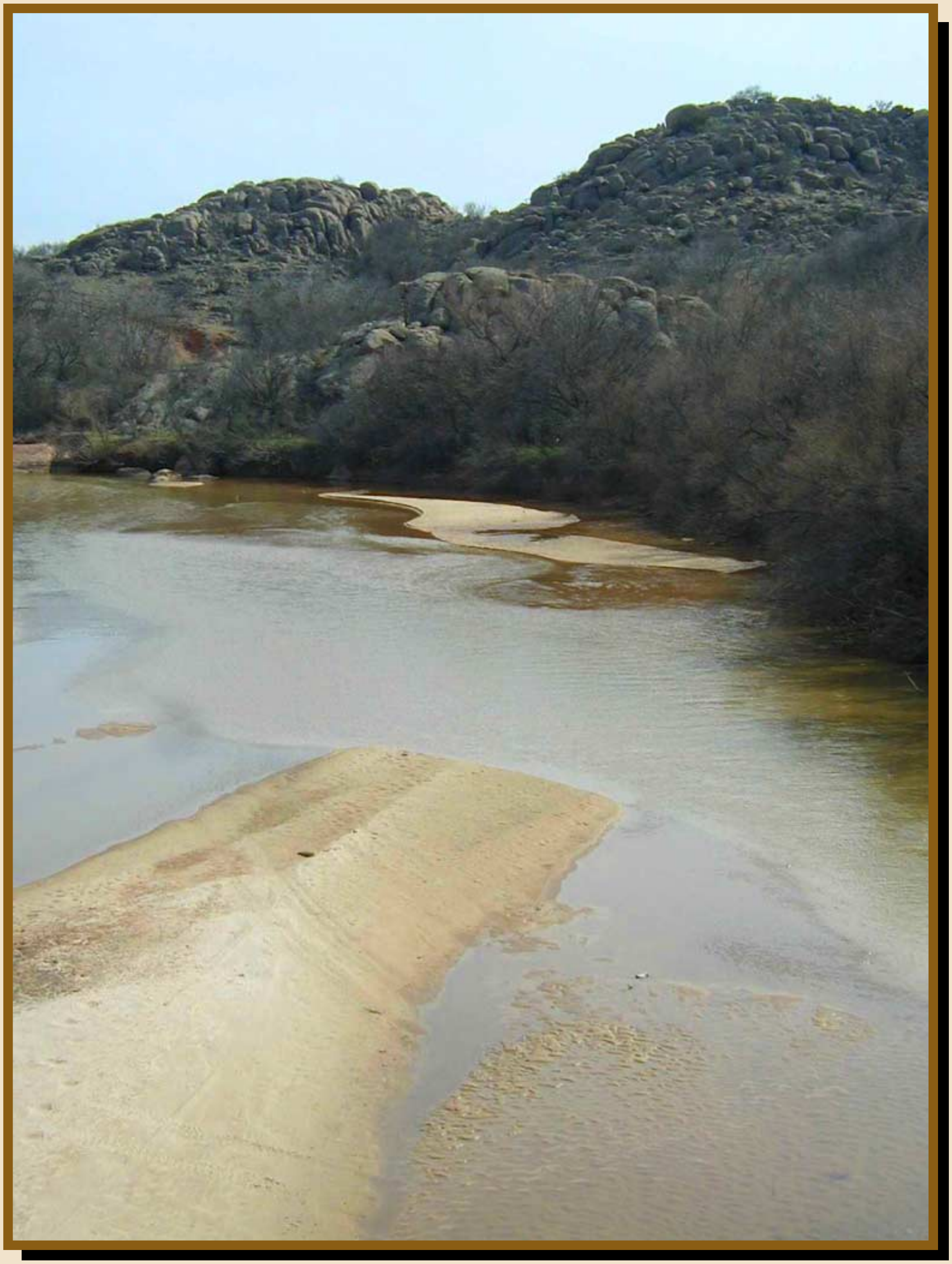
Update of the Hydrologic Survey of the Tillman Terrace Groundwater Basin, Southwestern Oklahoma



By Noël I. Osborn

Oklahoma Water Resources Board
Technical Report GW2002-1

Update of the Hydrologic Survey of the Tillman Terrace Groundwater Basin, Southwestern Oklahoma

By Noël I. Osborn

Oklahoma Water Resources Board
Technical Report GW2002-1

March 2002

Cover Photograph: The North fork of the Red River deposits alluvial sediments at the base of a hill of Wichita granite. Photograph by Crystal Stephens, Oklahoma Water Resources Board.

This publication is prepared, printed and issued by the Oklahoma Water Resources Board under statutory directive. Fifty (50) copies have been prepared at a cost of $168.00. Copies have been deposited with the Publications Clearinghouse at the Oklahoma Department of Libraries. Any use of trade names in this publication is for descriptive purposes and does not imply endorsement by the State of Oklahoma.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The Tillman Terrace Groundwater Basin (Basin) encompasses about 290 square miles in western Tillman County (Figure 1). Groundwater from the Basin is used extensively for irrigation, public water supply, agriculture, mining, stock, and domestic purposes. The primary industry is agriculture, which relies on groundwater from the Basin to irrigate cotton, wheat, alfalfa, and peanuts.

Purpose and Objectives

In accordance with Oklahoma statutes, the Oklahoma Water Resources Board (OWRB) made a hydrologic survey of the Tillman Terrace Groundwater Basin. In December 1978, the OWRB issued its first Board order for the allocation of water rights in Oklahoma, approving a maximum annual yield proportioned at 1.0 acre-foot per acre from the Basin. Oklahoma statutes direct the OWRB to update the hydrologic surveys at least every twenty years after issuance of the final order determining the maximum allowable yield. The purpose of this study is to update the hydrologic survey.

The objectives of this update are to: (1) summarize hydrologic information of the Basin from existing reports; (2) evaluate data and information collected after 1978; and (3) determine if any changes that could have an impact on the allocation of water rights have occurred since 1978.

Background

By 1950, the Tillman Terrace aquifer was heavily used for irrigation and municipal use. In anticipation of increased demands for the groundwater, the U.S. Geological Survey (USGS) in cooperation with the Division of Water Resources of the Oklahoma Planning and Resources Board (the predecessor of the OWRB), conducted a study on the aquifer (Barclay and Burton, 1953). This comprehensive study incorporated information from water level measurements, borehole descriptions, aquifer pump tests, stream discharge measurements, and precipitation data.

Irrigation development increased during the next 20 years, resulting in declining water levels and

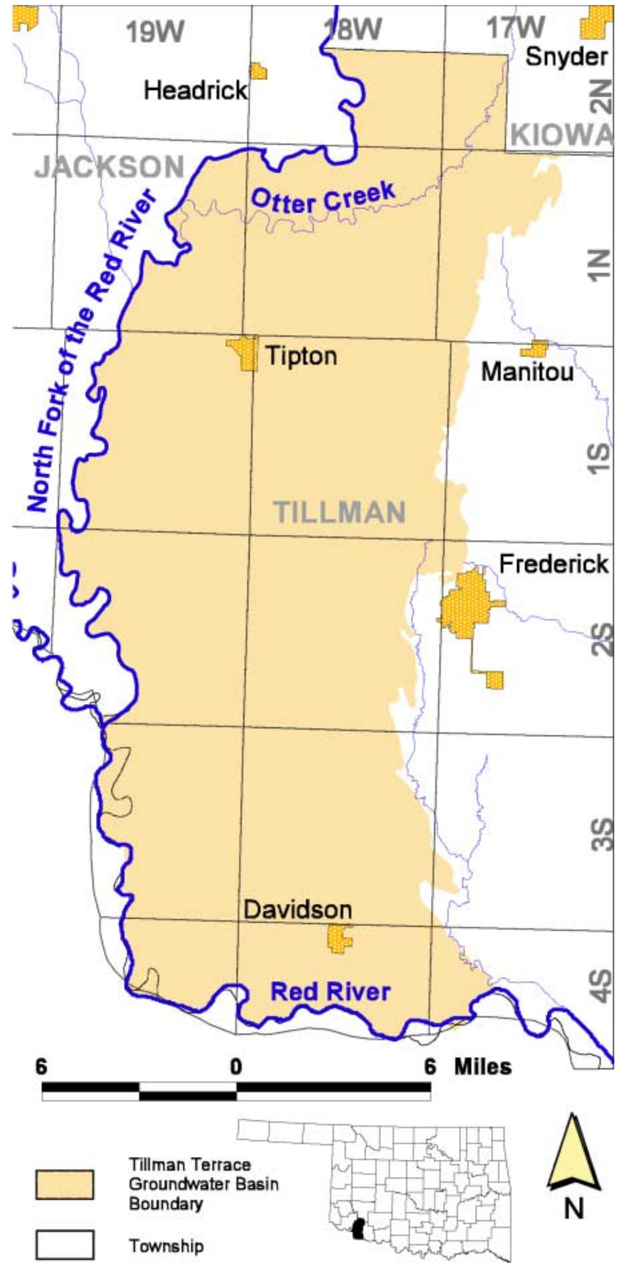


__Figure 1.__ Location of the Tillman Terrace Groundwater Basin, southwestern Oklahoma.

problems with encroaching salt water from the rivers. In 1968, the OWRB declared Tillman County to be a critical groundwater area. From 1970 to 1975 the OWRB and USGS measured water levels annually in 165 wells in the Tillman Terrace aquifer (OWRB, 1976). In 1974, the OWRB conducted a hydrologic survey of the aquifer and concluded that if existing pumping rates continued, the aquifer would be depleted in 10-20 years (Wickersham, 1974).

Under a cooperative agreement with the OWRB, Oklahoma State University constructed a computer groundwater flow model of the aquifer to determine the maximum allowable yield (Al-Sumait, 1978). The model results are summarized by Kent and Naney (1978).

PHYSICAL SETTING

Physiography and Drainage

The study area lies within the Osage Plains physiographic province. The surface is generally flat with sand dunes occurring adjacent to the rivers. The ground surface slopes westward toward the North Fork of the Red River, southward toward the Red River, and eastward toward the Permian redbeds. The altitudes of the land surface range from 1,396 feet in the center of the deposit, to 1,131 feet in the southwest corner (Barclay and Burton, 1953).

The soils in the study area consist primarily of the Tipton-Hardeman-Grandfield association, which is comprised of loamy and sandy soils. The soils occur on uplands, and are deep and well drained. Nearly all of these soils are cultivated (U.S. Department of Agriculture, 1974).

The study area is drained by the North Fork of the Red River to the west and the Red River to the south. Otter Creek, a perennial stream, flows from the Tom Steed Reservoir into the North Fork of the Red River. Five unnamed intermittent streams flow into the Red River.

The flow of the North Fork of the Red River has been regulated since 1943 by storage and diversion at Lake Altus. The river's average rate of flow past the gauging station near Tipton during the years 1984-1998 was 700 cubic feet per second (cfs) (Blazs and others, 1998). The river flows south with a gradient of about 5.5 feet per mile across the study area (Cannon, 1967). The flow of Otter Creek has been regulated since 1975 by Tom Steed Reservoir. The creek's average rate of flow

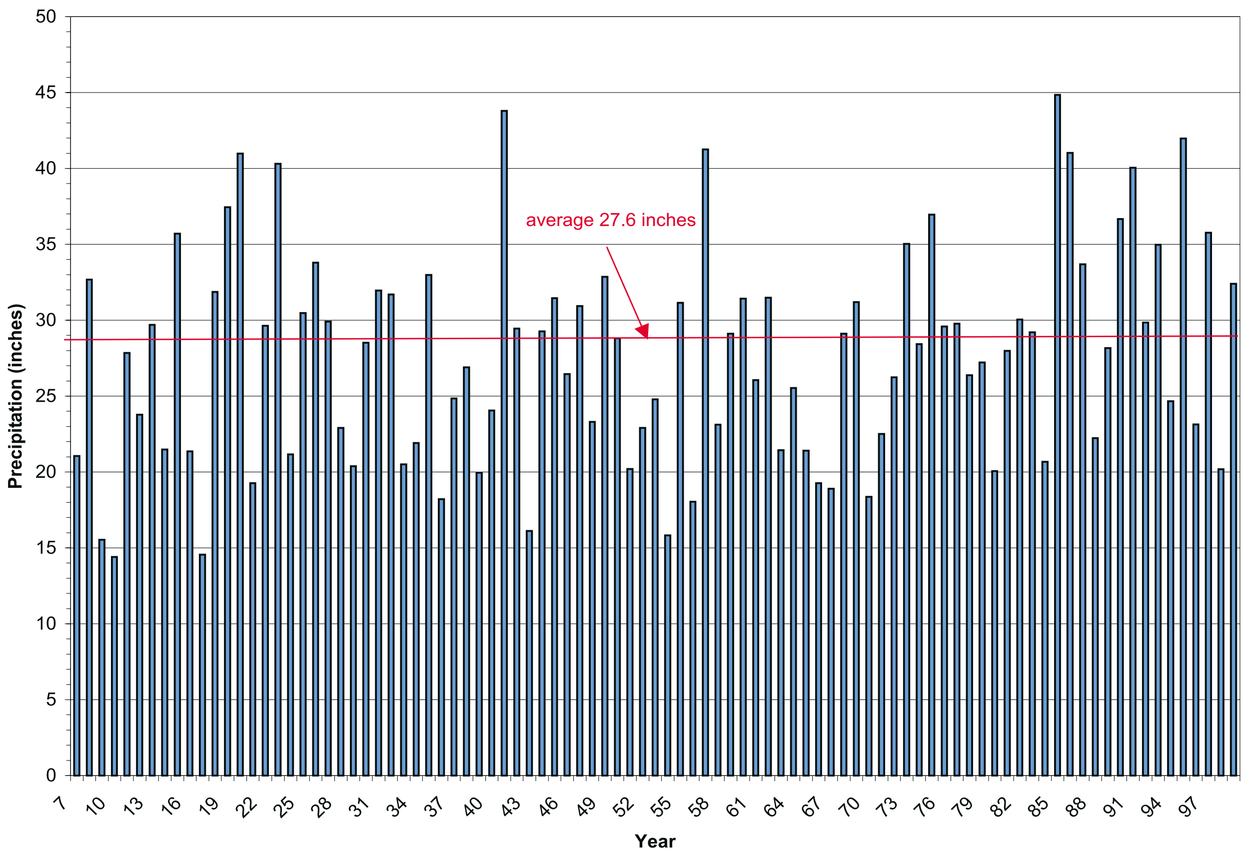


Figure 2. *Annual precipitation measured at the Frederick gage from 1907 to 1999. Data from U.S. Department of Commerce, National Climatic Data Center and the Oklahoma Climatological Survey.*

near Mountain Park during the years 1976-1998 was 14.2 cfs (Blazs and others, 1998).

Land Use and Population

Land use in the study area is predominantly cropland and pasture. Primary crops are cotton, wheat, alfalfa, and peanuts. Some mixed rangeland occurs along the Red River and north of Otter Creek (U.S. Geological Survey, 1990).

The study area is sparsely populated. Tipton and Davidson are the only incorporated towns, with 2000 populations of 916 and 375, respectively. Frederick, which lies just east of the study area, had a 2000 population of 4,637. The population of Tillman County declined 16 percent from 1980-90, and was estimated to decline an additional 7 percent from 1990-97 (U.S. Census Bureau, 1998). According to census data, the population of Tipton and Frederick declined about 24 percent between 1970 and 1998.

Climate

The area has a dry, subhumid climate characterized by long, hot summers and generally mild winters. The mean annual temperature for Tillman County is 61.8^{o} F. On average, the temperature exceeds 100^{o} F more than 30 days, and is below 32^{o} F between 70 and 79 days (Oklahoma Climatological Survey, 1997). The average annual lake evaporation for the region is 65 inches, and the average annual class A pan evaporation is 94 inches (OWRB, 1967).

Most precipitation occurs in the spring and summer as torrential rains of short duration. The mean annual precipitation (1961-1990) for Tillman County is 28.7 inches. The highest monthly normal precipitation is in May (4.4 inches) and the lowest is in January (1.0 inches) (Oklahoma Climatological Survey, 1997).

Figure 2 shows annual precipitation at Frederick from 1907 to 1999. Annual precipitation varied from 14.4 inches in 1910 to 44.85 inches in 1985, and averaged 27.6 inches. The 1910s, 1930s, 1950s, and 1960s were characterized by lower than average precipitation, while the 1980s and 1990s were higher than average. The average precipitation from 1981 to 1999 was 31.4 inches.

GEOLOGY

Most of the study area overlies the Hollis structural basin. The Hollis basin developed in Early Pennsylvanian time with uplift of the Wichita block to the north and the Red River block to the south (Johnson, 1990). Along the northern edge of Tillman County, the aquifer overlies the Wichita uplift, where Quaternary sediments and Permian rocks truncate against Cambrian granites and gabbros of the Wichita Group (Havens, 1977).

Figure 3 shows the surficial geology of the study area (from Havens, 1977 and Cederstrand, 1996). Except for a few small areas, the Basin is covered with Quaternary-age sediments. Two small hills of Wichita Granite are present along the northern boundary of Tillman County, and Permian age rocks crop out in a small area south of Otter Creek.

Permian-age redbeds of the Garber Sandstone and the Hennessey Group underlie the Quaternary sediments. The Garber Sandstone consists of reddish-brown, fine-grained sandstone and mudstone conglomerate, ranging in thickness from 160 to 210 feet. The Hennessey Group consists of reddish-brown to gray shale with some sandstones, 130 to 200 feet thick (Havens, 1977). Rocks in the Garber Sandstone and Hennessey Group yield small amounts of usable water. The redbeds underlying the Tillman Terrace Groundwater Basin are in the Hennessey-Garber Groundwater Basin, a minor basin delineated by the OWRB (Belden and others, 1996).

The surface of the redbeds is uneven due to erosion. Figure 4, modified from Barclay and Burton (1953), is a map showing the altitude of the top of the redbed surface. The altitude of the redbed surface ranges from greater than 1,350 feet in the northeast portion of the Basin to 1,100 feet along the Red River. The contours indicate a major valley east of the present North Fork of the Red River, which represents the old drainage system of the river (Barclay and Burton, 1953).

Unconsolidated sediments of Quaternary age rest unconformably on the eroded surface of the Permian redbeds. The Quaternary sediments pinch out to the east against Permian redbeds in a north-south trending contact that passes just

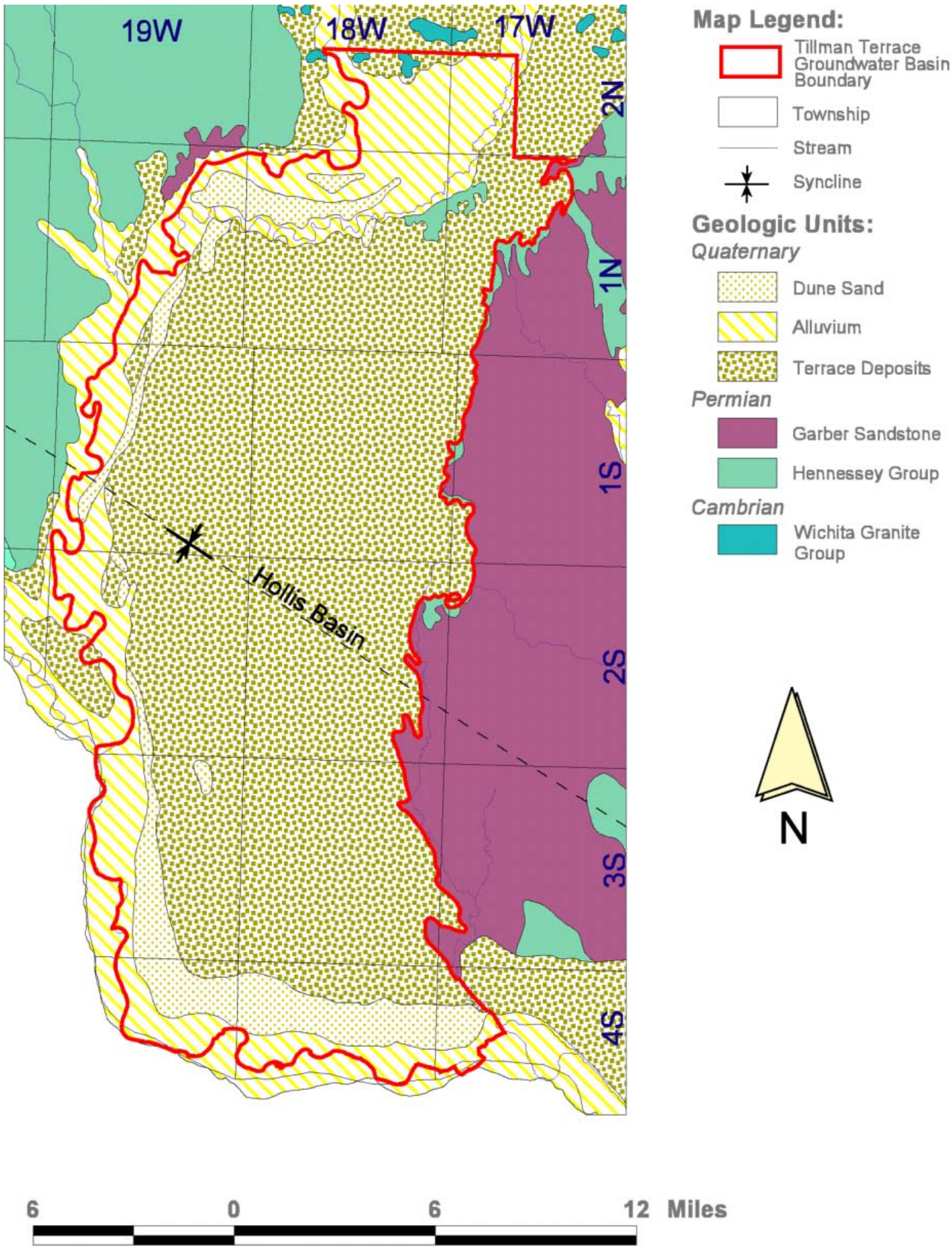


Figure 3. *Surficial geology of the study area (modified from Havens, 1977 and Cederstrand, 1996)*

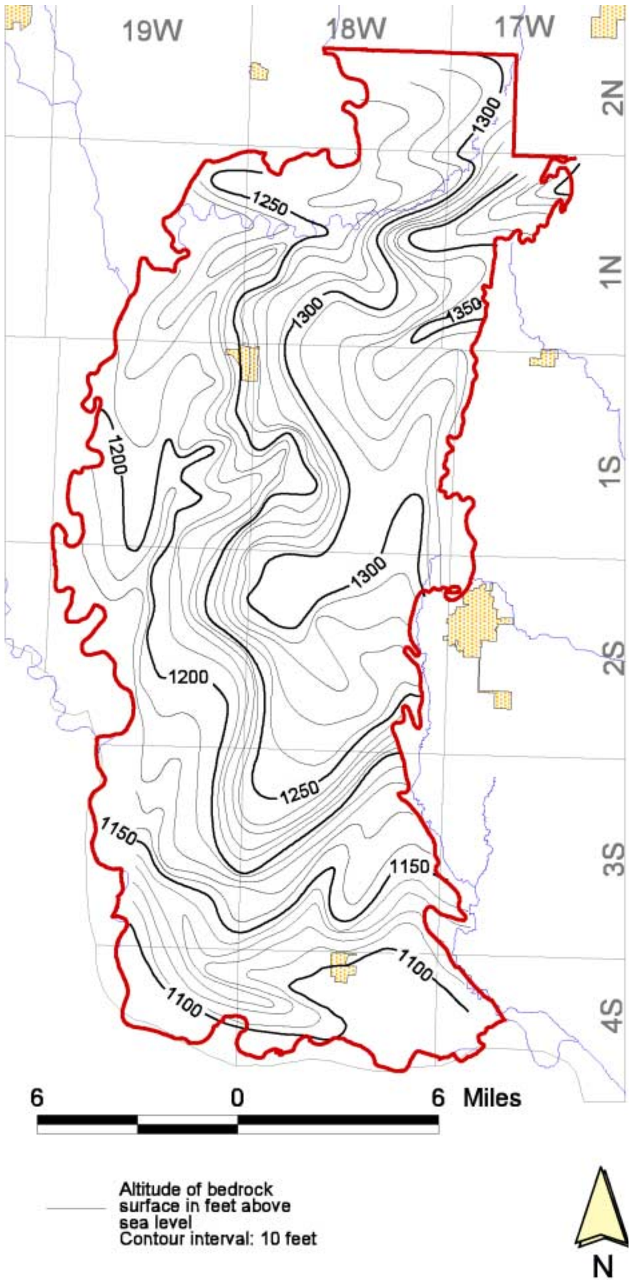


Figure 4. *Altitude of the base of the Tillman Terrace Groundwater Basin, defined as the top of the Permian surface (modified from Barclay and Burton, 1953).*

west of Frederick. The sediments extend northward into Kiowa County where they truncate against Cambrian granites and gabbros. The Quaternary sediments consist of terrace deposits, alluvium, and dune sand.

Terrace deposits overlie most of the Basin. The thickness of the terrace deposits varies, but averages about 42 feet (Barclay and Burton, 1953). Low and intermediate terrace deposits were laid down by the ancestral Red River and North Fork of the Red River. Low terrace deposits rest upon Permian bedrock and are composed of small gravels, sand, silt, and clay (Cannon, 1967). Intermediate terrace deposits are composed of light-red and reddish-brown sands and gravels. The gravels are composed predominantly of quartz pebbles with some shale. The deposits contain arkosic material derived from the igneous rock of the Wichita Mountains. The intermediate terrace material changes in character south of Manitou where it is part of a terrace associated with the Red River (Cannon, 1967). Lithology descriptions of water wells and test holes indicate that layers of caliche as much as one foot thick are encountered throughout the terrace deposits (Barclay and Burton, 1953).

Recent alluvium deposits are distributed along the rivers and Otter Creek. The alluvium consists of stream-laid, dark-gray to red sand and silt, clay, and gravel, and is composed of eroded bedrock and terrace material (Cannon, 1967; Barclay and Burton, 1953). Thickness of the alluvium ranges from 27 to 47 feet, and averages 34 feet. Most of the saturated portion consists of gravel and very coarse sand, which is highly permeable (Barclay and Burton, 1953).

Dune sands occur in a narrow strip along the north side of the Red River and along the east side of the North Fork of the Red River. The dune sands in the Basin range in thickness from 15 to 69 feet, and average 46 feet (Barclay and Burton, 1953).

GROUNDWATER

The Quaternary alluvium and terrace deposits are hydrologically connected and comprise the Tillman Terrace aquifer. Overlying dune sands occur above the water table and are not a source of groundwater. Although the underlying Permian redbeds yield small amounts of water, vertical and lateral flow between the redbeds and terrace deposits is probably small because the hydraulic conductivity of the redbeds is much smaller than the terrace deposits.

Basin Boundaries

The OWRB defines a groundwater basin as a distinct underground body of water overlain by contiguous land and having substantially the same geological and hydrological characteristics. The OWRB classifies the Tillman Terrace Groundwater Basin as a major basin because the average basinwide yield from wells in the alluvium and terrace aquifer is greater than 150 gallons per minute (gpm).

The Tillman Terrace Groundwater Basin consists of the Quaternary alluvium and terrace deposits in western Tillman County. The total land area overlying the Basin is about 186,000 acres, or 290 square miles. The Basin is bounded on the south by the Red River, on the west by the North Fork of the Red River, on the north by Kiowa County, and on the east by the outcrop of Permian redbeds.

The base of the Basin is defined by the top of the underlying Permian redbeds (Figure 4), easily identified on well drillers' logs. Because the Tillman Terrace aquifer is unconfined, the upper surface of the Basin is the water table. The water table surface changes over time in response to climatic conditions, land use, and groundwater withdrawals.

Discharge

Groundwater discharge into rivers and streams is the principal means of discharge from the Basin. Groundwater in the northern portion of the Basin discharges into Otter Creek, which is a perennial stream in the lower six miles of its course. Base flow measurements taken by the USGS in November 1945, February 1953, and April 1953 indicate the creek gained 1,416,000 gallons per day (gpd), 487,000 gpd, and 554,000 gpd, respectively, from Basin discharge (Barclay and Burton, 1953).

When the water table is higher than the river stage, groundwater discharges to the North Fork of the Red River, making the river a gaining stream. However, when the water table is lower than the river stage, water from the river contributes to the aquifer, making the river a losing stream. Base-flow measurements collected in November 1945 and February 1953 showed a decrease in flow along the North Fork, indicating a losing stream, while measurements collected in April 1953 showed an increase in flow, indicating a gaining stream. Base-flow measurements along the Red River showed an increase in flow during each of the three measurement periods, indicating a gaining stream (Barclay and Burton, 1953).

Groundwater also discharges to springs and seeps along the terrace-redbed contact at the eastern margin of the Basin. Some groundwater may also discharge to the Permian redbeds along this boundary. However, the volume of flow is probably small due to the relatively small hydraulic conductivity of the redbeds as compared to the terrace deposits.

Some groundwater discharges as evapotranspiration. Evaporation from the zone of saturation occurs where the water table is within a few feet of the land surface. Saline seeps occur near the Tillman-Kiowa County line (USDA, 1974), suggesting evaporation of groundwater. Transpiration occurs along major streams, where the water table is near the land surface, and phreatophytes (such as cottonwood and willow) grow.

Discharge by subsurface outflow occurs at the southeastern boundary of the Basin along the Red River, where the alluvium and terrace deposits extend beyond the limits of the Tillman Terrace Groundwater Basin into the alluvium and terrace deposits of the Red River. The amount of groundwater discharging from the Basin by subsurface outflow is small because of the small cross-sectional area through which the flow occurs.

Recharge

The primary source of recharge to the Basin is infiltration of precipitation. Factors which influence how much precipitation will infiltrate to the water table include the permeability of the soil and sediments above the water table, the opportunities for the rain to leave the area by runoff or evapotranspiration before it can reach the water table, and the amount and distribution of rainfall. Although the sandy soil of the area favors a high rate of infiltration, discontinuous layers of clay and caliche that are present above the water table can slow the rate of infiltration (Barclay and Burton, 1953). Al-Sumait (1978) determined from the groundwater flow model that the average recharge rate for the Basin was 2.87 inches per year, or about 12 percent of the mean annual precipitation.

Another source of recharge is from infiltration of streams. As noted above, surface water from the North Fork of the Red River contributes to the aquifer when the water table is lower than the river stage. Some water is also recharged by subsurface inflow. This occurs at the upstream boundary of the Basin along the Tillman-Kiowa County line, from alluvium and terrace deposits that extend north of the Basin.

Groundwater Flow and Water Level Fluctuations

A map of the water table surface of the aquifer during 1969 is shown in Figure 5 (modified from Al Sumait, 1978 and Becker and others, 1997). Groundwater flows perpendicular to water level contours, from high to low elevations. A groundwater divide occurs about five miles east of Tipton from which groundwater flows west toward the North Fork of the Red River, south toward the Red River, and north toward Otter Creek. The hydraulic gradient ranges from 0.001 to 0.005, with an average of 0.003. The depth to water in the Basin ranges from about 5 to 45 feet.

Water levels in the aquifer fluctuate in response to recharge from precipitation and discharge from well pumping. Figure 6 is a hydrograph of a well located about 4 miles south of Tipton, showing water-level measurements collected annually during winter months from 1945 to 2001. The water level in the well declined 11 feet from 1963 to 1972 in response to lower than average precipitation and increased irrigation. The water level then rose 24 feet from 1972 to 1993 in response to higher than average precipitation and less irrigation.

Similar increases in water levels have been observed in both bedrock and alluvium and terrace deposits across the state. Over the last 20 years, most of the state's aquifers exhibited rising water levels (Belden, 1999). One notable exception is the Ogallala aquifer in the panhandle, which is being depleted from pumping at a greater rate than it is replenished from precipitation (Belden, 1999; Luckey and others, 2000).

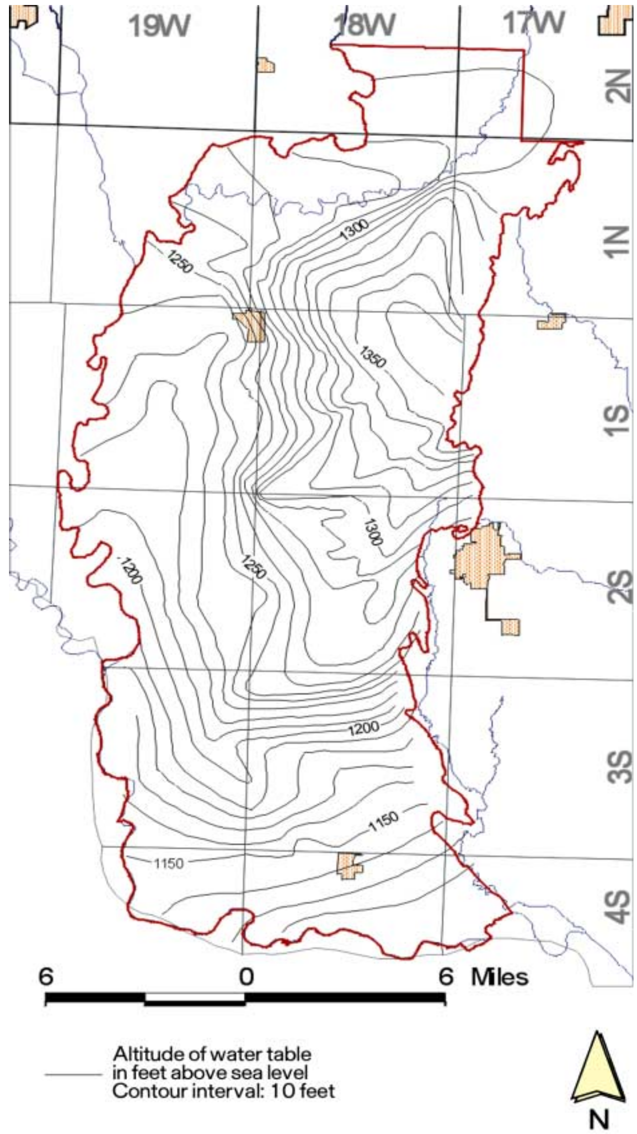


Figure 5. *Altitude of 1969 water table surface of the Tillman Terrace Groundwater Basin (modified from Al Sumait, 1978 and Becker and others, 1997).*

Heavy irrigation pumping can have a long-term impact on the aquifer. Between 1953 and 1974 water levels in high pumping areas declined as much as 20 feet, while water levels rose as much as 10 feet in areas of little or no pumping (Wickersham, 1974). However, water levels recovered between 1974 and 1993, when precipitation was higher than average. Water levels measured in 17 wells during the winters of 1974 and 1993 (on file at the OWRB) indicate that water levels rose as much as 20 feet (Figure 7). The greatest increases occurred in heavily irrigated areas.

Quarterly water-level measurements col-

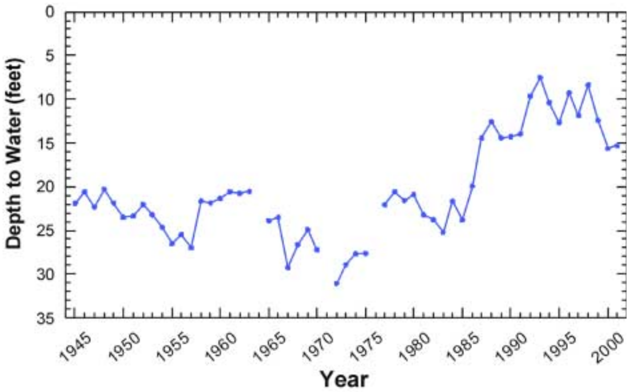


Figure 6. *Hydrograph of a well located south of Tipton (25-IS-19WI), showing annual water-level measurements from 1945 to 2001.*

lected by the OWRB from September 1989 to September 1990 indicate a variety of seasonal water level responses in the aquifer. Hydrographs of representative wells are shown in Figure 8 along with a graph of the monthly precipitation measured at the Frederick gage for the same period of time. Precipitation was highest in September 1989 and between February and August 1990, and most irrigation pumping occurred from June through September. Water levels increased as much as 6 feet in upgradient areas, in response to recharge from precipitation. Changes in water level were smaller (less than 2 feet) in downgradient areas.

Aquifer Characteristics

Saturated thickness of the Basin ranges from less than 10 feet to greater than 40 feet. The average saturated thickness in 1952 was estimated to be 23 feet (Barclay and Burton, 1953), and the average saturated thickness in 1974 was estimated to be 16 feet (Wickersham, 1974). There is insufficient water level coverage to determine an accurate 2000 saturated thickness. Water level elevations derived from measurements collected in 2000 are similar to elevations on the water table map (Barclay and Burton, 1953) representing early 1950's elevations. It is therefore reasonable to assume that the 2000 saturated thickness approximates the 1952 saturated thickness of 23 feet.

Barclay and Burton (1953) estimated the average transmissivity for the Basin to be 2,680 ft^2/day, based on seven aquifer tests. Assuming an average saturated thickness of 23 feet, the average hydraulic conductivity is 117 ft/day. Using a grain size distribution-coefficient of permeability envelope method developed by Kent and others (1973), Al-Sumait (1978) estimated hydraulic conductivity ranged from 20 to 300 ft/day. The average transmissivity was estimated to be about 1,750 ft^2/day.

A specific yield of 0.10 was estimated by Barclay and Burton (1953) to be representative of

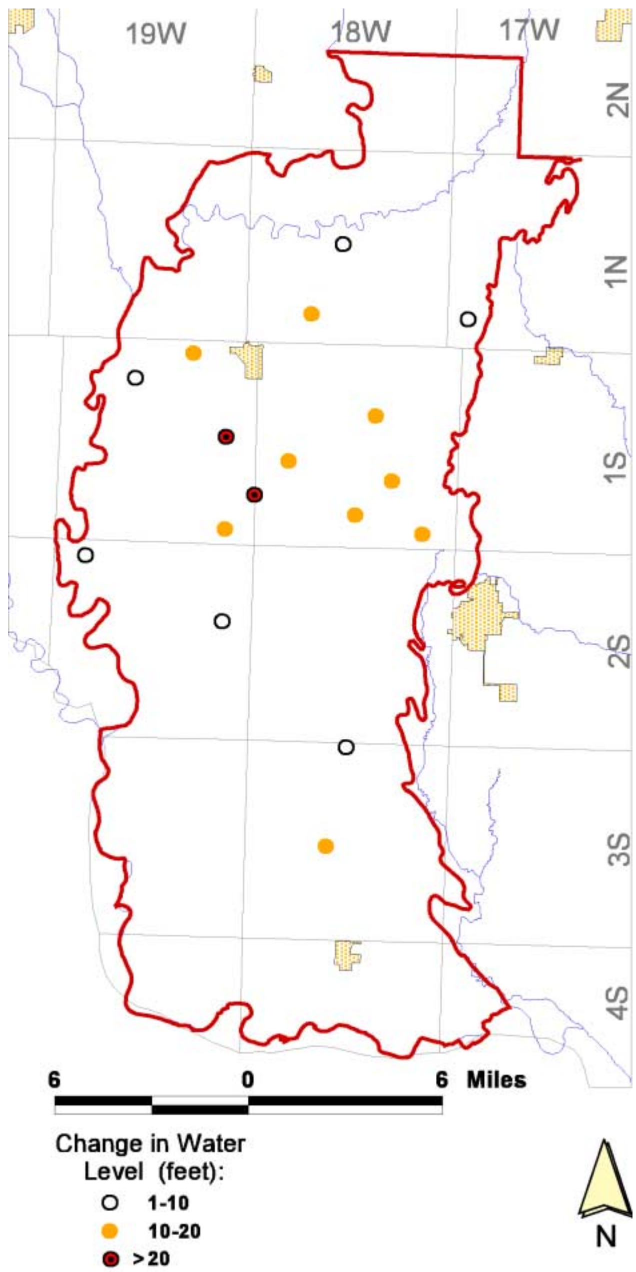


Figure 7. *Increase in water-level from 1974 to 1993 in measured wells.*

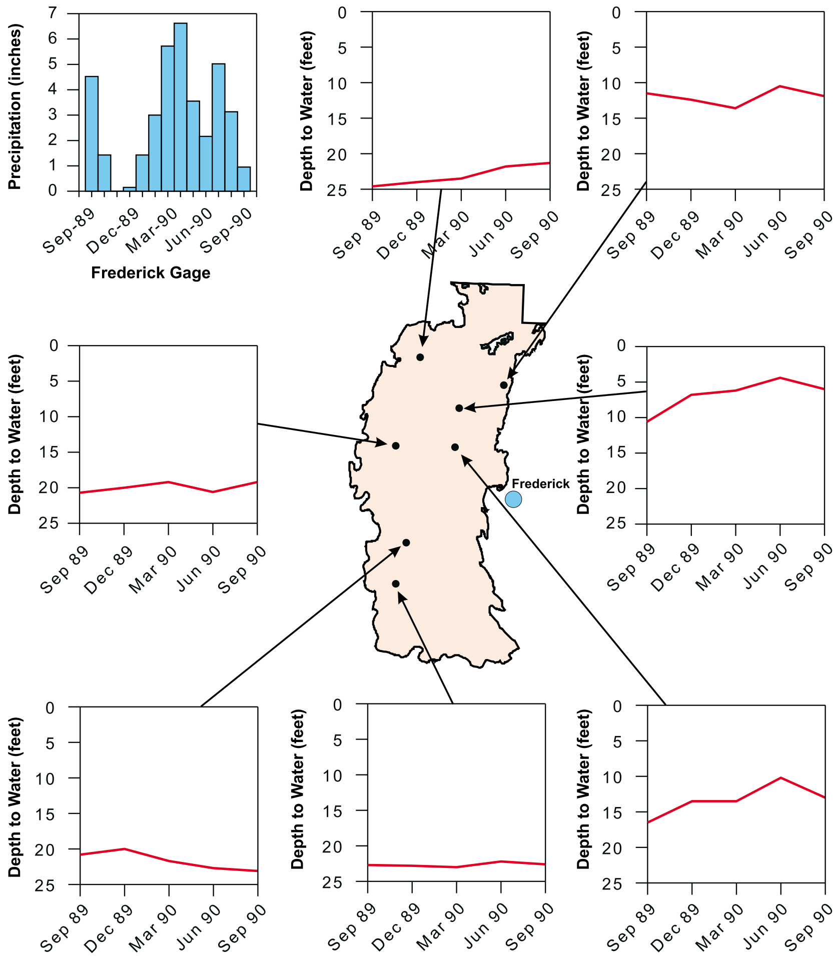


Figure 8. *Hydrographs of representative wells showing seasonal groundwater fluctuations from September 1989 to September 1990 and graph showing monthly precipitation measured at the Frederick gage.*

the upper part of the terrace deposits, and a specific yield of 0.15 to be representative for the entire saturated thickness. Al-Sumait (1978) estimated specific yield to range from 0.245 to 0.32, and to average 0.30.

Using the results from the calibrated groundwater flow model, Al-Sumait (1978) calculated the 1973 storage of the Basin to be 1,047,000 acre-feet. The 2000 Basin storage is estimated to be about 1,283,000 acre-feet assuming an area of 186,000 acres, an average saturated thickness of 23 feet, and an average specific yield of 0.30.

GROUNDWATER PRODUCTION

Wells

Figure 9 shows locations of irrigation, domestic, and public water supply wells with drillers' logs on file at the OWRB. Wells in the Basin are usually drilled one to two feet into the Permian redbeds. Well depths range from 16 to 85 feet, and average 50 feet. Irrigation wells are typically cased with 10-inch diameter steel casing, gravel-packed, and screened across the lower foot. Domestic wells are usually cased with 5-inch diameter PVC casing, gravel-packed, and screened across the lower 10 feet.

Where the permeability of the deposits is relatively high and the saturated thickness is great, irrigation wells yield more than 500 gpm, and some yield more than 1,000 gpm. On average, irrigation wells yield 400 gpm.

Water Use

Groundwater from the Basin is withdrawn primarily for irrigation (97 percent in 1999), while minor amounts are withdrawn for public water supply, agriculture (such as dairies), mining, stock, and domestic purposes. The towns of Tipton, Davidson, and Manitou rely at least partially on groundwater for their water supply.

Under Oklahoma groundwater law, the OWRB allocates withdrawals for all beneficial uses except for stock and domestic. As of February 2001, the OWRB had issued more than 390 groundwater permits in the Basin totaling about 45,000 acre-feet per year. Ninety-four percent of the allocated amount is for irrigation, and 5 percent is for public water supply. About 300 of the permits are prior groundwater rights, which were established before July 1, 1973. Prior groundwater rights total about 30,000 acre-feet, which is about 67 percent of the total allocated amount.

The OWRB requires permitted water users to report their annual water use. Reported water use for the years 1967 to 1999 is displayed in Figure 10. Highest reported water use was 17,869 acre-feet in

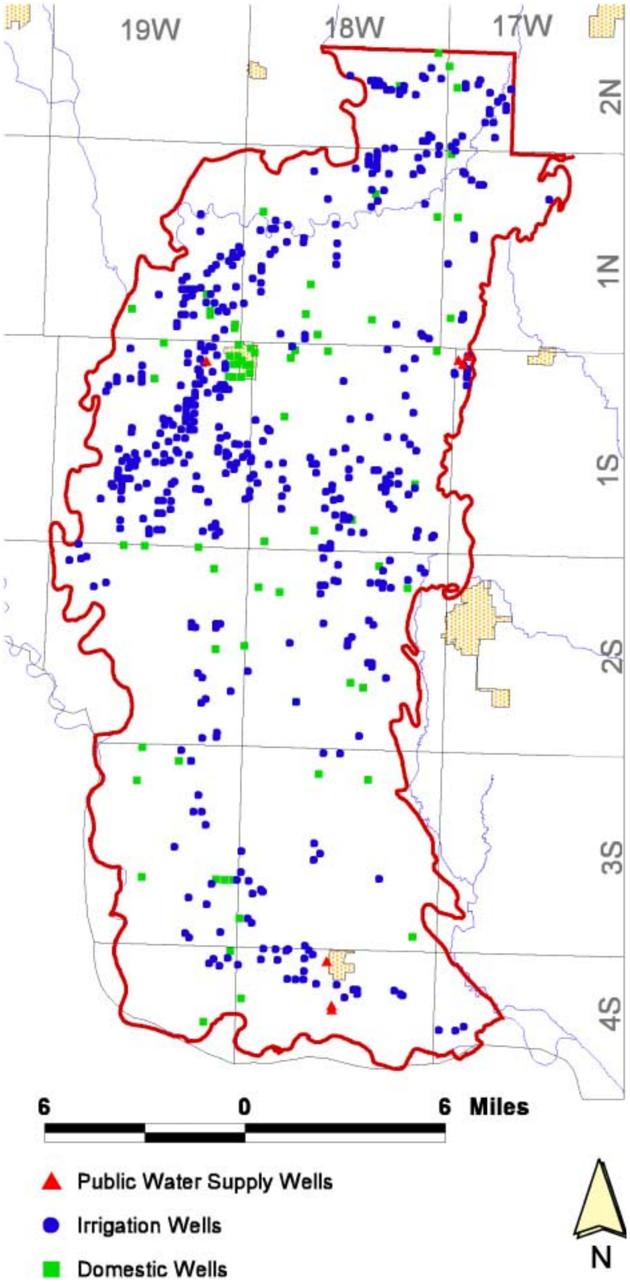


Figure 9. *Location of reported public water supply, irrigation, and domestic wells in the Tillman Terrace Groundwater Basin.*

1969, and the lowest was 4,864 acre-feet in 1995. As can be seen in Figure 10, reported water use has declined since 1980. This may be attributed to several reasons including increase in precipitation, decrease in use for public water supply, increase in irrigation efficiency, methodology of estimating irrigated water use, changes in irrigated crops, and allocation of water rights.

Irrigated water use is influenced by water consumption required by the crop, precipitation during the growing season that is available for use by the crop, soil moisture, and temperature. An evaluation of these factors was beyond the scope of this study. However, as discussed in the section on climate, annual precipitation has been above average since 1985. Higher precipitation results in increased recharge to the aquifer and decreased irrigation pumping.

Because of high concentrations of nitrate in the groundwater, municipalities are withdrawing more of their water from surface water than from groundwater. In 1975, Frederick switched to Lake Frederick for its primary water supply. By 2000, the city had completely discontinued use of its 26 wells.

Irrigation efficiency has increased since 1980. When fuel costs increased after 1978, many flood irrigation systems were converted to center pivot systems and other types of sprinkler systems. Center pivots are more efficient than flood or other types of sprinkler systems because they reduce both runoff and deep percolation. Figure 11 shows the percent of irrigation type by water use permit for selected years between 1980 and 1999. The percent of irrigation water use permits using flood irrigation decreased from 62 percent in 1980 to 37 percent in 1999, while the percent using center pivots increased from 8 to 57 percent.

The methodology used by the OWRB to estimate irrigated water use by crop changed in 1980. Prior to 1980, the OWRB used an algorithm to estimate water use using the number of acres irrigated and number of times applied for each crop type. After 1980, the OWRB calculated the amount used by multiplying the number of acres by the number of times applied by the amount per application. The change in methodology might account for at least some of the decrease in reported water use after 1980.

Land is irrigated primarily for cotton, alfalfa, wheat, and pasture. Since the 1980s, land has also been irrigated for peanuts. Other irrigated crops include grain, sorghum, oats, and barley. The percent groundwater used for irrigation by crop for

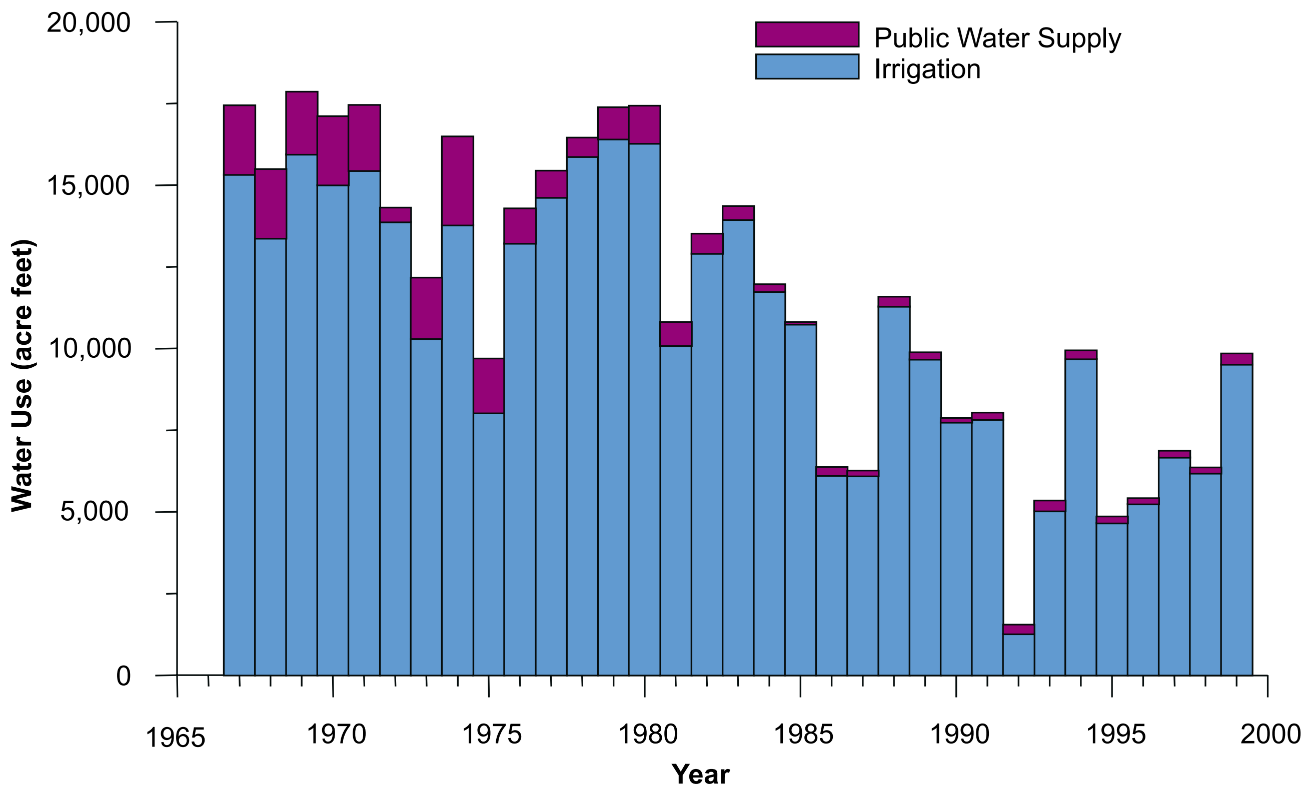


Figure 10. *Reported groundwater use from the Tillman Terrace Groundwater Basin for the years 1967 to 1999.*

selected years is shown in Figure 12. Some changes in water use occurred from 1970 to 1999. Water use for sorghum decreased from 21 to one percent; water use for wheat increased from 7 to 16 percent; and use for peanuts increased from zero to 14 percent. Water use for irrigation of cotton and alfalfa was variable.

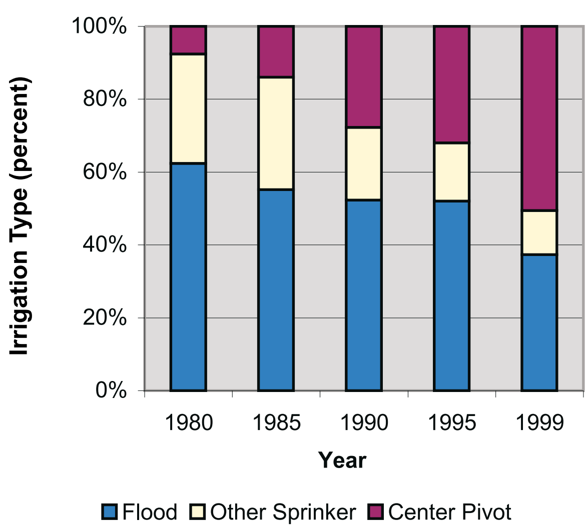


Figure 11. *Percent of irrigation type, by water use permit, for selected years between 1980 and 1999.*

Another change that occurred was the allocation of water rights. With the establishment of Oklahoma groundwater law on July 1, 1973, prior rights were allocated to existing water users. Water users who applied for a permit after that date were issued a temporary permit, with a maximum allocation statutorily set at 2 acre-feet per acre per year. Temporary permits were changed to regular permits after December 1978, when the OWRB issued a Board order allocating an equal proportionate share of 1.0 acre-foot per acre per year. This allocation applies to all groundwater permits other than prior rights.

Projected Groundwater Demand and Supply for 2000-2020

The population of Tipton, Davidson, and Frederick is projected to increase about 8 percent between 2000 and 2020, with most of the growth in Frederick (U.S. Census Bureau, 1998). A slight increase in population may result in more domestic wells, but should not have a significant impact on

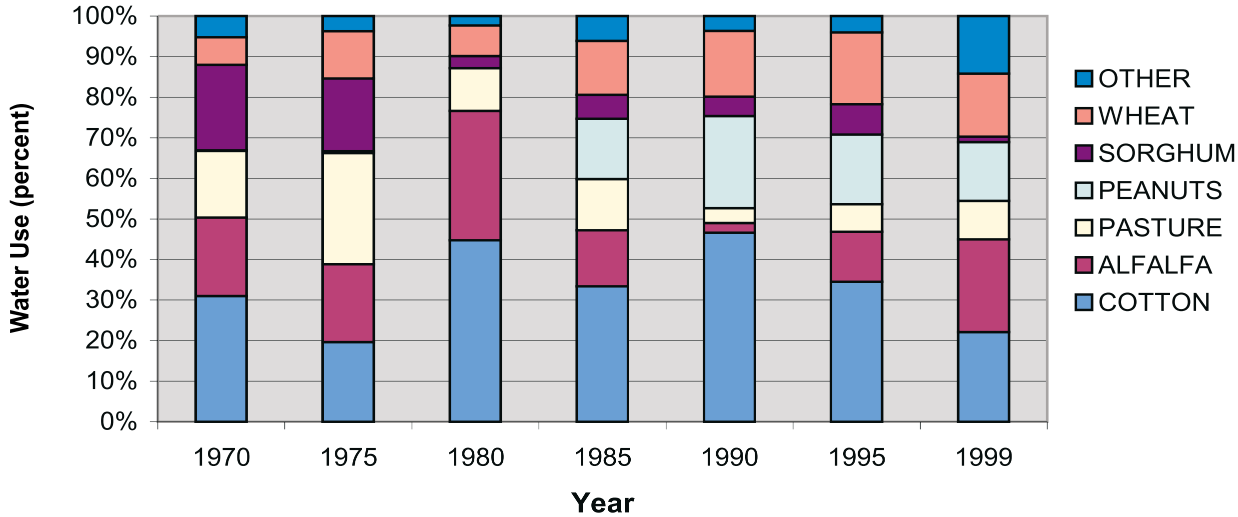


Figure 12. *Percent groundwater used for irrigation by crop for selected years between 1970 and 1999.*

water withdrawals. People living in the cities rely predominantly on public water supply. Frederick obtains all of its water supply from surface water, and Tipton and Davidson supplement their supplies from surface water.

The land overlying the Basin has been developed as much as possible for crops. There may be a trend toward other types of agriculture such as dairies or swine operations. However, water use would probably remain the same or decrease, because such operations use less water than irrigation.

Demand for groundwater would probably increase from current levels if the study area experiences a period of below average precipitation or prolonged drought conditions during the growing season. However, it is unlikely that withdrawals will ever be as great as they were in 1971, because irrigation efficiency has improved since then.

WATER QUALITY

Stream Water

Waters of the Red River and the North Fork of the Red River are saline, with high concentrations of chloride, sulfate, and dissolved solids. The primary source of saline water is the dissolution of halite (sodium chloride) and gypsum (calcium sulfate) in the Permian geologic units. Natural brine springs discharge to the Elm Fork River, a tributary to the North Fork of the Red River, and to the Red River upstream from the Tillman Terrace aquifer.

Groundwater

As part of a statewide monitoring program, the OWRB collected 35 groundwater samples from 12 wells in the Tillman Terrace aquifer between 1984 and 1992. Well locations and general water type are shown in Figure 13. Table 1 lists the concentrations of chemical constituents for representative samples and the summary statistics.

Concentrations of total dissolved solids (TDS) were generally high, with a median TDS concentration of 787.5 mg/L. Eight of the 12 samples had TDS concentrations exceeding the secondary maximum contaminant level (SMCL) of 500 mg/L. Major cations are sodium, calcium, and magnesium, and major anions are chloride and sulfate. Chloride and sulfate concentrations were generally below the SMCL of 250 mg/L, but exceeded the SMCLs in two samples.

As illustrated in Figure 13, water changed from a mixed bicarbonate type in the eastern portion of the aquifer to a sodium-chloride type in the western portion. Sodium chloride and sulfate waters within the terrace deposits were most likely from recharge from river water or from upward leakage from underlying Permian geologic units. The sample from well 9-0320, located half a mile from the North Fork of the Red River, is a sodium chloride type. The owner of the well, which is located near large irrigation wells, reported that the water quality had progressively become more saline over the years. It is likely that irrigation pumping has induced infiltration of the river water into the aquifer.

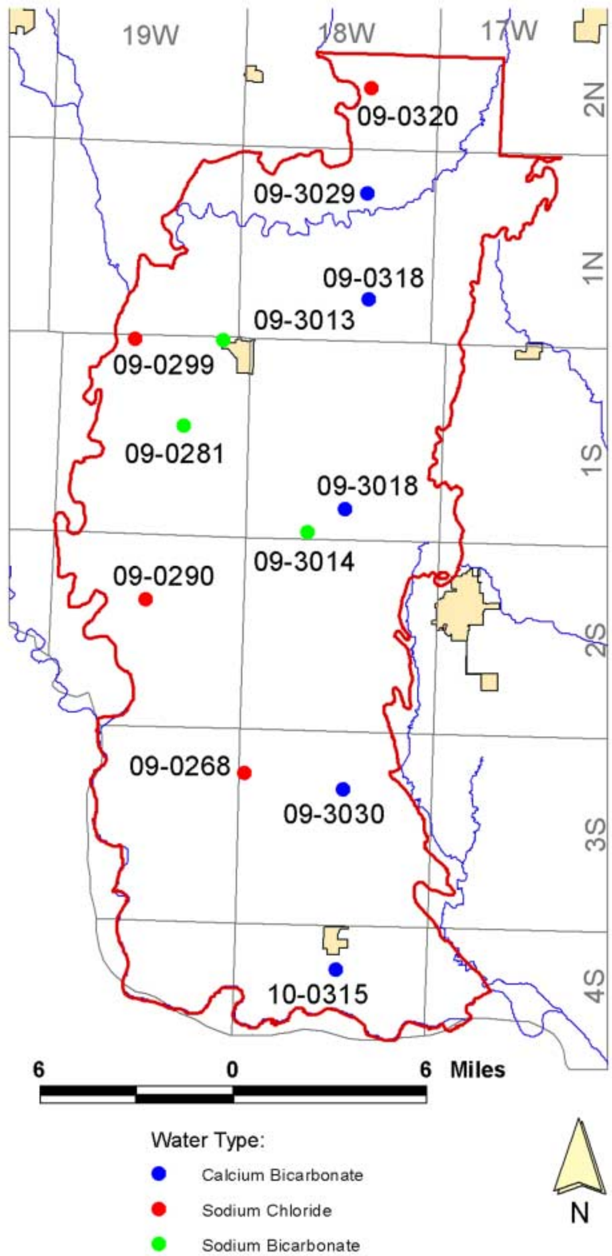


Figure 13. *Location of 12 wells completed in the Tillman Terrace Groundwater Basin that were sampled between 1984 and 1992 and general water type of samples.*

Nitrate was detected in all but one sample. The median concentration was 10.35, which exceeds the maximum contaminant level (MCL) of 10 mg/L. Probable sources of nitrate include chemical fertilizer, animal manure, and septic tanks.

Groundwater in the Basin is classified as highly vulnerable to contamination from surface sources. The aquifer's high porosity, permeability, and shallow water table, along with the permeable soil and low slope of the land surface make it particularly susceptible to pollution (Osborn and Hardy, 1999).

SUMMARY

The Tillman Terrace Groundwater Basin consists of the Quaternary alluvium and terrace deposits in western Tillman County. The total land area overlying the Basin is about 186,000 acres, or 290 square miles. Groundwater from the Basin is used extensively for irrigation, public water supply, agriculture, mining, stock, and domestic purposes. The Basin is the primary source of irrigation water for cotton, wheat, alfalfa, and peanuts.

Groundwater discharges from the Basin into rivers and streams. When the water table is higher than the river stage, groundwater discharges to the North Fork of the Red River, making the river a gaining stream. However, when the water table is lower than the river stage, water from the river contributes to the aquifer, making the river a losing stream. The primary source of recharge to the Basin is infiltration of precipitation. The average recharge rate for the Basin is estimated to be 2.87 inches per year, or about 12 percent of the mean annual precipitation.

Groundwater flows west toward the North Fork of the Red River, south toward the Red River, and north toward Otter Creek. The hydraulic gradient ranges from 0.001 to 0.005, with an average of 0.003. The depth to water in the Basin ranges from about 5 feet to 45 feet. Water levels in the aquifer fluctuate in response to recharge from

Table 1. *Concentrations (mg/L) of chemical constituents for representative groundwater samples collected in the Tillman Terrace Groundwater Basin.*

Site ID	Date	Hardness	Alkalinity	TDS	Calcium	Magnesium	Sodium	Chloride	Sulfate	Nitrate as N	Iron	Fluoride
09-0268	06/21/85	626	500	2286	95	80	616	565	391	12.2	<0.1	1.21
09-0281	07/10/84	396	405	1063	86	45	227	185	165	22	<0.1	1.36
09-0290	07/10/84	239	364	1060	52	30	320	245	181	11.2	0.12	1.78
09-0299	06/21/85	447	184	1031	101	42	225	228	238	5.2	<0.1	0.56
09-0318	07/10/84	261	200	389	80	14	29	17	27	13.8	<0.1	0.38
09-0320	06/21/85	991	72	4104	240	90	1103	1536	685	<0.5	0.19	0.65
09-3013	06/21/85	428	257	831	92	43	150	145	102	18.7	<0.1	1.26
09-3014	06/20/85	350	257	744	84	29	146	105	123	8.1	<0.1	1.11
09-3018	07/24/91	256	298	491	58	11	80	41	74	9.5	0.051	0.79
09-3029	07/24/91	382	345	592	76	35	70	64	77	11.7	0.372	0.51
09-3030	07/24/91	303	236	396	75	16	20	23	75	9.5	0.104	0.42
10-0315	07/10/84	318	257	471	61	42	48	52	41	9.2	<0.1	0.74
Minimum		239	72	389	52	11	20	17	27	<0.5	<0.1	0.38
Median		366	257	787.5	82	38.5	148	125	112.5	10.35	<0.1	0.765
Maximum		991	500	4104	240	90	1103	1536	685	22	0.372	1.78

precipitation and discharge from well pumping. Water levels in the Basin declined as much as 20 feet from 1953 to 1974, and then increased as much as 20 feet from 1974 to 1993 in response to higher than average precipitation and less irrigation.

Saturated thickness of the Basin ranges from less than 10 feet to greater than 40 feet. The average saturated thickness in 2000 is estimated to be closer to the 1952 saturated thickness (23 feet) than to the 1974 saturated thickness of 16 feet, because water level elevations measured in 2000 are similar to those measured in the early 1950s. Previous investigators conducted aquifer tests to estimate an average transmissivity of 2,680 ft^2/day. Hydraulic conductivity was estimated to range from 20 to 300 ft/day, and specific yield was estimated to average 0.30. The Basin storage in 2000 is estimated to be about 1,283,000 acre-feet. Where the permeability of the deposits is relatively high and the saturated thickness is great, irrigation wells yield more than 500 gpm, and some yield more than 1,000 gpm. On average, irrigation wells yield 400 gpm.

Groundwater from the Basin is withdrawn primarily for irrigation (97 percent in 1999) while minor amounts are withdrawn for public water supply, agriculture (such as dairies), mining, stock, and domestic purposes. In February 2001, about 45,000 acre-feet of groundwater per year were allocated to permitted water users. Ninety-four percent of the allocated amount was for irrigation and 5 percent was for public water supply. Prior groundwater rights established before July 1, 1973 total about 30,000 acre-feet, or about 67 percent of the total allocated amount. Water withdrawals were highest (17,457 acre-feet) in 1971 and the lowest (4,864 acre-feet) in 1995.

Groundwater samples were collected from 12 wells in the Basin between 1984 and 1992. TDS concentrations were generally high. The median TDS concentration was 787.5 mg/L, and eight of the 12 samples had TDS concentrations exceeding the SMCL of 500 mg/L. Chloride and sulfate concentrations were generally below the SMCL of 250 mg/L, but exceeded the SMCLs in two samples. Water changed from a bicarbonate type in the eastern portion of the aquifer to a sodium-chloride type in the western portion. Sodium chloride and sulfate waters within the terrace deposits were most likely from recharge from river water or from upward leakage from underlying Permian geologic units. Nitrate was detected in all but one sample. The median concentration was 10.35, which exceeds the MCL of 10 mg/L.

Probable sources of nitrate include chemical fertilizer, animal manure, and septic tanks.

Pollution from natural sources could occur along the western and southern boundaries of the Basin, where saline waters from the North Fork of the Red River and the Red River could recharge the aquifer. Pumping from wells located near the rivers could further induce encroachment of saline water. Groundwater in the Basin is classified as highly vulnerable to contamination from surface sources. The aquifer's high porosity, permeability, and shallow water table, along with the permeable soil and low slope of the land surface make it particularly susceptible to pollution.

Several changes have occurred between 1974, when the OWRB conducted the hydrologic survey of the Basin, and the time of this update. These are summarized below:

1. In December 1978, the OWRB issued a Board order allocating an equal proportionate share of 1.0 acre-foot per acre per year, which applies to all groundwater permits other than prior rights.
2. The average annual precipitation has increased. The average annual precipitation at Frederick from 1981 to 1999 was 31.4 inches, which is 3.8 inches above the historic annual average of 27.6 inches.
3. Between 1974 and 1993, groundwater levels in the Basin rose as much as 20 feet.
4. Water withdrawals have declined since 1980.
5. Irrigation efficiency has increased since 1980. The more efficient central pivot systems have increased while less efficient flood irrigation has decreased.
6. Some changes in crop irrigation have occurred. Water use for sorghum decreased while water use for wheat and peanuts increased.
7. Lake Frederick was completed in 1974, and Tom Steed Reservoir was completed in 1975. Although the reservoirs are not located within the Basin, they have provided water to municipalities that previously relied on groundwater. Tom Steed Reservoir also affects the flow of Otter Creek.
8. Because of high nitrate levels in groundwater, municipalities are withdrawing more of their water from surface water than from groundwater. In 1975, Frederick switched its primary water supply from wells to Lake Frederick.
9. The population of the study area has declined. The population of Tipton and Frederick declined about 24 percent between 1970 and 1998.

The most significant change to the Basin has been the change in water levels. In 1974, water levels were historically low. The hydrologic survey concluded that if existing pumping rates continued the aquifer would be depleted in 10-20 years. Fortunately, this did not occur. Since the time of the survey, water levels in the aquifer have risen as much as 20 feet to historically high levels in 1993.

Rising water levels in the Tillman Terrace Groundwater Basin indicate the aquifer is being replenished from precipitation at a greater rate than it is being depleted from pumping. This is primarily due to higher than average precipitation over the last 20 years. Higher precipitation has increased the recharge to the aquifer and decreased the need for irrigation pumping. Other factors that may have contributed to lower pumping include an increase in irrigation efficiency, a change to crops that require less irrigation, decreased withdrawals for public water supply, and allocation of water rights.

Demand for groundwater is not expected to increase in the foreseeable future. A slight increase in population may result in more domestic wells, but should not have a significant impact on water withdrawals. Demand for groundwater would probably increase from current levels if the Basin experiences a period of below average precipitation or prolonged drought conditions during the growing season. However, it is unlikely that withdrawals will ever be as great as they were in 1971, because irrigation efficiency has improved since then.

REFERENCES

Al-Sumait, A.J., 1978, A Computer Ground-Water Model for the Tillman Alluvium in Tillman County, Oklahoma: Oklahoma State University unpublished M.S. thesis, 152 p.

Barclay, J.E. and Burton, L.C., 1953, Ground-Water Resources of the Terrace Deposits and Alluvium of Western Tillman County, Oklahoma: Oklahoma Planning Resources Board Water Resources Div. Bull. 12, 71 p.

Becker, C.J., Runkle, Donna., and Rea, Alan, 1997, Digital Water-Level Elevation Contours for the Tillman Terrace and Alluvial Aquifer in Southwestern Oklahoma: U.S. Geological Survey Open-File Report 96-452, based on a scale of 1:249,695, 1 diskette.

Belden, M.H., 1999, Groundwater Level Changes in Oklahoma 1978-1998: Oklahoma Water Resources Board Technical Report 99-4.

Belden, M., Sullivan, K., and Wilkins, K., 1996, Hydrologic Report of the Minor Groundwater Basin in Comanche, Cotton and Tillman Counties: Oklahoma Water Resources Board Technical Report 96-3, 29 p.

Blazs, R.L., Walters, D.M., Coffey T.E., Boyle, D.L., Kerestes, J.F., and Johnson, R.E., 1998, Water Resources Data Oklahoma Water Year 1998: U.S. Geological Survey Water-Data Report OK-98-2, vol. 2.

Cannon, P.J., 1967, Pleistocene Geology of Salt Fork and North Fork of Red River, Southwestern Oklahoma: University of Oklahoma Masters thesis, 38 p.

Cederstrand, J.R., 1996, Digital Geologic Map of Lawton Quadrangle, Southwestern Oklahoma: U.S. Geological Survey Open-File Report 96-377, based on a scale of 1:250,000, 3 diskettes.

Kent, D.C. and Naney, J.W., 1978, Results of Computer Modeling of Alluvium and Terrace Deposits in Western Tillman County and Along the Washita River, Southwestern Oklahoma, for Water Supply Capability: Oklahoma Water Resources Board and Oklahoma State University Cooperative Agreement No. 12-14-7001-825, 52 p.

Havens, J.S., 1977, Reconnaissance of the Water Resources of the Lawton Quadrangle, Southwestern Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 6, 4 sheets, scale 1:250,000.

Johnson, K.S., 1990, Hydrogeology and Karst of the Blaine Gypsum-Dolomite Aquifer, Southwestern Oklahoma, Field Trip #15 Guidebook: Oklahoma Geological Survey Special Publication 90-5, 31 p.

Luckey, R.R., Osborn, N.I., Becker, M.F., and Andrews, W.J., 2000, Water Flow in the High Plains Aquifer in Northwestern Oklahoma, U.S. Geological Survey Fact Sheet 081-00.

Oklahoma Climatological Survey, 1997, Data and Products: http://climate.ocs.ou.edu/.

Oklahoma Water Resources Board, 1967, Appraisal of the Water and Related Land Resources of Oklahoma, Region One: OWRB Pub. 17, 60 p.

Oklahoma Water Resources Board, 1976, Basic Data Report on Ground Water Levels in Western Tillman County, Oklahoma, 1944-1975: OWRB Pub. 73, 16 p.

Osborn, N.I., and Hardy, R.H., 1999, Statewide Groundwater Vulnerability Map of Oklahoma: OWRB Technical Report 99-1, 34 p.

U.S. Census Bureau, 1998, General Profile for USA Counties: http//www.census.gov.

U.S. Department of Agriculture, 1974, Soil Survey of Tillman County, Oklahoma: Soil Conservation Service, 64 p.

U.S. Geological Survey, 1990, USGeoData 1:250,000 and 1:000,000 Scale Land Use and Land Cover and Associated Maps Digital Data.

Wickersham, Ginia, 1974, Ground Water Resources of Tillman Terrace Deposits, Tillman County, Oklahoma: Oklahoma Water Resources Board Hydrologic Investigations Pub. 58, 3 sheets, scale 1:140,000.