Report 276

OCCURRENCE, AVAILABILITY, AND QUALITY OF GROUND WATER IN TRAVIS COUNTY, TEXAS

TEXAS DEPARTMENT OF WATER RESOURCES

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OCCURRENCE, AVAILABILITY, AND QUALITY OF GROUND WATER IN TRAVIS COUNTY, TEXAS

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CONCLUSIONS

Geologic and hydrologic units which yield fresh to moderately saline ground water in Travis County, in the order of their importance as aquifers, are: the Edwards and associated limestones, the Trinity Group, the alluvium and terrace deposits, the Austin Chalk, the Navarro and Taylor Groups, igneous rocks around Pilot Knob, and the Midway Group.

The primary aquifer is the Edwards and associated limestones located within the Balcones fault zone in the central portion of the county.

Permeability in the Edwards is high and water moves rapidly through the aquifer. Well yields are often very large, and the aquifer usually contains fresh quality water. However, the ground water in the aquifer is very susceptible to pollution through the many open sink holes where recharge occurs.

Based on the long-term average annual spring discharge and ground-water pumpage from the Edwards and associated limestones within Travis County, the total average annual recharge to the aquifer was estimated to be slightly less than 40,000 acre-feet (49.3 hm^3). This estimate is probably representative for the long-term annual recharge; however, during a prolonged drought, this would be too high. Using a minimum annual spring flow at Barton Springs in 1956 of 9,262 acre-feet (11.4 hm^3) and an annual pumpage or withdrawal rate from the aquifer of 472 acre-feet (0.582 hm^3), the approximate amount of ground water which could be reliably developed annually during a period of prolonged drought would be 9,734 acre-feet (12.0 hm^3) or just slightly less than 10,000 acre-feet (12.3 hm^3).

The Trinity Group aquifer is subdivided into the lower Trinity, the middleTrinity, and the upper Trinity. They are all located mainly in the western half of the county.

The lower Trinity aquifer consists of the Hosston and Sligo Members of the Travis Peak Formation. Low permeability and transmissibility coefficients limit the rate of movement of water, and ground-water pumpage has caused declines of water levels in this aquifer especially around the Jonestown area in northwestern Travis County. Water from this hydrologic unit is often used for municipal purposes; however, it is usually slightly saline. Well yields range from small to moderate. In north-central Travis County, the ground-water quality is moderately saline.

The middle Trinity aquifer is comprised of the Hensell Sand and Cow Creek Limestone Members of the Travis Peak Formation and the lower member of the Glen Rose Formation. Permeabilities and transmissibilities are very low. Ground water derived from the aquifer is slightly saline and contains high sulfate which is derived from gypsum beds. Well yields are usually small but sufficient for domestic and livestock purposes.

The upper Trinity aquifer produces water from the upper member of the Glen Rose Formation and the Paluxy Formation. Permeabilities of the aquifer are very low and, therefore, yields are generally very small but sufficient for domestic and livestock use. The quality of water from the aquifer is usually fresh.

It is estimated that the total annual effective recharge to the Trinity Group aquifer within Travis County is about 25,000 acre-feet (30.8 hm^3). Total ground-water pumpage from the aquifer during 1976 was approximately 1,540 acre-feet (1.90 hm^3) and the estimated annual discharge by springs and flowing wells was 3,250 acre-feet (4.01 hm^3) giving a total annual discharge from the aquifer of about 4,790 acre-feet (5.91 hm^3). Therefore, approximately 20,200 acre-feet (24.9 hm^3) is available annually for additional development from the aquifer, much of which at the present time is lost by natural rejection.

Small to very large quantities of fresh to slightly saline ground water are produced from the alluvium and terrace deposits located adjacent to the Colorado River. The total estimated effective recharge to the aquifer within Travis County is about 6,000 acre-feet (7.40 hm^3). During 1976, approximately 2,550 acre-feet (3.14 hm^3) of ground water was pumped from the aquifer. Additionally, spring flow is estimated at 300 acre-feet (0.370 hm^3) annually. Thus, the amount of ground water available annually for additional development from the aquifer is approximately 3,150 acre-feet (3.88 hm^3).

Other minor aquifers which yield ground water in Travis County include the Austin Chalk, Navarro and Taylor Groups, igneous rocks around Pilot Knob, and the Midway Group. Well yields in these aquifers are very small with the water quality ranging from fresh to moderately saline. Ground water is usually high in sulfate, chloride, and nitrate content.

Pumpage of ground water from all aquifers within Travis County is not large when compared with surface-water use. During 1976, ground-water pumpage was 4,930 acre-feet (6.08 hm^3) and surface-water use was 55,233 acre-feet (68.1 hm^3). Springs and flowing wells account for an additional average annual ground-water discharge of 43,000 acre-feet (53.0 hm^3). Of this 43,OOO acre-feet (53.0 hm^3), approximately 36,400 acre-feet (44.9 hm^3) represents the average annual flow at Barton Springs based on the period from 1917-76.

A frequent problem in well construction is the failure of drillers to use heavy mud during the drilling operation. As a consequence, holes often cave or close before casing can be installed. When this happens, much of the potential well yield may be reduced or the hole lost. Acidizing may be used to a great advantage in increasing yields of wells, primarily in the lower Trinity and Edwards and associated limestones aquifers.

Contamination of ground water from oil-field brine does not appear to be a problem. However, other pollution sources such as sewage plants, septic tanks, and a former magnesium plant have caused pollution problems.

INTRODUCTION

Purpose and Scope

This ground-water investigation of Travis County was carried out during the period from January 1966 through April 1979. The purpose of the investigation is to determine and evaluate the ground-water resources of the county. The results of the investigation are presented in this report, which includes an analytical discussion of the occurrence and availability of the ground-water supplies, together with a tabulation of basic data obtained during the investigation.

The scope of the investigation encompassed the collection, compilation, and analysis of data related to ground water, including a determination of the location and extent of the water-bearing units or formations, the chemical quality of the water they contain, contamination problems, the hydraulic properties of the principal water-bearing units or formations, and estimates of the quantities of ground water available for development.

For those readers interested in using the International System (SI) of units, the metric equivalents of English units of measurements are given in parentheses in the text. The English units used in this report may be converted to metric units by the following conversion factors:

From	Multiply by	To obtain
Acres (ac)	0.4047	Square hectometers (hm^2)
Acre-feet (ac-ft)	.001233	Cubic hectometers (hm^3)
Barrels (42 gallons)	.159	Cubic meters (m^3)
Cubic feet (ft^3)	.002832	Cubic hectometers (hm^3)
Cubic feet per second (ft^3/s)	.02832	Cubic meters per second (m^3/s)
Feet (ft)	.3048	Meters (m)
Feet per mile (ft/mi)	.189	Meters per kilometer (m/km)
Gallons (gal)	3.785	Liters (l)
Gallons per minute (gal/min)	.06309	Liters per second (l/s)
Gallons per minute per foot [(gal/min)/ft]	.207	Liters per second per meter [(l/s)/m]

From	Multiply by	To obtain
Gallons per day per square foot [(gal/d)/ft^2]	40.74	Liters per day per square meter [(l/d)/m^2]
Gallons per day per foot [(gal/d)/ft]	12.418	Liters per day per meter [(l/d)/m]
Inches (in)	2.54	Centimeters (cm)
Miles (mi)	1.609	Kilometers (km)
Square miles (mi^2)	2.590	Square Kilometers (km^2)

To convert degrees Fahrenheit to degrees Celsius, use the following formula:

$$°C = (°F-32)\ (0.556)$$

Location and Extent

Travis County is located in central Texas as shown in Figure 1. It has an approximate area of 1,015 square miles (2,629 km^2). It is bordered on the north by Williamson County, on the east by Bastrop and Caldwell Counties, on the south by Hays County, and on the west by Blanco and Burnet Counties. Austin, the county seat and capital of the State of Texas, is centrally located in the county.

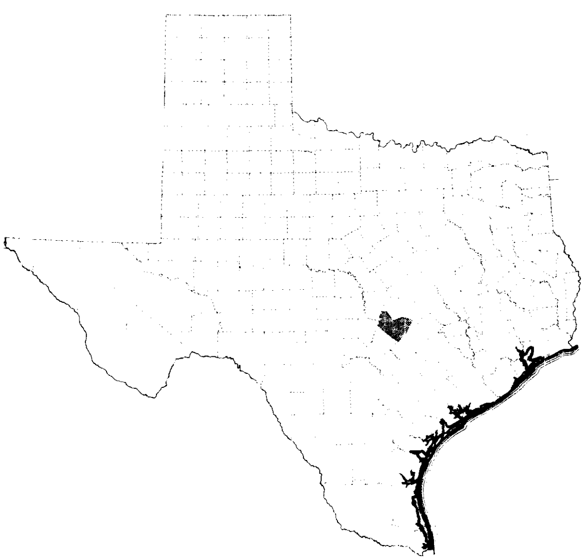

Figure 1.—Location of Travis County

Topography and Drainage

Travis County is roughly divided into three physiographic regions namely the Edwards Plateau, Blackland Prairie, and Grand Prairie. The Edwards Plateau lies west and southwest in Travis County and is locally referred to as the Hill Country. This region is dissected by the Colorado River and its many tributaries. East of the Edwards Plateau is the gently roiling Blackland Prairie which is a slightly to moderately dissected area. The northwestern part of the county is occupied by the Grand Prairie, locally referred to as the Lampasas Cut Plain.

Topographically, the altitude above sea level varies from 1,350 feet (411 m) in the northwest corner of the county to 365 feet (111 m) in the bed of the Colorado River where it crosses the eastern boundary.

The Colorado River flows through the center of the county from northwest to southeast. A number of reservoirs have been built on this river, primarily for hydroelectric power generation and flood control. The uppermost reservoir in Travis County is Lake Travis (Mansfield Dam), which backs up into Burnet County. The 266-foot (81 m) high dam was completed in 1942. The normal water level is 681 .1 feet (208 m) above sea level. The capacity is 1,172,600 acre-feet (1,443 hm^3) and the surface area 18,930 acres (7,661 hm^2) at this level. The reservoir provides flood control and hydroelectric power.

The next reservoir downstream is Lake Austin (Tom Miller Dam). The 100-foot (30 m) high dam was completed in 1940. Two previous dams were destroyed by floods in 1900 and 1915. The normal water level is 492.8 feet (150 m) above sea level. The capacity is 21,000 acre-feet (25.9 hm^3) and the surface area is 1,830 acres (741 hm^2) at this level. The reservoir is used primarily for hydroelectric power generation.

Just downstream from Lake Austin is Town Lake(Longhorn Dam). This reservoir was built for cooling purposes for a steam-electric power plant. The dam is 65 feet (20 m) high and the normal operation level 428 feet (130 m) above sea level. The capacity is 3,520 acre-feet (4.34 hm^3) and the area 416 acres (168 hm^2) at this level.

Walter E. Long Lake, about 10 miles (16 km) east of Austin, was completed in 1967. The dam is 83 feet (25 m) high and the normal operating level is at 555 feet (169 m) above sea level. The capacity is 33,940 acre-feet (41.8 hm^3) and the area is 1,269 acres (514 hm^2) at this level. The lake is used for cooling purposes in a steam-electric power plant.

Several tributaries enter the Colorado River in Travis County. Near the western boundary of the county, the Pedernales River enters Lake Travis from the south. Farther east, Barton and Onion Creeks enter the river from the south. Barton Springs, widely known as a recreational center, rise along Barton Creek a short distance above its mouth. The chief tributaries entering from the north are Cow and Sandy Creeks, which flow into Lake Travis, and Gilleland Creek, which enters the Colorado River near the east county line.

Climate

The climate of Travis County is humid subtropical with hot summers. The average annual temperature at Austin is 68 degrees Fahrenheit (20° C). Winters are mild, with below-freezing temperatures occurring on an average of less than 25 days each year. The mean maximum temperature for July is around 95 degrees Fahrenheit (35^0 C) and the mean minimum temperature for January is about 41 degrees Fahrenheit (5^0 C).

Precipitation is fairly evenly distributed throughout the year with heaviest amounts occurring in late spring. A secondary rainfall peak occurs in September. Precipitation records furnished by the U.S. National Weather Service at Austin from 1900 through 1976 show an average annual precipitation of 33.5 inches or 85.1 cm (Figure 2). The maximum officially recorded annual rainfall occurred in 1919 with 64.68 inches (164.3 cm). The minimum officially recorded annual rainfall occurred in 1954 with 11.42 inches (29.0 cm).

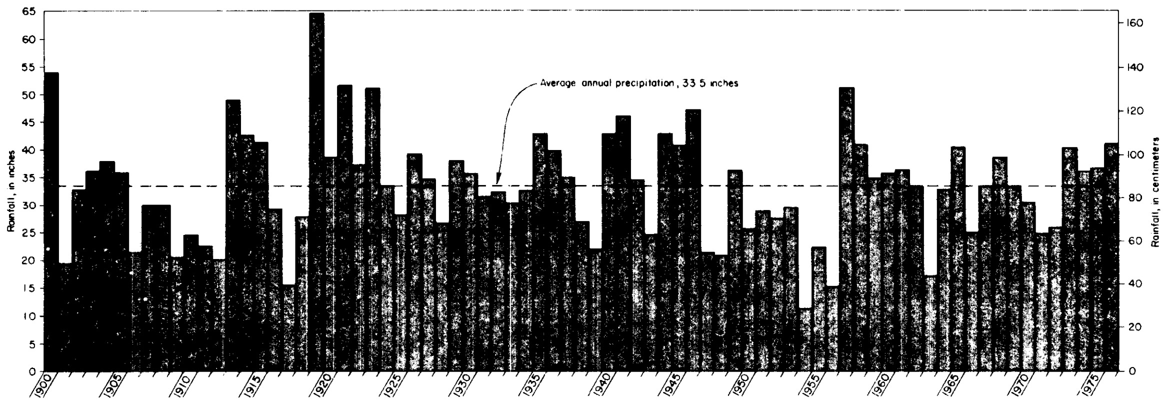

Figure 2.—Annual Precipitation at Austin, 1900-76
(Data from records of U.S. National Weather Service)

Monthly gross lake-surface evaporation ranges from 2.3 inches (5.8 cm) in January to 9.2 inches (23 cm) in August. Average annual gross evaporation is 61.7 inches or 158 cm (Kane, 1967).

The average length of the growing season (frost-free period) is 270 days. The average date of the last freeze in spring is March 3; the average date of the first freeze in fall is November 28. Freezing temperatures or below have occurred as late as April 13 (in 1940) and as early as October 26 (in 1924).

Population and Economy

The first modern settlements were made along the banks of the Colorado River in the 1830's. In 1839, the streets of Austin were laid out and the first Capitol of Texas was built. Travis County was created in 1840 from Bastrop County and formally organized in 1843. It was named for William B. Travis, the Commander of the Texans at the Alamo.

According to a special census conducted by the U.S. Department of Commerce in 1976, Travis County had a population of 373,275. Austin had a population of 308,952. Other cities examined during this census included: Lakeway, 538; Manor, 967; Pflugerville, 662; Rollingwood, 898; San Leanna, 274; Sunset Valley, 302; and West Lake Hills, 1,747.

Travis County provides many widely varied interests and pursuits. The principal ones are government, education, research and science-oriented industries, recreation, armed forces, and agriculture. The University of Texas main campus and several smaller colleges are located here. Total annual income in 1976 was $2,110,936,000. Federal expenditures for the 1976 fiscal year were $1,076,292,000. Annual agricultural income was over $18 million.

The value of mineral extractions in Travis County accounts for $97 million of the total income for the county. Several quarries produce lime for agriculture, highway construction, and other uses. A number of sand and gravel pits operate in the alluvium and terraces along the Colorado River. Only three oil fields are active in eastern Travis County which produce annually approximately 8,500 barrels (1,352 m^3) of oil and 720 million cubic feet (2 million hm^3) of casinghead gas.

Probably the most valuable natural resource of the county lies in the recreational value of the Hill Country and its associated lakes and springs. Lake Travis, Lake Austin, and Town Lake are part of a chain of seven lakes that extend from Austin westward for about 150 miles (241 km). These and other lakes provide recreation for thousands of people.

Previous Investigations

The first known investigation of ground water in Travis County was by Shumard (1860) when he described the formations encountered in a detailed geologic log on the old State Capitol water well (58-43-707).

Hill and Vaughn (1898) described in detail the geology of the Edwards Plateau and Rio Grande plain in the vicinity of Austin and San Antonio. They discussed many artesian wells and springs in the area and included a number of chemical analyses of ground water.

Meinzer (1927), in writing of large springs in the United States, described the geology and flow of Barton Springs.

George, Cumley, and Follett (1941) prepared records of wells and springs in Travis County. Also, White and Livingston (1941) wrote on the water resources of Austin, describing the various aquifers.

Follett (1956) compiled the records of water-level observation wells in Travis, Hays, and Williamson Counties. Several water-level hydrographs were included in his study. Arnow(1957) updated the records of wells and springs in Travis County, including 970 records, with many driller's logs and chemical analyses of ground water.

William F. Guyton and Associates (1958) concluded that there is a ground-water divide in the Edwards Limestone reservoir near Buda.

Baker and Watson (1971) studied the quantity of low flow in Barton Creek. The study considered the recharge and discharge of the Edwards Limestone reservoir in this area.

The most recent investigation in the area was completed by Klemt, Alvarez, and Perkins (1975) and it considered the Antlers and Travis Peak Formations of central Texas. This study included northern Travis County. It listed records of 122 wells in Travis County, with many chemical analyses of ground water and a digital computer simulation of pumpage on the Antlers and Travis Peak Formations.

Many other previous investigations dealing with geology and related subjects are listed in the references at the end of this report.

Methods of Investigation

During this investigation, an inventory was made of all existing water wells used for municipal, industrial, and irrigation purposes. In addition, an inventory was made of representative domestic and livestock wells. Information on selected oil wells, test holes, and springs was also obtained; and, where possible, on previous large wells which have been abandoned or destroyed. Figure 25 shows the locations of the wells and springs inventoried and information on each is listed in Table 5.

Many well records were obtained from drillers' reports on file with the Texas Department of Water Resources, well drillers, consultants, and individual well owners. A total of 1,064 wells, test holes, and springs were inventoried. Some more important wells in adjacent counties were included.

Water levels were measured and records of past measurements were used to determine the effects of pumping. Wells which are or have been used as water-level observation wells are indicated in Table 6 and their locations are shown on Figure 25.

Chemical analyses of water samples collected from wells and springs in Travis and adjacent counties during this and previous investigations(a total of 1,035 analyses) were compiled and are listed in Table 7. This information was used to prepare maps showing the chemical quality and composition of the ground water in each aquifer. Ground-water contamination problems of various types, their causes, and possible remedies were analyzed.

The lithologic character, depth, and thickness of the formations as presented in this report are based largely on studies and correlations of geophysical logs. Copies are on file with the Texas Department of Water Resources.

Well-Numbering System

The Texas Department of Water Resources statewide well-numbering system is used in this report. As indicated on Figure 3, the system is based on longitude and latitude, with each well or spring being assigned a seven-digit number. In addition, a two-letter county designation prefix is used.

Each 1 -degree quadrangle in or overlapping into the State is given a two-digit number from 01 to 89. These are the first two digits of a well number. Each 1 -degree quadrangle is further divided into sixty-four 7 1/2 minute quadrangles which are each assigned a two-digit number from 01 to 64. These two digits constitute the third and fourth digits of a well number. Each 7 1/2-minute quadrangle is subdivided into nine 2 1/2-minute quadrangles which are numbered 1 to 9. This is the fifth digit of a well number. Finally, each well or spring within the 2 1/2-minute quadrangles is assigned a two-digit number beginning with 01. These twodigits constitute the sixth and seventh digits of a well number.

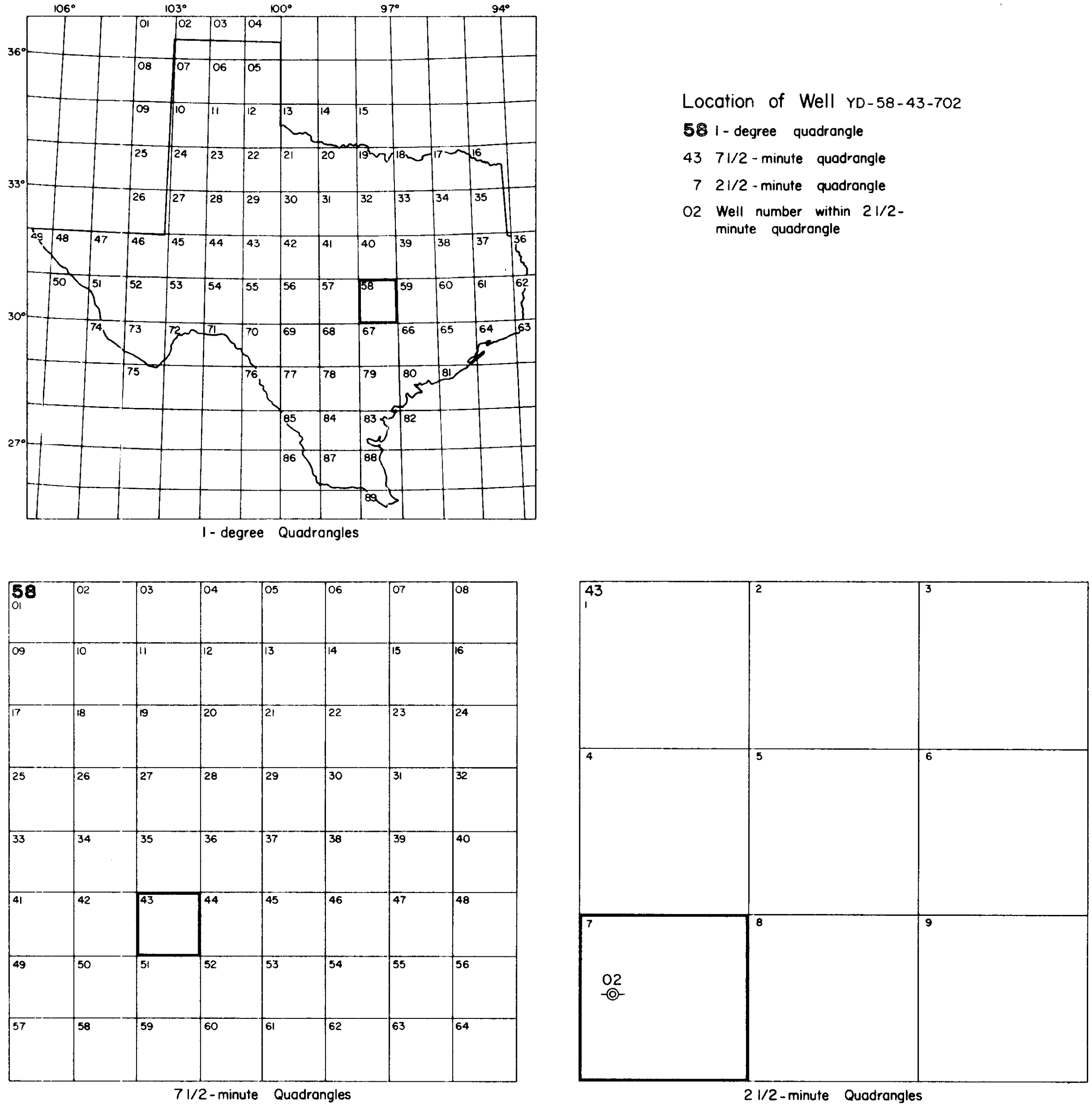

Figure 3.—Well-Numbering System

Each seven-digit number has a two-letter prefix to identify the county in which the well or spring is located. The prefixes for Travis and the adjoining counties are as follows:

County	Prefix
Bastrop	AT
Blanco	AZ
Burnet	BT
Caldwell	BU

County	Prefix
Hays	LR
Travis	YD
Williamson	ZK

Travis County lies in that part of Texas covered by one-degree quadrangle numbers 57 and 58. These lie between the latitudes of 30 and 31 degrees north. Quadrangle 57 lies between 98 and 99 degrees west longitude and quadrangle 58 lies between 97 and 98 degrees west longitude. The 7 1/2-minute quadrangles are numbered on the well-location map, Figure 25. On this map, the 2 1/2-minute quadrangles are not numbered, because of space limitations. However, their notation occurs as the first digit of the three-digit number beside each well or spring location.

Well YD-58-43-702 indicates that it is within Travis County; within 1 -degree quadrangle 58; within 7 1/2-minute quadrangle 43; within 2 1/2-minute quadrangle 7; and is the second (02) well to be numbered in that. quadrangle. This well was drilled on the State Capitol grounds in 1890.

Acknowledgements

The authors are indebted to the many property owners who supplied information about their water wells and permitted access to their property; to the well drillers who supplied information on wells; and to the numerous municipalities, industries, and water districts for supplying data and cooperating in aquifer tests on their wells.

The U.S. Geological Survey furnished numerous records of wells and springs and records of several water-level recorders. The Texas Department of Health provided many chemical analyses of public water supplies. The former Texas Water Quality Board furnished data on ground-water contamination within the county. The Bureau of Economic Geology, The University of Texas at Austin, and F. E. Lozo were very helpful in the preparation of the geologic map of the county.

The City of Austin provided information on its large wells and on the areas of the county which are supplied with water from Austin. The Austin-Travis County Health Department furnished information on regulations regarding septic tanks, which are threatening to contaminate ground-water supplies.

Many consultants, including William F. Guyton and Associates and Rollin W. Harden, furnished data on recharge and pumping tests of the various aquifers. The Trinity Engineering Testing Corporation supplied the results of their extensive test-drilling program for the crosstown wastewater interceptor tunnel. Bryant Curington, Inc., provided information on the Aqua Water Supply Corporation and Roger L. Erickson furnished data on the Manville Water Supply Corporation.

The Railroad Commission of Texas supplied detailed information on oil and gas production and brine disposal in the county. Numerous oil companies contributed valuable drillers' and geophysical logs of oil and gas tests.

This report was prepared under the general direction of C. R. Baskin, Director of the Data and Engineering Services Division of the Texas Department of Water Resources, and Tommy R. Knowles, Chief of the Data Collection and Evaluation Section.

Definitions of Terms

For convenience and clarification, certain technical terms used in this report are defined as follows:

Aquifer—A geologic formation, group of formations, or part of a formation that is water bearing.

Coefficient of permeability—The rate of flow of water in gallons per day through a cross sectional area of 1 square foot under a unit hydraulic gradient (1 foot of fall for each foot of lateral movement). Also called hydraulic conductivity, in which case it is measured in feet, or meters, per day.

Coefficient of transmissibility—The number of gallons of water that will move in 1 day through a vertical strip of the aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity. It is the product of the field coefficient of permeability, or hydraulic conductivity, and the saturated thickness of the aquifer. It is also called transmissivity, and may be measured in square feet, or square meters, per day.

Dip—The angle at which a stratum is inclined from the horizontal. It may be measured in degrees, feet per mile, or meters per kilometer.

Fault—A fracture or fracture zone in rocks along which there has been displacement of the two sides relative to one another parallel to the fracture.

Hydraulic gradient—The change in static head of a fluid per unit of distance in a given direction.

Perched ground water—Ground water separated from an underlying body of ground water by unsaturated rock. Its water table is a perched water table.

Potentiometric surface—The imaginary surface to which water will rise in artesian wells, or the surface formed by the water table in the outcrop areas. The terms "water table" and "potentiometric surface" are synonymous in the outcrop area, but potentiometric surface alone is applicable in artesian areas. Also called piezometric surface, a term which has been used by many in the past.

Specific capacity—The discharge of a well expressed as the rate of yield per unit of drawdown, generally in gallons per minute per foot of drawdown.

Specific conductance—A measure of the ability of a solution to conduct electricity, expressed in micromhos at 25°C. It is approximately proportional to the content of dissolved solids. The values of specific conductance and specific conductivity are equivalent, however, the units for specific conductivity are expressed in micromhos per centimeter at 25°C.

Specific yield—The ratio expressed in percentage of (1) the volume of water which a rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock or soil.

Storage coefficient—The volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface.

Strike—The course or bearing of the outcrop of an inclined bed, joint, or fault, on a level surface. It is perpendicular to the direction of the dip.

Vug—A solution-caused cavity in rock, from smaller than the size of a pea to several feet in diameter.

Water level; static level; or hydrostatic level—In an unconfined aquifer, the distance from the land surface to the water table. In a confined (artesian) aquifer, the level to which the water will rise either above or below land surface.

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

History

During Precambrian time, deposits consisting of limestone, sandstone, and carbonaceous shales were laid down in central Texas and in the Travis County area. Later, these sediments were intruded by ingneous magmas and were metamorphosed and folded. Following this and prior to the beginning of the Paleozoic era, these rocks were extensively eroded (Klemt and others, 1975).

A sedimentary basin existed during most of the Paleozoic era, and the Travis County area received sediments consisting of limestone, sandstone, shales, and minor amounts of other marine sediments. Deposition in this basin was terminated by late Pennsylvanian time by movement in the Ouachita fold belt and the Llano uplift area.

Folding and thrusting of these Paleozoic formations in the Ouachita fold belt began in Mississippian time and extended into the Permian in some areas. The man deformation, however, took place during Pennsylvanian time (Flawn and others, 1961). At about the same time, the Llano area to the west of Travis County was raised above sea level. This folding and uplift caused regional tilting to the west and faulting in the uplift area.

Following the close of the Paleozoic, extensive erosion continued throughout Triassic time in the central Texas area. At the end of Jurassic time, most of Texas was dry land as the seas had retreated from most of the North American Continent.

At the beginning of the Cretaceous period, the sea advanced from the south and east and eventually covered all of central Texas. This major transgression was marked by several minor regressions which resulted in the deposition of present day sequences of sandstones, shales, and limestones found in Travis County. During late Cretaceous (Gulf Series), many volcanoes rose from the sea, producing pyroclastic sediments, basalt intrusions and flows, part of which later altered to serpentine. The uplift continued and the Cretaceous seas retreated to the south and east marking the end of the Cretaceous period in central Texas.

In Tertiary time, only the extreme eastern portion of Travis County was transgressed by the sea. At this time, the Eocene Midway Group was deposited.

During the Cenozoic era, in Miocene and Pliocene times, much readjustment of the previously deposited sediments took place, resulting in the extensive faulting in the Balcones fault zone. During Pleistocene time, the many river terraces and high gravel deposits were laid down upon the older sediments.

Stratigraphy

Stratigraphic units underlying Travis County range in age from the Ordovician Ellenburger Group to Recent alluvium. Of these, the most important water-bearing units are of Cretaceous age. The Smithwick Shale, Strawn Group, Hammett Shale, Walnut Formation, Del Rio Clay, and Eagle Ford Group carry no significant amounts of fresh water.

The stratigraphic units underlying the county are composed largely of limestone, chalk, shale, sand, and clay. Smaller amounts of gravel, silt, dolomite, gypsum, anhydrite, conglomerate, siltstone, and sandstone are also present. In some localities, igneous basalt and pyroclastics and metam orphic phyllites and quartzites also occur. Table 1 summarizes the approximate maximum thickness, lithologic characteristics, and water-bearing properties of these units.

Pre-Cretaceous stratigraphic units, including the Ellenburger Group and those above it, have a maximum thickness of about 3,200 feet (975 m). Normally the thickness is considerably less, however, because of erosion of the upper formations. According to Table 1, Cretaceous and younger formations have a maximum thickness of approximately 5,980 feet (1,822.7 m).

The Cret:aceous System is divided in two series, Comanche and Gulf. The oldest is the Comanche Series which is composed of three groups: Trinity, Fredericksburg, and Washita. The Gulf Series is divided into four groups: Eagle Ford, Austin, Taylor, and Navarro. Lithologically, the Eagle Ford, Austin, Taylor, and Navarro Groups consist predominantly of marl, shale, limestone, and igneous rocks. With the exception of the Eagle Ford, they all yield very small quantities of ground water.

The Trinity, Fredericksburg, and Washita Groups are the most important water-bearing units in Travis County. Each group is divided into separate stratigraphic units (Table 1).

Listed in order from the oldest to youngest, the Trinity Group is divided into the Travis Peak, Glen Rose, and Paluxy Formations.

The Travis Peak Formation is composed of the Hosston, Sligo, Hammett Shale, Cow Creek Limestone, and Hensell Sand Members. The Hosston, Sligo, Cow Creek Limestone, and Hensell Sand Members of the Travis Peak Formation consist of limestone, sand, and shale, which are capable of yielding small to moderate quantities of water. The Hammett Shale is composed of shale and is not known to yield usable water in Travis County.

Table 1.—Geologic Units and Their Water-Bearing Properties

System	Series	Group	Stratigraphic unit	Hydrologic unit	Approximate maximum thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Recent		Alluvium	Alluvium and terrace deposits	60	Water-stratified deposits of unconsolidated calcareous gravel, sand, silt, and clay, with coarser materials usually concentrated in the lower section.	Yields small to very large quantities of fresh to slightly saline water, chiefly along the Colorado River in eastern Travis County.
	Pleistocene		Terrace deposits		60	Water-stratified deposits of unconsolidated calcareous gravel, sand, silt, and clay, with the coarser materiels at the base.	Yields very small to moderate quantities of fresh to moderately saline water.
			Onion Creek Marl		50	Water-stratified deposits of calcareous gravel, sand, silt, and clay, often cemented with calcium carbonate.	
			High gravel		20	Gravel and sand, sometimes mixed with clay from underlying formations.	
Tertiary	Eocene	Midway		Midway	300	Clay, silt, glauconitic sand, and thin beds of limestone and sandstone with gypsum, phosphatic nodules, and calcareous concretions.	Yields very small quantities of fresh to moderately saline water.
Cretaceous	Gulf	Navarro		Navarro and Taylor Groups	1,200	Massive beds of shale and marl with clayey chalk, clay, sand, and some nodular and phosphatic zones.	Yields very small quantities of fresh to moderately saline water.
		Taylor					
		Austin	Igneous rocks	Igneous rocks	700	Altered pyroclastics, limburgite, basalt intrusions and flows, and nontronite.	Yields very small quantities of fresh water.
				Austin Chalk	500	Massive beds of chalk and marl with bentonitic seams, glauconite, and pyrite nodules.	Yields small to very small quantities of fresh water.
		Eagle Ford			45	Massive calcareous shale with thin interbeds of silty and sandy, flaggy limestone.	Not known to yield water in Travis County.
	Comanche	Washita	Buda Limestone		50	Massive, fine-grained, burrowed, shell-fragment limestone. The upper portion is harder and bluff-forming.	Not known to yield water in Travis County.
			Del Rio Clay		75	Clay and marl with gypsum, pyrite, and a few thin siltstone and sandstone beds.	Not known to yield water in Travis County.
			Georgetown Formation	Edwards and associated limestones	100	Thin interbeds of richly fossiliferous, nodular, massive fine-grained limestone and marl.	Yields small to very large quantities of fresh water, especially from cavernous zones in the Edwards Limestone.
		Fredericksburg	Kiamichi Formation		10	Marl, thin limestone seams, clay, and shell aggregates. Not present at the surface in Travis County.	Not known to yield water in Travis County.
			Edwards Limestone		360	Massive, brittle, vugular limestone and dolomite with nodular chert, gypsum, anhydrite, and solution-collapse features.	Yields small to very large quantities of fresh water, especially from cavernous zones.
			Comanche Peak Limestone		60	Fine-grained, fairly hard, nodular, fossiliferous, marly, extensively burrowed limestone.	Yields little or no water in Travis County.
			Walnut Formation		120	Hard and soft limestones, marls, clays, and shell beds.	Yields little or no water in Travis County.
		Trinity	Paluxy Formation	Upper Trinity	10	Fine-grained quartz sand, in part indurated by calcium carbonate cement. Locally contains thin beds of limestone and marl.	Yields very small to moderate quantities of fresh, and occasionally slightly saline water.
			Glen Rose Formation: Upper Member		600	Alternating beds of limestone, dolomite, shale, and marl with some anhydrite and gypsum.	
			Glen Rose Formation: Lower member	Middle Trinity	330	Massive, fossiliferous limestone and dolomite in the basal part grading upward into thin beds of limestone, shale, marl, and gypsum. **Corbula martinae** bed at top.	Yields very small to moderate quantities of fresh to moderately saline water. The moderately saline water appears to be confined to north-central Travis County. Many small and medium springs issue from the base of the Hensell Sand in Travis County.
			Travis Peak Formation: Hensell Sand Member		70	Sand, gravel, conglomerate, sandstone, siltstone, and shale in western Travis County. Grades into sandy limestone and dolomite in eastern Travis County.	
			Travis Peak Formation: Cow Creek Limestone Member		100	Massive, often sandy, dolomitic limestone, frequently forming cliffs and waterfalls. Contains gypsum and anhydrite beds.	
			Travis Peak Formation: Hammett Shale Member		60	Shale and clay with some sand, dolomitic limestone, and conglomerate.	Not known to yield water in Travis County.
			Travis Peak Formation: Sligo Member	Lower Trinity	300	Limestone, dolomite, occasionally sandy, and shale. Thins to the west and is not present in northwest Travis County.	Yields small to moderate, and with acidizing, large quantities of fresh to moderately saline water.
			Travis Peak Formation: Hosston Member (Sycamore Sand in outcrop)		800	Basal conglomerate grading upward into a mixture of sand, siltstone, and shale, with some limestone beds.	
Pennsylvanian	Lower Pennsylvanian	Strawn			800	Alternating beds of sandstone and shale, with some conglomerates.	Not known to yield water in Travis County.
		Bend	Smithwick Shale		500	Shale with sandstone and siltstone in the upper portion. Metamorphosed to phyllites and quartzites in the Ouachita Fold Belt.	Not known to yield water in Travis County.
			Marble Falls Limestone		400	Cavernous, massive, siliceous, fossiliferous limestone.	Not known to yield water in Travis County, but may yield small to moderate quantities of slightly to moderately saline water.
Ordovician	Lower Ordovician	Ellenburger			1,500	Cavernous, crystalline, fossiliferous limestone and dolomite.	Not known to yield water in Travis County.

The Glen Rose Formation is predominantly a limestone and yields small to moderate quantities of water. In this report, the Glen Rose is divided into an upper and a lower member.

The Paluxy Formation consists of a fine-grained sand which crops out only in a very small area in the northwest corner of the county. It is capable of yielding small quantities of water. The Trinity Group will be discussed in detail in the section covering the stratigraphy of water-bearing units.

Four formations make up the Fredericksburg Group. These are the Walnut Formation, Comanche Peak Limestone, Edwards Limestone, and Kiamichi Formation. The Walnut and Comanche Peak consist of shale and limestone and yield little or no water. The Edwards is a massive vugular limestone and in some areas yields large amounts of good quality water. The Kiamichi is a shale and is not known to yield water.

The Washita Group is divided into the Georgetown Formation, Del Rio Clay, and Buda Limestone. The Georgetown is a fine-grained limestone and yields small amounts of usable quality water. The Georgetown Formation and the Edwards Limestone are in hydraulic continuity and are discussed in this report as the Edwards and associated limestones. The Del Rio Clay and Buda Limestone consist of shale and limestone and neither are known to yield water in Travis County.

Those formations or stratigraphic units, which are exposed at the surface, are shown on the geologic map (Figure 4). The geologic units generally crop out in northeast-southwest trending bands. However, in western Travis County, where topographic relief is prominent, the outcrops of the various units are controlled principally by surface elevation.

Principal faults and fault zones in the area are also shown on the geologic map. Faults with little displacement are not shown. Pre-Cretaceous stratigraphic units or formations (the Strawn Group and older rocks) do not now crop out on the surface in the county. Barnes (1948) mapped some small areas of Smithwick Shale in western Travis County along the Colorado River, but these are now covered by Lake Travis.

Geologic sections (Figures 26 through 30) show the stratigraphic relationship and structural attitude of each unit. Three of the sections (Figures 26, 28, and 29) are oriented in a downdip direction and two (Figures 27 and 30) lie along the strike of the formations.

Structure

Geologic structures affecting ground water within Travis County are the regional dip and the uneven pre-Cretaceous erosional surface, the Balcones fault zone, the Llano uplift, the San Marcos arch, and the Luling-Mexia-Talco fault zone. These regional structures are shown in Figure 5.

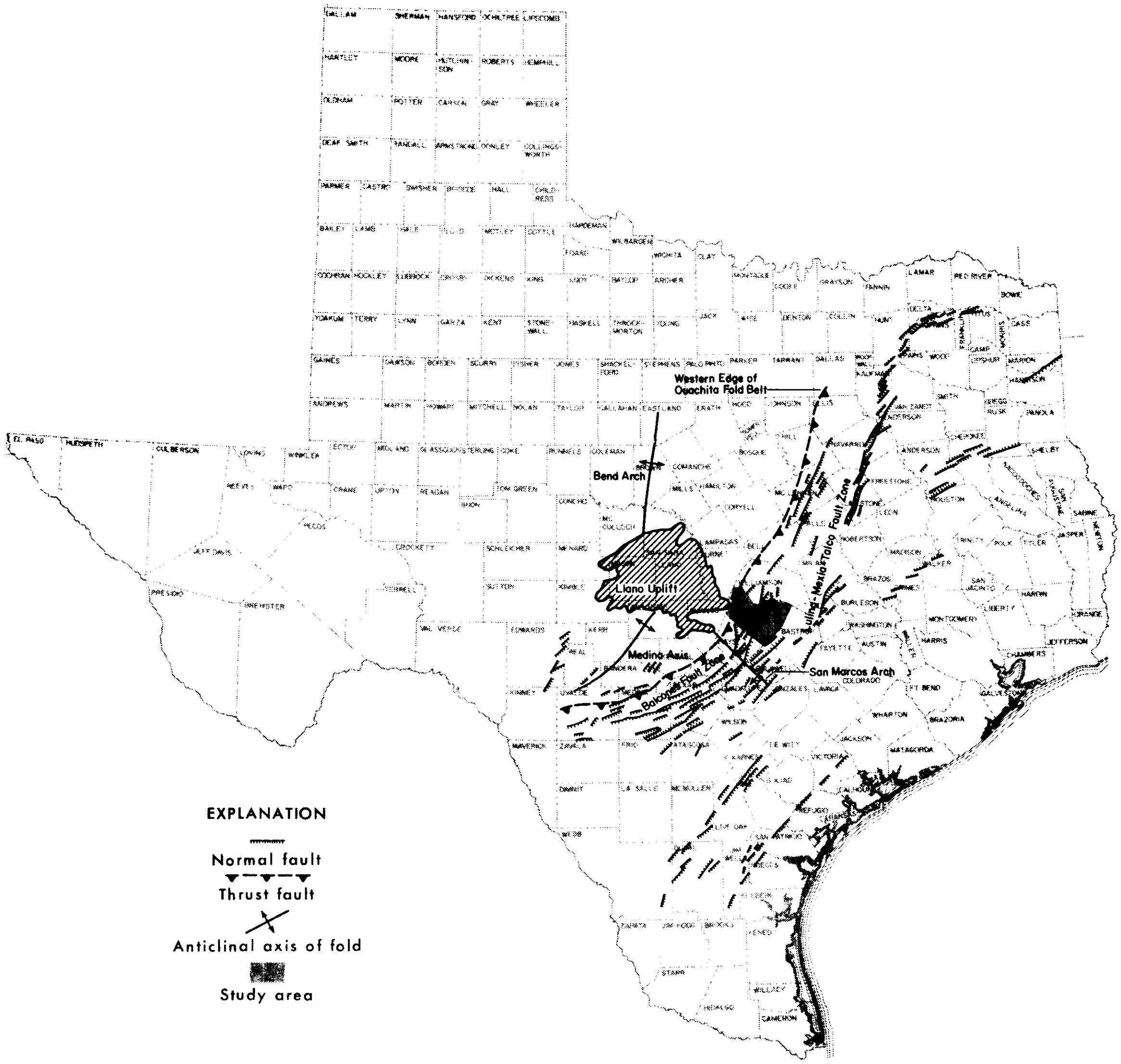

Figure 5.—Major Structural Features in Central Texas

Pre-Cretaceous geologic units dip steeply to the east. Their dip ranges from 10 to 70 degrees and, in some cases, the beds may be overturned as a result of the Ouachita thrusting and folding action (Barnes, 1948). Pre-Cretaceous beds are truncated. Deposited across them, unconformably, are the Cretaceous units, beginning with a massive conglomerate at the base of the Hosston Member. The dip of Cretaceous beds is toward the southeast, ranging from about 10 feet per mile (1.9 m/km) in northwestern Travis County to 300 feet per mile (57 m/km) in the southeast portion. This does not include the effects of faulting. The dip increases with depth, as shown in Figures 26, 28, and 29.

The Balcones fault zone passes through the center of Travis County from northeast to southwest, roughly paralleling the strike of the geologic units. This fault system is about 6 to 8 miles (10 to 13 km) wide. In most cases, the downthrown blocks are to the southeast, but in a few cases the reverse is true. The net total displacement of the downthrown or southeast blocks ranges from about 600 feet (183 m) in the northeast to over 1,000 feet (305 m) in southwestern Travis County. Mount Bonnell fault has a downward displacement to the southeast which ranges from about 50 feet (15 m) in northeast Travis County to 600 feet (183 m) in the southwest. These faults have had a profound effect upon movement of ground water in the hydrologic units, particularly in the Edwards and associated limestones, by forming natural paths for solution channels and by forming underground barriers, Caves are very numerous in Travis County. Nearly all of the large and extensive caverns are in the Edwards and associated limestones along the Balcones fault zone. Smaller caverns or shelters have been formed beneath bluffs of the Cow Creek Limestone Member, where the underlying Hammett Shale Member has been eroded away, and also in the Glen Rose Formation.

In the Llano uplift area just west of Travis County, large areas of granite, gneiss, and schist have been uplifted and are now exposed at the surface. This has had the effect of greatly reducing the area of outcrop of the Sycamore Sand Member of the Travis Peak Formation and hence has affected its recharge. The western edge of the Ouachita fold belt passes through extreme northwestern Travis County from northeast to southwest. Southeast of this belt, Pennsylvanian sandstones and shales have been highly metamorphosed into phyllites, quartzites, and schists (Barnes, 1948).

The San Marcos arch extends from the Llano uplift to the southeast through Hays County, adding a slight northeast tilt to the Cretaceous structure in Travis County. The Luling-Mexia-Talco fault zone trends northeast to southwest immediately southeast of Travis County.

STRATIGRAPHY OF THE WATER-BEARING UNITS

Pre-Cretaceous Rocks

Wells are not known to produce water from Paleozoic rocks in Travis County. However, to the west in Blanco County, usable water is obtained from the Marble Falls Limestone and Ellenburger Group.

The Marble Falls Limestone of Pennsylvanian age is composed of dark gray, cavernous, massive, siliceous, fossiliferous limestones. This formation does not crop out in Travis County, but is present in the subsurface. The Marble Falls conformably underlies the Smithwick Shale. It dips to the southeast at about 500 feet per mile or 95 m/km (Barnes, 1948).

The Ellenburger Group of Ordovician age consists of white and pinkish-gray, cavernous, crystalline, cherty, fossiliferous limestones and dolomites. The Ellenburger lies unconformably beneath the Marble Falls Limestone and dips to the southeast at a steeper gradient than the Marble Falls (Barnes and others, 1972). The rock units composing the Ellenburger Group become progressively metamorphosed into marble as they enter the Ouachita fold belt in western Travis County. Consequently, it is doubtful that they could contain appreciable water more than 5 miles into the northwest part of the county. The depth to the top of the Ellenburger is nearly 4,000 feet (1,220 m) below the surface at the western edge of Travis County, and it becomes progressively deeper to the southeast. It is, therefore, very doubtful that usable quality water (less than 3,000 mg/l of dissolved solids) can be obtained from the Ellenburger in Travis County.

Trinity Group Aquifer

Due to their hydrologic relationships, the water-bearing rocks of the Trinity Group aquifer have been organized into the following aquifer units: (a) the lower Trinity aquifer consisting of the Sligo and Hosston Members of the Travis Peak Formation; (b) the middle Trinity aquifer consisting of the lower member of the Glen Rose Formation and the Hensell Sand and Cow Creek Limestone Members of the Travis Peak Formation; and (c) the upper Trinity aquifer consisting of the upper member of the Glen Rose Formation and the Paluxy Formation.

Lower Trinity

Stratigraphic units which make up the lower Trinity aquifer, in ascending order, are the Hosston and Sligo Members of the Travis Peak Formation (Table 1).

Total thickness of the lower Trinity aquifer ranges from a few feet in northwestern Travis County to nearly 1,000 feet (305 m) in the downdip area in the southeast. The thickening of the Hosston and Sligo is well illustrated in Figures 26, 28, and 29.

Regionally, beds of the lower Trinity aquifer dip east-southeast at a rate ranging from 15 to 320 feet per mile or 2.8 to 60 m/km (Figure 6). In the vicinity of the Balcones fault zone, the dip may be much steeper than 320 feet per mile (60 m/km).

Hosston Member of the Travis Peak Formation

The Hosston Member of the Travis Peak Formation is the lowest rock unit of the aquifer and is equivalent to the Sycamore Sand at the surface (Stricklin, Smith, and Lozo, 1971). Surface outcrops of the Sycamore Sand are scarce and exist only in small areas of western Travis County as shown in Figure 4. In the subsurface, the lower Trinity aquifer or its equivalent is present from northeast Texas to central Texas. It can also be found in scattered areas westward to the vicinity of El Paso. In western Travis County where Barnes (1948) described the Sycamore Sand, it overlies the truncated Marble Falls Limestone and Smithwick Shale and underlies the Hammett Shale Member of the Travis Peak Formation.

Lithologically, the Hosston is composed of pebbly, sandy conglomerate, sometimes containing sandstone boulders more than 1 foot in diameter, generally poorly sorted, multi-colored, and cemented with calcite or silica; fine-to very coarse-grained sand and sandstone, gray, tan, and reddish-brown in color, and cemented with calcite or less commonly with silica cement; various colored shales; and occasionally streaks of limestone. Cross-bedding is commonly associated with the conglomerate beds, and the sand ranges from thin-to massively-bedded. The conglomerate beds commonly occur at or near the base. Clays and shales are interbedded and gradational both vertically and laterally. The Hosston is often called the “lower Trinity sand” or the “second Trinity sand” by water well drillers. It varies in thickness in the downdip areas from about 150 feet (45 m) in northwest Travis County to 800 feet (244 m) in the southeast.

Sligo Member of the Travis Peak Formation

The Sligo Member exists only in the subsurface in Travis County (Figure 7). It is present only in the southeast part of the county where it attains a maximum thickness of about 300 feet (90 m). Here the Hosston grades transitionally upward into a fossiliferous, dolomitic limestone which is crystalline to chalky. Occasionally it is sandy or shaly and is interbedded with shale. This transitional unit is known as the Sligo and it is, at least in part, age equivalent of the Hosston (Stricklin, Smith, and Lozo, 1971).

Hammett Shale Member of the Travis Peak Formation

The Hammett Shale Member of the Travis Peak Formation is impermeable and acts as a hydrologic barrier which separates the lower and middle Trinity aquifers (Table 1). The Hammett is the result of the second transgressive marine phase which covered the Sligo and the eroded surface of the Hosston with shaly marine sediments. The Hammett is predominantly a shale, gray to buff in color, with some dolomitic limestone in the upper part. Its dip corresponds generally with that of the Sligo and Hosston Members, and the unit has a relatively constant thickness of about 60 feet (18 m) throughout Travis County.

Middle Trinity

Stratigraphic units which are included in the middle Trinity aquifer, listed in order from oldest to youngest, are as follows: Hammett Shale, Cow Creek Limestone, and Hensell Sand Members of the Travis Peak Formation, and the lower member of the Glen Rose Formation.

Figure 8 illustrates the total thickness of the middle Trinity aquifer. Total thickness of the aquifer varies from 300 feet (91 m) in northwest Travis County to more than 450 feet (137 m) in the south-central part of the county.

The middle Trinity aquifer dips toward the east-southeast at about 30 feet per mile (5.7 m/km) from the northwestern corner of the county to the Balcones fault zone. East of the fault zone, the dip is approximately 120 feet per mile (23 m/km) to the southeast (Figure 9). The middle Trinity aquifer is cut by numerous faults in the Balconesfault zone. Some of the faults have large displacement. In the vicinity of faults, the dip can be much greater than 120 feet per mile (5.7 m/km).

Cow Creek Limestone Member of the Travis Peak Formation

The Cow Creek Limestone overlies the Hammett Shale and is composed of cream to tan colored, massive, often sandy, dolomitic, fossiliferous limestone with some gypsum or anhydrite beds. It is occasionally porous due to presence of vugs and fractures. Because of its massive nature and its position just above the easily eroded Hammett Shale, it often forms prominent cliffs and overhangs. Springs from the Hensell Sand above these overhangs frequently form water falls, resulting in travertine deposition. Thickness of the Cow Creek ranges from 50 feet (15 m) in the northwest part of the county to 100 feet (30 m) in the southeast.

Hensell Sand Member of the Travis Peak Formation

Overlying the Cow Creek Limestone is the Hensell Sand which is often called the "first Trinity" or "upper Trinity sand." It consists of poorly sorted, cross-bedded conglomerate cemented with silica and varicolored sand, sandstones, silts, clays, and shales. Conglomerate usually occurs near the base and is found only in the area of or immediately adjacent to the outcrop. The grain size and amount of sand decreases in a southeastward direction, grading into silts and sandy shales. Farther to the southeast, the Hensell grades into sandy limestone and dolomite beds which are difficult to distinguish on electric logs from the underlying Cow Creek and overlying lower member of the Glen Rose Formation. No attempt has been made to delineate this limestone facies of the Hensell on the geologic sections (Figures 26 through 30). The downdip limit of the continental or sandy facies of the Hensell Sand Member is shown on Figure 8. Within Travis County, the thickness of the Hensell ranges from 0 to 70 feet (0 to 21 m) in the southeast and northwest parts, respectively.

Lower Member of the Glen Rose Formation

The lower member of the Glen Rose Formation consists of massive, fossiliferous limestone and dolomite in the basal part, grading upward into thin beds of limestone, shale, marl, anhydrite, and gypsum. The beds of gypsum are often partially dissolved, leaving solution channels. A thin accumulation of the fossil clam *Corbula martinae* (Whitney, 1952) forms an iron-stained ledge marking the top of the lower member of the Glen Rose. The "Corbula bed", which is about 1 foot thick, is traceable over a wide outcrop area in central Texas and is easily distinguished as a resistive bed on electric logs. Consequently, it serves as a convenient boundary between the lower and upper members of the Glen Rose Formation. Subsurface thickness of the lower member increases from about 180 feet (55 m) in northwestern Travis County to 330 feet (101 m) in the southeastern part of the county. This southeastward thickening is illustrated on the geologic sections (Figures 26, 28, and 29). In the outcrop area, the thickness may be much less.

Upper Trinity

Two units, the upper member of the Glen Rose Formation and the overlying Paluxy Formation, are included in the upper Trinity aquifer (Table 1). The upper Trinity is overlain by the Walnut Formation of the Fredericksburg Group. The Walnut is composed of limestones, marls, and clays. The upper Trinity includes that portion of the Glen Rose Formation which lies above the *Corbda* bed (Table 1). Geologic sections (Figures 26 through 30) show the stratigraphic position of the upper Trinity and its relation to other geologic units in Travis County.

Thickness of the upper Trinity aquifer in the subsurface ranges from 230 feet (70 m) in northwestern Travis County to about 600 feet (183 m) in the southeast. Thickening to the southeast is shown on Figures 26,28, and 29. In the outcrop, the thickness may be considerably less.

The upper Trinity aquifer dips toward the southeast. The dip is very erratic, and ranges from about 10 feet per mile (1.9 m/km) in the northwestern part of the county to about 130 feet per mile (25 m/km) in the southeast.

Upper Member of the Glen Rose Formation

The upper member of the Glen Rose Formation consists of shale and marl alternating with thin beds of impure limestone and dolomite. Beds of gypsum and anhydrite may occur, but often these have been dissolved, leaving solution channels. Gypsum and anhydrite are not known to occur in surface outcrops and usually not above the water table, since they have been removed by solution (Stricklin, Smith, and Lozo, 1971). A stair-step topography, formed by the alternating beds of limestone and shale or marl, typifies the upper member of the Glen Rose. As shown in Figure 4, the upper member outcrops in the northwestern two-thirds of Travis County. Its downdip thickness ranges from 220 feet (67 m) in the northwestern part of the county, to about 600 feet (183 m) in the southeast. The upper 100 feet (30 m) contains much weathered, soft, porous dolomite and burrowed limestone (Rodda, Garner, and Dawe, 1970). Hence, it forms relatively gentle slopes and has many springs.

Paluxy Formation

The Paluxy Formation is present only in a very small area in the north-northwest corner of Travis County (Figure 4). It consists of fine- to very fine-grained, compact, white quartz sand, partially indurated with calcium carbonate, interbedded with silty and calcareous clay and shale. Some lenses and thin beds of limestone and marl occur locally. To the southeast, there is a facies change from sand to limestone. On electric logs this facies is indistinguishable from the upper member of the Glen Rose and is included with it. The Paluxy is approximately 10 feet (3 m) thick.

Edwards and Associated Limestones

Table 1 summarizes the water-bearing properties of the Edwards and associated limestones aquifer. The Edwards and associated limestones represent the upper portion of the Fredericksburg Group and the lower portion of the Washita Group of the Cretaceous System. They lie above the Walnut Formation and below the Del Rio Clay. Collectively, these limestones are considered the principal aquifer in Travis County and include, in ascending order, the Comanche Peak Limestone, Edwards Limestone, Kiamichi Formation, and Georgetown Formation.

The Comanche Peak Limestone consists of marly, grayish-white limestone containing nodules and fossils. It has considerable flaking and jointing which gives it a fractured appearance. In the northwest part of the county, the Comanche Peak is approximately 20 feet (6 m) thick. The Comanche Peak reaches 60 feet (18 m) in the subsurface, and it pinches out to the east and south (Garner and Young, 1976). Because it is believed to be hydrologically connected with the Edwards Limestone, the two formations are not separated on the geologic sections (Figures 26 through 30). The Comanche Peak does not appear to be present south of the Colorado River. This formation yields little or no ground water.

The Edwards Limestone outcrops extensively within the Balcones fault zone east of the Mount Bonnell fault and caps the high topography in the west as shown in Figure 4. This outcrop is part of the water-table portion of the aquifer which extends from Travis County west through the Edwards Plateau to west Texas. The formation also outcrops northward into Williamson and Bell Counties. In the subsurface, the Edwards consists of 200 to 360 feet (61 to 107 m) of brittle, thick-bedded to massive limestone, commonly dolomitic, containing minor beds of shale, clay, and siliceous limestone. Beds of chert and flint are common. “Honeycomb” limestone beds are also common and represent voids, many interconnected, from which shell material has been dissolved. Dolomitic beds commonly have a sugary texture and often are designated as “sandstone” or “sandy limestone” by many drillers.

There are several solution-collapse zones in the Edwards Limestone which represent former beds of gypsum (originally anhydrite) that have been removed by solution (Rodda, Garner, and Dawe, 1970). About 60 to 80 feet (18 to 24 m) from the base is a 5- to 1 O-foot (2- to 3-m) thick solution-collapse zone. One-third to one-half of the distance from the top of the formation is a 20-foot (6-m) thick, iron-stained, cavernous, solution-collapse zone containing brecciated limestone, dolomite, chert, crystalline calcite, and residual red clay. This widespread zone in central Texas represents the former extent of a thick gypsum and anydrite unit called the Kirschberg Evaporite. Where the gypsum and anhydrite have largely been removed, it is called the Kirschberg solution zone. It can be readily recognized on geophysical logs about 50 to 75 feet (15 to 23 m) below the Kiamichi Formation. Near the top of the Edwards Limestone is another thin solution zone. These solution-collapse zones, especially the Kirschberg solution zone, are the main water-bearing horizons in the Edwards and associated limestones aquifer. Well yields vary from small (10 to 30 gallons per minute or 0.63 to 1.9 liters per second) to very large (over 300 gallons per minute or over 19 liters per second) and the quality of the ground water is fresh.

About 10 feet (3 m) of marl, clay, thin limestone seams, and shell aggregates make up the Kiamichi Formation. It is recognizable only in the subsurface in Travis County where it can readily be picked on geophysical logs. It is equivalent to the “Regional Dense Bed” (Rose, 1972). In northern Travis County, it separates the Edwards Limestone and the Georgetown Formation, and in the southern part of the county, it occurs within the Edwards Limestone. Because the Kiamichi is not known to contain water in Travis County, it is included in the Edwards Limestone and is not shown on the geologic sections (Figures 26 through 30).

The Georgetown Formation is a nodular limestone, usually gray to tan, massive, and interbedded with layers of marl or marly shale. It is fossiliferous, commonly contains burrows filled with fossil fragments, and also contains some minor solution zones. Downdip thicknesses of the formation range from 40 to 100 feet (12 to 30 m). The Georgetown and Edwards are hydrologically connected throughout Travis County and are seldom differentiated by drillers in the area.

Total thickness of the Edwards and associated limestones aquifer, where fresh to slightly saline water occurs, ranges from 250 to 450 feet (76 to 137 m).

Regionally, the dip of the Edwards and associated limestones aquifer is to the east-southeast at a rate of 50 to 100 feet per mile (9 to 19 m/km). The direction and rate of dip at the top of the aquifer is shown on Figure 10.

Austin Chalk

The Austin Chalk consists of a light gray chalk, limy marl, and chalky limestone. Some bentonite, glauconite, and pyrite nodules are also present in the unit. Near igneous intrusions and extrusions, such as those around Pilot Knob in the southeast portion of the county, the Austin Chalk is partially metamorphosed into a recrystallized limestone. In the downdip area, its thickness within Travis County ranges from 300 to 500 feet (92 to 153 m). In the outcrop, the thickness is considerably less.

The Austin Chalk has an extensive outcrop which trends completely across Texas from northeast to southwest. It has a surface exposure of over 75 square miles (194 km^2) in Travis County. This is primarily in the Balcones fault zone which trends from the northeast to the southwest through the county (Figure 4). Geologic sections, Figures 26,28,29, and 30, show the stratigraphic position, dip, and thickness of the Austin. The Austin Chalk yields small to very small quantities of water generally confined to the outcrop area.

Igneous Rocks

During the time of upper Austin deposition, there was considerable volcanic activity in Travis County. Pilot Knob, located in the southeastern part of the county, was a marine volcano that formed during this period (Figure 4). The dark, vitreous, extrusive rock which makes up Pilot Knob is called limburgite (Harrison, 1957). It was probably originally extruded as ash and cinders. Plugs and dikes of igneous material were also intruded into the volcanic mounds at this time. This grayish-green, pyroclastic, calcareous detritus, extruded in upper Austin and lower Taylor times, rapidly altered to “serpentine” (Harrison, 1957). This material should be called nontronite, a montmorillonite clay mineral formed by the alteration of igneous rocks. The nontronite was later reworked by water to a porous, calcareous sandstone or conglomerate. These igneous rocks are considered to be part of the Gulf Series of the Cretaceous System as shown in Table 1.

About 5 square miles (13 km^2) of igneous rocks are exposed at the surface in the vicinity of Pilot Knob (Figure 4). Total thickness of the material ranges from 0 to 700 feet (0 to 213 m). The reworked nontronite and limburgite beds have dips which are approximately the same as those of the Austin Chalk. The dips range from 10 to 160 feet per mile (0.38 to 30 m/km) to the southeast.

The igneous rocks yield very small quantities of ground water. The water occurs in the weathered outcrop portion of the aquifer in approximately the upper 50 feet (15 m) where there are many joints and fractures. The aquifer may not be completely saturated, and the water is primarily under water-table conditions.

Taylor and Navarro Groups

Lithologically, the Taylor Group and overlying Navarro Group are very similar and are treated as a single hydrologic unit. These units represent the uppermost portion of the Gulf Series of the Cretaceous System (Table 1). They consist of massive beds of shale, siltstone, marl, and chalk with clay. They also include beds of sands and some nodular and phosphatic zones.

The Taylor and Navarro Groups extend across Texas from Bowie County on the, State’s northeast boundary to Maverick County on its southwest border. Figure 4 delineates the hydrologic unit in the eastern part of Travis County.

The dip of the water-bearing unit is to the southeast and varies from 10 to 130 feet per mile (1.9 to 25 m/km). Downdip thicknesses of the unit range from 900 to 1,200 feet (274 to 366 m); however, it is much thinner in the outcrop. Very small quantities of fresh to moderately saline ground water occur in the weathered outcrop portion, primarily in the upper 50 feet (15 m) of the Taylor and Navarro Groups.

Quaternary System

Scattered remnants of terrace deposits and stream or river alluviums, ranging in age from Pleistocene to Recent, occur in the east-southeast portion of Travis County (Figure 4). For the purposes of this report, these are collectively considered in this discussion.

Terrace deposits are of Pleistocene age. They are found chiefly in the southeastern part of the county (Figure 4). Relatively young terrace deposits occur along the Colorado River. These consist of gravel, sand, silt, and clay, sometimes cemented with calcium carbonate, with the coarser materials concentrated at the base. They occur at higher elevations than the more recent flood-plain deposits. The older Onion Creek Marl, which has a maximum thickness of 50 feet (15 m), is found only in small areas along Onion Creek in southern Travis County. It contains much calcareous gravel and is often cemented with calcium carbonate. Thin sheets of gravel and sand representing very old terraces are found on the ridges in the southeastern part of the county. These are known as high gravel deposits. Often these materials are so thin, usually 20 feet (6 m) or less, that they have been mixed by plowing with the clays of the underlying Navarro and Taylor Groups. Terrace deposits range in thickness up to 60 feet (18 m) with the thickest sediments located along the Colorado River. These terrace deposits produce very small to moderate amounts of fresh to moderately saline ground water under water-table conditions.

Stream or river alluviums of Recent or Holocene age are composed of up to 60 feet (18 m) of unconsolidated material, chiefly gravel, sand, and silt. The extent of these alluvial deposits is shown on Figure 4. The thickest flood-plain deposits, which also have the greatest areal extent, are found along the Colorado River in eastern Travis County. In this area, they rest upon the underlying Navarro and Taylor Groups. Small areas of thin alluvium can also be found in scattered localities along minor tributaries throughout the county. Alluvium deposits yield small to very large quantities of fresh to slightly saline water.

GENERAL GROUND-WATER HYDROLOGY

Hydrologic Cycle

Water used by humans whether it be from rain, spring discharge, or water from wells, is captured in transit, and after its use and reuse, is returned to the hydrologic cycle. The different courses water may take to complete the hydrologic cycle are shown in Figure 11.

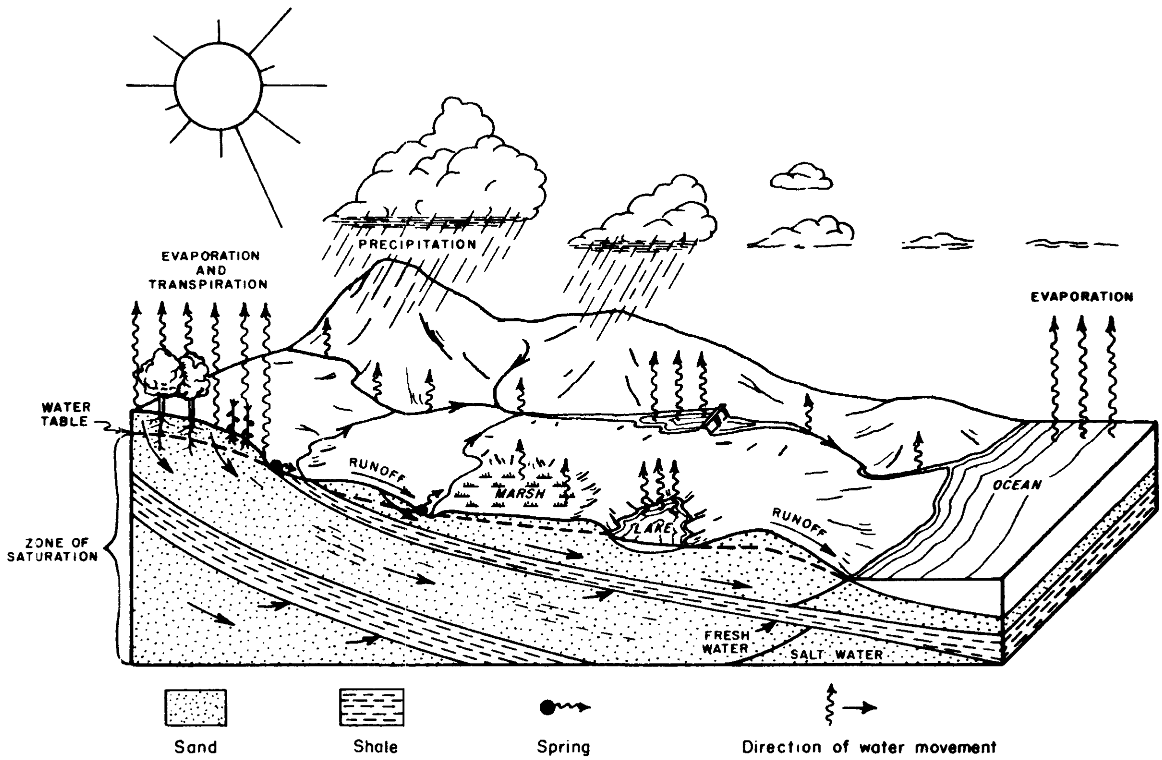

Figure 11.—Hydrologic Cycle

Source and Occurrence

The original source of ground water in Travis County is the infiltration of precipitation either directly in the outcrop or indirectly through seepage from streams and lakes. That small portion of the total precipitation which seeps down through the soil mantle and reaches the water table is called *ground water.*

Ground water is said to occur under either water-table or artesian conditions. Ground water in the outcrop of many formations is unconfined and under water-table conditions. Water under these conditions is under atmospheric pressure and will rise or fall in response to changes in the volume of water stored. In most places, the configuration of the water table approximates the topography of the land surface. In a well penetrating an unconfined aquifer, water will rise to the level of the water table.

Downdip from the outcrop, ground water in the aquifer may occur beneath a relatively impermeable bed. The water is under artesian or confined conditions and the impermeable bed confines the water under a pressure greater than atmospheric. In a well penetrating an artesian aquifer, water will rise above the confining bed and, if the pressure head is large enough to cause the water in the well to rise above the land surface, the well will flow. Flowing wells commonly are found in areas of low altitudes, especially in the valley of the Colorado River in Travis County.

Recharge, Movement, and Discharge

Water-bearing units receive recharge in the outcrop from precipitation, streamflow, and lakes. Part of the time much of this recharge is rejected because water-bearing units are full and the water flows into the stream valleys crossing the outcrops where it is discharged by springs, evapotranspiration, and seepage. The Colorado River and its chain of lakes have a profound effect upon the ground water of the county, recharging some aquifers and receiving water from others. Some of the recharge moves downdip along water-bearing units for many miles and along the way slowly seeps upward through confining beds and fault planes eventually being discharged at the surface through seeps and springs.

Pumping from a well changes the flow pattern so that water moves into the well from all directions. Ground vvater under artesian conditions generally moves in the direction of the dip of the water-bearing unit, whereas under water-table conditions, the ground-water movement generally follows the slope of the land surface. The rate of movement is directly related to the porosity and permeability of the aquifer. In sand formations, the limiting factor is the transmissibility of the formation, which controls the amount of head loss, or drawdown of the potentiometric surface, caused by water moving from the recharge area to the well. However, in cavernous limestone this is not a factor because the transmissibility is usually very high, and any water which enters a sinkhole or crevice will be readily transmitted through the aquifer.

Water that is pumped from wells must be balanced by a reduction in natural discharge, a reduction in the amount of recharge being rejected, withdrawal of water from storage, and movement of water downdip. Thus, to have a perennial supply which does not continue to withdraw water from storage and eventually deplete the aquifer, the pumpage must be balanced by an equal amount of recharge being diverted to the wells. The two major quantitative factors which limit the amount of ground water that can be obtained on a perennial basis, therefore, are the recharge available for interception by pumping and the rate at which water can flow from the recharge area to the wells.

Discharge is the process which removes water from the aquifer either by natural or artificial means. Natural discharge of water from an aquifer occurs in the form of spring flow, effluent seepage, transpiration by vegetation, evaporation through the soil where the water table is close to the surface, and loss through interforrnational leakage. Artificial discharge is usually from flowing or pumped water wells.

Hydraulic Characteristics

Water-producing capabilities of an aquifer depend upon its ability to store and transmit water. Formulas have been developed to show the relationship of the yield of a well and shape and extent of the cone of depression to the properties of the aquifer including specific yield and coefficients of storage, transmissibility, and permeability. These formulas indicate that, within limits, the discharge from a well varies directly with the drawdown; that is, doubling the drawdown will nearly double the amount of discharge. The discharge per unit of drawdown or specific capacity is of value in estimating the probable yield of a well and the required pump setting. However, the type of well construction and thoroughness of well development also effect the specific capacity.

In an artesian aquifer, as ground water is withdrawn the hydrostatic pressure is lowered and the weight of the overlying sediments compress the aquifer causing the water to be released from storage. The coefficients of storage in artesian aquifers are small compared to those in water-table aquifers. Therefore, as an artesian well is pumped, a cone of depression is developed over a wide area in a short time.

In a water-table aquifer, the coefficient of storage is much larger since it reflects the removal of water from storage by gravity drainage. Under these conditions, the coefficient of storage is essentially equal to the specific yield.

The coefficients of storage and transmissibility of an aquifer are determined from pumping tests, which involve pumping a well at a constant rate for a period of time and making periodic measurements of water levels in the pumping well and, if possible, in one or more observation wells. The recovery of the water level is also measured after pumping stops. From the data obtained, the coefficients of transmissibility and storage can be calculated and used in computing the effects that pumping will have on water levels in an aquifer at various times and distances from a pumped well. In addition to providing a means for computing the quantity of water that will flow through a given section of the aquifer, the coefficients can also be used in estimating the availability of ground water in storage.

Fluctuations of Water Levels

There are several causes that change the water levels in wells. Some of these causes are regional while others are local. The major factors, that generally control the changes in water levels are the amount of recharge to and discharge from the aquifer.

Daily fluctuations, especially those wells completed in artesian aquifers, are generally in response to barometric pressure, tidal effects, earthquakes, or changes in the evapotranspiration rate. The magnitude of these fluctuations is very small. Seasonal fluctuations occur as the result of changes in the amount of rainfall and evapotranspiration on an aquifer's outcrop area which in turn affects recharge. During periods of a drought when recharge is reduced, some of the water discharged from the aquifer must be withdrawn from storage and water levels decline. However, when adequate rainfall resumes, the volume of water drained from storage may be replaced and water levels will rise.

When a water well is pumped, water levels in the vicinity are drawn down in the shape of an inverted cone with its apex at the pumped well. The development of cones of depression depends on the aquifer's coefficients of transmissibility and storage, and on the rate of pumping. As pumping continues, these cones will expand until they intercept a recharge source which will satisfy the pumping demand. If the cone of one well overlaps the cone of another, interference and an additional lowering of water levels will occur as the wells compete for water by **expanding** their cones of depressions. The amount or extent of interference between the cones depends on the rate of pumping from each well, the spacing, and the hydraulic characteristics of the aquifer in which the wells are completed.

For water-table aquifers, changes in water levels are generally less pronounced than in artesian aquifers because changes in water levels reflect changes in the ground-water storage.

CHEMICAL QUALITY

General Chemical Quality or Standards

The types and concentrations of dissolved minerals carried in ground water are derived mainly from the soil and rocks through which the water percolates. As the water moves through its environment, the solvent action of water dissolves some of the minerals from the surrounding rocks. The concentration of the various dissolved-mineral constituents depends upon the solubility of the minerals in the formation, the length of time the water is in contact with the rock, and the concentration of carbon dioxide present within the water. Therefore, the chemical character of the water mirrors the general mineral composition of the earth through which it has passed. Additionally, dissolved-mineral concentrations increase with depth and temperature.

Table 7 is a tabulation of 1,035 chemical analyses of water from wells and springs in Travis and adjacent counties. The sampled wells are indicated on Figure 25 by a bar over the well number. Table 2 lists the principal mineral constituents found in ground water and discusses their source, significance, and range for the various aquifers in the study area. Concentrations of sulfates, chlorides, and dissolved solids from samples taken from selected wells and springs in Travis County are shown on Figures 12 and 13.

The degree and type of mineralization of ground water determines its suitability for municipal, industrial, irrigation, and other uses. Several criteria for water-quality requirements have been developed through the years which serve as guidelines in determining the suitability of water for various uses. Subjects covered by the guidelines are bacterial content; physical characteristics, includihg color, taste, odor, turbidity, and temperature; and chemical constituents. Water-quality problems associated with the first two subjects can usually be alleviated economically. However, the neutralization or removal of most of the unwanted chemical constituents is usually difficult and often very costly.

The dissolved-solids content is usually the main factor which limits or determines the use of ground water. Winslow and Kister (1956, p. 5) used an excellent, and very applicable, general classification of waters based on the dissolved-solids concentration in parts per million (ppm). The classification is as follows:

Description	Dissolved-solids content (ppm)
Fresh	Less than 1,000
Slightly saline,	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Table 2.—Source, Significance, and Concentration of Dissolved-Mineral Constituents and Properties of Water

(Adapted from Doll and others, 1963, p. 39-43)

Only analyses which were representative of native ground water were used. Analyses are in milligrams per liter except percent sodium, specific conductance, pH, and SAR.

Constituent or property	Source or Cause	Significance	RANGE IN CONCENTRATIONS, BY AQUIFFER							
			Hosston	Hensell	Lower member Glen Rose	Upper member Glen Rose	Edwards and associated limestones	Austin chalk	Taylor-Navarro Groups	Alluvium and terrace deposits
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline water.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.	2—23	3—20	2—28	7—17	3—35	6—29	5—53	6—41
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stain laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. Texas Department of Health (1977) drinking water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.	0—5.7	—	0—5.0	.7—1.9	0—13	0—.1	—	0—.02
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.	(Ca) 8—414 (Mg) 5—208	(Ca) 37—375 (Mg) 17—227	(Ca) 14—560 (Mg) 7—304	(Ca) 7—533 (Mg) 15—230	(Ca) 1—515 (Mg) 2—316	(Ca) 25—142 (Mg) 3—26	(Ca) 27—915 (Mg) 5—211	(Ca) 20—894 (Mg) 1—303
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in oil-field brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.	(Na) 6—1,700 (K) 0—28	(Na) 7—1,020 (K) 5—9	(Na) 2—890 (K) 1—63	(Na) 2—1,050 (K) 0—31	(Na) 1—2,680 (K) 1—2,680	(Na) 9—82 (K) 1—13	(Na) 10—2,010 (K) 15—52	(Na) 7—1,120 (K) <1—19
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.	(HCO_3) 7—700	(HCO_3) 243—520	(HCO_3) 194—510	(HCO_3) 220—520	(HCO_3) 50—511	(HCO_3) 49—394	(HCO_3) 55—864	(HCO_3) 9—640
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Texas Department of Health (1977) drinking water standards recommend that the sulfate content should not exceed 300 mg/l.	15—1,750	14—2,920	5—3,360	4—2,600	4—2,750	4—98	11—2,230	< 4—2,544
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in oil-field brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. Texas Department of Health (1977) drinking water standards recommend that the chloride content should not exceed 300 mg/l.	13—2,700	13—620	4—670	8—640	4—6,050	8—46	21—3,590	6—2,500
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950, p. 1120-1132).	0.1—5.3	.2—4.0	.2—7	0—5.5	0—4.8	0.3—1.9	0.1—3.1	<.1—5.8
Nitrate (NO_3) or Nitrate (as N)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. Texas Department of Health (1977) drinking water standards suggest a limit of 45 mg/l (as NO_3) or 10 mg/l (as N). Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding (Maxcy, 1950, p. 271). Nitrate shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.	(NO_3) 0—69	(NO_3) .4—64	(NO_3) 0—34	(NO_3) .4—88	(NO_3) 0—88	(NO_3) 2—47	(NO_3) 1.5—564	(NO_3) <.4—540

Table 2.—Source, Significance, and Concentration of Dissolved-Mineral Constituents and Properties of Water—Continued

Constituent or property	Source or cause	Significance	Range in Concentrations, by Aquifer: Hosston	Hensell	Lower member Glen Rose	Upper member Glen Rose	Edwards and associated limestones	Austin Chalk	Taylor-Navarro groups	Alluvium and terrace deposits
Boron (B)	A minor constituent of rocks and of natural waters.	An excessive boron content will make water unsuitable for irrigation. Wilcox (1955, p. 11) indicated that a boron concentration of as much as 1.0 mg/l is permissible for irrigating sensitive crops; as much as 2.0 mg/l for semitolerant crops; and as much as 3.0 mg/l for tolerant crops. Crops sensitive to boron include most deciduous fruit and nut trees and navy beans; semitolerant crops include most small grains, potatoes and some other vegetables, and cotton; and tolerant crops include alfalfa, most root vegetables, and the date palm.	0–4.7	–	.1–2.8	.1–2.3	.1–1.3	.1–.4	.1–1.0	.1–.6
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	Texas Department of Health (1977) drinking water standards recommended that waters containing more than 1,000 mg/l dissolved solids not be used if other less mineralized supplies are available. For many purposes the dissolved-solids content is a major limitation on the use of water. A general classification of water based on dissolved-solids content, in mg/l, is as follows (Winslow and Kister, 1956, p. 5): Waters containing less than 1,000 mg/l of dissolved solids are considered fresh; 1,000 to 3,000 mg/l, slightly saline; 3,000 to 10,000 mg/l, moderately saline; 10,000 to 35,000 mg/l, very saline; and more than 35,000 mg/l, brine.	186–4,852	308–5,401	180–5,690	103–4,759	173–10,190	39–538	333–9,060	170–6,953
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness up to 60 mg/l are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.	56–1,890	161–1,870	91–2,450	213–2,280	12–2,580	77–376	106–3,160	105–3,390
Percent Sodium (% Na)	Sodium in water.	A ratio (using milliequivalents per liter) of the sodium ions to the total sodium, calcium, and magnesium ions. A sodium percentage exceeding 50 percent is a warning of a sodium hazard. Continued irrigation with this type of water will impair the tilth and permeability of the soil.	3.12–94.98	4.79–73.13	1.90–88.01	1.27–60.49	.48–97.58	6.15–39.04	5.32–84.40	5.32–72.95
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.	450–6,800	554–5,790	312–10,500	443–5,900	214–19,700	475–825	601–3,600	274–10,000
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals. The Texas Department of Health (1977) recommends a pH greater than 7.	7.0–8.4	7.1–8.9	6.9–8.3	7.0–8.4	6.6–8.9	7.2–7.9	7.1–8.6	6.3–10.1
Sodium-adsorption ratio (SAR)	Sodium in water.	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil (U.S. Salinity Laboratory Staff, 1954, p. 72, 156). Defined by the following equation: $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$, where Na^+, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.	.1–38.5	.1–10.3	0–18.7	0–11.8	0–28	.2–2.1	.2–16	.1–10.5

In recent years, most laboratories have begun reporting analyses in milligrams per liter (mg/l) instead of parts per million. These units, for practical purposes, are identical until the dissolved-solids concentration of water reaches or exceeds 7,000 units (ppm or mg/l). Most of the chemical concentrations in the study area are below 7,000 mg/l and therefore, the units are interchangeable. For the more highly mineralized waters, a density correction should be made using the following formula:

$$\text{parts per million} = \frac{\text{milligrams per liter}}{\text{specific gravity of the water}}$$

Public Supply

As the first step in setting national standards for drinking water quality under the provisions of the Safe Drinking Water Act of 1974, the U.S. Environmental Protection Agency (EPA) issued drinking water regulations on December 10, 1975. These standards apply, selectively, to all types of public water systems of Texas and became effective June 1977. The responsibility for enforcement of these standards was assumed by the Texas Department of Health on July 1,1977. Minor revision of the standards became effective on November 30, 1977.

As defined by the Texas Department of Health, municipal systems are classified as follows:

1. A “public water system” is any system for the delivery to the public of piped water for human consumption, if such a system has four or more service connections or regularly serves at least 25 individuals daily at least 60 days out of the year.

2. A “community water system” is any system which serves at least four or more service connections or regularly serves 25 permanent-type residents for at least 180 days per year.

3. A “non-community water system” is any public water system which is not a community water system.

Standards which relate to municipal supplies are of two types: (1) primary and (2) secondary. Primary standards are devoted to constituents and regulations affecting the health of consumers and secondary standards are those which deal with the aesthetic qualities of drinking water. Contaminants for which secondary maximum contaminant levels are set in these standards do not have a direct impact on the health of the consumers, but their presence in excessive quantities may discourage the use of the water.

Primary Standards

Primary standards for dissolved minerals apply to community water systems and are as follows:

Contaminant	Maximum concentration (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	.010
Chromium (Cr)	.05
Lead (Pb)	.05
Mercury (Hg)	.002
Selenium (Se)	.01
Silver (Ag)	.05
Nitrate (as NO_3)	45
Nitrate (as N)	10

Except for nitrate content, none of the above contaminant levels for toxic minerals applies to non-community water systems. The maximum of 10 mg/l nitrate as nitrogen (about 45 mg/l nitrate as NO_3) applies to community and non-community systems alike.

Maximum fluoride concentrations are applicable to community water systems and they vary with the annual average of the maximum daily air temperature at the location of the system. These are given in the following tabulation:

Temperature (°F)	Temperature (°C)	Maximum concentration (mg/l)
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Maximum contaminant limits for organic chemicals apply to community water systems and are specified as follows:

Constituent	Maximum concentration (mg/l)
1. **Chlorinated hydrocarbons**:	
Endrin (1,2,3,4,10, 10-hexachloro-6,7,-epoxy-1,4,4a,5, 6,7,8,8a-octahydro-1,4-endo, endo-5, 8-dimethano napthalene).	0.0002
Lindane (1,2,3,4,5,6-hexachloro-cyclohexane, gamma isomer).	.004
Methoxychlor (1,1,1-Trichloro-2,2-bis [p-methoxyphenyl] ethane).	.1

Constituent	Maximum concentration (mg/l)
Toxaphene ($C_{10}H_{10}Cl_8$-Technical chlorinated camphene, 67-69 percent chlorine).	0.005
2. **Chlorophenoxys**:	
2,4-D (2,4-Dichlorophenoxyacetic acid).	.1
2,4,5-TP Silvex (2,4,5-Trichloro-phenoxypropionic acid).	.01

Maximum levels for coliform bacteria, as specified by the Texas Department of Health, apply to community and non-community water systems. The limits specified are basically the same as in the 1962 U.S. Public Health Service Standards which have been widely adopted in most states.

In addition to the previously stated requirements, there are also stringent rules regarding general sampling and the frequency of sampling which apply to all public water systems. Additionally, community water systems are subject to rigid radiological sampling and analytical requirements.

Secondary Standards

Recommended secondary standards applicable to all public water systems are given in the following table:

Constituent	Maximum level
Chloride (Cl)	300 mg/l
Color	15 color units
Copper (Cu)	1.0 mg/l
Corrosivity	non-corrosive
Foaming agents	.5 mg/l
Hydrogen sulfide (H_2S)	.05 mg/l
Iron (Fe)	.3 mg/l
Manganese (Mn)	.05 mg/l
Odor	3 Threshold Odor Number
pH	> 7.0
Sulfate (SO_4)	300 mg/l
Dissolved solids	1,000 mg/l
Zinc (Zn)	5.0 mg/l

The above secondary standards are recommended limits, except for water systems which are not in existence as of the effective date of these standards. For water systems which are constructed after the effective date, no source of supply which does not meet the recommended secondary standards may be used without written approval by the Texas Department of Health. The determining factor will be whether there is an alternate source of supply of acceptable chemical quality available to the area to be served.

After July 1, 1977, for all instances in which drinking water does not meet the recommended limits and is accepted for use by the Texas Department of Health, such acceptance is valid only until such time as water of acceptable chemical quality can be made available at reasonable cost to the area in question from an alternate source. At such time, either the water which was previously accepted would have to be treated to lower the constituents to acceptable levels, or water would have to be secured from the alternate source.

Domestic and Livestock

Ideally, waters used for rural domestic purposes should be as free of contaminants as those used for municipal purposes; however, this is not economically possible. At present there are no controls placed on private domestic or livestock wells. In general, the chemical constituents of waters used for domestic purposes should not exceed the concentrations shown in the following table, except in those areas where more suitable supplies are not available.

Substance	Maximum concentration (mg/l
Chloride (Cl)	300
Fluoride (F)	1.4*
iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (as N)	10.
Nitrate (as NO_3)	45.
Sulfate (S04)	300.
Dissolved solids	1.000.

*Maximum fluoride limit based on annual average of maximum daily air temperature range of 79.3-90.5°F (26.3-32.5°C) (After Texas Department of Health, 1977)

It is not generally recommended that water used for drinking purposes contain more than a maximum of 2,000 mg/l dissolved solids; however, water containing somewhat higher mineral concentrations has been used where water of better quality was not available.

Generally, water used for livestock purposes is subject to the same quality limitations as those relating to drinking water for humans; however, the tolerance limits of the various chemical constituents as well as the dissolved-solids concentration may be considerably higher for livestock than that which is considered satisfactory for human consumption. The type of animal, the kind of soluble salts, and the respective amount of soluble salts determine the tolerance limits (Heller, 1933, p. 22). In the western United States, cattle may tolerate drinking water containing nearly 10,000 mg/l dissolved solids providing these waters contain mostly sodium and chloride (Hem, 1970, p. 324). Waters containing high concentrations of sulfate are usually considered undesirable for livestock use. Many investigators recommend an upper limit of dissolved solids near 5,000 mg/l. Obviously, concentrations considerably below the upper limit are necessary for maximum growth and reproduction. Hem (1970, p. 324) cited a publication of the Department of Agriculture of the state of Western Australia as recommending the following maximum upper limits for dissolved-solids concentration in livestock water.

Animal	Maximum dissolved solids concentration (mg/l
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,100
Sheep (adult)	12,900

Irrigation

The suitability of water for irrigation is determined in part by its chemical quality, but also in part by the climate, soils, management practices, crops grown, drainage, and the quantity of water applied.

The most important characteristics in determining the quality of ground water for irrigation, according to the U.S. Salinity Laboratory staff (1954, p. 69) are: (1) total concentration of soluble salts; (2) relative proportion of sodium to other cations; (3) concentration of boron or other elements that may be toxic; and (4) under some conditions, the carbonate and bicarbonate concentration as related to the concentration of calcium and magnesium. These have been termed the salinity, sodium, boron, and bicarbonate ion hazards, respectively.

High concentrations of dissolved salts in irrigation water may cause a buildup of salts in the soil solution and may make the soil saline. Increased salinity of the soil may drastically reduce crop yields by decreasing the ability of the plants to take up water and essential plant nutrients from soil solution. The tendency of irrigation water to cause a high buildup of salts in the soil is called the salinity hazard of the water. The specific conductance of the water is used as an index of the salinity hazard. The specific conductance is measured in micromhos at 25°C. In general, water having a specific conductance below 750 micromhos at 25°C is satisfactory for irrigation; however, salt-sensitive crops, such as strawberries and green beans, may be adversely affected by irrigation water having a specific conductance in the range of 250 to 750 micromhos at 25°C. Table 7 gives the specific conductance for selected water samples analyzed within the study area.

High concentrations of sodium relative to the concentrations of calcium and magnesium in irrigation water may adversely affect soil structure. Cations in the soil solution become fixed on the surface of the soil particles; calcium and magnesium tend to flocculate the particles, whereas sodium tends to deflocculate the colloidal soil particles. Consequently, soils may become plastic, movement of water through the soil can be restricted, drainage problems can develop, and cultivation can be rendered difficult. This adverse effect on soil structure caused by high sodium concentrations in an irrigation water is called the sodium hazard. An index used for predicting the sodium hazard is the sodium-adsorption ratio (SAR) which is defined by the equation given in Table 2. A high SAR in irrigation water affects the soil by forming a hard impermeable crust that results in cultivation and drainage problems. Under most conditions, irrigation waters having a sodium percentage of less than 60, and a low bicarbonate content are probably satisfactory. The sodium hazard becomes progressively greater as the sodium percentage increases above 60.

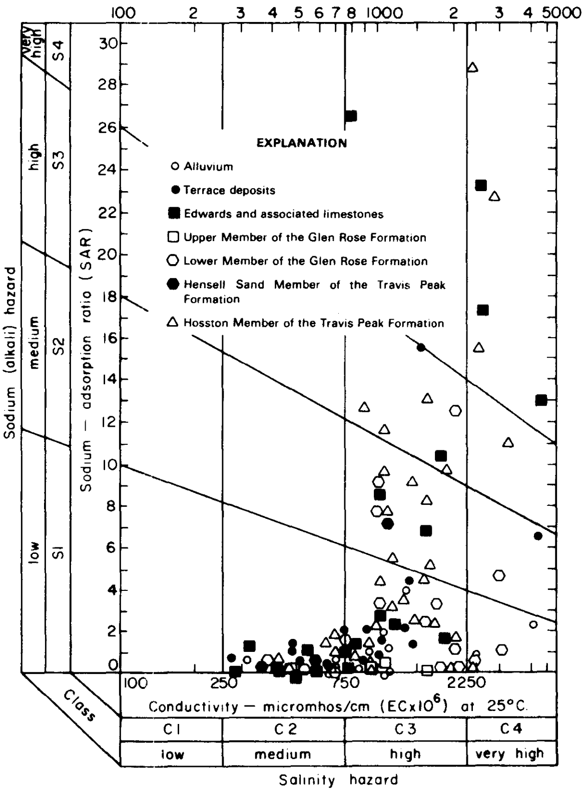

Figure 14.—Diagram for the Classification of Irrigation Waters, Showing Quality of Water From Selected Wells in Travis County

The U.S. Salinity Laboratory staff (1954, p. 69-82) has prepared a classification diagram for irrigation waters in terms of salinity and sodium hazards. This diagram reproduced in modified form in Figure 14, uses SAR and specific conductance in classifying irrigation waters. With respect to both the salinity and sodium hazards, waters are divided into four classes: low, medium, high, and very high. The classification range encompasses those waters which can be used for irrigation of most crops on most soils as well as those generally unsuitable for irrigation. The results of representative water samples collected from all aquifers have been plotted on Figure 14.

Boron is necessary for good plant growth; however, excessive boron content will render water unsuitable for irrigation. Wilcox (1955, p. 11) stated that concentrations of boron as high as 1.0 mg/l are permissible for irrigation of boron-sensitive crops; as high as 2.0 mg/l on semi-tolerant crops, and as much as 3.0 mg/l for tolerant crops. Examples of sensitive crops are deciduous fruit and nut trees and navy beans; semi-tolerant crops include most grains, cotton, potatoes, and some other vegetables; and tolerant crops are alfalfa and most root vegetables (Table 2).

A concentration of bicarbonate in irrigation water often causes calcium and magnesium carbonate to precipitate from solution upon drying which results in an increase in the proportion of sodium in solution. The effect of higher proportions of sodium has been previously discussed. Water containing 1.25 to 2.5 me/l (milliequivalents per liter) of residual sodium carbonate (RSC) are considered marginal and those containing greater than 2.5 me/l probably are not suited for irrigation use (Wilcox, 1955).

Industrial

The type of industry determines the water-quality standards for an industrial water supply. The main concern to many industries is that the water selected for their supply does not contain corrosive or scale-forming constituents. Both magnesium and calcium affect the hardness and are of major concern in any water to be considered for boiler use. Excessive amounts of silica and iron cause scale deposits which reduce the efficiency of many industrial processes. The water quality must be rigidly controlled where the water is used in the processing of food, paper, or some chemicals. Mineral impurities affect color, taste, odor, and turbidity; therefore, water with a high content of dissolved solids is usually avoided. The effects that most of the minerals have on industrial use are shown in Table 2.

OCCURRENCE AND AVAILABILITY OF GROUND WATER

Trinity Group Aquifer

Source and Occurrence

Primary sources of ground water in the Trinity Group aquifer are rainfall which falls on the outcrops and infiltration of surface water from unlined earthen ponds, lakes, and streams on or crossing its outcrops.

As shown on the geologic map (Figure 4), the areal extent of the lower Trinity hydrologic units are limited in the outcrop. The Sycamore Sand which is the surface outcrop of the Hosston Member of the Travis Peak Formation occurs only in the extreme west and southwestern parts of the county. On the surface, the Sycamore is composed chiefly of a conglomerate which is not very permeable except when weathered. In addition, the unit is capped by tight, reddish-brown clayey soils. Sycamore wells are not known to produce water in the outcrop, and the member appears to be largely non-water bearing. However, beneath the surface of Lake Travis more permeable facies of the aquifer exist, and these are subject to recharge from the lake.

In the subsurface, the lower Trinity aquifer is overlain by the impervious Hammett Shale Member of the Travis Peak Formation and, as a result, artesian conditions exist. The aquifer is completely water saturated and hydrologically connected through the joints and cavities in the limestone of the Sligo member of the Travis Peak Formation as well as the pore spaces in the sands of the Hosston Member. The hydrostatic pressure is sufficient to cause static water levels to rise above the aquifer and, in some cases, to cause the wells to flow. There are many flowing Hosston wells particularly in lower areas along the Colorado River.

The three units of the middle Trinity aquifer are hydrologically connected to some extent. While beds of shale, clay, or massive limestone may act as barriers and prevent the movement of water through them, these beds are not continuous and the lithology changes frequentlyto more permeable facies, or they are broken by faults.

Ground water in the middle Trinity aquifer occurs under water-table conditions in the outcrop area in western Travis County, however, in this area the units of this aquifer are not completely water-saturated. Water occurs in the void spaces of the gravels, sands, and silts in the Hensell Sand, and in marly and sandy beds, cavities, joints, and faults in the Cow Creek Limestone and the lower member of the Glen Rose Formation. The basal limestone sequence of the lower member of the Glen Rose contains vugs and solution channels which carry significant quantities of water.

Artesian conditions exist downdip because the Hensell Sand is overlain by relatively impervious shales and limestone of the lower member of the Glen Rose. The aquifer is completely water saturated, and the hydrostatic pressure is great enough to cause static water levels to rise above the top of the aquifer. In some areas, wells developed in the middle Trinity aquifer will flow, particularly those drilled in lower areas along Lake Austin and in the City of Austin.

Where the Paluxy Formation is present, it is hydrologically connected with the upper member of the Glen Rose Formation. This is particularly true where the limestone is jointed and cut by faults and solution channels. Water enters the aquifer from rainfall and infiltration from stock ponds, and also from Lake Travis, which is in contact with the aquifer in its lower reaches.

Ground water in the upper Trinity aquifer occurs primarily under water-table conditions in the outcrop area in northwestern Travis County where the formations are not completely water-saturated. Water occurs in the void spaces of the Paluxy Formation, and in sandy and marly beds and solution zones of the upper member of the Glen Rose Formation. In addition, perched water tables and artesian conditions occur locally in the outcrop area due to sand lenses and limestones interbedded with shales within the upper member of the Glen Rose.

Artesian conditions exist in the subsurface. The aquifer is completely water saturated and the hydrostatic pressure is great enough to cause water levels to rise above the aquifer. However, no flowing wells or springs in the upper Trinity aquifer were located within Travis County. Within the artesian area in southeastern Travis County, water from the upper Trinity aquifer is not used because of poor chemical quality, small yields, and the availability of other sources of ground water at shallower depths.

Recharge, Movement, and Discharge

Recharge to the Trinity Group aquifer is derived primarily from rainfall on the outcrop, underflow, vertical leakage, and seepage from lakes and streams. The upper and lower members of the Glen Rose Formation and the Hensell Sand Member of the Travis Peak Formation outcrop over the majority of western Travis County; therefore, these units receive the maximum amount of recharge. The Hosston Member of the Travis Peak Formation probably receives very little recharge from rainfall because of its limited surface outcrop and the type of soils. This condition also exists in Burnet County (Klemt and others, 1975). Lake Travis appears to be a source of recharge to the middle Trinity aquifer (Figure 26).

A study by Ashworth (1983) on the Lower Cretaceous formations in the Guadalupe River basin determined that approximately 4 percent of precipitation on the outcrop area can be considered as effective recharge to the aquifer. Klemt and others (1975) determined that an estimated 3 percent of the average annual precipitation is available as effective recharge. Their study was confined principally to the Brazos, Colorado, and Trinity River basins.

In computing the amount of recharge in the study area, an estimated 4 percent of the mean annual rainfall of 33.5 inches (85.1 cm) was applied to the outcrop area which covers approximately 224,870 acres (91,000 hm^2). This is approximately 0.11 foot per year (0.03 m/yr) and amounts to about 25,000 acre-feet per year (30.8 hm^3/yr) which is available as effective recharge to the Trinity Group aquifer. Slightly less than 1,000 acre-feet (1.23 hm^3) of recharge as leakage from Lake Travis is included in this figure. The amount of leakage from the lake was determined by using the 1978 gradients of the potentiometric surface (Figure 15) and aquifer reservoir characteristics.

Ground water in the Trinity Group aquifer moves slowly downdip to the south and east-southeast. The direction of the ground-water movement is perpendicular to the water-level contour lines and toward lower elevations as shown in Figures 15 and 16. Water-level measurements indicate the hydraulic gradient of the potentiometric surface is about 5 to 100 feet per mile (0.95 to 19 m/km). In areas of continuous pumpage, as at Jonestown, cones of depression have developed in the potentiometric surface with hydraulic gradients as much as 130 feet per mile (25 m/km) and water levels greater than 500 feet (152 m) below land surface. Because of low permeability and numerous confining beds, movement of ground-water in the upper member of the Glen Rose is generally in the same direction as the slope of the land surface.

There are no known springs discharging from the lower Trinity aquifer within Travis County. Most of the discharge occurs from flowing wells and pumpage. Discharge from the middle and upper Trinity aquifers is from pumping and flowing wells and springs.

Hydraulic Characteristics

Aquifer coefficients of transmissibility, permeability, and storage for different aquifers are shown in Table 3. This table was compiled from existing literature and aquifer tests conducted by Texas Department of Water Resources personnel. Data from the aquifer tests were analyzed by using the Theis nonequilibrium formula, as modified by Walton (1962). Permeability coefficients were computed by dividing the test transmissibility coefficients by the effective sand thickness.

Aquifer tests indicate that the artesian portion of the Hosston Member of the Travis Peak Formation is characterized by permeabilities ranging from approximately 4.8 to 32 gallons per day per square foot [(gal/d)/ft^2] or 196 to 1,304 liters per day per square meter [(l/d)/m^2]. Because of this range in permeability and the great variations in the thickness of the water-saturated sand, transmissibility values of 0 to 5,000 gallons per day per foot [(gal/d)/ft] or 0 to 62,100 liters per day per meter [(l/d)/m] can be expected. To the north in Williamson County, transmissibility values as high as 32,700 (gal/d)/ft or 406,100 (l/d)/m have been reported by Myers (1969). The Hosston Member in Williamson County is believed to be much more porous than it is in Travis County and also does not contain large quantities of calcareous or siliceous cement or shale.

Data are not available to determine the value of the coefficients of storage for the hydrologic units of the Trinity Group aquifers. Klemt and others (1975) cited values of 0.000042 in Burnet County and 0.000077 in Williamson County. The lower end of this range is probably the approximate range for the Hosston Member of the Travis Peak Formation in Travis County, since the voids in the hydrologic unit are usually cemented by calcite and silica, and shale often replaces sand in much of the lower Trinity aquifer.

Coefficients of transmissibility and storage can be used to evaluate a well or well field completed in the Trinity Group aquifer in terms of yield and water-level drawdown. For example, in Figure 17, if the coefficients of transmissibility and storage for the lower Trinity aquifer are 1,000 (gal/d)/ft or 12,400 (l/d)/m and 0.00005, respectively, the drawdown or decline in the water level would be about 44 feet (13 m) at a distance of 1,000 feet (305 m)from a well or group of wells discharging 50 gallons per minute (gal/min) or 3.0 l/s for one year. As another example, in Figure 18, the drawdown or decline in the water level 1,000 feet (305 m) from a well or group of wells is about 12 feet (4 m) after discharging 50 gal/min (3.0 l/s) for one month and about 17 feet (5 m) at the end of 1 year at the same rate of discharge. The total decline at any one place within the cone of depression or influence of wells within a well field would be the sum of the influences within the well field.

Table 3.—Results of Pumping Tests

Aquifer: Qal, Alluvium; Kce, Edwards and associated limestones; Kcgru, upper member of the Glen Rose Formation; Kcgrl, lower member of the Glen Rose Formation; Kcho, Hosston Member of the Travis Peak Formation.

Coefficient of transmissibility values shown are the average of drawdown and recovery values computed from test data unless indicated in remarks.

Well	Aquifer	Saturated thickness (feet)	Average yield (gal/min)	Time after well turned on or off (hours)	Drawdown or recovery (feet)	Specific capacity [(gal/min)/ft]	Transmissibility [(gal/d)/ft]	Permeability [(gal/d)/ft²]	Coefficient of storage	Remarks
					Travis County					
YD-58-33-403	Kcho	10	24	4.17	106.00	0.22	140	14	—	[1]
35-701	Kce	299	184	24.20	60.90	3.02	2,590	8.7	—	Drawdown test.[1]
42-613	Kce	38	29	5.00	1.22	31.10	33,300	877	—	Drawdown test.
907	Qal	27.8	—	9.92	.60	—	228,000	8,200	0.15	Drawdown test with YD-58-42-909.[1]
908	Qal	20.7	—	9.92	.38	—	293,000	14,200	.08	Do.
909	Qal	21.9	544	10.37	9.37	58.10	319,000	14,600	—	Recovery test.[1]
43-702	Kcgrl	15	13	40.40	22.60	.57	700	47	—	—
703	Kcho	—	20	8.03	53.20	.37	600	—	—	—
706	Kce	180	130	4.52	101.00	1.29	1,930	11	—	Recovery test.[1]
801	Kcgru	—	40	1.68	50.50	.79	1,400	—	—	[1]
44-201	Kcho	60	49	1.10	50.90	.96	1,900	32	—	Recovery test.
204	Kcho	291	250	12.00	250.00	1.00	1,400	4.8	—	Data from Roll in Harden, 1974.
51-103	Kcgrl	25	87	5.02	72.40	1.20	2,870	115	.0000019	Recovery test.
					Williamson County					
ZK-58-35-406	Kcgru	130	16	21.10	207.00	.08	47	.36	—	Drawdown test.

[1] Additional data given in Myers, 1969.

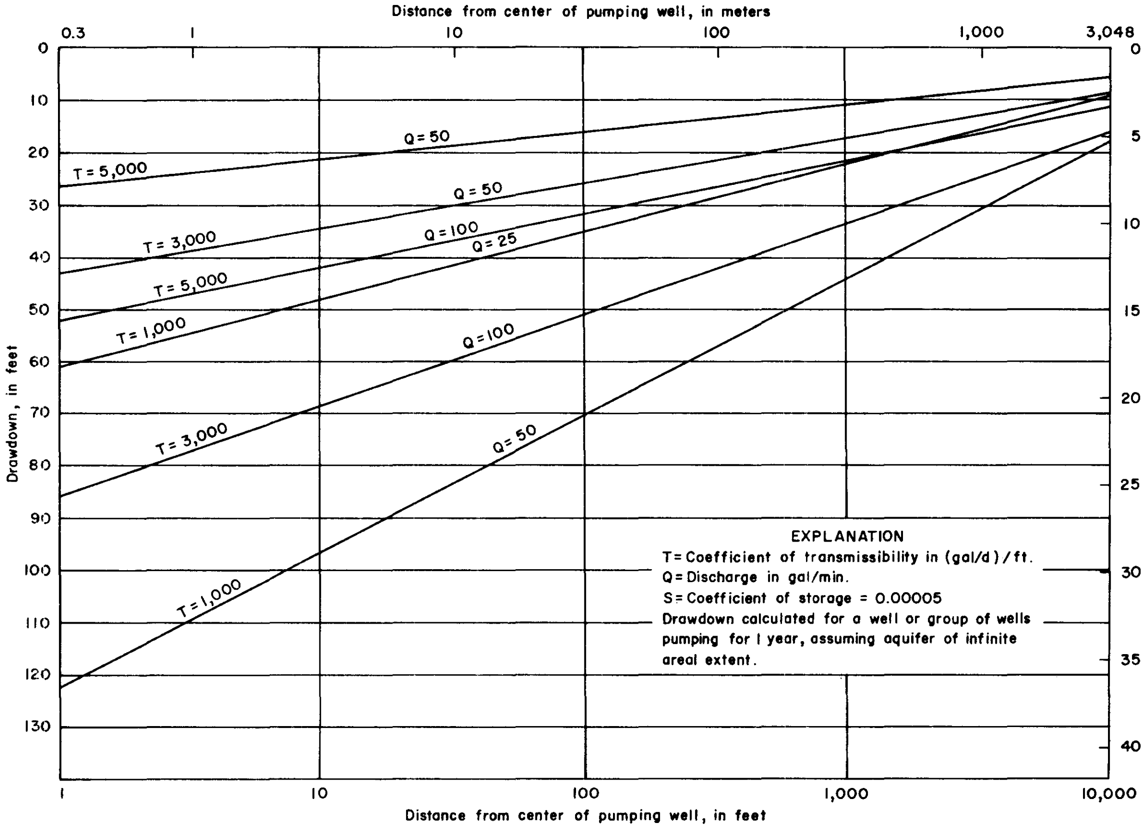

Figure 17.—Relation of Decline in Water Levels to Transmissibility, Discharge, and Distance in the Lower Trinity Aquifer

Test data included in Table 3 pertaining to the middle Trinity aquifer in the downdip region, show coefficients of permeability ranging from approximately 47 to 115 (gal/d)/ft^2 or 1,915 to 4,685 (l/d)m^2. Because of the extreme range in permeability and variation in thickness of the different members of the aquifer, coefficient of transmissibility values of 0 to 4,000 (gal/d)/ft or 0 to 49,700 (l/d)/m may be expected.

Klemt and others (1975) cite two instances of transmissibility for the Hensell Sand Member of the Travis Peak Formation of 1,800 (gal/d)/ft or 22,400 (l/d)/m in Williamson County. This agrees reasonably well with the values obtained for Travis County of 700 to 2,870 (gal/d)/ft or 8,690 to 35,640 (l/d)/m. Lack of sufficient test data prohibits assigning a coefficient of storage to the middle Trinity aquifer. However, storage values should be somewhat less than the lower Trinity aquifer.

Only one test was made on a well pumping from the upper Trinity aquifer and the results are shown in Table 3. A coefficient of permeability of 0.36 (gal/d)/ft^2 or 15 (l/d)/m^2 and a coefficient of transmissibility of 47 (gal/d)/ft or 584 (l/d)/m were obtained. Because of the variation in permeability and thickness of the aquifer, a range in transmissibility values from 0 to 100 (gal/d)/ft or 0 to 1,242 (l/d)/m may be expected. No information was available to estimate the coefficient of storage.

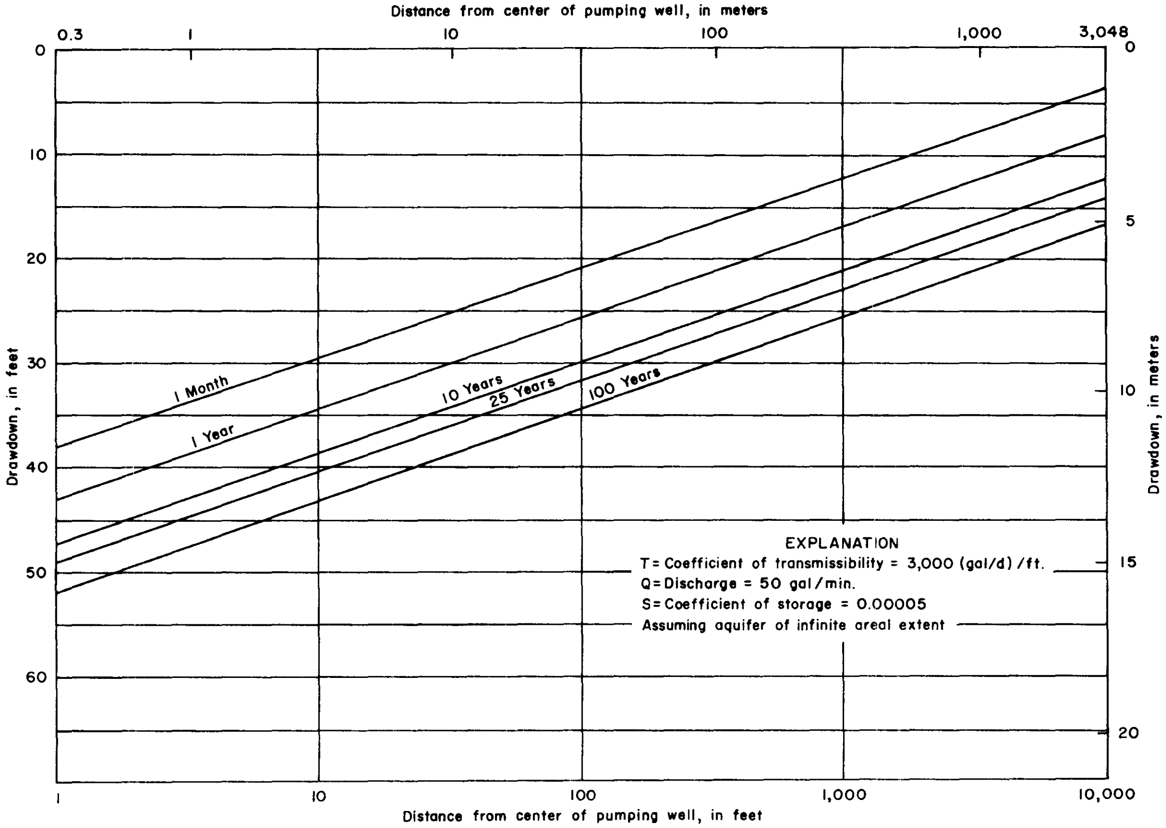

Figure 18.—Relation of Decline in Water Levels to Time and Distance as a Result of Pumping Under Artesian Conditions From the Lower Trinity Aquifer

Changes in Water Levels

The approximate altitude of the 1978 water levels from observation wells completed in the lower and middle Trinity aquifers are shown in Figures 15 and 16. Table 6 presents water levels for these aquifers in selected observation wells. The hydraulic gradient is generally toward the southeast, but is influenced locally by the topography, recharge from Lake Travis, and cones of depression in heavily pumped areas. Water-level data are scarce in the upper Trinity aquifer, but Figure 19 shows the fluctuations of water levels in a well completed in the upper member of the Glen Rose Formation. It is apparent that since 1940 there has been no significant change in water levels.

Figure 19 includes a hydrograph of a water well completed in the Hosston Member of the Travis Peak Formation showing a decline in the water levels. Data for determining estimates of average rates of decline are scanty. However, new flowing wells do not appear to flow with as great a volume as did some of the first flowing wells. Some of these earlier wells have now ceased flowing.

Water-level declines in the Trinity Group aquifer appear to be greatest around Jonestown where a large cone of depression has developed due to heavy pumpage of the Hosston Member (Figure 16). In this area, the Hosston has low permeability and transmissibility. Limited water-level data suggest that the drawdown in the potentiometric surface in the center of the cone of depression at Jonestown may be on the order of 500 feet (152 m) below land surface.

Chemical Quality

Ground water in the Trinity Group aquifer can be described as a calcium carbonate water in western Travis County, becoming a sodium sulfate or chloride type downdip. The water is usually neutral and very hard and its quality ranges from fresh to slightly saline in most cases. The quality of the water tends to decrease downdip to the southeast. Low permeability, restricted water circulation, and an increase in temperature cause the ground water to become more highly mineralized in the downdip portion of the aquifer.

Records of chemical analyses from selected wells in Travis and adjacent Counties are given in Table 7. Chloride, sulfate, and dissolved-solid content from selected wells completed in the lower, middle, and upper Trinity aquifers are shown in Figure 12.

The Trinity Group aquifer yields fresh to slightly saline water throughout most of Travis County. Faults appear to greatly restrict the movement of water through the aquifers. As a result of this restricted movement, ground-water quality in the lower and middle Trinity aquifers has become moderately saline in one area updip from the Balcones fault zone (Figure 12). Downdip from the fault zone, the quality of ground water improves in the lower Trinity as shown by chemical analyses of water from the City of Manor well (58-44-204).

The source, significance, and range in concentration of chemical constituents of ground water are given, by aquifer, in Table 2. In appraising the quality of public and domestic ground-water supplies, the recommended primary and secondary constituent levels, as discussed earlier, should be considered.

Iron content in water collected from the Trinity Group aquifer ranged from 0 to 5.7 mg/l in 29 samples; the Hosston Member of the Travis Peak Formation had the greatest number of samples (47 percent) exceeding the recommended 0.3 mg/l. Sulfate content ranged from 5 to 3,360 mg/l in 234 samples; the Hosston Member had the greatest number of samples (47 percent) exceeding 300 mg/l. Chloride content ranged from 4 to 2,700 mg/l in 236 samples with the greater number being in the Hosston Member which had 17 percent of samples containing more than the recommended limit of 300 mg/l. Fluoride content is a problem in the Trinity Group aquifer with a range of 0 to 7 mg/l in 220 samples. Within Travis County, the Hosston Member again had the highest number of samples exceeding the maximum standard with 37 percent containing over 1.4 mg/l. The range in nitrate content was 0 to 88 mg/l in 219 samples. Three percent of the samples containing 45 mg/l or more of nitrate was from the Hosston Member. The dissolved-solids content in the Trinity Group aquifer ranged from 103 to 5,690 mg/l in 236 samples; with the lower member of the Glen Rose Formation having the larger number (43 percent) of samples exceeding 1,000 mg/l.

The suitability of ground water from the Trinity Group aquifer for irrigation purposes is illustrated on Figure 14. It uses the system developed by the U.S. Salinity Laboratory (1954) based on the salinity hazard, measured by the specific conductance, and the sodium (alkali) hazard, measured by the sodium-adsorption ratio or SAR. The specific conductance and SAR for sampled Trinity Group waters are shown in Table 7. Figure 14 shows that the majority of Trinity Group waters fall in the medium (C2) to high (C3) salinity hazard classes and low (Sl)to medium (S2) sodium hazard classes.

The specific conductance of water samples collected from the Trinity Group aquifers ranged from 312 to 10,500 micromhos at 25°C. Fifty-seven percent of the samples exceeded 750 micromhos at 25°C. Normally, waters with a specific conductance of less than 750 micromhos at 25°C are considered satisfactory for irrigation.

The sodium-adsorption ratio (SAR) ranged from 0 to 38.5 in water samples collected from the Trinity Group aquifer. Fourteen percent of the samples showed ratios higher than 10.

In appraising the quality of an irrigation water, first consideration must be given to salinity and sodium hazards. Then consideration should be given to independent characteristics such as boron and bicarbonate, either of which may change the quality rating. The use of water of any quality must take into account such factors as land and crop management practices and soil drainage.

Utilization and Development

Early settlers who came to Travis County used water from the springs because of the ready availability of a constant flow, and because it was a source of power. The influx of settlers was accelerated by the establishment of the Republic of Texas in 1836, the creation of Travis County and designation of Austin as capital of the Republic in 1840, and by the annexation of Texas to the United States in 1845.

As the population increased, most of the choice land located near or downstream from springs was soon taken. The remaining settlers had no choice but to dig wells in order to provide their household and livestock with water. These dug wells rarely exceeded 40 feet in depth and were confined largely to the eastern portion of the county because the limestone of western Travis County was too hard to permit dug wells, except in rare instances.

The revolution in use of ground water in the county, and in Texas, began in 1857. In that year, the Texas Legislature authorized the drilling of an artesian well, probably the first drilled well in Texas. The purpose, according to Shumard (1860) was “to determine whether an abundant supply of good water could be obtained at the surface near the Capitol Building.” The well was drilled with horse and steam power and was abandoned when the drill pipe was lost in the hole. However, when it was discovered that flowing wells could be obtained in many parts of the county, the drilling of deep wells greatly accelerated.

Most of the well development in the Trinity Group aquifer has occurred since 1900, although there were several Trinity wells drilled in Travis County prior to that year. Most of the water from these earlier wells was used for medicinal purposes, both bathing and internal use. Historically, ground water from the Trinity has been used mainly for public supply and domestic and livestock purposes.

During this study, there were 474 wells and springs inventoried which produce ground water from the Trinity Group aquifer in the county. Of this number, 53 were used for public supply, 7 for irrigation, 4 for industrial supply, and 310 for domestic and livestock supply. There were approximately 99 wells which were not used and were either abandoned or destroyed. A select number of of domestic and livestock wells were inventoried to provide adequate well coverage. An attempt was made to include all the irrigation, public supply, and industrial wells in the study area.

About 4,930 acre-feet (6.08 hm^3) of ground water was pumped from the principal Cretaceous and Quaternary aquifers in Travis County in 1976 (Table 4). The 1976 ground-water pumpage from the Trinity Group aquifer was approximately 1,540 acre-feet (1.90 hm^3), which is about 31 percent of the total usage.

A total of 2,790 acre-feet (3.44 hm^3) of ground water was pumped for municipal use. Municipal pumpage from the Trinity Group aquifer was about 385 acre-feet (0.474 hm^3), which represents 14 percent of the total pumpage. The majority of the ground water used by towns, small communities, and developments is produced from the lower Trinity aquifer, with the remainder from the middle Trinity aquifer.

Ground water used for irrigation in Travis County has decreased from 270 acre-feet (0.333 hm^3) in 1955 to 70 acre-feet (0.086 hm^3) in 1976. About 14 acre-feet (0.017 hm^3) was used from the Trinity Group aquifer for irrigation in 1976, mainly on golf courses.

In 1976, a total of 2 acre-feet (0.002 hm^3) of ground water was used for industrial purposes. The majority of industrial usage is from the Edwards and associated limestones aquifer.

There was an estimated total of 2,070 acre-feet (2.55 hm^3) of ground water used in 1976 for domestic and livestock purposes. The Trinity Group aquifer supplied 1,140 acre-feet (1.41 hm^3) of ground water for domestic and livestock needs. This represents about 55 percent of the total usage.

Flowing wells are used to a small extent for irrigation, domestic and livestock, and medicinal or health purposes. Spring flow is used chiefly for domestic and livestock purposes and recreational functions. Most of the spring flow goes unused, except to augment surface water supplies in downstream reservoirs.

Availability of Ground Water for Development

Based on an estimated annual effective recharge of 25,000 acre-feet (30.8 hm^3), the amount of fresh to slightly saline ground water available for additional development from the Trinity Group aquifer annually in Travis County would be approximately 20,200 acre-feet (24.9 hm^3). In 1976, approximately 1,540 acre-feet (1.90 hm^3) of ground water was used from the aquifer in the downdip areas for municipal, industrial, irrigation, and domestic and livestock purposes. During the period from March 1972 through September 1973, springs and flowing wells inventoried and completed in the Trinity Group aquifer were measured. It is estimated that 3,250 acre-feet (4.01 hm^3)is discharged annually from springs and flowing wells; thus the total annual discharge from the aquifer is about 4,790 acre-feet (5.91 hm^3).

Theoretically, all of the 20,200 acre-feet (24.9 hm^3) could be developed by wells; however, it would be impractical to capture all of this water. To do this would require the interception of all natural discharge by numerous evenly spaced low-capacity wells. It would also require constant year-round pumpage.

Table 4.—Estimated Ground-Water Pumpage, 1955-76

(Figures are approximate because some of the pumpage is estimated. Totals are rounded.)

Use	Pumpage (acre-feet)																					
	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Municipal	460	500	500	540	1,160	1,280	1,340	1,590	1,780	1,940	2,120	2,170	2,320	2,030	2,130	2,140	2,440	3,000	2,570	2,600	2,910	2,790
Irrigation	270	270	270	270	270	260	240	220	200	190	190	190	180	180	180	170	150	130	110	100	80	70
Industrial	–	–	–	–	–	–	–	–	–	–	–	10	10	10	10	10	5	10	10	10	5	2
Domestic and livestock	1,010	1,020	1,040	1,050	1,060	1,080	1,170	1,270	1,360	1,510	1,470	1,670	1,550	1,950	1,950	1,630	1,440	720	1,720	970	1,570	2,070
Totals	1,740	1,790	1,810	1,860	2,490	2,620	2,750	3,080	3,340	3,640	3,780	4,040	4,060	4,170	4,270	3,950	4,040	3,860	4,410	3,680	4,570	4,930

Development of ground water in the Trinity Group aquifer should be primarily confined to the upper and lower members of the Glen Rose Formation, and the Hensell Sand Member of the Travis Peak Formation because these hydrologic units crop out over the majority of western Travis County; therefore, these units receive the maximum amount of recharge. Future lower Trinity aquifer development should be confined locally to areas that are not experiencing marked decline in water levels. Also, areas near streams often have a better chance of developing solution channels necessary for larger well yields from shallow zones. Any future development of ground water from the Trinity Group aquifer should be based on a program of test drilling, test pumping, and chemical analyses of water from the producing aquifer.

Edwards and Associated Limestones Aquifer

Source and Occurrence

The source of ground water in the Edwards and associated limestones aquifer is from infiltration of rainfall and by seepage from streams that cross the outcrop. Because of the high rate of streamflow seepage into the underlying Edwards, some streams crossing the outcrop flow only during flood stage.

Water occurs primarily in the Kirschberg solution zone and other less important solution-collapse zones in the Edwards Limestone. The Kirschberg zone contains large caverns and underground channels through which large quantities of ground water can readily move. In addition to the solution zones which parallel the bedding planes, a network of steeply dipping faults and joints is present, especially in the Balconesfault zone. These faults and joints intersect the water-bearing beds, providing channels along which water can move.

West of the Balcones fault zone, erosional remnants of the aquifer cap the hills. Here, the aquifer is not completely water-saturated and water-table conditions prevail. In the Balcones fault zone, the entire aquifer is usually saturated and water occurs under artesian conditions. The hydrostatic pressure is sufficient to cause static water levels to rise above the top of the aquifer and in many cases to cause flowing wells and springs.

Recharge, Movement, and Discharge

The source of the water which recharges the Edwards and associated limestones aquifer is precipitation in the drainage areas of Barton Creek, Onion Creek, and other creeks west of the Balcones fault zone. Some of this precipitation infiltrates the upper member of the Glen Rose Formation and reappears downstream as spring flow. By far the largest part of the precipitation, however, flows directly downstream to the Balconesfault zone. Here, numerous faults and joints traverse the aquifer and the overlying rocks. These faults and joints have been enlarged by solution and often are characterized by sinkholes especially in stream channels. Streamflow enters these sinkholes and moves downward into the aquifer, which underlies the Balcones fault zone.

A study of Figure 20 illustrates the effect of precipitation on recharge, the rate of ground-water movement within the aquifer, as-well-as discharge from the Edwards and associated limestones. This graph compares the flow of Barton Springs with precipitation at Austin for a 60-year period from 1917 through 1976. An increase in the spring flow usually follows an above normal rainfall, unless the rainfall is strictly local to Austin and does not extend into the recharge area of the springs on Onion and Barton Creeks. This increase in spring flow can come immediately after a rainfall or as much as one week or even longer after a rainfall. Quick increases in spring flow result from recharge, chiefly to Barton Creek, immediately upstream from Barton Springs. The slower increases in spring flow are believed to originate from recharge on Onion Creek, as much as 20 miles (32 km) from the springs.

A study of the amount of recharge to the Edwards between Kyle and Austin was conducted by Guyton (1958). With minor modifications, this investigation was used as a basis for recharge calculations. Additionally, the basic hydrologic principle that in any aquifer the average annual recharge approximately equals the average annual discharge was also applied. Except for evapotranspiration, the major portion of the average annual discharge from the Edwards and associated limestones is from spring flow and ground-water pumpage. Based on data for the period 1917-76 for Barton Springs (Figure 20) and on ground-water pumpage for the period 1955-76, the average annual discharge from the aquifer from these two sources was estimated to be approximately 37,000 acre-feet (45.6 hm^3). In addition to the flow at Barton Springs, a flow of about 2,900 acre-feet per year (3.57 hm^3/yr) was attributed to other springs in the county. Thus the total amount of average annual discharge from the Edwards and associated limestones aquifer would be slightly less than 40,000 acre-feet (49.3 hm^3). This average annual discharge is approximately equal to the average annual recharge. Therefore, the average annual effective recharge to the Edwards and associated limestones aquifer is approximately 40,000 acre-feet (49.3 hm^3).

A study of the quantity of low flow in Barton Creek by Baker and Watson (1971) illustrates the mechanism of the recharge to the aquifer. On July 6-8, 1970, the discharge increased in a downstream direction to a maximum of about 11 cubic feet per second (ft^3/s) or 0.31 m^3/s at a point immediately upstream from the Mount Bonnell fault. From here to a point 1.5 miles(2.4 km) downstream from the Mount Bonnell fault all of the flow entered the aquifer as recharge.

Since ground water in the Edwards and associated limestones moves largely by turbulent flow in underground channels, it travels relatively fast. The direction of movement is generally to the east-southeast in the northern section of the county and towards the southeast and northeast in the southern portion as shown in Figure 21. The present hydraulic gradient of the potentiometric surface ranges from less than 20 to 200 feet per mile (3.8 to 38 m/km).

As shown in Figures 26,28, and 29, the downfaulting to the southeast in the Balcones fault zone has frequently placed the relatively impervious Del Rio Clay, Buda Limestone, and Eagle Ford Group opposite the aquifer to the southeast. This has resulted in a series of underground dams or barriers which restrict the movement of water in the artesian portion of the aquifer.

Springs make up by far the greatest portion of the discharge of the aquifer. A relatively small amount is pumped from wells and very small amounts come from flowing wells. Barton Springs are considered large springs based on a spring flow classification used by Brune (1975). With an average annual flow (Figure 20) of approximately 50 ft^3/s (1.42 m^3/s) or 36,400 acre-feet per year (44.9 hm^3/yr), they are ranked as the fourth largest springs in Texas. They are exceeded in size only by Comal Springs at New Braunfels, San Marcos Springs at San Marcos, and San Felipe Springs at Del Rio, all of which flow from the Edwards and associated limestones. Barton Springs are composed of at least five groups of springs. On February 6,1973, the flow was measured from each of the following: Main Springs (58-41-914), 47 ft^3/s (1.33 m^3/s); Upper Springs (58-42-920), no flow; Eliza or Left Bank Springs (58-42-921), 5 ft^3/s (0.14 m^3/s); and Walsh or Old Mill Springs (58-42-922), 9 ft^3/s (0.25 m^3/s). Barton Springs reached their lowest recorded flow of 9.59 ft^3/s (0.27 m^3/s) on March 29, 1956. This was near the end of the long drought of the 1950's when Comal Springs at New Braunfels, the largest springs in Texas, completely stopped flowing for a period of time in 1956. Highest recorded flow at Barton Springs was 166 ft^3/s (4.70 m^3/s) on May 10, 1941.

Several moderately large springs reported by Brune (1975), include Cold or Deep Eddy Springs (58-42-916), which had a reported flow in May 1972 of 2.9 ft^3/s (0.082 m^3/s); Power House or Dam Spring (58-42-610) 0.05 ft^3/s (0.001 m^3/s) on February 5,1973; Mount Bonnell Springs (58-42-611) and Mormon or Taylor Springs (58-42-618), 2.2 ft^3/s (0.062 m^3/s) on February 6, 1973. In addition, there are a large number of medium and small springs which average a flow of less than 450 gal/min (28.4 l/s).

Hydraulic Characteristics

Aquifer coefficients for the Edwards and associated limestones in Travis County are shown in Table 3. The great variability in the results of the tests is caused by the nature of the aquifer itself. Most of the ground water moves by turbulent flow through channels and crevices in the rock. Therefore, it is questionable whether such aquifer tests can provide reliable information.

As shown in Table 3, the permeability coefficients vary from 8.7 to 877 (gal/d)/ft^2 or 350 to 35,700 (l/d)/m^2. Because of the extreme range in permeability and variation in the thickness of the water-bearing zones, transmissibility values from 400 to 300,000 (gal/d)/ft or 4,970 to 3,725,400 (l/d)/m can be expected.

Data on the values of specific yield and coefficient of storage for the Edwards and associated limestones in Travis County are not readily available. However, based on core data assembled on the Edwards in the San Antonio area, Sieh (1975) determined that the estimated effective porosity (specific yield) for the unit would realistically range from 4 to 6 percent. A reasonable estimate of the artesian coefficient of storage can be made using the total thickness of the aquifer times 1×10^{-6}. Based on a range in thicknesses within Travis County of from 250 to 450 feet (76 to 137 m), an estimated artesian coefficient of storage would range from 0.00025 to 0.00045.

Changes in Water Levels

The approximate altitude of the 1978 water levels from observation wells completed in the Edwards and associated limestones aquifer is shown in Figure 21. Table 6 presents water levels for this aquifer in selected observation wells. The hydraulic gradient is generally toward the east-southeast and is greatly influenced by the topography. A slight cone of depression has developed around the Manchaca area.

Hydrographs on Figure 19 show water-level fluctuations in the Edwards and associated limestones from April 1937 to June 1976. The yearly precipitation at Austin is also shown for comparison. Fluctuations in water levels are predominantly a result of seasonal climatic changes which affect the amount of ground water in storage. Examination of these hydrographs shows a slight rise in water levels during the period of record especially in well 58-58-301. The lowest water levels occurred in late 1956 and early 1957, toward the end of the seven-year drought.

Chemical Quality

Ground water in the Edwards and associated limestones aquifer may be described as a calcium carbonate, and sometimes magnesium carbonate water, generally becoming a sodium sulfate water downdip. Still farther downdip, it becomes a sodium chloride water. It is very hard, usually fresh, and normally neutral. Its quality decreases rapidly downdip or to the southeast (Figure 12). Decreasing water circulation through faults, increasing temperature as the depth of the aquifer increases, and solution of the rocks cause the ground water to become more highly mineralized downdip.

Records of chemical analyses from selected wells in Travis and adjacent counties are given in Table 7. The chloride, sulfate, and dissolved solids from selected wells completed in the Edwards and associated limestones aquifer are shown in Figure 12. The water is generally within the recommended limits for drinking water as established by the Texas Department of Health, except near its downdip limit of fresh to slightly saline water where higher concentrations of dissolved minerals occur. In most areas, except in the extreme downdip area, water from the Edwards and associated limestones aquifer is suitable for public supply, irrigation, and industrial use.

The source, significance, and range in concentrations of chemical constituents for ground water collected from the Edwards and associated limestones aquifer are given in Table 2. The recommended primary and secondary constituent levels should be considered when evaluating the quality of water for public and domestic use. It should be noted that these concentration limits will apply except where suitable public water supplies are not available or cannot be made available at a reasonable cost.

Iron content in the Edwards and associated limestones aquifer ranged from 0 to 13 mg/l in 32 samples with 31 percent exceeding the recommended 0.3 mg/l. Sulfate content ranged from 4 to 2,750 mg/l in 182 samples with less than 9 percent exceeding 300 mg/l. Chloride content ranged from 4 to 6,050 mg/l in 184 samples with 10 percent of the sampfes containing more than the recommended amount of 300 mg/l. Fluoride content ranged from 0 to 4.8 mg/l in 147 samples with 35 percent of the samples collected in Travis County exceeding the recommended upper limit of 1.4 mg/l. The range in nitrate content was 0 to 88 mg/l in 163 samples with less than 4 percent of the samples exceeding 45 mg/l. Dissolved-solids content ranged from 173 to 10,190 mg/l in 185 samples with only 11 percent exceeding 1,000 mg/l.

Specific conductance and SAR values for the Edwards and associated limestones water samples are shown in Table 7. Figure 14 shows that the majority of Edwards waters falls in the medium (C2) salinity hazard class and low (S1)sodium hazard class.

Specific conductance of water samples collected from the Edwards aquifer ranged from 214 to 19,700 micromhos at 25°C. Twenty-five percent of the samples exceeded 750 micromhos at 25°C. Normally, waters with a specific conductance of less than 750 micromhos at 25°C are considered satisfactory for irrigation.

The sodium-adsorption ratio (SAR) ranged from 0 to 28 in water samples collected from the Edwards and associated limestones aquifer. Eight percent of the samples showed ratios higher than 10. All of the collected samples were well below the upper recommended limit of 60.

Utilization and Development

Indians were the first to use springs as camp sites many years ago. Barton Springs (58-42-917, 920, 921, and 922) was a stop on an old Comanche trail from Bandera County to Nacogdoches. The earliest white settlers established a trading post at the springs. Three Spanish missions were located here from 1730 to 1731. In 1839, the five commissioners named to select an area as the capital described Barton Springs as "perhaps the greatest and most convenient water power to be found in the Republic". A number of saw and grist mills used the water power of the springs. The springs were used as a stop on the Chisholm Cattle Trail from 1867 to 1895. They have always been popular for swimming and recreation (Brune, 1975).

The use of Cold or Deep Eddy Springs (58-42-916) by early settlers is indicated by the many artifacts which have been found at the springs and in the nearby Bat Cave and Bee Cave.

Mormon Springs (58-42-618) were used by a Mormon settlement in 1846 and 1847 to power a grist mill. From 1864 to 1900, a group of springs located in northern Travis County (58-34-102, 103, 104, 411, 412, and 501) provided the water to operate the downstream Anderson's Mill.

It is apparent that the springs, primarily Barton Springs, were a deciding factor in selecting Austin as the capital. However, recreation, instead of water power, has become the prime use of the springs. A small part of the spring flow is used for domestic, livestock, and irrigation purposes. One important use of the springs is to furnish a large quantity of good quality water to Town Lake.

At one of the earliest drilled wells in Texas, (well 58-43-707), water from the Edwards and associated limestones aquifer flowed at the surface in 1859 (Baker and others, 1973). The water was to be used to operate the capitol elevator, but the well was abandoned when drill pipe was lost in it. The water was used for medicinal purposes for many years.

There were approximately 265 wells, test holes, and springs inventoried during this study which produce ground water from the Edwards and associated limestones aquifer in Travis and adjacent counties. Of this amount, 38 were used for public supply, 12 for irrigation, 10 for industrial supply, and 116 for domestic and livestock supply. There also were approximately 89 wells inventoried which were not used and were either abandoned or destroyed. A select number of domestic and livestock wells were inventoried to provide adequate well coverage, and an attempt was made to include all the irrigation, public supply, and industrial wells in the study area.

Table 4 shows the amount of ground water pumped from all aquifers during the period 1955-76. The average annual pumpage from the Edwards and associated limestones for this period was approximately 600 acre-feet (0.74 hm^3). The 1976 municipal ground-water pumpage from this aquifer was about 255 acre-feet (0.314 hm^3) which is about 9 percent of the total municipal usage.

About 28 acre-feet (0.035 hm^3) was used from the aquifer for irrigation in 1976.

In 1976, only 2 acre-feet (0.002 hm^3) of ground water was used in the county for industrial purposes. This total amount was from wells completed in the Edwards and associated limestones aquifer.

The Edwards and associated limestones aquifer supplied approximately 414 acre-feet (0.510 hm^3) of ground water in 1976 for domestic and livestock purposes which represented about 20 percent of the total domestic and livestock usage.

Availability of Ground Water for Development

Theoretically, the amount of water which can be developed annually from an aquifer is limited by the amount of recharge. During years of drought, discharge can exceed recharge with the deficit being pumped from storage. This condition can exist only temporarily, or until the supply in storage is exhausted. Fortunately, droughts are eventually interrupted by years in which precipitation is normal or above normal. During periods in which recharge exceeds discharge, ground water previously removed from storage is partly or completely replaced.

As previously discussed, the total average annual recharge to the Edwards and associated limestones aquifer was estimated to be slightly less than 40,000 acre-feet (49.3 hm^3). This amount is probably representative for the long-term recharge. However, during the period of a prolonged drought, the recharge figure would be much too high and a more realistic estimate would be one based on the minimum annual flow at Barton Springs plus the annual pumpage from the aquifer during that same year. It is felt that there would be no flow from smaller springs under these conditions.

US. Geological Survey surface-water records indicate that all time minimum flow of 9.59 cubic feet per second (0.27 m^3/s) occurred at Barton Springs on March 29, 1956. This minimum flow was the result of the long drought of the 1950's which ended in 1957. In 1956, the minimum annual flow at the springs was 9,262 acre-feet (11.4 hm^3). During this same year, approximately 472 acre-feet (0.582 hm^3) was pumped from the aquifer. Based on a minimum annual spring flow of 9,262 acre-feet (11.4 hm^3) and a pumpage or withdrawal rate from the aquifer of 472 acre-feet (0.582 hm^3), the approximate amount of ground water which could be reliably developed on an annual basis would be 9,734 acre-feet (12.0 hm^3) or just slightly less than 10,000 acre-feet (12.3 hm^3). Theoretically, all of this 10,000 acre-feet (112.3 hm^3) could be available for development; however, withdrawals of this magnitude from the aquifer during a drought period would dry up all streamflow and directly affect surface-water supplies.

Alluvium and Terrace Deposits

Source and Occurrence

Recent alluvium and terrace deposits which occur in the east-southeast portion of Travis County are treated as one undifferentiated hydrologic unit because of their similar hydrologic and lithologic characteristics. The Recent alluviums have the largest outcrop area and the thickest deposits which consist of unconsolidated material, chiefly gravel, sand, and silt. They are located along the Colorado River in eastern Travis County.

Primary sources of ground water to the alluvium and terrace deposits are rainfall, lakes, and streams which cross their outcrops. Water occurs primarily in the void spaces between particles of gravel and sand. It is usually under water-table conditions, and the aquifer may not be completely saturated.

Recharge, Movement, and Discharge

Recharge to the alluvium and terrace deposits is mainly from rainfall which falls on the outcrops and from the tributaries of the Colorado River which cross the outcrops. A small amount of recharge probably originates as underflow from Town Lake. Additionally, small amounts may be contributed by the Colorado River during periods of flooding. In the area along the Colorado River between Town Lake and the east county line, much recharge is undoubtedly rejected, as the aquifer is in constant contact with the river. The configuration of the water table also confirms this movement (Figure 22).

The average annual recharge to the alluvium and terrace deposits probably ranges from 5 to 8 percent of the mean annual rainfall. Using 5 percent of the mean annual rainfall or 1.68 inches over the outcrop area, the amount of effective recharge available would be about 6,000 acre-feet per year (7.40 hm^3/yr).

Ground water in the alluvium and terrace deposits moves slowly downdip to the east and south parallel to the recharging streams and rivers. Water-level measurements indicate that the hydraulic gradient of the potentiometric surface is about 16 to 44 feet per mile (3 to 8 m/km).

Pumpage from wells accounts for nearly all the discharge from the Recent alluviums. A small amount is believed to return to stream channels in the form of seepage during periods of low streamflow. Springs at the base of the terrace deposits account for most of their discharge. These springs are especially numerous in an area southeast of Manor, where they issue from the base of high gravel deposits which overlie clay and shale of the Navarro, Taylor, and Midway Groups.

Hydraulic Characteristics

Results of pumping tests performed on wells developed in the Recent alluvium in Travis County are shown in Table 3. Permeability coefficients range from 8,200 to 14,600 $(gal/d)/ft^2$ or 334,100 to 594,800 $(l/d)/m^2$. Because of the great range in permeability and in the thickness of water-saturated materials, transmissibility coefficients of 0 to 400,000 (gal/d)/ft or 0 to 4,967,200 (l/d)/m may be expected. It should be pointed out that the tested wells penetrated a large amount of coarse gravel. In most cases, the alluvium contains a large percentage of fine materials; consequently, the permeability and transmissibility will usually be much lower than the values obtained in these tests. As shown in Table 3, the coefficient of storage varies from 0.08 to 0.15.

Changes in Water Levels

The approximate altitude of water levels in selected wells completed in the alluvium and terrace deposits in 1978 is shown in Figure 22. Table 6 presents water levels for these aquifers in selected observation wells. The hydraulic gradient is generally to the south and east parallel to the river. The fluctuation of water levels in well 58-50-802, completed in the terrace deposits, indicates no definite trend in water levels (Figure 19). The fluctuations are caused chiefly by changes in the stage of nearby streams.

Chemical Quality

Ground water in the alluvium and terrace deposits is generally a calcium carbonate water, very hard, usually fresh, and is normally neutral. Sulfate, chloride, and dissolved-solids content in water from selected wells in the alluvium and terrace deposits are shown in Figure 13. Records of chemical analyses from selected wells completed in the alluvium and terrace deposits are given in Table 7.

The source, significance, and range in concentrations of chemical constituents of ground water collected from the alluvium and terrace deposits are given in Table 2. Iron content in the alluvium and terrace deposits ranged from 0 to 0.02 mg/l in four samples. Sulfate content ranged from less than 4 to 2,544 mg/l in 134 samples with only 9 percent exceeding 300 mg/l. Chloride content ranged from 6 to 2,500 mg/l in 134 samples with 5 percent of the samples containing more than the recommended 300 mg/l. Fluoride content ranged from less than 0.1 to 5.8 mg/l in 113 samples with only 3 percent of the samples collected in Travis County exceeding the upper recommended limit of 1.4 mg/l. The range in nitrate content was from less than 0.4 to 540 mg/l in 127 samples with 17 percent exceeding 45 mg/l. Dissolved-solids content ranged from 170 to 6,953 mg/l in 134 samples with only 8 percent exceeding the recommended 1,000 mg/l.

The majority of alluvium and terrace deposits waters fall in the medium (C2) to high (C3) salinity hazard class and low (Sl) sodium hazard class as shown in Figure 14.

Water samples collected from the alluvium and terrace deposits had a specific conductance which ranged from 274 to 10,000 micromhos at 25°C. Fifty-three percent of the samples exceeded 750 micromhos at 25°C. Usually, ground waters with a specific conductance of less than 750 micromhos at 25°C are considered satisfactory for irrigation.

The sodium-adsorption ratio (SAR) ranged from 0.1 to 10.5 in water samples collected from the alluvium and terrace deposits. Less than 1 percent of the samples showed ratios higher than 10.

Utilization and Development

Alluvium and terrace deposits are used extensively as a source of public supply and domestic water. Although the City of Austin primarily uses surface water from the Colorado River, it is also a relatively large user of ground water. Its usage of ground water from the alluvium deposits began about 1934. At the present time, the water is used to air-condition the city auditorium and as a supply for Deep Eddy swimming pool. Many other smaller communities such as Garfield (well 58-52-304), River Timbers (well 58-52-313), Colorado River Ranchettes (wells 58-52-614 and 615), and other municipal water-supply corporations use ground water from the alluvium and terrace deposits. Many of the farms and ranches in the county, when usable supplies are available, obtain their water from the alluvium and terrace deposits.

There were approximately 177 wells and springs inventoried during this study which produced from the alluvium and terrace deposits in Travis and adjacent counties. Of this amount, 25 were used for public supply, 10 for irrigation, 1 for industrial purposes, and 98 for domestic and livestock supply. There were also approximately 43 unused wells either abandoned or destroyed.

During 1976, approximately 2,550 acre-feet (3.14 hm^3) of ground water was pumped from the alluvium and terrace deposits which was approximately 52 percent of the total ground water used in the county. Approximately 2,153 acre-feet (2.65 hm^3) of ground water was used for municipal purposes from the alluvium and terrace deposits in 1976 which was about 77 percent of the total municipal usage. About 25 acre-feet (0.31 hm^3) was used from these aquifers for irrigation in 1976.

There was only one industrial well inventoried during this study and no pumpage record was available.

The alluvium and terrace deposits supplied approximately 373 acre-feet (0.460 hm^3) of ground water for domestic and livestock purposes in 1976, which represented about 18 percent of the total domestic and livestock usage.

Availability of Ground Water for Development

Based on the previously discussed conservative estimate of effective recharge of 6,000 acre-feet per year (7.40 hm^3/yr), the amount of fresh to slightly saline ground water available for additional development from the alluvium and terrace deposits annually in Travis County would be approximately 3,150 acre-feet (3.88 hm^3). This availability is based on the following data. In 1976, approximately 2,550 acre-feet (3.14 hm^3) of ground water was used for municipal, irrigation, and domestic and livestock purposes. During the period from September 1972 through April 1973, springs were inventoried and measured which were flowing from the terrace deposits. They had an estimated total annual discharge of about 300 acre-feet (0.370 hm^3). Therefore, the total annual discharge from the alluvium and terrace deposits is about 2,85O acre-feet (3.51 hm^3). This figure subtracted from an estimated effective recharge of 6,000 acre-feet per year (7.40 hm^3/yr) leaves approximately 3,150 acre-feet per year (3.88 hm^3/yr) for future development.

Theoretically, the entire 3,150 acre-feet (3.88 hm^3) would be available for development by wells. However, it would be impractical to do this because it would require the interception of all of the natural ground-water discharge by numerous, evenly spaced, low-capacity wells.

Other Aquifers

Other hydrologic units which produce a small amount of ground water in Travis County are the Austin Chalk and the Taylor and Navarro Groups. Igneous rocks around Pilot Knob also produce small quantities of good quality water. There were only two water wells in Travis County that were completed in the igneous rocks. Additionally, the Midway Group is an unreliable source of very small quantities of fresh to moderately saline ground water.

Twenty-three wells and springs were inventoried during this study that were completed in the Austin Chalk. Out of this total, eight wells were either abandoned or not presently in use. Twenty-eight wells were inventoried in the Navarro and Taylor Groups with 16 of them either abandoned or not used. Only one well (58-45-206) was inventoried in the Midway Group, and it had a depth of 20 feet.

In the Austin Chalk and Taylor and Navarro Groups, ground water usually occurs in the upper, weathered outcrop portion of the units which is the most permeable. The Austin Chalk contains numerous fractures and joints which are now water saturated. Water can also be present in the softer marls which occur throughout the Austin Chalk. The Taylor and Navarro Groups contain montmorillonitic clays which are known for their swelling and shrinking characteristics. During dry periods, large cracks may open in the surface of the outcrop which may allow water to enter the water-bearing unit. Water also occurs in the voids in some thin sand beds. Ground water occurs primarily under water-table conditions in the Austin Chalk-and Taylor and Navarro Groups. Although the Midway is not generally considered to be a significant aquifer, a small amount of water occurs in the thin sandy layers. The formations are not completely saturated, and the ground water occurs primarily under water-table conditions.

All of these water-bearing units are recharged from rainfall which falls on their outcrops, streams which cross them, and farm ponds or lakes which lose water into them. Ground water moves in various directions, largely controlled by the topography, through joints, crevices, faults, and the more permeable bedding planes. Spring flow accounts for most of the discharge from the Austin Chalk. Ground water in the Navarro, Taylor, and Midway Groups is discharged by pumping wells.

Hydraulic properties of the Austin, Taylor, Navarro, and Midway are undetermined due to a lack of sufficient data. To compensate for the low specific capacity, wells are often constructed with a large diameter so that the storage capacity in the well will offset drawdown during periods of use. These shallow wells sometimes fail during periods of prolonged drought.

Fluctuations in water levels in an Austin Chalk well are shown in Figure 19. There seems to be no definite trend to water levels. Minor fluctuations are caused chiefly by variations in rainfall and recharge. The lowest levels were reached from 1954 to 1956, near the end of the drought in this area. There was no historical water-level data for the Taylor, Navarro, and Midway Groups, but water levels fluctuate in response to rainfall.

Ground water in the Austin Chalk may be described as a calcium carbonate type. It is very hard, usually fresh, and is normally neutral. As shown in Figure 13, its quality appears to range within the same limits regardless of the location within the county. Ground water in the Navarro and Taylor Groups may be described as a calcium carbonate water which becomes a sodium chloride water downdip. The westernmost portion of the outcrop contains fresh water while in the southeast the water rapidly deteriorates to slightly saline and then moderately saline (Figure 13). A chemical analysis of the water from well 58-45-206 shows it to be a calcium carbonate water with a dissolved-solids content of 254 mg/l. The water is hard. Ranges of the chemical constituents and the source and significance of the dissolved minerals found in waters of the Austin Chalk and Taylor and Navarro Groups are presented in Table 2.

The Austin Chalk and Taylor and Navarro Groups are used mainly as a source of domestic, livestock, and irrigation water. There were three Austin Chalk springs inventoried during this study. On March 22, 1973, spring 58-35-606 had a measured yield of 250 gal/min (16 l/s). In 1976, the estimated amount of ground water used from the Austin Chalk and Taylor and Navarro Groups was approximately 150 acre-feet (0.18 hm^3), which was about 3 percent of the total amount of ground water used in Travis County.

GROUND-WATER PROBLEMS

Well Construction and Completion

Improper well construction in Travis County can be related to one or all of the following: (1) well casing, (2) well screens, (3) gravel packing, (4) cementing, and (5) well development.

Wells having insufficient casing or no casing at all may permit the bore hole to collapse at any point or sand-up at the water-producing interval. Some of the more common types of wells used in Travis County and their casing requirements are shown in Figure 23. For deep wells, the casing size is generally determined by the size of the pump to be used. New or used steel casing is ordinarily used. Polyvinyl chloride (PVC) plastic casing is coming into increasing use. It is cheaper and is not subject to corrosion. However, it is not as strong as steel and cannot be forced through resistant shale and clay beds without breaking. For shallow wells, where storage capacity is of primary concern, large-diameter concrete rings are usually employed as shown in Figure 23a. A common mistake in Travis County is to drill the well without the use of drilling mud and then attempt to place casing in the well. This mistake is usually made in drilling to the Hosston Member of the Travis Peak Formation. The Hosston is overlain by the Hammett Shale Member of the Travis Peak Formation and without the use of a heavy drilling mud, the Hosston will cave in immediately after drilling. More serious than this, however, is that the Hammett Shale begins to expand into the freshly drilled well immediately when water from the underlying Hosston saturates the shale. As a result, the casing cannot be forced past the Hammett Shale, and the shale below the casing closes the well and prevents the Hosston water from ascending the borehole. In some hard units such as the limestones of the Edwards and Glen Rose aquifers, no casing is required as shown in Figure 23c. However, casing may be required above these aquifer units when incompetent beds are encountered.

Some typical well-screen installations in Travis County are shown in Figures 23b and 23d. A well should usually be drilled deep enough to penetrate all of the water-bearing zones of an

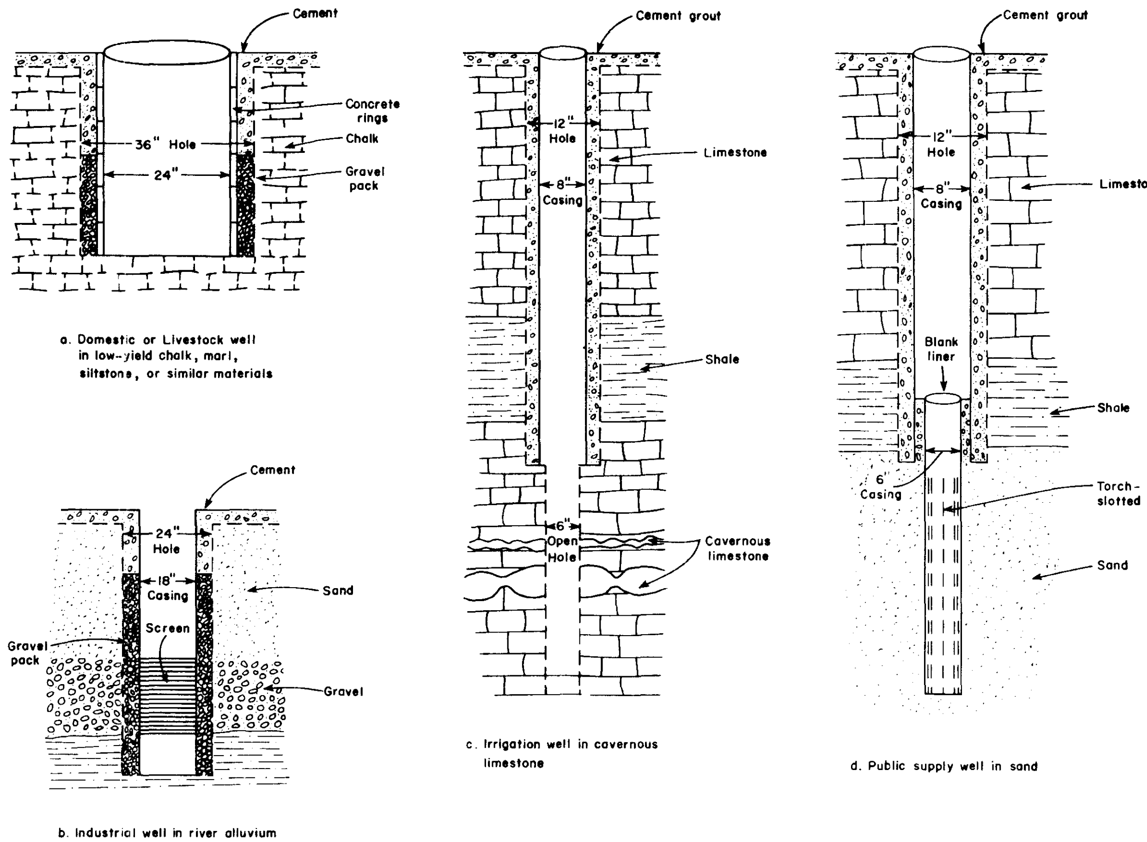

Figure 23.—Typical Construction of Water Wells

aquifer, and each of these should be completely screened. This permits higher specific capacity, reduced drawdowns, and greater yields. However, hard limestones, which are not likely to break down, do not require well screens. Most domestic and livestock wells in sand or gravel have slotted or perforated steel casing as a well screen. The slot width, length, and number per foot vary with the grain size of the aquifer. For the larger municipal, industrial, and irrigation wells, a manufactured well screen is preferable to slotted casing, since it permits much greater yields. Waters high in dissolved solids have an electrical conductivity high enough to cause serious electrolytic corrosion. The Hosston Member of the Travis Peak Formation usually has this problem. If corrosion is expected, the well screen slots should be made slightly narrower than normal to allow for enlargement. Waters which are high in carbonate, sulfate, or iron, such as those of the middle Trinity aquifer, may cause serious incrustation of well screens.

Examples of the use of a gravel pack in shallow wells are shown in Figures 23a and 23b. Gravel packing may be substituted for development of a well by removing the aquifer material adjacent to the well and replacing it with an artificially graded coarser material. In Travis County, gravel packs are used only rarely in deep wells such as those in the lower Trinity aquifer. Most commonly they are used in shallow wells in the alluvium and terrace deposits and the Navarro and Taylor Groups.

Cementing the annulus between the casing and the borehole, in the nonproductive intervals in the borehole, is an important step in optimum water-well construction. This well construction procedure is especially important where bad water zones exist above a usable water zone.

Without cementation, bad water is allowed to flow in the space between the casing and borehole and contaminates the usable water. Many water wells in Travis County are cemented only 20feet (6 m) at the top to prevent surface pollutants from entering the well.

Well-development tests should be continued as long as necessary. The well should be pumped at a reduced pumping rate to insure maximum production with minimum drawdown. Maximum pumping may leave some of the fine aquifer material bridged, thus only partially stabilizing the aquifer. Over-pumping seldom affords the best results of full stabilization of the aquifer. Acidizing is usually the most effective way of developing wells in limestone where the yield is inadequate. In cavernous or vugular limestone, often a large channel of water may lie only a few feet from a well and still be unavailable to it. In such cases, acid will often open up passages through which this water can reach the well. Acidizing is also very helpful in increasing the yield of sand aquifers such as the Hosston which contain much calcareous cementing material. Acid removes this cementing material, leaving the voids between the sand grains free to transmit water. Usually 1,000 to 3,000 gallons (3,785 to 11,355 liters) of 15 percent hydrochloric acid are necessary to adequately acidize a well.

Ground-Water Contamination

The only oil field which still reports brine production is the Elroy East field located in the southeast portion of Travis County. This brine is injected back into oil-bearing strata for pressure maintenance and secondary oil recovery. The only hydrologic units located in the oil-field areas are the Navarro and Taylor Groups and some small patches of high terrace gravel. Although the water from some wells in these areas shows unusually high chloride concentrations, such as well 58-45-205, there is no conclusive evidence of contamination of the ground water by oil-field brines.

In 1967, complaints of contamination were received from landowners using wells 58-43-901, 902, 904, and 915 through 923 near the City of Austin's Walnut Creek sewage treatment plant, about 5 miles east of Austin. The plant's oxidation ponds were located on the alluvium deposits. The results of a study showed the presence of coliform bacteria in nearly all of these wells. The Walnut Creek oxidation ponds are now being phased out. A new sewage treatment plant has been built at this location. It uses an electric sludge and filtration process without oxidation ponds. A number of years may be required to flush the contaminants from the alluvium deposits.

In Travis County, a large number of people live outside the city limits and use septic tanks for the disposal of household sewage. Most of the county is not suitable for the use of septic tanks because the surface soil is too rocky or clayey. Effluent which cannot be absorbed by the soil runs off. If it reaches sinkholes or faults which lead into the Edwards and associated limestones aquifer, pollution of the ground water could occur. Some landowners are reported to have drilled holes into the Edwards and other limestones to dispose of sewage effluent which cannot be absorbed by surface soils. However, studies conducted in the Rollingwood area in southwest Austin indicate that suburban development over the past 25 years has not resulted in detectable degradation of water quality in the Edwards aquifer.

The Austin-Travis County Health Department (1972), with assistance from the Texas Water Quality Board (now part of the Texas Department of Water Resources), prepared regulations for septic tank installation and operation. Generally, septic tanks must be 50 feet (15 m) downslope from a water well and absorption systems must be at least 150 feet (46 m) downslope from any water well.

Deterioration of the quality of native ground water may also occur by pollution from organic matter, commonly sewage, which may result in bacterial contamination and high concentrations of nitrates. Several water samples taken in Travis County showed a high concentration of nitrates. Concentrations of nitrate in excess of 45 mg/l have been known to cause infant cyanosis. Usually the contaminated wells are shallow, uncased or improperly cased, into which surface water can enter. Casing and cementing wells properly will help prevent this type of contamination.

Another contamination problem in Travis County involved the “magnesium plant” formerly located at the University of Texas Balcones Research Center, about 9 miles (14 km) north of downtown Austin. In 1943 and 1944, complaints were received which indicated that the effluent from the plant had contaminated water from wells in the area to the extent that the wells could no longer be used for domestic use. The water from some of the wells had been sampled prior to the time that the magnesium plant began operations. These wells were monitored during the period between 1943 and 1973. Increases in the calcium, sulfate, and chloride content in the waters were noted and recorded.

Fortunately, magnesium is not considered harmful for human consumption in concentrations less than 125 mg/l. In only one well, 58-35-704, did the concentration exceed this value. Unfortunately, the contaminated well has long since been destroyed, and recent water samples could not be obtained to determine if the contamination is still present.

In some cases, the chemical content of water from a well may vary depending on which aquifer is being sampled. For example, water from well 58-42-505 was sampled during drilling and after the well was completed. The first sample was taken from the lower member of the Glen Rose Formation which was high in sulfates and had a dissolved-solids content of 2,017 mg/l. The second sample was taken from the Hosston Member of the Travis Peak Formation with the water from the lower member of the Glen Rose Formation sealed off. The dissolved-solids content dropped to 861 mg/l. In other cases, poorer quality water may lie beneath better quality water as in wells 58-34-802 and 803. Samples taken from 58-34-802, at various depths, showed that the quality of water deteriorated from 3,249 mg/l in the lower member of the Glen Rose Formation to 4,663 mg/l in the Hosston Member of the Travis Peak Formation. In this case, well 58-34-803 was completed in the upper member of the Glen Rose and the quality of water improved to 466 mg/l.

AREAS FAVORABLE FOR POTENTIAL GROUND-WATER DEVELOPMENT

Areas within Travis County are classified for potential ground-water development from the different aquifers as shown in Figure 24. In selecting the various categories of favorability, consideration has been given to possible well yields, quality of water, and interference between wells because of aquifer characteristics.

Most favorable areas for additional development are the Edwards and associated limestones aquifer, located in the central portion of Travis County, and the alluvium deposits adjacent to the

Colorado River in the eastern half of the county. Large to very large yields can be expected in these areas. The water quality is fresh to slightly saline. The permeability of both aquifers is very high, particularly in the Kirschberg solution zone of the Edwards, and there is little interference between wells.

The Austin Chalk outcrops within the same area in which the Edwards is favorable for additional development. However, because of the small to very small well yields and very low permeability, the Austin would be less favorable for development.

Moderately favorable areas for additional development include the upper, middle, and lower Trinity aquifers located in the western half of the county. Well yields from the lower Trinity aquifer are small to moderate and the water is fresh to moderately saline in quality. Because of very low permeability, water-level drawdowns in wells are excessive and may cause interference between wells. The middle and upper Trinity aquifers generally have lower yields and permeabilities than the lower Trinity. The upper Trinity aquifer generally has better quality water, nearly always fresh In some parts of the moderately favorable areas, the Edwards and associated limestones aquifer is also present, but it is so thin that the well yields are small. In the Colorado River terrace deposits, well yields are very small to moderate. Permeabilities are high and interference between wells is not a problem. The water is fresh to moderately saline.

A less favorable area for additional development is located in the north-central portion of the county which includes the lower and middle Trinity aquifers. In this area, the quality of water in the lower and middle Trinity aquifers is slightly saline to moderately saline. Within this area, only the upper Trinity aquifer contains small quantities of fresh water.

Unfa vorable areas for additional development are west of the Sycamore Sand outcrop along the Pedernales River and Lake Travis in the southwest portion of Travis County and in the Navarro and Taylor Groups located in the eastern portion of the county. The outcrop area of the Sycamore Sand is not known to yield ground water in the county. The only other possible aquifer west of the outcrop would be the Marble Falls; however, it is not known to yield water in the county. The Taylor and Navarro Groups provide only very small well yields, have very low permeabilities, and frequently furnish only moderately saline water in the northeast part of the county. In this area, there is slightly saline water available in the lower Trinity aquifer, but the depth is so great that it would be very expensive to develop a well. Just north of New Sweden, the Austin Chalk yields small to very small amounts of good quality ground water.

RECOMMENDATIONS

At the present time, there are 31 observation wells in which water levels are measured annually by personnel of the Texas Department of Water Resources. These wells are representative of all the aquifers of the county. Ten additional Edwards aquifer wells within the county are measured monthly by the U.S. Geological Survey. These observation wells are measured in order to determine the long-term changes in water levels. Additional observation wells should be located in areas not presently covered, especially in areas where there has been a rapid rate of decline in the potentiometric surface. In addition to the annual measurements, a number of observation wells should be set up and measured monthly or quarterly to determine seasonal variations in water levels. At the present time, there is only one automatic water-level recorder, located in northwest Travis County (well 58-33-403). Additional recorders should be located in other aquifers, especially in suspected problem areas.

A network of water-quality observation wells also needs to be established. Water from all large-yield wells should be sampled when they are drilled and at regular intervals thereafter. Periodic sampling and analysis of the water from each of the major aquifers will enable detection of changes resulting from contamination and saline-water encroachment due to heavy pumpage.

The periodic collection of water-use information should be continued and expanded in order to improve the quality of data received. Geophysical logs should be run throughout Travis County in order to better define the hydrologic units.

Additional aquifer tests, using observation wells, are needed especially in the Trinity Group aquifer in order to refine information on the aquifer characteristics and capabilities.

Developing and utilizing ground water for maximum efficiency requires adequate planning. Some areas in Travis County have experienced water shortages and water-quality problems because of inadequate planning. Future development should be based on a program of test drilling, test pumping, and water-quality sampling from various producing intervals. Information obtained will determine the most efficient well completion method, pump settings, well spacing, and the feasibility of drilling additional wells.

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