Report 273

GROUND-WATER AVAILABILITY OF THE LOWER CRETACEOUS FORMATIONS IN THE HILL COUNTRY OF SOUTH-CENTRAL TEXAS

TEXAS DEPARTMENT OF WATER RESOURCES

January 1983

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By

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CONCLUSIONS

The Trinity Group aquifer is essentially the only ground-water source for all but the extreme updip, northern portion of the study region and is divided, in ascending order, into the lower, middle, and upper aquifer units.

The lower Trinity aquifer, which includes the Hosston Sand and Sligo Limestone Members of the Travis Peak Formation, yields small to large quantities of ground water. The quality is good in the Kerrville to Bandera area but becomes slightly more saline throughout the remainder of the study area. The water is utilized for municipal purposes in Kerrville and Bandera and for irrigation in a few other localities. Because of its depth and poor quality, overall development of the lower Trinity aquifer has been minimal. The lower Trinity is not present in Gillespie and portions of Blanco and Kerr Counties.

The middle Trinity aquifer is comprised of the Cow Creek Limestone, Hensell Sand, the lower member of the Glen Rose Limestone, and is the most widely utilized of the three aquifer units. The middle Trinity aquifer yields small to moderate quantities of fresh to slightly saline water throughout the study region.

The upper Trinity aquifer produces water from the upper member of the Glen Rose Limestone. Yields are generally very small due to the low porosity and permeability of the limestone, and the chemical quality is normally poor because of the presence of evaporite beds. This unit is utilized only for limited domestic and livestock purposes.

Chemical quality of water in the Trinity Group aquifer is variable. Water acceptable for human consumption, although very hard, is available over most of the study region. Poor quality of water in the Trinity is usually due to excessive concentrations of sulfate and chloride. High concentrations of iron, nitrate, and fluoride are also common problems. The dissolved-solids content generally increases downdip toward the south and southeast. There had been no widespread pollution of the aquifer in the study region although local problems do exist. The chemical quality of the water produced from a well can often be improved by properly casing off zones of undesirable water. The yield and life expectancy of a well can likewise be improved by utilizing proper well completion and development procedures.

Although approximately 200,000 acre-feet (247 hm^3) of rainfall is estimated to be available as recharge to the aquifer annually, much of this recharge is lost by natural rejection, principally to springs. During dry periods, recharge is limited and water levels decline. Also, continuous heavy pumpage results in rapid water-level declines due to the aquifer's rather low capability to transmit water. Therefore, moderate to severe water-level declines can be expected over a major part of the study region where both drought and heavy concentrated pumpage occur.

INTRODUCTION

Purpose and Scope

The ground-water study of the Lower Cretaceous formations in south-central Texas, commonly referred to as the Hill Country, was conducted during the period from December 1974 to October 1978. The primary purpose of the study was to describe the hydrologic characteristics of the Trinity Group, which includes the Glen Rose Formation and the Hensell Sand, Bexar Shale, Cow Creek Limestone, Hammett Shale, Sligo Limestone, and Hosston Sand Members of the Travis Peak Formation.

Principal objectives of the investigation included: (a) collection and evaluation of previously compiled geologic and hydrologic data; (b) determination of the quantity and quality of the available ground waters on a regional basis; (c) determination of the hydrological characteristics of the various formations; (d) determination of hydrologic connections between formations; (e) determination of the annual amount of recharge and discharge of the aquifers; and (f) the initiation of a continuing ground-water quality monitoring program.

For the purpose of this report, hydrologic: data were gathered primarily from high-capacity wells which include public supply, industrial, and irrigation wells. Also an attempt was made to inventory all perennial springs.

Location and Extent

The area of investigation includes the southern edge of the Edwards Plateau and extends southeastward into the Balcones fault zone. It includes all or parts of the following 11 counties: Bandera, Bexar, Blanco, Comal, Gillespie, Hays, Kendall, Kerr, Medina, Real, and Uvalde. The study area is within -the drainage basins of the Guadalupe, San Antonio, Nueces, and Colorado Rivers and covers approximately 5,800 square miles (15,000 km^2). The study region is shown on Figure 1.

Geography

Topography and Drainage

The land surface in the study region is characterized by a rough and rolling terrain. The nearly flat-lying, erosion-resistive limestone rocks forming the surface of the Edwards Plateau have been deeply incised into the less resistive, marly limestone rocks of the Glen Rose Formation. Wermund (1974) describes three different terrains in the study region:

> "Along the West Nueces and Nueces Rivers, most of the terrain consists of broad divides. Along the Dry Frio, Frio, and Sabinal Rivers, the terrain comprises both highly dissected divides and incised stream valleys. About the Medina and Guadalupe Rivers, most terrain lies in broad valleys and less occupies narrow divides."

Elevations range from a maximum of 2,400 feet (730 ml above mean sea level in the northwest Plateau region to a minimum of 780 feet (240 m) in the drainage basins in the east.

Four major drainage basins occupy the study region. Drainage in the Nueces River basin is to the south. In the San Antonio River basin, drainage is to the southeast. And in the Guadalupe and Colorado River basins the drainage is to the east. The larger rivers are dominantly effluent and form wide valleys. The smaller creeks and streams are characterized by two dominant types: the perennial spring-fed streams, and the intermittent creeks that only transport precipitation runoff. Many of the-streams revert underground when encountering cavernous zones or areas of gravel accumulation and later resurface as gravity springs. Most of these streams that are perennial in their lower reaches are diverted underground where they cross the Balcones fault zone. Most of this water is probably captured in the down-faulted Edwards Formation.

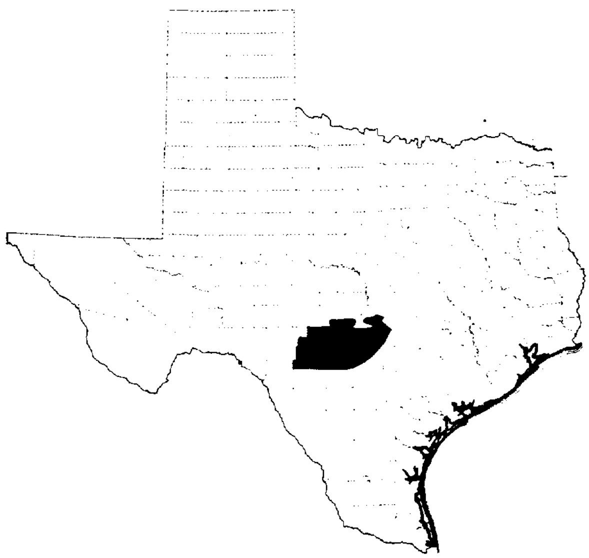

Figure l.-Location of Study Region

Population

Based on studies conducted by the Department's Economics, Water Requirements and Uses Section, the 1970 population of this area is estimated to be slightly over 67,000 and it is projected to be over 100,000 by the year 2020. Most of the population resides on rural farms and ranches although several tow-ns and residential developments are showing rapid growth. Some of the larger population centers are the cities of Bandera, Blanco, Boerne, Comfort, Fredericksburg, Kerrville, Leakey, Wimberly, and the area surrounding Canyon Lake.

Economy and Land Use

The economy of this area is based prirnarily on the raising of cattle, sheep, and goats. Because of the ruggedness and beauty of the area, much of the land is being used for recreational purposes such as hunting leases, public parks, private camps, weekend resorts, and retirement areas. Numerous large tracts of land in the more scenic areas are being subdivided for resrdential development.

Farming is predominantly limited to the growing of grass and feed crops in the stream valleys. Because of the limited supply of ground water and the rising cost of fuel, there is very little irrigation in the area although trickle irrigation systems are gaining popularity for watering orchards.

Minor incomes are derived from the cutting of cedar posts and the quarrying of building stone.

Vegetation

A variety of vegetation inhabits the study region. Prairie grasses and stands of Live and Spanish Oak grow on the karstic surface of the upper plateau. “Cedar” (scrub Juniper) and Live Oak are prominent in the marly dissected region. Lining the banks of the creeks and rivers are Cypress trees while the terraces support growths of Live and Post Oak, “Cedar”, Elm, Hackberry, Cottonwood, Sycamore, and Willow. Varieties of natural grasses include Little Bluestem, Indian Grass, Sideoats Grama, and Texas Winter Grass. The most common introduced grasses include Coastal Bermuda, Plains Lovegrass, Kte in Grass, and King Ranch Bluestem (Cuyler, 1931).

A number of studies have shown that grasses utilize one-third to one-half as much water as trees and shrubs. Trees, such as the “Cedar” or Juniper, are especially inefficient water users. Several residents of the Hill Country have indicated that creeks and springs on their property have increased in flow since they converted their land from tree growth to grass.

Climate

A subhumid to semiarid climate prevails throughout the study area. The average annual precipitation ranges from 35 inches (89 cm) in the east to 25 inches (64 cm) in the west. During the drought period from 1950 to 1956, the average annual precipitation was about 22 inches (56 cm). Measurements by the National Weather Service of average annual precipitation during the 30-year period 1931 to 1960 are illustrated on Figure 2 along with average monthly precipitation for periods of record at selected stations.

The average monthly temperature for the period 1905 to 1973 ranged from a minimum of 33°F (1°C) in January in the northwest to a maximum of 96°F (36°C) in July throughout most of the study region. The annual mean temperature for the period 1931 to 1960 ranged from 65°F (18°C) in the northwest to 68°F (2O°C) in the south and east (Carr, 1967).

The average annual gross lake-surface evaporation for the period 1940 to 1965 ranged from 73 inches (185 cm) in the northwest to 65 inches (165 cm) in the southeast (Kane, 1967), or more than twice the average annual precipitation.

Previous Investigations

Ground-water investigations have been conducted in all but Gillespie County in the study region by personnel of the U.S. Geological Survey in cooperation with the Texas; Department of Water Resources. A portion of Gillespie County around the city of Fredericksburg was discussed in a memorandum report by the Texas Department of Water Resources.

A number of local water-availability studies have been made by private consulting firms at the request of municipalities.

Principal regional stratigraphic studies include: (a) Hill (1901); (b) Imlay (1945); (c) Barnes (1948); (d) Lozo and Stricklin (1956); and (e) Stricklin, Smith, and Lozo (1971).

The geologic map was adapted from the San Antonio, Seguin, and Austin Geologic Atlas sheets; geologic quadrangle maps for parts of Gillespie and Blanco Counties; and the Geologic Map of Eastern Edwards Plateau (Rose, 1972). All were published by the University of Texas Bureau of Economic Geology.

Acknowledgements

The author appreciates the cooperation of the property owners within the study region for supplying information concerning their wells and allowing access to their property and use of their wells to measure water levels and sample for water quality. Appreciation is also extended to the water well drillers, city officials, water superintendents, and consultants for information, assistance, and cooperation rendered throughout this investigation. The cooperation of Federal and other State agencies, especially the State Department of Highways and Public Transportation, is also gratefully acknowledged.

This report was prepared under the general direction of C. R. Baskin, director of the Department's Data and Engineering Services Division, and Tommy R. Knowles, Chief of the Data Collection and Evaluation Section.

Well-Numbering System

The well-numbering system in this report, illustrated on Figure 3, was adopted by the Texas Department of Water Resources for statewide use. It was designed to identify, facilitate the location of, and avoid duplication of well numbers in present and future studies. The system is based upon the division of the State into quadrangles of latitude and longitude and the repeated division of these quadrangles into smaller ones.

The State is first divided into one-degree quadrangles which are numbered 01 through 89. Each

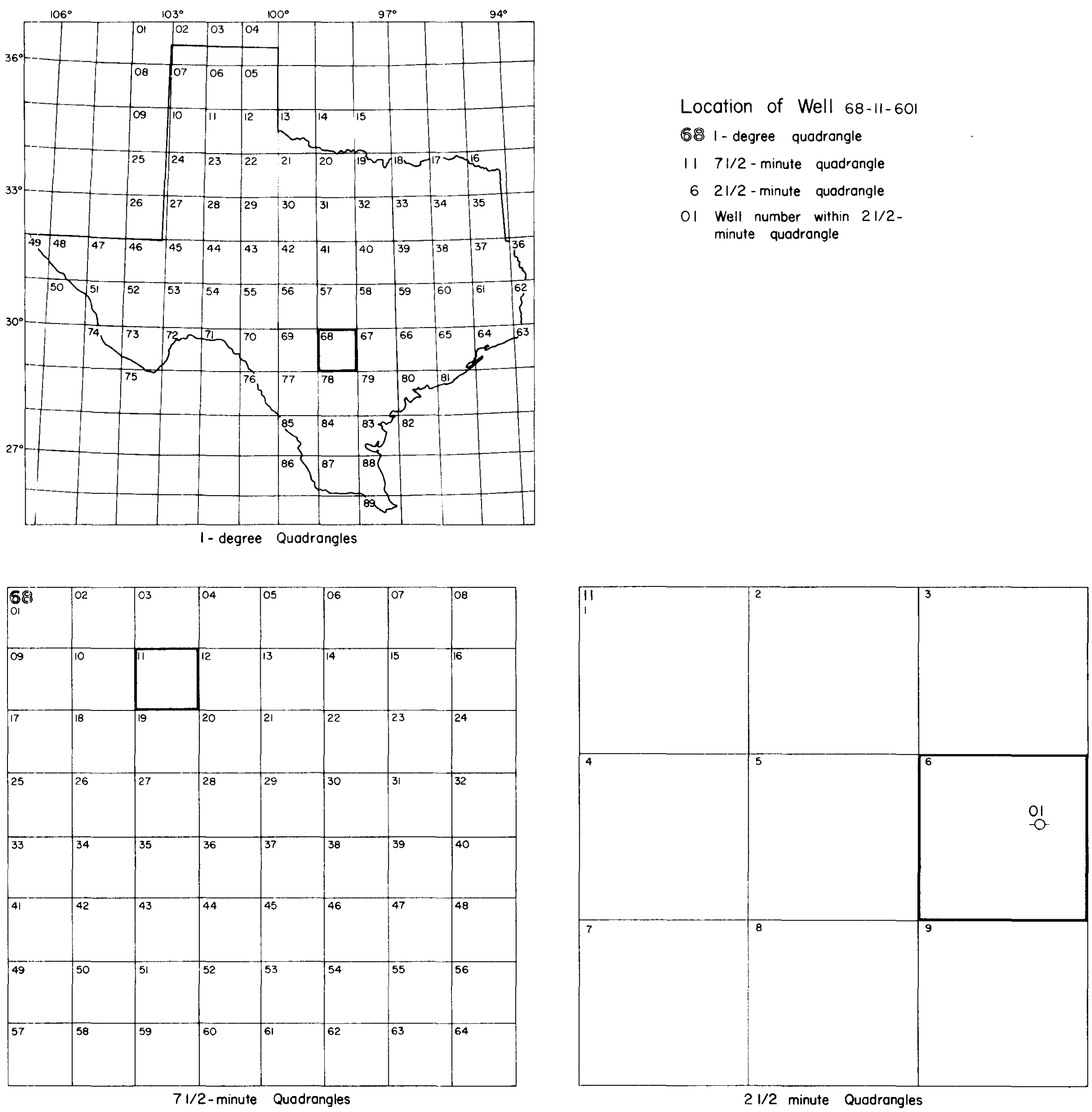

Figure 3.—Well-Numbering System

one-degree quadrangle is then subdivided into sixty-four 7½-minute quadrangles. And lastly, each 7½-minute quadrangle is subdivided into nine 2½-minute quadrangles. Within each 2½-minute quadrangle, each well is assigned a two-digit number in the sequence inventoried, beginning with 01; these are the last two digits of the well number.

Each well or spring is assigned a seven-digit number. The first two digits of a well number identify the one-degree quadrangle in which the well or spring is located. The second two digits identify the 7½-minute quadrangle. The fifth digit identifies the 2½-minute quadrangle and the sixth and seventh digits identify the particular well within the 2½-minute quadrangle.

In addition to the seven-digit number, a two-letter prefix is used to identify the county. The prefixes for the 11 counties covered by this report are:

Prefix	County
AS	Bandera
AY	Bexar
AZ	Blanco
DX	Comal
KK	Gillespie
LR	Hays
RB	Kendall
RJ	Kerr
TD	Medina
WA	Real
YP	Uvalde

Definition of Terms

This section is intended to acquaint the reader with some of the terms used in this report. Many of these definitions were selected from previous reports and from the "Glossary of Geology and Related Sciences" prepared by the American Geological Institute (1957).

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

Aquifer test, pumping test—The test consists of the measurement at specific intervals of the discharge and water level of the well being pumped and the water levels in nearby observation wells. Formulas have been developed to show the relationship among the yield of a well, the shape and the extent of the cone of depression, and the properties of the aquifer such as the specific yield, porosity, and the coefficients of permeability, transmissibility, and storage.

Artesian aquifer, confined aquifer—Artesian (confined) water occurs where an aquifer is overlain by rock of lower permeability (such as clay) that confines the water under pressure greater than atmospheric. The water level in an artesian well will rise above the top of the aquifer even without pumping.

Coefficient of storage—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.

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 extending the vertical thickness of the aquifer when the hydraulic gradient is 1 foot per foot. It is the product of the field coefficient of permeability and the saturated thickness of the aquifer.

Cone of depression—Depression of the water table or potentiometric surface surrounding a discharging well, more or less in the shape of an inverted cone.

Electric log—A graph log showing the relation of the electrical properties of the rocks and their fluid contents penetrated in a well. The electrical properties are natural potentials and resistivities to induced electrical currents, some of which are modified by the presence of the drilling mud.

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

Hydraulic gradient—The slope of the water table or potentiometric surface, usually given in feet per mile.

Outcrop—That part of a rock layer which appears at the land surface.

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

Permeability of an aquifer—The capacity of an aquifer for transmitting water under pressure.

Porosity—The ratio of the aggregate volume of interstices (openings) in a rock or soil to its total volume, usually stated as a percentage.

Potentiometric surface—An imaginary surface that everywhere coincides with the static level of the water in the aquifer. The surface to which the water from a given aquifer will rise under its full head.

Recharge of ground water-The process by which water is absorbed and is added to the zone of saturation. Also used to designate the quantity of water that is added to the zone of saturation, usually given in acre-feet per year or in million gallons per day.

Secondary porosity-Porosity developed after the formation of a rock deposit and resulting from subsequent fracturing, replacement, solution, or weathering.

Water level-Depth to water, in feet below the land surface, where the water occurs under water-table conditions (or depth to the top of the zone of saturation). Under artesian conditions the water level is a measure of the pressure in the aquifer, and the water level may be at, below, or above the land surface.

Water-table aquifer (unconfined aquifer)-An aquifer in which the water is unconfined; the upper surface of the zone of saturation is under atmospheric pressure only snd the water is free to rise or fall in response to the changes in the volume of water in storage. A well penetrating an aquifer under water-table conditions becomes filled with water to the level of the water table.

Yield of a well-The rate of discharge, commonly expressed as gallons per minute, gallons per day, or gallons per hour.

Metric Conversions

For those readers interested in using the metric system, metric equivalents of English units of measurement are given in parentheses. The English units used in this report may be converted to metric units by the following conversion factors:

From	Multiply by	To obtain
inches (in)	2.54	centimeters (cm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
feet per mile (ft/mi)	.189	meters per kilometer (m/km)
square miles (mi^2)	2.590	square kilometers (km^2)
acre-feet (acre-ft)	.001233	cubic hectometers (hm^3)

From	Multipl	obtain
gallons (gal)	3.785	liters (l)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
gallons per minute (gal/min)	.06309	liters per second (l/s)
gallons per day (gal/d)	3.785	liters per day (l/d)
gallons per day per foot [(gal/d)/ft]	12.418	liters per day per meter ((l/d)/ml
gallons per day per square foot [$(gal/d)/ft^2$]	40.74	liters per day per square meter [$(l/d)/m^2$]

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

$$^\circ C = (^\circ F - 32)(0.556)$$

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

Depositional History

At the beginning of the Cretaceous Period, the topography in the study region was characterized by an eroded, uneven, faulted surface known as the Comanche Shelf that sloped to the south and southeast away from the uplifted Llano area. The sea transgressed inland from the southeast during Cretaceous time, with occasional interruptions by short regressive periods. During deposition of the Trinity Group, the earliest set of Cretaceous rocks present, the Llano uplift remained the primary contributor of land-derived sediments. The resulting Trinity Group sediments form a wedge-like, overlapping sequence that thickens seaward and pinches out against the slope of the Llano uplift. Subsequently, during depositions of lower Glen Rose sediments, a laterally extensive reef complex known as the Stuart City Trend formed on the edge of the shelf south and east of the study area (Bebout and Loucks, 1974). This reef trend existed until late Cretaceous time and formed an energy barrier and sediment catchment basin with water depths remaining relatively shallow in the back reef zone.

Stratigraphy

The Trinity Group of Cretaceous age is the most important water-bearing unit in the st region. It overlies rocks of Paleozoic age and is overlain in a portion of the study region by younger rocks of the Fredericksburg Group of Cretaceous age. The Trinity Group is divided into the following formations in order from the oldest to youngest: Travis Peak and the Glen Rose. The Travis Peak Formation is subdivided into the following members in order from oldest to youngest: Hosston Sand, Sligo Limestone, Hammett Shale, Cow Creek Limestone, and Bexar Shale and Hensell Sand. These strata within the Trinity Group will be discussed in detail in the section covering the stratigraphy of the water-bearing units. The stratigraphic units and their water-bearing properties are summarized in Table 1.

Structure

The study region, locally known as the South-Central Texas Hill Country, is bounded on the north by the Llano uplift, on the south and east by the Balcones fault zone, and on the northwest by the Edwards Plateau. Geologic structures affecting ground water within the study area include the regional dip, the Balcones fault system, the Llano uplift, the San Marcos arch, and the uneven pre-Cretaceous surface. The regional structural trends are shown in Figure 4.

The dip of the formations in the western half of the study region is to the south and increases from about 10 to 15 feet per mile (1.9 to 2.8 m/km) in updip areas to about 100 feet per mile (19 m/km) or more downdip near the Balcones fault zone. The regional dip in the eastern half of the study area is to the east and southeast at the same approximate rate of dip. Although the general subsurface water flow will be in the direction of the regional dip, the direction of flow in any local area may be determined by local anomalies and heavy pumpage.

The Balcones fault zone forms the southern and eastern boundary of the study region (Figure 4). The zone is comprised of numerous, more or less parallel, mostly normal faults, some having individually as much as 600 feet (180 m) of displacement although 200 to 300 feet (60 to 90 m) of displacement is more common among the major faults. Some faults act as ground-water barriers and thus deflect the flow in the direction of the fault strike. George (1952) observed in one fault that the level of water in the Glen Rose Formation on the northwest, upthrown side of the fault was higher than the level of the water in the Edwards Formation on the opposite, downthrown side of the fault. Also, water qualities often differ on opposing sides of the rnajor faults. Other observations indicate that at least the upper portion of the faults may transmit water. This is indicated by the observation of some streams that are diverted underground when crossing the fault plane, particularly where the Glen Rose Formation is in contact with the Edwards Formation. The fault planes are possible passageways for surface contamination as well as recharge water to enter an aquifer. Contamination may also occur from subsurface sources if undesirable saline water enters the fault plane. In addition to major faulting along the Balcones fault zone, numerous northeast-trending faults occur throughout the study area. These faults are laterally discontinuous with small displacement and have only small local effect on ground water.

The Llano uplift is a structural dome of igneous and metamorphic rocks located north of the study region. This dome was a source area for the terrigenous. sediments of the Hosston and Hensell Sands.

The San Marcos arch or platform as described by Adkins (1933) is a broad anticlinal extension of the Llano uplift whose axis plunges southeastward through the city of San Marcos in Hays County. The anticline is evidenced by an increased altitude of the tops of the formations and a thinning of the formations across the axis (Figure 7). Other, less substantial folded trends can be delineated in the study area. The presence of a subsurface high would generally cause a restriction of ground water movement.

The uneven surface upon which the Hosston Sand Member of the Travis Peak Formation was deposited was a result of the faulting and erosion of pre-Cretaceous marine sediments. The Hosston sediments filled the valleys and covered the ridges producing a geologic unit of variable thickness which influences the occurrence and movement of ground water in the unit. The approximate altitude of and depth to the base of the Cretaceous rocks are shown on Figure 8.

Caverns formed by the solution of limestone and evaporites by ground water are common in the Trinity formations, particularly in the Glen Rose Limestone. These caverns are characteristically influenced by the jointing structure of the limestone and may extend both vertically and laterally for great distances and provide major conduits for the flow of ground water. When caverns grow to such a size as to no longer support their overburden, they collapse thus forming sinkholes that are visible from the surface as circular depressions that may transmit large quantities of surface water to a passage below ground. Sinkholes are a common occurrence in streambeds flowing over the Glen Rose Limestone and provide a passageway for a substantial amount of recharge to the aquifer.

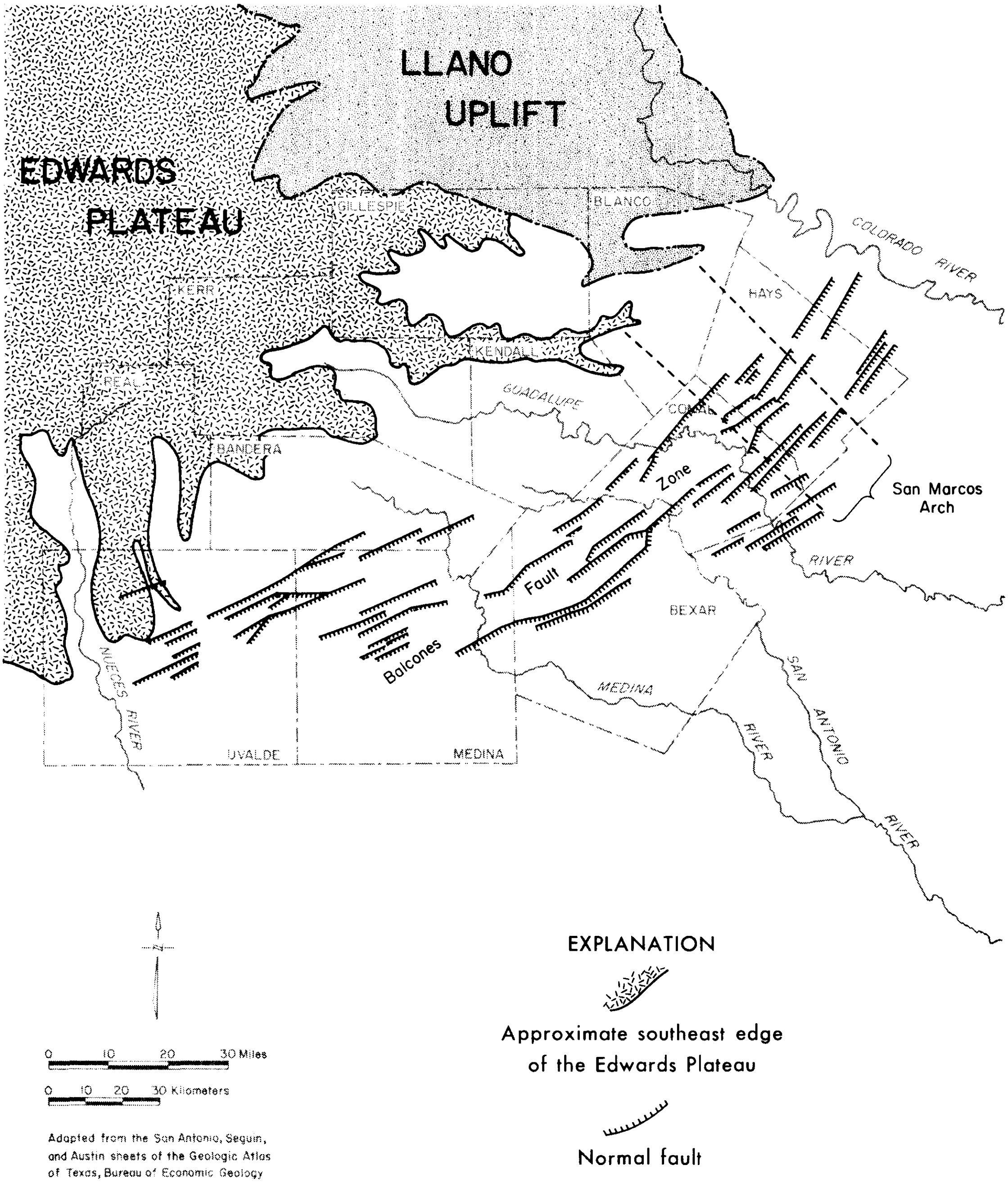

Figure 4

Regional Structural Trends

Table 1.—Stratigraphic 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 and Pleistocene		Flood plain, terrace, and fan alluvium	Alluvium	50	Gravel, sand, silt, clay, caliche.	Yields small quantities of fresh water.
Cretaceous	Comanche	Fredericksburg	Edwards Limestone	Edwards and associated limestones	500	Hard, massive, cherty limestone.	Yields small to moderate quantities of fresh water in the northwestern portion of the study area.
			Comanche Peak Limestone		60	Marly, nodular limestone.	
			Walnut Clay		15	Marly clay and shale aggregate.	Not known to yield water.
		Trinity	Glen Rose Limestone: upper member	Upper Trinity	500	Alternating resistant and nonresistant beds of blue shale, nodular marl, and impure, fossiliferous limestone. Also contains two distinct evaporite zones.	Yields very small to small quantities of relatively highly mineralized water.
			Glen Rose Limestone: lower member	Middle Trinity	320	Massive, fossiliferous limestone grading upward into thin beds of limestone, dolomite, marl, and shale. Numerous caves and reefs occur in the lower portion of the member.	Yields small to moderate quantities of fresh to slightly saline water.
			Travis Peak Formation: Hensell Sand Member / Bexar Shale Member		300	Red to gray clay, silt, sand, conglomerate, and thin limestone beds grading downdip into silty dolomite, marl, calcareous shale, and shaley limestone.	
			Travis Peak Formation: Cow Creek Limestone Member		90	Massive, fossiliferous, white to gray, argillaceous to dolomitic limestone with local thinly bedded layers of sand, shale, and lignite.	
			Travis Peak Formation: Hammett Shale Member		80	Dark blue to gray, fossiliferous, calcareous and dolomitic shale with thinly interbedded layers of limestone and sand.	Not known to yield water.
			Travis Peak Formation: Sligo Limestone Member	Lower Trinity	120	Sandy dolomitic limestone.	Yields small to large quantities of fresh to slightly saline water.
			Travis Peak Formation: Hosston Sand Member		350	Red and white conglomerate, sandstone, claystone, shale, dolomite, and limestone.	
Pre-Cretaceous rocks						Black, red, and green, folded shale, hard massive dolomite, limestone, sandstone, and slate.	Yield moderate quantities of fresh water in the northern portion of the study area.

STRATIGRAPHY OF THE WATER-BEARING UNITS

In the description of the vvater-bearing properties of the geologic units, yields of wells are described according to the following ratings:

Description	Yield (gallons per minute)
Very Small	0- 5
Small	5- 20
Moderate	20- 100
Large	More than 100

Pre-Cretaceous Rocks

Pre-Cretaceous rocks are exposed in the study area only along or north of the Pedernales River in Gillespie and Blanco Counties (Figure 5). These formations provide usable water in the vicinity of the outcrop area. It is possible that fresh to slightly saline water might be obtained from these formations in the northern one-third of the study area.

The Ellenburger, San Saba, and Hickory aquifers are the primary Paleozoic wetter-producing units. The aquifers include the San Saba Limestone Member of the Wilberns Formation and the Hickory Sandstone Member of the Riley Formation, both of Cambrian age, and the Ellenburger Group of Ordovician age. These aquifers yield small to large quantities of fresh to slightly saline water to wells in the Fredericksburg and Johnson City area.

Trinity Group

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

Lower Trinity Aquifers

The Hosston Sand Member of the Travis Peak Formation is the oldest Cretaceous rock unit in the study area and overlies Paleozoic rocks. Imlay (1945) correlates the Hosston Sand and the overlying Sligo Limestone with the Durango and Nuevo Leon Groups of the Coahuila Series of Mexico. Local drillers often refer to the Hosston as the “lower Trinity” or “second sand”.

The Hosston and its surface equivalent, the Sycamore Sand, form a wedge of alluvial sediments deposited by aggrading streams on an uneven surface. Updip the unit consists predominantly of terrigenous clastics comprised of red and white conglomerate, sandstone, and claystone with the main constituent being a quartz sand. Downdip it becomes increasingly more dolomitic and shaly. Thin conglomeritic zones, near the base, persist through the downdip limit of the study area.

The thickness of the Hosston varies because of the uneven surface upon which it was deposited. At its updip limit, a portion of the Hosston or Sycamore has been eroded to form a disconformable surface upon which the Hammett Shale was deposited. Downdip the Hosston grades upward into the Sligo Limestone.

While the Hosston Sand Member of the Travis Peak Formation represents continental deposition, the Sligo Limestone Member was contemporaneously laid down in transgressive shallow marine waters.

The Sligo exists downdip where the Hosston grades upward into a sandy dolomitic limestone. The Sligo pinches out in the subsurface approximately along a line as shown in Figure 9. The Hosston and Sligo thicken south and southeast (Figure IO) to as much as 500 feet (150 m) near the Balcones fault zone. The approximate altitude of and depth to the top of the lower Trinity aquifer is shown on Figure 9.

Middle Trinity Aquifer

The Hammett Shale or its outcrop equivalent, the Pine Island Shale, is the result of the second transgressive marine phase which covered the Sligo and the updip eroded surface of the Hosston with shaly marine sediments. The Hammett is composed predominantly of dark blue to gray, fossiliferous, calcareous and dolomitic shale with thinly interbedded layers of limestone and sand. The unit pinches out in the northern portion of the study area and thickens downdip to approximately 80 feet (24 m). It consists of a heaving shale that caves in a newly drilled well and must be cased off if further depth is desired. The unit is impermeable, thus confining the water in the underlying strata and serving as a hydrologic barrier between the lower and middle Trinity aquifers with the possible exception of leakage where faulting occurs.

The Cow Creek Limestone overlies the marine Hammett Shale and represents a seaward growth of the shoreline. Structural features within the Cow Creek indicate that the limestone was deposited in a beach or near-shore environment. The approximate altitude of and depth to the top of the Cow Creek are shown on Figure 11.

The Cow Creek is a massive, fossiliferous, white to gray, shaly to dolomitic limestone composed of a fine to medium grained calcarenite with local thinly bedded layers of sand, shale, and lignite. It forms steep overhanging bluffs and cliffs where it crops out along the Pedernales, Blanco, and Guadalupe Rivers in the eastern part of the study area. The unit is often honeycombed in the outcrop. The Cow Creek attains a maximum thickness of approximately 90 feet (27 m) downdip, although 50 to 60 feet (15 to 18 m) is average over most of the area. Updip it thins to approximately 20 feet (6 m) before it becomes indistinguishable by grading into sand and shale (Figure 6). The updip portion of the Cow Creek has been eroded to form a disconformable surface for the deposition of Hensell sand. This disconformity disappears midway through the study area in the downdip direction.

The Cow Creek yields small to moderate amounts of fresh to slightly saline water.

The Hensell Sand Member of the Travis Peak Formatior. is a time-transgressive unit that consists of alluvial and near-shore sediments deposited as the sea transgressed across the eroded Cow Creek, and is time-equivalent to the Glen Rose Limestone that was being deposited offshore.

The Hensell consists of both continental and marine deposits. Updip, in the outcrop along the Pedernales River, the Hensell (Gillespie Formation of Hill and Vaughan, 1898) is composed of thick continental deposits of red clay, silt, sand, and conglomerate with limestone beds in the subsurface, and rests on highly faulted pre-Cretaceous rocks. In the outcrop, the Hensell breaks down to a loose sand due to lack of induration and forms gentle slopes. The unit becomes gray and less sandy as it grades upward into the lower Glen Rose. Farther downdip past the pre-Hensell disconformity, the Hensell grades into marine deposits of silty dolomite, marl, calcareous shale, and shaly limestone (Figure 6). This zone is designated as the Bexar Shale (Forgotson, 1956).

The thickness of the Hensell varies considerably because of the nature of its upper gradational boundary with the Glen Rose and the uneven erosional surface on which it was deposited. A maximum thickness of 300 feet (91 m) is reported by Mount (1963) in Gillespie County. In northern Gillespie County, the Hensell a buts abruptly with pre-Cretaceous rocks of the Llano uplift. In general, the Hensell thins by interf ingering into the Glen Rose in a downdip direction from an average 150 feet (46 m) to 80 feet (24 m). This aquifer is often referred to locally as the “first Trinity” or the “upper Trinity” sand. The approximate altitude of and depth to the top of the Hensell Sand are shown on Figure 12.

The Glen Rose Limestone is the uppermost formation of the Trinity Group and is exposed over approximately three-fourths of the study region (Figure 5). The Glen Rose along with the Hensell Sand represents a wedge of sediments deposited in a transgressing sea. In Comal County, George (1952) separated the Glen Rose into upper and lower members. The boundary between the two members is identified by a thin l imestone bed containing numerous fossils of *Corbula martinae* (Whitney, 1952) that persists throughout the study area except where erosion has lowered the land surface below the bed.

The lower member of the Glen Rose Limestone consists of a massive, fossiliferous limestone at the base grading upward into thin beds of limestone, dolomite, marl, and shale. The top 15 to 20 feet (5 to 6 m) of the lower member, designated the *Salenia texana* zone, is a highly fossiliferous, nodular marl and limestone which is capped by the “Corbula bed.” The member has a maximum thickness of approximately 320 feet (98 m) in the southern part of the study area and thins updip by grading laterally into the underlying Hensell Sand.

Rudist and coral reefs are characteristic of the basal massive section. A number of reefs exposed in the study area have been described by Perkins (1968, 1970) and Stricklin, Smith, and Lozo (1971). The reefs consist of two basic types: the small, circular to slightly elongate mounds or patch reefs are less than 75 feet (23 m) in diameter and 30 feet (9 m) in thickness; the second type is the less numerous but more extensive tabular reef. The full dimensions of these reefs have not been determined but are on the magnitude of several hundred feet laterally by 50 feet (15 m) in thickness. A number of wells have been drilled through material that has been described as reef rock. The majority of the reefs are composed of rudists and only a few are composed of coral with *Montastrea* being the predominant type. Some of the reefs show a high degree of porosity due to the dissolving of the original shell material and leaving a cavity; however, unless the zone has become fractured the permeability remains low.

Because the lower member of the Glen Rose is massive, it is more susceptible than the upper member to the development of secondary porosity which results from jointing, faulting, and the dissolving action of ground water, and hence is generally the more prolific water-producing zone. The zone is hydrologically connected to the underlying Hensell Member. Figure 13 shows the approximate a l titude of and depth to the top of the lower member of the Glen Rose Limestone, which is the top of the middle Trinity aquifer. Total thickness of the middle Trinity is shown on Figure 14.

Upper Trinity Aquifer

The upper member of the Glen Rose Limestone consists of laterally continuous, alternating resistant and nonresistant beds of blue shale, nodular marl, and impure, fossiliferous limestone. The uneven resistance to erosion by the alternating beds results in the characteristic “stairstep” topography. The upper member thins updip from a maximum thickness of approximately 450 feet (137 m). In the northern portion of the study region where the lower member has pinched out, the upper member thins rapidly by grading laterally into the underlying Hensell Sand. The Glen Rose Limestone pinches out just north of the Pedernales River (Figure 6).

Two evaporite zones occur within the upper member. The first zone occurs at the base and because of its high resistivity curve on electric logs, it serves as a convenient correlation marker between the upper and lower members. The second evaporite zone is located near the middle of the member and has the same characteristics. At the outcrop and within the zone above the water table, the evaporite has been leached out, resulting in slumping and distortion of the overlying rocks.

Fredericksburg Group

The Fredericksburg Group, which forms the caprock of the Edwards Plateau, overlies the Trinity Group deposits at the upper elevations to the north and west of the study area and to the south and east where it has been downfaulted along the Balcones fault zone (Figure 5). Many of the higher hilltops are capped by the resistant limestone. The group is composed of, in ascending order, the Walnut Clay, Comache Peak Limestone, and the Edwards Limestone (Table 1).

The Fredericksburg Group yields small to moderate amounts of fresh water to wells primarily in the sparsely populated northwestern portion of the study area. Many springs of very good chemical quality issue from near the base of the group throughout its extent in the study area.

Quaternary Alluvium

Alluvial deposits ranging in age from Pleistocene to Recent occur predominantly within stream valleys and consist of flood-plain, terrace, and alluvial fan deposits. The material is derived from locally eroded limestone and forms longitudinal or fan-shaped beds of gravel, sand, silt, and clay, often cemented by calcium carbonate. The beds are highly permeable, have a lovv dip, a maximum thickness of approximately 50 feet (15 m), small areal extent, and yield only small amounts of good quality water.

CHEMICAL QUALITY OF GROUND WATER AS RELATED TO USE

General Chemical Quality of Ground Water

All ground water contains minerals carried in solution, the type and concentration of which depend upon the environment, movement, and source of the ground water. Rainfall is relatively free of minerals until it comes in contact with the various constituents which make up the soils and component rocks of the aquifer; then, as a result of the solvent power of water, minerals are dissolved and carried into solution as the water passes through the aquifer. The concentration depends upon the solubility of the minerals present, the length of time the water is in contact with the rocks, and the amount of dissolved carbon dioxide in the water. In addition, concentrations of dissolved minerals in ground water generally increase with depth and especially increase where circulation has been restricted due to faulting or zones of lower permeability. Restricted circulation retards the flushing action of fresh water moving through the aquifers, causing the water to become highly mineralized.

The source and significance of dissolved mineral constituents and properties of natural waters are given in Table 2. Chemical analyses of water from selected wells and springs in the study region are given in Table 6. The sampled wells and springs are indicated on the county well-location maps by a bar over the well number. Concentrations of sulfate, chloride, and total dissolved solids from samples taken from selected wells and springs in the study region are also shown on Figure 15.

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, including color, taste, odor, turbidity, and temperature; and the chemical constituents. Water-quality problems associated with the first two subjects can usually be alleviated economically. The neutralization or removal of most of the unwanted chemical constituents is usually difficult and often very costly.

Total dissolved-solids content is usually the main factor which limits or determines the use of ground water. Winslow and Kister (1956) 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

In recent years, most laboratories have begun reporting analyses in milligrams per liter (mg/l) instead of ppm. These two units, for practical purposes, are identical until the dissolved-solids concentration of water reaches or exceeds 7,000 units (ppm or mg/l). The concentrations of chemical constituents reported in this report are in mg/l. All of the chemical concentrations are below 7,000 mg/l and, therefore, the units are interchangeable. For 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 IO, 1975. These standards apply to all of the 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: (l) primary and (2) secondary. Primary standards are devoted to constituents and regulations affecting the health of consumers. Secondary standards are those which deal with the esthetic

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

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

Constituent or property	Source or cause	Significance
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 waters.	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.
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.
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.
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.
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.
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.
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.
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).
Nitrate (NO_3)	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 (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 has been shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.

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

Constituent or property	Source or cause	Significance
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.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	Texas Department of Health (1977) drinking-water standards recommend 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.
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.
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.
Residual sodium carbonate (RSC)	Sodium and carbonate or bicarbonate in water.	As calcium and magnesium precipitate as carbonates in the soil, the relative proportion of sodium in the water is increased (Eaton, 1950, p. 123-133). Defined by the following equation: $$RSC = (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++})$$ where CO_3^{--}, HCO_3^-, Ca^{++} and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.
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.
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.

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^6)	.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. Water having a concentration of nitrate (as NO_3) in excess of 45 mg/l poses a potential health hazard. A high concentration of nitrate is an indication of organic decomposition, usually within the source well. Steps should be taken to identify and rectify the source of the contamination.

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 shown 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, as specified, apply to community water systems and are 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-dimenthano 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
	Toxaphene ($C_{10}H_{10}Cl_8$ - Technical chlorinated camphene, 67-69 percent chlorine).	.005
2.	Chlorophenoxys:	
	2,4-D (2,4-Dichlorophenoxyacetic acid).	.1
	2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic 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

Constituent	Maximum level
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 (Texas Department of Health, 1977):

Substance	Concentration (mg/l)
Chloride (Cl)	300
Fluoride (F)	1.4 to 1.6*
iron (Fe)	.03
Manganese (Mn)	.05
Nitrate (as N)	10
Nitrate (as NO_3)	45
Sulfate (SO_4)	300
Dissolved solids	1,000

*Maximum fluoride concentration based on annual average of maximum daily air temperatures within the range of 70.7 to 90.5^{O}F (21.5 to 32.5^{O}C) in the study region.

Many areas of south-central Texas do not have and cannot obtain domestic water supplies which meet the above recommended standards; however, supplies which do not meet these standards have been used for long periods of time without any apparent ill effects to the user. 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 of 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 as necessary for maximum growth and reproduction. Hem (1970, p. 324) cited a publication of the Department of Agriculture of the state of VVestern Australia as recommending the following maximum upper limits for dissolved-solids concentration in livestock water:

Animal	Dissolved solids (mg/l)
Poultry	2,860
Hogs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,000
Adult sheep	12,900

Water having concentrations of chemical constituents in excess of the Texas Department of Health's standards may be objectionable for many reasons. Brief explanations for these objections, as well as the signif cance of each constituent, are given in Table 2.

Irrigation

The suitability of ground water for irrigation purposes is largely dependent on the chemical composition of the water. The extent to which the chemical quality will affect the growth of crops is in part determined by the climate, soil, management practices, crops grown, drainage, and quantity of water applied.

Primary characteristics that determine the suitability of ground water for irrigation, according to the U.S. Salinity Laboratory Staff (I 954), are: (I) total concentration of soluble salts; (2) relative proportion of sodium to other cations (magnesium, calcium, and potassium); (3) concentration of boron or other toxic elements; and (4) under some conditions, the carbonate and bicarbonate concentration as related to the concentration of calcium and magnesium. These have been termed, respectively, the salinity hazard, the sodium (alkali) hazard, the boron hazard, and the bicarbonate ion hazard (U.S. Salinity Laboratory Staff, 1954, p. 69-82; Wilcox, 1955, p. 1 I-12; and Lyerly and Longenecker, 1957, p. 13-I 5).

A high concentration of soluble salts in irrigation water may cause a buildup of salts in the soil. Saline soils decrease the ability of plants to take up moisture and nutrients from the soil resulting in decreased yields. This salinity hazard is expressed in terms of specific conductance, measured in micromhos per centimeter at 25°C (77°F). In general, water having a conductance below 750 micromhos per centimeter is satisfactory for irrigation; however, salt-sensitive crops, such as strawberries and green beans, may be adversely affected by irrigation water having a conductance in the range of 250 to 750 micromhos per centimeter. Table 6 gives the specific conductance for selective water samples analyzed within the study area.

The physical condition of soil can be adversely affected by a high concentration of sodium relative to the concentration of calcium and magnesium in irrigation water. The sodium hazard is expressed as the sodium-adsorption ratio (SAR; see Table 6) which is the measurement of the relative activity of sodium ions in exchange reaction5 with soil. 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 percent sodium less than 60 (Table 6) and a low bicarbonate content are probably satisfactory. The sodium hazard becomes progressively greater as the sodium percentage increases above 60.

Boron is necessary for good plant growth, but rapidly becomes highly toxic at concentrations above acceptable levels. Maximum tolerable levels for various crops range from 1.0 to 3.0 mg/l (Scofield, 1936). High concentrations of Boron are not known to be a problem within the study region. Consult Table 2 for specific crops and their tolerance ranges.

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 1.24 to 2.5 me/l (milliequivalents per liter) of residual sodium carbonate (RSC; see Table 6) are considered marginal and those containing greater than 2.5 me/l probably are not suited for irrigation use (Wilcox, 1955).

Industrial

Chemical quality standards for ground water used for industrial purposes vary greatly with the type of industry utilizing the water. The primary concern with many industries is that the water does not have constituents that are corrosive or scale-forming. Also of concern are those minerals that affect color, odor, and taste; therefore, water with a high content of dissolved solids is usually avoided. Table 2 lists the effect that most of the minerals have on industrial usage.

Treatment of Water

When ground water does not meet specific requirements for usage, various methods of treatment can be implemented to alter the chemical composition. Such treatments include softening, aeration, filtration, cooling, dilution, and the addition of chemicals. The type of treatment is dependent on the particular problem; however, the primary limiting factor is economics.

Chemical Quality of Ground Water from the Trinity Group Aquifer

The Trinity Group aquifer yields fresh to slightly saline water with very high content of hardness as calcium carbonate ($CaC0_3$) to almost all of the wells within the study region (Table 6). The majority of water samples that were analyzed indicated hardness within a range of 250 to 500 mg/l although many samples were substantially higher and only a few were lower. This water would be classed as very hard (Table 2). Figure 15 illustrates the dissolved solids, sulfate, and chloride concentrations from selected wells.

The lower Trinity aquifer provides fresh water with dissolved-solids content usually under 500 mg/l in much of Kerr and Bandera Counties. To the west and east of this area, the content of dissolved solids increases and usually ranges from 900 to 1,500 mg/l.

The middle Trinity aquifer yields fresh to slightly saline water to almost all of the study area. Water in the lower member of the Glen Rose Limestone is normally of very good quality although hard. Spring water from the lower Glen Rose is of excellent quality with dissolved solids often under 250 mg/l. The Hensell Sand yields fresh quality water in the northern half of the study area although high quantities of iron occur in a number of localities. Good quality water also occurs in the Cow Creek Limestone. Near the downdip limit of the study area, water from the lower Glen Rose and Cow Creek increase rapidly in dissolved solids (Table 6). Much higher quantities of sulfate are the primary reason for the increase. Water from wells in a few localities contains fluoride in amounts greater than the recommended limit.

Wells developed in the upper Trinity aquifer generally produce water of poor quality. The low permeability of the upper member of the Glen Rose Limestone restricts water movement which causes an increase in mineral concentration. Slow movement and long contact of ground water with highly soluble evaporite zones result in excessive sulfate content. The approximate downdip limits of fresh to slighly saline water in the upper Trinity and middle Trinity aquifers are shown on Figure 15.

OCCURRENCE OF GROUND WATER IN THE TRINITY GROUP AQUIFER

Recharge, Movement, and Discharge

The primary source of recharge to the Trinity Group aquifer is from rainfall on the outcrop and seepage from lakes and streams. The upper and lower members of the Glen Rose Limestone and the Hensell Sand crop out over most of the study region, therefore, these units receive the greatest amount of direct recharge. The other units, Cow Creek Limestone, Sligo Limestone, and Hosston Sand, are recharged primarily by vertical leakage from the other strata. Average annual precipitation over the outcrop ranges from 25 to 35 inches (64 to 89 cm). The estimated effective recharge to the Trinity Group aquifer is about 200,000 acre-feet per year (247 hm^3/yr) within the study area. This estimate is based on the base-flow gain in the Guadalupe River between the Comfort and Spring Branch gaging stations which is a region of very little ground-water pumpage. The base-flow gain is a result of discharge of ground water into the stream, and this discharge should approximately equal the amount of recharge, assuming that the aquifer remained approximately filled. The gain in base flow equates to an average annual recharge of 31,800 acre-feet (39.3 hm^3) from precipitation in the 477.6-square-mile (1,237 km^2) drainage area between the two gages. The 67 acre-feet per square mile per year (0.032 hm^3/km^2/yr) as applied to the total Trinity Group outcrop area of 2,985 square miles (7,731 km^2) thus provides an estimate of the average annual recharge or sustained annual yield for the study region. This value is approximately 4 percent of the average annual rainfall.

The majority of streams in the study area traverse predominantly the middle Trinity members of the Travis Peak Formation. Although some recharge to the aquifer does occur, most of the streams show increases in base flow in the downstream direction indicating that ground water is moving from the formations to the streams. This is exemplified on the Guadalupe River where an average annual increase in base flow of 31,800 acre-feet (39.3 hm^3) occurs between the Comfort and Spring Branch gaging stations. The principle exception is in the Cibolo Creek channel. Except during flooding conditions, all water in Cibolo Creek is diverted underground through sinkholes. The largest loss is observed between Boerne and Bulverde where the creek traverses the lower Glen Rose outcrop.

Lakes also recharge the aquifer at least locally. The water level in well DX-68-07-401, which is one-half mile from the shoreline of Canyon Lake, was measured before and during a major flood on the Guadalupe River. The water level in the well rose in relationship to the change in elevation of the lake surface which indicates a hydrologic connection. Not all wells in the vicinity of a lake should be expected to be recharged by the lake, due to impermeable barriers existing between the well and lake.

The Hosston Sand and Sligo Limestone Members of the Travis Peak Formation do not crop out within the study area but derive recharge by leakage from the overlying water-bearing strata. This source is primarily the Hensell Sand in the updip northern area where the Hammett Shale, which usually forms a hydrologic barrier at the base of the Hensell, is thin or absent. In the remainder of the study area where the Hosston exists, particularly in faulted areas, some leakage probably occurs through the Hammett. Figure 16 shows hydrographs of water levels in wells completed in the middle and lower Trinity aquifers superimposed on the hydrograph of the gain in base flow of the Guadalupe River (between the Comfort and Spring Branch gages) near the wells during the same time period. The fluctuations in water levels of both wells appear to coincide approximately with fluctuations in the river's base flow, indicating that water in the middle Trinity is recharging the lower Trinity.

Recharge to the Cow Creek Limestone is also primarily due to vertical leakage from the overlying Hensell Sand in the northern half of the study region. Midway through the area, the Hensell Sand grades into the Bexar Shale (Figures 6 and 12) which acts as a barrier to vertical recharge.

Water entering the Trinity Group aquifer generally moves slowly downdip to the south and southeast. The direction of flow is normally at right angles to the contours of the potentiometric surface and in the direction of decreasing altitude which is illustrated in Figures 17 and 18. Water-level measurements indicate that the average gradient of the potentiometric surface is 20 to 25 feet per mile (3.8 to 4.7 m/km). In areas of continuous pumpage, however, the ground water will flow toward these points of discharge. Locally, ground-water movement is also toward the points of natural discharge through springs.

Discharge from the lower Trinity aquifer occurs primarily by pumpage from wells. Middle Trinity discharge occurs both artificially by pumpage from wells and naturally by springs and seeps. Discharge from the upper Trinity is predominantly from natural rejection through springs and seeps. Discharge in the form of vertical leakage to underlying beds occurs from the middle and upper Trinity.

Hydraulic Characteristics

Hydraulic characteristics of an aquifer are generally described in terms of its coefficients of transmissibility and storage (see Definition of Terms). These values in the Trinity Group aquifer are highly variable due to the nature of the lithology. Limestones and calcareous-cemented sandstone and conglomerates depend on secondary porosity in the form of solution channels for the transmission of water. These solution channels are nonuniform in their occurrence and dimensions which results in unpredictable yields at any one location. Units composed of sand and conglomerate, such as the Hensell and Hosston, have higher yields updip to the north where there is less cementation.

Table 3 lists results from several pumping tests. The values were obtained from a combination of previously published results and recent pumping tests conducted by the Department's staff and private individuals. For added coverage, additional coefficients of transmissibility were determined from specific capacities obtained from water well drilling contractors.

The average coefficient of transmissibility in the lower Trinity aquifer is about 10,000 (gal/d)/ft [124,000 (l/d)/m] . Highest values are in the Kerrville area. An average value of 1,700 (gal/d)/ft [21,000 (l/d)/ml occurs in the middle Trinity. No values were determined for the upper Trinity aquifer although they can be expected to be substantially lower with respect to the lower and middle Trinity.

The coefficient of storage is a measurement of an aquifer's ability to store or release ground water from storage. In an artesian aquifer the coefficient of storage is small compared to that in a water-table aquifer, therefore a discharging artesian well will develop a cone of depression over a wider area in a shorter time. Artesian wells will have a storage coefficient generally ranging from 10^{-5} to 10^{-3} and this is usually about 10^{-6} per foot of thickness, while wells under water-table conditions will range from approximately 0.1 to 0.3.

Four test holes were drilled by the Department of Water Resources in the study area to determine the hydrologic characteristics of the water-bearing units by laboratory analysis of cores taken from the holes. The results of the core analyses are listed in Table 4.

Water Levels

Ground water in the Trinity Group aquifer is predominantly under artesian conditions except in shallow wells in the outcrop where water-table conditions occur. The artesian conditions are a result of the water-bearing unit being overlain by a confining bed such as the Hammett Shale or Bexar Shale. Hydrostatic pressures are thus created which cause the static water level to rise in well bores above the level of the top of the aquifer.

Fluctuations in water levels are predominantly a result of seasonal climatic changes which affect the amount of ground water in storage. Water levels are usually highest in late spring and fall when rainfall is abundant and low during late summer when rainfall is scarce (Figure 16). In areas of heavy pumpage this does not always hold true.

There are no records to indicate long-term trends in water levels in the Hill Country region. Figure 19 shows some more recent trends. Over most of the study region, long-term trends will probably be dependent on climatic conditions. Historically, extended droughts have

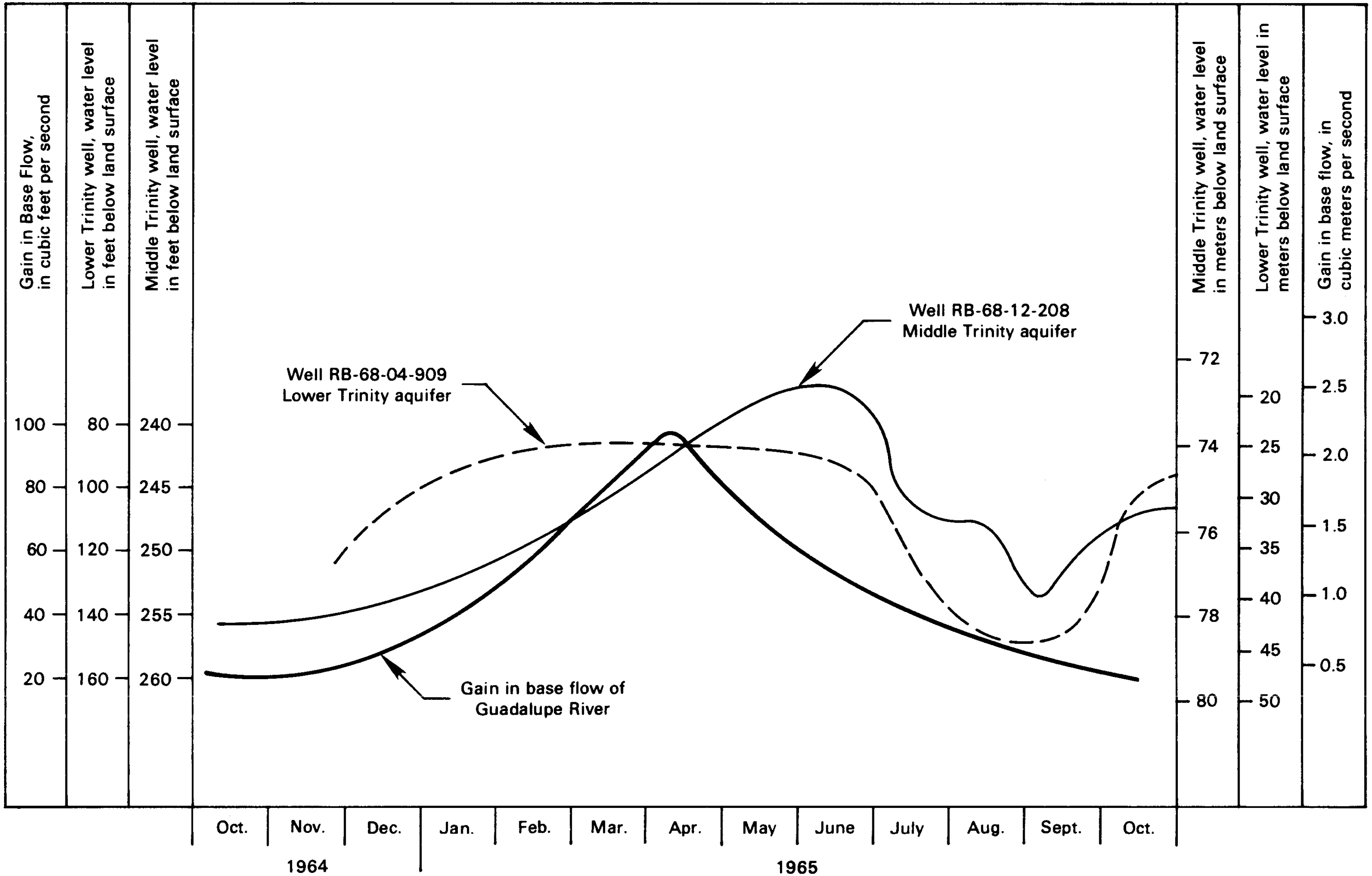

Figure 16

Comparison of Water Levels in Lower and Middle Trinity Wells and the Gain in Base Flow of the Guadalupe River Between the Comfort and Spring Branch Gages

Table 3.-Results of Pumping Tests

County/Well	Member or Formation	Coefficient of Transmissibility [(gal/d)/ft]	Coefficient of Storage
Kerr			
RJ-56-63-603	Sligo and Hosston	22,000	5×10^{-5}
RJ-56-63-604	Sligo and Hosston	24,000	–
RJ-56-63-607	Sligo and Hosston	20,000	2×10^{5}
RJ-56-63-608	Cow Creek, Sligo and Hosston	46,000	7.4×10^{-4}
RJ-56-63-604	Sligo and Hosston	19,000	5×10^{-5}
RJ-56-63-901	Sligo and Hosston	15,000	3×10^{-5}
Gillespie			
KK-57-4l-902	Hensell	600	7×10^{-5}
Kendall			
RB-68-01-301	Hensel l	1,130	—
RB-68-02-807	Hosston	1,195[a]	—
RB-68-l l-412	Lower Glen Rose	7,100	—
Bexar			
AY-68-21-406	Glen Rose	3,312[a]	-
AY-68-19-501	Hosston	900	–

[a] Determined from specific capacity.

Table 4.—Results of Laboratory Analyses of Cores from Test Wells

Stratigraphic Unit**	Core Depth Interval (ft)	Porosity (Percent)	Specific Gravity	Permeability: Vertical [(gal/d)/ft²]	Permeability: Horizontal [(gal/d)/ft²]	Modulus of Elasticity (lb/in²)
			KENDALL COUNTY Well RB-57-57-907			
Kcgrl	160 –161	14.2	2.46	0.00048	Imp.*	602,000
	166 –167	25.1	2.48	.00035	0.0020	485,000
Kche	317.5–318.5	21.2	2.24	.51	1.14	–
	323 –323.7	22.4	2.36	.00328	.0086	–
	327.5–329	–	2.37	sample crumbled		431,600
	335 –335.9	–	2.57	–	–	530,000
	340 –341	31.3	2.28	.0039	sample crumbled	–
	345 –345.8	31.4	2.36	.0115	.0263	–
	347.8–348.7	31.3	2.46	.29	.0134	408,600
	354 –354.6	24.8	2.20	2.12	–	–
	360 –360.7	30.9	2.18	.22	23.95	–
	362 –362.7	29.2	2.52	55.91	–	–
	374.5–375	13.4	2.47	12.43	–	–
Kccc	378.5–379	9.1	2.67	Imp.*	.0009	857,700
	383 –383.5	6.4	2.57	.0005	.00027	–
	388.5–389	5.6	2.59	.016	.032	–
	392 –392.6	35.2	2.06	8.45	52.99	–
	398.6–399.3	12.2	2.49	.0017	.0214	746,300
	402 –402.8	7.3	2.51	.0047	.0017	921,300
	409 –409.8	13.2	2.50	.0089	.0012	804,900
	419.4–420	11.3	2.52	.0019	.0026	622,800
	422.4–423.2	32.3	2.31	.266	1.86	809,700
Oe	508.5–509	1.2	2.79	.00006	.0037	1,259,000
			KENDALL COUNTY Well RB-68-11-718			
Kcgrl	254.8–255.8	9.1	–	0.0012	0.0063	792,700
	258.2–259.3	25.0	–	.0082	.0042	910,100
	301 –302	22.7	–	.108	.012	721,300
	308.5–309.5	27.6	–	.063	.0056	1,042,100
	311.2–312.2	26.5	–	.072	.028	365,500

* Impervious
** Kcgrl — lower member of the Glen Rose Limestone
Kche — Hensell Sand
Kccc — Cow Creek Limestone
Kcho — Hosston Sand
Oe — Ellenburger Limestone

Table 4.—Results of Laboratory Analyses of Cores from Test Wells—Continued

Stratigraphic Unit**	Core Depth Interval (ft)	Porosity (Percent)	Specific Gravity	Permeability Vertical [(gal/d)/ft^2]	Permeability Horizontal [(gal/d)/ft^2]	Modulus of Elasticity (lb/in^2)
			KENDALL COUNTY Well RB-68-11-718—Continued			
Kche	322 –323	11.2	–	Imp.*	.002	1,639,700
	335.7–336.6	16.4	–	.0018	.0032	924,100
	341.5–342.2	24.5	–	3.83	.899	426,900
	346 –346.8	24.8	–	1.81	.091	586,700
	355 –356.3	25.9	–	.0466	.066	865,100
	358 –358.8	20.5	–	.044	.003	697,300
	365.4–366.4	17.5	–	.0126	.0106	949,900
	370.9–371.7	25.1	–	.0127	.00007	–
	376.8–377.8	14.1	–	.00137	.0032	1,097,600
	400 –400.9	24.3	–	.0021	.0238	804,400
	414.5–415.3	19.9	–	22.91	20.92	–
Kccc	435 –436	25.5	–	.72	.53	–
	437.8–438.7	26.1	–	1.15	.0107	707,100
	444.8–445.6	27.5	–	.72	.0116	741,400
	455 –456	14.3	–	.0041	.0028	1,146,200
	457.5–458.3	9.1	–	.00053	.0658	1,113,600
Kcho	845.5–846.5	5.6	–	Imp.*	.0077	–
	848.5–849	22.9	–	.023	.896	–
	852 –853	10.9	–	Imp.*	.002	615,300
	859 –860	–	–	sample crumbled		468,400
			KENDALL COUNTY Well RB-68-02-807			
Kcgrl	186.2–187.4	17.2	2.32	0.005	0.00937	937,700
Kche	220 –221	17.4	2.30	.0035	.00033	780,600
	228.6–230	27.8	2.14	.0931	.048	532,600
	233.2–234	33.4	2.22	.0128	.0034	–
	239.1–240	23.5	2.18	.085	.025	188,100
	249.2–250	26.9	2.23	.002	.0026	390,600
	293 –294	21.7	2.33	.032	.0099	796,000

* Impervious

** Kcgrl — lower member of the Glen Rose Limestone
Kche — Hensell Sand
Kccc — Cow Creek Limestone
Kcho — Hosston Sand
Oe — Ellenburger Limestone

Table 4.—Results of Laboratory Analyses of Cores from Test Wells—Continued

Stratigraphic Unit**	Core Depth Interval (ft)	Porosity (Percent)	Specific Gravity	Permeability Vertical [(gal/d)/ft²]	Permeability Horizontal [(gal/d)/ft²]	Modulus of Elasticity (lb/in²)
			KENDALL COUNTY Well RB-68-02-807—Continued			
Kccc	340 –341	37.5	2.18	2.61	0.026	345,000
	350 –350.5	24.1	2.10	4.18	.887	—
	354 –355	18.2	2.17	.025	.0186	430,200
	360.5–361.5	22.3	2.24	.0067	.010	788,000
	373 –373.5	26.8	2.24	.20	.103	—
	379 –380	24.2	2.31	.024	.00182	489,300
	391 –392	—	—	.001	—	360,500
Kcho	556 –557	24.2	2.27	.024	.0086	757,100
	662 –663	14.1	2.63	Imp.*	.00022	1,012,300
	668 –669	7.4	2.66	Imp.*	Imp.*	671,000
	677 –678	16.1	2.65	.0211	.00069	1,136,100
	682 –683	1.0	2.80	—	—	—
			BEXAR COUNTY Well AY-68-19-208			
Kche	356 –357	21.9	2.33	0.00129	0.00359	595,000
	396 –397	30.0	2.27	.723	.189	454,600
Kccc	405 –406	31.9	2.15	.292	.096	264,200
	416 –417	18.0	2.43	.0045	.0038	1,016,500
	423 –424	17.7	2.43	.013	.053	1,085,300
	430 –431	9.6	2.48	.00049	.00523	935,000
	438 –439	13.7	2.43	.033	.0378	1,432,000
	453 –454	20.4	2.43	.00126	.0104	590,800
	462 –463	17.0	2.40	.0079	.0024	660,300
Kcho	667 –668	28.1	2.30	Imp.*	.00136	942,200
	821 –822	22.0	2.67	.044	—	547,500
	828 –829	25.2	2.41	.276	.0736	1,274,100
	839 –840	6.3	2.51	Imp.*	.000918	649,800
	857 –858	17.5	2.51	.139	.017	1,226,200
	864 –865	17.3	2.40	.15	.021	1,072,300
	873 –874	26.2	2.38	.169	.0076	659,500

*Impervious

**Kcgrl — lower member of the Glen Rose Limestone
Kche — Hensell Sand
Kccc — Cow Creek Limestone
Kcho — Hosston Sand
Oe — Ellenburger Limestone

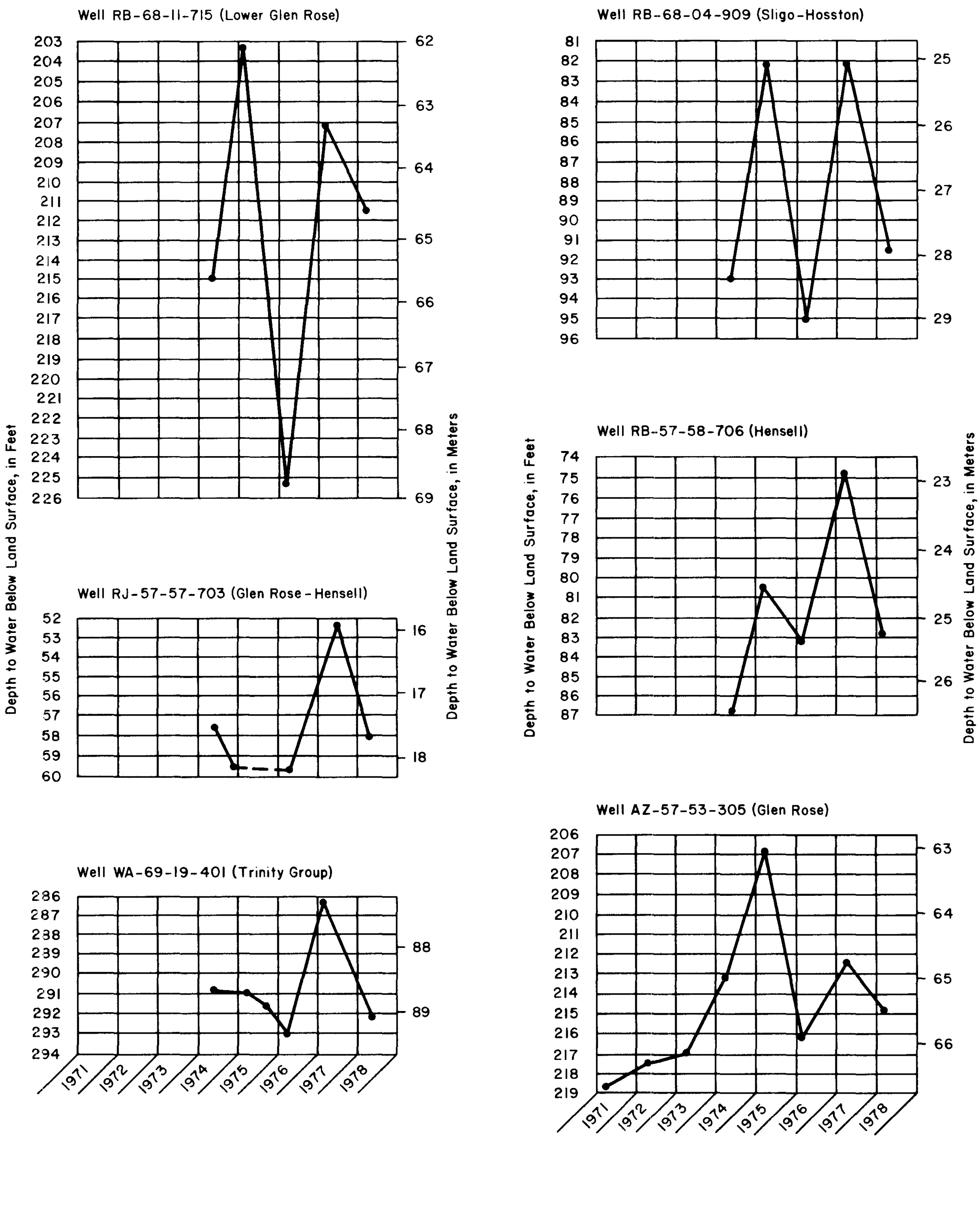

Figure 19

Hydrographs of Water Levels in Selected Wells

caused abnormal lowering of water levels and in many instances wells have actually gone dry. Because the Cow Creek, Sligo, and Hosston are not directly recharged by rainfall, these units will be less affected by droughts than the Hensell and Glen Rose. High pumpage in areas of rising population growth is also trending toward rapid decline in water levels.

Figures 17 and 18 show the altitude of water levels in selected wells in the middle and lower Trinity aquifers, respectively. Water levels in numerous wells are also listed in Table 5.

Utilization and Development

Historically, ground water from the Trinity Group aquifer has been used for public supply, irrigation, industrial, domestic, and livestock purposes. With increased population growth and changing economic conditions, ground-water usage in the hill country has undergone some alteration.

Water from the lower Trinity aquifer is used almost exclusively for municipal and irrigation purposes. The cities of Kerrville and Bandera rely heavily on water from the Hosston Member of the Travis Peak Formation. Other areas such as southern Kendall and northern Bexar Counties have attempted to use lower Trinity water for public supply but have found that the chemical quality will not meet the standards of the Texas State Department of Health. In the past, several large ranches, primarily in Bandera, Bexar, Kendall, and Kerr Counties, have used lower Trinity water to irrigate large grass fields but few of these wells remain active due to the cost of operating the pumps. Depth to the water-producing zone and the necessity to case off the Hammett Shale make drilling to the lower Trinity expensive and infeasible for most domestic needs.

The middle Trinity aquifer is the most widely used ground-water source because of its accessability and good chemical quality. It is the primary source for most domestic and livestock supplies as well as for many small communities and residential developments. Because of its high level of hardness, only a very few industries have been able to utilize the water. Irrigation, primarily in Gillespie County, is increasing, mostly in the form of drip systems for fruit and pecan orchards.

Comparatively few wells have been completed in the upper Trinity aquifer. These wells are exclusively for domestic and livestock use. Almost no new wells are being completed in this zone because of the poor quality and small quantity of the ground water being produced from the upper members of the Glen Rose Limestone.

AVAILABILITY OF GROUND WATER IN THE TRINITY GROUP AQUIFER

The amount of fresh to slightly saline ground water available for development from the Trinity Group aquifer annually in the study region is approximately 200,000 acre-feet (247 hm^3), which is the approximate average annual recharge to the aquifer as discussed earlier. Much of this recharge is lost by natural rejection in the form of small springs, seeps, and evapotranspiration. Theoretically, this 200,000 acre-feet (247 hm^3) annually of ground water can be developed without reducing the quantity of ground water in storage, although pumpage of this rate would probably cause a total depletion of the base flow of the rivers and streams that traverse the study region. In considering these figures of ground-water availability, it should be recognized that a single well, or a well field, cannot recover the total sustainable annual yield of the Trinity Group aquifer. This would require a large number of wells evenly spaced over the study region.

Ground-water availability should be of primary concern for any future development within the study region. Because of the small storage capacity of the Trinity Group aquifer, any large-scale pumpage should be preceded by adequate planning. Best yields generally occur in the outcrops of the lower member of the Limestone and the Hensell Sand (Figure 5) where rainfall has a better chance of entering the aquifer without being discharged through spring flow. Also, areas near creeks often have a better chance of developing solution channels that are necessary for large yield wells. Areas presently experiencing ground-water depletion due primarily to concentrated pumpage are in the Kerrville area and in northern Bexar and western Comal Counties.

GROUND-WATER PROBLEMS

Most ground-water problems in the south-central Texas hill country are related to insufficient well yield, less than desirable chemical quality, or a combination of the two. Before a well is drilled, it is important to consider the expected needs and the actual capacity of the tapped aquifer to meet those needs. As the well is drilled, there are several steps that can be taken to improve its efficiency.

Location of the well is the first point to consider. As a well is pumped, the drawdown of the water will form a cone of depression that expands outward from the well. When this cone of depression encounters the cone of depression from another pumping well, both wells will experience a barrier effect resulting in decreased yields. It is, therefore, helpful to know the hydraulic characteristics of the aquifer in order to properly space the wells. This knowledge can be gained by conducting aquifer tests on nearby wells. The well site should also be located away from sources of surface contamination such as livestock pens and septic tanks.

Proper well completion is vital to an efficient well. An insufficiently cased borehole may collapse or sand-up at the water-producing interval. The type of rock encountered when drilling the well will determine the amount of casing needed. A well drilled in limestone will usually require only surface casing to protect from surface contamination. If sand or shale is encountered, the casing should extend through those zones. Wells drilled to the lower Trinity aquifer particularly require casing through the Hammett Shale. The entire length of casing should be cemented. For wells drilled in a loose, unconsolidated material such as the Hensell Sand in Gillespie County, the casing should be perforated or slotted, extend the entire depth of the hole, and then be gravel packed at the water-producing zone. Screens are often used instead of perforated or slotted casing. Proper well completion impoves the yield, protects from contamination, and extends the life of the well.

Acidizing a limestone water-bearing zone will often increase the yield by increasing the permeability of the adjacent formation. The amount of acid applied depends on the results desired and cost and normally ranges from 5,000 to 20,000 gallons (I 8,900 to 75,700 liters) of 15 percent concentration of hydrochloric acid. Most domestic wells do. not require acidizing for sufficient yields but the process is recommended for high-capacity wells.

Well development and pumping tests should be continued as long as is necessary to adequately clean out the bore hole and adjacent passages and to determine the most efficient pump size to install.

Chemical-quality problems in a well can be a dangerous health hazard. Pollution in the form of organic matter, such as sewage, may result in bacterial contamination and is usually identified by a high nitrate concentration. Bacterial contamination is most common in shallow wells and in wells where surface runoff is allowed to enter the borehole. Wells should be properly cased and cemented to help prevent surface contamination.

Ground water that contains excessively high levels of dissolved solids is encountered in many wells. The upper member of the Glen Rose Limestone in particular contains water with excessive amounts of sulfate. This highly mineralized water, even when mixed with better quality water from other zones, will often render water from the well unusable. Again this contamination can be minimized or eliminated by proper casing and cementing of the problem zones.

Heavy pumpage of ground water from the Trinity Group aquifer in certain areas is resulting in a rapid decline of water levels. Further residential development is continuing in these areas, and continued water-level declines can be expected. Many areas throughout the study region are beginning to develop rapidly and in time will probably also experience water-level decline. A combination of heavy pumpage and drought conditions will likely result in many wells going dry.

RECOMMENDATIONS

Water levels in 89 observation wells in the study region are being measured annually to determine long-term changes. Additional observation wells should be established in areas not presently covered and especially in areas of suspected problems. In addition to the annual measurements, a number of observation wells should be measured monthly or quarterly to determine seasonal variations in water levels throughout the study region. Automatic recording equipment should be installed on wells both in the artesian zone and the water-table zone to determine more precisely the effect of rainfall on recharge.

A water quality monitoring program consisting of 77 wells has been instigated. These wells should continue to be monitored to detect any changes in water quality resulting from well contamination and from possible saline-water encroachment due to heavy pumpage.

Aquifer tests should be conducted, especially in problem areas, to better determine the capabilities and future potential of the aquifer. Well logging should be continued in order to better define the formation horizons so that better well depth recommendations can be made.

A large portion of the study area is covered by “Cedar” (Juniper) trees which have been shown to be especially inefficient water users. Substantial increases in aquifer recharge could be expected by reverting much of this land back to grass. Small dams along creeks would also improve recharge by slowing the rate of surface runoff.

Homeowners can benefit by installing larger water storage units and practicing water conservation. Rainwater retained in cisterns can be used in conjunction with ground water for increased supplies.

Adequate septic tanks should be installed, and raw sewage should never be allowed to drain into an abandoned well or into a creek or river.

The efficient utilization of ground water, especially for large-demand purposes, requires adequate planning. Some developments have experienced severe water shortages and water quality problems primarily due to the lack of such planning. Before development begins, a program of test drilling, test pumping, and water-qua I ity sampling should be instigated. The information gained will determine the' most efficient well completion method, pump setting, well spacing, and feasibility of drilling additional wells. Large concentrated withdrawals in small areas should be avoided, and housing developments should not contain more housing units than their water system can support, Whenever possible, surface-water supplies should be considered to supplement the ground-water supply.

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