

Report 318

**Evaluation of
Water Resources in Part of
North-Central Texas**

January 1990



Texas Water Development Board



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by

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January 1990

Texas Water Development Board

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CONCLUSIONS

The study area is within the North-Central Texas Region which lies in the Brazos, Red, Sulphur, Sabine, and Trinity River basins, and includes all or parts of Collin, Cooke, Dallas, Delta, Denton, Ellis, Fannin, Grayson, Henderson, Hood, Hunt, Jack, Johnson, Kaufman, Lamar, Montague, Navarro, Palo Pinto, Parker, Red River, Rockwall, Tarrant, and Wise Counties.

The geologic formations underlying the study area range in age from Paleozoic to Recent. The principal water-bearing formations are the Antlers, Twin Mountains, and Paluxy Formations of the Trinity Group, and the Woodbine Group, all of Cretaceous age. The Nacatoch and Blossom Sands, also of Cretaceous age, supply water to wells in relatively limited areas in the eastern and northeastern part of the study area.

In 1985, about 110,000 acre-feet of ground water was pumped from all aquifers in the study area, with about 47,000 acre-feet or 42 percent of the total pumped for public supply (cities and towns with populations of 1,000 or more). An additional 35,000 acre-feet (or 32 percent) was pumped to supply the needs of towns and communities of less than 1,000 population and rural domestic uses.

Extensive cones of depression have developed in the piezometric surface of each of the region's principal aquifers, coinciding with areas of large ground-water withdrawals. During the 13-year period 1976 to 1989, water-level declines of 25 feet (1.9 feet per year) were common in the aquifers throughout the study area. Declines have been especially severe in the Antlers and Twin Mountains aquifers, where declines of 100 to 250 feet (7.6 to 19.2 feet per year) have occurred over extensive areas. Water-level declines in the Paluxy and the Woodbine, while not as severe or as extensive as that experienced in the Antlers and Twin Mountains are still significant with declines of up to 150 feet (11.5 feet per year) in some locations.

The study identified a number of existing and potential water-quality problems. Some of these are naturally occurring and are related to geologic structure and/or deposition. In some areas, anomalies in the chemical makeup of water samples suggest that changes in water quality may have occurred due to poor well completion techniques or interformational leakage due to pumpage. In other areas, elevated levels of some chemical constituents suggest contamination related to oil-field activities and other industrial sources. Additional detailed studies will be required to isolate the extent and sources of these contaminated areas.

The projected water demands for the study area by the year 2010 total over 1.4 million acre-feet. Existing surface-water reservoirs can supply 1.6 million acre-feet of water under 2010 conditions, an amount greater than the projected demands. Most of this water, however, is either currently owned or under contract to supply current and future needs in the study area. An additional 179,000 acre-feet of surface water will become available with the completion of the Cooper

Reservoir and completion of the delivery system from Lake Palestine. Reallocation of existing and future surface-water supplies will need to be negotiated between entities facing water shortages and owners of surplus water supplies.

The amount of ground water currently pumped exceeds the estimated annual effective recharge to the area's aquifers. Because the ground-water demands exceed the recharge, a portion of the water pumped is drawn from aquifer storage resulting in water-level declines. Even though the study area has sufficient surface water to meet projected needs through 2010, rural areas that depend on a ground-water supply could face shortages before 2010 due to the limited availability of ground water and the high cost of converting to a surface-water supply.

TABLE OF CONTENTS

	Page
CONCLUSIONS	v
INTRODUCTION	1
Purpose	1
Location and Extent	1
Topography and Drainage	1
Climate	1
Economy	3
Previous Investigations	3
Acknowledgements	4
GEOHYDROLOGY	5
Geologic Framework	5
Source and Occurrence	5
Recharge, Movement, and Discharge	19
Hydraulic Characteristics	20
GROUND-WATER PROBLEMS	22
Water-Level Declines	22
<i>Antlers Formation</i>	22
<i>Twin Mountains Formation</i>	31
<i>Paluxy Formation</i>	32
<i>Woodbine Group</i>	32
Water Quality	32
WATER DEMANDS	51
Population	51
Water Use	51
<i>Public Supply</i>	53
<i>Irrigation</i>	54
<i>Industrial</i>	54
<i>Domestic and Livestock</i>	54
Projected Water Demands, 1990-2010	54
AVAILABILITY OF WATER	57
Current Availability of Ground Water	57
Current Availability of Surface Water	57
Potential for Conjunctive Use of Ground and Surface Water	57
Potential Methods of Increasing Aquifer Recharge	61
<i>Outcrop (Unconfined) Areas</i>	61
<i>Downdip (Confined) Areas</i>	62
Projected Availability Through the Year 2010	62
SELECTED REFERENCES	63

TABLES

1. Geologic Units and Their Water-Bearing Properties	8
2. Current and Projected Population in the Study Area, 1980-2010	52
3. Historical and Projected Demands for Ground and Surface Water in the Study Area	55

TABLE OF CONTENTS - (continued)

FIGURES

	Page
1. Location of Study Area	2
2. Regional Structure in North-Central Texas	7
3. Geologic Map	9
4. Hydrogeologic Section A-A'	11
5. Approximate Altitude of Water Levels in the Antlers and Twin Mountains Formations, 1989	13
6. Approximate Altitude of Water Levels in the Paluxy Formation, 1989	15
7. Approximate Altitude of Water Levels in the Woodbine Group, 1989	17
8. Hydrographs of Selected Wells in the Antlers and Twin Mountains Formations	23
9. Hydrographs of Selected Wells in the Paluxy Formation	25
10. Hydrographs of Selected Wells in the Woodbine Group	27
11. Approximate Water-Level Changes in the Antlers and Twin Mountains Formations, 1976-1989	29
12. Approximate Water-Level Changes in the Paluxy Formation, 1976-1989	33
13. Approximate Water-Level Changes in the Woodbine Group, 1976-1989	37
14. Distribution of Leaking Storage Tanks	39
15. Areas with Significant Water-Quality Problems in the Antlers and Twin Mountains Formations	41
16. Possible Brine Contamination in Southeastern Wise County	45
17. Areas with Significant Water-Quality Problems in the Woodbine Group	47
18. Areas with Significant Water-Quality Problems in the Paluxy Formation	49
19. Surface Reservoirs and River Basins	59

INTRODUCTION

In 1985, the Texas Legislature recognized that certain areas of the State are experiencing, or will experience in the future, critical ground-water problems. This study of ground-water conditions in part of North-Central Texas is in response to the 1985 passage of House Bill 2 by the Sixty-ninth Texas Legislature that called for the identification of critical ground-water areas in the State. The purpose of this report is to describe the geohydrologic conditions of the Trinity Group and other aquifers, and to identify problems related to pumpage overdrafts and contamination of ground water as they exist or are expected to occur.

Purpose

The study area is located in the North-Central Texas Region as shown on Figure 1. The study area has an areal extent of 12,503 square miles and represents about 4.7 percent of the State's total area. The study area includes all or parts of 23 counties: Collin, Cooke, Dallas, Delta, Denton, Ellis, Fannin, Grayson, Henderson, Hood, Hunt, Jack, Johnson, Kaufman, Lamar, Montague, Navarro, Palo Pinto, Parker, Red River, Rockwall, Tarrant, and Wise Counties. The study area lies within the Red, Sulphur, Sabine, Trinity, and Brazos River basins. Primary consideration was given to only that portion of each county in which usable ground water is found within the aquifers of the Trinity and Woodbine Groups. For the purposes of this report, usable ground water is considered to be water containing less than 3,000 milligrams per liter (mg/l) dissolved solids.

Location and Extent

Drainage of the study area is to the east and southeast by the Red, Sulphur, Sabine, Trinity, and Brazos Rivers and their tributaries. Elevations range from about 1,300 feet in the western part of the area to about 280 feet along the Trinity River near the Ellis - Navarro County line.

Topography and Drainage

The land surface of the area is generally flat to undulating in the east, becoming gently rolling westward and giving way to a hilly terrain along the westernmost margins of the study area.

The climate of the region covered by this report is characterized by long, hot summers and short, mild winters. The average minimum temperature for January, the coldest month, ranges from 32°F (0°C) in the northwest to 36°F (2°C) in the southeast. The average maximum temperature for July, the hottest month, is about 96°F (36°C) throughout most of the study area. The annual mean free air temperature for the period 1931-70 averaged 65°F (18°C).

Climate

The average annual precipitation ranges from 30 inches in the northwest to 45 inches in the northeast. These figures are based on National Weather Service records for the 77-year period 1900-76.

The average annual gross lake surface evaporation for the period 1940-70 ranges from 78 inches in the north-central area to 61 inches in the southeast.

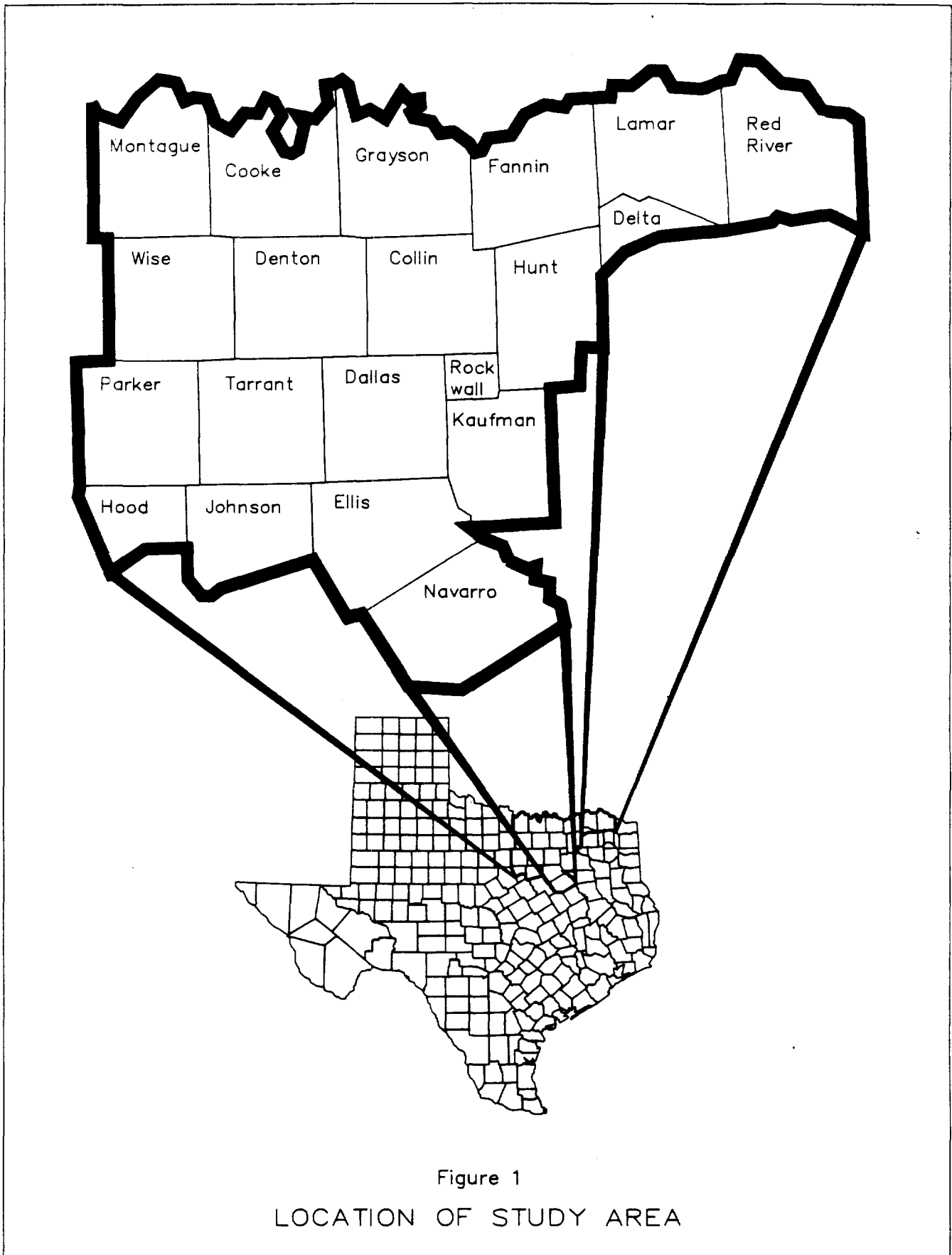


Figure 1

LOCATION OF STUDY AREA

Economy

The area boasts of a truly diversified economy based on agribusiness, mineral production, varied manufacturing and processing, banking and insurance, marketing, distribution and transportation industries, tourism, recreation, and education.

Agriculture production is extensive and varied. Principal crops include grain sorghum, wheat, oats, and other grains; soybeans, peanuts, cotton, and hay. Lamar County is among the leading hay producing counties in the state. Livestock production includes beef and dairy cattle, horses, hogs, and poultry. Dairying is practiced throughout much of the area and is an important industry. Johnson and Wise Counties are among the leading dairy counties in the state.

Mineral production in the area includes oil and gas, sand and gravel, clays, and stone.

Manufacturing and processing industries are generally located in or near the cities and towns in the area. Products include food, clothing, building materials and supplies, plastics, glass and rubber products, electronic equipment, oil field equipment and supplies, heating and cooling equipment, chemicals, metal and wood products, aircraft, automobiles, mobile homes, medical and surgical supplies, farm supplies and equipment, furniture, office supplies and equipment, boats and other recreational equipment, and many others.

Dallas and Fort Worth, the State's second and fourth largest cities respectively, along with their suburbs, constitute the Dallas-Fort Worth metroplex. The metroplex is a center for national and world trade, commerce, finance and insurance. In addition, more than 4,000 manufacturing plants produce a wide variety of products. Transportation facilities, including one of the nation's largest airports, make it a major center for wholesale and retail trade distribution and business management. The metroplex offers outstanding convention, recreation, and cultural facilities.

Large federal expenditures, especially in the defense industries, contribute substantially to the area's economy.

Over 30 institutions of higher education are located in the area.

Extensive recreational facilities contribute substantially to the area's economy. Numerous lakes provide opportunities for fishing, boating, and other water sports. Several state parks are also located in the area.

Many local festivals and events, historical sites, county fairs, and the Texas State Fair, the largest in the nation, all add to the area's tourist trade.

The ground-water resources in the North-Central Texas Region have been discussed in varying degrees of detail in several previously published reports. Early investigations include those of Stramel (1951) and Leggatt (1957) which describe the geology and ground-water resources in Parker County and Tarrant County, respectively.

Previous Investigations

Reconnaissance level studies of the Red, Sulphur, and Cypress River basins, (Baker, et al., 1963); Trinity River basin, (Peckham, 1963); and the Brazos River basin (Cronin, et al., 1963) provided general information on the geology and ground-water resources in most of the area of the North-Central Texas Region.

Since 1960, detailed reports on ground-water resources have been published in five counties of the region. These county reports include: Ellis (Thompson, 1967a), Grayson (Baker, 1960b), Johnson (Thompson, 1967b), Montague (Bayha, 1967), and Navarro (Thompson, 1972).

A regional investigation of ground-water resources in an area encompassing most of the North-Central Texas Region was accomplished by Nordstrom (1982). This investigation which began in January 1975 and concluded in August 1978, is the most comprehensive study of ground-water resources in the region.

Studies of the ground-water resources of the Nacatoch Sand (Ashworth, 1988) and the Blossom Sand (McLaurin, 1988) provide detailed information on these important aquifers in the eastern and northeastern-most parts of the North-Central Texas Region.

In addition to the above publications, several reports describing the geology and ground-water resources in areas smaller than counties have been prepared from time to time. Some of these reports have been published. Others are available in the files of the U.S. Geological Survey and the Texas Water Development Board. The most important ones are listed in the selected references at the end of this report.

Acknowledgements

The Texas Water Development Board wishes to express its appreciation to the many water well owners in the North-Central Texas Region for permitting access to their properties and permitting water levels in their wells to be measured and water samples to be taken for analysis. Special thanks are due to those well owners who, often at some inconvenience, agreed to shut off their pumps for extended periods of time to permit static water levels to be determined. Their cooperation and assistance are gratefully acknowledged.

In addition, thanks are due to those public supply and industrial well owners in the region who annually participate in the Board's water-use inventory, thus providing valuable information necessary to evaluate the effects of ground-water pumpage on water levels and water quality in the various aquifers.

This report was prepared under the general supervision of T.R. Knowles, Director of Planning, and Henry Alvarez, Chief of the Texas Water Development Board's Ground Water Section.

GEOHYDROLOGY

Geologic Framework

Stratigraphic units that supply fresh to slightly saline water to wells in the study area range in age from Paleozoic to Recent. The North-Central Texas Region includes several prominent geologic structures as shown in Figure 2. The most important structural features affecting the Trinity Group and subsequent geologic formations are the southeast regional dip of the pre-Cretaceous erosional surface and the extensive fault trends in the eastern part of the area.

The Trinity Group of Cretaceous age contains the largest and most prolific aquifer in the study area. The aquifer consists of the Antlers, Twin Mountains and Paluxy Formations. The Antlers is a coalescence of the Paluxy and Twin Mountains in the northern part of the study area where the Glen Rose Formation is no longer traceable (Table 1). The lower sands and shales of the Twin Mountains are the hydrologic equivalent of the basal portion of the Antlers. The younger Woodbine Group overlies the Fredricksburg and Washita Groups that function as an aquitard between the Woodbine and the stratigraphically lower Paluxy Formation. The outcrop areas of the various geologic units are shown on Figure 3. The stratigraphic relationship, approximate thickness, brief description, and water-bearing characteristics of the geologic units occurring in the North-Central Texas Region are summarized in Table 1. A hydrogeologic section portraying the structure and relationship of the various stratigraphic units is shown on Figure 4.

Additionally, the geology of the study area has been presented in varying detail in several county and regional reports which are listed in the selected references at the end of this report. Especially recommended is "Occurrence, Availability, and Chemical Quality of Ground Water in the Cretaceous Aquifers of North-Central Texas" by Nordstrom (1982). The Nacatoch and Blossom Sand aquifers are discussed in Texas Water Development Board Reports 305 and 307. These reports summarize the geologic history, structure, and stratigraphic framework, and their effects on the occurrence of ground water in the study area. Consequently, it is beyond the scope of this report to present a detailed description of the geology of the study area, which would repeat much of the material previously published. It is hoped, however, that the condensed geologic information provided in Table 1 along with Figures 2 through 7 will be sufficient to utilize the ground-water information presented in this report.

The Antlers Formation is a coalescence of the Twin Mountains and Paluxy Formations. It occurs northwest of a line where the Glen Rose Formation thins to extinction and is no longer a traceable or distinguishable unit separating the Paluxy and Twin Mountains Formations. The Antlers Formation crops out mainly in Cooke, Montague, and Wise Counties (Figure 3), and dips below younger strata to the southeast.

The primary source of ground water in the Antlers Formation is precipitation on the outcrop. The average annual precipitation on the outcrop is about 32 inches. Surface-water seepage from lakes

Source and Occurrence

and streams on the outcrop is also a source of recharge. Water in the outcrop area is unconfined and therefore under water-table conditions. Downdip from the outcrop, the water is confined under hydrostatic pressure and is under artesian conditions.

The Twin Mountains Formation crops out in the western part of the study area in Hood, Parker, and Wise Counties. Figure 3 shows the location and extent of the outcrop. The Twin Mountains directly overlies older Paleozoic rocks and is stratigraphically the lowest formation in the Trinity Group. The Twin Mountains is overlain by the Glen Rose Formation. In Wise, Denton, Cooke, and Grayson Counties where the Glen Rose Formation thins and is no longer traceable or distinguishable, the Twin Mountains is considered to be the stratigraphic and lateral equivalent of the lower sands of the Antlers Formation. The Twin Mountains dips eastward beneath younger strata.

The primary source of ground water in the Twin Mountains is precipitation falling on the outcrop. Other minor sources include surface-water seepage from ponds, lakes, and streams cutting the outcrop. The average annual precipitation is about 30 inches. Downdip, however, the ground water is confined by impermeable strata and is under artesian conditions.

The Paluxy Formation crops out in Hood, Parker, Tarrant, and Wise Counties (Figure 3). The Paluxy overlies the Glen Rose Formation which separates the Paluxy from the basal Trinity, Twin Mountains Formation. In Wise, Denton, Cooke, and Grayson Counties, the Glen Rose thins and is no longer a distinguishable unit. In this area, the Paluxy coalesces with the underlying Twin Mountains to form the Antlers Formation. The Paluxy is considered to be the stratigraphic equivalent of the upper sand units of the Antlers Formation. East of the outcrop, the Paluxy dips eastward beneath younger strata.

The primary source of recharge to the Paluxy is precipitation on the outcrop. Secondary sources include recharge from streams flowing across the outcrop and surface-water seepage from lakes. The Brazos and Trinity River systems and Eagle Mountain Reservoir are a few examples. The average annual precipitation on the outcrop is about 31 inches.

Water in the outcrop area is under water-table conditions and water levels remain fairly constant with only normal seasonal fluctuations. In downdip areas, water is under artesian conditions, and is confined under hydrostatic pressure by overlying formations.

The Woodbine is exposed at the surface in a north-south trending zone across Johnson, Tarrant, Denton, Cooke, and Grayson Counties and then eastward generally paralleling the Red River across parts of Fannin, Lamar, and Red River Counties (Figure 3). From its outcrop, the Woodbine dips eastward beneath younger strata.

The primary source of ground water in the Woodbine is rainfall on the outcrop. This area receives an average annual rainfall from 33 inches in the south to 37 inches in the north. Other sources of ground water include surface-water seepage from lakes and streams. Water occurs in saturated sand beds under both water-table and

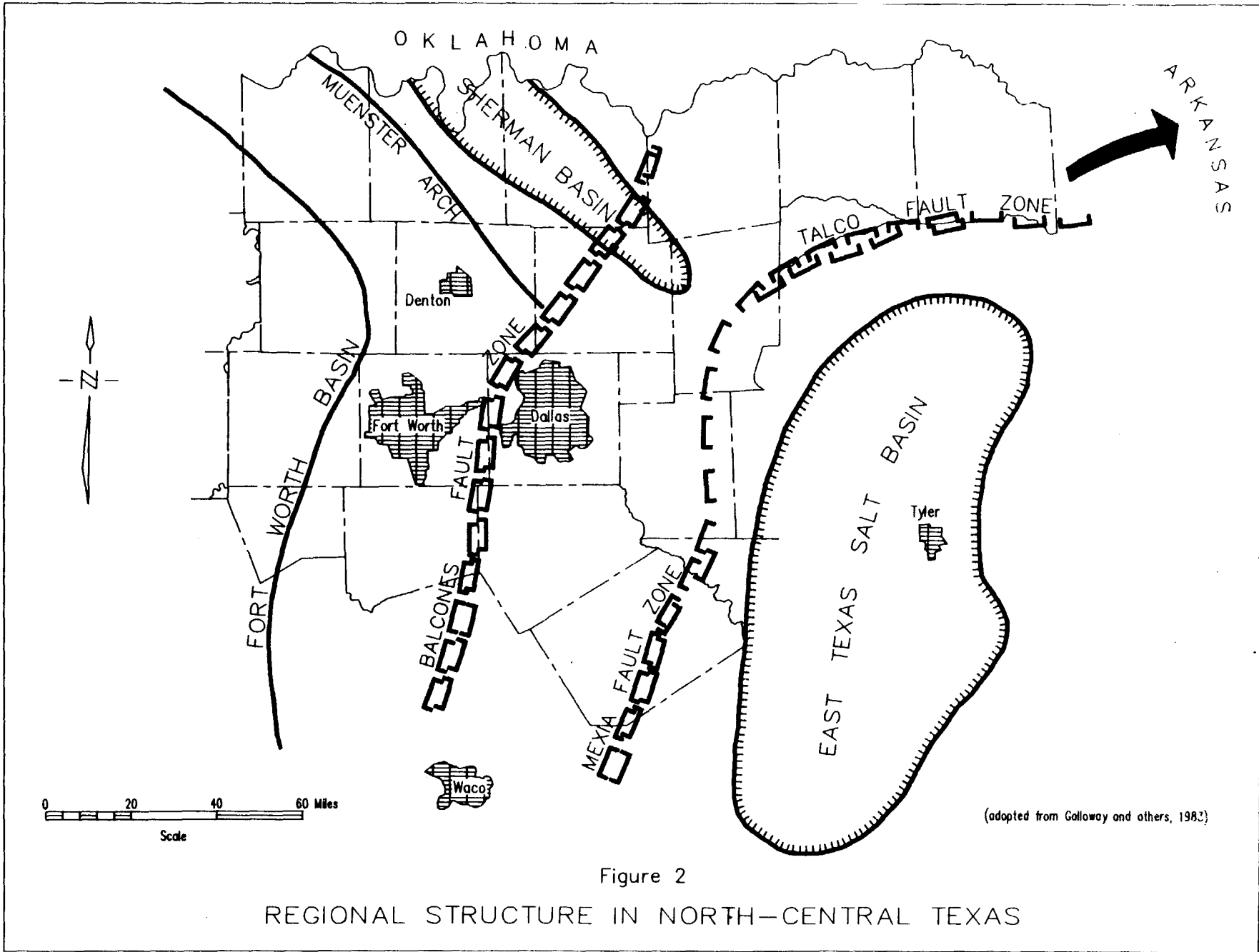


Figure 2
REGIONAL STRUCTURE IN NORTH-CENTRAL TEXAS

Table 1. Geologic Units and Their Water-bearing Properties

Era	System	Series	Group	Stratigraphic units	Approximate maximum thickness (feet)	Character of rocks	Water-bearing characteristics*	
Cenozoic	Quaternary	Holocene		Alluvium	75	Sand, silt, clay and gravel.	Yields small to large amounts of fresh water to wells along the Red River.	
		Pleistocene		Fluviatile terrace deposits				
Mesozoic	Cretaceous	Gulf	Navarro	Kemp Clay Corsicana Marl Nacatoch Sand	800	Fossiliferous clay and hard limy marl; fine sand, fossiliferous.	Upper members are not known to yield water to wells in area; lower member yields small to moderate quantities of fresh to slightly saline water near the outcrop.	
			Taylor	Marlbrook Marl Pecan Gap Chalk Wolfe City - Ozan Formations	1,500	Clay, marl, mudstone, and chalk.	Yields small quantities of water to shallow wells.	
			Austin	Gober Chalk Brownstown Marl Blossom Sand Bonham Formation	700	Chalk, limestone and marl; fine to medium sand, fossiliferous.	Yields small to moderate quantities of fresh to moderately saline water to wells in the northeastern part of the area; very limited as an aquifer.	
			Eagle Ford		650	Shale with thin beds of sandstone and limestone.	Yields small quantities of water to shallow wells.	
			Woodbine		700	Medium to coarse iron sand, sandstone, clay and some lignite.	Yields moderate to large quantities of fresh to slightly saline water to municipal, industrial and irrigation wells.	
		Comanche	Washita		1,000	Fossiliferous limestone, marl, and clay; some sand near top.	Yields small quantities of water to shallow wells.	
			Fredericksburg		250	Limestone, clay, marl, shale, and shell agglomerates.	Yields small quantities of water to shallow wells.	
			Trinity	Antlers Formation	Paluxy Formation	400	Fine sand, sandy shale, and shale.	Yields small to moderate quantities of fresh to slightly saline water to wells.
					Glen Rose Formation	1,500	Limestone, marl, shale, and anhydrite	Yields small quantities of water in localized areas.
					Twin Mountains Formation	1,000	Fine-to-coarse sand, shale, clay, basal gravel, and conglomerate	Yields moderate to large quantities of fresh to slightly saline water to wells.
Paleozoic				Paleozoic rocks undifferentiated	Sandstone, limestone, shale and conglomerate	Yields small quantities of water in the western part of the area.		

* Yields of wells: *small* - less than 100 gallons per minute (gpm); *moderate* - 100 to 1,000 gpm; *large* - more than 1,000 gpm
 Chemical Quality of Water: *fresh* - less than 1,000 milligrams per liter (mg/l); *slightly saline* - 1,000 to 3,000 mg/l
moderately saline - 3,000 to 10,000 mg/l; *very saline* - 10,000 to 35,000 mg/l; *brine* - more than 35,000 mg/l.

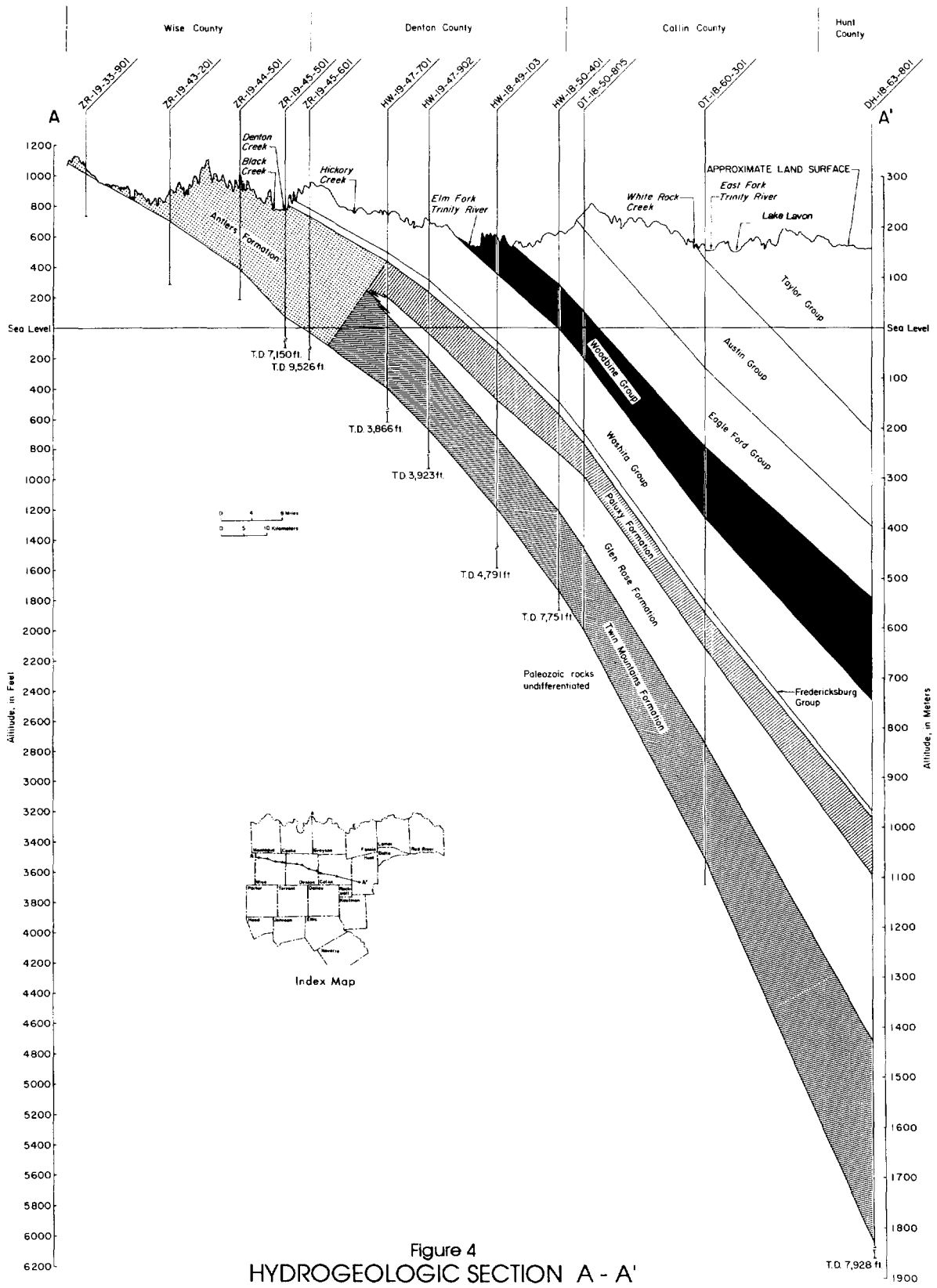


Figure 4
HYDROGEOLOGIC SECTION A - A'

(Modified from Nordstrom, 1992)

artesian conditions. Water-table conditions occur in or near the outcrop, while artesian conditions prevail downdip.

The Nacatoch and Blossom Sands of the Navarro and Austin Groups, respectively, are important aquifers in the eastern part of the study area (Figure 3).

The outcrop of the Nacatoch Sand extends in a northerly direction from Limestone to Hunt County where it trends to the northeast and passes through Red River County into Bowie County (Ashworth, 1988). The Blossom Sand crops out in central Fannin County and extends eastward through Lamar and Red River Counties (McLaurin, 1988). The primary source of ground water in the Nacatoch and Blossom Sands is rainfall on the outcrop, and indirectly, through seepage from streams and lakes.

Water occurs in saturated sand beds under both water-table and artesian conditions; downdip water is under artesian conditions and is confined under hydrostatic pressure by overlying formations.

Total effective recharge for the Trinity Group aquifers in the study area in each river basin was modified from Texas Department of Water Resources Report 238, "Ground-Water Availability in Texas." The annual effective recharge to the Trinity Group aquifers is a little less than 50,000 acre-feet.

Recharge, Movement, and Discharge

The average rate of movement of ground water in the Antlers, Twin Mountains, and Paluxy Formations of the Trinity Group is about 1 to 2 feet per year (Nordstrom, 1982). Ground water moves generally in an east-southeast direction. The approximate piezometric surface of ground water of the Trinity Group aquifers illustrating direction of flow is shown on Figures 5 and 6. In areas of heavy pumpage, a cone of depression forms in the piezometric surface and the direction of ground-water movement is toward these points of discharge from all directions.

Ground water is discharged naturally from the Trinity Group aquifers by springs and evapotranspiration, and artificially by pumpage. In 1985, over 106,000 acre-feet of ground water was pumped from the Trinity and Woodbine Group aquifers in the study area.

Recharge to the Woodbine occurs in the outcrop area which consists of a permeable, sandy soil conducive to infiltration of rainfall and seepage from streams. The annual effective recharge to the Woodbine is a little over 24,000 acre-feet (Texas Department of Water Resources, 1984). The movement of water follows an east-southeast direction from the outcrop, generally paralleling the dip of the beds. The hydraulic gradient varies from over 37 feet per mile to less than 13 feet per mile within the study area except for minor local variations. Heavy pumpage around the City of Sherman is reflected in the deflection of the contours on Figure 7, which shows the appropriate altitude of water levels in the Woodbine aquifer for 1989.

Recharge to the Nacatoch aquifer is primarily accomplished by the downward percolation of precipitation on the formation outcrop. Soils associated with the Nacatoch outcrop are described by the Soil

Conservation Service as generally being loose, acidic, sandy to silty loam at the surface and underlain by dense clay subsoils (Ashworth, 1988).

In the Nacatoch aquifer, the downdip movement of ground water is controlled in part by the numerous faults which traverse the formation. Movement of water is in the direction at right angles to the contours of the potentiometric surface and in the direction of its decreasing elevation.

Locally, ground water is diverted toward areas of heavy pumpage in the Nacatoch that produces extensive cones of depression. Discharge from the Nacatoch aquifer occurs primarily as pumpage from wells with municipalities representing the largest users.

Recharge of the Blossom Sand aquifer occurs primarily through infiltration of precipitation. Deep loamy soils on most of the Blossom Sand outcrop are derived from argillaceous sediments and are generally very slowly permeable. High-level terrace deposits in places cover the Blossom Sand aquifer and form a good recharge facility to the Blossom (McLaurin, 1988).

Ground water in the Blossom Sand aquifer moves down-gradient and perpendicular to the contours of the potentiometric surface, normally in a south-southeasterly direction.

Discharge of ground water in the Blossom Sand aquifer occurs naturally through seeps and springs and artificially through pumpage of wells. In 1985, the estimated amount of ground-water pumped for all uses from the Nacatoch and the Blossom Sand aquifers was 3,300 acre-feet.

Hydraulic Characteristics

The quantity of water an aquifer yields depends upon its ability to store and transmit water. Not all water in storage is recoverable by pumping because of the molecular attractions between rock particles and water molecules. Formulas have been developed to show relationships between well yields and the coefficients of permeability, transmissibility, and storage.

Test results from Nordstrom (1982) show that transmissibility values are generally higher in the central, northern, and eastern sections of the study area. The range of coefficients of transmissibility determined in the Twin Mountains Formation was 1,950 to 12,700 gallons per day per foot [(gal/d)/ft]. The average for tests in Dallas County was 12,700 (gal/d)/ft; in Tarrant County 8,450 (gal/d)/ft; and Johnson and Ellis Counties 6,480 (gal/d)/ft. Permeability values ranged from 8 to 165 (gal/d)/ft², with an average value of 68 (gal/d)/ft². Storage coefficients ranged from 0.0005 to 0.00004 with an average value of 0.0001.

Results of pumping tests within the study area on Paluxy public-supply wells showed that transmissibility values ranged from 1,263 to 13,808 (gal/d)/ft, with an overall average of 3,700 (gal/d)/ft. (Nordstrom, 1982). Coefficients of permeability ranged from 6 to 150 (gal/d)/ft², with an overall average of 50 (gal/d)/ft² (Nordstrom, 1982).

Generally, the more permeable sands of the Woodbine occur on or near the outcrop, where permeability ranged from 84 to 167 (gal/d)/ft² (Nordstrom, 1982). Farther downdip, the average coefficient of permeability was 44 (gal/d)/ft² (Nordstrom, 1982). Transmissibility values ranged from 1,320 to 14,700 (gal/d)/ft with an average value of 4,700 (gal/d)/ft (Nordstrom, 1982). Downdip, where the aquifer is under artesian conditions, the average coefficient of storage is approximately 0.00015 (Nordstrom, 1982).

Pumping tests from the Nacatoch in Hunt and Delta Counties indicated an average transmissibility of 2,506 (gal/d)/ft (Ashworth, 1988). Coefficients of storage in the artesian portion of the aquifer generally ranged from 0.00001 to 0.001 (Ashworth, 1988).

The transmissibility of the Blossom Sand aquifer ranged from 636 to 4,107 (gal/d)/ft (McLaurin, 1988). Two pumping tests conducted on the wells of the City of Clarksville in Red River County showed coefficients of storage of 0.00007 and 0.00003, respectively (McLaurin, 1988).

GROUND-WATER PROBLEMS

Water-Level Declines

A ground-water problem of regional consequence in the study area is the decline of water levels and the reduction of artesian pressure in the aquifers.

Ground-water conditions pertaining to water levels of the principal aquifers in the study area during the first half of 1989 are presented on the following pages. The principal aquifers are the Antlers, Twin Mountains, and Paluxy Formations of the Trinity Group, and the Woodbine Group. Because each has its own unique history of development and water-bearing characteristics, each unit is discussed separately. The Twin Mountains and the Antlers Formations are closely related hydrologically, and are grouped together on the illustrations.

The static water level in an artesian well defines the piezometric surface of an aquifer at that specific location. Fluctuations in this surface can be caused by many different factors. Small daily changes can occur in response to barometric pressure, tidal effects, and temperature. Seasonal fluctuations are the result of changes in the amount of precipitation and evapotranspiration around the recharge zone, and rates of aquifer discharge. In general, the rate of recharge versus discharge in an aquifer controls the water level. The primary factor causing fluctuations in the water level in a developed area is the amount of pumpage or withdrawal by wells. In the North-Central Texas Region, water is being withdrawn from the aquifers in amounts exceeding recharge. This causes water to be removed from storage and water levels to decline. Figures 8, 9, and 10 illustrate water-level fluctuations for aquifers in the study area.

Antlers Formation

On or near the outcrop of the Antlers Formation the aquifer is unconfined and water-table conditions occur. Historical data indicates that water levels in the outcrop area tend to fluctuate seasonally in response to the amount of rainfall and pumpage. A hydrograph of well 19-20-801, Figure 8, illustrates water-level fluctuations typical of the outcrop area. These fluctuations may be due to pumpage for irrigation purposes; however, no long-term declines have developed.

In the downdip or confined portion of the aquifer, static water levels have continued to decline in wells completed in the Antlers Formation. Figure 5 shows the approximate configuration of the piezometric surface of ground water in the Antlers Formation in 1989. An extensive cone of depression occurs in the vicinity of Sherman in Grayson County, corresponding to large ground-water withdrawals in the area. Smaller areas of depression occur at other pumping centers in the vicinity of Gainesville, Muenster, and Era.

The approximate changes in water levels of select wells in the Antlers Formation between 1976 and 1989 are shown on Figure 11. Declines in excess of 200 feet have occurred in wells that are part of the City of Sherman's field south of the city. Declines over 100 feet have occurred near Gainesville in Cooke County. Well 19-24-702, located

east of Gainesville, showed a net water-level decline of 118 feet between 1976 and 1989, which averages to just over a 9 feet per year decline. Declines of similar magnitude have occurred in most of southeastern Cooke County and northern Denton County. Hydrographs showing typical water-level changes in the Antlers are depicted on Figure 8.

Ground water in the Twin Mountains Formation occurs under water-table conditions in or near the outcrop. Downdip, the ground water is confined by less permeable strata and is under artesian conditions. The approximate altitude of water levels in the Twin Mountains aquifer for the year 1989 is shown in Figure 5. The predominate feature in the illustration is the ellipsoidal cone of depression encompassing eastern Tarrant and western Dallas Counties and extending southward into Johnson and Ellis Counties and northward into Denton County. Two localized cones are present within the large regional depression corresponding to pumpage centers at the Cities of Hurst, Irving, and Grand Prairie. The present long axis of the elongate depression is oriented roughly north-south. This depicts a change in the historical pumping pattern and a shift from the east-west trending depression that encircled Tarrant and Dallas Counties in 1976 that was centered near the City of Euless.

*Twin Mountains
Formation*

Many large volume ground-water users concentrated in the Dallas-Fort Worth area have converted to surface-water supply sources. Reduction of pumpage by these major users has been offset by continued increases by numerous smaller municipal users, utility districts, and water-supply corporations outside the Dallas-Fort Worth metroplex area. Changing pumpage patterns are reflected in changing water levels, which are declining in areas of increased pumpage and recovering in some local areas where total ground-water withdrawals have been reduced. This is well illustrated in Figure 11, which shows the water-level changes from 1976 to 1989 for the Twin Mountains Formation. Well 32-16-101 in Tarrant County has registered a 126-foot gain in its water level over this 13-year period.

Areas experiencing significant water-level declines are now located north of the metroplex area, in southern Denton County, and south of the metroplex area, in Johnson County. In Denton County, recorded declines range from 65 to 292 feet over this same 13-year period, representing average decline rates of 5 to 22 feet per year. In western Ellis and much of Johnson County, declines over 150 feet are common. In the vicinity of the City of Alvarado, declines are in excess of 200 feet which is over a 15 feet per year average.

A Texas Water Development Board water-level observation recorder well in Dallas County has undergone a net decline of only a little over 40 feet since 1976, and since 1986 the water level has actually risen. Figure 8 shows a hydrograph of this well (33-19-101) and others completed in the Twin Mountains Formation.

The Paluxy Formation dips eastward beneath younger strata, at rates varying from 30 feet per mile near the outcrop to about 80 feet per mile near the down-dip limit of fresh to slightly saline water.

Near the outcrop, the hydraulic gradient is approximately the same as the dip of the strata. The approximate piezometric surface of ground water in the Paluxy Formation is illustrated in Figure 6. The dominate feature is the broad cone of depression located in western Dallas and eastern Tarrant Counties. Also, notice the smaller cone in Johnson County that corresponds to withdrawals in the communities of Alvarado and Lillian.

Paluxy Formation

The same general trend in water-level declines that was noted in the Twin Mountains Formation is also occurring in the Paluxy Formation. This is illustrated on the water-level change map on Figure 12. During the past 13 years, water levels have actually risen in parts of Tarrant County. A Texas Water Development Board observation well in the City of Hurst showed a net rise of 14 feet since 1976. Areas of decline have migrated north and south of the metroplex area and now occur in central Denton County with declines of over 100 feet near the communities of Cross Roads, Krugerville, and Lincoln Park, and in eastern Johnson County with declines approaching 150 feet near the pumpage center of the City of Alvarado. These trends are also depicted by select hydrographs shown in Figure 9.

Woodbine Group

The outcrop of the Woodbine Group occurs as a thin band extending north-south through the approximate geographic center of the study area. The approximate altitude of water levels in the Woodbine Group for the year 1989 is shown in Figure 7. Unlike the other main aquifers discussed, there is no regional cone of depression, and in fact, the contours are relatively linear in nature. The only deviation to this is the deflection of the contours around the City of Sherman in Grayson county due to heavy pumpage in the area.

Water Quality

The approximate changes in water levels from 1976 to 1989 in selected wells completed in the Woodbine Group are shown on Figure 13. The main feature is the cone of depression in eastern Grayson, southwestern Fannin, and northern Collin Counties. Declines ranging from 57 to 123 feet have occurred near the City of Sherman, and declines in excess of 100 feet have occurred near Anna and Blue Ridge in Collin County. The largest decline was found in well 18-38-302, a public-supply well for the City of Randolph in Fannin County, which showed a net decline of 159 feet or 12.2 feet per year over the past 13 years. Much more moderate declines of less than 50 feet have occurred in the rest of the study area. Hydrographs that depict typical trends in water-level changes in the Woodbine Formation Group are shown on Figure 10.

The chemical character of water mirrors the mineral composition of the rocks through which it has passed. As water moves through its environment, its solvent power dissolves some of the minerals from surrounding rocks. These dissolved mineral concentrations generally increase with depth and temperature. Neutralizing or removing the unwanted constituents is usually difficult and can be very costly.

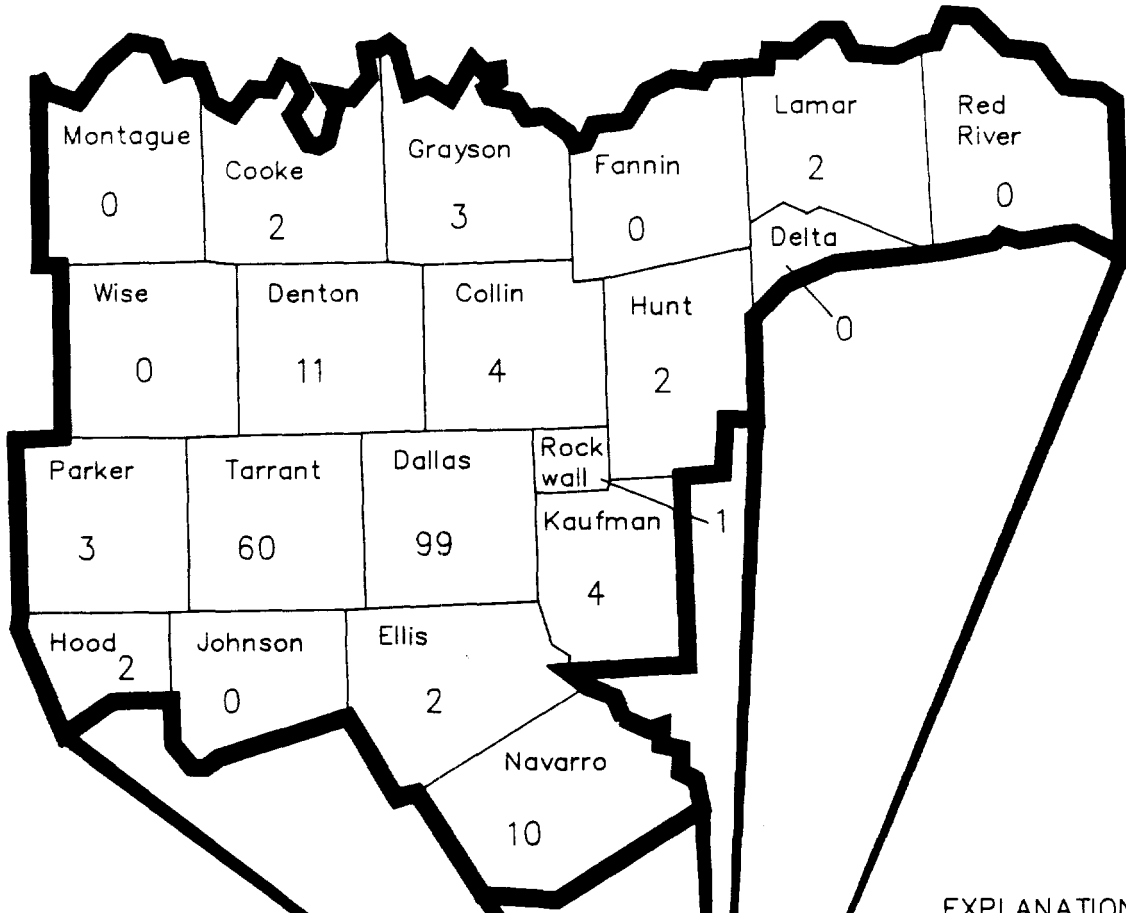
Standards for specific mineral constituents are thoroughly discussed in Texas Water Development Board Report 269 (Nordstrom, 1982), as well as publications of the Texas Department of Health. These standards vary according to the type of water usage.

Chemical analyses of 320 water samples collected by the Texas Water Development Board staff provided the data base for this portion of the study. These samples were collected over the past 5 years throughout the study area. In addition to routine chemical analysis, many samples were analyzed for heavy metals, radioactivity, and total organic carbons (TOC). Together, these analyses identified several water-quality problems in the study area.

Aquifers are especially susceptible to contamination on the outcrop, where direct infiltration to the water table can cause immediate problems. A densely populated industrial area located on the outcrop can host many sources of contamination. Figure 14 illustrates the large number of confirmed leaking storage tanks in the study area that are known to have caused a degradation of water quality according to current Texas Water Commission records. The Woodbine Group outcrops in a thin belt extending north and south in this same area, and is most susceptible to this source of contamination. Additionally, high concentrations of oil and gas fields are located on the outcrops of the Antlers, Twin Mountains, and Paluxy Formations. Brines are waters containing more than 35,000 mg/l of total dissolved solids, and are a by-product of oil and gas operations. Brine disposal has produced vegetative kills in areas where it was allowed to flow onto the ground (Bayha, 1967; and Texas Water Commission, 1989). Because of the sandy nature of the soil on the outcrop, brines can readily percolate downward to contaminate the ground water. Figure 15 shows an area in southeastern Wise and adjoining parts of Tarrant and Denton Counties where elevated concentrations of dissolved solids, chloride, and sodium suggest possible brine contamination. An increase in any of these constituents can make the water unsuitable for drinking or irrigation. Also, poorly plugged or abandoned oil or gas wells can be conduits allowing poor quality water to encroach into fresh-water sands. Figure 16 illustrates a case of possible brine contamination in southeastern Wise County. Concentrations of chemical constituents in water from an apparently brine contaminated well (19-51-903) are compared with chemical concentrations typical of the native quality water from the Twin Mountains Formation.

Generally, ground water pumped from the outcrops of the Antlers, Twin Mountains, and Paluxy aquifers meets all Texas Department of Health primary and secondary standards for public water-supply systems. Water samples from the Woodbine Group's outcrop in southern Tarrant and Johnson Counties exhibit naturally occurring levels of sulfate that exceed the Health Department's recommended limits. Figure 17 shows the extent of this sulfate-rich facies.

As these formations dip below the surface, other factors can have an influence on the ground water. For example, in Grayson County, ground-water flow in the Antlers Formation is restricted within the Sherman basin (Figure 2). The consequence of this structural feature is a resulting saline water mass within the basin trap (Caughey, 1977). This structurally induced geochemical change is illustrated on Figure 15. Baker and others (1963) consider this feature a contamination source in the heavily pumped area around the City of Sherman.



EXPLANATION

25 - Number of tanks having an impact on ground water or other drinking sources as of October 13, 1989

(Source: Texas Water Commission Files)

Figure 14
 DISTRIBUTION OF LEAKING STORAGE TANKS

Two anomalies of water quality that occur in the Twin Mountains Formation in southeastern Wise, southwestern Denton, and Tarrant Counties are also delineated in Figure 15. The larger anomaly indicates an area of higher than normal dissolved-solids concentrations and may be the result of large ground-water declines. The increased dissolved solids of the water may also be due to leakage of water from the overlying Glen Rose Formation which is usually high in sodium, chloride, and sulfate content. The leakage between formations would be increased where poor well completion occurs along with heavy pumpage. An additional source of contamination may be the movement of poor-quality ground water into the centers of pumping due to changes in flow direction. These possibilities are difficult to assess because the poorer quality water moving toward the centers of pumpage may not reach the wells for years. Another reason is historical data for comparison is scarce, and finally, any apparent changes may be enhanced by poor well construction, which may allow water of poorer quality to enter the well bore and mix with formational water.

In addition to the problems described above, the smaller anomaly (Figure 15) exhibits levels of chloride concentrations which exceed the Texas Department of Health's recommended standard for public-supply systems, as well as very high concentrations of sodium. Wells recently sampled have reflected elevated concentrations of strontium and bromide. These elements are all indicative of possible contamination from oil and gas production as well as various other forms of industry. Additional studies are being conducted by other entities within the area.

In general, ground-water quality in the Paluxy is good throughout the study area. However, two areas occur within the Paluxy aquifer where ground water has high levels of sodium and chloride. One occurs to the southeast of Lake Lewisville in Denton County and the other in Johnson and Ellis Counties (Figure 18). In Denton County, no historical data exists to determine whether Lake Lewisville or the large water-level declines, or both (Figure 12) contribute to the poor quality water. The area further south has historical data back to the 1950's and 60's that indicates the high levels of chloride and sodium are probably naturally occurring.

Ground-water production from the Paluxy aquifer is very limited in Lamar and Red River Counties because of the change in hydrogeologic characteristics of the aquifer. This is due to a facies change from sand to muds and shales that limit water movement and consequently produce poor quality water.

Other investigations along with sampling for this study indicate that high levels of strontium, barium, bromide, and iodide are present in Paluxy wells in parts of Tarrant County. These are believed to represent local industrial sources of contamination and are still being studied.

As mentioned earlier, the Woodbine aquifer in the southern outcrop area of Tarrant and Johnson Counties has consistently high levels of sulfate. This is also true within the southern artesian portion of the aquifer (Figure 17). This is apparently naturally occurring and is associated with extensive non-commercial lignite beds. Boron levels

are also high throughout the Woodbine Group. This is naturally occurring and is a result of ancient vulcanism depositing layers of ash (Plummer and Sargent, 1931). This renders the ground water in this area unsuitable for irrigation due to the toxicity of boron to plants.

Finally, large and continuing water-level declines can reverse the natural water-level gradient and direction of flow near the downdip (eastern) side of the study region. Mineral concentrations may, in time, become more pronounced on a regional basis due to the induced reversal of ground-water flow. This study did not develop conclusive evidence of water-quality deterioration along any of the slightly saline water (3,000 mg/l) lines. However, the potential for the updip movement of poor-quality water exists and is likely to become more acute if water levels continue to decline.

POSSIBLE BRINE CONTAMINATION IN SOUTHEASTERN WISE COUNTY

Units are in milligrams per liter

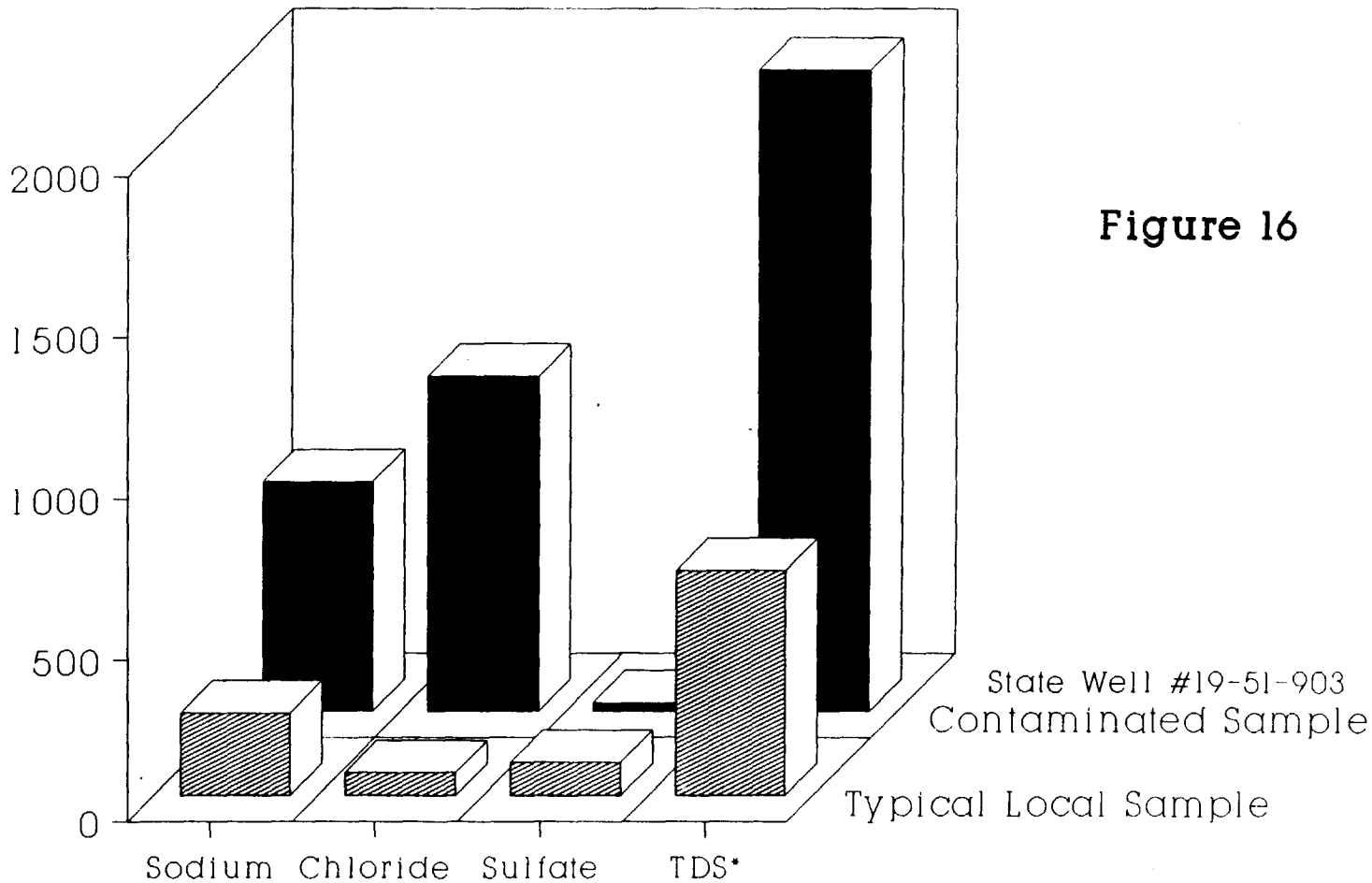


Figure 16

State Well #19-51-903
Contaminated Sample

Typical Local Sample

* TDS - Total Dissolved Solids

WATER DEMANDS

Population

The 1980 and 1985 population for cities, rural areas, and counties included in the study area along with projected estimates for the year 1990, 2000, and 2010 are shown in Table 2.

The population of the study area in 1980 was determined from the 1980 census population data gathered by the U.S. Department of Commerce, Bureau of the Census. The populations of cities with over 1,000 people were taken from Bureau of Census statistics. Rural areas and cities with less than 1,000 population are considered collectively as "County Other." The percent of area of each enumeration district or Census tract lying only partially in the study area was calculated. This percent was applied to the population of the given tract or district to estimate the 1980 population residing in the study area. The 1985 population for cities was determined by interpolating the Bureau of Census 1984 and 1986 city population estimates. The 1985 "County Other" population estimates were produced by projecting previously calculated growth rates to 1990 and interpolating for 1985. Population projections were estimated by extending Bureau of Census Statistics according to growth rates used in the 1988 Texas Water Development Board Revised Data Series.

The population of the study area increased 19 percent during the period 1980 to 1985. The projected population of the study area is forecast to increase by 62 percent from 1980 to the year 2000 and by 86 percent from 1980 to 2010. The highest projected growth for a major city within the study area is Flower Mound in Denton County with a 445 percent increase from 1980 to 2010. The least amount of growth of a major city in the study area is Clarksville in Red River County with an 8 percent increase from 1980 to 2010.

In 1985, a total of 109,718 acre-feet of ground water was pumped from the water-bearing strata in the study area for public supply, irrigation, industrial, domestic, and livestock purposes. Of this total, a little over 106,400 acre-feet or 97 percent was pumped from the Trinity Group aquifer and Woodbine Group. The remaining 3 percent was pumped from other water-bearing strata in the study area, principally the Nacatoch and Blossom Sands. The following table shows the pumpage from all aquifers by use for 1985.

Water Use

<u>Use</u>	<u>1985 Pumpage (Acre-feet)</u>
Public Supply	46,801
Irrigation	6,497
Industrial	16,233
Domestic	34,843
Livestock	5,344
Total	<u>109,718</u>

Table 2
Current and Projected Population in the Study Area ¹, 1980-2010

	1980	1985	1990	2000	2010
Major Cities ²	2,862,379	3,392,798	3,859,417	4,456,468	5,083,444
County Other ³	286,521	357,339	436,530	628,202	774,298
Total	<u>3,148,900</u>	<u>3,750,137</u>	<u>4,295,947</u>	<u>5,084,670</u>	<u>5,857,742</u>
*Collin	141,771	193,112	248,827	346,633	449,517
Cooke	26,676	27,917	29,498	33,295	37,874
Dallas	1,575,807	1,814,126	1,992,524	2,210,422	2,483,521
*Delta	1,435	1,807	1,817	1,955	2,012
Denton	130,380	165,540	223,122	312,752	404,737
*Ellis	60,290	73,958	86,161	118,488	143,421
Fannin	24,349	24,682	25,034	28,076	32,664
Grayson	92,355	99,655	106,969	115,193	125,441
*Henderson	22	22	22	22	22
*Hood	17,133	24,763	30,823	46,302	62,328
*Hunt	4,769	5,885	7,055	7,967	8,688
*Jack	310	345	353	377	397
Johnson	70,647	91,615	109,518	144,262	185,622
*Kaufman	6,231	9,434	12,234	15,719	19,080
*Lamar	41,420	43,922	45,693	53,040	59,674
*Montague	7,959	8,476	8,804	10,085	11,147
*Navarro	6,359	9,473	10,270	11,658	12,173
*Palo Pinto	162	180	206	271	331
*Parker	43,564	54,977	65,058	73,721	79,180
*Red River	12,454	11,906	11,829	12,303	13,403
*Rockwall	12,605	18,248	26,761	39,572	46,765
Tarrant	852,026	1,045,490	1,223,565	1,462,179	1,632,379
*Wise	20,176	24,604	29,804	40,378	47,346
Total	<u>3,148,900</u>	<u>3,750,137</u>	<u>4,295,947</u>	<u>5,084,670</u>	<u>5,857,742</u>

¹ 1980 and 1985 population is based on Bureau of Census statistics. 1990, 2000 and 2010 population is based on 1988 TWDB Revised Data Series population projections.

² The term "Major Cities" includes incorporated cities with a 1980 population of 1,000 or greater, or a county seat with less than 1,000 population in 1980.

³ The term "County Other" includes cities and unincorporated areas with a 1980 population of less than 1,000 and all rural population.

* Indicates a county where only that portion of the population that falls within the study area is included.

While each aquifer has experienced a variety of development patterns, in recent years regional and local pumpage have tended to follow trends established in the 1960's and early 70's. Specifically, the total volume of water reported pumped in the study area has gradually increased.

Many large-volume ground-water users, concentrated in the Dallas-Fort Worth area, have in recent years converted to surface-water sources. Reduction of pumpage by these large users has been offset by continued sharp increases by numerous smaller municipal users, utility districts, and water-supply corporations outside of the Dallas-Fort Worth area.

The calculated amount of ground water pumped for public supply in 1985 was approximately 46,801 acre-feet, which was approximately 43 percent of the total pumpage from all aquifers in the study area.

Public Supply

The City of Grand Prairie in Dallas County was the largest user of ground water for public supply. The City pumped a little over 6,000 acre-feet of ground water, which was approximately 13 percent of the total amount of ground water used for public supply from the Antlers, Paluxy and Twin Mountains Formations and Woodbine Group. Grand Prairie obtains its ground water from wells completed in the Paluxy and Twin Mountains Formations and Woodbine Group.

The City of Irving, also in Dallas County, was the second largest user of ground water for public supply. The City pumped a little over 5,000 acre-feet of ground water, which was approximately 11 percent of the total amount of ground water used for public supply from the Antlers, Paluxy, Twin Mountains Formations and Woodbine Group. The water is pumped from wells completed in the Twin Mountains Formation and Woodbine Group.

The City of Sherman in Grayson County was the third largest user of ground water. The City used a little over 3,400 acre-feet of ground water, or about 7 percent of the total amount used for public supply from the Antlers, Paluxy, Twin Mountains Formations and Woodbine Group. The City of Sherman's wells are completed in the Antlers Formation and Woodbine Group.

The Cities of Bedford in Tarrant County and Gainesville in Cooke County were the fourth and fifth largest users of ground water for public supply. Bedford used a little over 2,400 acre-feet, while Gainesville used a little over 2,300 acre-feet for public supply. This amounted to approximately 5 percent of the total used for public supply. Both cities have wells completed in the Antlers, Paluxy, and Twin Mountains Formations.

Other towns which used between 500 and 1,725 acre-feet of ground water from the Antlers, Paluxy, and Twin Mountains Formations and Woodbine Group in 1985 were as follows: Euless, about 1,725 acre-feet; Benbrook, about 1,613 acre-feet; Lancaster, about 1,495 acre-feet; Hurst, about 1,343 acre feet; The Colony, about 800 acre-feet; Midlothian, about 783 acre-feet; Richland Hills, about 738 acre-feet; Grandbury, about 725 acre-feet; Everman, about 657 acre-feet; White Settlement, about 635 acre-feet; Highland Village, 598

acre-feet; Clarksville, about 581 acre-feet; Kennedale, about 556 acre-feet; Whiteboro and Southlake, both about 555 acre-feet; Cedar Hill, about 548 acre-feet; and Frisco, about 530 acre-feet.

Irrigation

Most irrigation wells in the study area are scattered over the Trinity and Woodbine outcrops with only a few areas of concentrated activity. Occasionally deeper wells are found downdip from the outcrop and are used primarily to irrigate golf courses. Approximately 6,497 acre-feet (6 percent of the total amount) of water was pumped for irrigation purposes in 1985, from Cretaceous formations in the study area, with about 55 percent of the water from the Woodbine Group. The largest concentration of irrigation wells is located on the Woodbine outcrop in southwestern Grayson county and the northeastern Denton County. Approximately 80 irrigation wells operate in this area and several produce as much as 900 gpm. Several smaller irrigation well developments are located in Hood County (Twin Mountains) and in Wise County (Antlers). There are also irrigation wells in Fannin County producing from the alluvium along the Red River.

Industrial

For the purpose of this report, industrial use includes manufacturing, power supply, and mining. In 1985, approximately 16,233 acre-feet of ground water was pumped for industrial purposes. This was approximately 15 percent of the total amount. The areas of largest use of ground water from the Antlers, Paluxy, and Twin Mountains Formations and Woodbine Group by industrial categories are: (a) manufacturing was Grayson County with 4,681 acre-feet; (b) power was Dallas County with 2,563 acre-feet; and (c) mining was Wise County with 605 acre-feet.

Domestic and Livestock

The amount of ground water pumped from all aquifers within the study area for rural, domestic, and livestock purposes in 1985 was approximately 40,187 acre-feet. This represents about 37 percent of the total amount of ground water used from all aquifers.

Projected Water Demands, 1990-2010

The total amount of both ground and surface water used in the study area for 1980 was estimated at 880,289 acre-feet, and for 1985, 963,116 acre-feet (Texas Water Development Board, 1988). Of these totals, 76 percent in 1980 and 83 percent in 1985 were for municipal use, 5 percent and 2 percent for irrigation use, 4 percent in both years for power generation, 13 percent in 1980 and 9 percent in 1985 for manufacturing, 1 percent in both years for mining operations, and 2 percent in both years for livestock use. Current and projected water demands for the study area are shown in Table 3.

Projections of future municipal and rural requirements are based upon the 1988 Texas Water Development Board Revised Data Series population projection and projected demands per capita water use. Future projections of irrigation, industrial, and livestock use are based upon projected demands and the apportioned share of total county demands. Projections take into account the demands that are likely to occur during drought conditions.

Table 3
Historical and Projected Demands for
Ground and Surface Water
in the Study Area
(Units in Acre-Feet)

	1980	1985	1990*	2000*	2010*
Municipal Use					
Major Cities ¹					
Ground	50,520	46,801			
Surface	578,197	695,815			
Subtotal	628,717	742,616	864,908	945,352	1,019,537
County Other ²					
Ground	29,720	34,843			
Surface	9,037	18,595			
Subtotal	38,757	53,438	70,144	95,464	110,822
Municipal Use:					
Total	667,474	796,054	935,052	1,040,816	1,130,359
Other Uses ³					
Ground	19,512	28,074			
Surface	193,303	138,988			
Total	212,815	167,062	195,471	240,739	284,678
Study Area					
Ground	99,752	109,718			
Surface	780,537	853,398			
Total	880,289	963,116	1,130,523	1,281,555	1,415,037

¹ The term "Major Cities" includes incorporated cities with a 1980 population of 1,000 or greater, or a county seat with less than 1,000 population in 1980.

² The term "County Other" includes cities and unincorporated areas with 1980 population of less than 1,000 and all rural population.

³ Includes irrigation, manufacturing, power, mining, and livestock.

* Includes Ground and Surface water.

Under projected conditions, the total annual water requirement for the study area is expected to increase by 47 percent from 1985 to the year 2010, at which time the annual demand is estimated to be 1,415,037 acre-feet. Municipal and rural requirements are expected to increase by 42 percent to 1,130,359 acre-feet by the year 2010. The greatest projected increase occurs in the category of mining, which will inflate 120 percent to 13,317 acre-feet by 2010. Manufacturing is projected to increase by 116 percent to 188,416 acre-feet by 2010. Power will only increase by 6 percent to 42,000 acre-feet by 2010. Livestock will increase by 24 percent to 23,022 acre-feet by 2010. Again, these projections are based on drought condition requirements. Actual water demand may never reach this level.

AVAILABILITY OF WATER

Current Availability of Ground Water

The recoverable volume of fresh to slightly saline ground water in storage for the Trinity Group aquifer within the study area was a little over 472,000 acre-feet in 1980, with an estimated annual effective recharge to the Trinity Group aquifer of a little less than 50,000 acre-feet per year. The availability in the study area in each river basin was modified from the Department's Report 238, "Ground-Water Availability in Texas". A little over 106,400 acre-feet of ground water was pumped from the Trinity Group aquifer in 1985, so that the annual withdrawal by pumpage far exceeds the replenished quantity, resulting in water-level declines in the artesian portion of the aquifer as shown in Figures 11 through 13. The recoverable volume of fresh to slightly saline ground water based on an estimated annual effective recharge to the Woodbine Group aquifer is a little over 24,000 acre-feet per year. The Nacatoch and Blossom aquifers have a recoverable volume of fresh to slightly saline ground water based on an estimated annual effective recharge of 3,000 and 800 acre-feet per year, respectively.

Currently, 36 major surface reservoirs with capacities of 5,000 acre-feet or more contribute all or part of their respective yields to supply the needs within the study area (Figure 19). These reservoirs have a combined surface area of more than 236,000 acres or 369 square miles. Combined capacities are more than 4.8 million acre-feet.

Current Availability of Surface Water

The combined yields of these 36 reservoirs total about 1.9 million acre-feet of which about 1.6 million acre-feet is committed to supply needs within the study area.

Surface-water supplies are adequate to meet current and projected needs through the year 2010. Upon completion of Cooper Reservoir in the Sulphur River basin, and with completion of the delivery system from existing Lake Palestine in the Neches River basin, an additional 179,000 acre-feet could be delivered to the study area which would be adequate to supply the area's needs well beyond 2010.

Conjunctive use ideally involves management of both ground and surface-water resources in order to obtain maximum utilization of the total resources in the most economic and equitable manner. The term conjunctive use is, however, commonly used in reference to any type of arrangement where one source is used to supplement the other in time of need.

Potential for Conjunctive Use of Ground and Surface Water

Conjunctive use in the study area is desirable, and undoubtedly substantial benefits could be derived from such an arrangement. Historically, however, there has been little incentive for conjunctive use. The availability of ample supplies of ground water at the point of use with minimal investment has favored its development over surface supplies, particularly during the first half of this century. Since water wells could supply all needs, there was little justification for cities, towns, and industries to finance expensive surface

reservoirs, transmission lines, and water treatment facilities. The trend away from ground-water sources to surface water has accelerated during the past 20 years with the recognition that the Trinity and Woodbine Group aquifers cannot supply all the area needs. In particular, municipal users have moved to acquire surface water to assure future needs. Once financial resources are committed to acquire surface water and adequate supplies are assured, there is no incentive to incur the additional expense of maintaining water wells and pumping equipment. The wells are usually maintained as a backup supply for a period of time, but are eventually abandoned.

Conjunctive use is currently practiced to some small degree in the study area. Of the 131 major cities or towns (over 1,000 population) in the area, 42 reported using both ground and surface sources to supply their needs in 1985. The great majority of these users are in Tarrant County.

A number of factors tend to limit the potential for conjunctive use of ground and surface waters in the study area. Some of the factors listed below are legal in nature, some physical, and some economic.

- (1) Because two opposing doctrines of water law are applied to surface and ground-water sources, no single authority exists to manage the development and distribution of the total resource.
- (2) The common practice of requiring that the total amount of surface water supplied under contract be paid for, whether used or not, offers little incentive for the user to conserve the surface water or adopt a conjunctive use program.
- (3) The aquifers have relatively low transmissive and storage characteristics. Consequently, the aquifers' potential for supplying large quantities of water in times of prolonged surface-water shortages is limited.
- (4) Unless shortages dictate, it is unlikely that individual users will voluntarily acquire and maintain both a ground and surface-water supply because of the costs.

Factors which determine the amount of recharge to the aquifers include the amount and frequency of precipitation, areal extent of the outcrop, topography, type and amount of vegetation and condition of the soil cover in the outcrop, and permeability of the aquifer.

Increased recharge would benefit the area by increasing the amount of water in storage in the Antlers, Twin Mountains, Paluxy, and Woodbine aquifers all of which have experienced significant water-level declines, particularly in the downdip or confined parts of the aquifers.

Numerous methods which enhance the recharge process (artificial recharge) have been studied (O'Hare and others, 1986). The most effective methods of increasing recharge include the use of runoff control structures in the outcrop, which in effect increases the time of contact between surface runoff and the aquifer, allowing the runoff

Potential Methods of Increasing Aquifer Recharge

*Outcrop
(Unconfined)
Areas*

water to percolate downward to the water table. Control structures which might be effective in the outcrop areas include check dams, pits, furrows, ditches, and field terracing. Spreading ponds might be utilized in some locales as a means of recharging treated sewage or excess surface water if available. In addition, brush control programs and grassland development could enhance recharge where brush infestation is a problem.

*Downdip
(Confined)
Areas*

Runoff control structures are not applicable in the downdip or confined portions of the aquifer where depths to the top of the aquifer vary from a few feet near the outcrop to more than 3,000 feet in the most downdip areas. Increasing the recharge to the aquifer in these areas would require the use of injection wells. Although recharge in the areas of large water-level decline would be desirable, a number of factors including technical, and economical are involved. Before using injection wells, a surface-water source must be available which equals or exceeds quality standards. The injected surface water must be compatible with the ground water from both a chemical and temperature standpoint to avoid the possibility of undesirable precipitates forming in the injection well and surrounding aquifer.

In addition, the storage capacities of confined aquifers such as the Trinity and Woodbine Groups are relatively small compared to water-table or unconfined aquifers.

Assuming that surface water is available for recharge, initial capital costs for injection wells and treatment plants as well as annual operation and maintenance costs are likely to be large.

If injection wells prove feasible both technically and economically, some type of entity would be required to manage the project to assure optimum operation and to regulate future development in the area.

**Projected
Availability
Through the
Year 2010**

With the 1985 population within the study area projected to increase 35.5 percent by the year 2000 and 56 percent by the year 2010, water demands will increase accordingly.

The amount of ground water needed to supply current demands exceeds the estimated effective recharge to the aquifers in the study area by 44 percent annually. For example, in 1985 about 110,000 acre-feet of ground water was pumped in the study area while only an estimated 76,000 acre-feet was recharged. The difference between the effective recharge and ground-water withdrawals from the aquifers is the net quantity of water removed from aquifer storage, resulting in continued water-level declines and increased pumpage lifts. This trend of withdrawing more ground water than is replenished is likely to continue at an accelerated rate with the expected increase in water needs in the study area.

Since available ground-water resources are insufficient to meet even current levels of demand in the study area, an increase in the use of surface water will be needed to meet future demands. The study area has sufficient surface-water resources to meet all projected needs of the area through 2010. However, local shortages could occur due largely to reliance on ground water from the area aquifers.

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