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Updated Evaluation of Water Resources within the Trinity Aquifer Area, Central Texas

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ABSTRACT

This report updates Texas Water Development Board (TWDB) Report 319, which evaluated large water-level declines and groundwater quality problems in the Trinity aquifer of Central Texas. This report documents that long-term water-level declines are still indicated in Bosque, Coryell, Falls, Hill, and McLennan Counties.

Significant water-level declines have occurred since 1960 in the eastern part of the study area. Regional cones of depression have developed in the Trinity aquifer in urban areas around Waco. Water-level declines are also present in Bosque County. Water-level declines in the study area are the result of groundwater withdrawals exceeding recharge and inflow to the Trinity aquifer.

Overall, groundwater quality throughout the study area is good. However, twelve out of eighteen counties have groundwater samples with total dissolved solids (TDS) concentrations exceeding the secondary constituent level (SCL) of 1,000 mg/l. Other constituents exceeding the SCL are chloride (300 mg/l) and sulfate (300 mg/l). Nitrate concentrations exceeded the maximum contaminant limit (MCL) of 44.3 mg/l. Typically, the western outcrop areas (Brown, Callahan, Comanche, Eastland, Erath, and Mills Counties) have elevated chloride and nitrate values, which indicate possible contamination.

Pumpage from the Trinity aquifer far exceeds recharge and continued overdraft is resulting in water-level declines in the confined portion of the Trinity aquifer. A comparison of historical pumpage and estimated supply shows Bosque, Falls, McLennan, and Somervell Counties are overdrafting the Trinity aquifer. Population and water demands are projected to increase through the year 2030, with major metropolitan areas expecting the greatest population and water demand growth.

The findings of this report hold up the previous conclusion stated in TWDB report 319. If the rate of conversion to surface water is maintained and expanded, as suggested in the 1997 State Water Plan, adequate water supplies should exist to meet the current and projected needs in the study area though year 2030. Careful management of the groundwater resources together with increased conversion to surface water supplies will be necessary to ensure adequate availability of water to this area through 2030.

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INTRODUCTION

Purpose

In 1997, the 75th Texas Legislature passed Senate Bill 1 (SB 1). This Act requires the identification of Priority Groundwater Management Areas (PGMAs) which are defined as "those areas of the State that are experiencing or that are expected to experience, within the immediately following 25-year period, critical groundwater problems, including shortages of surface water or groundwater, land subsidence resulting from groundwater withdrawal, and contamination of groundwater supplies."

The TWDB is directed under this Act to prepare a report including an appraisal of the hydrogeology and supply needs of the PGMA study areas. This report, in response to SB 1, is an update to Report 319, *Evaluation of Water Resources in Part of Central Texas* by Baker and others (1990). Report 319 was prepared in response to House Bill 2, passed in 1985 by the 69th Texas Legislature. This bill called for the "identification and study of areas that were experiencing or were anticipated to experience critical groundwater problems within the next 20 years".

The purpose of the present report is to evaluate changes in water-levels, water quality, water demands, and water availability in the study area since the publication of Report 319 (Baker and others, 1990).

Location

The Central Texas study area (Figure 1) includes all or parts of Bell, Bosque, Brown, Burnet, Callahan, Comanche, Coryell, Eastland, Erath, Falls, Hamilton, Hill, Lampasas, Limestone, McLennan, Milam, Mills, and Somervell Counties. The study area is also located in the Brazos, Colorado, and Trinity River Basins. The portion of each county where useable groundwater is found in the Trinity aquifer defines the boundaries of this study area (Figure 2). However, the study area only encompasses the part of Bell County that lies north of the Lampasas and Little Rivers. The Woodbine aquifer occurs in the northeastern extent of the study area (Figure 2).

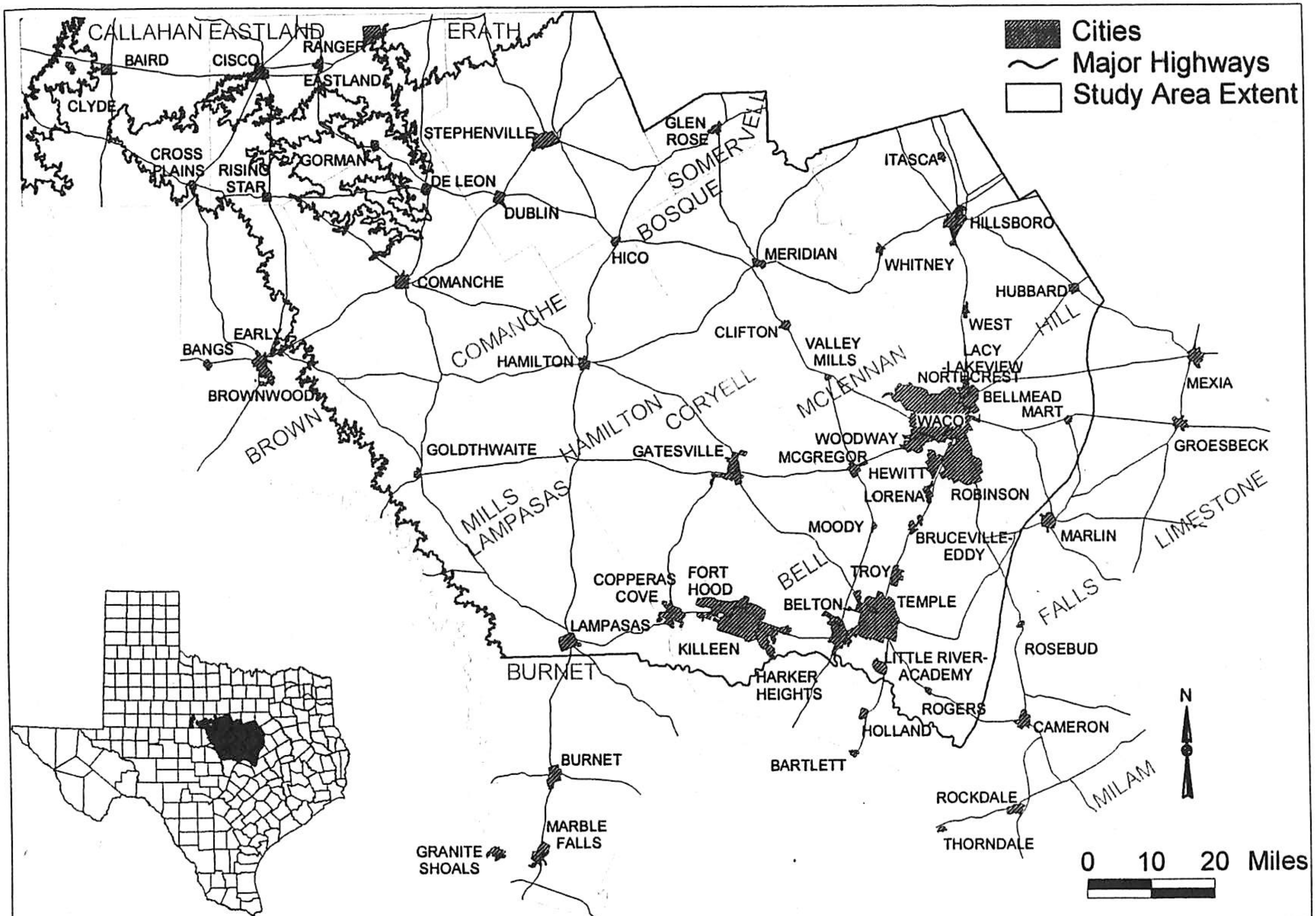

Figure 1. Location of the study area.

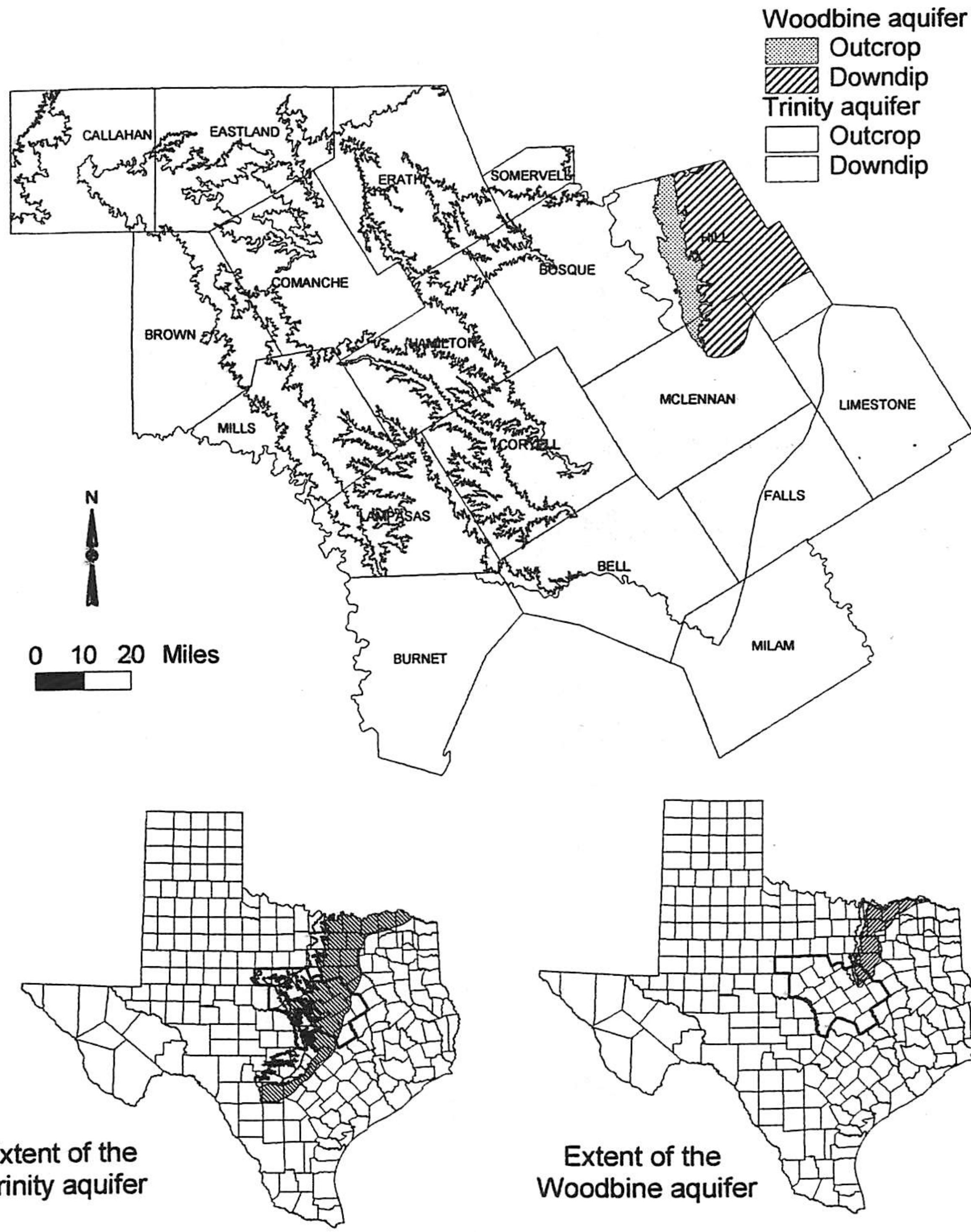

Figure 2. Extent of the Trinity and Woodbine aquifers in the study area.

HYDROGEOLOGY

Geology

The Trinity aquifer is comprised of the Paluxy, Glen Rose, Hensell, Twin Mountains, Travis Peak, and Hosston Formations of the Trinity Group (Ashworth and Hopkins, 1995 p.19; Muller and Price, 1979, p.24).

In the study area, the Trinity Group is divided into three distinctive sequences, the Antlers Formation, Twin Mountains Formation, and the Travis Peak Formation (Fisher and Rodda, 1966) (Figures 3 and 4). The sand and gravel dominated Twin Mountains Formation occurs over the majority of the study area, and transitions toward the southwest into the limestone dominated Travis Peak Formation. Updip from the Pearsall Formation pinchout, the Twin Mountains Formation is divided into upper and lower units. Downdip, where the Pearsall Formation exists, the upper Trinity sand is called the Hensell Formation and the lowermost Trinity sand is called the Hosston Formation. West of the Glen Rose Formation pinchout, the Paluxy and Twin Mountains Formations converge into the Antlers Formation (Figures 3 and 4). Details of the geology in the area can be found in Klemt and others (1975), Nordstrom (1987), and Baker and others, (1990).

Water-Level Fluctuations

Water-level fluctuations were analyzed to determine how water levels have changed over time. Decreasing water levels are indicative of decreasing aquifer storage and may suggest mining of groundwater. Rebounding water levels can indicate increases in aquifer storage and response to recharge. Seasonal water-level fluctuations may correlate with seasonal variations in precipitation and suggest how rapidly water levels in an aquifer respond to recharge events.

To evaluate water-level fluctuations and long-term trends since the completion of Report 319 (Baker and others, 1990), hydrographs for five wells 40-05-701, 40-31-802, 40-45-402, 41-07-501, and 32-55-304 included in Report 319 were updated and evaluated. Three other wells included in Report 319 were not used because measurements for these wells were discontinued prior to 1993.

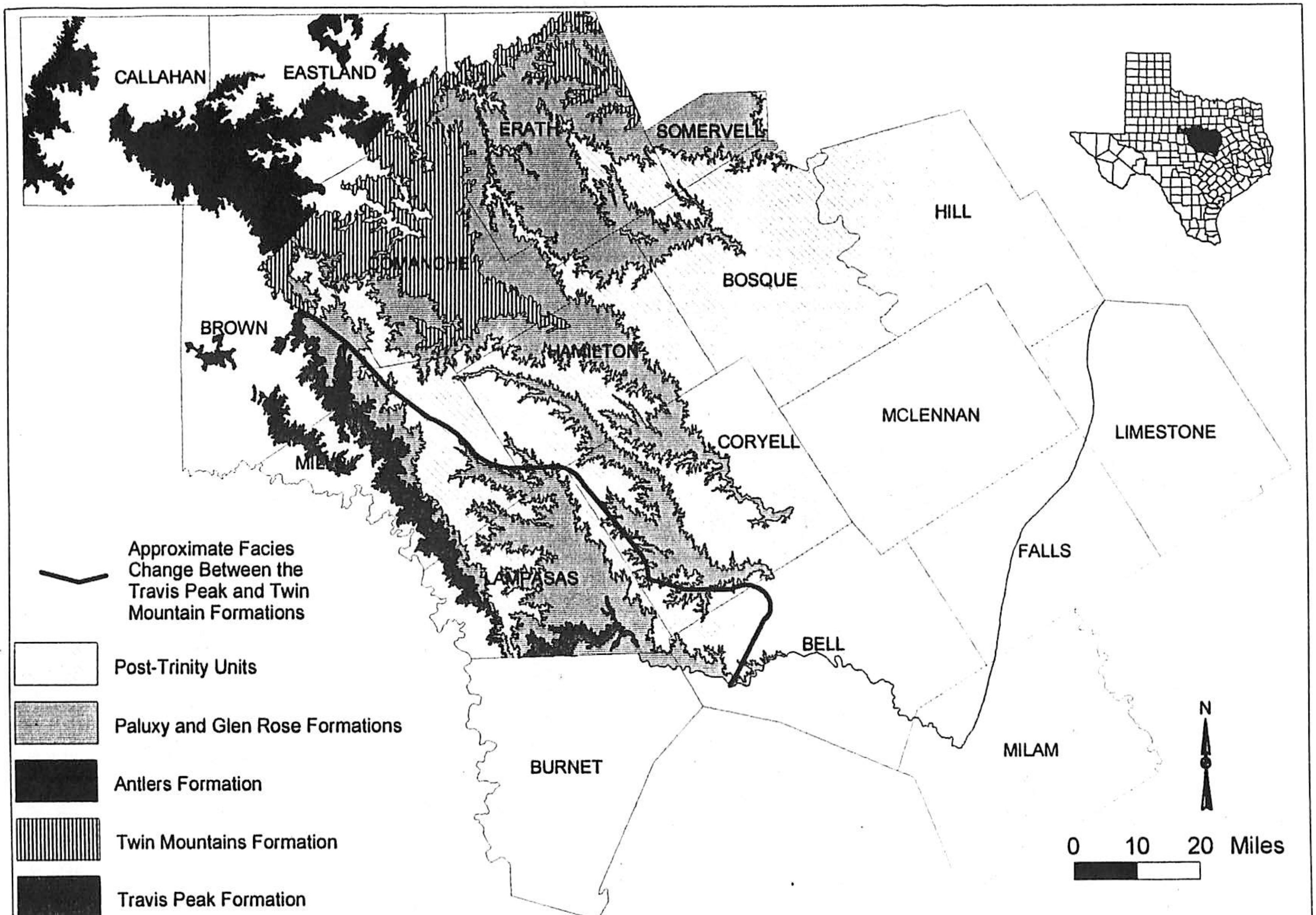

Figure 3. Geologic map of the study area (Modified from Baker and others, 1990 ; Fisher and Rodda, 1966,: and BEG, 1992)

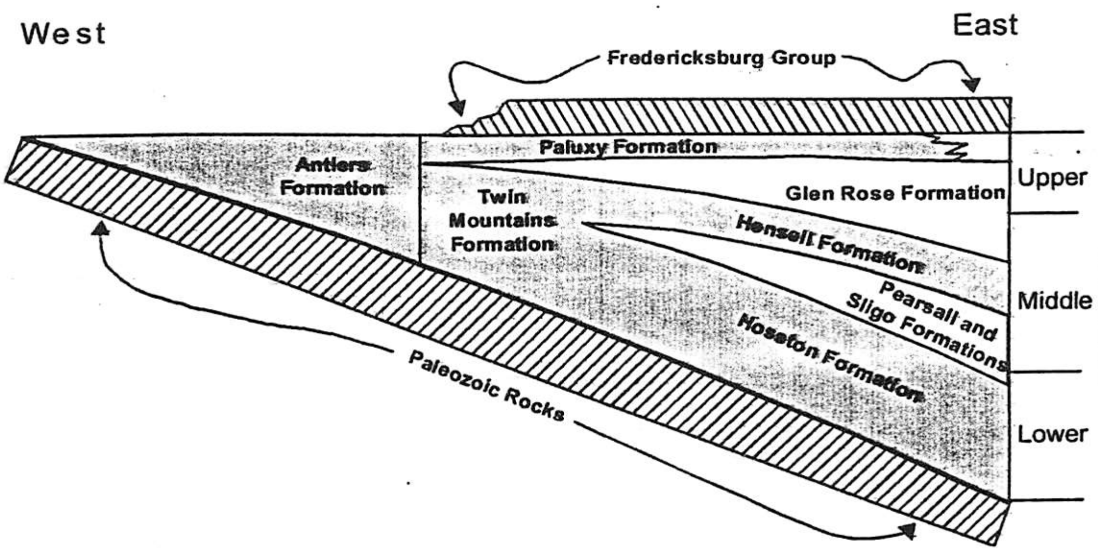

Figure 4. Generalized cross section of the Trinity Aquifer (Modified from Fisher and Rodda, 1966, and Atchley, 1983).

All water-level data for this report were obtained from the TWDB Groundwater Database (TWDB, 1998a).

Eleven additional wells were added to augment the water-level analysis of the Trinity aquifer. Four new wells completed in the Hosston Formation are included. These wells are 40-48-201 and 40-64-101 in Falls County, 39-09-201 in Hill County, and 40-31-612 in McLennan County. Five additional wells, 31-55-803 in Erath County, 31-58-703 in Comanche County, 32-43-406 in Somervell County, and 40-05-903 and 40-03-901 in Bosque County are all completed in the Twin Mountains Formation. Two additional hydrographs were constructed for wells completed in the Paluxy Formation, 41-31-603 in Hamilton County and 40-26-401 in Coryell County.

Water levels in individual wells in the Hosston Formation show significant declines (Figure 5; Table 1). The greatest declines are exhibited by wells in the Waco metropolitan area of McLennan County (40-31-612, 40-31-802). These wells show declines over 400 feet (Table 1). Water levels in Falls and Hill Counties (40-48-201, 40-64-101, 39-09-201) have smaller overall declines between approximately 157 and 307 feet. Between the winters of 1983-84 and 1993-94, water levels in selected wells completed in the Hosston Formation have declined as much as 123 feet and rebounded only 4 feet (Table 1). Rates of water-level changes between the winters of 1983-84 and 1993-94 for individual wells range from –12.30 to +0.40 feet per year.

The Hensell Formation has also recorded significant water-level declines in Central Texas. The only well completed in the Hensell Formation and reevaluated from Report 319 (Baker and others, 1990; Figure 6; Table 1), 40-45-402 in Coryell County, shows a total decline of 234.3 feet between 1966 and 1996, with an average decline rate of about 7.8 feet per year. This well also shows a decline of 31.1 feet between the winters of 1983-84 and 1993-94 and a water-level decline rate of 3.1 feet (Figure 6; Table 1).

Two wells completed in the Twin Mountains Formation (31-55-803, 31-58-703) are located on the outcrop and are under unconfined conditions. No long-term declines are indicated in these two wells (Figure 6; Table 1). Four wells completed in the Twin Mountain Formation (32-43-406, 40-05-701, 40-05-903, 40-03-901) do show long-term declines (Figure 6; Table 1). Water levels in these wells have overall declines ranging from about 171 feet to 337 feet (Table 1). Between the winters of 1983-84 and 1993-94 water levels in these wells have declined as much as about 88 feet and rebounded as much as 4 feet (Table 1). Rates of water-level changes between the winters of 1983-84 and 1993-94 range from –8.80 to +0.40 feet per year (Table 1).

Completion Formation	County	State Well Number	Measurement Period	Average Yearly Difference (feet)	Total Water-Level Difference (feet)
Hosston	Falls	40-48-201	1964-1994	-7.80	-232.95
			1984-1994	-5.30	-53.01
		40-64-101	1965-1998	-4.80	-156.81
			1984-1993	-5.30	-47.65
	Hill	39-09-201	1960-1997	-8.30	-306.57
			1984-1994	0.40	4.42
	McLennan	40-31-612	1960-1994	-13.30	-438.40
			1984-1994	-6.20	-61.90
		40-31-802	1964-1996	-13.20	-420.95
			1983-1994	-12.30	-122.75
Hensell	Coryell	40-45-402	1966-1996	-7.80	-234.27
			1984-1994	-3.10	-31.10
Twin Mountains	Bosque	40-03-901	1962-1997	-5.50	-193.32
			1984-1994	-5.20	-51.73
		40-05-701	1965-1994	-7.90	-228.20
			1983-1994	-3.30	-36.01
		40-05-903	1964-1997	-10.20	-336.89
			1984-1994	-8.80	-88.13
	Comanche	31-58-703	1965-1998	0.20	6.33
			1984-1994	0.40	4.35
	Erath	31-55-803	1963-1998	-0.30	-11.39
			1984-1994	0.70	7.43
	Somervell	32-43-406	1962-1997	-4.80	-171.23
			1984-1994	-5.30	-52.86
Paluxy	Coryell	40-26-401	1968-1998	0.20	6.66
			1984-1994	0.00	0.40
	Hamilton	41-07-501	1967-1998	0.20	6.82
			1984-1995	0.90	9.94
		41-31-603	1966-1998	0.10	2.57
			1984-1994	0.10	0.92
Woodbine	Hill	32-55-304	1969-1997	0.40	10.17
			1984-1994	0.60	6.26

Table 1. Water-level differences of selected wells in the study area (based on data from TWDB, 1998a).

The hydrograph for well 32-55-304 (Figure 7) completed in the Woodbine Formation shows significant temporal variations, with changes up to approximately 22 feet. Since 1979, it appears the water level in this well has generally risen.

Hydrographs for wells completed in the Paluxy Formation show a range of responses (Figure 7). Wells 41-31-603 in Hamilton County and 40-26-401 in Coryell County show relatively steady water levels as compared with the hydrograph for well 41-07-501, which shows significant temporal variations up to approximately 20 feet between consecutive years.

Precipitation data in the Trinity outcrop areas were analyzed to determine long-term trends. Figure 8 shows precipitation between water years 1960 through 1996. A water year is from October of the year shown, through September of the following year. All of these stations are on the Trinity aquifer outcrop. Included on the graphs are the annual water year precipitation measurements, the average annual precipitation between water years 1960 and 1996, and a three-year moving average (Figure 8) (Hydrosphere Data Products, 1998).

All four stations generally show similar precipitation patterns, with a period of lower precipitation ranging from the mid 1970s to the mid 1980s. A comparison of precipitation (Figure 8) and water-level measurements in the Paluxy Formation in well 41-07-501 (Figure 7) shows a general response to rainfall over time indicating recharge into Paluxy Formation. Wells completed in the Twin Mountains Formation do not exhibit any appreciable response to precipitation.

Approximately 20 percent of recharge to the Trinity aquifer, exclusive of the Paluxy and Glen Rose Formations, is from precipitation falling on the outcrops of the Antlers and Twin Mountains Formations. The remainder of the recharge (80 percent) to the Twin Mountains, Hensell, and Hosston Formations is from the overlying Paluxy and Glen Rose Formations (Rapp, 1988 p.26, 29).

Two maps were created illustrating the water levels in the study area based on the most recent available data. The first map is based on wells completed in the Antlers, Twin Formation (undifferentiated), lower Twin Mountains, Travis Peak, and the Hosston Formations. The grouping of aquifers is the same as in Baker and others (1990). The measurements used for this map were recorded between September 1997 and February 1998 (Figure 9). The second map includes water levels for the upper Twin Mountains and Hensell Formations. The data set for this water-level map consists of measurements recorded in January 1997 (Figure 10).

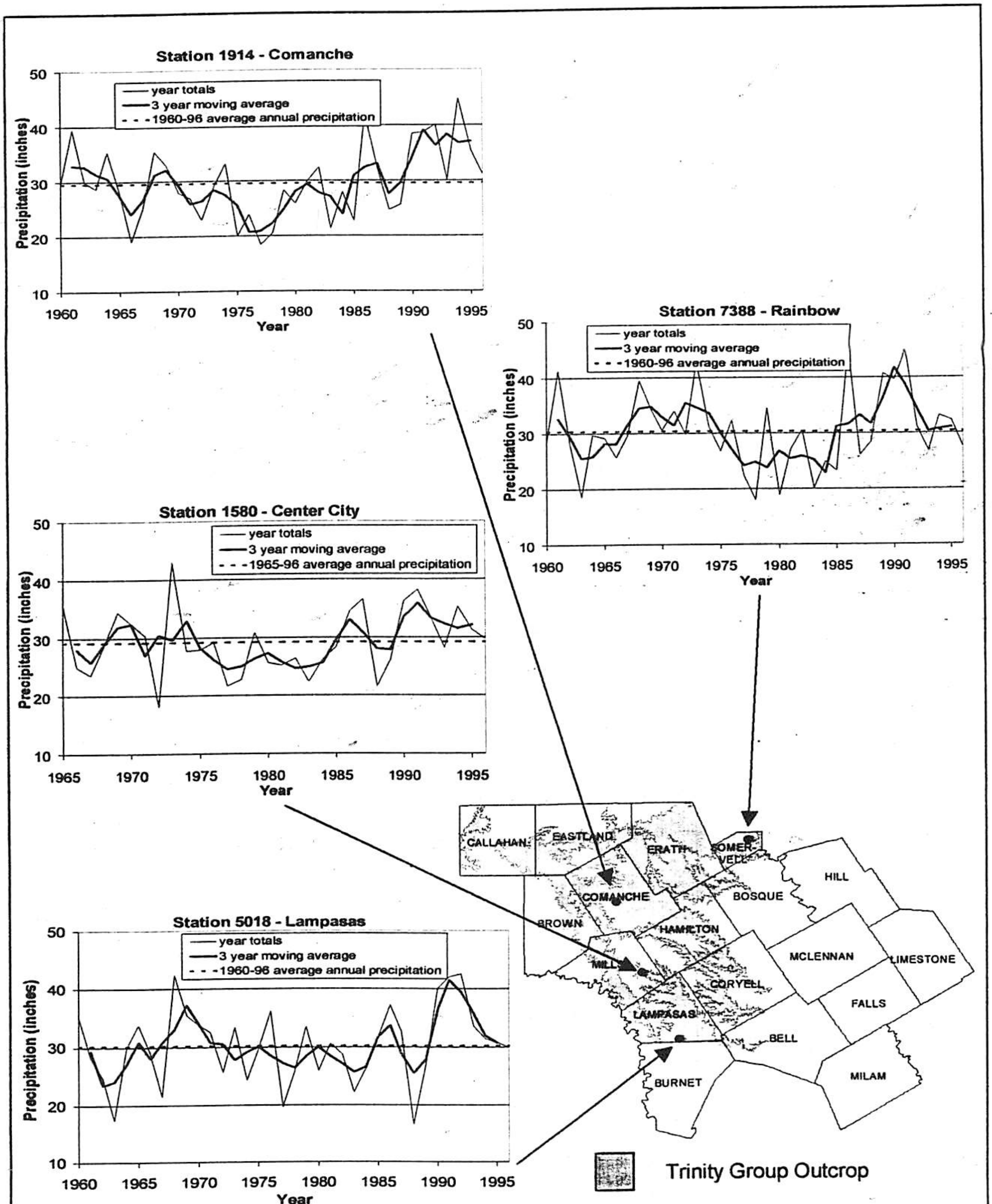

Figure 8. Precipitation data from selected stations on the Trinity aquifer outcrop (Water Years 1960 to 1996)(Hydrosphere Data Products, 1998).

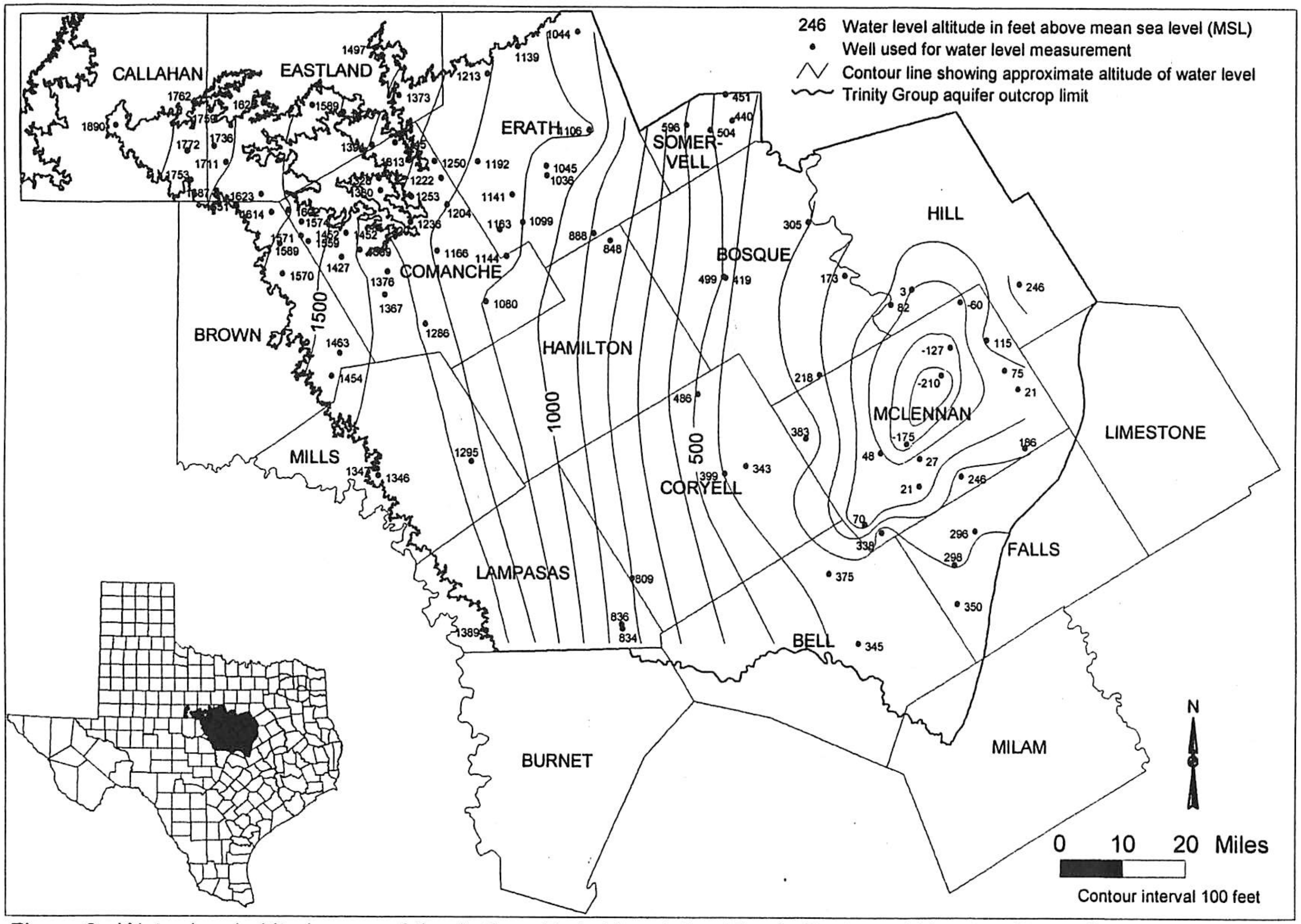

Figure 9. Water-level altitude map of the Antlers, Twin Mountains, Travis Peak, and Hosston Formations (fall 1997 - spring 1998) (data from TWDB, 1998a).

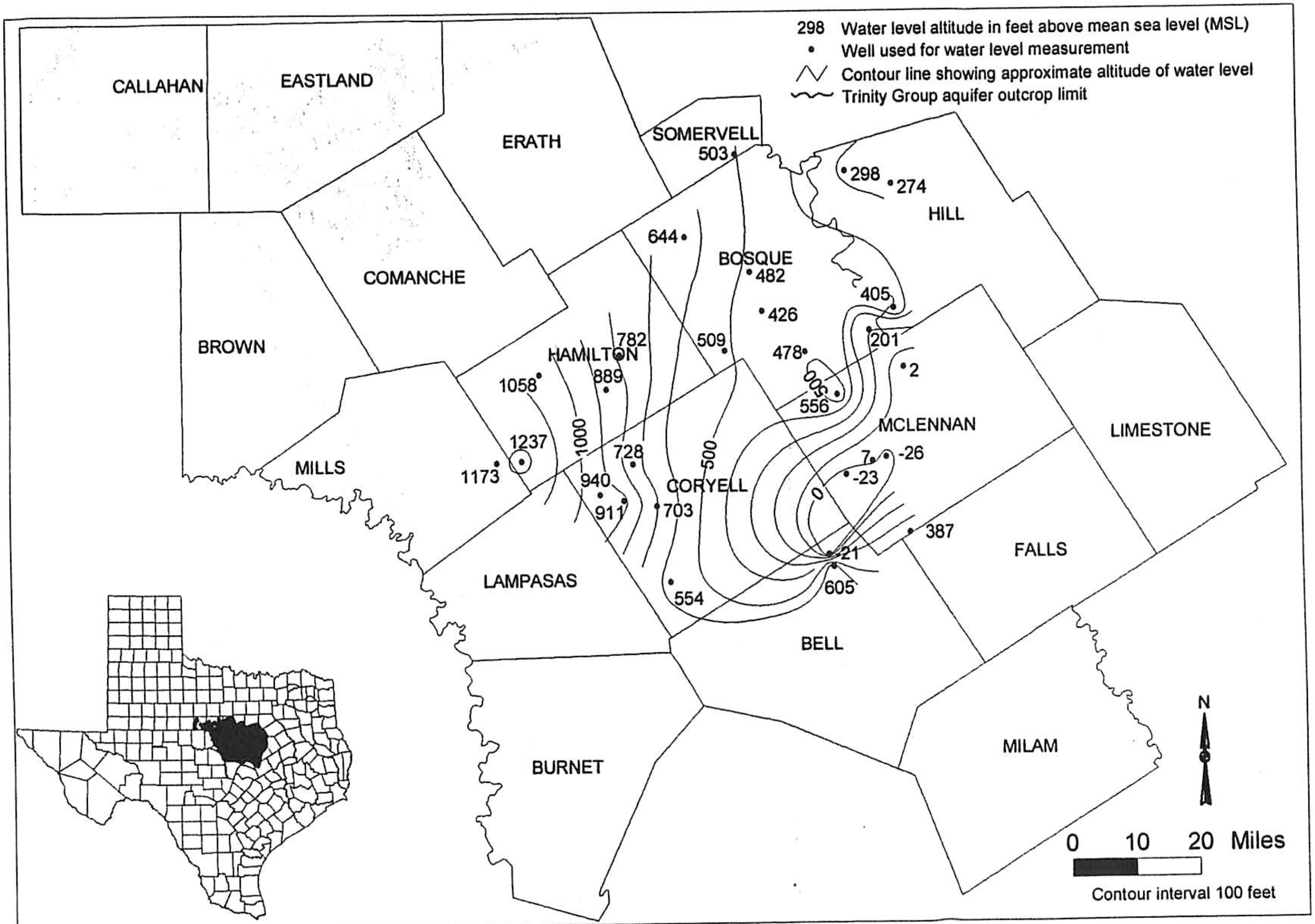

Figure 10. Water-level altitude map of the upper Twin Mountains and Hensell Formations (January 1997)(data from TWDB, 1998a).

As seen in Figure 9, a regional cone of depression exists in McLennan County, centered in the Waco metropolitan area. This appears to be the effect of localized cones of depression around the Waco area previously reported in Report 319 (Baker and others, 1990, p.21). Water-level trends generally show a gentle gradient of about 15 feet per mile from west to east across the study area. The steepest gradient of approximately 90 feet per mile occurs in McLennan County, along the southern edge of the cone of depression.

Water levels in the Hensell Formation also indicate a cone of depression in southwestern McLennan County, western Coryell County, and northern Bell County (Figure 10). A steep gradient of over 300 feet per mile exists in northern Bell County. Very little information is available for the southernmost well 40-53-102 in Bell County (Figure 10) except for total depth and water level. This well may be completed in part of the Pearsall or Sligo Formations, therefore reflecting the water-level conditions of these formations.

Water Quality

Water quality of the Trinity and Woodbine aquifers was evaluated to determine if any significant deterioration had occurred since Report 319 (Baker and others, 1990) was issued. Water-quality data were obtained from the TWDB Groundwater Database (TWDB, 1998a). Elevated levels of total dissolved solids (TDS), chloride, nitrate, sulfate, and fluoride were reported in Report 319 (Baker and others, 1990, p. 30), but the previous report did not list the data set used for water-quality evaluations. Therefore, no attempt was made to duplicate the previous data set. Samples used for the present evaluation include those collected between 1988 and 1998 by the Groundwater Monitoring Unit of the TWDB, in accordance with standardized procedures outlined in *A Field Manual for Ground-Water Sampling* (Nordstrom and Benyon, 1991).

The Texas Administrative Code (TAC), 1999, □290 defines the secondary constituent level (SCL) for TDS at 1,000 mg/l, and the chloride and sulfate SCLs at 300 mg/l. Additionally, this section defines the maximum contaminant level (MCL) for nitrate as nitrogen at 10 mg/l (44.3 mg/l as nitrate).

TDS concentrations in groundwater samples collected between 1988 and 1995 from the Twin Mountains, Travis Peak, Hensell, and Hosston Formations range from 171 to 2,710 mg/l and average 664 mg/l. Samples exceeding the 1,000 mg/l occur in Bell, Brown, Comanche, Coryell, Eastland, Erath, Falls, Hamilton, Hill, Lampasas, McLennan, and Milam Counties (Figure 11).

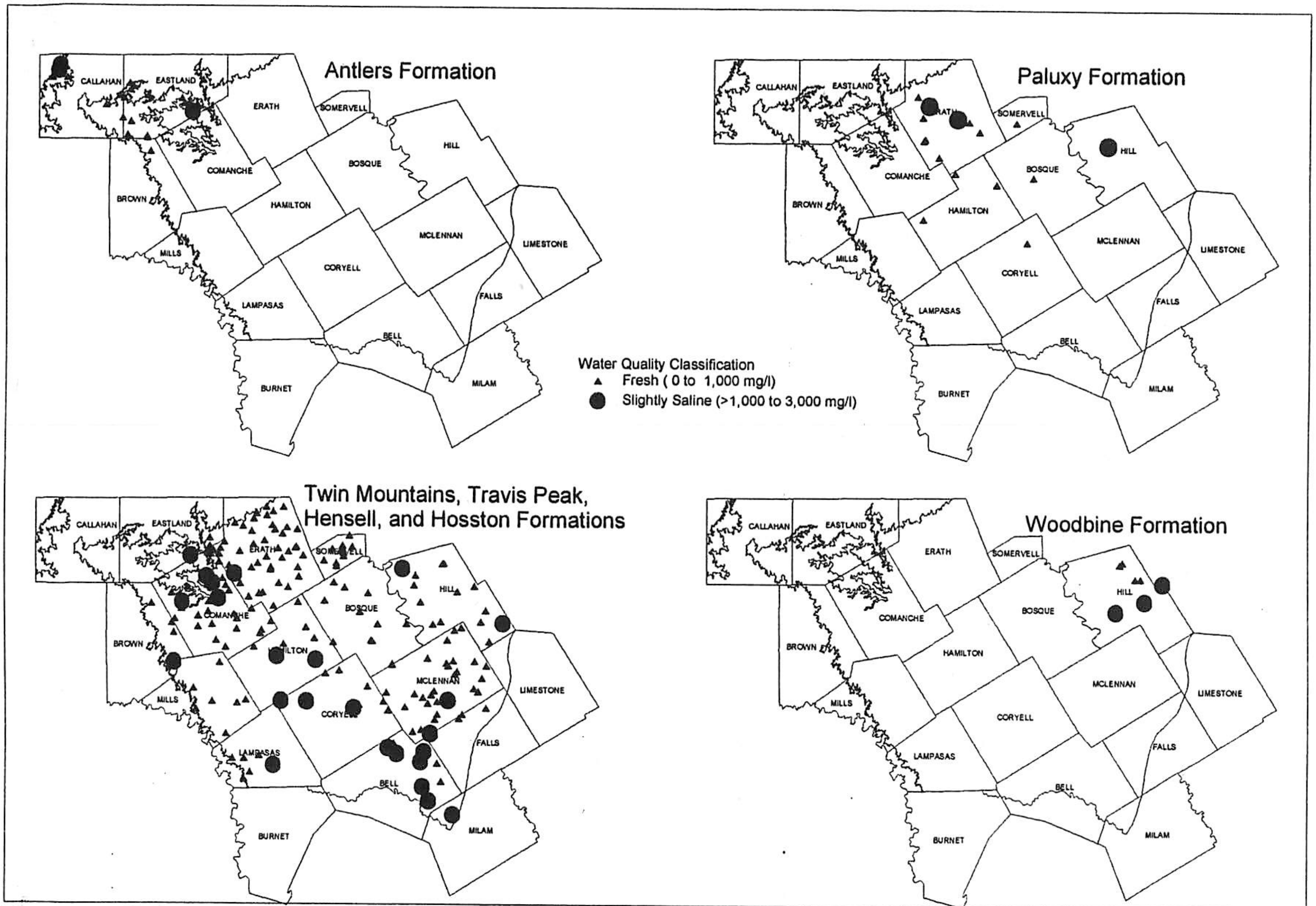

Figure 11. TDS concentrations for groundwater samples collected from various formations in the study area (data from TWDB, 1998a; Texas Ground Water Protection Commitee, 1991).

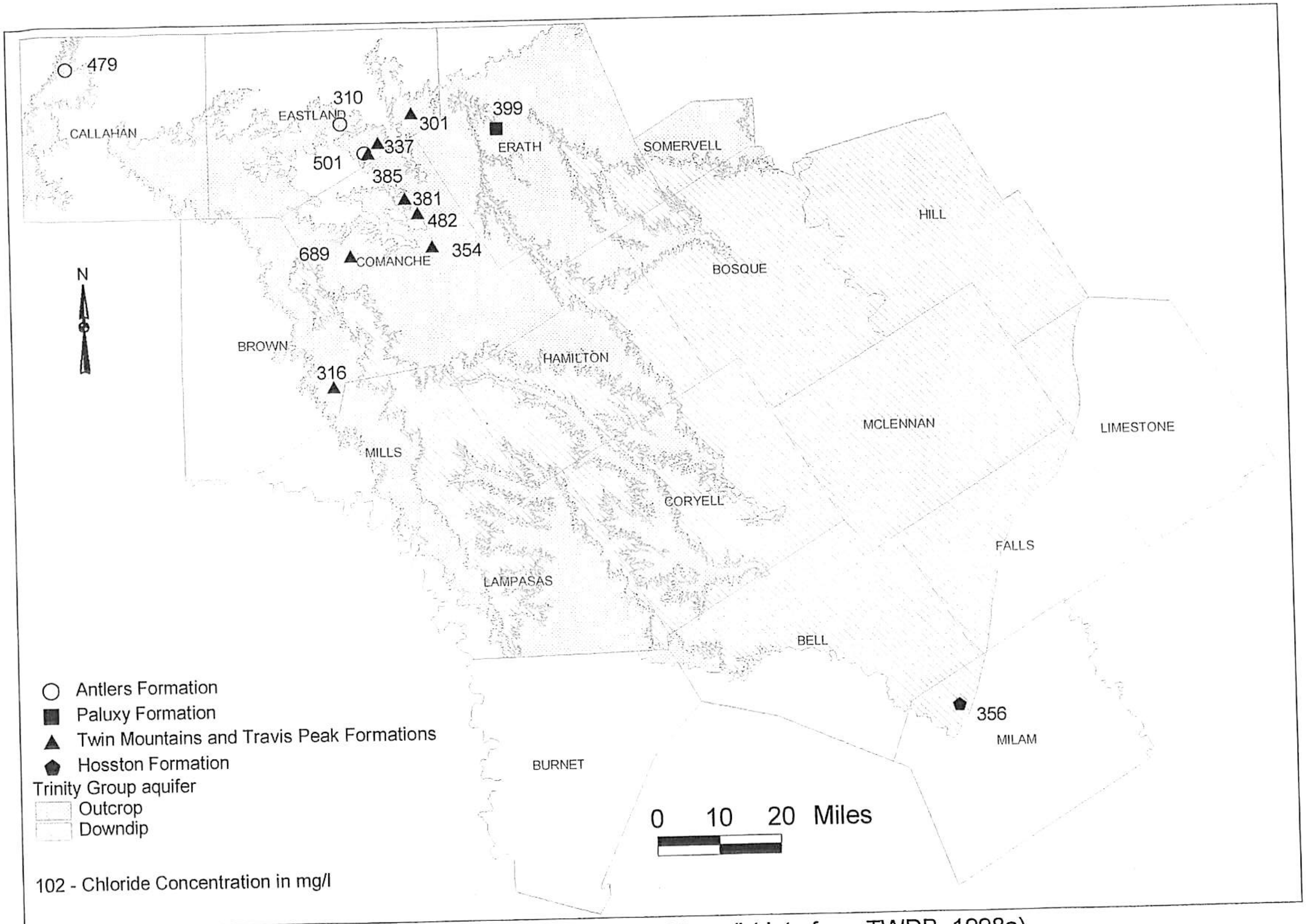

Figure 12. Chloride concentrations exceeding the SCL of 300 mg/l (data from TWDB, 1998a).

TDS concentrations in groundwater from the Antlers Formation, collected between 1990 and 1995, ranged from 356 to 1,438 mg/l and average 671 mg/l. Concentrations exceeding the SCL occur in Callahan and Eastland Counties (Figure 11). TDS concentrations in groundwater from the Paluxy Formation, for 1988 to 1994, range from 290 to 1,716 mg/l and average 631 mg/l. Concentrations exceeding the 1,000 mg/l SCL occur in Erath and Hill Counties (Figure 11).

TDS concentrations for eight Woodbine aquifer samples, collected between 1993 and 1998 in Hill County (Figure 11), range from 481 to 1,992 mg/l and average 987 mg/l. Three of the eight samples collected exceed the SCL for TDS.

Only two samples were collected from wells completed in the Glen Rose Formation. The TDS concentrations were 1,141 mg/l in a Lampasas County well and 400 mg/l in a Bosque County well.

Chloride concentrations in groundwater samples from the Twin Mountains, Travis Peak, Hosston and Hensell Formations range from 9 to 689 mg/l and average 85 mg/l. Nine samples exceed the chloride SCL (Figure 12). Most of these wells are on the western outcrop. Two Hosston wells exceed the SCL for chloride.

Groundwater from the Antlers Formation had chloride concentrations ranging from 26 to 501 mg/l and averaging 146 mg/l. Two samples out of three exceed the chloride SCL. Two samples collected from wells completed in the Glen Rose Formation had chloride concentrations of 20 and 210 mg/l. Paluxy Formation groundwater chloride concentrations range from 5 to 399 mg/l and average 61 mg/l. One Paluxy Formation groundwater sample exceeded the chloride SCL. Woodbine aquifer chloride concentrations range from 15 to 289 mg/l and average 76 mg/l.

Nitrate concentrations in groundwater from the Twin Mountains, Travis Peak, Hosston and Hensell Formations samples range from 0 to 233 mg/l and average 8 mg/l. Nine samples exceed the MCL for nitrate (Figure 13).

Nitrate concentrations in groundwater samples from the Antlers Formation range from 2 to 102 mg/l and average 24 mg/l. Two out of 23 groundwater samples exceeded the nitrate MCL. Groundwater nitrate concentrations from the Paluxy Formation range from 0 to 127 mg/l with an average concentration of 15 mg/l. Two out of 17 samples exceeded the nitrate MCL (Figure 13).

Almost all of the Trinity aquifer wells exceeding the MCL for nitrate are located on the outcrop area (Figure 13). Groundwater from Glen Rose Formation and Woodbine aquifer showed nitrate concentrations of less than 1 mg/l.

Sulfate concentrations in groundwater from for the Twin Mountains, Travis Peak, Hosston, and Hensell Formations range from 12 to 1,478 mg/l and average 114 mg/l. Nine out of 197 samples exceed the sulfate SCL of 300 mg/l (Figure 14)(TAC, 1999, §290). The highest concentration occurs in Hill County (well 32-53-902) indicating possible interconnection with the gypsum-rich Glen Rose Formation (Baker and others, 1990, p.30, 41)

Only one of the two groundwater samples for the Glen Rose Formation had sulfate concentrations exceeding 300 mg/l (Figure 14). Groundwater samples from the Paluxy Formation had sulfate concentrations from 18 to 729 mg/l and average 136 mg/l. One out of 17 groundwater samples for the Paluxy Formation exceeded the sulfate SCL.

Antlers Formation groundwater samples range from 21 to 219 mg/l sulfate and average 70 mg/l. None of the 23 Antlers Formation samples had sulfate concentrations exceeding the SCL.

Samples from the Woodbine aquifer had sulfate values ranging from 61 to 618 mg/l and averaging 240 mg/l. Two samples from the Woodbine aquifer (in Hill County) exceeded the sulfate SCL.

Nordstrom (1987, p.111 and 113) delineated areas of oil-field contamination occurring in Eastland and Comanche Counties. This contamination was the result of open-pit brine disposal that occurred prior to the issuance of a "no-pit" order from the Texas Railroad Commission in January 1969. These areas were delineated based on eight samples taken between 1959 and 1973. Recent water-quality samples in this area show TDS for the Antlers and Twin Mountains Formations ranging between 171 mg/l to 1,907 mg/l. The upper end of the range is in the same area as the contamination as reported by Nordstrom (1987). Chloride concentrations in the outcrop area where oil-field brine was disposed are higher than in surrounding areas. High nitrate values in the western outcrop area (Figure 13) can be attributed to livestock waste, fertilizers, and old cesspools or septic systems (Benyon, 1991, p.31).

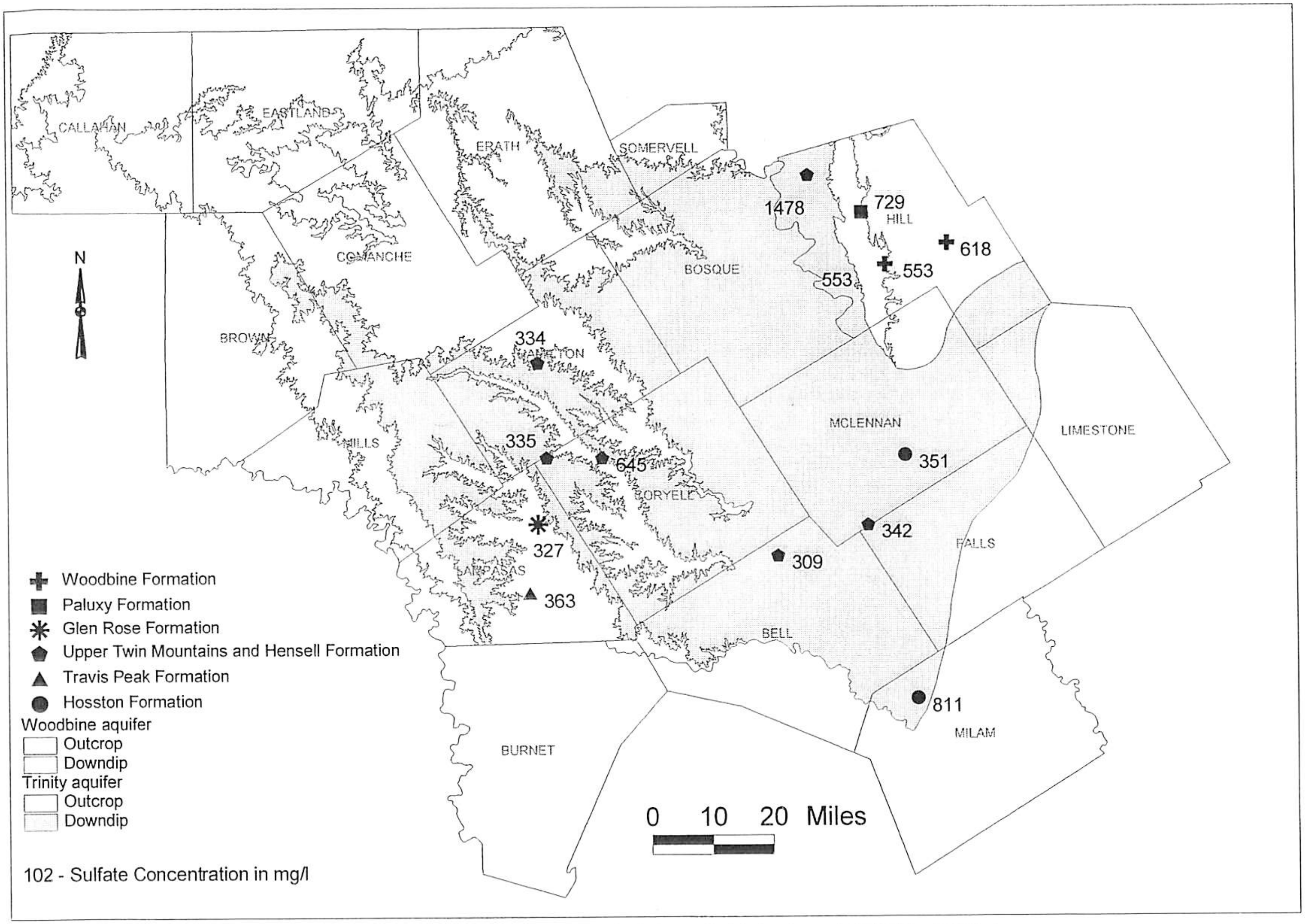

Figure 14. Sulfate concentrations exceeding the SCL of 300 mg/l (data from TWDB, 1998a).

WATER DEMANDS

Population

Population estimates by the TWDB are divided into two categories: major city and county-other. Cities that are county seats or have a population of at least 1,000 people are classified as major cities. Other cities and the rural county population are normally compiled or aggregated on a county basis and are classified as county-other. Table 2 breaks out the population for some smaller communities that had previously been classified as county-other in the 1997 Water Plan (TWDB, 1997). Table 2 shows the population for years 1985, 1990, and 1995 and the projected population for years 2000, 2010, 2020, and 2030 for the study area.

The population summary for Report 319 calculated the area of partial enumeration districts or census tracts around the boundaries of the study area (Baker and others, 1990, p.47). Determination of population for this study within the study area was facilitated using of the 1990 census block and tract data that was manipulated with ArcInfo® Geographic Information System (GIS) software. This program was used to calculate the area and population percentages for each partial census block or tract included within the study area.

The population of the study area increased approximately 16 percent between 1985 and 1995 (Table 2) (TWDB, 1998b) and is projected to increase by 35 percent between 1995 and 2030. The highest projected growth for a major city within the study area is Hewitt, with a 62 percent increase between 1995 to 2030. The highest projected growth for a county within the study area is predicted to occur in Coryell County, with a 38 percent increase between 1995 and 2030. Callahan, Comanche, Eastland, and Hamilton Counties have population decline estimates that range from 0 to 31 percent between 1995 and 2030. All other counties have projected population increases ranging from 6 to 38 percent between 1995 and 2030. Altogether, the study area population is projected to increase by approximately 218,000 people between 1995 and 2030 (Table 2)(TWDB, 1998b).

Water Uses

Estimated groundwater pumpage, surface-water use, and groundwater use are valuable indicators of historical trends. A distinction is made between the estimated pumpage from a county and the estimated water use within the county. Pumpage is groundwater produced from a county but not necessarily used in that county.

	1985	1990	1995	2000	2010	2020	2030
Bell County							
Belton	12,537	12,476	13,382	16,517	18,149	19,917	21,219
Fort Hood	18,036	17,021	18,107	17,021	17,021	17,021	17,021
Harker Heights	8,554	12,841	15,270	15,857	19,709	23,612	25,224
Killeen	58,344	63,535	78,616	84,753	100,541	116,767	124,751
Little River	1,150	1,390	1,599	1,618	1,811	2,024	2,162
Morgans Point	1,285	1,766	2,239	2,320	2,881	3,450	3,917
Nolanville	1,830	1,834	2,350	2,460	2,865	3,285	3,463
Rogers	1,426	1,131	1,165	1,235	1,356	1,487	1,583
Temple	46,413	46,109	49,489	55,062	56,996	59,513	60,836
Troy	1,661	1,395	1,670	1,606	1,729	1,933	2,065
County Other	15,391	23,317	23,874	24,445	22,711	21,424	25,025
Total	166,627	182,815	207,761	222,894	245,769	270,433	287,266
Bosque County							
Clifton	3,201	3,195	3,577	3,443	3,667	4,102	4,507
Meridian	1,360	1,390	1,437	1,504	1,603	1,791	1,966
Valley Mills(P)	1,363	1,085	1,134	1,090	1,107	1,118	1,149
Walnut Springs	NA	716	759	804	819	819	819
County Other	8,277	8,739	9,453	10,228	12,000	13,712	15,452
Total	14,201	15,125	16,360	17,069	19,196	21,542	23,893
Brown County							
Early	1,483	1,123	1,227	1,222	1,348	1,468	1,552
County Other	1,160	1,920	2,042	1,892	1,929	1,982	2,001
Total	2,643	3,043	3,269	3,114	3,277	3,450	3,553
Callahan County							
Clyde	3,139	3,002	3,298	3,146	3,190	3,284	3,296
Cross Plains	893	807	839	815	786	736	683
County Other	3,590	3,381	3,529	3,270	3,442	3,390	3,297
Total	7,622	7,190	7,666	7,231	7,417	7,410	7,276

Table 2. Historical and projected population for the study area (data from TWDB, 1998b).

	1985	1990	1995	2000	2010	2020	2030
Comanche County							
Comanche	4,139	4,087	4,397	4,107	4,146	4,234	4,346
DeLeon	2,564	2,190	2,305	2,195	2,215	2,263	2,323
County Other	6,045	6,277	6,463	6,084	6,142	6,273	6,440
Total	12,748	12,554	13,165	12,386	12,503	12,770	13,109
Coryell County							
Copperas Cove	20,775	24,079	28,415	29,489	35,517	43,053	50,399
Fort Gates	NA	818	869	923	952	964	976
Fort Hood(P)	13,202	18,559	19,676	18,559	18,559	18,559	18,559
Gatesville	6,935	11,492	11,901	15,638	11,423	30,958	39,289
County Other	16,269	9,265	10,409	9,902	9,388	7,866	6,362
Total	57,181	64,213	71,270	74,511	75,839	101,400	115,585
Eastland County							
Cisco	821	694	756	692	677	666	639
Gorman	1,315	1,290	1,336	1,287	1,259	1,238	1,188
Ranger	415	342	352	342	334	326	312
Rising Star	1,198	859	864	862	837	799	752
County Other	1,660	1,679	1,750	1,557	1,525	1,508	1,453
Total	5,409	4,864	5,058	4,740	4,632	4,537	4,343
Erath County							
Dublin	2,828	3,190	3,559	3,241	3,450	3,517	3,500
Stephenville	12,845	13,502	15,403	14,485	15,384	15,663	15,570
County Other	8,815	10,877	12,379	13,022	15,597	16,788	17,572
Total	24,488	27,569	31,341	30,748	34,431	35,968	36,642
Falls County							
County Other	5,550	5,402	5,522	5,710	5,893	6,182	6,532
Total	5,550	5,402	5,522	5,710	5,893	6,182	6,532

Table 2. Historical and projected population for the study area (data from TWDB, 1998b)(continued).

	1985	1990	1995	2000	2010	2020	2030
Hamilton County							
Hamilton	2,883	2,937	2,960	2,766	2,730	2,710	2,327
Hico	1,402	1,342	1,486	1,312	1,295	1,285	1,104
County Other	3,803	3,454	3,616	3,264	3,222	3,198	2,746
Total	8,088	7,733	8,062	7,342	7,247	7,193	6,177
Hill County							
Hillsboro	7,350	7,072	7,661	7,234	7,479	7,822	8,209
Hubbard	1,820	1,589	1,648	1,604	1,658	1,734	1,820
Itasca	1,693	1,523	1,608	1,545	1,598	1,671	1,754
Whitney	2,035	1,626	1,672	1,673	1,717	1,748	1,803
County Other	14,500	15,336	16,452	15,580	16,120	16,906	17,776
Total	27,398	27,146	29,041	27,636	28,572	29,881	31,362
Lampasas County							
Lampasas	6,789	6,382	7,394	7,647	7,737	7,708	7,628
County Other	6,556	6,961	7,650	8,910	10,316	11,507	12,214
Total	13,345	13,343	15,044	16,557	18,053	19,215	19,842
Limestone County							
County Other	438	562	569	591	627	651	679
Total	438	562	569	591	627	651	679
McLennan County							
Bellmead	8,162	8,336	8,406	10,047	10,867	11,006	11,592
Beverly Hills	2,365	2,048	2,128	2,387	2,676	2,852	3,031
Bruceville-Eddy	1,137	1,074	1,247	1,159	1,230	1,239	1,279
Crawford	NA	631	648	667	653	632	532
Gholson	NA	692	697	703	667	643	618
Hewitt	8,097	8,983	10,555	15,060	20,713	26,099	27,977
Lacy-Lakeview	2,922	3,617	4,383	4,330	4,950	5,379	5,770
Lorena	NA	1,158	1,479	1,889	2,612	3,304	3,787

Table 2. Historical and projected population for the study area (data from TWDB, 1998b)(continued).

	1985	1990	1995	2000	2010	2020	2030
McLennan County (continued)							
Mart	2,480	2,004	2,015	2,323	2,592	2,751	2,917
McGregor	4,751	4,683	4,804	5,228	5,670	5,845	6,106
Moody	1,522	1,329	1,364	1,396	1,457	1,976	2,048
Northcrest	2,086	1,725	1,875	1,802	1,880	1,892	1,904
Riesel	NA	839	882	724	709	667	657
Robison	6,491	7,111	8,045	8,183	9,086	9,595	10,149
Valley Mills(P)	10	10	10	12	12	11	11
Waco	104,808	103,590	108,191	119,455	135,407	143,723	161,819
West	2,552	2,515	2,800	2,611	2,659	2,612	2,565
Woodway	7,704	8,695	9,212	11,313	13,161	14,335	15,397
County Other	29,008	30,083	31,925	29,748	27,416	24,820	16,882
Total	184,095	189,123	200,666	219,037	244,417	259,381	275,041
Milam County							
County Other	935	831	854	871	907	940	974
Total	935	831	854	871	907	940	974
Mills County							
Goldthwaite	1,874	1,658	1,846	1,783	1,823	1,869	1,908
County Other	2,120	2,136	2,230	2,224	2,279	2,364	2,413
Total	3,994	3,794	4,076	4,007	4,102	4,233	4,321
Somervell County							
Glen Rose	2,250	1,949	2,142	2,173	2,377	2,520	2,545
County Other	2,395	3,411	3,455	3,676	4,021	4,264	4,307
Total	4,645	5,360	5,597	5,849	6,398	6,784	6,852
Area Total	539,407	570,667	625,320	660,293	719,279	791,969	843,447

Table 2. Historical and projected population for the study area (data from TWDB, 1998b)(continued).

(P) – Indicates city is partially included within the study area

1. *1990 data are based upon Bureau of Census statistics, while 1985 and 1995 data are estimates based upon county demographic data and Bureau of Census statistics for 1980 and 1990, respectively.*
2. *2000, 2010, 2020 and 2030 figures are based upon projections used in "Water for Texas, A Consensus-Based Update to the State Water Plan, Volume II, Technical Planning Appendix." (TWDB, 1997).*
3. *Population estimates are for the area of each county or city that falls within the study area delineated on Figure 1.*

Water use refers strictly to use within the county, while the water source could be located within or outside of the area. Generally, pumpage numbers will differ from water use numbers.

Estimated pumpage amounts for all aquifers in the study area for 1985, 1990 and 1995 (TWDB, 1998c) are listed in Table 3. Total estimated groundwater pumpage for the study area increased by roughly 7880 acre-feet (9 percent) between 1985 and 1995. Of all groundwater pumped in the study area for 1995, about 94 percent was produced from the Trinity aquifer.

	Aquifer	Brazos River Alluvium[1]	Trinity[2]	Woodbine	Total
Year	Use	Ac-Ft	Ac-Ft	Ac-Ft	Ac-Ft
1985	Municipal	117	27,371	45	27,533
	Manufacturing	0	2,957	0	2,957
	Power	0	378	0	378
	Mining	61	1,383	72	1,516
	Irrigation	4,269	43,787	0	48,056
	Livestock	129	4,593	117	4,839
	Total	4,576	80,469	234	85,279
1990	Municipal	113	25,332	41	25,486
	Manufacturing	0	1,943	0	1,943
	Power	0	261	0	261
	Mining	55	991	0	1046
	Irrigation	5,627	44,296	0	49,923
	Livestock	104	6,039	128	6,271
	Total	5,899	78,862	169	84,930
1995	Municipal	3	25,758	23	25,784
	Manufacturing	0	1,512	0	1,512
	Power	0	185	0	185
	Mining	133	1,315	118	1,566
	Irrigation	5,293	49,654	0	54,947
	Livestock	105	8,917	143	9,165
	Total	5,534	87,341	284	93,159

1. Pumpage values for the Brazos River alluvium are for whole counties.
2. All of the pumpage from Bell County is included, because historical pumpage information is not readily available for partial areas within a county. However, all pumpage from Bell County comprises less than 2 percent of the total amount pumped for all years listed.

Table 3. Historical Trinity aquifer pumpage (data from TWDB, 1998c).

The primary increases in Trinity aquifer pumpage over time are associated with irrigation and livestock uses. Irrigation pumpage from the Trinity aquifer increased 5,867 acre-feet (21 percent), and livestock increased by 4,324 acre-feet (94 percent). Municipal use declined about 1,613 acre-feet (6 percent) between 1985 and 1995, and increased by approximately 426 acre-feet (2 percent) between 1990 and 1995. Manufacturing use shows a decline of about 1,445 acre-feet (49 percent) between 1985 and 1995.

A comparison of estimated supply and historical pumpage for eight counties between 1985 and 1997 is shown in Table 4. The supply numbers listed are from the 1997 Water Plan Allocation Files (TDWR, 1990; TWDB, 1997; TWDB, 1998d). These supplies were originally based upon the annual effective recharge estimates and groundwater depletion estimates as described in Muller and Price (1979).

The counties listed are the easternmost counties in the study area, which coincide with the area of greatest groundwater declines (Figures 5, 6, 9, and 10). Bell, Hill, and Limestone Counties historical pumpage (Table 4) does not exceed the estimated supply. Coryell County shows an increasing trend of groundwater use being less than the estimated available supply (Table 4).

In Bosque, Falls, McLennan, and Somervell Counties between 1985 and 1997, historical pumpage is greater than estimated supply. McLennan County shows a continuous supply deficit ranging between 8,918 acre-feet in 1989 up to 11,297 acre-feet in 1994. In 1997, McLennan County had a supply deficit of 11,280 acre-feet. Bosque County shows a supply deficit ranging between 708 acre-feet in 1989 up to 1,838 acre-feet in 1991. In 1997, Bosque County had a supply deficit of 1,318 acre-feet. Falls County shows a supply deficit ranging between 205 acre-feet in 1986 up to 362 acre-feet in 1990. In 1997, Falls County had a supply deficit of 261 acre-feet. Somervell County shows a supply deficit ranging between 713 acre-feet in 1989 up to 1,192 acre-feet in 1997.

Approximately 233,228 acre-feet of water were used within the study area in 1995 (Table 5). This is an increase of 13 percent over the 1985 total usage of approximately 206,177 acre-feet. Groundwater accounted for approximately 36 percent of the water used within the study area in 1995. Groundwater usage increased by approximately 5,581 acre-feet (or 7 percent) between 1985 and 1995.

In 1995, 25,015 acre-feet of groundwater produced from the Trinity aquifer was used for municipal purposes. The City of Woodway, in McLennan County, was the largest user of groundwater for municipal use within the study area for this year (Table 5). Woodway pumped approximately 2,237 acre-feet of groundwater, which is roughly 9 percent of the total amount of groundwater used from the Trinity aquifer for municipal supply in 1995.

County		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Bell	Estimated Supply	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318
	Pumpage	1,020	1,068	882	899	914	1,353	885	1,309	1,468	1,394	1,448	1,524	2,061
	Difference	2,298	2,250	2,436	2,419	2,404	1,965	2,433	2,009	1,850	1,924	1,870	1,794	1,257
Bosque	Estimated Supply	2,636	2,636	2,636	2,636	2,636	2,636	2,636	2,636	2,636	2,636	2,636	2,636	2,636
	Pumpage	3,475	3,537	3,435	3,580	3,344	3,751	4,474	3,585	3,688	3,861	3,692	4,218	3,954
	Difference	-839	-901	-799	-944	-708	-1,115	-1,838	-949	-1,052	-1,225	-1,056	-1,582	-1,318
Coryell	Estimated Supply	2,750	2,750	2,750	2,750	2,750	2,750	2,750	2,750	2,750	2,750	2,750	2,750	2,750
	Pumpage	4,264	4,177	4,138	2,649	1,493	1,236	1,103	1,013	1,075	1,018	972	1,166	875
	Difference	-1,514	-1,427	-1,388	101	1,257	1,514	1,647	1,737	1,675	1,732	1,778	1,584	1,875
Falls	Estimated Supply	344	344	344	344	344	344	344	344	344	344	344	344	344
	Pumpage	639	549	632	640	692	706	774	605	603	609	589	653	605
	Difference	-295	-205	-288	-296	-348	-362	-430	-261	-259	-265	-245	-309	-261
Hill	Estimated Supply	3,556	3,556	3,556	3,556	3,556	3,556	3,556	3,556	3,556	3,556	3,556	3,556	3,556
	Pumpage	2,313	2,326	2,328	2,405	2,313	2,272	2,227	2,094	2,309	2,307	2,302	2,487	2,485
	Difference	1,243	1,230	1,228	1,151	1,243	1,284	1,329	1,462	1,247	1,249	1,254	1,069	1,071
Limestone	Estimated Supply	124	124	124	124	124	124	124	124	124	124	124	124	124
	Pumpage	51	54	51	51	43	49	40	84	58	13	12	12	11
	Difference	73	70	73	73	81	75	84	40	66	111	112	112	113
McLennan	Estimated Supply	2,096	2,096	2,096	2,096	2,096	2,096	2,096	2,096	2,096	2,096	2,096	2,096	2,096
	Pumpage	12,455	12,056	11,539	12,146	11,014	12,054	11,140	12,189	12,946	13,393	12,856	13,094	13,376
	Difference	-10,359	-9,960	-9,443	-10,050	-8,918	-9,958	-9,044	-10,093	-10,850	-11,297	-10,760	-10,998	-11,280
Somervell	Estimated Supply	584	584	584	584	584	584	584	584	584	584	584	584	584
	Pumpage	1,468	1,387	1,370	1,395	1,322	1,297	1,319	1,504	1,506	1,484	1,335	1,697	1,776
	Difference	-884	-803	-786	-811	-738	-713	-735	-920	-922	-900	-751	-1,113	-1,192
Total	Estimated Supply	15,408	15,408	15,408	15,408	15,408	15,408	15,408	15,408	15,408	15,408	15,408	15,408	15,408
	Pumpage	25,685	25,154	24,375	23,765	21,135	22,718	21,962	22,383	23,653	24,079	23,206	24,851	25,143
	Difference	-10,277	-9,746	-8,967	-8,357	-5,727	-7,310	-6,554	-6,975	-8,245	-8,671	-7,798	-9,443	-9,735

Estimated supply for each county is the supply available from the 1997 State Water Plan allocation files (TDWR, 1990;TWDB, 1997; TWDB, 1998d) and pumpage is from the TWDB water use survey database (TWDB, 1998c). All of the estimated supply and pumpage from the Trinity aquifer in Bell County is included.

Table 4. Estimated supply and pumpage from the Trinity aquifer in the eastern portion of the study area.

	1985		1990		1995	
	Ground	Surface	Ground	Surface	Ground	Surface
Bell County						
Belton	0	1,881	0	2,194	0	2,019
Fort Hood (P)	201	4,201	0	3,227	0	3,142
Harker Heights	0	1,797	0	1,985	0	2,276
Killeen	0	7,912	0	7,953	0	9,376
Little River	149	57	146	76	138	78
Morgans Point	0	221	0	264	0	275
Nolanville	0	206	0	233	0	260
Rogers	0	155	0	203	0	158
Temple	1	9,395	9	10,483	13	10,735
Troy	36	91	5	162	74	150
County Other	442	2,523	729	3,772	986	3,623
Total Municipal Use	829	28,439	889	30,552	1,211	32,092
Other Water Use						
Manufacturing	245	589	388	607	365	959
Irrigation	34	533	152	393	247	503
Steam-Electric	0	0	0	0	0	0
Mining	83	0	0	0	103	0
Livestock	70	633	70	629	73	653
County Total	1,261	30,194	1,499	32,181	1,999	34,207
Bosque County						
Clifton	490	0	495	0	474	0
Meridian	242	0	233	0	206	0
Valley Mills(P)	190	0	162	0	169	0
County Other	1,053	0	1,323	1	1,228	3
Total Municipal Use	1,975	0	2,213	1	2,077	3
Other Water Use						
Manufacturing	601	0	766	0	683	0
Irrigation	229	1,411	159	975	0	1,726
Steam-Electric	0	0	0	0	0	0
Mining	72	0	61	0	276	0
Livestock	592	592	614	614	677	677
County Total	3,469	2,003	3,813	1,590	3,713	2,406

P – City is partially within the study area or is split between counties.

Table 5. Historical water use for the study area (data from TWDB, 1998c).

	1985		1990		1995	
	Ground	Surface	Ground	Surface	Ground	Surface
Brown County						
Early(P)	0	231	0	204	0	219
County Other	4	186	32	270	13	291
Total Municipal Use	4	417	32	474	13	510
Other Water Use						
Manufacturing	0	0	0	0	0	0
Irrigation	251	2,306	319	993	221	1,345
Steam-Electric	0	0	0	0	0	0
Mining	15	20	16	0	43	636
Livestock	28	250	278	30	45	405
County Total	296	2,993	645	1,497	322	2,896
Callahan County						
Clyde	0	322	0	439	0	468
Cross Plains	251	0	176	0	151	0
County Other	298	112	267	116	311	127
Total Municipal Use	549	434	443	555	462	595
Other Water Use						
Manufacturing	0	0	0	0	0	0
Irrigation	363	156	381	223	472	185
Steam-Electric	0	0	0	0	0	0
Mining	70	0	42	0	25	0
Livestock	19	173	31	281	33	295
County Total	1,001	763	897	1,059	992	1,075
Comanche County						
Comanche	0	609	0	575	0	559
DeLeon	0	333	0	299	0	278
County Other	763	22	768	27	738	29
Total Municipal Use	763	964	768	901	738	866
Other Water Use						
Manufacturing	22	62	2	13	3	14
Irrigation	21,946	21,946	22,490	22,490	27,166	19,672
Steam-Electric	0	0	0	0	0	0
Mining	70	0	66	0	71	0
Livestock	281	1,123	420	1,680	713	2,850
County Total	23,082	24,095	23,746	25,084	28,690	23,402

P – City is partially within the study area or is split between counties.

Table 5. Historical water use for the study area (continued)(data from TWDB, 1998c).

	1985		1990		1995	
	Ground	Surface	Ground	Surface	Ground	Surface
Coryell County						
Copperas Cove	0	2,969	0	2,881	0	3,327
Fort Hood(P)	147	3,075	0	3,519	0	3,475
Gatesville	1,358	0	0	1,715	0	2,462
County Other	1,697	87	465	1,022	136	1,908
Total Municipal Use	3,202	6,131	465	9,137	136	11,172
Other Water Use						
Manufacturing	2	80	0	8	0	3
Irrigation	20	480	13	317	11	351
Steam-Electric	0	0	0	0	0	0
Mining	96	0	86	0	100	0
Livestock	600	600	588	588	719	719
County Total	3,920	7,291	1,152	10,050	966	12,245
Eastland County						
Cisco	0	181	0	91	0	90
Gorman	0	159	0	158	0	137
Ranger	0	91	0	44	0	49
Rising Star	80	0	78	0	92	0
County Other	96	185	13	301	64	210
Total Municipal Use	176	616	91	594	156	486
Other Water Use						
Manufacturing	225	13	1	14	1	26
Irrigation	8,614	2,429	7,630	3,758	8,796	3,421
Steam-Electric	0	0	0	0	0	0
Mining	160	10	112	0	30	1
Livestock	30	270	35	314	44	399
County Total	9,205	3,338	7,868	4,680	9,027	4,333
Erath County						
Dublin	0	313	0	428	0	391
Stephenville	2,390	0	2,397	0	2,105	0
County Other	1,001	75	1,246	94	1,293	80
Total Municipal Use	3,391	388	3,643	522	3,398	471

P – City is partially within the study area or is split between counties.

Table 5. Historical water use for the study area (continued)(data from TWDB, 1998c).

	1985		1990		1995	
	Ground	Surface	Ground	Surface	Ground	Surface
Erath County (continued)						
Other Water Use						
Manufacturing	126	2	84	2	179	13
Irrigation	8,212	1,564	7,376	2,329	7,418	2,216
Steam-Electric	0	0	0	0	0	0
Mining	0	0	0	0	0	0
Livestock	1,243	1,243	2,661	2,661	4,435	4,435
County Total	12,972	3,197	13,764	5,514	15,430	7,135
Falls County						
County Other	425	215	470	232	282	485
Total Municipal Use	425	215	470	232	282	485
Other Water Use						
Manufacturing	0	0	0	0	0	0
Irrigation	403	189	464	155	283	133
Steam-Electric	0	0	0	0	0	0
Mining	29	0	26	0	63	0
Livestock	108	968	84	753	84	755
County Total	965	1,372	1,044	1,140	712	1,373
Hamilton County						
Hamilton	0	459	0	637	0	556
Hico	236	0	241	0	230	0
County Other	452	37	415	56	393	91
Total Municipal Use	688	496	656	693	623	647
Other Water Use						
Manufacturing	9	4	0	0	2	2
Irrigation	605	655	1,228	431	502	590
Steam-Electric	0	0	0	0	0	0
Mining	0	0	0	0	0	0
Livestock	611	611	146	1,322	206	1,850
County Total	1,913	1,766	2,030	2,445	1,333	3,089

P – City is partially within the study area or is split between counties.

Table 5. Historical water use for the study area (continued)(data from TWDB, 1998c).

	1985 Ground	1985 Surface	1990 Ground	1990 Surface	1995 Ground	1995 Surface
Hill County						
Hillsboro	0	1,018	0	1,095	0	1,410
Hubbard	47	165	32	151	55	121
Itasca	247	0	165	0	145	0
Whitney	167	0	196	0	284	0
County Other	1,651	69	1,905	109	1,907	459
Total Municipal Use	2,112	1,252	2,298	1,355	2,391	1,990
Other Water Use						
Manufacturing	199	42	39	23	38	142
Irrigation	217	116	54	229	126	446
Steam-Electric	0	0	0	0	0	0
Mining	72	0	0	0	118	0
Livestock	117	1,062	128	1,160	143	1,290
County Total	2,717	2,472	2,519	2,767	2,816	3,868
Lampasas County						
Lampasas	0	1,360	0	1,280	0	1,262
County Other	551	316	459	531	410	644
Total Municipal Use	551	1,676	459	1,811	410	1,906
Other Water Use						
Manufacturing	0	153	0	106	0	42
Irrigation	0	49	7	6	2	29
Steam-Electric	0	0	0	0	0	0
Mining	32	53	77	0	171	0
Livestock	283	283	293	293	357	357
County Total	866	2,214	836	2,216	940	2,334
Limestone County						
County Other	47	6	55	12	54	18
Total Municipal Use	47	6	55	12	54	18
Other Water Use						
Manufacturing	0	0	0	0	0	0
Irrigation	0	0	0	0	0	0
Steam-Electric	0	0	0	0	0	0
Mining	40	0	0	0	0	97
Livestock	24	219	21	187	20	181
County Total	111	225	76	199	74	296

P – City is partially within the study area or is split between counties.

Table 5. Historical water use for the study area (continued)(data from TWDB, 1998c).

	1985		1990		1995	
	Ground	Surface	Ground	Surface	Ground	Surface
McLennan County						
Bellmead	1,116	0	1,170	0	1,300	0
Beverly Hills	0	503	0	453	0	410
Bruceville-Eddy	61	272	137	379	275	293
Hewitt	1,077	0	1,132	22	1,296	171
Lacy-Lakeview	401	0	334	0	317	4
Lorena	NA	NA	180	0	271	0
Mart	591	0	220	118	296	1
McGregor	343	496	74	830	30	711
Moody	0	183	0	181	7	180
Northcrest	286	0	159	0	370	5
Robinson	828	0	919	0	855	53
Valley Mills(P)	1	0	2	0	0	0
Waco	9	22,279	11	22,920	1	20,828
West	402	0	526	0	387	0
Woodway	1,446	0	1,917	258	2,237	21
County Other	3,552	1,090	3,877	1,393	4,246	1,325
Total Municipal Use	10,113	24,823	10,658	26,554	11,888	24,002
Other Water Use						
Manufacturing	1,771	1,731	819	1,879	657	1,840
Irrigation	1,748	822	737	2,333	983	1,826
Steam-Electric	356	14,983	216	14,150	117	12,875
Mining	0	197	0	0	0	1,735
Livestock	137	1,239	158	1,430	218	1,964
County Total	14,125	43,795	12,588	46,346	13,863	44,242
Milam County						
County Other	102	24	78	26	78	22
Total Municipal Use	102	24	78	26	78	22
Other Water Use						
Manufacturing	0	0	0	0	0	0
Irrigation	43	1,375	71	1,341	619	787
Steam-Electric	0	0	0	0	0	0
Mining	1	0	1	0	1	0
Livestock	62	92	56	83	57	86
County Total	208	1,491	205	1,450	755	895

P – City is partially within the study area or is split between counties.

Table 5. Historical water use for the study area (continued)(data from TWDB, 1998c).

	1985		1990		1995	
	Ground	Surface	Ground	Surface	Ground	Surface
Mills County						
Goldthwaite	140	83	99	663	59	397
County Other	252	2	246	22	289	3
Total Municipal Use	392	85	345	685	348	400
Other Water Use						
Manufacturing	0	0	0	0	0	0
Irrigation	3	165	62	328	7	358
Steam-Electric	0	0	0	0	0	0
Mining	0	0	0	0	0	0
Livestock	226	226	313	313	427	427
County Total	621	476	720	1,326	782	1,185
Somervell County						
Glen Rose	404	0	358	0	306	0
County Other	297	0	413	0	444	0
Total Municipal Use	701	0	771	0	750	0
Other Water Use						
Manufacturing	1	55	0	0	4	0
Irrigation	396	204	158	192	126	357
Steam-Electric	0	0	45	9,800	68	4,035
Mining	291	8	261	69	310	28
Livestock	51	51	64	64	77	77
County Total	1,440	318	1,299	10,125	1,335	4,497
Area Totals						
Municipal	26,020	65,966	24,334	74,104	25,015	75,665
Manufacturing	3,201	2,731	2,099	2,652	1,932	3,041
Irrigation	43,082	34,400	41,301	36,493	46,979	33,945
Steam-Electric	356	14,983	261	23,950	185	16,910
Mining	1,031	288	748	69	1,311	2,497
Livestock	4,479	9,635	5,958	12,404	8,326	17,419
Study Area Total	**78,174**	**128,003**	**74,703**	**149,670**	**83,750**	**149,478**

P – City is partially within the study area or is split between counties.

Table 5. Historical water use for the study area (continued)(data from TWDB, 1998c).

1. *Data are based upon statistics used in "Water for Texas, A Consensus-Based Update to the State Water Plan, Volume II, Technical Planning Appendix." (TWDB, 1997).*
2. *Figures were derived by determining the acre feet of water use for each category for the portion of each county that falls within the study area, then proportioning that amount into surface and groundwater use based upon county-wide percentages.*

Other significant users in 1995 include Stephenville (2,105 acre-feet), Bellmead (1,300 acre-feet), and Hewitt (1,296 acre-feet) (Table 5). Municipal groundwater usage for the study area declined by 1,005 acre-feet (4 percent) between 1985 and 1990, and increased by 681 acre-feet (3 percent) between 1990 and 1995.

Based on 1985, 1990, and 1995 usage data, only the City of Gatesville and the rural parts of Coryell County show a significant switch in usage from groundwater to surface water (TWDB, 1998c).

Irrigation is the largest use for groundwater in the study area. In 1995, approximately 46,979 acre-feet of groundwater were used for irrigation. This is approximately 56 percent of all groundwater used within the study area. Irrigation occurs primarily in Comanche, Eastland, and Erath Counties. In 1995, these three counties used about 43,380 acre-feet for irrigation, which is approximately 52 percent of the total groundwater used within the study area. Comanche County alone used 27,166 acre-feet in 1995, which for the study area represents about 58 percent of the irrigation use and roughly 32 percent of total groundwater use.

The amount of groundwater used within the study area for livestock purposes in 1995 was 8,326 acre-feet. This is an increase of 3,847 acre-feet (86 percent) since 1985, and represents about 10 percent of the total groundwater usage for the study area. Industrial usage (manufacturing, power generation, and mining) amounted to 3,428 acre-feet in 1995. This represents about 4 percent of the groundwater used within the study area.

Projected Water Demands

Water demands refer the amount of water a city and county require for a range of uses including municipal, manufacturing, power, mining, irrigation, and livestock. These demands are projected into the future based on estimates of population growth and historical use in order to plan for future needs.

Municipal use is divided into major city (cities that are a county seat or have a population over 1,000) and county other (cities with a population of less than 1,000 and which are not county seats, as well as rural municipal type use). Categories that are included in non-municipal use (Table 6) are manufacturing, steam-electric generation, mining, irrigation, and livestock. The results shown in Table 6 are TWDB estimates, which were used to develop the 1997 State Water Plan (TWDB, 1998c; TWDB, 1997).

Under projected conditions, the total annual water requirements for the study area are expected to increase by approximately 9 percent between the year 2000 and 2030. In 2030, the projected water demands are estimated to be 290,901 acre-feet per year (Table 6). Of the 2030 water demands, 6 percent are expected to be met with Trinity aquifer groundwater.

	Source	Aquifer	2000	2010	2020	2030
			Acre-feet per year			
Municipal Demands						
Major Cities						
	Ground	Trinity	6,739	3,542	2,989	3,055
	Surface		91,951	101,251	106,397	112,726
	Subtotal		98,690	104,793	109,386	115,781
County Other						
	Ground	Trinity	9,981	9,395	8,838	7,916
		Woodbine	343	343	343	343
		Brazos River Alluvium	167	335	335	335
	Surface		12,019	11,102	10,103	10,614
	Subtotal		22,510	21,175	19,619	19,208
	Total		121,200	125,968	129,005	134,989
Other Demands						
	Ground	Trinity	6,970	7,752	8,488	7,517
		Woodbine	4	4	4	4
		Brazos River Alluvium	3,201	2,969	2,948	2,825
	Surface		135,652	140,095	139,393	145,566
	Subtotal		148,534	153,565	153,625	158,743
Study Area						
	Ground	Trinity	23,690	20,689	20,315	18,488
		Woodbine aquifer	347	347	347	347
		Brazos River Alluvium	3,368	3,304	3,283	3,160
	Subtotal		27,405	24,340	23,945	21,995
	Surface		239,622	252,448	255,893	268,906
	Total		267,027	276,788	279,838	290,901

Table 6. Projected water demands by source for the study area (data from TWDB, 1998d).

1. *Data are based upon statistics used in "Water for Texas, A Consensus-based update to the State Water Plan , Volume II, Technical Planning Appendix." (TWDB, 1997).*
2. *Major cities are defined as those with populations exceeding 1,000 or are county seats.*

All major city groundwater use is projected to come from the Trinity aquifer. Major city groundwater use is projected to decrease by 3,684 acre feet per year (or 55 percent) from 2000 to 2030 (Table 6)(TWDB, 1998d). By the year 2030, major city groundwater use is projected to be approximately 3,055 acre-feet per year. Surface water use for major cities is projected to increase by 20,775 acre-feet (or 23 percent) between 2000 and 2030.

County other Trinity aquifer groundwater use is projected to decline by 2,065 acre-feet (or 21 percent) between 2000 and 2030 (Table 6). County other surface water use is projected to decline 1,405 acre-feet (or 12 percent) between 2000 and 2030 (Table 6).

All other uses of groundwater within the study are projected to increase by roughly 171 acre-feet (2 percent) between 2000 and 2030. Projected groundwater demands in the Trinity aquifer show a peak of 8,488 acre-feet in 2020 but then falls off to 7,517 acre-feet by 2030. Surface water is estimated to increase by 9,914 acre-feet (7 percent) between 2000 and 2030.

WATER AVAILABILITY

Water availability refers to the amount of water available to meet demands of a city and county. Available water supplies are sourced from groundwater and surface water.

Groundwater Availability

The annual recoverable volume of usable water from the Trinity aquifer was approximately 202,000 acre-feet within the study area in 1980 (Baker and others, 1990, p.54). Estimated effective annual recharge to the study area is approximately 26,000 acre-feet (Baker and others, 1990, p.54; Rapp, 1988, p.30). Groundwater pumpage from the Trinity aquifer within the study area in 1995 was approximately 87,341 acre-feet (TWDB, 1998b). Therefore, the annual withdrawal by pumpage exceeds the replenished quantity by 336 percent, and resulted in water-level declines in the artesian portion of the aquifer (Figures 5 and 6; Table 1). McClennan County experiences the greatest groundwater declines and largest difference between estimated supply and annual pumpage (Table 3).

Recharge into the aquifer may be locally increased by return flow from irrigation, particularly in counties located in the outcrop zone (Comanche, Eastland, and Erath) where significant irrigation occurs. Currently, no estimates are available for how much water may be entering the aquifer as return flow from irrigation.

Continued overdraft of the Trinity aquifer will result in continued water-level declines in the confined portions of the aquifer. However, in the unconfined areas of the aquifer, where estimated recharge exceeds pumpage, water levels have remained relatively stable (Figures 5; Table 1).

Surface-Water Availability

Currently, there are seven major water supply reservoirs within the study area with storage capacities greater than 5,000 acre-feet. An additional reservoir that lies partially outside of the study area is Navarro Mills Lake. The firm yield of this reservoir is 23,100 acre-feet. All of these reservoirs have total combined firm yield of 340,876 acre-feet (TWDB, 1997, p.3-138, p.3-150). In addition, three special-purpose reservoirs supply water for power generation. These reservoirs have a total combined supply of 4,500 acre-feet (TWDB, 1998d).

Recommended options for increasing supply sources presented in the 1997 State Water Plan (TWDB, 1997; TWDB, 1998d) are the Paluxy Reservoir project and reallocation of supplies from Lake Whitney. The proposed Paluxy Reservoir would supply 12,000 acre-feet of water to the study area (TWDB, 1997, p.3-150, 3-156). The reallocation of Lake Whitney water rights entails the conversion of hydropower storage to water supply storage. This water could then be used for downstream needs increasing the supply available in Lake Whitney by about 124,700 acre-feet (TWDB, 1997,p.3-150, 3-156).

Lake Grandbury, which is outside of the study area, is projected to supply approximately 27,000 acre-feet per year for power generation in Somervell County by 2030.

Based on current projections the study area will have adequate surface water supplies through 2030. A firm yield of approximately 281,916 acre-feet of surface water will be available in 2030, with about 268,906 acre-feet as the projected demand in 2030 (Table 6)(TWDB, 1998d).

DISCUSSION AND CONCLUSIONS

Significant water-level declines have occurred since 1960 in the eastern part of the study area (Figures 5,6,9 and 10). Regional cones of depression have developed in the Waco metropolitan area in the Trinity aquifer (Figure 9 and 10). Additional water-level declines between 193 and 301 feet are recorded in Bosque County (Figure 5). Groundwater in the Paluxy and Woodbine Formations show variable water-level trends and some of the wells reflect a general response to rainfall over time (Figures 7 and 8).

Water-level declines in the study area are the result of groundwater withdrawals exceeding recharge and inflow to the Trinity aquifer. Recharge to the entire study area is estimated to be 26,000 acre-feet per year (Baker and others, 1990, p.54; Rapp, 1988, p.30). However, in Comanche County alone, over 27,000 acre-feet of groundwater were pumped from the Trinity aquifer in 1995 (TWDB, 1998c).

Groundwater quality is generally good with water quality ranging from fresh (less than 1,000 mg/l TDS) up to slightly saline (1,000 to 3,000 mg/l TDS). Concentrations exceeding the SCL (1,000 mg/l) are found in twelve out of eighteen counties within the study area (Figure 11). TDS and barium concentrations reported in this report may indicate that oil-field contamination still exists on the western outcrop, as reported by Nordstrom (1987) and Baker and others (1990).

Chloride concentrations for the Trinity aquifer exceeded the SCL of 300 mg/l in the western outcrop areas and the southeastern downdip areas (Figure 12). Nitrate concentrations exceed the SCL of 44.3 mg/l (as nitrate) in the western outcrop of the study area (Figure 13).

Sulfate concentrations of the Trinity aquifer exceed the SCL of 300 mg/l in the central and eastern portions of the study area. High sulfate values may indicate an interconnection between the gypsum rich Glen Rose Formation and the formations it overlies (Rapp, 1988, p.29)

Total pumpage from the Trinity aquifer increased by about 6,872 acre feet (or 8.5 percent) between 1985 and 1995, however municipal pumpage dropped approximately 1,613 acre-feet (or 6 percent) during the same time. The major increase in pumpage during this time is from irrigation. Irrigation use between 1985 and 1995 increased 5,867 acre-feet (or 13 percent).

A comparison of estimated supply and historical pumpage (Table 3) shows Bosque, Falls, McLennan, and Somervell Counties have supply deficits between

1985 and 1997. McLennan County alone shows a continuous supply deficit ranging between 8,918 acre-feet in 1989 up to 11,297 acre-feet in 1994. In 1997, McLennan County had a supply deficit of 11,280 acre-feet.

Based on historical water use information, Gatesville and other water users in Coryell County have converted from groundwater to surface water (Table 3), and this has allowed some rebounding of the water levels within this area. Additional conversions from groundwater sources to surface-water sources should impact the Trinity aquifer in a similar way in the groundwater dependent communities in central McLennan County.

With the population and water demands projected to increase through the year 2030 (Tables 1 and 5), it is important that existing and proposed surface water supplies be utilized to meet the projected needs of the area. This is especially important for municipalities overlying the confined portion of the Trinity aquifer, because water levels in this area will likely decline further with continued pumpage for municipal uses.

REFERENCES

Ashworth, J.B., and Hopkins, J., 1995, Aquifers of Texas: Texas Water Development Board Report 345, 69p.

Atchley, S.C., 1983, The nature and origin of the Wichita Paleoplain in north Texas: Bachelor's Thesis Baylor University, Waco, Texas, 97p.

Baker, B., Duffin, G., Flores, R, and Lynch, T., Evaluation of Water Resources in Part of Central Texas: Texas Water Development Board Report 319, 67p.

Bureau of Economic Geology, 1992, Geologic map of Texas: The University of Texas Bureau of Economic Geology, Virgil E. Barnes, Project Supervisor, map.

Driscoll, F.G., 1987, Groundwater and wells, second edition: Johnson Division, St. Paul Minnesota, 1,089p.

Fisher W.L. and Rodda, P.U., 1966, Nomenclature revision of basal Cretaceous rocks between the Colorado and Red Rivers, Texas: University of Texas Bureau of Economic Geology, Report of Investigations No. 58, 20p.

Hydrosphere Data Products, 1998, Climate Data, Volume 9.3, NCDC Summary of the Day – West 2, CD-ROM.

Klemt, W.B., Perkins, R.D., and Alvarez, H.J., 1975, Ground-Water Resources of Part of Central Texas with emphasis on the Antlers and Travis Peak Formations: Texas Water Development Board Report 195, volume 1, 63p.

Muller, D.A and Price, R.D., 1979, Ground-water availability in Texas, Estimates and projections through 2030: Texas Water Development Board Report 238, 77p.

Nordstrom, P.L., 1987, Ground-water resources of the Antlers and Travis Peak Formations in the outcrop area of North-Central Texas: Texas Water Development Board Report 298, 280p.

Nordstrom, P.L., and Beynon, B.E., 1991, A field manual for ground-water sampling (revised): Texas Water Development Board Users Manual 51, 57p.

Rapp, K.B., 1988, Groundwater recharge in the Trinity aquifer, Central Texas: Baylor University, Baylor Geological Studies, bulletin no. 46, Waco, Texas, 47p.

Texas Administrative Code, 1999, Title 30, Chapter 290: Texas Natural Resource Commission.

Texas Department of Water Resources, 1990, Groundwater availability estimates, unpublished data.

Texas Ground Water Protection Committee, 1991, Ground Water Classification System: Texas Ground Water Protection Committee, 4p.

Texas Natural Resource Conservation Commission, 1997, Groundwater Conservation Districts, report to the 75th Legislature: Texas Natural Resource Conservation Commission, Water Planning and Assessment Division, SFR-053, 83p.

TWDB, 1997, Water for Texas, A Consensus-Based Update to the State Water Plan, Volume II, Technical Planning Appendix. GP-6-2, vol. 2: Texas Water Development Board, 345 pp.

TWDB, 1998a, Groundwater database: Texas Water Development Board.

TWDB, 1998b, Current and projected population and consumptive water demand forecasts: Texas Water Development Board, Water Resources Planning Division.

TWDB, 1998c, Water use survey database: Texas Water Development Board.

TWDB, 1998d, MADNESS (MAtching Demands and NEcessary Supplies) water allocation model, Texas Water Development Board, Water Resources Planning Division.