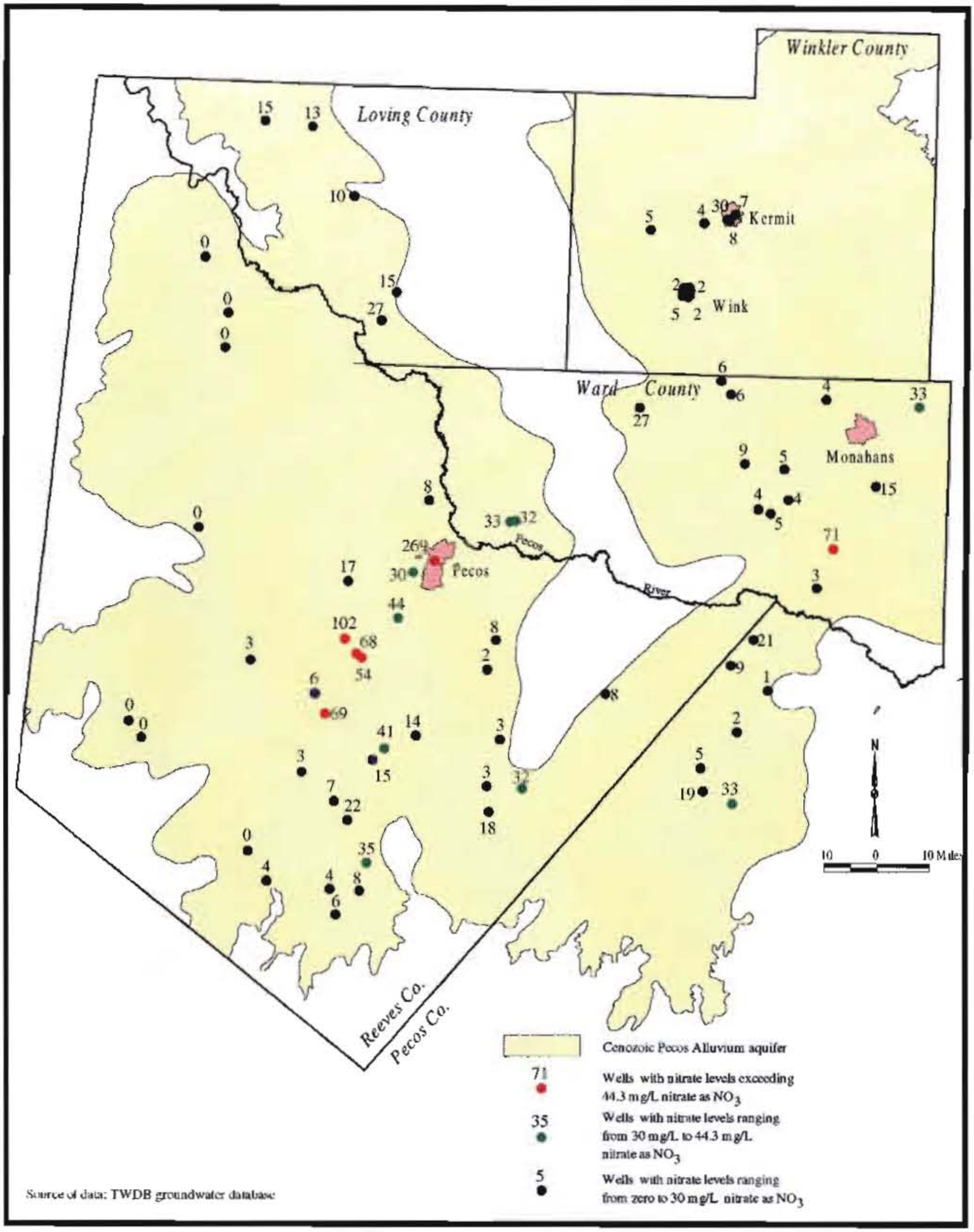

Figure 7. Nitrate concentrations in groundwater, 1995

All but one of the 1995 high-nitrate samples were collected in and around the City of Pecos, Reeves County. Use of groundwater in this area is almost exclusively for irrigation, suggesting that the source of nitrate could be the ammonia in the fertilizers being applied to crops. Ten additional wells showed elevated levels of nitrate (greater than 30 mg/L) while still meeting the EPA primary standards. They are shown as green dots on figure 7.

The sodium adsorption ratio or SAR (Richards, 1969), measures the degree to which sodium in irrigation waters replaces the adsorbed calcium and magnesium in the soil clays, and thus damages the soil structure (Hounslow, 1995). Irrigation waters are usually classified in terms of salinity hazard (conductivity or TDS) and sodium hazard (SAR).

A plot of SAR versus conductivity for fifty-two samples collected in 1995 shows that groundwater in parts of the study area has a high to very high salinity hazard (Figure 8). The sodium hazard for these waters covers the entire range, with about half of the samples being of medium-to-very high risk.

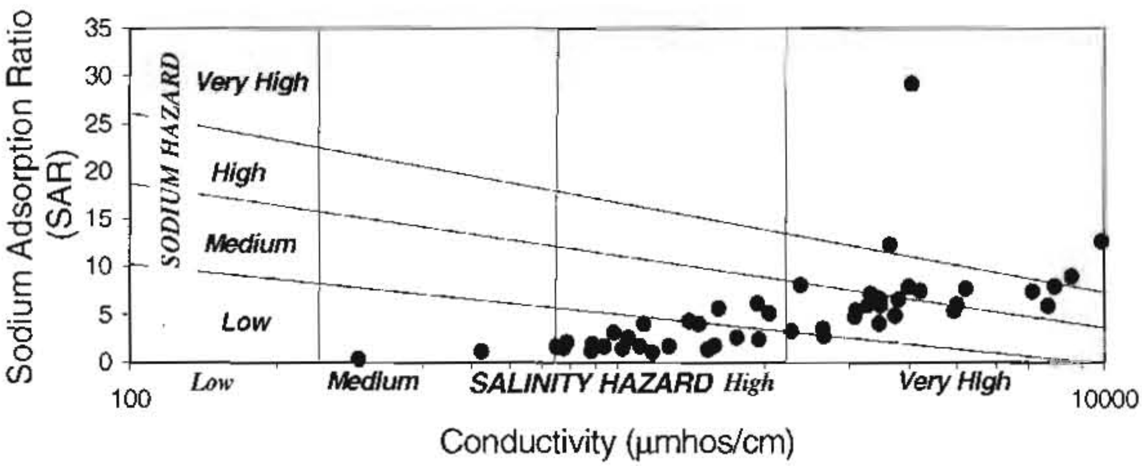

Figure 8. SAR-conductivity plot for Cenozoic Pecos Alluvium groundwaters

Total dissolved solids (TDS) is the primary limiting factor for groundwater use. Twenty wells area-wide had TDS data for both 1988/89 and 1995. Changes in TDS levels during this time interval (Figure 9) were minimal for fifteen of the wells. The rest had TDS concentrations fluctuating by more than 100 mg/L. The largest increases in TDS occurred in wells 46-40-313 (367 mg/L) and 46-48-505 (497 mg/L), located in the southeastern portion of the study area in Pecos and Ward Counties.

The greatest decrease in salinity took place in well 46-10-701 (-208 mg/L) in northwest Pecos County. With few exceptions, however, concentrations for selected ions (Table 2) have not changed significantly over time.

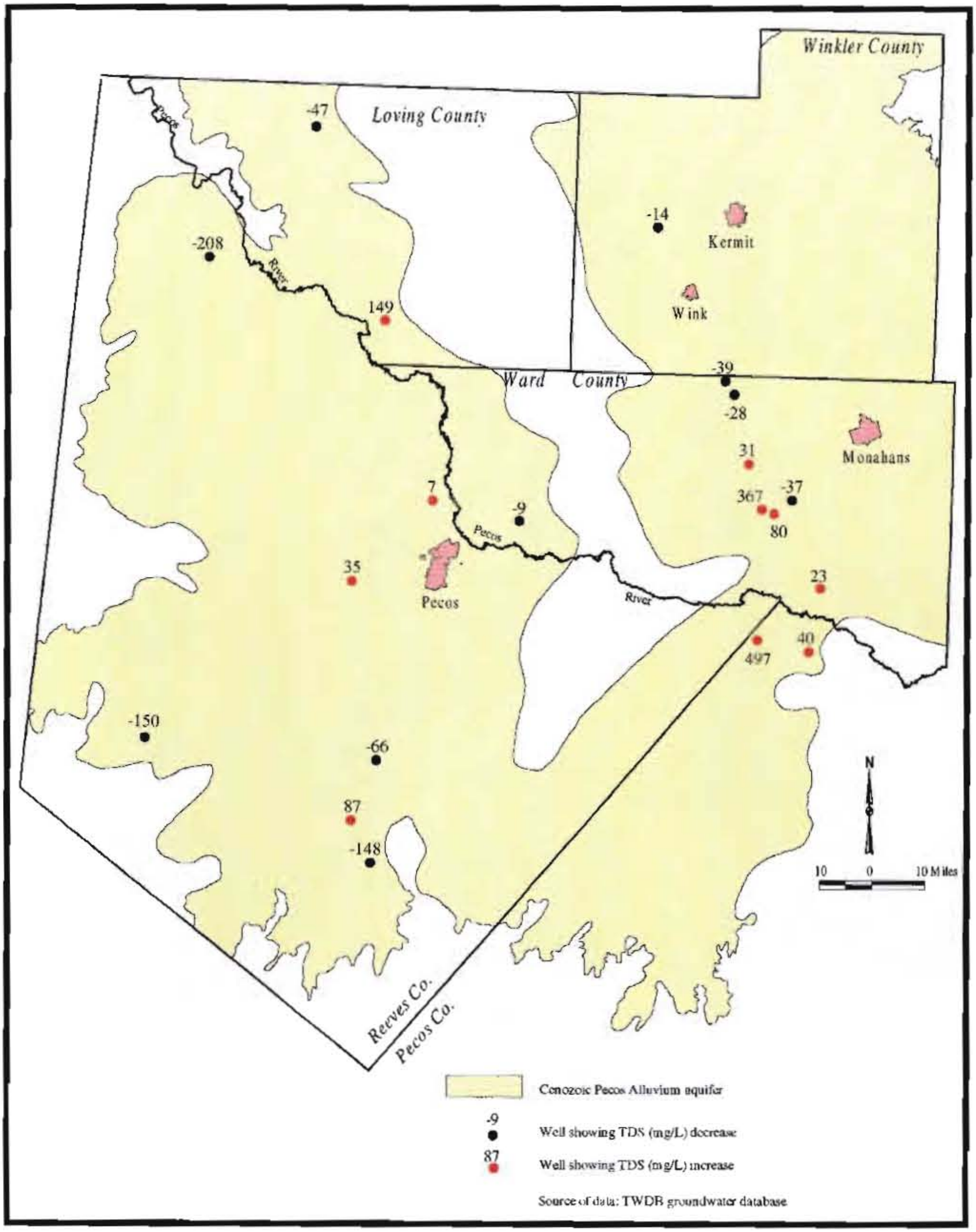

Figure 9. Changes in TDS concentrations in groundwater, 1989 to 1995

Well no.	County	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	TDS
4615402	Winkler	+1.3	-4.4	+44.2	-4.3	-18.3	-44.0	-2.0	-1.5	-14.0
4533109	Ward	+8.2	+1.7	-40.0	+0.4	-7.3	-4.0	-1.0	+0.3	-37.0
4624715	Ward	-1.8	+2.0	-8.7	+0.4	-7.3	-11.0	-5.0	-6.7	-39.0
4624718	Ward	-3.6	+1.4	-5.3	-0.2	-7.3	-8.0	-9.0	+0.8	-28.0
4632516	Ward	+16.2	+5.2	-14.0	-0.2	-10.8	+12.0	14.0	-0.6	+31.0
4637301	Ward	-7.0	-8.0	-98.0	+4.1	-3.7	+626.0	-531.0	-8.2	-9.0
4640311	Ward	+1.4	+5.5	+9.0	-6.3	-9.8	+15.0	+60.0	-0.5	+80.0
4640313	Ward	+19.0	+8.9	+69.0	+4.3	-8.6	+82.0	+189.0	-0.6	+367.0
4635905	Reeves	+27.0	+8.2	-28.0	+1.8	+13.5	-7.0	+15.0	+7.7	+35.0
4610701	Reeves	-84.0	-8.0	-56.0	-3.3	-15.9	-87.0	+30.0	-0.4	-208.0
4636302	Reeves	+2.0	+3.0	-6.0	-5.2	-1.2	-12.0	+15.0	+0.5	+7.0
4649505	Reeves	-35.7	-15.2	-49.0	+26.1	+5.9	-44.0	-55.0	-3.5	-150.0
4652709	Reeves	-34.0	-6.0	-49.0	+2.1	+1.2	-8.0	+19.0	+1.5	-66.0
4660402	Reeves	+6.0	-0.4	-13.0	+0.8	+3.7	+14.0	+65.0	+3.2	+87.0
4660704	Reeves	-91.0	-5.3	-9.0	+11.3	+28.1	-25.0	-47.0	-4.5	-148.0
4541401	Pecos	+10.6	+2.9	+17.0	-3.4	+20.8	+1.0	+1.0	+0.0	+40.0
4648505	Pecos	+11.0	-7.2	+70.0	-0.2	+1.2	+214.0	+215.0	-11.6	+497.0
4603501	Loving	-19.0	-8.2	-22.0	+0.3	-19.5	-3.0	+5.0	+2.1	-47.0
4620406	Loving	+30.0	+21.0	+37.0	+0.0	-9.8	-148.0	+180.0	+26.7	+149.0

Table 2. Changes in concentration of selected ions (in mg/L), 1988/89 to 1995

The groundwater quality in the Cenozoic Pecos Alluvium aquifer is controlled by both natural and anthropogenic factors. The type (1) and (2) waters described at the beginning of the water quality section are illustrative of dissolution of evaporitic rocks, principally gypsum ($CaSO_4 \cdot 2H_2O$) and halite (NaCl).

Evaporite beds commonly occur in the northern and western parts of the study area as shown by the high SO_4 and Cl concentrations in groundwater samples from that region. The Ca-HCO_3 signature observed in type (3) waters suggests input of water flowing through carbonate rocks. Cross-formational flow from the Edwards-Trinity (Plateau) aquifer could explain the presence of low-TDS water in parts of Pecos and Reeves Counties (Boghici, 1997). The belt of sand dunes in northeastern Ward County is very permeable, thus permitting rapid infiltration of rainfall (White, 1971). Recharge from precipitation then moves downgradient and is present in wells southwest of Monahans.

Recent and historical data indicate salinization as the main concern regarding groundwater quality in the Cenozoic Pecos Alluvium aquifer. Salinization depends to one degree or another on several factors, including thickness of freshwater-saturated sediments, hydrochemistry of the trough fill, distribution and continuity of mud interbeds, density of saline water, and location, construction, and pumping rate of wells.

The ion concentrations in type (1) and (2) waters can be increased through input of highly saline irrigation return flow. Solutes in irrigation water become concentrated in soils due to low atmospheric moisture and high evaporation rates. These salts are then readily remobilized by leaching to the aquifer. LaFave (1987) indicated irrigation return flow as the probable cause for increased TDS concentrations in the Toyah Basin, Reeves County. Agricultural activities have been cited to cause elevated nitrate levels in groundwater (Ashworth, 1990). Continued application of fertilizers to crops could explain the persistent nitrate contamination of several samples collected south of Pecos City in 1995. Fluid exchange and salt recycling between the saline Pecos River and the aquifer is another mechanism of groundwater salinization. Wells with TDS levels higher than 3,000 mg/L are a common occurrence along the Pecos River throughout the study area. The interaction between river and aquifer is enhanced by groundwater withdrawals in wells near the river. In the Coyanosa area, for instance, irrigation pumpage reversed the hydraulic gradient (Boghici, 1997), causing saline river water to recharge the aquifer, thus accelerating its degradation. Effective January 1st, 1969 the "no pit" order of the Texas Railroad Commission made it illegal to dispose of oilfield brines in unlined pits. The result of pre-order dumping of an estimated 800,000 acre-feet of formation water (Ashworth, 1990) can be seen to this day in Winkler County, where an area between Wink and Kermit still produces 1,000-3,000 mg/L TDS groundwater (Figure 5).

Based on the limited available data (Figure 9 and Table 2), the groundwater quality in the Cenozoic Pecos Alluvium aquifer between 1989 and 1995 can be described as static. With few exceptions, the TDS levels in wells did not fluctuate by more than 10 percent of the 1989 value. The larger increases in major ion concentrations are associated with areas of active pumpage such as Coyanosa in Pecos County and Wickett in Ward County. This is not, however, typical for the entire study region. Several of the processes outlined here may combine to exert a substantial influence on water quality in wells. More work on this phenomenon, possibly using environmental isotopes, will be helpful to assess the mechanisms of water quality changes with time.

Pecos River

The Pecos River crosses the study area from northwest to southeast (see Figure 1). River flow is largely dependent on releases from the Red Bluff Reservoir located just south of New Mexico State line. Water from the Pecos River is diverted for irrigation purposes in Loving, Pecos, Reeves, and Ward counties. The groundwater quality in the Cenozoic Pecos Alluvium aquifer is affected by irrigation practices, which include the use of both surface and groundwater. Pecos River water applied to crops can reach the aquifer in the areas with shallow water table, consequently impacting the groundwater quality. Aquifer pumping in areas adjacent to the river can cause river water to recharge the aquifer, thus changing its chemical characteristics. Figure 10 shows Pecos River flow and specific conductance measurements taken by the USGS between 1989 and 1997 at Orla (Reeves County).

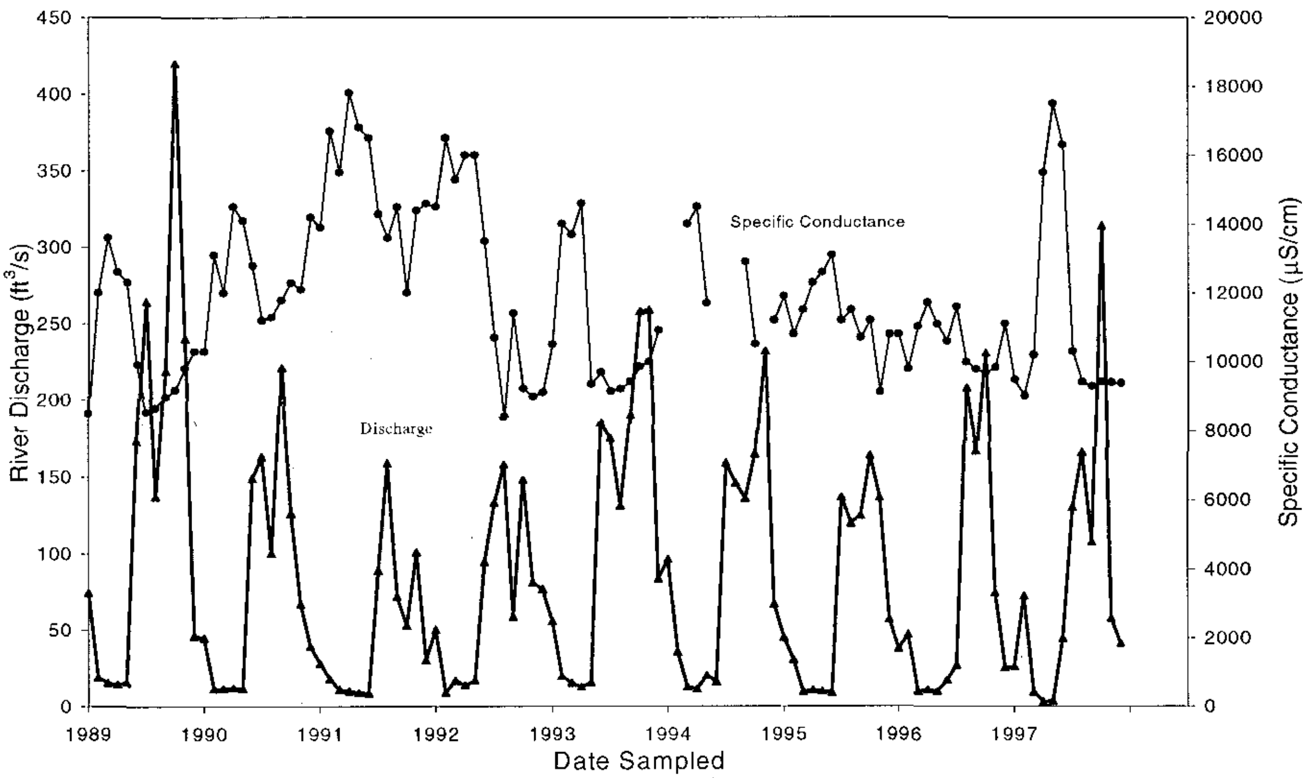

Figure 10. Flow and conductivity measurements in Pecos River

The flow of the Pecos River at Orla shows large seasonal variations and is controlled by releases from the Red Bluff Reservoir. Specific conductance is typically used as a general indicator of water quality. The inverse correlation between seasonal river stage and specific conductance indicates that river water quality improves when flow is high during the irrigation season. This is a result of dilution by large quantities of fresher water released from the reservoir upstream.

When the river stage is high, the saline baseflow from the aquifer into the stream is halted, and thus the improvement in the quality of the river waters. Conversely, increased saline baseflow from the alluvium during low stage can account for the water quality deterioration in the Pecos River during the winter months.

Groundwater-Surface Water Relationships

The water level contour map prepared with data collected in 1998 (Figure 2) illustrates baseflow and losing stream conditions on different segments of the alluvial plain.

The condition of baseflow prevails between the Pecos River gauging station at Orla and the Ward/Loving County line. Groundwater flow is oriented subperpendicular to the river channel and groundwater discharges to the Pecos River. The condition of losing stream is apparent along the Pecos River in Ward and Pecos Counties where depression cones from irrigation well fields have reversed the hydraulic gradient between the river and the Cenozoic Pecos Alluvium aquifer (see Figure 2).

No recent seepage studies along the Pecos River in the study area are available to illustrate the interaction between the river and the aquifer in 1998. Work by Grozier et al. (1967) concluded that the Pecos River reach was losing up to 4.17 ft^3/s per mile between the gauging station at Orla and Ward County Irrigation District No. 1 canal (see Figure 1 for locations). On the reach between the City of Pecos gauging station and Ward County Water Improvement District (WID) No. 2 diversion dam (Figure 1), the river was losing up to 2.12 ft^3/s per mile. The referenced volumes represent water loss due to both evapotranspiration and canal seepage.

POPULATION AND WATER DEMANDS

Population

The TWDB organizes its population estimates into two categories: *major city* and *county-other*. County seats and localities with more than 1,000 inhabitants are classified as major cities. All other cities and the county-other population are classified as rural.

	1985	1990	1995	2000	2010	2020	2030
Loving County							
Mentone	26	50	51	45	35	29	24
Rural	35	43	42	41	40	37	34
Total	61	93	93	86	75	66	58
Pecos County							
Rural	227	376	413	410	450	477	484
Reeves County							
Pecos	13,276	12,069	11,831	13,389	14,746	15,857	16,415
Rural	2,776	3,373	3,404	3,735	4,096	4,392	4,535
Total	16,052	15,442	15,235	17,124	18,842	20,249	20,950
Ward County							
Monahans	9,219	8,101	7,845	8,392	8,847	9,054	8,857
Rural	2,842	2,371	2,442	2,352	2,276	2,162	2,070
Total	14,801	12,736	12,501	13,262	13,821	13,994	13,681
Winkler County							
Kermit	8,289	6,875	6,540	7,348	7,952	8,393	8,523
Wink	1,553	1,189	1,134	1,303	1,430	1,517	1,544
Rural	704	487	539	547	572	597	604
Total	10,546	8,551	8,213	9,198	9,954	10,507	10,671
Total study area	**41,687**	**37,198**	**36,455**	**40,080**	**43,143**	**45,293**	**45,844**
Odessa	101,165	89,504	95,245	101,355	110,784	118,960	124,808

Table 3. Historical and projected population, 1985–2030. Sources of data: Bureau of Census statistics and TWDB population projections

Table 3 shows the 1985, 1990, and 1995 major city and rural population, along with projected estimates for the years 2000, 2010, 2020, and 2030. These population numbers refer exclusively to the study area as delineated in Figure 1, and were estimated using GIS techniques on the basis of the 1990 census data. Population estimates for the City of Odessa are listed because 16 percent of their water supply (3,341 acre-feet) in 1997 was obtained from a well field in Ward County.

Overall, the total population in the study area decreased by 12.5 percent, or 5,232 people, between 1985 and 1995. The major cities estimated population declined by 4,962 people, or 15 percent, during the same time period. In contrast, the rural population increased by 4 percent, or 256 people, between 1985 and 1995.

It is projected that the population within the study area will grow by approximately 9,389 people, or 26 percent, between 1995 and 2030. A total of 7,964 or 29 percent more people will reside in major cities in the year 2030 as compared with the 1995 population estimates. At the same time, the rural areas are projected to experience a population growth of 887 people, or 13 percent. The greatest population change is expected to occur in Reeves County, with an increase of 5,715 inhabitants, or 38 percent.

Historical Water Uses

In 1995, approximately 181,300 acre-feet of water were used to meet the needs of the study area and surrounding regions using water extracted from the study area (TWDB 1998a, 1998b, 1998c). This amount is a 30 percent increase compared with the 1985 use, and is the result of a substantial surge in 1995 irrigation operations in Reeves County. This change reverses a twenty-year long decline in irrigation pumpage (Ashworth, 1990). Table 4 below shows the area-wide estimated water use for 1985, 1990, and 1995. The table is broken up according to water use by county, and within each county, by major city, municipal, rural municipal, and other (manufacturing, irrigation, steam-electric, mining, and livestock) uses.

Loving County	**1985**		**1990**		**1995**	
	Acre-feet		**Acre-feet**		**Acre-feet**	
	GW	SW	GW	SW	GW	SW
Mentone						
Municipal water use	3	0	6	0	6	0
Rural						
Municipal Water Use	4	0	5.3	0	5	0
Total Municipal Water Use	7	0	11	0	11	0

Table 4. Historical water use, 1985 to 1995

Loving County	**1985**		**1990**		**1995**	
	Acre-feet		**Acre-feet**		**Acre-feet**	
Other Water Use	GW	SW	GW	SW	GW	SW
Manufacturing	0	0	0	0	0	0
Irrigation	0	0	0	65	0	379
Steam-Electric	0	0	0	0	0	0
Mining	0	0	1	0	2	0
Livestock	16	3.6	12	2.9	18	4.6
Water use by Source	**23**	**3.6**	**24**	**68**	**31**	**384**
Total Water Use	***27***		***92***		***415***	
Pecos County	**1985**		**1990**		**1995**	
	GW	SW	GW	SW	GW	SW
Rural						
Municipal Water Use	55	0	44	0	54	0
Total Municipal Water Use	55	0	44	0	54	0
Other Water Use						
Manufacturing	0	0	0	0	0	0
Irrigation	39,876	0	31,581	3,009	41,006	752
Steam-Electric	0	0	0	0	0	0
Mining	17	0	23	0	25	0
Livestock	106	5.4	81	4.2	100	5.3
Water Use by Source	**40,054**	**5.4**	**31,729**	**3,013**	**41,185**	**757**
Total Water Use	**40,059**		**34,742**		**41,942**	
Reeves County	**1985**		**1990**		**1995**	
	GW	SW	GW	SW	GW	SW
Balmorhea						
Municipal Water Use	36	90	57	38	137	31
Pecos						
Municipal Water Use	2,924	0	2,269	0	2,623	0
Rural						
Municipal Water Use	285	224	364	115	431	78
Total Municipal Water Use	3,245	314	2,690	153	3,191	109
Other Water Use						
Manufacturing	99	0	11	0	1,404	0
Irrigation	58,501	12,929	36,040	16,344	105,041	1,925
Steam-Electric	0	0	0	0	0	0
Mining	284	0	128	0	202	0
Livestock	1,977	104	864	46	1,114	59
Water Use by Source	**64,106**	**13,347**	**39,733**	**16,543**	**110,952**	**2,093**
Total Water Use	**77,453**		**56,276**		**113,045**	

Table 4. Historical water use, 1985 to 1995 (continued)

Ward County	1985		1990		1995	
	Acre-feet		**Acre-feet**		**Acre-feet**	
	GW	SW	GW	SW	GW	SW
Monahans						
Municipal Water Use	2,766	0	2,768	0	2,519	0
Rural						
Municipal Water Use	1,125	0	1,014	0	1,074	0
Total Municipal Water Use	3,891	0	3,782	0	3,593	0
Other Water Use						
Manufacturing	84	0	3	0	8	0
Irrigation	1,125	0	189	10,950	318	7,628
Steam-Electric	6,520	0	5,570	0	5,216	0
Mining	102	0	71	0	16	0
Livestock	8.6	0.4	11	0.6	11	0.6
Water Use by Source	**11,731**	**0.4**	**9,626**	**10,950**	**9,162**	**7,629**
Total Water Use	***11,731***		***20,576***		***16,791***	

Winkler County	1985		1990		1995	
	GW	SW	GW	SW	GW	SW
Kermit						
Municipal Water Use	2,816	0	1,779	0	1,917	0
Wink						
Municipal Water Use	266	0	212	0	299	0
Rural						
Municipal Water Use	170	0	94	0	120	0
Total Municipal Water Use	3,252	0	2,085	0	2,336	0
Other Water Use						
Manufacturing	54	20	7	0	1	0
Irrigation	800	0	0	0	0	0
Steam-Electric	0	0	0	0	0	0
Mining	1,230	0	898	0	1,437	0
Livestock	80	4	96	4.5	105	5
Water Use by Source	**5,416**	**24**	**3,086**	**4.5**	**3,879**	**5**
Total Water Use	**5,440**		**3,091**		**3,884**	

Table 4. Historical water use, 1985 to 1995 (continued)

Entire study area	**1985**		**1990**		**1995**	
	Acre-feet		**Acre-feet**		**Acre-feet**	
	GW	SW	GW	SW	GW	SW
Total Municipal Water Use	10,450	314	8,612	153	9,185	109
Other Water Use						
Manufacturing	237	20	21	0	1,413	0
Irrigation	100,302	12,929	67,810	30,368	146,365	10,684
Steam-Electric	6,520	0	5,570	0	5,216	0
Mining	1,633	0	1,121	0	1,682	0
Livestock	2,188	117	1,064	58	1,348	75
City of Odessa	6,841	0	4661	0	5,282	0
Water Use by Source	**128,171**	**13,380**	**88,859**	**30,579**	**170,491**	**10,868**
TOTAL WATER USE	**141,551**		**119,168**		**181,359**	
Note: GW=groundwater; SW=surface water; Water quantity in acre-feet						

Table 4. Historical water use, 1985–1995 (continued).

The water needs throughout the study area continue to be fulfilled primarily with groundwater from the Cenozoic Pecos Alluvium aquifer. In 1995, groundwater represented a 94 percent share in the area water use, up from 91 percent in 1985. The remainder was water released from the Red Bluff Reservoir and surface water from the Balmorhea Lake.

More water is used for irrigation than for any other purpose in the study area. In 1995, irrigation accounted for 157,049 acre-feet or 87 percent of the total amount of water used, up from 113,231 acre-feet, or 80 percent in 1985. Most of the regional irrigation needs were fulfilled with groundwater pumped from the Cenozoic Pecos Alluvium and, in Pecos County, the Edwards-Trinity (Plateau) aquifer. In 1995, 146,365 acre-feet, or 93 percent of region's irrigation was supplied with groundwater, up from 100,302 acre-feet (89 percent) in 1985.

Area-wide municipal pumping accounted for 19,744 acre-feet, or 5 percent of the 1995 total water use, 98 percent of it being groundwater. In 1985, 10,764 acre-feet or 8 percent of the total were allocated to municipal users, 97 percent of it being groundwater. The cities of Pecos, Monahans, and Kermit accounted for 7,059 acre-feet or 76 percent of the region's municipal pumpage, the remainder being used by smaller towns and rural areas. The city of Odessa, in Ector County, is not within the study region, but relies partially on groundwater pumped from the Cenozoic Pecos Alluvial aquifer in Ward County. In 1995, the city of Odessa pumped 5,282 acre-feet of groundwater. This quantity is in addition to the area-wide municipal water use from all sources and amounts to 36 percent of this water use category.

Smaller amounts of water are being used for manufacturing, power generation, mining, and livestock (see Table 4).

Projected Water Demands

Table 5 shows the projected water demands and supply sources for the study area by major cities, rural, and other uses (TWDB, 1997).

		Acre-feet per year			
		2000	**2010**	**2020**	**2030**
Municipal use					
Major Cities	[1]Ground	8,545	8,850	8,903	8,872
	Surface	0	0	0	0
	Subtotal	*8,545*	*8,850*	*8,903*	*8,872*
Rural	[1]Ground	2,222	2,221	2,185	2,155
	[3]Surface	97	90	83	76
	Subtotal	*2,319*	*2,311*	*2,268*	*2,231*
Other Uses	[1]Ground	72,853	71,273	70,140	69,091
	[2]Ground	33,189	32,524	31,873	31,238
	[4]Surface	17,598	17,598	17,598	17,598
	Subtotal	*123,640*	*132,556*	*130,782*	*129,030*
Entire Study Area	**Ground**	**116,809**	**114,868**	**113,101**	**111,356**
	Surface	**17,695**	**17,688**	**17,681**	**17,674**
	Total	**134,504**	**132,566**	**130,782**	**129,030**
City of Odessa	Ground	4,760	4,760	4,760	4,760
	Surface	0	0	0	0
	Total	4,760	4,760	4,760	4,760

[1]Source of water: Cenozoic Pecos Alluvium aquifer
[2]Source of water: Edwards-Trinity (Plateau) aquifer
[3]Source of water: Spring-fed lakes in Reeves County
[4]Source of water: Pecos River (releases from the Red Bluff Reservoir)

Source of data: TWDB, 1997

Table 5. Projected water demands by source type

The *Major City* category includes projected municipal demands for the Cities of Pecos, Monahans, Kermit and Wink. The *Rural* category includes smaller towns and all rural population use, including the domestic surface water use in the Balmorhea area. The manufacturing, power, livestock, mining, and irrigation uses are grouped under the *Other Uses* category. The projections for the City of Odessa, Ector County are listed separately and reflect only the amount of water the city will require from sources inside the study area.

The allocation of water supplies to future water demands (see Table 5) was analyzed at the individual city and county level. In assigning water resources, priority was given to water use and supply management measures that have less impact and are cost-effective. Then, water use and supply management measures that are more costly, environmentally sensitive, or controversial were considered. The allocation method was designed to incorporate water conservation savings into all water uses, thus allowing for more efficient operation of existing resources and delaying the need for new supply development. If necessary, the allocation method then considered the possibility of expanding the existing supply, followed by enlarging the local undeveloped water sources. Alternative methods such as reallocation of reservoir storage and water marketing were also investigated. Finally, new reservoir development and inter-basin water transfers were also considered if needed to meet projected water demands.

Under projected conditions, the annual water requirement area-wide, excluding the City of Odessa, is projected to decrease by approximately 23 percent from 1995 to the year 2000, subsequently declining at a rate of about 1.4 percent per decade until the year 2030. Groundwater is expected to account for approximately 86 percent of the total water use from year 2000 through 2030. Considering that the 1995 proportion was 94 percent, this illustrates an effort to reduce the stress on the regional groundwater supply. Surface water use is anticipated to increase by 62 percent from 1995 to 2000, but should be less than the 1990 amount (see Tables 4 and 5).

WATER AVAILABILITY

Groundwater Availability

Previous research estimated the effective recharge to the Cenozoic Pecos Alluvium aquifer in the study area to be approximately 67,800 acre-feet per year (Ashworth, 1990, p. 43). This amount represents the safe yield or usable water available on a perennial basis from the aquifer and is based on the results of a seepage study performed along the Pecos River prior to extensive groundwater development in the area (Grover et al., 1922).

Ashworth (1990) has determined the total amount of groundwater in storage in the Cenozoic Pecos Alluvium within the study area to be approximately 98 million acre-feet. Due to large variations in water chemistry, both laterally and vertically, only 30 million acre-feet of usable (fresh-to-slightly saline) groundwater are available for extraction (Muller and Price, 1979). The same authors state that of this amount, only 9.48 million acre-feet could be pumped if significant groundwater quality deterioration is to be avoided.

Year	Groundwater Demand	Average Annual Effective Recharge	Yearly Storage Depletion	Water Remaining in the Aquifer
1985	128,171	67,800	60,371	8,991,468
1990	88,859	67,800	21,059	8,807,549
1995	170,490	67,800	102,690	8,457,359
2000	121,569	67,800	53,769	8,090,670
2010	119,628	67,800	51,828	7,563,651
2020	117,861	67,800	50,061	7,055,085
2030	116,116	67,800	48,316	6,564,068

Water quantity in acre-feet

Table 6. Projected groundwater availability through year 2030

Table 6 shows the estimated storage depletion rate for the time interval 1985 to 2030 for the Cenozoic Pecos Alluvium aquifer area-wide. The groundwater demand figures include the City of Odessa. The calculation assumed a balance of 9.48 million acre-feet of groundwater available at the beginning of 1980 (Muller and Price, 1979). The demand for groundwater consistently exceeds the recharge to the aquifer and, therefore, the difference must be supplied with water from storage. The storage depletion was calculated by subtracting the area-wide groundwater demand from the effective recharge for each subsequent year. Table 6 presents only the remaining groundwater in storage at five- or ten-year intervals. The water demand quantities at the beginning and the end of each five- or ten-year interval were averaged and assigned to each year in between.

Based on the storage depletion rate calculated above, by the year 2030 the Cenozoic Pecos Alluvium aquifer within the study area will have approximately 6.5 million acre-feet of usable-quality groundwater remaining in storage. It is expected that 22 percent of the water held in storage in 1995 will have been used by the year 2030.

Surface Water Availability

It is estimated that approximately 34,000 acre-feet of water from the Red Bluff reservoir will be available for release every year into the Pecos River through year 2030 (TWDB, 1997). It is important to note, however, that channel losses in excess of 45 percent have been calculated along the river (TWDB water allocation model, file 17), the adjusted amount of surface water available to users downstream thus being approximately 18,700 acre-feet. This quantity exceeds the yearly projected surface water demand area-wide for the time interval 2000 through 2030 (Table 5).

CONCLUSIONS

Between 1988 and 1998 the Cenozoic Pecos Alluvium aquifer has been experiencing water-level decline in areas of continued irrigation overdraft and water-level recovery elsewhere. The groundwater quality has been relatively steady during this time interval. Current and projected water demands to the year 2030 are in excess of the estimated recharge rate and they will have to be met at the expense of aquifer storage. The aquifer should have enough fresh-to-slightly saline water to meet the projected needs, although future deterioration of groundwater quality could limit the use of this water. Sufficient resources will likely satisfy the projected surface water demands.

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