Texas Water Development Board

Open-File Report 98-04

Updated Evaluation of Groundwater Resources in the Vicinity of the Cities of Henderson, Jacksonville, Kilgore, Lufkin, Nacogdoches, Rusk, and Tyler in East Texas

December, 1998

Texas Water Development Board
Open-File Report 98-04

Updated Evaluation of Groundwater Resources in the Vicinity of the Cities of Henderson, Jacksonville, Kilgore, Lufkin, Nacogdoches, Rusk, and Tyler in East Texas

By
Tom Culhane

December, 1998

ABSTRACT

This report is an update to Texas Water Development Board Report 327 (Preston and Moore, 1991), which addressed previously large water-level declines in the Carrizo-Wilcox aquifer within the study area. Decreased reliance upon groundwater during the 1970s and 80s has continued to slow and, in some cases reverse, otherwise declining water level trends. Nonetheless, recent data suggest that certain areas continue to experience water-level declines - particularly in the vicinity of Tyler. Around Tyler, increased groundwater use (at least through 1995) and recent water-level declines (through 1997) appear to correlate well. In other portions of the study area, however, apparent changes in groundwater levels do not directly correspond to patterns of groundwater use. There are numerous explanations for this and these include the inability to directly compare groundwater use and water-level changes due to the differing time periods, limitations on the amount of data available for calculating water-level differences, and the lack of aquifer-specific groundwater extraction data.

In the early 1990s, annual groundwater availability of the Carrizo-Wilcox aquifer was also determined by the Texas Water Development Board through development of a Carrizo-Wilcox digital groundwater flow model (TWDB, 1997). Presently, this model is the most accurate means of determining availability from the aquifer. Simulations indicate that with the exception of one location in Gregg County, all groundwater pumping needs through the year 2050 can be met by regional groundwater development. In general, water-level data indicate that hydraulic heads remain high, with the large volume of water thus far preventing wells from going dry. The artesian nature of the aquifer, coupled with the large distance from areas of recharge, however, has locally resulted in decreased water levels and increasing pumping lifts. Based upon the results of the TWDB's groundwater flow modeling, it appears this latter problem can largely be addressed through improved well spacing.

TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

Purpose

This report is the Texas Water Development Board (TWDB)'s update to Report 327, *Evaluation of Water Resources in the Vicinity of the Cities of Henderson, Jacksonville, Kilgore, Lufkin, Nacogdoches, Rusk, and Tyler in East Texas* by Richard D. Preston and Stephen W. Moore, published in 1991. Report 327 was prepared in response to the 1985 passage of House Bill 2 by the 69th Texas Legislature. This bill called for the identification and study of areas that were experiencing or are anticipated to experience critical groundwater problems within the next 20 years.

The present study is in response to Senate Bill 1, passed in 1997 by the 75th Texas Legislature. This bill requires the identification of those areas of the State that are experiencing or are expected to experience critical 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.

Report 327 addressed the major groundwater declines which have occurred within the study area since World War II. That report concluded that declines had slowed by 1988 and that stabilization might be occurring due to reduced groundwater pumpage by Tyler, Nacogdoches, and industrial users, along with the increased use of surface water. Based upon these changes, it was unclear whether the study area was experiencing or could be expected to experience critical groundwater problems within the following 20 years. Subsequently no groundwater districts were formed and it was recommended that the study area be revisited at some later date. Now, approximately ten years later, more data are available and this update report has been produced. Although other aquifers exist within the study area, this report focuses mainly on the Carrizo-Wilcox aquifer, because major groundwater declines have historically occurred in this aquifer.

Location

The study area is located within the East Texas basin and is characterized by a warm, subhumid climate receiving 43 to 47 inches of rainfall yearly. The area includes portions of Angelina, Cherokee, Gregg, Nacogdoches, Rusk, and Smith Counties, and is located within the Sabine, Neches, and Angelina River basins. Principal cities include Henderson, Jacksonville, Kilgore, Lufkin, Nacogdoches, Rusk, and Tyler. Figure 1 shows the extent of the study area, encompassing a total of about 3,600 square miles.

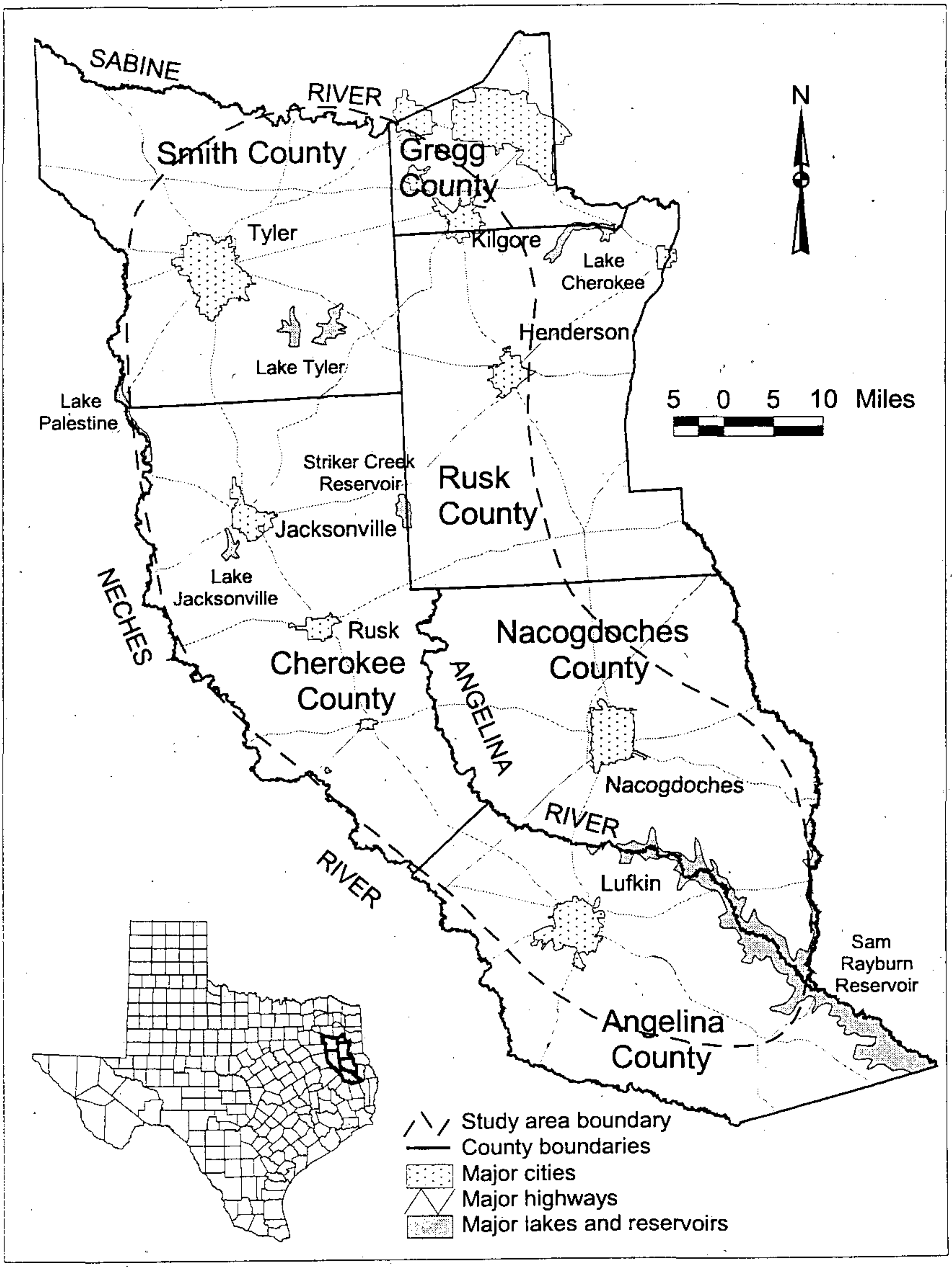


Figure 1. Location of study area

HYDROGEOLOGY

Geology

This update to Report 327 refers readers to that document for a detailed description of the geology of the study area. Information on all major and most minor aquifers in Texas is also discussed in "Water for Texas, A consensus-based update to the State Water Plan, Volume II, Technical Planning Appendix" (TWDB, 1997). The major source of groundwater in the area is the Carrizo-Wilcox aquifer, though significant quantities are also produced from the Queen City and Sparta aquifers (Figures 2, 3 and 4). As mentioned previously, major groundwater declines in the area historically have occurred within the Carrizo-Wilcox aquifer; therefore, this report focuses mainly on that aquifer.

Table 1 presents the geologic units and their water bearing properties for the study area. The Carrizo-Wilcox aquifer is a hydrologically connected system comprised of the Wilcox Group and the overlying Carrizo Formation of the Claiborne Group. This aquifer generally occurs at the surface along a narrow band that parallels the Gulf Coast and dips beneath land surface toward the coast. The exception to the state-wide trend is in the East Texas structural basin, including the study area, where formations form a structural trough related and adjacent to the Sabine Uplift.

The Carrizo-Wilcox aquifer is predominantly composed of sand, locally interbedded with gravel, silt, clay and lignite, deposited during the Tertiary period. The aquifer is unconfined where exposed at the surface, and is confined where not exposed. Due to their similarities, this report will always refer to the Carrizo aquifer and the Wilcox aquifer as a single Carrizo-Wilcox aquifer, unless further discretization is warranted.

Water-Level Fluctuations

As described in Report 327, some water-level declines have occurred in most wells completed in the Carrizo-Wilcox aquifer throughout the study area. Since the 1940s, the confined portion of the aquifer has experienced water-level declines of as much as 500 feet around the Tyler and Lufkin-Nacogdoches areas. Much of the pumpage leading to this has been for municipal supply, though industrial pumpage has also been significant, especially for paper mills northeast of Lufkin. The aquifer northeast of Lufkin occurs at depths in excess of 750 feet, and is also under confined conditions.

All well data referenced below were obtained from the Texas Water Development Board groundwater database (TWDB, 1998a). In order to evaluate water-level fluctuations and potential long-term water-level trends since the completion of Report 327, hydrographs for eleven wells were constructed. Ten of the wells chosen were those referenced in the original TWDB report, and their hydrographs were expanded to

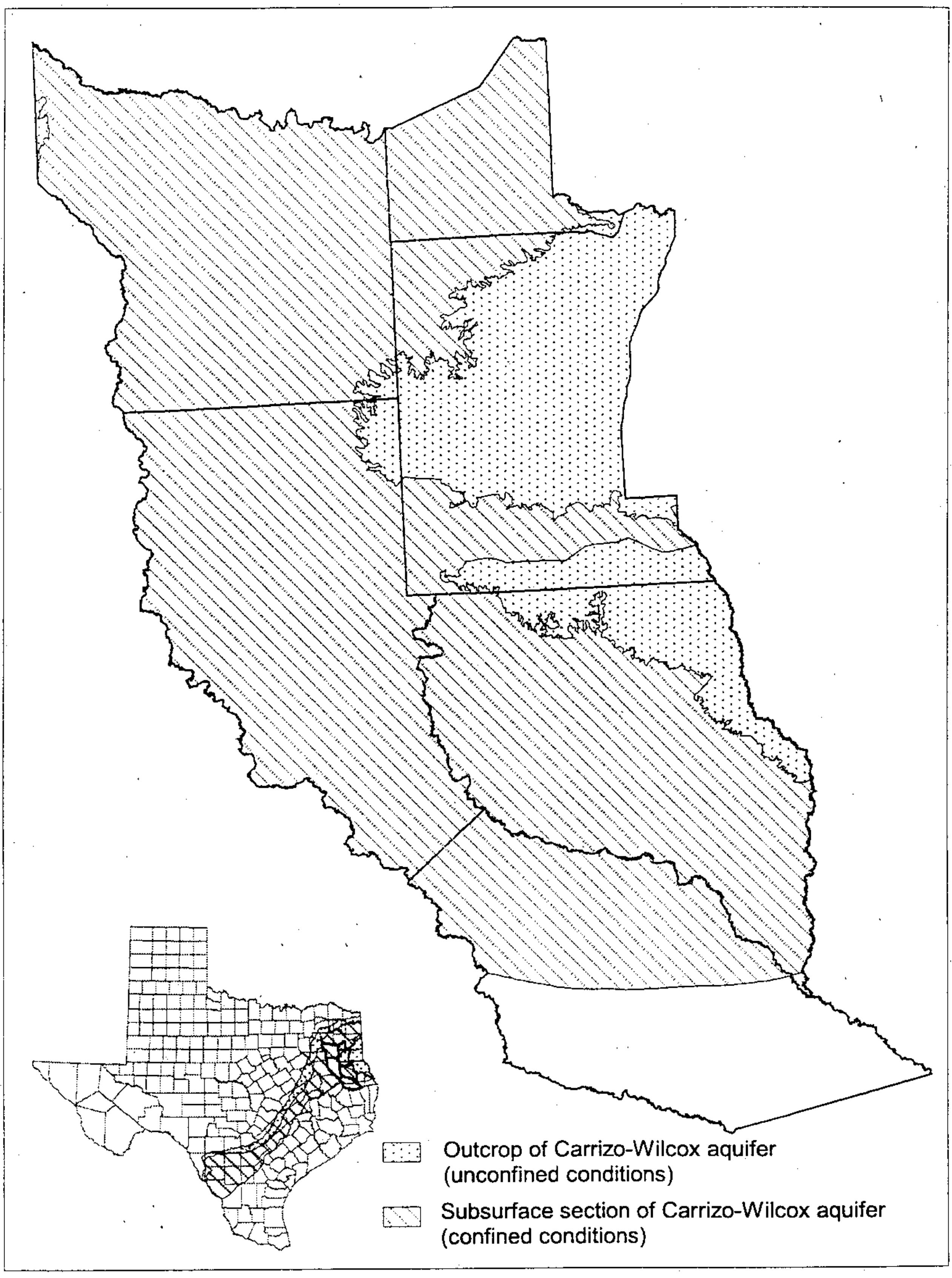


Figure 2. Location of Carrizo-Wilcox aquifer

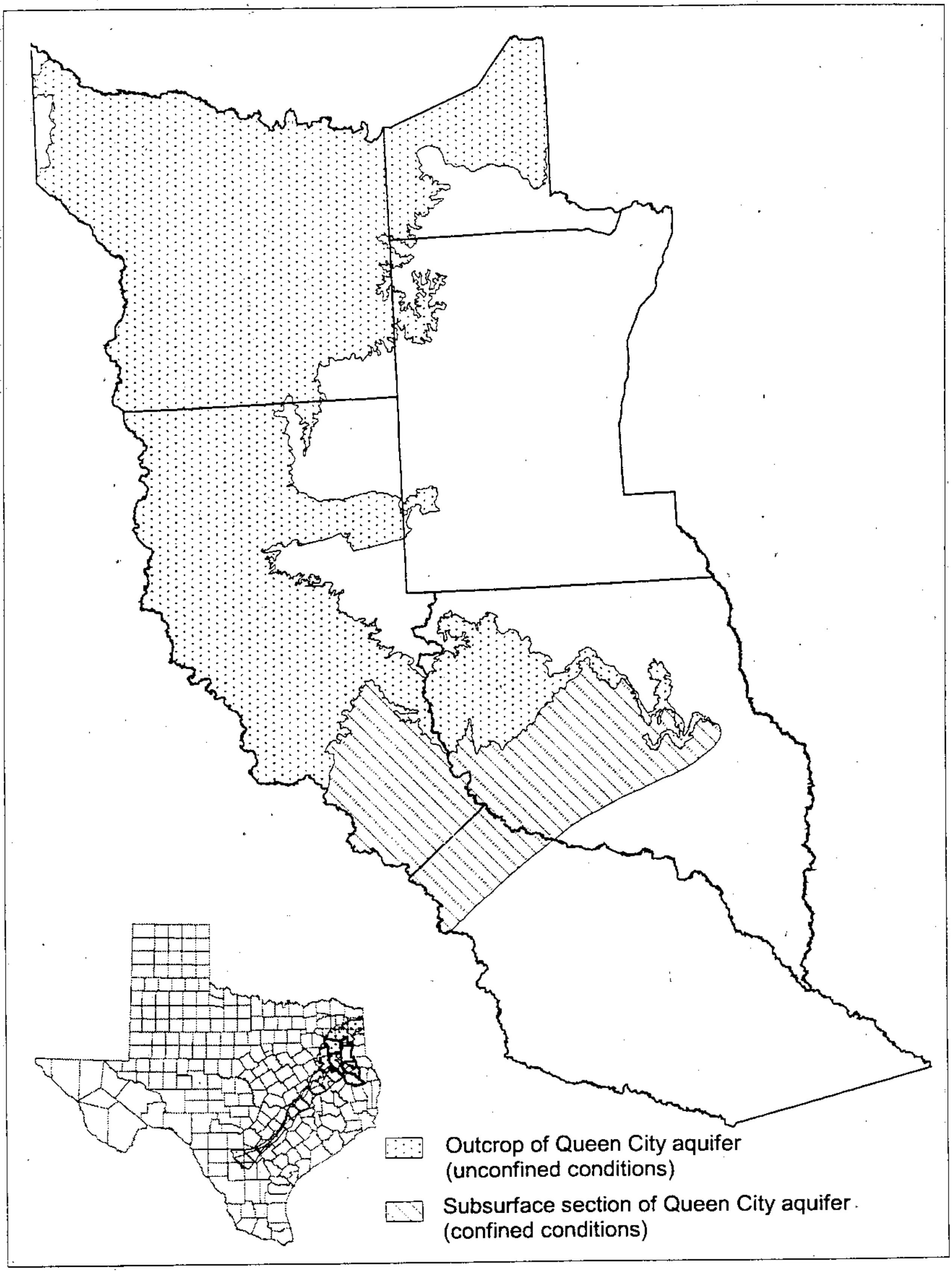


Figure 3. Location of Queen City aquifer

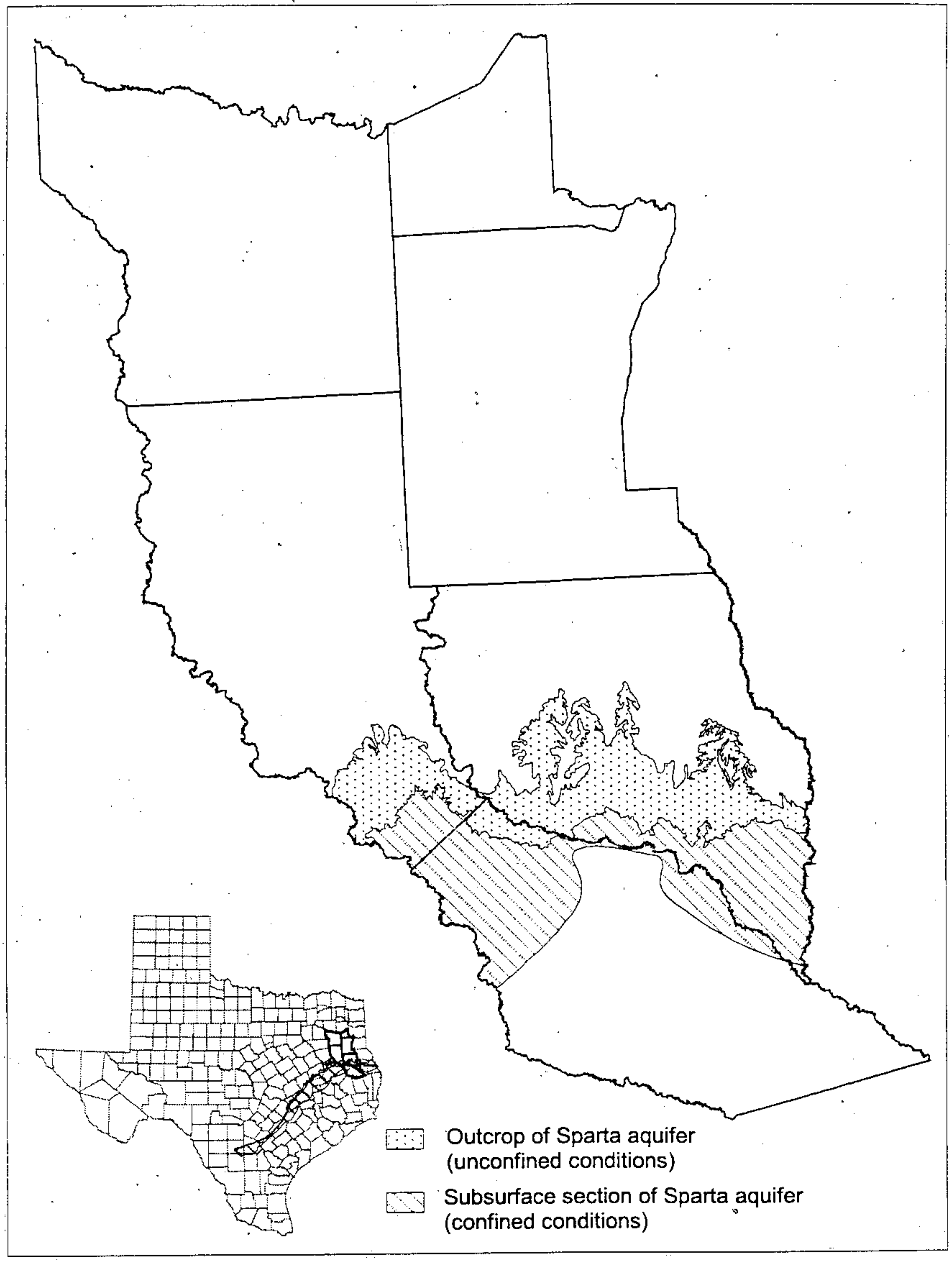


Figure 4. Location of Sparta aquifer

<table>
<tr><th>System</th><th>Series</th><th>Group</th><th colspan="2">Stratigraphic Unit</th><th>Hydrologic Name</th><th>Water-bearing Properties</th></tr>
<tr><td rowspan="9">Tertiary</td><td rowspan="8">Eocene</td><td>Jackson</td><td colspan="2"></td><td rowspan="2"></td><td rowspan="2">May yield small to moderate amounts of useable-quality water in isolated areas on or near the outcrop.</td></tr>
<tr><td></td><td colspan="2">Cook Mountain and Yegua Formations</td></tr>
<tr><td rowspan="5">Claiborne</td><td colspan="2">Sparta Formation</td><td>Sparta Aquifer (minor)</td><td>Yields small to moderate amounts of useable-quality water over much of the study area.</td></tr>
<tr><td rowspan="3">Mount Selman</td><td>Weches Formation</td><td></td><td>May yield small amounts of useable-quality water over much of the study area.</td></tr>
<tr><td>Queen City Formation</td><td>Queen City Aquifer (minor)</td><td>Yields moderate amounts of useable-quality water over much of the study area.</td></tr>
<tr><td>Reklaw Formation</td><td></td><td>May yield small amounts of useable-quality water in isolated areas on the outcrop.</td></tr>
<tr><td colspan="2">Carrizo Formation</td><td rowspan="2">Carrizo-Wilcox Aquifer (major)</td><td rowspan="2">Yields large amounts of useable-quality water throughout the study area.</td></tr>
<tr><td>Wilcox</td><td colspan="2"></td></tr>
<tr><td>Midway</td><td colspan="2"></td><td rowspan="2"></td><td rowspan="2">Not known to yield useable-quality water within the study area.</td></tr>
<tr><td>Cretaceous</td><td></td><td colspan="2"></td></tr>
</table>

Table 1. Geologic units and their water bearing characteristics (after Preston and Moore, 1991).

incorporate water-level measurements collected since 1987. In the case of well 38-24-802, recent data were lacking, so this well was replaced by well 38-23-406, also completed in the Carrizo aquifer. Well 38-07-305, which had been included in Report 327, was dropped due to the lack of reliable recent data. Figure 5 illustrates the locations of the eleven wells chosen for this report, with their completion aquifers and other information listed on individual hydrographs.

Within the Carrizo aquifer, water levels have generally risen in Angelina and Nacogdoches counties over the last ten years, presumably in response to decreased groundwater withdrawals. As shown on Figure 5, starting in the late 1980s wells 37-34-505, 37-36-102 and 37-36-501, north of Lufkin, had their water levels recover between 40 to 70 feet. In the case of well 37-36-501, approximately eight miles northeast of Lufkin, recovery peaked in 1992, followed by a renewed period of water-level decline.

Following publication of Report 327, the largest groundwater decline occurred in well 34-38-805 northwest of Tyler. That well, completed within the Wilcox aquifer, experienced a decline of over 100 feet since 1988. Less dramatic declines occurred in wells completed in both the Carrizo and Wilcox aquifers south of Rusk (38-23-406), east of Jacksonville (38-07-305), northeast of Tyler (34-40-102), and near Henderson (35-30-801), with declines ranging from 10 to 30 feet. The trend in well 35-33-501, west of Kilgore, is unclear, as its water level remained fairly stable until 1997, at which point it dropped nearly 50 feet. Additional data would be needed to verify or disregard this last measurement. Only two wells, 35-34-403 and 37-10-402, maintained stable water levels since publication of Report 327, and these are located north of Kilgore and within northwest Nacogdoches County.

In addition to the hydrographs, potentiometric surface maps for the study area were developed. First, an analysis was conducted to evaluate potential head differences between the Carrizo and Wilcox aquifers. October–December 1997 potentiometric data were used to calculate hydraulic head differences between wells completed in different aquifers. Based upon the large head differences computed (up to 200 feet near Henderson), it was determined that separate potentiometric surface maps would be needed for each aquifer.

For this update, data collected since 1988 (the year of Report 327) were reviewed. The goal was to retrieve data with maximum well coverage for the shortest time interval possible. Based upon this criterion, November 4 through December 14, 1988 and October 1 through November 30, 1997 time periods were chosen for the Carrizo aquifer, and November 8 through December 9, 1988 and October 1 through November 21, 1997 time periods were chosen for the Wilcox aquifer. In some instances, it was necessary to include data from beyond the specified time period or outside the study area in order to produce a better map. Once data were chosen, potentiometric contour maps were prepared for both the 1988 and recent time periods. The latter data are presented for the Carrizo and Wilcox aquifers in Figures 6 and 7, respectively. Readers are referred to Figure 1 for the geographic locations referenced below.

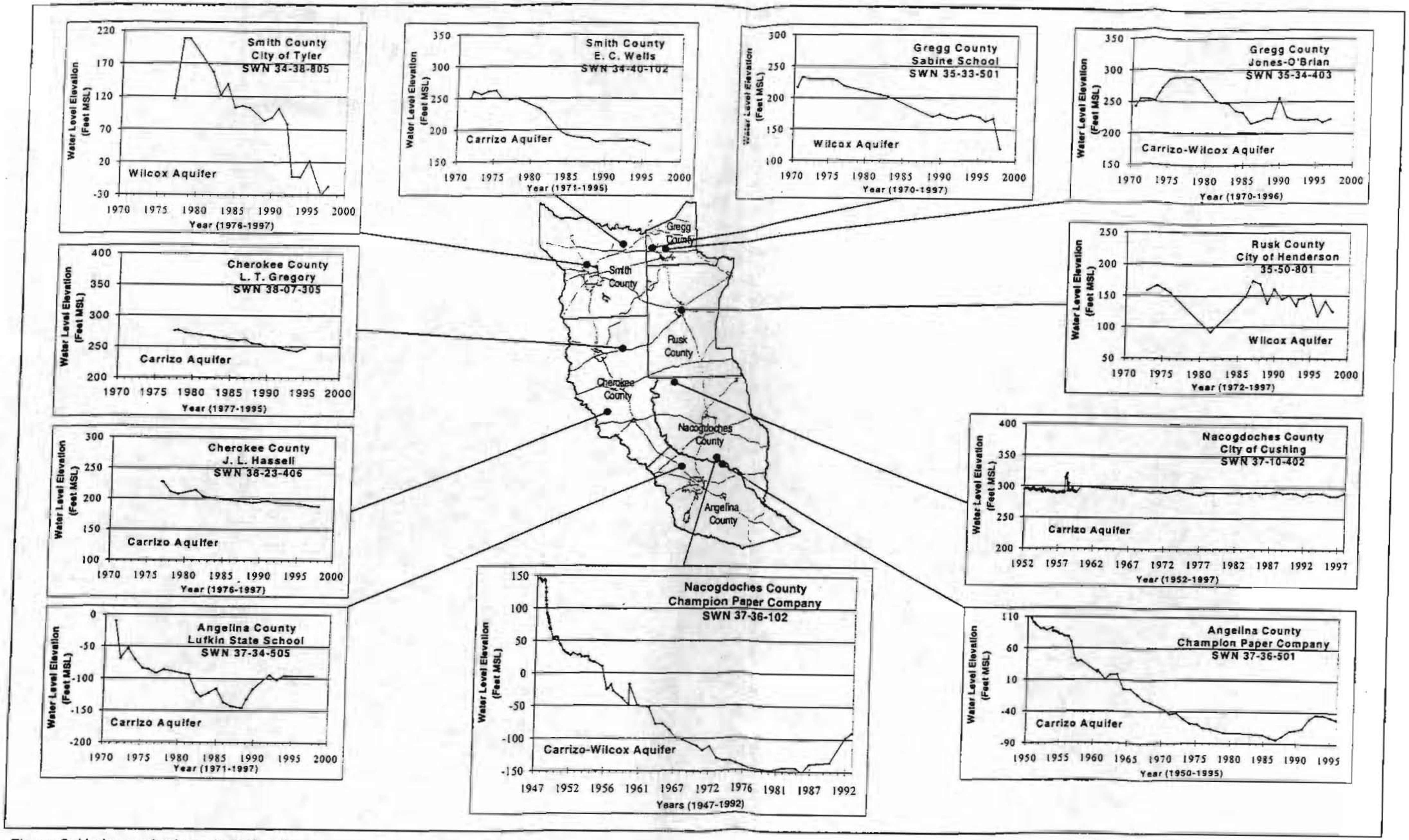


Figure 5. Hydrographs for selected wells

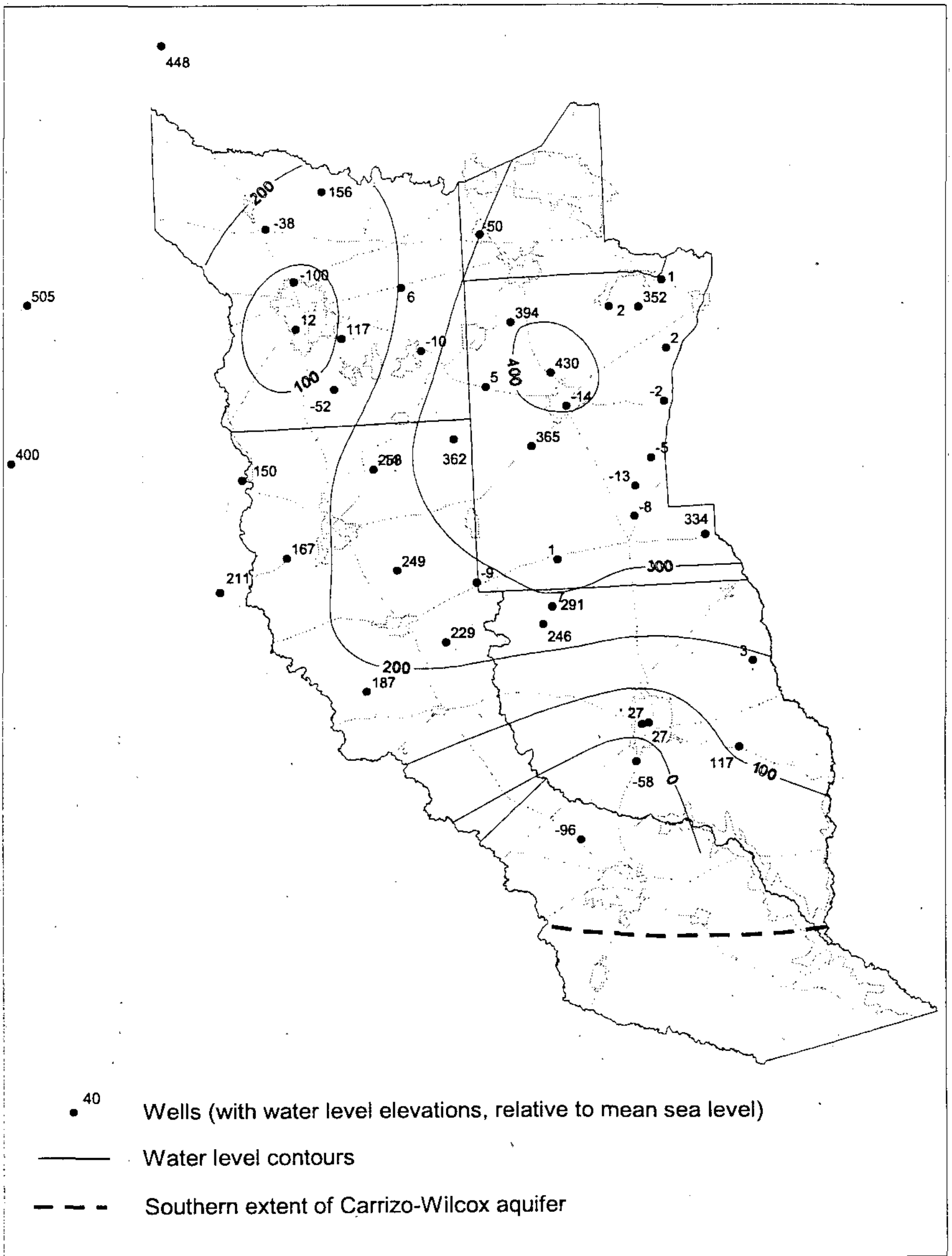


Figure 6. Carrizo aquifer potentiometric surface map (10/97 - 11/97)

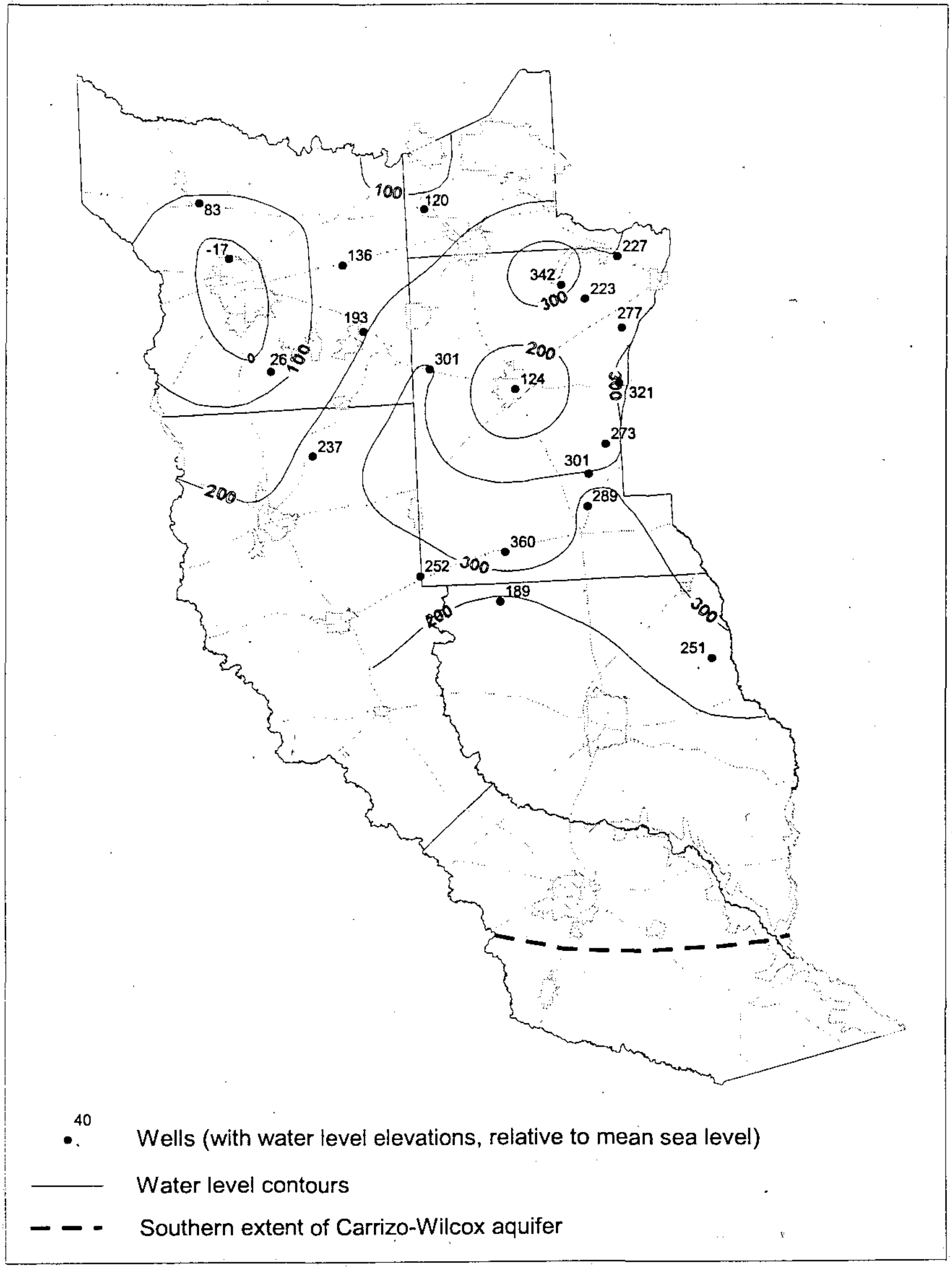


Figure 7. Wilcox aquifer potentiometric surface map (10/97 - 11/97)

Figure 6 indicates a potentiometric high in the Carrizo aquifer within Rusk County near Henderson. From this point groundwater gradients are mainly to the west and south, with the water level dropping below mean sea level in the vicinity of Lufkin. For the Wilcox aquifer, Figure 7 also denotes a potentiometric high mainly within Rusk County, with a below sea level depression to the west near Tyler.

Using the two sets of time periods outlined above, water-level difference maps were prepared for both the Carrizo and Wilcox aquifers. In order to reduce errors, only wells physically measured during both time periods were used.

Figure 8 depicts the changes in water level experienced in the Carrizo aquifer from 1988 through 1997. This map indicates a significant decline in the vicinity of Tyler, reaching a 95-foot maximum decline just southeast of the city. Smith and Cherokee County well hydrographs 34-40-102 and 38-07-305, shown in Figure 5, also demonstrate this decline. Two instances of water-level rise are also depicted on Figure 8, one south of Kilgore in Rusk County (25 feet), and another south of Nacogdoches in Nacogdoches County (40 feet).

Figure 9, the 1988 through 1997 water-level difference map for the Wilcox aquifer, indicates a significant decline near Tyler, reaching a 100-foot maximum decline in well 34-38-805, just to the northwest of Tyler (Figure 5). The hydrograph for this well indicates a fairly steady downward progression since 1978. Water-level difference contours in Figure 9 also indicate a continued decline around the Kilgore area (-50 feet), which corresponds with well 35-33-501 in Figure 5. At this well, the contours may be somewhat skewed by a 1997 measurement, which was significantly lower than previous measurements. As mentioned above, conclusions based upon any single measurement must be treated with caution.

Precipitation

The Carrizo-Wilcox aquifer is recharged by precipitation and by streams crossing the outcrop area. Typically, precipitation changes affect water levels in unconfined portions of the aquifer rapidly, while confined areas experience delayed effects. In order to analyze the aquifer, records for the precipitation gage near Henderson were evaluated. This gage was chosen largely due to its complete records and its location over the aquifer's outcrop. Most recharge occurs at the outcrops which, in this instance, exist east and west of the study area, as well as throughout much of Rusk and Nacogdoches counties. Groundwater mounds indicated on Figures 6 and 7 document the significance of the Henderson vicinity as a focal point of recharge.

All rainfall data were obtained from a Hydrosphere Climate Data CD-Rom (1998). Figure 10 presents Henderson gage precipitation data from 1970 through 1997, and the graph includes a moving 3-year average in order to better discern trends. Since data were first recorded, long-term average annual precipitation at the Henderson gage has been 45 inches (1908 – 1997), with a minimum of 23.2 (1963) and a maximum of 68.8

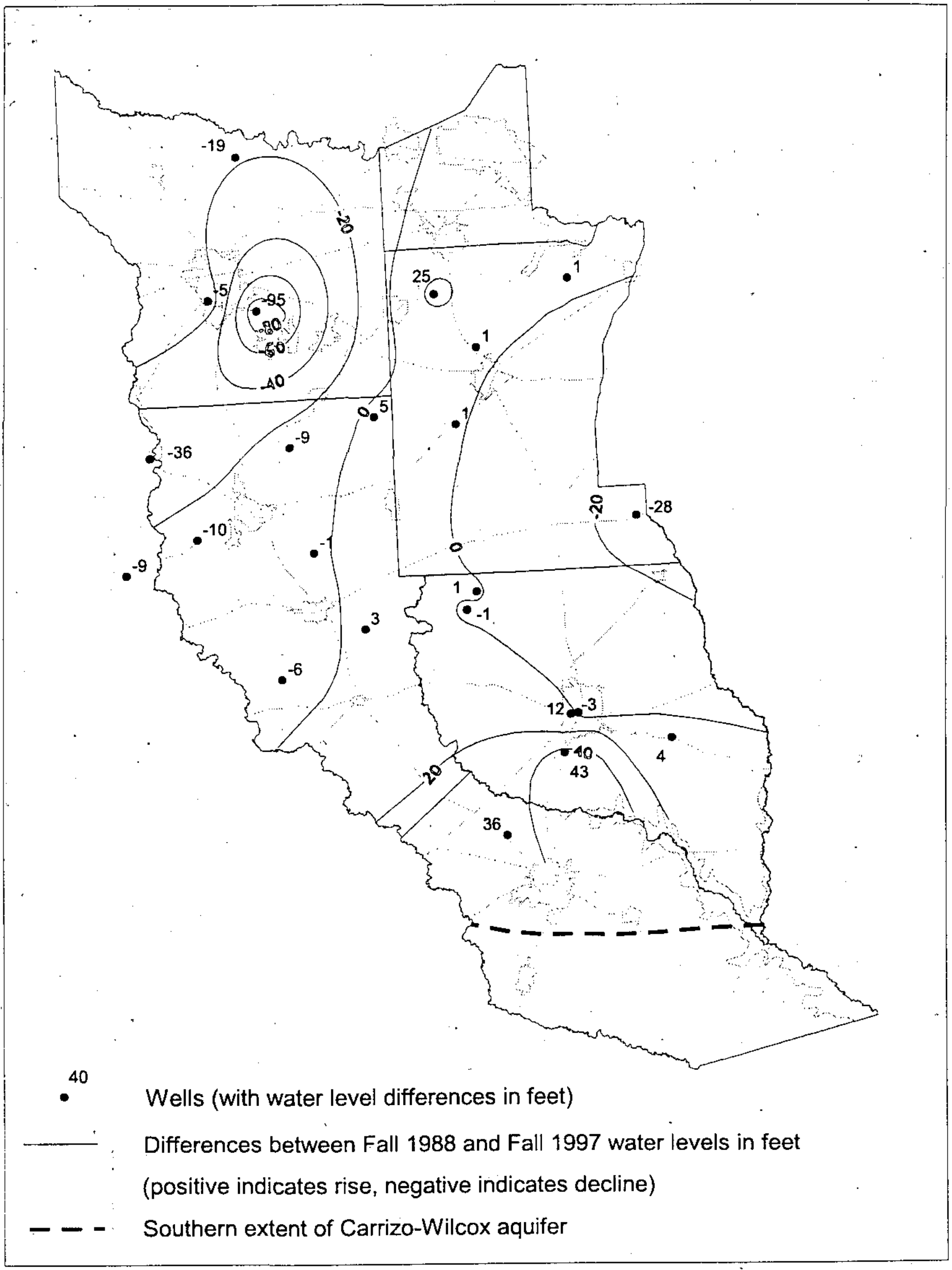
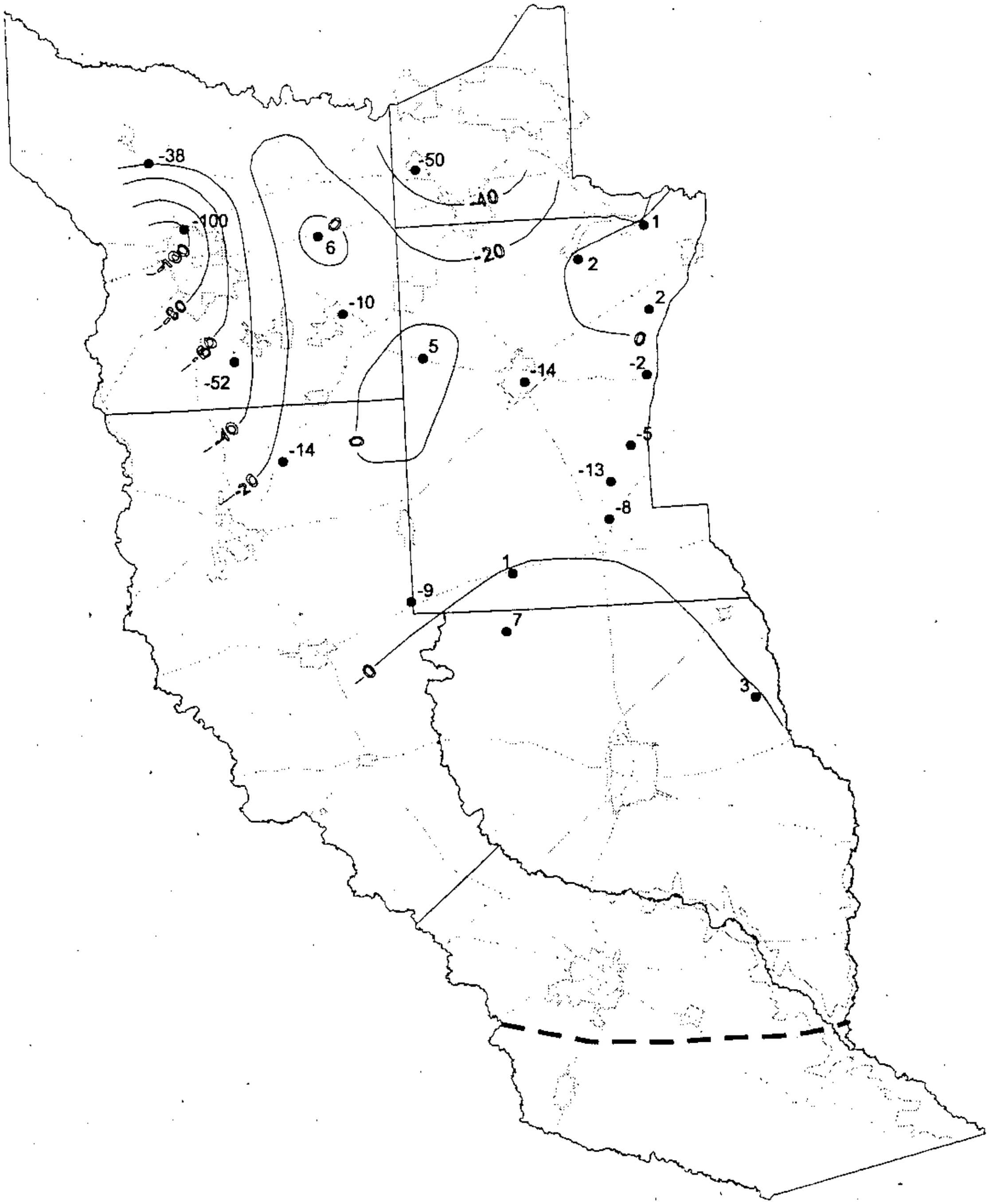


Figure 8. Carrizo aquifer water-level difference map (11/88 - 12/88 through 10/97 - 11/97)



40

Wells (with water level differences in feet)

Differences between Fall 1988 and Fall 1997 water levels in feet
(positive indicates rise, negative indicates decline)

Southern extent of Carrizo-Wilcox aquifer

Figure 9. Wilcox aquifer water-level difference map (11/88 - 12/88 through 10/97 - 11/97)

(1991) inches. Based upon a comparison between long-term average precipitation (indicated on Figure 10) and the location of the 3-year moving average, precipitation has primarily been above average since the year most Report 327 data collection was completed (1988), with a peak occurring in 1990, followed by a declining trend since.

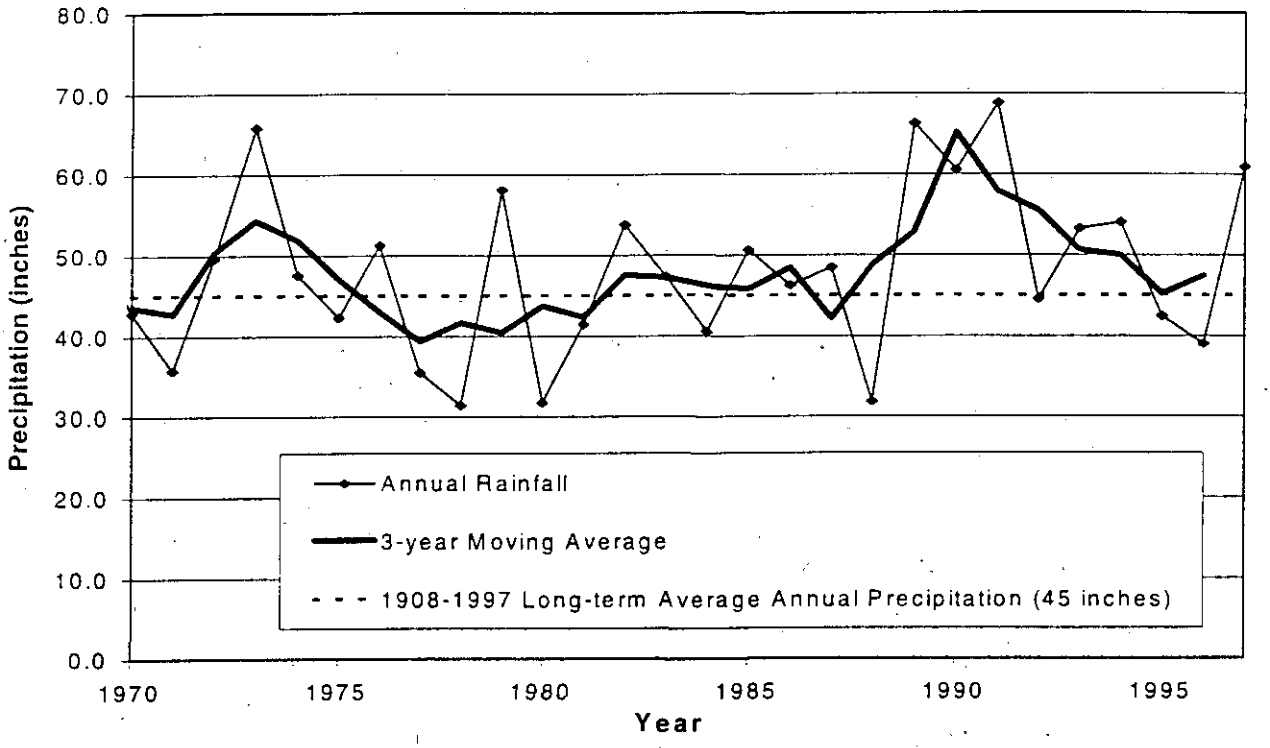


Figure 10. Precipitation at Henderson, Rusk County

Water Quality

Report 327 described the chemical quality of the groundwater as generally good, with the most significant problem being high iron concentrations found sporadically throughout the study area. Additionally, the report noted elevated levels of total dissolved solids (TDS), sulfate, and chloride, as well as evidence of past contamination of groundwater by oil field brine. The most current water quality data analyzed in Report 327 were collected in 1988.

For the purposes of this report, data were obtained from the TWDB groundwater database (TWDB, 1998a) and compared with State drinking water standards (Texas Administrative Code, §290, 1997). In instances where the State secondary constituent level (non-enforceable) is different than the U.S. Environmental Protection Agency secondary drinking water standard (1998), this has been noted. As the coverages of sampled wells are not always complete, maps in this report include all wells within the six subject counties, regardless of whether they are inside the study area. As this report is an update to Report 327, data collected since 1988 were evaluated for significant water quality deterioration. Additionally, in the case of TDS, data collected since 1970 are included to provide additional information about trends. For a single well with multiple records in the database, the most recent record is shown.

State and federal drinking water standards list a secondary constituent level of 300 µg/l for iron. Figure 11 presents all wells within the study area which have had dissolved iron analyses since 1988. Sixteen wells completed within the Carrizo-Wilcox aquifer and three wells within "Other aquifers" have produced water exceeding 300 mg/l since 1988. Areas of elevated concentrations are found all through the six-county area and likely are largely the result of poor well construction techniques, with wells having been poorly sealed or screened across clay and/or shale layers (in addition to their target sands).

Previous reports have described waters as slightly saline if they contained 1,000 to 3,000 mg/l TDS, and moderately saline if they contained 3,000 to 10,000 mg/l TDS (Winslow and Kister, 1956). State drinking water standards describe 1,000 mg/l as the secondary constituent level for TDS, while the federal standard is 500 mg/l. All water samples collected within the study area since 1988 have contained TDS concentrations less than 1,000 mg/l. Figure 12 presents wells with TDS analyses since 1970. This figure includes nine wells completed in the Carrizo-Wilcox and eleven in "Other aquifers" which produced water with TDS exceeding 1,000 mg/l between 1970 and 1987. These 20 wells are found scattered throughout the study area and are completed in a total of six different aquifers, thus indicating dispersed salinity problems.

The State and EPA federal maximum contaminant level (MCL) for nitrate as nitrate is 44.3 mg/l. Since 1988 all wells sampled within the study area have produced water with nitrate levels less than this value. From 1971 to 1975, one well completed in the Carrizo aquifer and three in the Queen City aquifer produced water with nitrate levels above this standard.

The State's secondary constituent level for chloride is 300 mg/l, while the EPA secondary standard is 250 mg/l. None of the wells sampled within the six counties have exceeded the State's 300 mg/l standard since 1988. Seven wells sampled between 1970 and 1987 did produce water with chloride concentrations exceeding 300 mg/l, with the highest value being 1,550 mg/l recorded in a well completed in the Wilcox aquifer about eight miles west of Henderson. Water with a pH above 7 exceeds State secondary constituent standards and such conditions exist within most aquifers throughout the study area. Approximately 500 wells have produced water with a pH concentration exceeding 7 since 1970. The State's secondary constituent level for sulfate is 300 mg/l, while the EPA secondary standard is 250 mg/l. Samples from four wells have exceeded 300 mg/l since 1970.

In addition to the above comparisons between water quality data and the State drinking water standards, standard analyses data from 24 wells with long-term records (15 to 49 years) which extend into the 1990s were reviewed. These analyses indicate no overall water quality trends.

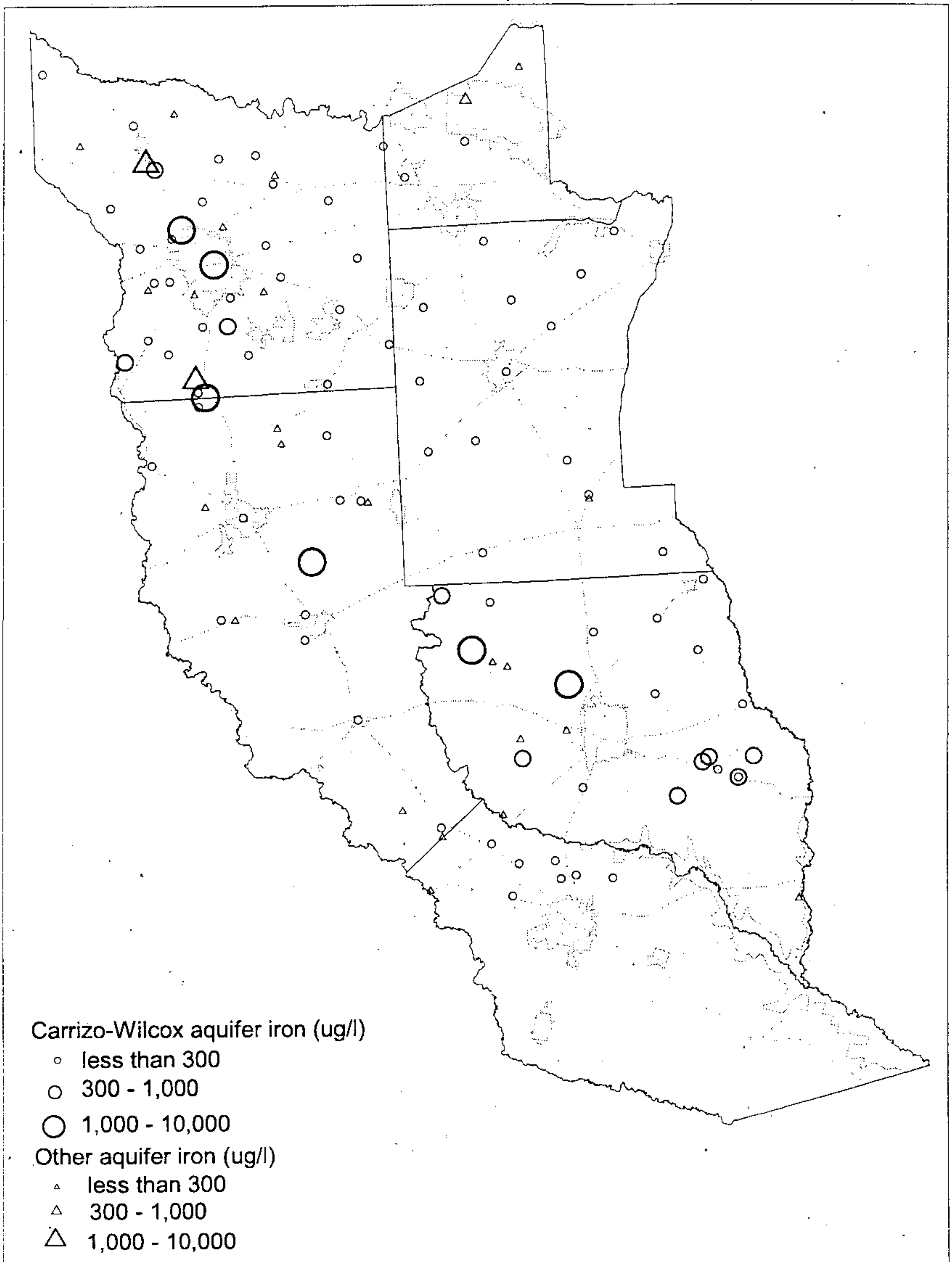


Figure 11. Iron concentrations in wells (1988-1997)

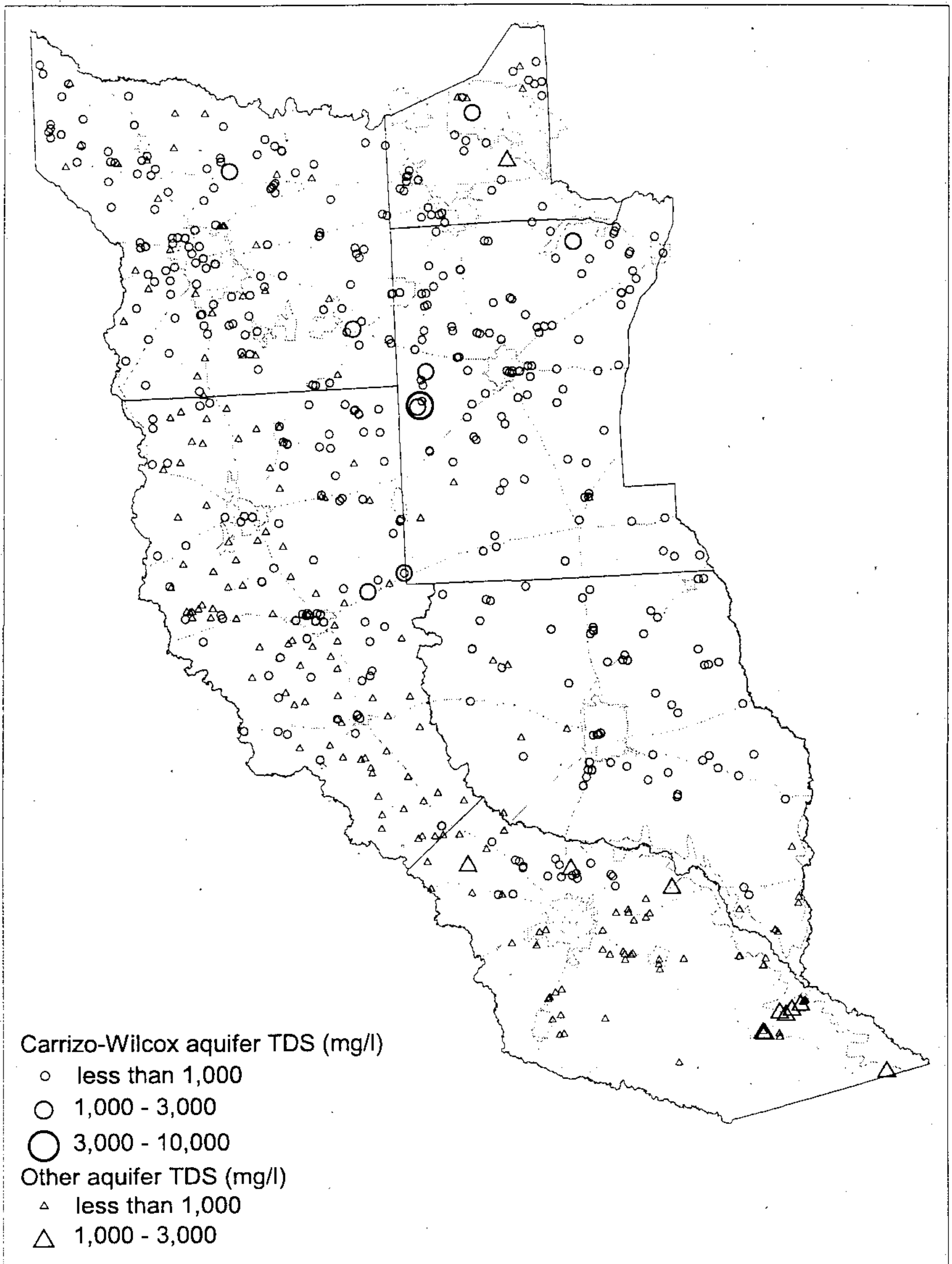


Figure 12. Total dissolved solids (TDS) in wells (1970-1997)

POPULATION AND WATER DEMANDS

Population

Table 2 includes current and projected population estimates (TWDB, 1998b), which include data presented in "Water for Texas, A consensus-based update to the State Water Plan, Volume II, Technical Planning Appendix" (TWDB, 1997). The data presented are only for the portion of each county that falls within the study area.

Kilgore is located within Gregg and Rusk counties, yet obtains groundwater from Smith County. Consequently, Report 327 listed all Kilgore-related statistics in Smith County. That convention is not maintained here in order to reduce confusion. For this report, Kilgore's statistics are included in the counties where this city is located.

Overall, the study area experienced a growth of 5,230 inhabitants, or less than 2 percent, from 1985 through 1990, and 20,702, or 6 percent, from 1990 to 1995. Comparison of the data indicate that total population progressively increased in Angelina, Cherokee, Nacogdoches, Rusk and Smith counties, while it temporarily dropped in Gregg County, then rebounded. The greatest growth from 1985 to 1990 occurred in Nacogdoches County, with an increase of 4,351 people (9 percent), while the greatest growth from 1990 to 1995 occurred in Smith County with an increase of 9,545 people (7 percent). Within Gregg County the population declined by 1,377 from 1985 to 1990 (8 percent), then increased 625 (4 percent) from 1990 to 1995, for a net decline of 752 (4 percent).

Projections contained in Table 2 suggest that from 2000 to 2030, overall population within the study area is expected to grow by 91,121, or 24 percent. The greatest increase is expected in Nacogdoches and Smith counties, with gains of 29,645 (51 percent) and 29,166 (19 percent), respectively, from 2000 to 2030. The smallest influx is expected in Cherokee and Rusk counties, where population is expected to increase by 6,602 and 6,665, respectively, from 2000 to 2030. Percentage-wise growth for these counties will still be significant, however, at 15 and 20 percent, respectively.

Historical Water Uses

Information on surface and groundwater use by various cities and use categories was compiled based upon estimates developed by the TWDB (TWDB, 1998b), which includes data presented in "Water for Texas" (TWDB, 1997). Due to the lack of more detailed information, water use estimates were derived by determining total water use for the portion of each county that falls within the study area, then subsequently proportioning those amounts into surface and groundwater use based upon county-wide percentages. As with the population data above, this section refers to areas by county name alone, even though the statistics are derived for the portion of each county

	1985(1)	1990 (1)	1995 (1)	2000 (2)	2010 (2)	2020 (2)	2030 (2)
Angelina County (3)							
Hudson	1,810	2,374	2,675	2,604	2,803	3,169	3,547
Huntington	2,072	1,794	2,124	2,202	2,575	2,914	3,265
Lufkin	31,347	30,206	32,522	35,631	38,777	41,875	44,995
County Other	23,254	24,796	26,762	25,689	27,115	28,501	29,879
Total	58,483	59,170	64,083	66,126	71;270	76,459	81,686
Cherokee County (3)							
Alto	1,224	1,027	1,067	1,104	1,155	1,211	1,271
Jacksonville	12,863	12,765	13,193	13,749	14,048	14,525	15,092
Rusk	4,486	4,366	4,483	4,510	4,623	4,751	4,979
Troup (3)	40	33	37	37	38	40	42
County Other	20,241	20,686	22,014	24,143	25,681	27,242	28,761
Total	38,854	38,877	40,794	43,543	45,545	47,769	50,145
Gregg County (3)							
Gladewater (3)	496	487	403	557	611	668	722
Kilgore (3, 4, 5)	9,594	8,258	8,627	9,560	10,297	11,125	11,819
Liberty City	1,215	1,607	1,673	2,177	2,565	2,863	3,073
County Other	6,535	6,111	6,385	5,526	5,491	5,533	5,690
Total	17,840	16,463	17,088	17,820	18,963	20,189	21,303
Nacogdoches County (3)							
Nacogdoches	28,416	30,872	32,229	36,709	42,108	47,855	55,415
County Other	17,399	19,294	20,272	21,469	24,593	27,970	32,408
Total	45,815	50,166	52,501	58,178	66,701	75,825	87,823
Rusk County (3)							
Henderson	11,852	10,916	11,526	11,766	11,918	11,629	11,352
Kilgore (3, 4, 5)	2,583	2,808	2,876	3,207	3,408	3,519	3,616
Overton (3)	2,247	1,982	2,095	2,069	2,102	2,062	2,018
County Other	14,058	15,478	16,054	16,679	18,033	20,688	23,399
Total	30,740	31,184	32,551	33,720	35,460	37,898	40,385
Smith County (3)							
Overton (3)	129	123	134	136	148	156	162
Troup (3)	1,952	1,626	1,823	1,887	2,050	2,153	2,236
Tyler	74,603	75,450	79,812	78,883	83,131	86,947	94,063
Whitehouse	3,894	4,032	5,266	7,230	9,535	11,289	11,724
County Other	55,458	55,907	59,648	66,121	72,579	75,476	75,238
Total	136,036	137,138	146,683	154,257	167,443	176,021	183,423
Total for Study Area	**327,768**	**332,998**	**353,700**	**373,645**	**405,382**	**434,160**	**464,766**

Table 2. Historical and projected population 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.*
4. *Due to the location of Kilgore's wells, Report 327 included population statistics for that city with those for Smith County. That convention is not maintained in this report and all statistics listed are for the counties indicated.*

that falls within the study area.

Table 3 indicates that total water use for all purposes within the study area decreased 1,540 acre-feet, or 2 percent, from 1985 to 1990, and increased 9,768 acre-feet, or 10 percent, from 1990 to 1995. Total water use in Angelina, Cherokee, Gregg, Rusk and Smith counties went down between 1985 and 1990, with the greatest drop occurring in Smith County at 2,465 acre-feet, or 8 percent. Total water use increased within Cherokee, Gregg, Nacogdoches, Rusk and Smith counties from 1990 to 1995, with the greatest gain occurring in Smith County at 6,322 acre-feet, or 21 percent.

Area-wide, municipal demands comprised 61 percent of the total water use in 1995, with 65 percent of that having been supplied by groundwater. Water uses for other than municipal purposes were almost equally supplied by surface and groundwater in 1995, with manufacturing having been the largest consumer.

Considering total groundwater use alone, the study area was equally divided, with Cherokee, Nacogdoches and Smith counties experiencing an increase, and Angelina, Gregg and Rusk counties experiencing a decrease from 1985 to 1995. The greatest increase during that period occurred in Nacogdoches County, where total groundwater use went up 3,485 acre-feet or 55 percent. The greatest decrease occurred in Angelina County, where total groundwater use declined 4,393 acre-feet, or 16 percent.

All six counties increased their dependence on surface water from 1985 to 1995, which resulted in a decreased dependence on groundwater. The largest increases occurred in Angelina and Smith counties (29 and 14 percent, respectively), with increases in all other counties being much more moderate. Historically, the study area's worst water-level declines occurred between Lufkin and Nacogdoches, but Report 327 indicates a reduction of groundwater pumpage by the paper industry there in the 1970s and 1980s, as well as a significant use of surface water from Lake Nacogdoches since 1979.

Although the figures in Table 3 combine withdrawals from all aquifers into a single use category, withdrawals from the Carrizo-Wilcox are by far the most dominant. Specifically, TWDB records (TWDB, 1998c) indicate that in 1996, for example, percentages of groundwater withdrawn for all uses from the Carrizo-Wilcox were 86, 90, 61, 94, 98 and 94 percent for Angelina, Cherokee, Gregg, Nacogdoches, Rusk and Smith counties, respectively. Unfortunately, for the purposes of comparison with water-level difference maps (Figures 8 and 9), it would also be useful to know the water use from the Carrizo and Wilcox aquifers separately.

	1985 (1, 2)		1990 (1, 2)		1995 (1, 2)	
	Ground	Surface	Ground	Surface	Ground	Surface
Angelina County						
Hudson	169	0	182	0	291	0
Huntington	171	0	251	0	199	0
Lufkin	5,076	0	4,739	0	4,858	0
County Other	2,396	0	2,722	0	2,908	0
Total Municipal	7,812	0	7,894	0	8,256	0
Manufacturing	18,597	6,500	15,953	9,329	14,072	8,408
Irrigation	383	0	0	0	26	0
Steam-Electric	0	0	0	0	0	0
Mining	0	0	0	0	19	0
Livestock	116	174	110	167	142	214
Total Other Water Use	19,096	6,674	16,063	9,496	14,259	8,622
Source Total	26,908	6,674	23,957	9,496	22,515	8,622
Total County	33,582		33,453		31,136	
Cherokee County						
Alto	117	0	186	0	241	0
Jacksonville	1,530	722	1,719	918	2,219	1,468
Rusk	759	0	1,027	6	883	0
Troup (P)	8	0	3	0	6	0
County Other	2,184	286	1,844	310	2,273	341
Total Municipal	4,598	1,008	4,779	1,234	5,622	1,809
Manufacturing	266	124	215	114	351	229
Irrigation	72	328	99	449	62	40
Steam-Electric	215	5,938	341	4,595	134	5,461
Mining	120	2	51	2	81	2
Livestock	625	938	680	1,021	906	1,358
Total Other Water Use	1,298	7,330	1,386	6,181	1,534	7,090
Source Total	5,896	8,338	6,165	7,415	7,156	8,899
Total County	14,235		13,580		16,055	
Gregg County						
Gladewater (P)	0	56	0	89	0	60
Kilgore (P)	1,366	529	874	776	1,242	1,058
Liberty City	150	23	127	71	244	33
County Other	374	475	320	522	315	472
Total Municipal	1,890	1,083	1,321	1,458	1,801	1,623
Manufacturing	0	0	3	159	5	59
Irrigation	0	26	0	0	10	0
Steam-Electric	0	0	0	0	0	0
Mining	51	32	9	30	0	52
Livestock	33	49	29	44	34	52
Total Other Water Use	84	107	41	233	49	163
Source Total	1,974	1,190	1,362	1,691	1,850	1,786
Total County	3,164		3,053		3,636	
Nacogdoches County						
Nacogdoches	3,462	2,213	3,613	2,617	4,636	2,389
County Other	2,203	389	2,670	421	3,106	96
Total Municipal	5,665	2,602	6,283	3,038	7,742	2,485

Table 3. Historical water uses (acre-feet) within the study area.

	1985 (1, 2)		1990 (1, 2)		1995 (1, 2)	
	Ground	Surface	Ground	Surface	Ground	Surface
Nacogdoches County (cont.)						
Manufacturing	188	122	548	389	700	360
Irrigation	35	9	126	126	914	229
Steam-Electric	0	0	0	0	0	0
Mining	0	11	0	9	0	198
Livestock	431	647	438	656	448	672
Total Other Water Use	654	789	1,112	1,180	2,062	1,459
Source Total	6,319	3,391	7,395	4,218	9,804	3,944
Total County	9,710		11,613		13,748	
Rusk County						
Henderson	2,095	0	2,219	0	2,369	0
Kilgore (P)	368	142	299	262	413	354
Overton (P)	481	0	331	0	547	0
County Other	1,618	67	1,631	68	1,789	135
Total Municipal	4,562	209	4,480	330	5,118	489
Manufacturing	0	0	151	153	80	0
Irrigation	23	37	16	29	90	202
Steam-Electric	0	0	0	0	0	0
Mining	1,496	3	980	230	714	261
Livestock	304	457	255	383	249	373
Total Other Water Use	1,823	497	1,402	795	1,133	836
Source Total	6,385	706	5,882	1,125	6,251	1,325
Total County	7,091		7,007		7,576	
Smith County						
Overton (P)	27	0	21	0	35	0
Troup (P)	366	0	164	0	280	0
Tyler	2,219	13,632	1,069	14,206	3,028	15,898
Whitehouse	406	0	57	459	129	569
County Other	8,616	454	8,537	356	10,455	436
Total Municipal	11,634	14,086	9,848	15,021	13,927	16,903
Manufacturing	1,578	2,318	954	2,205	1,088	2,343
Irrigation	0	900	8	154	90	385
Steam-Electric	0	0	0	0	0	0
Mining	693	7	534	5	213	141
Livestock	365	547	374	560	358	537
Total Other Water Use	2,636	3,772	1,870	2,924	1,749	3,406
Source Total	14,270	17,858	11,718	17,945	15,676	20,309
Total County	32,128		29,663		35,985	
Area Total Municipal	36,161	18,988	34,605	21,081	42,462	23,309
Manufacturing	20,629	9,064	17,824	12,349	16,296	11,399
Irrigation	512	1,300	249	758	1,192	856
Steam-Electric	215	5,938	341	4,595	134	5,461
Mining	2,360	55	1,574	276	1,027	654
Livestock	1,874	2,812	1,886	2,831	2,137	3,206
Area Total Other	25,590	19,169	21,874	20,809	20,786	21,576
Area Source Total	61,751	38,157	56,479	41,890	63,248	44,885
Area Total Water Use	**99,909**		**98,369**		**108,137**	

Table 3. Historical water uses (acre-feet) within the study area (continued).

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 water and groundwater use based upon county-wide percentages.*

Projected Water Demands

Table 4 documents the projected water demands by use type for the study area by major city, county other and other uses categories. These numbers are based upon estimates (TWDB, 1998d) which include data presented in "Water for Texas" (TWDB, 1997). The data presented were derived by analyzing projected water demands at the city and county level – initially, by identifying water use and supply measures that have less impact and are cost effective. Measures that are more costly, such as those which are environmentally sensitive or controversial, were then considered if needed.

Generally, the process involves incorporating water conservation savings into water uses and thus delay the need for new supply development. If necessary, the allocation method then considers expanded use of existing supplies, followed by expanded use of local undeveloped supplies. Alternative opportunities for additional supplies are also identified, including reallocation of reservoir storage or type of use, water marketing, and other measures. Finally, access to additional water supplies, through long distance conveyance, interbasin transfers, or new reservoir development, are evaluated, if needed to meet projected demands. However, entities are expected to achieve an advanced level of water conservation before new reservoir development and interbasin transfers are to be considered. Under projected conditions, the total annual water requirement for the study area is expected to increase 15 percent from the year 2000 to 2030. In 2030, the water demand is projected to be about 124,514 acre-feet per year.

Total groundwater use is expected to increase 5,348 acre-feet, or 10 percent, from the years 2000 through 2030. Although the Carrizo-Wilcox is expected to remain the dominant groundwater source through 2020, Table 4 suggests a 5,000 acre-feet pumping increase from the Queen City aquifer between the years 2020 and 2030. This increase is based upon an anticipated steam-electric plant in Cherokee County and, if realized, would cause Queen City pumping to exceed that from the Carrizo-Wilcox.

A comparison between Table 3 and 4 suggests an overall shift within the study area from groundwater to surface water from 1995 through the year 2000. Table 3 describes 1995 historical groundwater and surface water use as 63,248 and 44,885 acre-feet, respectively, while Table 4 projects year 2000 water use to be 52,314 and 56,073 acre-feet, respectively. Table 4 projections are based on long-term trends, while Table 3 presents historical data representing a snapshot in time. Consequently, the two do not correspond exactly. At present, surface water is supplied to the study area by Lakes Tyler East and West, Lake Jacksonville, Striker Creek Reservoir, Lake Kuruth, Lake Nacogdoches, and Lake Palestine. Lake Cherokee, located east of the study area, supplies water to Kilgore.

	2000(1)	2010(1)	2020(1)	2030(1)
Municipal Use				
Major Cities (2)				
Ground				
Carrizo-Wilcox	23,028	23,076	23,087	23,375
Other Aquifer	699	768	817	868
Total	23,727	23,844	23,904	24,243
Surface				
	18,848	19,863	20,705	23,088
County Other				
Ground				
Carrizo-Wilcox	18,464	18,782	18,729	18,558
Queen City	457	400	331	418
Sparta	58	58	58	58
Other Aquifer	803	804	805	807
Total	19,782	20,044	19,923	19,841
Surface				
	2,487	2,687	2,907	3,464
Total Municipal				
Ground	43,509	43,888	43,827	44,084
Surface	21,335	22,550	23,612	26,552
Total	64,844	66,438	67,439	70,636
Non-Municipal Uses				
Ground				
Carrizo-Wilcox	5,173	5,340	5,517	5,475
Queen City	3,534	2,917	2,706	7,996
Sparta	97	99	103	107
Other Aquifer	0	0	0	0
Total	8,804	8,356	8,326	13,578
Surface				
	34,738	34,606	40,283	40,300
Total Non-Municipal	43,542	42,962	48,609	53,878
ALL USES (Municipal and Non-Municipal uses combined)				
Ground				
Carrizo-Wilcox	46,665	47,198	47,333	47,408
Queen City	3,992	3,317	3,037	8,414
Sparta	155	157	161	165
Other Aquifer	1,502	1,572	1,622	1,675
Total	52,314	52,244	52,153	57,662
Surface				
	56,073	57,156	63,895	66,852
Ground and Surface Total	108,387	109,400	116,048	124,514

Table 4. Projected water demands (acre-feet) by source type for the study area

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.*

WATER AVAILABILITY

Groundwater Availability

Estimates of water availability from the subject aquifers were developed for TWDB Report 238 – Ground-Water Availability in Texas (Muller and Price, 1979). That report describes two groundwater sources for the Carrizo-Wilcox aquifer: (1) the estimated effective recharge (infiltration of rainfall on outcrops and the ability of sediments to transmit water), and (2) the estimated groundwater recoverable from aquifer storage (considering aquifer transmission capacity and pumping lift costs). For confined portions of the aquifer, the latter is described as the amount of storage removable such that no more than 400 feet of drawdown occurs in the potentiometric surface. For unconfined portions, the method involved calculating such characteristics as saturated thickness and aquifer transmissibility. Overall, Report 238 assumes that if recharge remains constant, after the year 2030 total recoverable storage from the Carrizo-Wilcox aquifer will be depleted and supply will revert to estimated effective recharge.

The sum of a county by county breakdown of Report 238's recharge estimates suggests the effective recharge for the six-county area is as follows: 101,506 acre-feet per year for the Carrizo-Wilcox, 208,456 acre-feet per year for the Queen City, and 31,063 acre-feet per year for the Sparta aquifer. Additionally, recoverable storage for the Carrizo-Wilcox aquifer was estimated to be over 131,250 acre-feet per year through the year 2030. Recharge to the aquifers occurs mainly at the outcrops, but the locations of the outcrops relative to the study area boundaries preclude use of the ratio of aquifer outcrop area within the study area, to the six-county aquifer area, as a means of adjusting the effective recharge to reflect the study area alone. As this water flows to confined portions of the aquifers, however, a ratio of aquifer area (outcrop and downdip) within the study area, to county-wide aquifer area, was applied to adjust both the recoverable storage and effective recharge estimates. Using this technique, annual effective recharge for the Carrizo-Wilcox, Queen City and Sparta aquifers within the study area are estimated to be 84,025, 175,722 and 28,648 acre-feet per year, respectively, while Carrizo-Wilcox recoverable storage is estimated to be over 105,930 acre-feet per year through the year 2030.

Annual groundwater availability was also determined through development of a Carrizo-Wilcox digital groundwater flow model (TWDB, 1997). This model simulates responses to changes in stress, such as recharge and pumpage, and predicts how the aquifer's water levels and flows may change under future conditions. Model output indicates those areas expected to experience problems in supplying future demands.

In the computer model, the criteria for development of the Carrizo-Wilcox aquifer allowed water-level declines beyond the 400-foot maximum decline assumed for Report 238, but short of total depletion of the aquifer during a 50-year period. Once the model was developed, consumptive water demand forecasts (TWDB, 1998b) were used to predict future maximum groundwater development conditions. The assumptions were for an extreme case – namely, that systems currently relying in part or wholly upon groundwater would rely solely upon groundwater for future development. The only exceptions were specific industrial uses that currently rely upon surface water, with the assumption being that these would continue to do so. Once future demand figures were developed, those were used in the model, and in all but one locality model results indicate that groundwater could meet all future demands through the year 2050. The exception was in Gregg County, where future demands were sufficient to require additional surface-water development at some point in the future.

The results of the Carrizo-Wilcox model are currently used as input files to the TWDB water allocation model (TWDB, 1998d). Collectively for the entire six-county area, these files suggest that the Carrizo-Wilcox, Queen City and Sparta aquifers are capable of producing at least 131,700, 213,146 and 31,063 acre-feet per year, respectively, with unused portions in the year 2000 of 72,555, 207,916 and 30,848 acre-feet per year, respectively. Applying a ratio of aquifer area in the study area, to aquifer area in each county, these same numbers suggest that the Carrizo-Wilcox, Queen City and Sparta aquifers within the study area are capable of producing at least 98,714, 176,731 and 28,648 acre-feet per year, respectively, with unused portions in the year 2000 of 55,134, 172,159 and 28,457 acre-feet per year.

With regard to the Queen City and Sparta aquifers, it is worth noting that high iron concentrations and low well yields generally make this water less desirable for development. Nonetheless, water systems are able to effectively reduce such iron.

Surface-Water Availability

Report 327 previously described the availability of surface water within the study area, and concluded that adequate quantities were available to supplement groundwater supplies. The current study verified this information against input files used in the TWDB water allocation model (TWDB, 1998d) and determined that little has changed regarding surface water availability.

At present, eight reservoirs with storage capacities greater than 5,000 acre-feet supply water to the study area. Lakes Tyler East and West supply water to the City of Tyler, and can provide about 38,500 acre-feet per year under current sedimentation conditions. Lake Jacksonville supplies water to Jacksonville, and that city has a permit to divert up to 5,000 acre-feet annually. Striker Creek Reservoir supplies water to the Champion Paper Company at a rate of up to 20,600 acre-feet per year under drought conditions. Lake Kuruth also supplies water to the Champion Paper Company, at a permitted diversion rate of 19,100 acre-feet per year. Lake Nacogdoches supplies water to the City of Nacogdoches with a maximum capacity of about 22,000 acre-feet annually. Lake Palestine supplies water to the City of Palestine, and eventually this source is projected to supply water to the cities of Dallas and Tyler.

Lake Cherokee, located outside the study area and east of Kilgore, supplies water to Longview, which in turn sells water to Kilgore. Additionally, the City of Lufkin owns yet undeveloped rights to divert 43,000 acre-feet annually from Sam Rayburn Reservoir.

DISCUSSION AND CONCLUSIONS

The area's large water-level declines which began in the 1940s have largely been addressed through reduced groundwater pumpage and conjunctive use of surface water. Reductions in groundwater pumpage have slowed annual water-level declines and, in some cases, even led to water-level rises. Nonetheless, areas persist where water levels have declined since publication of Report 327.

One locality where Carrizo aquifer heads have risen since publication of Report 327 is between Lufkin and Nacogdoches (Figures 5 and 8). Historically, the study area's worst water-level declines have occurred there, but significant use of surface water from Lake Nacogdoches since 1979 has changed this trend. That shift, and the reduction of groundwater pumpage by the paper industry in the 1970s and 1980s, has apparently led to the observed water-level recovery. Within the Wilcox aquifer no significant water level increases were detected (Figure 9).

The study area's greatest groundwater decline appears to have occurred within the Wilcox aquifer just north of Tyler, with a secondary depression northwest of Kilgore (Figures 5 and 9). Within the Carrizo aquifer the most significant depression was detected southeast of Tyler (Figure 8). That city has been practicing conjunctive surface and groundwater use for many years, and currently uses groundwater for only about 15 percent of its supply. Decreasing water levels in the aquifers there, however, suggest continued localized overdraft of both the Carrizo and Wilcox aquifers. Overall, water-levels within the aquifers of the study area remained fairly constant from 1988 to 1997, and the declines in the Tyler vicinity are somewhat unusual.

Throughout the study area, heads generally remain high and the large volume of water in storage thus far has prevented wells from totally dewatering. The aquifer's confined nature, coupled with the large distance from areas of recharge, however, has in some instances resulted in greater cones of depression.

Records indicate that precipitation has primarily been above average since the 1988 publication of Report 327, and one would expect this to lessen the impact of groundwater extraction on water levels as compared with periods of drought. In order to take advantage of the most recent water-level information, 1997 data were used for development of a recent groundwater elevation map. A comparison of precipitation data, however, indicates that 1997 rainfall was much higher than that in 1988 (31.8 versus 60.9 inches). A comparison of the 3-year moving average for 1988 and 1996 (the latter being the most recent for rainfall data), suggests much more negligible differences in precipitation (48.8 inches for 1988, versus 47.4 inches for 1996).

Water demands have grown due to population growth in the area, however, population has not increased as rapidly as projected in Report 327. Figures suggest the total number of people within the study area grew only 2 percent from 1985 and 1990, and 6 percent from 1990 to 1995. Current projections suggest the population will grow 24 percent from 2000 and 2030. Total water use for all purposes decreased 2 percent from 1985 to 1990, and increased 10 percent from 1990 to 1995.

A direct comparison between water use data and the Carrizo aquifer and Wilcox aquifer water-level difference maps (Figures 8 and 9) is not possible because the available groundwater data in Table 3 does not specify from which aquifer water was withdrawn. Nevertheless, the effects of groundwater withdrawal can be observed qualitatively in these maps.

When groundwater use patterns in Table 3 are compared with water-level elevation changes over time, it appears that observed heads sometimes do not correlate. Cherokee and Nacogdoches counties, for example, both experienced increased groundwater use between 1985 and 1995, yet Figure 8 suggests water-level elevations in these areas generally rose over time. Apparent discrepancies such as this may partially be explained by the inability to directly compare groundwater use data and water-level information, due to the differing time periods. Furthermore, limitations on the amount of data available for calculating water level differences, as well as lack of information regarding whether groundwater was extracted from the Carrizo or Wilcox aquifers, may also help to explain these apparent differences.

In the case of the Tyler vicinity, the water use data in Table 3 and the recent water-level declines appear to correlate well. Tyler decreased groundwater use by 1,150 acre-feet from 1985 to 1990, then increased this by 1,959 acre-feet from 1990 to 1995. Smith County (the county in which Tyler lies), similarly decreased groundwater use by 2,552 acre-feet from 1985 to 1990, then increased groundwater use by 3,958 acre-feet from 1990 to 1995. In both instances, groundwater use increased from 1990 to 1995, thus perhaps explaining at least some the declines experienced in both the Carrizo and Wilcox aquifers in this vicinity between 1988 and 1997.

A comparison between availability estimates in Report 238 (for both effective recharge and recoverable storage) and the projected water demands by source type suggests that available groundwater supply can easily meet projected demands from all three aquifers within the study area. Still, this is not the best means of determining groundwater availability for the vicinity. As a means of getting beyond a simple volumetric analysis, the TWDB developed a Carrizo-Wilcox numerical model. Results of this model indicate that, with the exception of one location in Gregg County, all groundwater pumping needs through the year 2050 can be met by regional development of the Carrizo-Wilcox. This is not to say, however, that local groundwater declines (such as those around Tyler) will not exist.

Water quality within the study area is generally good, and excessive concentrations of iron appear to present the only relatively widespread problem. Since 1988, a total of 19 study area wells within the Carrizo-Wilcox aquifer have produced water exceeding the State's 300 µg/l secondary constituent level for iron. As for the Queen City and Sparta aquifers, however, high iron concentrations and relatively low well yields make much of this water economically less desirable for development.

Lastly, there is the issue of groundwater/surface water interactions. In general, water-level declines in confined portions of the area's aquifers have little effect upon local surface water bodies due to the low permeability of the intervening confining layer(s). In the case of Carrizo-Wilcox outcrop (Figure 2), however, a drop in the water table may result in a subsequent reduction in water in storage in surface water bodies. A comparison between stream and reservoir elevations within the outcrop area and heads for the Carrizo and Wilcox aquifers (Figures 6 and 7), suggests these aquifers largely have heads exceeding the elevations of the surface water bodies. If this is correct, groundwater is likely discharging to surface water, and a drop in the water table would reduce the groundwater discharge. These effects could be analyzed through further computer simulations of the aquifer, however, at present the existing Carrizo-Wilcox model does not address this issue.

REFERENCES

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

Nordstrom, P.L. and Beynon, B.E., 1991, A Field Manual for Ground Water Sampling (Revised): Texas Water Development Board Users Manual 51, 57 p.

Preston, R.D., and Moore, S.W., 1991. Evaluation of Water Resources in the Vicinity of the Cities of Henderson, Jacksonville, Kilgore, Lufkin, Nacogdoches, Rusk, and Tyler in east Texas, Texas Water Development Board Report 327, 51 pp.

Texas Administrative Code, 1997, Chapter 290 – Water Hygiene, Subchapter F: Drinking Water Standards Governing Drinking Water Quality and Reporting Requirements for Public Water Systems, §290.101-290.121.

Muller, D.A., and Price, R.D., 1979. Ground-Water Availability in Texas, Estimates and Projections through 2030. Texas Department of Water Resources Report 238, 77 pp.

Texas Water Development Board, 1997. Water for Texas, A consensus-based update to the State Water Plan, Volume II, Technical Planning Appendix. GP-6-2, vol. 2, 345 pp.

Texas Water Development Board, 1998a, Groundwater database: Texas Water Development Board, Water Resources Network.

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

Texas Water Development Board, 1998c, Estimated groundwater summary by major aquifer: Texas Water Development Board, Water Resources Planning Division.

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

U.S. Environmental Protection Agency, 1998, National Primary and Secondary Drinking Water Regulations: Office of Ground Water and Drinking Water.

Winslow, A.G., and Kistner, L.R., Jr., 1956, Saline-water resources of Texas: U.S. Geological Survey Water Supply paper 1365, 105 p.