TEXAS WATER DEVELOPMENT BOARD

REPORT 308

OCCURRENCE AND QUALITY OF GROUND WATER
IN JACK COUNTY, TEXAS

By

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ABSTRACT

Jack County is underlain by Pennsylvanian rocks of the Canyon and Cisco Groups which crop out over much of the county, but are overlain by Cretaceous deposits along the eastern corner of the county. Limited amounts of fresh to saline ground water occur erratically in discontinuous Pennsylvanian sandstone units. Canyon Group units form part of the Perrin delta system consisting of limestone sequences separated by shale, mudstone, and sandstone. Cisco Group units were derived from a fluvial-deltaic system consisting primarily of sandstone units with beds of limestone, shale, mudstone, and conglomerate. Due to the discontinuous nature of the sandstone units and the wide range laterally and vertically in water quality, maps delineating water levels and base of usable-quality water were deemed to be both impracticable and misleading. Maps delineating water-bearing units, net-sandstone thicknesses, and water quality are presented in this report in an attempt to provide data to be used as a guide in recommending protection of ground water from contamination and as an aid to Jack County land owners in determining approximate water well depths and water quality.

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OCCURRENCE AND QUALITY OF GROUND WATER

IN JACK COUNTY, TEXAS

INTRODUCTION

Purpose and Scope

The general purpose of the study was to determine the occurrence and quality of the ground-water resources of Jack County; to determine the sources of and depth to water suitable for domestic, livestock, public supply, and irrigation uses; and to recommend how to protect the water from contamination. The general scope of the study was the collection, compilation, and analysis of data pertaining to the distribution and quality of ground water in Jack County.

Field work on this study was carried out during the period of June 1982 through January 1984. The results of the investigation are presented in this report, which includes an analytical discussion of the occurrence and quality of the ground-water supplies together with a tabulation of basic data obtained during the investigation.

Figure 1.–Location of Jack County

Location and Extent

Jack County, having an areal extent of 945 square miles, is located in north-central Texas (Figure 1). The county is bounded on the east by Wise and Montague Counties, on the north by Clay County, on the west by Archer and Young Counties, and on the south by Palo Pinto and Parker Counties. Jacksboro, the county seat, is centrally located in the County.

Topography and Drainage

Jack County is located in the Osage Section of the Central Lowland Province (Carr, 1967, p. 3). Topographically, the county consists of rolling plains heavily dissected by Trinity and Brazos River drainage. The altitude of the land surface ranges from 825 to 1,485 feet above mean sea level.

Jack County lies within two major drainage systems; the Trinity River basin, which covers the northeastern two-thirds of the county, and the Brazos River basin, which covers the southwestern third. The northern third of the county is dissected from the rest by the West Fork of the Trinity River, which enters the county in the northwest corner and exists at the center of the eastern boundary. Major tributaries in the county are Cameron, Crooked, Lodge, North, and Snake Creeks in the Trinity River basin, and East and West Fork Keechi and Rock Creeks in the Brazos River basin.

Climate

The climate of Jack County is warm subhumid. The average annual mean free-air temperature for the priod 1951-80 is about 64°F. The mean maximum temperature for July is about 97°F and the mean minimum temperature for January is about 32°F. Figure 2 shows the average maximum-minimum monthly temperature at Jacksboro (1941-81). Average freeze dates according to the Dallas Morning News (1979) is November 5 as the first and April 1 as the last, providing a growing season of about 218 days.

Precipitation is fairly evenly distributed throughout the year with heaviest amounts occurring in late

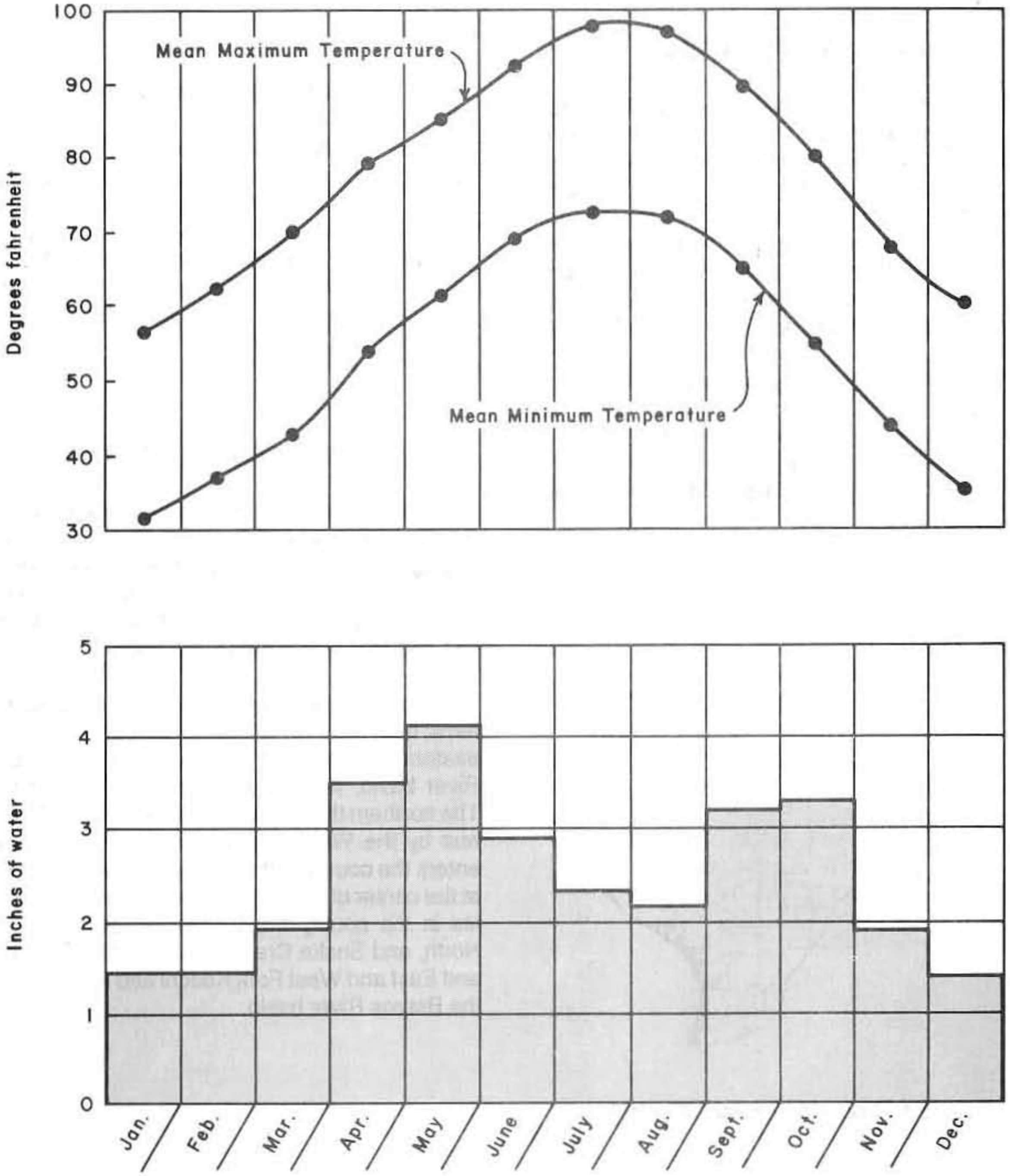


Figure 2.–Average Monthly Precipitation, and Average Maximum-Minimum Monthly Temperature at Jacksboro (From Records of U.S. Weather Service)

spring and a secondary peak occurring in the September-October period (Figure 2). During the period 1941 through 1981, the average annual precipitation at Jacksboro was 30.1 inches (Figure 3). During the same time interval, the maximum annual precipitation was 54.2 inches recorded in 1957, and the minimum was 17.6 inches in 1956.

Data collected for the period 1940-65 and compiled by Kane (1967) reflect that the average annual gross lake-surface evaporation is approximately 71 inches; however, the average annual net lake-surface evaporation is only 45 inches. Monthly gross lake-surface evaporation ranges from 2.1 inches in January to 11.1 inches in August.

Population and Economy

Jack County is named for the brothers P. C. and W. H. Jack, local leaders in Texas' struggle for independence. The county was created in 1856 from Cooke County, and organized a year later. The population estimate in 1980 was 7,408, with Jacksboro, the county seat, contributing 4,000 of the total. Other towns of appreciable size include Antelope, Bryson, Jermyn, Perrin, Vineyard, and Wizard Wells.

The major part of the economy in Jack County is centered around the production of petroleum and natural gas. Agricultural income is derived primarily from beef cattle production, with some sheep and goat ranching and crops of wheat, oats, and barley. Recreational hunting leases also contribute to the income of the county.

Previous Investigations

Numerous reports containing information on the geology and depositional systems of north-central Texas are available; however, no detailed ground-water investigation of the entire county has been made prior to this study. Selected references are listed at the end of this report.

A report on the ground-water conditions in the vicinity of Jacksboro (Preston, 1977) was published, but covers only a small part of the study area. Reconnaissance investigations were made of groundwater resources of the Brazos River basin (Cronin and others, 1963), and the Trinity River basin (Peckham and others, 1963), each of these including part of Jack County, but information pertaining to the study area was of a generalized nature.

Methods of Investigation

An inventory was made of all municipal, industrial, and irrigation wells, as well as some springs and selected domestic and livestock wells. A total of 465 wells, springs, and test holes were inventoried and included in this study. Selected wells in adjacent counties were included for continuity. Figure 31 shows the locations of the wells, springs, and test holes inventoried. Information was gathered, when available, on well depths, well construction, drillers' logs, driller, date drilled, water-bearing zones, and water levels. Surface elevations of all wells inventoried were determined from topographic maps and electric log well records. A total of 389 water samples were collected for chemical analysis from 314 selected wells, springs, or test holes. Surface and subsurface geologic data were collected and compiled, placing special emphasis on their relationship to ground water. Test holes were drilled in areas where information on possible water-bearing strata was absent. Data were tabulated, analyzed, and the necessary illustrations prepared for coherent presentation in a report.

Well-Numbering System

The Texas Water Development Board statewide well-numbering system is used in this report. As indicated on Figure 4, the system is based on longitude and latitude, with each well or spring being assigned a seven-digit number. In addition, a two-letter county designation prefix is used.

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

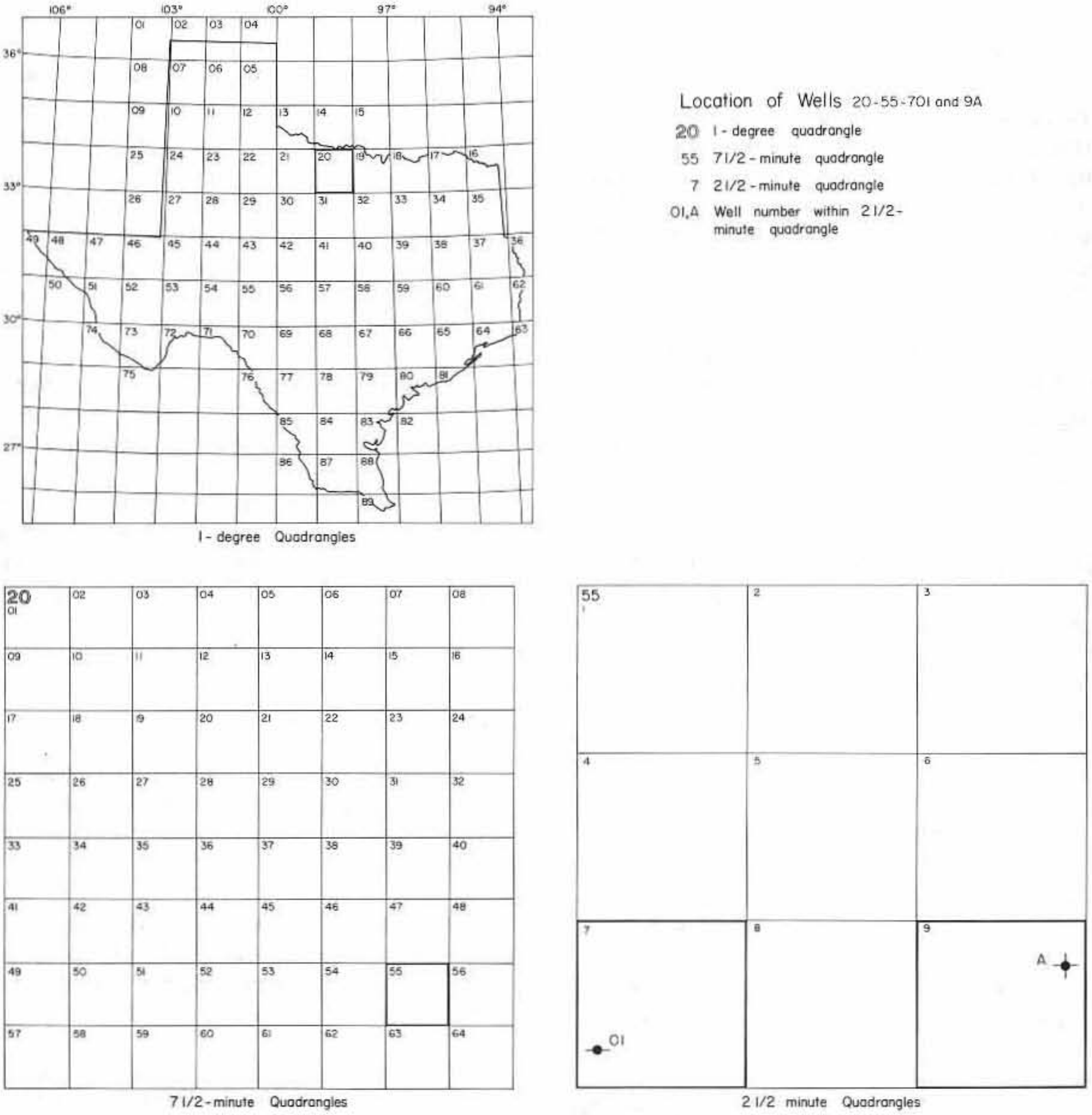
Each seven-digit number has a two-letter prefix to identify the county in which the well or spring is located. The prefixes for Jack and the adjoining counties are as follows:

County	Prefix
Archer	AJ
Clay	DL
Jack	PL
Montague	TR
Palo Pinto	UK
Parker	UP
Wise	ZR
Young	ZU

Jack County lies in that part of Texas covered by one-degree quadrangle numbers 19 and 20. These lie within the latitude of 33 degrees north, and between 97 and 98 degrees west longitude.

The 7 1/2-minute quadrangles are numbered on the well-location map, Figure 31. On this map, the 2 1/2-minute quadrangles are not numbered, because of space limitations. However, the notation occurs as the first digit of the three-digit number beside each well or spring location.

Well PL-20-55-701 indicates that it is within Jack County; within 1-degree quadrangle 20; within 7 1/2-



1-degree Quadrangles

7 1/2-minute Quadrangles

2 1/2 minute Quadrangles

Figure 4.–Well-Numbering System

minute quadrangle 55; within 2 1/2-minute quadrangle 7; and is the first (01) well to be numbered in that quadrangle.

Oil tests used in the geologic cross sections were not assigned statewide well numbers. These data control points were assigned a temporary well number, using a letter in place of the two-digit number within the 2 1/2-minute quadrangles. For example, well PL-20-55-9A indicates that it is within Jack County; within 1-degree quadrangle 20; within 7 1/2-minute quadrangle 55; within 2 1/2-minute quadrangle 7; and is the first data control point (A) to be numbered in that quadrangle.

Acknowledgements

The author wishes to thank the property owners within the study area for their cooperation in providing information concerning their wells and allowing access to their properties. Special thanks to Pete Armstrong, Billy Craft, and Bill Dennis for providing additional information on ground-water conditions in Jack County.

Special thanks are given to the State Department of Highways and Public Transportation for allowing test holes to be drilled on highway right-of-way. Cooperation by Leroy Fitzgerald and James Logan of District 2 in Jacksboro was greatly appreciated.

Since a considerable amount of information concerning the groundwater conditions within the State is based on data provided on drillers' report forms, a special thanks is given to the numerous drillers who completed wells in the study area and provided said data to the Board.

Definitions of Terms

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

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

Aquitard–A semipermeable, semiconfining geologic formation adjacent to or between aquifers and partially restricts the movement of ground water.

Argillaceous–Applied to all rocks or substances composed of clay, slate, or shale. They are readily distinguished by the peculiar odor they emit when breathed on, known in mineralogy as the "argillaceous odor".

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.

Clastic–Rock composed of fragmental material derived from preexisting rocks or from the dispersed consolidation products of magmas or lavas. The most common clastics are sandstones and shales.

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.

Confining bed–One which, because of its position and its impermeability or low permeability relative to that of the aquifer, keeps the water in the aquifer under artesian pressure.

Contact–The place or surface where two different kinds of rock or geologic units come together, shown on both maps and cross sections.

Dip of rocks or attitude of beds–The angle or amount of slope at which a bed is inclined from the horizontal; direction is also expressed (for example, one degree west or 90 feet per mile west).

Discharge–Refers to water withdrawn, either naturally or artificially, from the zone of saturation (see definition of ground water).

Dissolved solids–A measure of the total concentration of dissolved material in water. Widely used in evaluating water quality and comparing waters with one another.

Drawdown–The lowering of the water table or potentiometric surface caused by pumping (or artesian flow). In most instances, it is the difference, in feet, between the static level and the pumping level.

Effective recharge–The amount of water that enters an aquifer and is available for development.

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.

Facies–The "aspect" belonging to a geological unit of sedimentation, including mineral composition, type of bedding, fossil content, etc. (such as sand facies). General appearance or nature of one part of a rock body as contrasted with other parts. A stratigraphic body as distinguished from other bodies of different appearance or composition.

Formation–A body of rock that is sufficiently homogeneous or distinctive to be regarded as a mappable unit, usually named from a locality where the formation is typical.

Ground water–Refers to water in that area below land surface in which all pore spaces and voids are filled with water (called the zone of saturation) and from which wells, springs, and seeps are supplied.

Head, or hydrostatic pressure–The pressure exerted by the water at any given point in a body of water at rest reported in pounds per square inch or in feet of water. That of ground water is generally due to the weight of water at high levels in the same zone of saturation.

Hydraulic Conductivity–The volume of water that will flow in one day through a cross sectional area of one square foot under unit hydraulic gradient (one foot of fall for each foot of lateral movement). It is measured in feet, or meters, per day. Also called the coefficient of permeability which is measured in gallons per day per square foot.

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

Hydrograph–A graph or line plot showing the fluctuation of the water level in a well over a period of time.

Impermeable–Impervious or having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Leaky aquifer system–A heterogeneous assemblage of interrelated permeable, poorly permeable, and relatively impermeable formations that function regionally as an aquifer. The system consists of two or more aquifers separated laterally by discontinuous aquitards and/or aquicludes. Differential changes of the hydrostatic pressure (head) in the system due to pumpage causes ground-water movement through the aquitards and from the interstices of the clays.

Lithology–The description of rocks, usually from observation of hand specimen, or outcrop.

Milliequivalents per liter (me/l)–An expression of the concentration of chemical substances in terms of the reacting values of electrically charged particles, or ions, in solution. One milliequivalent per liter of a positively charged ion (such as Na^+) will react with 1 milliequivalent per liter of a negatively charged ion (such as Cl^-).

Milligrams per liter (mg/l)–Metric units commonly used in chemical analyses of water to indicate a ratio of dissolved substances, by weight, in a unit volume of water. To illustrate in more common terms, 0.000035 of an ounce of a dissolved substance in a quart of water is equivalent to one milligram of dissolved substance in one liter of water. For water containing less than one 7,000 mg/l dissolved solids, one milligram per liter is equivalent to one part per million.

Observation well, current–A well from which the Texas Water Development Board is presently collecting and maintaining records either on water-level or water-quality data or both.

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.

Percolation–The movement, under hydrostatic pressure, of water through the interstices of a rock or soil, except the movement through large openings such as caves.

Permeable–Pervious or having a texture that permits water to move through it perceptibly under the head differences ordinarily found in subsurface water. A permeable rock has communicating interstices of capillary or supercapillary size.

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

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.

Recoverable storage–That portion of underground reservoir capacity estimated as capable of being economically and physically withdrawn from an aquifer.

Resistivity (electrical log)–The resistance of the rocks and their fluid contents penetrated in a well to induced electrical currents. Permeable rocks containing fresh water have high resistivities.

Sedimentary rocks–Rocks formed by the accumulation of sediments in water or from air. The sediment may consist of rock fragments or particles of various sizes; of the remains or products of animals or plants; of the product of chemical action or evaporation; or of mixtures of these materials.

Specific capacity–The discharge of a well expressed as the rate of yield per unit of drawdown, generally in gallons per minute per foot of drawdown. If the yield is 250 gallons per minute and the drawdown is 10 feet, the specific capacity is 25 gallons per minute per foot.

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

Specific yield–The quantity of water that an aquifer will yield by gravity if it is first saturated and then allowed to drain; the ratio expressed in percentage of the volume of water drained to volume of the aquifer that is drained.

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

Structural feature, geologic–The result of the deformation or dislocation (such as faulting) of the rocks in the earth's crust. In a structural basin, the rock layers dip toward the center or axis of the basin. The structural basin may or may not coincide with a topographic basin.

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-level, pumping–The water level during pumping, measured in feet below the land surface.

Water level, static–The water level in an unpumped or nonflowing well, measured in feet above or below the land surface or sea level datum.

Water table–The upper surface of a zone of saturation except where the surface is formed by an impermeable body of rock.

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

From English Units	Multiply by	To Obtain Metric Units
acres	0.4047	square hectometers (hm^2)
acre-feet (acre-ft)	0.001233	cubic hectometers (hm^3)
feet (ft)	0.3048	meters (m)
feet per mile (ft/mi)	0.189	meters per kilometer (m/km)
gallons (gal)	3.785	liters (l)
gallons per minute (gal/min)	0.06309	liters per second (l/s)
gallons per minute per foot [(gal/min)/ft]	0.207	liters per second per meter [(l/s)/m]
gallons per day per foot [(gal/d)/ft]	12.418	liters per day per meter [(l/d)/m]
gallons per day per square foot [(gal/d)/ft^2]	40.74	liters per day per square meter [(l/d)/m^2]
inches (in)	2.54	centimeters (cm)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)

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

$$^{0}C = (^{0}F-32)\ (0.556)$$

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

Geologic History

The geologic setting in and around Jack County was greatly influenced by the tectonic development of the Fort Worth Basin, Red River Uplift (Electra Arch), Eastern Shelf (Concho Platform), Ouachita fold belt, and Wichita-Arbuckle Mountains (Figure 5). Tectonic activities such as these provided the majority of geologic material comprising the varied formations to be discussed in regards to their water-bearing characteristics (Table 1).

During Late Mississippian and Early Pennsylvanian times, orogenic activity in the Ouachita geosyncline produced a thrust-faulted fold belt. Resultant mountains provided a sediment source during the remainder of the Paleozoic Era (Kier and others, 1979). Coincidental to this event, the Fort Worth Basin subsided, forming a foreland basin between the western margin of the Ouachita foldbelt and Eastern Shelf. Thick, terrigenous, clastic deposits of mudstone and sandstone of the Atoka and Strawn Groups essentially filled the Fort Worth Basin by the beginning of Missourian (Canyon) time (Erxleben, 1975). Wedges of clastic material interfingered westward with basinal shales of the western Fort Worth Basin and eastern Concho Platform. These deposits both interfered with and coexisted with calcareous depositional systems. As Middle Pennsylvanian time approached, several events occurred that greatly influenced deposition. Uplift of the eastern portion of the Fort Worth Basin provided clastic sediments to fuel Strawn deltas. Also carbonate

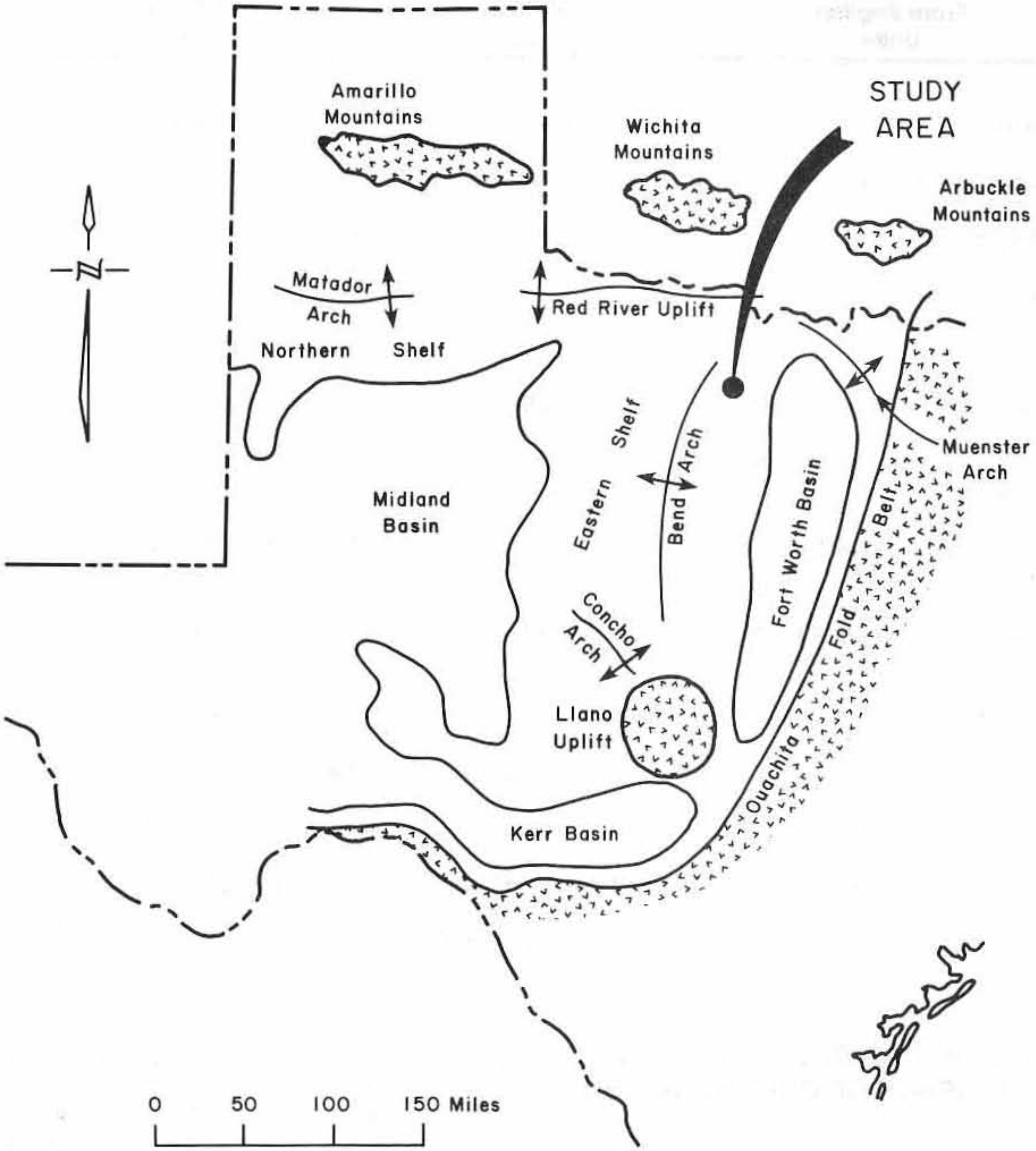


Figure 5.–Regional Geologic Setting and Location of Study Area

reefs and banks developed as subsidence of the Midland Basin increased. The stable area separating these two tectonic features is referred to as the Bend Arch.

During Missourian (Canyon) and early Virgilian (Cisco) time, the Ouachita foldbelt and Wichita-Arbuckle Mountains were the prominent upland sources of terrigenous, clastic sediments in the area. Thick arkosic wedges extended south and southwest into north-central Texas as fluvial and fandelta deposits, sometimes interfering with calcareous bank deposition (Brown and others, 1973). The resulting influx of clastics derived from the Arbuckle Uplift are apparent in the Canyon Group, for chert conglomerates locally replaced some of its limestone members in Jack and Young Counties, and a very notable increase of shale and sandstone thicknesses developed in Jack and Wise Counties (Cheney, 1929, p. 19). As Canyon deposition came to a close, rejuve-

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

ERA	SYSTEM	SERIES	GROUP	FORMATION	STRATIGRAPHIC UNITS	APPROXIMATE MAXIMUM THICKNESS (FT)	CHARACTER OF ROCKS	WATER-BEARING PROPERTIES
Cenozoic	Quaternary	Recent			Alluvium	60	Surficial floodplain and terrace Alluvium along the streams consisting of gravel, sand, silt, and clay.	Yields small quantities of fresh to moderately saline water.
		Pleistocene			Fluviatile terrace deposits			
Mesozoic	Cretaceous	Comanche	Trinity	Antlers Paluxy Glen Rose Twin Mountains		200	Red sand, gray to red-brown clay and shale separated from basal sand, sandrock and shale by limestone and gray clay.	Yields small quantities of fresh to slightly saline water.
Paleozoic	Permian	Wolfcamp	Cisco	Pueblo	Camp Colorado Limestone Salt Creek Bend Shale Stockwether Limestone Camp Creek Shale	100	Thin limestone beds, separated by shale units. Siltstone, sandstone, and coal beds are also present.	Not known to yield water in Jack County.
	— ? —	— ? —		Harpersville	Saddle Creek Limestone Waldrip Shale Crystal Falls Limestone	200	Numerous lenticular sandstone and conglomerate deposits, thin limestones, shale, siltstone, and thin coal beds.	Not known to yield water in Jack County.
		Virgil		Thrifty	Breckenridge Limestone (shale) Blach Ranch Limestone (shale) Ivan Limestone Avis Sandstone	300	Numerous lenticular sandstone deposits, thin limestones, shale, and siltstone, with some thin coal beds.	Yields small quantities of fresh to slightly saline water.
				Graham	Wayland Shale Gunsight Limestone Necessity Shale Bunger Limestone Gonzales Creek Member Finis Shale	600	Numerous lenticular sandstone deposits, thin limestones, shale, and siltstone, with some thin coal beds.	Yields small quantities of fresh to slightly saline water.
			Canyon	Caddo Creek	Home Creek Limestone Colony Creek Shale	300	Limestones separated by units of lenticular sandstone, calcareous shale, siltstone, conglomerate, thin limestone beds, silty shale, and shale.	Yields small quantities of fresh to slightly saline water.
				Brad	Ranger Limestone Placid Shale	400		
	Pennsylvanian	Missouri		Graford	Winchell Limestone (Devil's Den) Wolf Mountain Shale	600		
				Palo Pinto	Wiles Limestone Oran Sandstone Posideon Shale Wynn Limestone	300		
			Strawn	Mineral Wells	Keechi Creek Shale Turkey Creek Sandstone Salesville Shale Dog Bend Limestone Lake Pinto Sandstone Village Bend Linestone Hog Mountain Sandstone	1,100	Limestone and sandstone beds separated by shale units.	Small quantities of slightly to moderately saline water from the Turkey Creek Sandstone occurs in some areas of Jack County.
		DesMoines		Brazos River		1,400	Sandstone, limestone, conglomerate, and shale with some coal beds.	Not known to yield water in Jack County.
				Mingus				
				Grindstone Creek				
				Lazy Bend				

nation in the foldbelt and eastern Fort Worth Basin increased the supply of clastics available for deposition both then and extending into Cisco time. Uplifted clastic rocks of the Atoka and Strawn Groups along the eastern flank of the Fort Worth Basin contributed considerable amounts of reworked sediments to Late Pennsylvanian delta environments.

The Eastern Shelf was a tectonically stable plain sloping gently to west and northwest during both Canyon and Cisco times. It was extensively inundated by shallow seas with cyclic progradation of fluvial and delta systems westward across a carbonate shelf environment. Clastic and limestone deposition were equally balanced and intertwined, remaining so into Early Permian time. During deposition of the upper Cisco Group (Permian), the supply of clastic sediments from east and north diminished, and shelf limestone deposition became prominent (Kier and others, 1979).

During the Triassic and Jurassic periods of the early Mesozoic era, withdrawal of the seas from the north-central Texas area along with subsidence in the Gulf Coast embayment led to a reversal of drainage direction. This resulted in an extensive truncation of Pennsylvanian strata in the Fort Worth Basin and surrounding area. By the close of Jurassic time, Paleozoic rocks had been reduced to a peneplain upon which marine sediments were deposited along an oscillating shoreline during the Cretaceous period. The Pennsylvanian-Cretaceous unconformity shows a tremendous period of emergence and erosion. One of the two major invasions of the sea during the Cretaceous period is represented by the Comanche Series.

General Stratigraphy

Stratigraphic units supplying fresh to slightly saline water to wells in the study area range in age from Pennsylvanian Canyon Group to Recent alluvium. Of these, the most important water-bearing units are of Pennsylvanian age, with minor contributions of ground water by units, where present, of the Trinity Group and alluvium.

Underlying the county are stratigraphic units composed largely of limestone, shale, mudstone, and sandstone with smaller amounts of sand, conglomerate, clay, and coal. The relationship, approximate maximum thickness, brief description of lithology, and summary of water-bearing properties of the units are shown in Table 1.

Both the Canyon and Cisco Groups of Pennsylvanian age consist predominantly of shale, sandstone, mudstone, and limestone. It is the sandstone bodies within these Groups that provide what little ground water is available for development to domestic and livestock wells.

Canyon Group sandstones constitute an important facies in the framework of the Perrin delta system, for it is in these sandstone bodies that ground water is stored. As components of the deltaic system, the progradational sandstone facies include delta-front, distributary channel-fill, and confined valley-fill fluvial deposits. Generally, delta-front deposits consist of thin-bedded sheet sandstone and siltstone. Distributary channel-fill sandstones are massive and coarser grained than delta-front deposits, and consist of fine- to medium-grained sand. Confined valley-fill fluvial deposits consist of gravel and coarse sand at the base, with gravel content decreasing upward. Conglomerate and coarse-grained sandstone are characteristic of basal valley-fill. Slumping and growth faulting is a common feature within Pennsylvanian deltas.

The Cisco Group is composed of mixed clastic and carbonate depositional systems. Water-bearing sandstones can be attributed to the Cisco fluvial-deltaic system, where fluvial systems eroded and were superimposed upon deltaic deposits. Elements of the delta system include: (1) distributary channel-fill of fine-to medium-grained sandstone; (2) distributary mouth-bar, siltstone to fine-grained sandstone; (3) deltafront, sheetlike siltstone and fine-grained sandstone with growth faulting; (4) massive bar-finger sandstone, fine- to coarse-grained with some conglomerate; and (5) prodelta and interdistributary embayment mudstone and sheet sandstone (Galloway and Brown, 1972; Brown and Others, 1973). Fluvial facies include: (1) tabular to sheetlike complexes of intertwined fine-grained sandstone; (2) meander belts of fine-grained sand bodies; (3) valley-fill and braided deposits of coarse gravel to medium-grained sand, fining upward; (4) crevasse splay siltstone and fine-grained sandstone; and (5) overbank sand and mudstone. Fluvial facies diminish basinward (northwest).

The Trinity Group is divided into the Paluxy, Glen Rose, Twin Mountains, and Antlers Formations. The Paluxy consists of sand and shale and provides a very small quantity of ground water in the southeast corner of Jack County. The Glen Rose consists of clay and limestone and does not provide water in the study area. The Twin Mountains is composed of sand, clay, and basal gravel and yields small amounts of water to wells in southeast Jack County. The name Antlers Formation is applied.north of the Glen Rose pinch-out, where the Paluxy and Twin Mountains coalesce to form one unit. Outcrops of Antlers occur along the northeast corner of the county, and due to limited thickness, do not produce sufficient amounts of water to wells in that area. It does, however, act as a recharge source to the underlying Pennsylvanian sandstone, as does the Twin Mountains Formation.

Outcrop areas of various formations are illustrated on the geologic outcrop map (Figure 6). Net sand thicknesses of the Pennsylvanian formations are shown on Figures 7 and 10 through 12. Geologic sections (Figures 32 through 35) show the stratgraphic relationship and structural attitude of each unit. Three of the sections (Figures 32, 33, and 34) are oriented in a downdip direction and one (Figure 35) lies along the strike of the formations.

Structure

Geologic structures affecting ground water in Jack County are the regional west-northwest dip, development of the Fort Worth Basin, Red River Uplift, Ouachita fold belt, and Wichita-Arbuckle Mountains. These regional structures are shown in Figure 5.

Water-bearing rocks in Jack County consist primarily of Pennsylvanian sandstones of the Cisco and Canyon Groups. The outcrop belt of the Cisco Group extends from Young, northwest Jack, south Clay, and into southwest Montague County. The outcrop belt of the Canyon Group extends from northwestern Palo Pinto, southeastern Jack, and into western Wise County, where they are unconformably overlain by eastward-dipping Cretaceous sediments.

Pennsylvanian rocks in Jack County dip in a northwesterly direction at approximately 50 to 55 feet per mile, with a regional strike of about N60°E. Both the Cisco and Canyon Groups exhibit depositional sequences with a maximum thickness of about 1,100 feet. The dip and overall thickness of both Groups are fairly constant as shown in the dip cross-sections (Figures 32, 33, and 34); however, thicknesses of the individual members of each Group vary considerably over the study area.

STRATIGRAPHY OF THE WATER-BEARING UNITS

Strawn Group

Several wells are known to yield potable water from the Strawn Group in northeast Palo Pinto County; however, no water wells were found producing from this group in Jack County. A test well drilled by the Board near Joplin, Jack County, produced usable quality water from the Turkey Creek Sandstone of the Mineral Wells Formation. The Mineral Wells Formation overlies the Brazos River Formation and lies beneath the Palo Pinto Formation of the Canyon Group (Table 1). Within Jack County, the only potential water-bearing unit in the Strawn Group is the Turkey Creek Sandstone. It is separated from Canyon Group units by the Keechi Creek Shale and overlies the Salesville Shale as depicted on the geologic sections and Table 1.

Strawn Group units occur only in the subsurface of Jack County. Formations strike N 75°E through Palo Pinto County, then veer northeast at N 60°E through Jack and into Wise Counties with a regional dip of about 50 feet per mile. A typical dip section as seen in geologic section A-A', Figure 32, shows an average dip of 40 feet per mile. The type locality of the Turkey Creek Sandstone, northwest of Mineral Wells, exposes a 10 foot thick section of dark reddish-brown, massive conglomerate consisting of small angular pebbles of quartz and quartzite in a coarse sand matrix (Plummer and Moore, 1921, p. 78). The Turkey Creek has a total thickness of 117 feet in test hole PL-19-57-104, with a net sandstone thickness of 88 feet. Sandstone beds are interrupted by stringers of dark-gray laminated mudstone containing finely divided plant material and thin lenses of siltstone and very fine sandstone.

Upper Strawn units were deposited as high-constructive, lobate delta sequences representing progradational facies within the Perrin Delta System. Figure 7 (modified from Cleaves, 1983) shows net sandstone thicknesses ranging from less than 50 feet to over 140 feet. The inferred sediment input direction indicates an east-to-west progradation from a probable source area in the northernmost part of the Ouachita Fold Belt of Texas. The multilateral pattern of sandstone facies in the Perrin delta sys-

tem, as illustrated in Figure 7, is inferred to have resulted from deposition on the structurally stable Concho Platform (Cleaves and Erxleben, 1983, p. 55).

Canyon Group

A series of carbonate and terrigenous clastic rocks of the Upper Pennsylvanian (Missouri Series) form the basis of the Canyon Group. Canyon Group units are composed of a sequence of 4 thick limestones with interstratified shales and sandstones. The group generally strikes northeast to southwest and dips toward the northwest at approximately 50 to 55 feet per mile. Of primary importance to this study is the high-constructive Perrin delta system which is composed of the terrigenous clastic facies within the Wolf Mountain, Placid, and Colony Creek stratigraphic units. The Perrin delta system prograded northwestward through eastern Jack and western Wise Counties. Deltaic abandonment and destruction were caused by marine transgressions and deposition of shelf carbonates (Brown and Others, 1973).

Stratigraphic formations include, in ascending order, the Palo Pinto, Graford, Brad, and Caddo Creek. The outcrop belt extends through northwest Palo Pinto, southeast Jack, and western Wise Counties. In southeast Jack County, the Canyon Group is unconformably overlain by eastward-dipping Cretaceous sediments. In the northwestern half of Jack County, units are overlain by rocks of the Cisco Group.

Stratigraphy of the water-bearing units can best be described by examining that portion of the deltaic depositional system from which the rocks are derived. Table 2 briefly describes the characteristics of delta constructional facies components which contain most of the potable ground water.

Palo Pinto Formation

Stratigraphic units included in the Palo Pinto Formation, listed in order from oldest to youngest, are the Wynn Limestone, Oran Sandstone, and Wiles Limestone. Also found in this interval are shales and silty shales derived from a prodelta-shelf environment (Posideon Shale), and discontinuous sandy shales and sandstones. The Palo Pinto Formation forms the base of the Canyon Group and is overlain by units of the Graford Formation (Figure 8).

Geologic section A-A', Figure 32, reveals a dip to the northwest of approximately 50 feet per mile and a total thickness of about 230 feet. Other than an outcrop of Oran Sandstone along the county line south of Perrin (Figure 9), the formation occurs mostly in the subsurface, being overlain by Cretaceous deposits in the southeast corner of Jack County.

Of primary importance to this study is the water-bearing sandstones comprising the Oran Sandstone and the discontinuous sandstone and sandy shale bodies overlain by Cretaceous sediments. The Oran Sandstone is fine- to medium-grained, ferruginous, locally cross-bedded, and thin-bedded at the base becoming more massive towards the top. It exhibits a thickness of up to 50 feet. A measured section, shown as number 28 on Figure 9, is described by Erxleben (1975, P. 73) as follows: 37 feet of silty, sandy, unfossiliferous shale of probably prodelta or interdeltaic origin, overlain by 25 feet of fine-grained, highly cross-stratified sandstone containing plant debris and clay pebbles.

Graford Formation

Two stratigraphic units are included in the Graford Formation, the Wolf Mountain Shale and the Winchell Limestone. The Graford is separated by the Palo Pinto Formation below and by the Brad Formation above, both of the Canyon Group. Sandstone units within the Wolf Mountain Shale are the primary source of potable ground water to water wells along and several miles downdip of the formation.

Commonly, the dip is less than 50 feet per mile, and the strike generally parallels the northeast trending outcrops of all Canyon Group formations through southeast Jack County. Figure 10, after Erxleben (1975), shows the areal extent of the sandstone outcrop of the Wolf Mountain Shale along with its net-sandstone thickness, which ranges from less than 50 feet to over 200 feet. The maximum thickness occurs 5 to 10 miles downdip from the outcrop south of Jacksboro in one of the Perrin delta system lobes.

Stratigraphy of the Wolf Mountain Shale units depends on that portion of the delta sequence exposed or penetrated. Typical stratigraphy of the various delta facies is described in Table 2. The sandstone facies containing potable water are of particular interest to this study and are generally depicted as occurring in areas delineated by Figure 10.

Table 2.—Characteristics of Perrin Deltaic Constructional Facies (Modified from Cleaves and Erxleben, 1982)

DELTA CONSTRUCTIONAL FACIES		COMPOSITION AND TEXTURE	BEDDING, THICKNESS AND LATERAL EXTENT	CONTACTS WITH ASSOCIATED FACIES	COMMON SEDIMENTARY STRUCTURES
FLUVIAL (COARSE GRAINED MEANDERBELT TO BRAIDED)		MEDIUM TO COARSE GRAINED QUARTZ SANDSTONE AND CHERT PEBBLE CONGLOMERATE	MASSIVE TO HEAVILY CROSS BEDDED; 10 FT. TO 20 FT. THICK; A FEW FEET TO SEVERAL HUNDRED FEET ACROSS INDIVIDUAL BODIES	CONTACTS SHART (EROSIONAL) BELOW; SHARP TO GRADATIONAL ABOVE; CHANNEL-LIKE UNITS PINCH OUT LATERALLY	ABUNDANT MEDIUM TO LARGE SCALE TROUGHS; CONGLOMERATES APPEAR LOCALLY HOMOGENEOUS
DELTA PLAIN		SANDY, SILTY MUDSTONE; LOCAL COALS AND COALY MUDSTONE—**NOTE**: NOT COMMON IN OUTCROPPING CANYON GROUP	COMMONLY LAMINATED TO THIN BEDDED TO HOMOGENEOUS; 1 FT. TO 10 FT. THICK; LOCAL AREAL EXTENT	ABRUPT TO GRADATIONAL BELOW; GENERALLY GRADATIONAL ABOVE; PINCHES OUT OR GRADES LATERALLY INTO EMBAYMENT FACIES	LAMINATED TO ROOT MOTTLED TO BURROWED; MAY APPEAR HOMOGENEOUS; COALS POORLY INDURATED AND "DIRTY", MANY OF DETRITAL ORGIN
DISTRIBUTARY CHANNEL		FINE TO MEDIUM GRAINED QUARTZ SANDSTONE; LOCALLY "DIRTY" WITH CLAY FLECKS; LOCAL CLAY CALL CONGLOMERATES	COMMONLY THICK BEDDED TO MASSIVE 8 FT. TO 40 FT. THICK; COMMONLY 10 FT. TO 20 FT. THICK; A FEW FEET TO A FEW HUNDERED FEET ACROSS	CONTACTS SHARP (EROSIONAL) TO SLIGHTLY GRADATIONAL ABOVE AND BELOW; UNIT THINS TO 0' LATERALLY	ABUNDANT TROUGH GROSS BEDS; MAY APPEAR HOMOGENEOUS; LOCAL CONTEMPORANEOUS FAULTS; LOCAL ABANDONED CHANNEL CUTOUTS WITH COALY MUDSTONE FILL; LOCALLY BURROWED
DELTA FRONT	**DISTRIBUTARY MOUTH BAR**	FINE GRAINED QUARTZ SANDSTONE, WELL SORTED, LOCAL CLAY FLECKS AND CLASTS	MEDIUM BEDDED TO MASSIVE AND CONTORTED; 10 FT. TO 150 FT. THICK; SEVERAL TENS OF FEET TO SEVERAL HUNDRED FEET ACROSS	ABRUPT ABOVE; GRADATIONAL TO RELATIVELY ABRUPT BELOW; GRADES LATERALLY INTO DELTA-FRONT, PRODELTA AND INTERDISTRIBUTARY FACIES	LARGE LOW ANGLE TROUGH CROSS BEDS; SANDSTONE LENSES, GROWTH FAULTS, LOAD FEATURES; MAY BE HIGHLY CONTORTED; COMMONLY BURROWED NEAR TOP
	PROXIMAL D.F.	FINE TO VERY FINE GRAINED QUARTZ SANDSTONE, WELL SORTED, LOCAL CLAY FLECKS	THIN TO THICK BEDDED WITH LOCAL SANDSTONE LENSES; A FEW FEET TO SEVERAL TENS OF FEET THICK; A FEW HUNDRED FEET TO A FEW MILES ACROSS (STRIKE)	GRADATIONAL TO ABRUPT ABOVE; GRADATIONAL TO RELATIVELY ABRUPT BELOW; GRADES LATERALLY INTO DISTAL DELTA-FRONT, PRODELTA, AND INTERDISTRIBUTARY FACIES	LOW ANGLE TROUGH CROSS BEDS; PARALLEL LAMINAE; CURRENT AND OSCILLATION RIPPLES ON TOP; LOAD FEATURES AND CONTORTED BEDS, GROWTH FAULTS; LOCAL BURROWS
	DISTAL D.F.	VERY FINE GRAINED SANDSTONE AND SILTSTONE BEDS IN SILTY, SANDY SHALE	THINLY BEDDED SANDSTONE IN LAMINATED SHALE; A FEW FEET TO 100 FEET THICK; A FEW HUNDRED FEET TO A FEW MILES ACROSS (STRIKE)	GRADATIONAL TO RELATIVELY ABRUPT ABOVE; GRADATIONAL BELOW; GRADES LATERALLY INTO PRODELTA AND SHELF MUDSTONE	SANDSTONES COMMONLY GRADED TO RIPPLED; LOAD AND FLUTE CASTS; HORIZONTAL BURROWS; SANDSTONES COMMONLY STRONGLY ROLLED AND CONTORTED.
PRODELTA		GRAY TO BLACK SILTY TO SANDY MUDSTONE WITH ABUNDANT RED FERRUCINOUS CLAYSTONE NODULES	WELL LAMINATED TO PLATY WITH THIN SANDSTONE AND SILTSTONE BEDS; 3 FT. TO 300 FT. THICK; A FEW YARDS TO A FEW MILES ACROSS (STRIKE)	GRADATIONAL ABOVE; GRADATIONAL TO ABRUPT BELOW; INTERFINGERS LATERALLY WITH SHELF MUDSTONE AND CARBONATE	HORIZONTAL LAMINAE, LOCAL HORIZONTAL BURROWS LOCALLY CONTORTED AND SWORLED

Brad Formation

The Brad Formation consists of two major units, the Placid Shale and the Ranger Limestone. The Brad is overlain by the Caddo Creek Formation and rests on the Graford Formation, both of the Canyon Group (Table 1). Potable ground water occurs in sandstone units within the Placid Shale interval.

Brad Formation units dip to the northwest at about 52 feet per mile through Jack County. Figure 11 depicts the areal extent of sandstone outcrops within the Placid Shale interval along with the net-sandstone thickness in the subsurface. The inferred sediment input direction is from the southeast with the thickest accumulation of sandstone in the northeast part of the county. Net-sandstone thickness ranges from less than 50 feet to over 150 feet.

Units of the Placid Shale containing potable water consist primarily of fine-grained sandstones of reworked shallow-water delta-front and bar finger origin; fine- to medium-grained, cross bedded sandstone of distributary channel and delta-front origin; and coarse-grained sandstone and chert-pebble conglomerate of fluvial channel origin.

Caddo Creek Formation

Major units of the Caddo Creek Formation consist of the Colony Creek Shale and the Home Creek Limestone. The Home Creek Limestone marks the top of the Canyon Group and is overlain by the Graham Formation of the Cisco Group. Brad Formation units occur immediately below the Caddo Creek

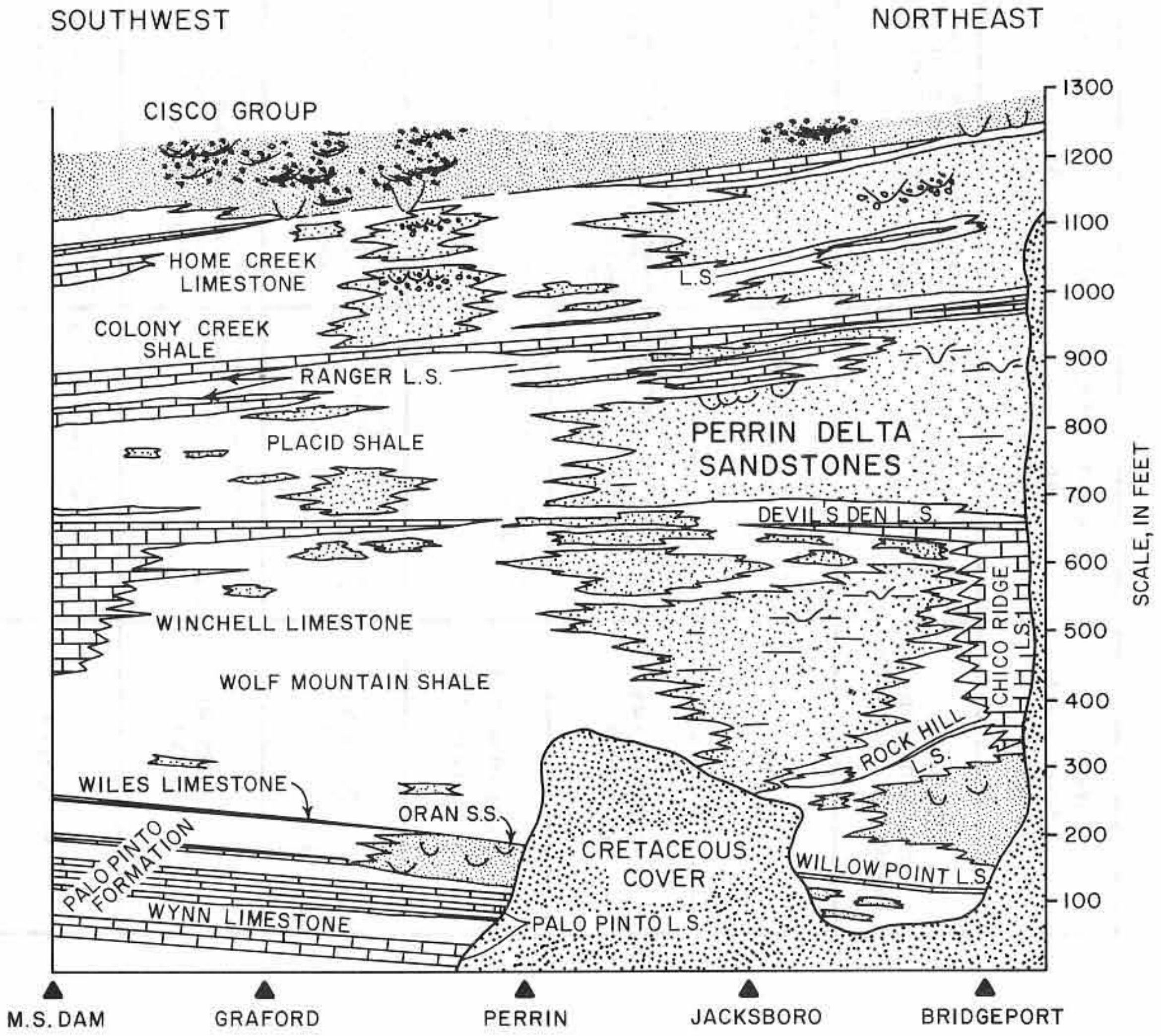


Figure 8.–Schematic Facies Section Along Outcrop, Canyon Group, Northern Palo Pinto, Southeastern Jack, and Western Wise Counties, Texas

(Table 1). Potable ground water is obtained primarily from sandstone units within the Colony Creek Shale interval.

Caddo Creek Formation units dip to the northwest at about 55 feet per mile through northwest Jack County. Figure 12 shows the areal extent of the sandstone and conglomerate outcrop, the net-sandstone thickness, and the inferred sediment input direction for the Colony Creek Shale interval. Net-sandstone thickness ranges from less than 50 feet to over 150 feet.

Units of the Colony Creek Shale containing potable water consist primarily of fine-grained sandstone of delta-destructional, delta front, and distributary channel origin; and coarse-grained sandstone and conglomerate of fluvial channel origin. The predominant sequence could be summed up as fine-grained deltaic sandstone units overlying and flanking sandy prodelta and interdeltaic mudstone facies (Erxleben, 1975). As with the previous formations, emphasis will be placed on the water-bearing sandstone facies.

Cisco Group

The Cisco Group is composed of both terrigenous clastics and carbonates deposited in the Cisco fluvial-deltaic depositional system. These systems crop out in a northeast-southwest trend through the northwestern half of Jack County. The regional dip is toward the northwest at approximately 50 feet per mile. Emphasis will be placed on the sandstone facies of the Graham and Thrifty Formations, which are the predominant source of potable ground water from the Cisco Group in Jack County.

Graham Formation

Units making up the Graham Formation, listed in order from oldest to youngest, are the Finis Shale, Gonzales Creek Member, Bunger Limestone, Necessity Shale, Gunsight Limestone, and Wayland Shale. Water-bearing sandstone units within the Gonzales Creek Member constitute the major source of potable ground water in the Graham Formation. Numerous other unnamed sandstone beds occurring between major limestone sequences also provide a source of ground water to domestic and livestock wells.

The Graham Formation forms the base of the Cisco Group and is overlain by the Thrifty Formation (Table 1). Thicknesses of sandstone units vary considerably, due to the discontinuous nature of the beds. Test hole PL-20-45-910 has a net-sandstone thickness of about 50 feet.

Sandstone origins are from two depositional systems, fluvial and deltaic. Fluvial system units consist of braided facies of medium- to coarse-grained sandstones and conglomerate with cross-beds, chert pebbles, and little mud; meander belts of siltstone and fine-grained sandstones; distributary-channel fill of fine- to medium-grained sandstone; and valley-fill fluvial of upward fining beds from coarse gravel to medium-grained sandstone with trough cross-beds. Typical deltaic system facies in the Cisco Group are similar to those described in Canyon Group sequences. Bar-finger sandstones consisting of delta-front, channel- mouth-bar, and distributary-channel facies are common, interspersed with mudstones of prodelta and interdistributary origin.

Thrifty Formation

Thrifty Formation units listed in order from oldest to youngest are the Avis Sandstone, Ivan Limestone, Blach Ranch Limestone, and Breckenridge Limestone. Interspersed between these limestone sequences are numerous unnamed sandstone and mudstone units. The Avis Sandstone and many of the unnamed sandstone units provide small quantities of potable ground water to wells in northwest Jack County. Origin and stratigraphy of the sandstone units are similar to that of the Graham Formation.

Trinity Group

Trinity Group formations of Cretaceous age crop out in southeast Jack County, with small outliers occurring along the eastern boundary of the county (Figure 6). Formations include the Twin Mountains, Glen Rose, Paluxy, and Antlers. Along the northeast boundary between Jack, Montague, and Wise Counties, outliers of Antlers Formation occur. The Antlers Formation is the lateral equivalent of the Twin Mountains and Paluxy Formations, occurring north of the updip limit of the Glen Rose Formation. Small quantities of potable ground-water are available primarily from the Twin Mountains Formation in the southeast-

ern corner of Jack County. Sands of the Twin Mountains and Antlers Formations provide a vehicle to the recharge of underlying Pennsylvanian sandstones.

In contrast to the Pennsylvanian units, Cretaceous formations dip to the southeast at about 20 feet per mile. Total thickness varies from a thin veneer to approximately 200 feet. According to drillers' logs of wells completed through the Cretaceous, the maximum thickness of the Twin Mountains Formation is about 120 feet.

Rocks of the Trinity Group in Jack County consist of basal conglomerate and gravel overlain by poorly consolidated, massive, crossbedded, fine- to coarse-grained, white to light-gray sand. Lenticular beds of multicolored clay occur within the sand. In the southeast corner of Jack County, sands are separated by the Glen Rose Limestone, which consists primarily of limestone with thin beds of shale and marl.

Alluvium

Alluvial deposits composed of fine sand, silt, clay, and gravel occur in the floodplains of and bordering many of the streambeds within the county. These stream deposits are probably derived from older Pleistocene sediments and from Permian and Pennsylvanian rocks. The thickness of the alluvium is believed to be no greater than 60 feet.

The geologic map (Figure 6) outlines the principal alluvium deposits. Alluvium is also present along numerous tributaries, but is not shown on the geologic map in all cases. A few wells with small yields produce water from the alluvium.

GENERAL GROUND-WATER HYDROLOGY

Hydrologic Cycle

Water used by humans whether it be from rain, spring discharge, or water from wells, is captured in transit, and after its use and reuse, is returned to the hydrologic cycle. The different courses water may take to complete the hydrologic cycle are shown in Figure 13.

Source and Occurence

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

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

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

Water occurs and is stored in pores or voids between the rock particles. The two fundamental rock characteristics which are important in the occurrence of ground water are porosity, or the ratio of the volume of void space to the total rock volume expressed as a percentage, and permeability, which is the ability of a porous material to transmit water. The porosity of a rock is dependent upon the shape, size, sorting, and the amount of cementation of the grains. Clays, silts, and soils which are fine-grained sediments, commonly have high porosity, however, they do not readily transmit water because of the small size of the voids and low permeabilities. Because of their high porosities, which range from 40 to 60 percent, the fine-grained sediments are capable of storing large quantities of water.

In aquifers containing sands and gravels which are relatively unconsolidated, ground water occurs in the spaces between the individual particles. In aquifers such as limestones, dolomites, and other more compact and well-cemented rocks, ground water occurs mainly in fractures and cracks caused by force of earth movement or in spaces dissolved by the action of water.

Recharge, Movement, and Discharge

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

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

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

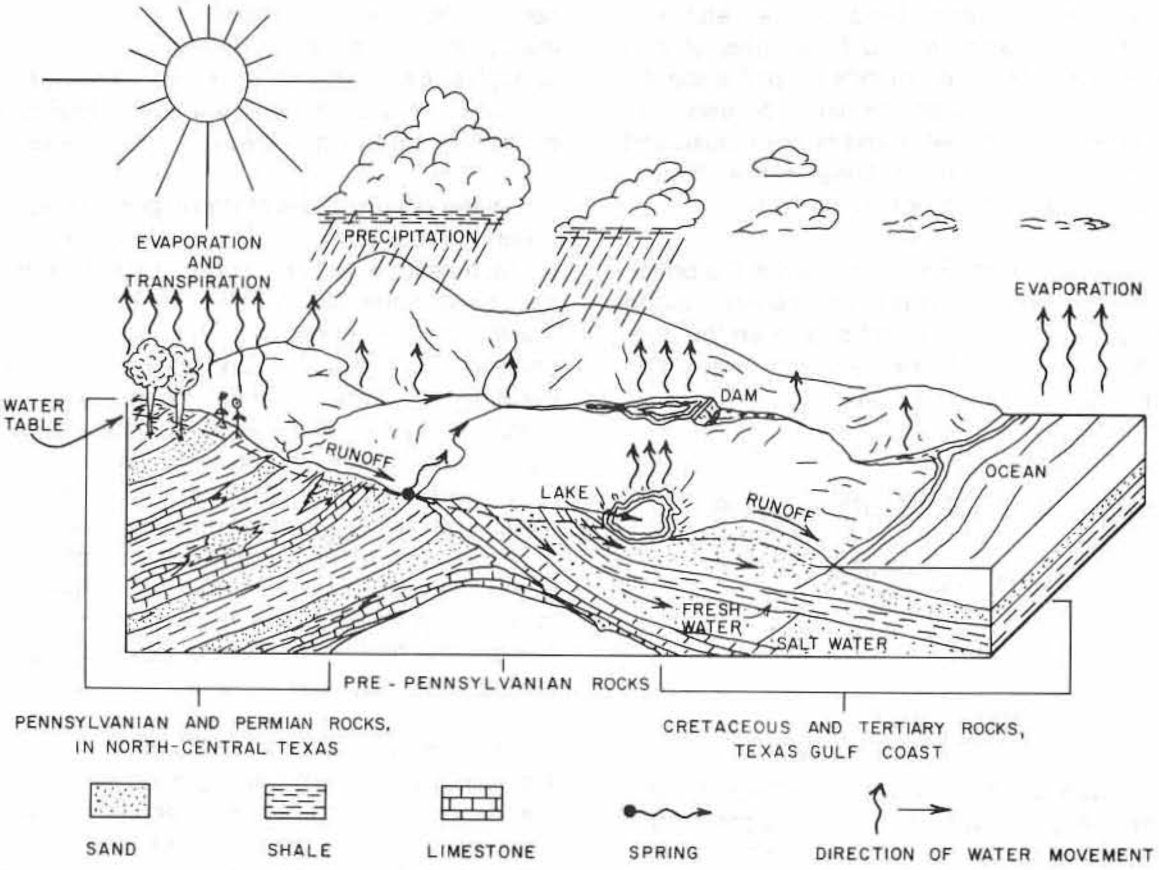


Figure 13.–Diagram of the Hydrologic Cycle

are the recharge available for interception by pumping and the rate at which water can flow from the recharge area to the wells.

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

Hydraulic Characteristics

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

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

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

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

Fluctuations of Water Levels

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

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

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

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

CHEMICAL QUALITY OF GROUND WATER

General Chemical Quality or Standards

The types and concentrations of dissolved minerals carried in ground water are derived mainly from the soil and rocks through which the water percolates. As the water moves through its environment, the solvent action of water dissolves some of the minerals from the surrounding rocks. The concentration of the various dissolved-mineral constituents depends upon the source of the ground water, the solubility of the minerals in the formation, the length of time the water is in contact with the rock, and the concentration of carbon dioxide present within the water. Therefore, the chemical character of the water mirrors the general mineral composition of the earth through which it has passed. Additionally, dissolved-mineral concentrations increase with depth and temperature, and in zones of restricted circulation. The source, significance, and concentration of dissolved-mineral constituents and properties of water in Jack County are given in Table 3.

A total of 389 chemical analyses of water from wells, springs, and test holes in Jack and adjacent Counties were used in this study. The sampled wells are indicated on Figure 31 by a bar over the well number. Concentrations of sulfates, chlorides, and dissolved solids from samples taken from selected wells and springs in Jack County are shown on Figure 14.

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 chemical constituents. Water-quality problems associated with the first two subjects can usually be alleviated economically. However, the neutralization or removal of most of the unwanted chemical constituents is usually difficult and often very costly.

The dissolved-solids content is usually the main factor which limits or determines the use of ground water. Winslow and Kister (1956) used an 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 parts per million. These units, for practical purposes, are identical until the dissolved-solids concentration of water reaches or exceeds 7,000 units (ppm or mg/l). Most of the chemical concentrations in the study area are below 7,000 mg/l and, therefore, the units are interchangeable. For the more highly mineralized waters, a density correction should be made using the following formula:

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

The property of water known as hardness is associated primarily with reactions of water to soap. As hardness increases, so does the soap-consuming ability of water. Since most of these effects result from the presence of calcium and magnesium, hardness is defined quantitatively as the summation of milliequivalents per liter of calcium, magnesium, barium, and strontium times 50.05 (Skougstad and others, 1979, p. 281). In many cases, the contribution of barium and strontium are insignificant compared to those of calcium and magnesium and can be safely ignored. Hardness is reported as an equivalent concentration of calcium carbonate ($CaCO_3$) in mg/l. Durfor and Becker (1964, p.27) of the U.S. Geological Survey use the following classification:

Table 3. - Source, Significance, and Concentration of Dissolved-Mineral Constituents and Properties of Water in Jack County

(Adapted from Doll and others, 1963, p. 39-43; Durfor and Becker, 1964, p. 16-35; and Hem, 1970)

Analyses are in milligrams per liter except percent sodium, SAR, RSC, specific conductance, and pH. In the concentration by aquifer chart, the figure above the line refers to the mean; figures below the line refer to minimum-maximum range.

Constituent or property	Source or cause	Significance	Concentration in natural water	MEAN AND RANGE IN CONCENTRATIONS, BY AQUIFER					
				Thrifty	Graham	Colony Creek	Placid	Wolf Mountain	Palo Pinto
Silica (SiO_2)	Mainly from feldspars, ferro-magnesium and clay minerals, and silica chert. Probably most dissolved silica observed in natural water results from chemical breakdown of silicate minerals during the weathering process.	In presence of calcium and magnesium, forms scale in pipes, boilers, and steam turbines that retards heat and is difficult to remove. Inhibits deterioration of zeolite-type water softeners. Can be added to soft water to inhibit corrosion of iron pipes.	Ranges generally from 1 - 30 mg/1, though concentrations up to 100 mg/1 are not uncommon in some areas. Median value for ground water is about 17 mg/1. Higher values are generally found in ground water and are related to rock type and temperature.	12 ◄1 - 20	13 1 - 29	13 ◄1 - 23	13 ◄1 - 24	17 9 - 23	13 9 - 23
Iron (Fe)	Mainly igenous rocks and sandstone rocks (oxides, carbonates, and sulfides of iron-clay-minerals). May also be derived from well casings, pipes, pumps, storage tanks, and other objects of cast iron and steel.	Even though clear when first drawn from a well, more than 0.1 mg/1 precipitates ferric hydroxide after exposure to air, thus causing reddish-brown coloration. Causes turbidity, stains plumbing fixtures, laundry, and cooking utensils, and imparts objectionable tastes and colors to food and drinks. May favor growth of iron bacteria. More than 0.2 mg/1 is objectionable for most industrial purposes. Texas Dept. of Health (1980) drinking water standards state that iron should not exceed 0.3 mg/1.	In many areas, occurrence of 1.0 - 10 mg/1 of iron in ground water is common. Ground water with pH between 6 and 8 may contain as much as 50 mg/1 ferrous iron. Very low pH's can result in extremely high concentrations. Recharge through strata containing oxidized iron minerals and organic debris provides favorable iron source.	.3 .02 - .6	3.9 .02 - 40.3	.18 .01 - 1.1	.09 .03 - .18	.34 .11 - .77	.03 .02 - .04
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxene, aragonite, calcite, dolomite, clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form heat-retarding, pipe-clogging scale in boilers and other heat-exchange equipment. Soap consuming (see hardness). Low concentrations desirable in electroplating, tanning, dyeing, and in textile manufacturing. High concentration of magnesium has a laxative effect, especially on new users of the supply.	In most instances, the magnesium concentration is much lower than that of calcium. Found in large quantities in some brines. Magnesium in sea water can exceed 1,000 mg/1.	60 2 - 340	73 .6 - 379	43 1 - 161	66 8 - 310	48 6 - 113	23 1 - 94
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals.			19 .2 - 152	22 .1 - 104	14 .5 - 63	18 1 - 104	19 2 - 29	10 .1 - 48
Sodium (Na)	Feldspars, clay minerals, evaporites, and industrial wastes.	Large amounts, in combination with chloride, give a salty taste, moderate quantities have little effect on the usefulness of water for most purposes. More than 50 mg/1 sodium and potassium in presence of suspended matter can cause foaming in steam boilers. A high sodium content may limit the use of water for irrigation.	As much as 1,000 ppm in some western streams; about 10,000 ppm in sea water; about 25,000 ppm in brines.	445 22 - 2,862	412 8 - 2,117	464 14 - 1,803	587 34 - 3,209	188 83 - 452	316 34 - 1,148
Potassium (K)	Feldspars, some micas, clay minerals		Generally less than 10 mg/1; as much as 100 mg/1 in hot springs; as much as 25,000 ppm in brines.	2.5 1 - 6.0	8.5 1.0 - 44	4.0 1.0 - 7.0	5.8 1.0 - 15	2.5 2.0 - 3.0	———
Carbonate (CO_3)	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.	Usually present when pH exceeds 8.3. Commonly less than 10 mg/1 in ground water.	3 0 - 20	8 0 - 270	8 0 - 169	3 0 - 26	4 0 - 29	6 0 - 22
Bicarbonate (HCO_3)			Commonly less than 500 mg/1. May exceed 1,000 mg/1 in water highly charged with carbon dioxide (CO_2).	424 110 - 724	439 49 - 700	468 154 - 744	428 225 - 871	417 193 - 835	494 248 - 789
Sulfate (SO_4)	Oxidation of sulfide ores; gypsum, anhydrite, industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. Water containing about 500 mg/1 sulfate tastes bitter; water containing about 1,000 mg/1 may be cathartic. Texas Dept. of Health (1980) drinking water standards recommend that the sulfate content not exceed 300 mg/1.	Commonly less than 1,000 mg/1. Low sulfate concentrations can result from bacterial reduction of sulfate in anaerobic sediments or ground-water aquifers. Magnesium and sodium sulfates are highly soluble, and water containing these components can attain sulfate concentrations in excess of 100,000 mg/1.	120 16 - 554	243 7 - 1,378	246 13 - 1,691	152 21 - 588	78 31 - 153	95 11 - 451
Chloride (Cl)	Chief source is sedimentary rocks (evaporites); present in sewage and found in large amounts in oil-field brines, sea water, and industrial wastes.	Chloride in excess of 100 mg/1 imparts a salty taste; in large quantities, increases the corrosiveness of water. Food processing industries usually require less than 250 mg/1; Texas Dept. of Health (1980) drinking water standards recommend a chloride content not to exceed 300 mg/1.	About 19,000 mg/1 in sea water and as much as 190,000 mg/1 in brines.	505 20 - 4,424	452 13 - 3,192	410 18 - 2,337	844 15 - 5,008	175 22 - 355	181 20 - 1,168
Fluoride (F)	Amphiboles, apatite, mica, fluorite. Added to many waters by fluoridation of public supplies.	Fluoride concentration between 0.6 and 1.7 mg/1 in drinking water has a beneficial effect on the structure and resistance to decay of childrens teeth. However, it may cause mottling of teeth depending on the concentration, age of child, amount of water consumed, and susceptibility of the individual (Maier, 1950, p. 1120-1132). Texas Dept. of Health (1980) drinking water standards recommend limits as shown on Figure 16.	Concentrations generally do not exceed 10 mg/1 in ground water or 1.0 mg/1 in surface water; may be as much as 1,600 mg/1 in brines.	1.2 .3 - 3.8	1.4 .1 - 4.2	1.8 ◄.1 - 7.5	1.3 .3 - 5.1	.6 .3 - 1.3	1.2 .2 - 4.0

Table 3. - Source, Significance, and Concentration of Dissolved-Mineral Constituents and Properties of Water in Jack County — Continued

Constituent or property	Source or cause	Significance	Concentration in natural water	MEAN AND RANGE IN CONCENTRATIONS, BY AQUIFER					
				Thrifty	Graham	Colony Creek	Placid	Wolf Mountain	Palo Pinto
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. Texas Dept. of Health (1980) drinking water standards suggest a limit of 10 mg/1 as N (44.3 mg/1 as NO_3). Water 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 (Maxey, 1950, p. 271). Nitrate shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.	Usually small when not influenced by sewage or ranching-farming activities. Some areas of high nitrates do occur naturally.	4.5 ◄ .04 - 62.0	4.8 ◄ .04 - 49.6	5.7 ◄ .04 - 79.8	30.0 ◄ .04 - 564.0	2.3 ◄ .04 - 12.5	4.0 ◄ .04 - 49.4
Dissolved solids	Mineral constituents dissolved in water.	Texas Dept. of Health (1980) drinking water standards recommend that waters containing more than 1,000 mg/1 dissolved solids not be used if other less mineralized supplies are available. For many purposes the dissolved-solids content is a major limitation on water use.	Ground water commonly contains less than 5,000 ppm; some brines contain as much as 300,000 ppm.	1,377 318 - 7,558	1,576 108 - 6,310	1,448 253 - 4,924	1,852 365 - 8,700	709 480 - 1,163	906 433 - 3,050
Hardness as $CaCO_3$	Caused principally by calcium and magnesium ions, but other alkaline earths (barium and strontium) and free acid and heavy-metal ions contribute to hardness.	Water low in hardness causes corrosion of metallic surfaces. Hard water consumes excessive amounts of soap. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the HCO_3 and CO_3 is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. A hardness value of less than 100 mg/1 is considered desirable for domestic use.	Hardness as $CaCO_3$ = me/1(Ca+Mg+Ba+Sr) × 50.05 or 2.5(mg/1 Ca) + 4.1(mg/1 Mg), since Ba and Sr content is usually small or not measured. Non-carbonate hardness (mg/1 $CaCO_3$ = (me/1 hardness - me/1 alkalinity) × 50.05.	222 6 - 1,476	310 2 - 1,882	172 8 - 549	252 18 - 1,160	198 23 - 399	72 5 - 488
Specific conductance (micromhos at 25°C)	Mineral content of water	Indicates degree of mineralization; is a measure of the electrical conductivity of water and varies with the amount of dissolved solids.	Used to approximate the dissolved-solids content; though not constant, dissolved solids is about 65 percent of the specific conductance.	2,736 610 - 16,200	2,603 180 - 13,100	3,000 670 - 17,900	3,874 670 - 17,900	983 870 - 3,180	1,683 830 - 5,920
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 attach metals.	pH of ground water commonly ranges from 6.0 to 9.0	8.2 7.2 - 8.8	8.1 7.2 - 10.5	8.1 7.3 - 9.8	8.1 7.2 - 8.5	8.1 7.5 - 8.4	8.4 7.7 - 8.9
Percent sodium (%Na)	Sodium in water.	A ratio of the sodium ions to total cations. A sodium percentage exceeding 60 percent is a warning of a sodium hazard. Continued irrigation with this type of water will impair the tilth and permeability of the soil.	$\%Na = \frac{me/1\ Na \times 100}{me/1(Na + K + Mg + Ca)}$	71 13 - 99	64 10 - 99	76 14 - 99	70 24 - 98	59 42 - 97	55 17 - 99
Sodium-adsorption ration (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).	$SAR = \frac{me/1\ Na}{\sqrt{\frac{me/1(Ca + Mg)}{2}}}$	24.7 .5 - 78.5	22.4 .3 - 206.0	24.0 .4 - 77.7	19.3 .8 - 68.1	8.5 2.3 - 41.0	26.8 .8 - 62.1
Residual sodium carbonate (RSC)	Sodium, carbonate, and bicarbonate in water.	As calicum and magnesium precipitates as carbonates in the soil, the relative proportion of sodium in the water is increased (Eaton, 1950, p. 123 - 133).	$RSC = me/1(CO_3 + HCO_3) - me/1\ (Ca + Mg)$	4.0 0 - 12.1	3.3 0 - 11.3	5.0 0 - 11.8	3.2 0 - 13.9	3.2 0 - 14.1	6.6 0 - 11.6

Hardness range (mg/l of $CaCO_3$)	Hardness description
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
More than 180	Very hard

For general domestic use, hardness of water is not particularly objectionable until it attains about 100 mg/l (Hem, 1970, p. 225).

Specific conductance is a measure of the ability of water to transmit a small electrical current, and is reported in this study as micromhos at 25°C. Values of specific conductance can be used as a quick determination of the amount of dissolved solids in water. The charged ions in solution makes it conductive, and as the ionic concentration increases, the specific conductance of the solution increases (Hem, 1970, p. 96). Normally, dissolved solids is approximately 65 percent of the specific conductance. This relationship is not constant from well to well, and may even change within the same well with a change in chemical composition. Generally, for highly mineralized water, the dissolved solids is more than 65 percent of the conductivity; for water containing large amounts of acid, caustic soda, or sodium chloride, the dissolved solids is less than 65 percent (Durfor and Becker, 1964, p. 29).

Figure 15 is a plot of the dissolved solids contained in samples of water from wells completed in the Cisco Group against the specific conductance of the samples. The resulting well-defined relationship indicated for this plot shows that for any given conductance value, a dissolved-solids value can be estimated. Most dissolved-solid values of the 141 samples fall in the range of 47 to 60 percent of the conductivity, with higher values generally associated with waters high in sulfate (SO_4) concentration. An overall average of 53 percent of the conductivity seems to be the average from water derived from the Pennsylvanian formations in Jack County.

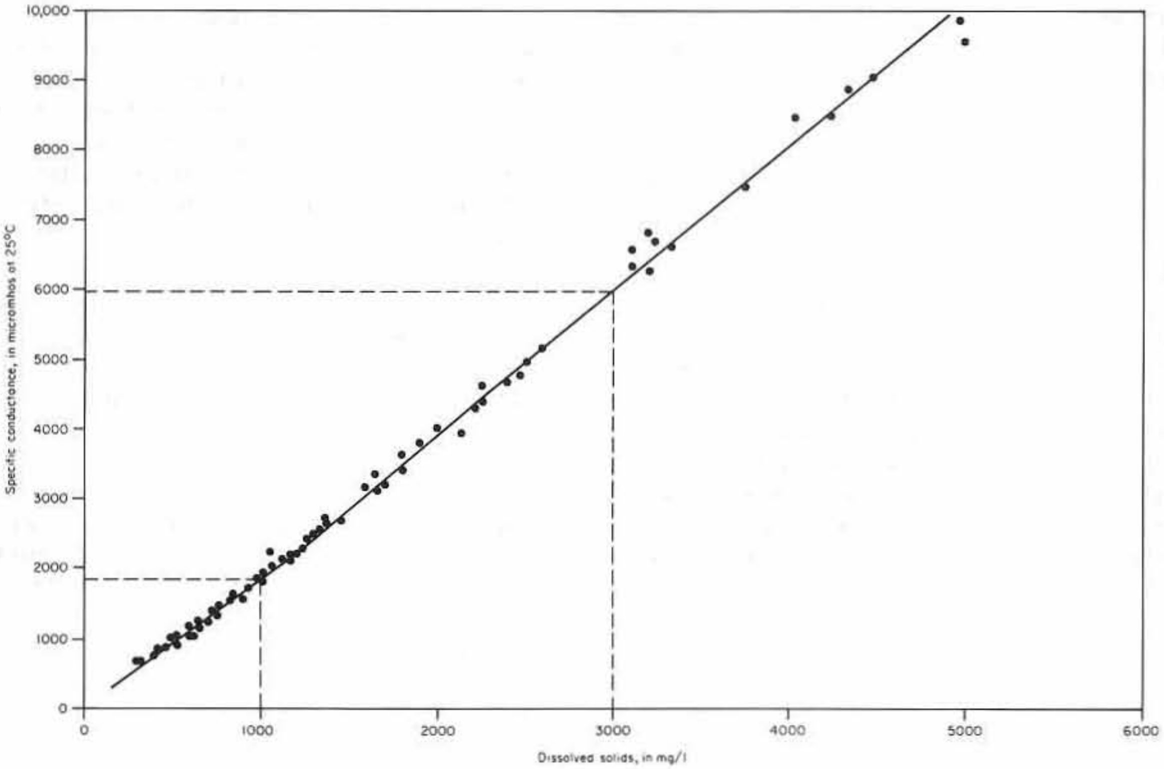


Figure 15.–Dissolved Solids and Specific Conductance of Water From Wells Completed in the Cisco Group, Jack County

Public Supply

As the first step in setting national standards for drinking water quality under the provisions of the Safe Drinking Water Act of 1974, the U.S. Environmental Protection Agency (EPA) issued drinking water regulations on December 10, 1975. These standards apply, selectively, to all types of public water systems of Texas and became effective July 1, 1977. The responsibility for enforcement of these standards was assumed by the Texas Department of Health. Minor revisions of the standards have occurred, the last one became effective on November 29, 1980.

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

1. A "public water system" is any system for the provision to the public of piped water for human consumption, if such a system has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year.

2. A "community water system" is a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

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

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

Primary Standards

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

Contaminant	Maximum concentration (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	.01
Chromium (Cr)	.05
Lead (Pb)	.05
Mercury (Hg)	.002
Nitrate (as N)	10.0
Selenium (Se)	.01
Silver (Ag)	.05

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 44.3 mg/l nitrate as $N0_3$) applies to community and non-community systems alike. Water having an excess concentration of nitrate 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 contamination.

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

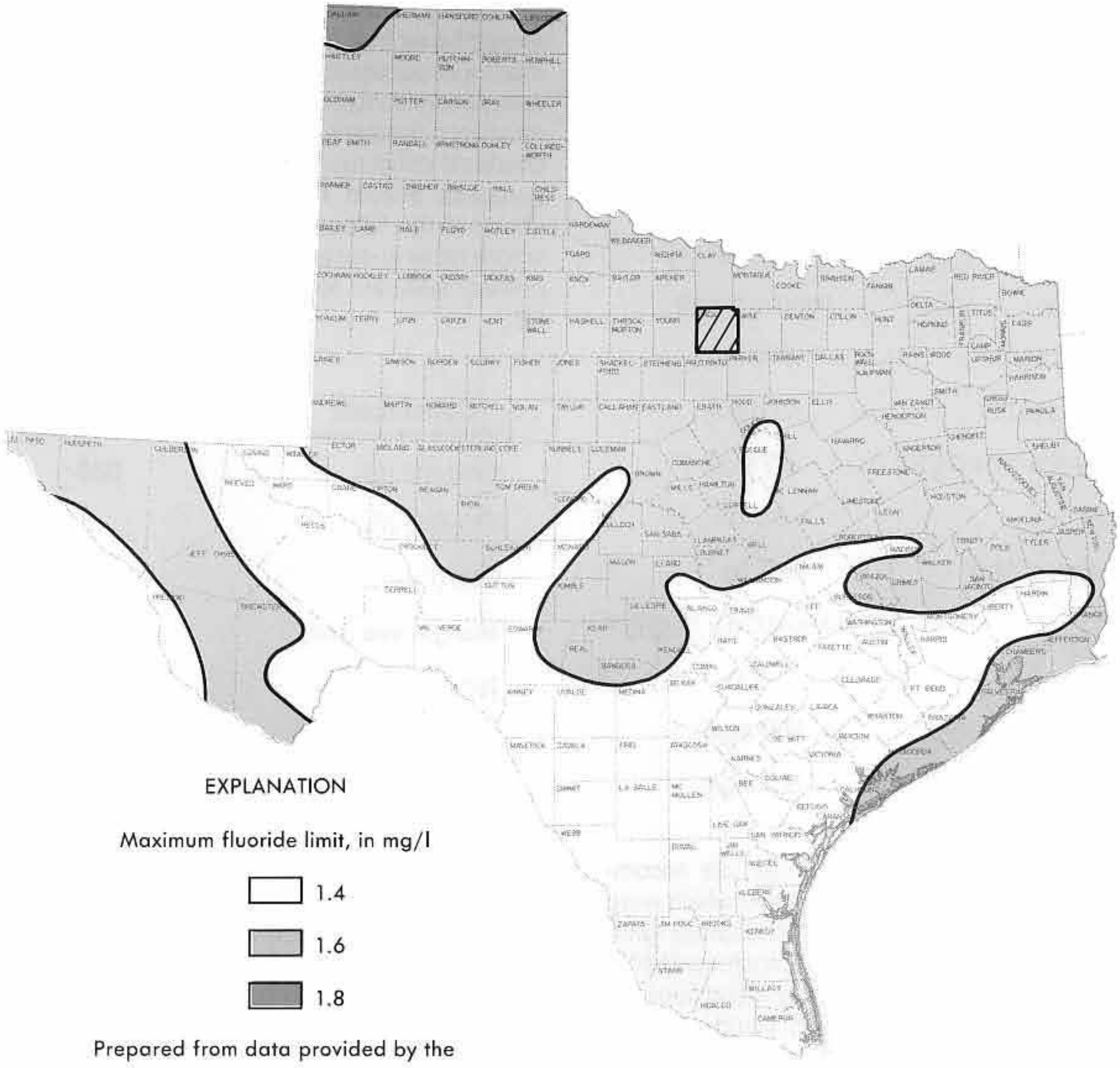
Temperature (°F)	Temperature (°F)	Maximum concentration (mg/l)
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Figure 16 shows the maximum fluoride limits in Texas based on the annual average daily maximum air temperature.

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

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



Prepared from data provided by the
Weather and Climate Section, Texas Water Commission

Figure 16.–Maximum Fluoride Limits in Texas

community and non-community water systems alike. 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
Dissolved solids	1,000 mg/l
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
Zinc (Zn)	5.0 mg/l

The above secondary standards are recommended limits, except for water systems which were 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 or not 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 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 (the primary standard for nitrate should still be adhered to):

Constituent	Concentration (mg/l)
Chloride (Cl)	300
Fluoride (F)	1.6*
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (as N)	10
Nitrate (as NO3)	44.3
Sulfate (SO4)	300
Dissolved solids	1,000

* Maximum fluoride limit for Jack County based on annual average ofmaximum daily air temperature range of 70.7-79.2°F.

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 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 similar 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 solubles salts determine the tolerance limits (Heller, 1933, p. 22). In the western United States, cattle may tolerate drinking water containing nearly 10,000 mg/l dissolved solids providing these waters contain mostly sodium and chloride (Hem, 1970, p. 324). Waters containing high concentrations of sulfate are usually considered undesirable for livestock use. Many investigators recommend an upper limit of dissolved solids near 5,000 mg/l. Obviously, concentrations considerably below the upper limit are necessary for maximum growth and reproduction. Hem (1970, p. 324) cited a publication of the Department of Agriculture of the state of Western Australia as recommending the following upper limits for dissolved-solids concentration in livestock water.

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

Irrigation

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

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

High concentrations of dissolved salts in irrigation water may cause a buildup of salts in the soil solution. Increased salinity of the soil may drastically reduce crop yields by decreasing the ability of the plants to take up water and essential plant nutrients from soil solution. The tendency of irrigation water to cause a high buildup of salts in the soil is called the salinity hazard of the water. The specific conductance of the water is used as an index of the salinity hazard. The conductivity is measured in micromhos per centimeter at 25°C. In general, water having a specific conductance below 750 micromhos at 25°C is satisfactory for irrigation; however, salt-sensitive crops, such as strawberries and green beans, may be adversely affected by irrigation water having a specific conductance in the range of 250 to 750 micromhos at 25°C. Water in the range of 750 to 2,250 micromhos at 25°C is widely used, and satisfactory crop growth is obtained under good management (U.S. Salinity Laboratory Staff, 1954).

High concentrations of sodium relative to the concentrations of calcium and magnesium in irrigation water may adversely affect soil structure. Cations in the soil solution become fixed on the surface of the soil particles; calcium and magnesium tend to flocculate the particles, whereas sodium tends to deflocculate the colloidal soil particles. Consequently, soils may become plastic, movement of water through the soil can be restricted, drainage problems can develop, and cultivation can be rendered difficult. This adverse effect on soil structure caused by high sodium concentrations in an irrigation water is called the sodium hazard. An index used for predicting the sodium hazard is the sodium-adsorption ratio (SAR) which is defined by the equation given in Table 3. A high SAR in irrigation water affects the soil by forming a hard impermeable crust that results in cultivation and drainage problems. Under most conditions, irrigation waters having a sodium percentage of less than 60, and a low bicarbonate content are probably satisfactory. The sodium hazard becomes progressively greater as the sodium percentage increases above 60.

The U.S. Salinity Laboratory Staff (1954, p. 69-82) has prepared a classification diagram for irrigation waters in terms of salinity and sodium hazards. This diagram, reproduced in modified form in Figure 17, uses SAR and specific conductance in classifying irrigation waters. With respect to both the salinity and sodium hazards, waters are divided into four classes: low, medium, high, and very high. The classification range encompasses those waters which can be used for irrigation of most crops on most soils as well as those generally unsuitable for irrigation.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Medium-sodium water (S2) will present an appreciable sodium hazard in certain fine-textured or organic soils having good permeability. High sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management such as good drainage and leaching and additional organic matter. Very high sodium water (S4) is generally unsatisfactory for irrigation unless special action is taken, such as addition of gypsum to the soil.

Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Crops of moderate salt tolerance, such as potatoes, corn, wheat, oats, and alfalfa, can be irrigated with C2 water without special practices. High-salinity water (C3) cannot be used on soils of restricted drainage. Very high-salinity water (C4) is not suitable for irrigation under ordinary conditions. It can be used only on very salt-tolerant crops and then only if special practices are followed, including a high degree of leaching. Relative tolerance of various crop plants, as determined by the United States Salinity Laboratory, are given in Table 4.

Another classification of irrigation waters, which is not as widely used as the classification depicted by Figure 17, is based on percent sodium versus specific conductance (Figure 18). It also includes soil texture and drainage in the interpretation.

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

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. Waters containing 1.25 to 2.5 me/l (milliequivalents per liter) of residual sodium carbonate (RSC) are considered marginal and those containing greater than 2.5 me/l probably are not suited for irrigation use (Wilcox, 1955). The equation for calculating RSC is given in Table 3.

Industrial

The type of industry determines the water-quality standards for an industrial water supply. The main concern to many industries in that the water selected for their supply does not contain corrosive or scale-forming constituents. Both magnesium and calcium

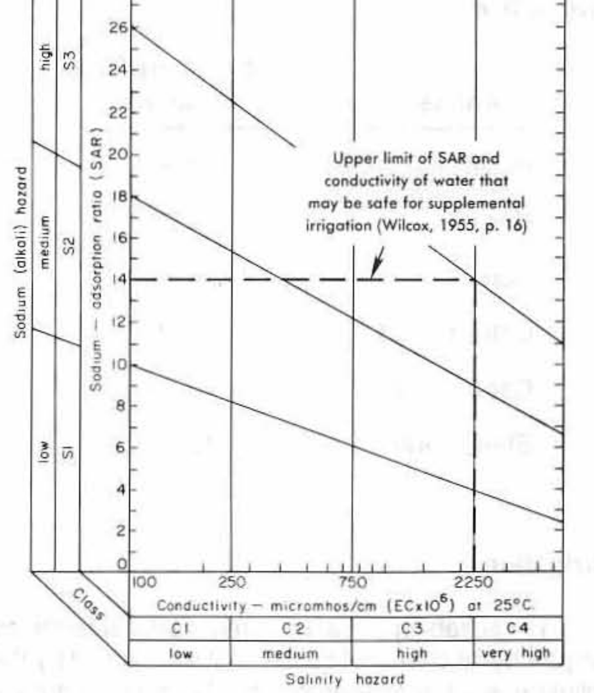


Figure 17.–Diagram for the Classification of Irrigation Waters

Table 4. — Relative Tolerance of Crop Plants to Salt

High Salt Tolerance

Fruit Crops

- Date palm

Vegetable Crops

- Garden beets
- Kale
- Asparagus
- Spinach

Forage Crops

- Alkali sacaton
- Saltgrass
- Nuttall alkali-grass
- Bermuda grass
- Rescue grass
- Canada wildrye
- Western wheatgrass
- Barley (hay)
- Birdsfoot trefoil

Field Crops

- Barley (grain)
- Sugar beet
- Rape
- Cotton

Medium Salt Tolerance

Fruit Crops

- Pomegranate
- Fig
- Olive
- Grape
- Cantaloup

Vegetable Crops

- Tomato
- Broccoli
- Cabbage
- Bell Pepper
- Cauliflower
- Lettuce
- Sweet corn

Medium Salt Tolerance
(Continued)

Vegetable Crops (Continued)

- Potatoes (White Rose)
- Carrot
- Onion
- Peas
- Squash
- Cucumber

Forage Crops

- White sweetclover
- Yellow sweetclover
- Perennial ryegrass
- Mountain brome
- Strawberry clover
- Dallis grass
- Sudan grass
- Hubam clover
- Alfalfa (California common)
- Tall fescue
- Rye (hay)
- Wheat (hay)
- Oats (hay)
- Orchardgrass
- Blue grama
- Meadow fescue
- Reed canary
- Big trefoil
- Smooth brome
- Tall meadow oatgrass
- Cicer milkvetch
- Sourclover
- Sickle milkvetch

Field Crops

- Rye (grain)
- Wheat (grain)
- Oats (grain)
- Rice
- Sorghum (grain)

Medium Salt Tolerance
(Continued)

Field Crops (Continued)

- Corn (field)
- Flax
- Sunflower
- Castor beans

Low Salt Tolerance

Fruit Crops

- Pear
- Apple
- Orange
- Grapefruit
- Prune
- Plum
- Almond
- Apricot
- Peach
- Strawberry
- Lemon
- Avocado

Vegetable Crops

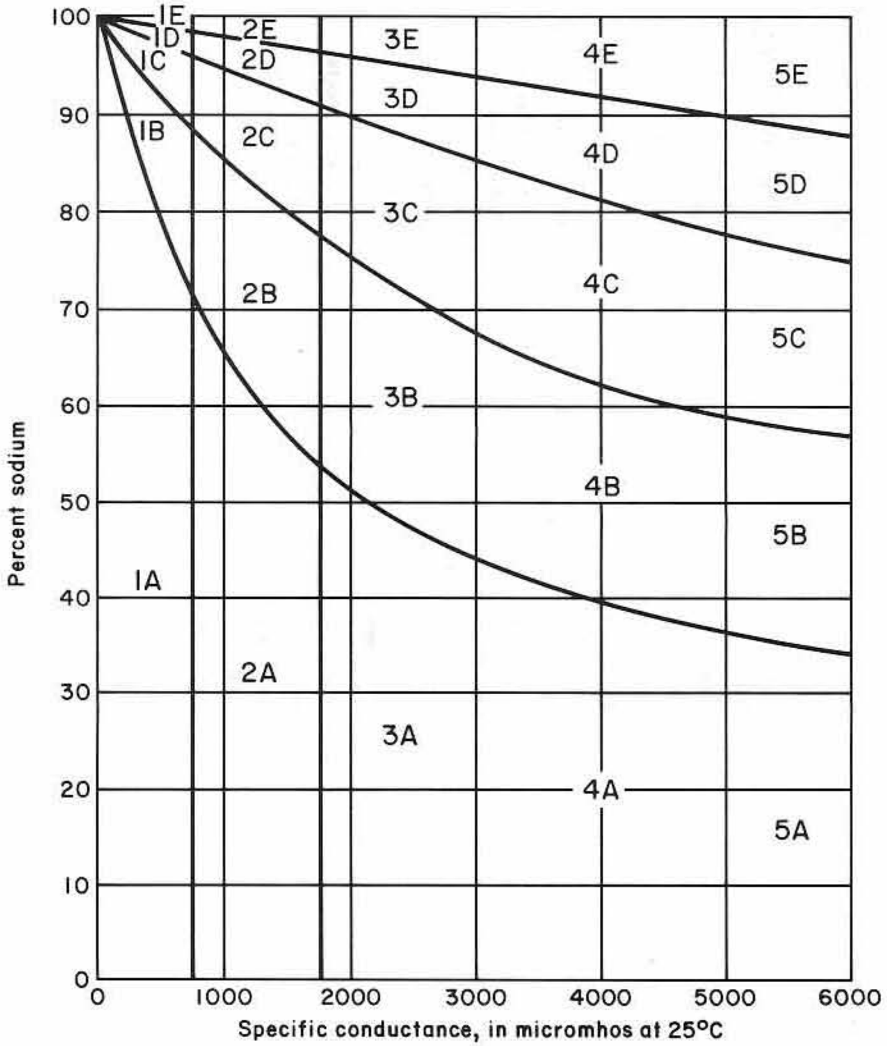
- Radish
- Celery
- Green beans

Forage Crops

- White Dutch clover
- Meadow foxtail
- Alsike clover
- Red clover
- Ladino clover
- Burnet

Field Crops

- Field beans



Interpretation of the Thorne and Thorne diagram (1951) is as follows:

Class	Rating
1	Water can be used safely on all soils.
2	It can be expected to cause salt problems where drainage is poor and leaching of residual salts from previous irrigation is not consistently practiced.
3	Water can be used on medium to high salt tolerance crops, on soils of good permeability, and with irrigation practices which provide some leaching.
4	It can only be used in successful farming with crops of high salt tolerance, on permeable and well-drained soils, and with carefully devised and conducted irrigation and soil management practices.
5	Waters are generally unsuitable and should be used for irrigation only under special situations.

Group	Rating
A	There should be no difficulty from sodium accumulation in soils.
B	Where soils are of fine texture and do not contain gypsum or lime, where drainage is poor, and where small quantities of water are applied with each irrigation, there may be some evidence of sodium accumulation but usually not enough to injure seriously soils or crops. Serious sodium accumulation may occur in waters high in carbonates or bicarbonates.
C	Serious alkali formation should not occur on permeable soils (sands to silt loams), unless poor drainage, residual carbonates in waters, or limited water use are problems. Fine-textured soils must be managed with care.
D	Some alkali formation should be expected in all soils irrigated with group D waters. Sandy or permeable soils high in gypsum might be irrigated with such waters without highly injurious sodium accumulations. Loams or finer textured soils irrigated for some time with 3D or 4D waters and then irrigated with waters of low salt content would probably puddle and require gypsum for reclamation.
E	Generally unsatisfactory for irrigation.

Note.—1C, 1D, and 1E waters often can be improved in quality by treating with gypsum to reduce the sodium percentage.

Figure 18

Diagram by Thorne and Thorne for Classification of Irrigation Waters affect the hardness and are of major concern in any water to be considered for boiler use. Excessive amounts of silica and iron cause scale deposits which reduce the efficiency of many industrial processes. The water quality must be rigidly controlled where the water is used in the processing of food, paper, or some chemicals. Mineral impurities affect color, taste, odor, and turbidity; therefore, water with a high content of dissolved solids is usually avoided. The effects that most of the minerals have on industrial use are shown in Table 3.

Differences in Field and Laboratory Analyses

Field and laboratory analyses of pH and alkalinity from groundwater samples were compared to determine if differences in analyses made from water collected at the well site and water analyzed later at the Texas Department of Health were great enough to cause misinterpretations of quality in a regional study. Large amounts of groundwater quality data are available for regional interpretations, but a limited amount of this data is determined at the time of collection. Alkalinity and pH were determined for 44 water samples at the well site, and then the samples were transported to the Department of Health for complete analysis. A comparison of values was tabulated and presented in Table 5. An average time interval of 32 days elapsed between the collection and laboratory analysis.

Field alkalinity of samples was determined by potentiometric titration of the water sample to pH 4.5 using 0.020N sulfuric acid. Total alkalinity as $CaCO_3$ was determined by the following equation:

$$\frac{1{,}000 \times (mL_{(a)} \text{to pH } 4.5)}{mL_{(s)}}$$

where: s = volume of sample
a = volume of acid

Phenolphthalein alkalinity was also determined for those samples with a pH in excess of 8.3 units to determine the concentration of carbonate ions in solution. Approximately 36 percent of the ground water from wells sampled in Jack County had a pH greater than 8.3. Field pH of samples was measured with a portable battery-operated meter (Orion Research model 231). The meter was standardized using buffer solutions with a pH of 7.0 and 9.18 units. Since ground-water samples generally have pH's greater than 7.0, the ground water in Jack County is considered to be alkaline.

A significant difference was found between laboratory and field analyses of pH. In 80 percent of the samples compared in Table 5, laboratory pH was greater than field pH by an average of 0.6 pH units. Six percent of the samples had identical values and in 14 percent, the field determination was greater. No significant difference was found between laboratory and field analyses of alkalinity. Results of these comparisons indicate the field pH is a more critical determination than field alkalinity.

Laboratory measurements of pH and alkalinity may be satisfactory for making certain regional water-quality interpretations, but significant errors could result in geochemical interpretations of ground water as it exists in its natural state. Also, differences between laboratory and field analyses may well be less than regional differences in an aquifer system (Bachman, 1984). A pH measurement taken at the moment of sampling may represent the original equilibrium conditions in the aquifer satisfactorily, but if the water is put into a sample container and the pH is not determined until the sample is taken out for analysis some days or weeks later, the measured pH may have no relation to original conditions (Hem, 1970, p. 95).

Differences between field and laboratory analyses may be due to the following:

1) Differences in accuracy between field and laboratory analysts and equipment.

2) Oxygen and CO_2 gas trapped in the bottle may cause reactions during transit which can change the constituent values (Bachman, 1984).

3) Precipitation during transit may occur in water supersaturated with certain ions.

4) Because water in the aquifer is in contact with a particular lithology, under a given pressure, and has a given temperature, both temperature and pressure changes during pumping of the well and transit of the sample will affect the concentration of dissolved gases, which in turn may affect other dissolved species (Claassen, 1982).

5) Basically, the farther the water flows or travels from the aquifer, the greater its potential for change.

According to Claassen (1982), ground-water hydrologists are faced with a dilemma: (1) laboratory

Table 5.—Comparison of Laboratory and Field Determinations of pH and Alkalinity in Water Samples Collected in Jack and Surrounding Counties.

Well	pH		Alkalinity as $CaCO_3$		Time interval (days)	Dissolved solids (mg/l)
	Lab	Field	Lab	Field		
39-20-37-303	7.8	6.9	365	356	—	500
39-205	7.7	7.0	222	226	59	584
39-301	8.2	7.9	383	388	45	1,357
40-201	8.0	6.8	305	316	44	617
40-302	8.6	8.6	316	318	45	643
40-303	8.4	8.5	283	272	45	564
119-19-33-501	8.1	7.6	323	314	—	727
33-702	8.3	7.9	257	270	27	4,924
41-801	8.4	8.2	409	418	23	1,163
57-104	8.7	8.7	588	594	35	1,453
20-38-801	8.5	8.4	424	410	19	816
45-804	8.2	6.9	321	316	20	723
45-910	8.5	8.6	488	494	23	1,374
46-809	10.5	11.5	517	528	20	1,803
46-810	8.3	7.8	543	528	26	2,590
48-503	8.1	7.4	307	308	26	457
53-904	7.6	6.8	292	295	—	669
54-201	8.1	7.7	327	322	22	660
54-405	7.9	7.2	299	300	18	950
54-604	7.7	7.6	408	386	21	701
54-803	8.3	7.8	368	368	21	2,099
55-111	8.4	7.8	482	520	22	3,968
55-224	8.5	8.5	530	516	42	913
55-317	7.9	7.5	290	276	16	7,390
55-319	8.1	8.2	438	462	15	3,518
55-404	8.3	8.0	360	396	30	3,965
55-802	8.2	7.8	561	526	14	3,369
56-204	8.0	7.6	344	330	17	3,639
62-303	7.9	7.1	405	410	23	1,186
63-801	8.4	8.1	534	520	35	1,830
169-19-33-404	7.3	7.0	360	350	—	950
182-31-06-201	8.5	8.6	443	452	37	752
06-301	8.0	6.7	453	454	37	1,154
07-302	8.3	8.0	838	830	—	1,756
07-305	8.5	8.7	532	524	42	1,683
184-32-01-202	8.3	7.3	313	312	38	546
20-64-811	7.5	6.8	357	338	—	639
249-19-33-901	8.1	6.8	256	270	58	388
33-903	8.1	8.0	243	237	58	294
41-304	8.0	7.0	213	236	58	287
41-902	8.1	7.3	565	644	37	1,304
57-302	7.7	6.8	233	306	38	1,195
57-601	8.0	7.5	330	354	38	494
252-20-61-806	7.6	6.7	315	302	—	425

analysis generally is more precise than onsite analysis, but no adequate preservation technique may exist to guarantee that the analysis is representative of truly dissolved species under natural conditions; and (2) onsite analysis generally is more difficult and less precise, but results may be more representative of the actual water quality.

Sampling Procedures

Since the chemical constituents and properties in ground water become unstable upon release from the aquifer, special collection procedures and field analyses are required to insure that geochemical relationships are more accurately evaluated. Some of the more important sampling techniques are as follows:

1. Potential contamination, solute precipitation, and loss of dissolved gases can be minimized by collecting the samples as close to the well head as possible (Wood, 1976).

2. Wells completed in more than one aquifer, or not fully penetrating a single aquifer, present special situations where water chemistry may not equate to aquifer representation. To recognize these situations, a complete description of the geohydrologic zones penetrated by the well and complete drilling history need to be known (Claassen, 1982).

3. The quality of water bailed from an unused well or pumped a short time from a standby, observation, new, or little-used well, generally does not accurately reflect the quality of water in the aquifer. Samples should be taken after the well has been pumped for an adequate period of time to insure that the water collected is directly from the formation and not the borehole. There is no specific volume of water that constitutes a minimum pumping time. Technically, to obtain a representative sample from an aquifer at a given location, a well must be pumped until the pH, temperature, and specific conductance are constant. The last parameter to obtain a representative reading is usually pH (Wood, 1976).

4. Completely fill the sample container to prevent entrapment of O_2 and CO_2, which could effect the accuracy of the results. Samples should be stored under constant temperature and processed in the lab as quickly as possible.

5. To understand the geochemical and hydrologic relationships in an aquifer, certain parameters require immediate analysis in the field. These are pH, specific conductance, alkalinity, temperature, and either Eh or dissolved oxygen (oxidation-reduction potential). These parameters may be altered considerably from the time the sample is caught to the time of laboratory analysis.

6. It is extremely important to note in the remarks section of the chemical water analysis report any conditions during sampling that might cause an erroneous interpretation of representative aquifer conditions.

OCCURRENCE AND QUALITY OF GROUND WATER

Canyon Group

Extent of Aquifer

As shown on the geologic map (Figure 6), the areal extent of the Canyon Group in Jack County occupies the southeastern half of the county except in those areas overlain by Cretaceous sediments of the Trinity Group. Ground water is primarily obtained from the sandstone units located between major limestone sequences. Major sandstone units are found within the Palo Pinto Formation, Wolf Mountain Shale, Placid Shale, and Colony Creek Shale. The extent of the sandstone outcrop for the Palo Pinto Formation is shown on Figure 9. The sandstone outcrops of the Wolf Mountain, Placid, and Colony Creek Shales are shown on Figure 19.

Source, Occurrence, and Movement

Primary sources of ground water in the Canyon Group are rainfall which falls on the outcrops and infiltration of surface water from unlined earthen ponds, lakes, and streams on or crossing its outcrops. Recharge from the Cretaceous sediments in those areas where they overlie the Canyon Group is also another significant source.

Ground water occurs primarily within the sandstone units of the Canyon Group. It exists under water-table conditions along the outcrop and under artesian conditions downdip, where confining beds of limestone and shale overlie the water-bearing units.

Movement of ground water is primarily down gradient, from high to low elevations, and at right angles to the contours which denote the configuration of the water table. Movement is also to the northwest and, locally, away from ground-water highs and toward the surface drainage system.

Chemical Quality

Ground-water chemistry of the major sandstone units comprising the Canyon Group is similar enough so that an overall discussion of water quality can be made without regards to stratigraphic formation terminology. If a difference had to be discerned, it would be in the Palo Pinto sandstones, as opposed to the Placid, Colony Creek, and Wolf Mountain Shales, due to the influence of the overlying Cretaceous sediments. These sandstones tend to provide water having a slightly higher pH, hardness, and carbonate/bicarbonate concentration. However, a relevent discussion of water quality can be made by lumping the sandstone units of the Canyon Group together.

A total of 169 water samples were collected for chemical analysis from 134 wells yielding ground water from Canyon Group sandstones, and their locations are shown on Figure 31. The source, significance, and range in concentration of dissolved-mineral constitutents and properties of ground water are given, by aquifer, in Table 3. This breakdown provides the mean and range according to stratigraphic units within the Canyon Group, whereas the remaining discussion of water quality will concentrate solely on a composite of Canyon Group sandstones.

The chemical quality of typical ground water from wells completed in the sandstones of the Canyon Group is graphically portrayed on Figure 20 by the use of circular diagrams. The center of the diagram is positioned at the location of the sampled well. The upper half of the diagram represents the percentages of major cation me/l (calcium, magnesium, sodium, and potassium) while the lower half represents the percentages of major anion me/l (carbonate, bicarbonate, sulfate, and chloride). Since the dissolved solids at each site is given, a quick picture of the water quality in that area can be ascertained.

Trilinear diagrams of ground-water quality provide a summary of ground-water evolution for Canyon Group water-bearing sandstones. Using Back's (1966) terminology in the interpretation of trilinear diagrams, Canyon Group water ranges in composition from a calcium to sodium water (Figure 20). In the anion triangle, the tendency is towards a bicarbonate water, with some chloride. Samples in the diamond figure were plotted in all fields of the diagram, with increased density in the sodium, bicarbonate, chloride area. When waters of Canyon Group sandstones were grouped into shallow ground waters (less than 120 feet) and deeper ground water (greater than 220 feet), the resulting trilinear diagrams showed a pronounced shift in the location of data point densities (Figure 21). For shallow waters the samples are predominantly a sodium, calcium, chloride, bicarbonate type, which is indicative of younger recharge waters. Deeper waters show a composition shift to a sodium, bicarbonate, chloride type which is a predictable trend as ground water flows from the recharge zone to deeper sections of the aquifer.

Figure 22 consists of a series of radial-pattern diagrams which illustrate the relative concentrations of dissolved minerals in typical ground water from the four major sandstone units within the Canyon Group. The percent of each major chemical constituent [the cations calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and the anions bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl)] is plotted on radial coordinates and the plots connected. The shape of the patterns thus illustrates the similarities and differences between the chemical analyses. As discussed previously, the percentage of sodium is usually greater than that of the remaining cations, while bicarbonate and chloride are the prevalent anions. In apparently contaminated groundwater (wells 20-55-317 and 20-61-202), sodium and chloride predominate and forms a distinctive shape, as compared to the shape of better quality ground water exhibited by the other samples. An important point to note is that in some areas of Jack County ground water is naturally high in dissolved solids, especially salt. Bill Dennis, a Jack County historian, mentioned that several areas within Jack County were settled late or not at all due to poor quality of natural ground water.

Even though the content of calcium and magnesium in ground water is usually not a deterent to use for domestic and livestock purposes, sufficient quantities of one or both make water hard enough to impose minor problems. Hard water consumes excessive amounts of soap, deposits soap curd on bathtubs, and forms scale in water heaters and pipes. Calcium content averaged 31 mg/l and magnesium averaged 17 mg/l in water collected from 134 wells completed in the Canyon Group. Using a hardness value of less than 100 as the amount desirable for domestic use, approximately 57 percent of the samples exceeded 100 mg/l hardness as $CaCO_3$, with an average hardness of 211 mg/l. Generally, ground water from Canyon Group sandstones is hard, with a ratio of calcium to magnesium (in mg/l) of 2:1.

Iron in comparatively small amounts is derived mainly from the sources listed in Table 3. Upon exposure to air, water that contains iron may leave a reddish stain. For this reason, ground waters containing excessive amounts of iron (greater than 0.3 mg/l) are objectionable for domestic use. The iron content was determined in 40 samples collected from the Canyon Group and ranged from 0.02 to 12.9 mg/l. A total of 4 samples, or 10 percent, exceeded the recommended limit.

Total and phenolphthalein alkalinity were determined for all samples and the carbonate/bicarbonate content calculated from the results. A pH value was also determined for each sample. Those samples with a pH in excess of 8.35 have carbonate ions in solution. Phenolphthalein alkalinity, from which CO_3 is calculated, is zero when the pH is less than 8.35 units. A total of 57 of the 128 samples measured for pH (44 percent) exceeded 8.35 units, resulting in the presence of carbonate ions in solution. The average pH for ground water in the Canyon Group is 8.2, which indicates an alkaline condition exists. Total alkalinity ranged from 126 to 758 mg/l as $CaCO_3$, with a mean of 386 mg/l. With an average pH of 8.2, an average total alkalinity of 386 mg/l would equate to a mean bicarbonate (HCO_3) content of 471 mg/l.

When either sulfate or chloride concentrations exceed the recommended upper limit of 300 mg/l, ground waters can have a taste which is at times unpleasant. Sulfate concentrations of Canyon Group water ranged from 11 to 1,691 mg/l with a mean amount of 190 mg/l. About 19 percent of the samples collected contained more than the recommended limit. Chloride concentrations ranged from 12 to 5,200 mg/l with a mean of 490 mg/l. About 37 percent of the samples exceeded the upper recommended limit. Figure 14 shows the sulfate and chloride concentration of selected wells completed in the Canyon Group.

Fluoride content of ground water from the Canyon Group ranged from less than 0.1 to 7.5 mg/l. Based on the annual average maximum daily air temperature within the county, as delineated on Figure 16, the maximum recommended upper limit of fluoride would be 1.6 mg/l. A total of 37 of 124 wells sampled (30 percent) contained more than the recommended upper limit. The range in nitrate was 0 to 564 mg/l in 128 samples with an average content of 13.2 mg/l. Only 5 percent of the samples contained in excess of the upper recommended limit of 44.3 mg/l.

The dissolved-solids content in the Canyon Group ranged from 245 to 8,715 mg/l, with a mean of 1,373 mg/l. About 43 percent of the samples exceeded the upper recommended limit of 1,000 mg/l for domestic purposes. This is a good indication that the overall quality of ground water for domestic use is fairly poor. Figure 14 shows the dissolved-solids content, along with sulfate and chloride, of selected wells in Jack County. Dissolved-solids content of water from the Canyon Group in Jack and adjacent Counties is portrayed on Figure 23 by the use of colored dots, the different colors representing various ranges of dissolved solids. With the use of this map, areas of poor quality can be quickly discerned, as well as areas where data is limited.

Even though in a strict sense no irrigation wells were found completed in the Canyon Group, ground water from numerous wells is used to water lawns and gardens throughout the county. So in this respect, the following discussion on the suitability of ground water for irrigation is pertinent. A widely used system for determining the quality of irrigation waters is shown on Figure 17 and is based on the salinity hazard as measured by the specific conductance and the sodium (alkali) hazard as measured by the SAR (U.S. Salinity Laboratory Staff, 1954, p. 69-82). Plots of representative Canyon Group waters are shown on Figure 24. All but 5 of 48 fall within sodium-hazard classes Sl and S4 and all but 7 of 48 fall within salinity-hazard classes C3 and C4. The importance of these classes was discussed previously. Generally, according to these criteria, ground water from the Canyon Group is not suitable for extensive irrigation practices.

An average of 440 mg/l sodium was determined from 121 analyses. Of these samples, an average percent sodium of over 75 was calculated. Generally, when the percentage of sodium to other cations is greater than 60, the sodium hazard becomes progressively greater. The sodium-adsorption ratio (SAR) ranged from 0.5 to 68.0 with a mean ratio of 23.8, which would be considered as a high to very high sodium hazard.

As discussed previously in the section on chemical quality of ground water, another method of evaluating the suitability of water for irrigation is by calculating the residual sodium carbonate (RSC). Waters containing 1.25 to 2.5 mg/l of RSC are considered marginal and those containing greater than 2.5 mg/l are not suited for irrigation. The equation for calculating RSC is contained in Table 3. RSC values of water samples from the Canyon Group ranged from 0 to 14.8 mg/l with a mean value of 4.8. About 30 percent of the samples contained less than 1.25 mg/l and 62 percent contained more than 2.5 mg/l. Again, the indication is that ground water from the Canyon Group is generally not suitable for irrigation.

Cisco Group

Extent of Aquifer

Figure 6, the geologic map, shows the areal extent of the Cisco Group as occupying the northwestern half of Jack County. Ground water is primarily obtained from sandstone units as opposed to limestone sequences and shale beds. Where possible, sandstone units were divided into those occurring within the Graham and Thrifty Formations, with emphasis on the Gonzales Creek Member and Avis Sandstone. These two units so emphasized are shown on Figure 25 and were selected not only because of their water-bearing properties, but because they also form the basal units of the Graham and Thrifty Formations, respectively. Ground water is not confined to these units, but is also obtained from numerous other sandstone units not identified in this report by name that are contributors to domestic and livestock wells in the area.

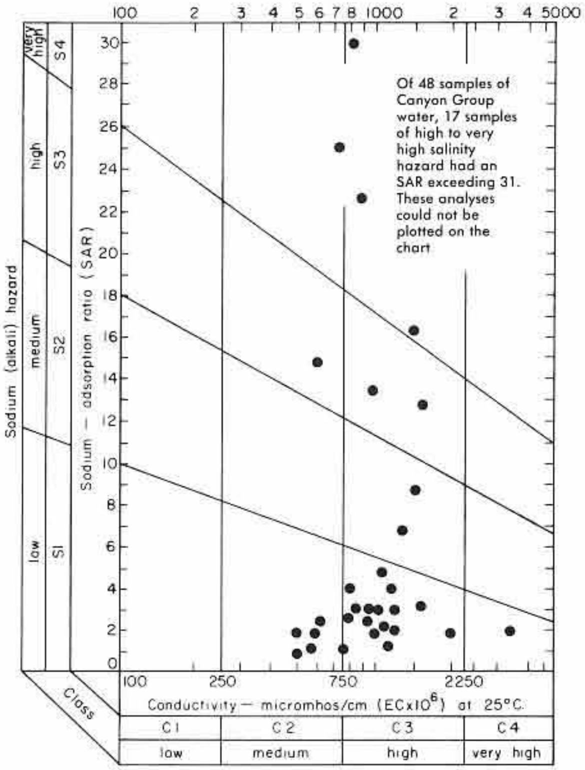


Figure 24.–Diagram for the Classification of Irrigation Waters, Showing Quality of Water From Selected Wells Completed in the Canyon Group

Source, Occurrence, and Movement

Primary sources of ground water in the Cisco Group are rainfall which falls on the outcrops and infiltration of surface water from unlined earthen ponds, lakes, and streams on or crossing its outcrops. Ground water occurs primarily within the sandstone units of the Cisco Group. It exists under water-table conditions along the outcrop and under artesian conditions downdip, where confining beds of limestone and shale overlie the water-bearing units.

Movement of ground water is primarily down gradient, from high to low elevations, and at right angles to the contours which denote the configuration of the water table. Movements is also to the northwest and, locally, away from ground-water highs and toward the surface drainage system.

Chemical Quality

Ground-water quality of the water-bearing sandstone units comprising the Cisco Group is similar enough so that an overall discussion of water quality can be made without regards to which Formation the well was completed in. A comparison of mean and range of ground water from the Thrifty and Graham Formations on Table 3 verify this similarity.

A total of 144 water samples were collected for chemical analysis from 112 wells completed in Cisco Group sandstones, with their locations shown on Figure 31. The source, significance, and range in concentration of dissolved-mineral constituents and properties of ground water are given, by aquifer, in Table 3.

The chemical quality of typical ground water from wells completed in the Cisco Group sandstones is graphically portrayed on Figure 26 by the use of circular diagrams. An explanation of the use and interpretation of map symbols was discussed previously with Figure 20. Generally, high percentages of calcium and magnesium occur along the northern boundary and southwestern corner of Jack County. The remaining area shows a very high percentage of sodium to other cations. Bicarbonate is the predominant anion over most of the area, with chloride percentages slightly less.

Trilinear diagrams of ground-water quality provide a summary of ground-water evolution for Cisco Group water-bearing sandstones. Using Back's (1966) terminology in the interpretation of trilinear diagrams, Cisco Group water is very similar in composition to Canyon Group water. A comparison of the diamond figure in the diagrams on Figures 20 and 26 reveals a tendency for Cisco Group water to have a higher density of points in the calcium-magnesium-bicarbonate-chloride area. This is also reflected on Table 3, where mean values of calcium, magnesium, and hardness are greater in the Cisco than in the Canyon Group. The results of trilinear diagrams of waters of the Cisco Group, when grouped into shallow and deep ground water, were similar to that of Canyon Group waters (Figure 21).

Figure 27 consists of a series of radial-pattern diagrams which illustrate the relative concentrations of dissolved minerals in typical ground water from the Gonzales Creek Member, Graham Formation, Avis Sandstone, and Thrifty Formation of the Cisco Group. The shape of the patterns illustrates the similarities and differences between the chemical analyses. In comparing Figure 27 with Figure 22, Cisco Group waters again show a slightly higher calcium and magnesium percentage than the Canyon Group waters as reflected in the resulting pattern shapes.

Calcium content averaged 72 mg/l and magnesium averaged 21 mg/l in water collected from 111 wells completed in the Cisco Group. Again, using a hardness value of less than 100 as the amount desirable for domestic use, about 61 percent of the samples exceeded this criteria, with a mean hardness as $CaCO_3$ of 266 mg/l.

Iron content seemed to pose a bigger problem in Cisco Group waters than that of the Canyon Group. The iron content was determined in 24 samples and ranged from 0.01 to 40.3 mg/l. A total of 16 samples, or 67 percent, exceeded the recommended limit of 0.3 mg/l.

Total and phenolphthalein alkalinity were determined for all samples and the carbonate/bicarbonate content calculated from the results. A pH value was also determined for each sample. Those samples with a pH in excess of 8.35 have carbonate ions in solution. Phenolphthalein alkalinity, from which CO_3 is calculated, is zero when the pH is less than 8.35 units. A total of 34 of the 112 wells sampled (30 percent) exceeded a pH of 8.35 units, resulting in the presence of carbonate ions in solution. The mean pH for waters from the Cisco Group is 8.1, which indicates an alkaline condition exists. Total alkalinity ranged from 40 to 625 mg/l as $CaCO_3$, with a mean of 351 mg/l. With an average pH of 8.1, an average total alkalinity of 351 mg/l would equate to a mean bicarbonate content of 428 mg/l.

Sulfate concentrations of Cisco Group water ranged from 7 to 1,378 mg/l with a mean amount of 185 mg/l. About 17 percent of the samples collected contained more than the recommended limit of 300 mg/l. Chloride concentrations ranged from 13 to 4,424 mg/l with a mean of 488 mg/l. About 31 percent of the samples exceeded the upper recommended limit of 300 mg/l. Figure 14 shows the sulfate and chloride concentrations of selected wells completed in the Cisco Group.

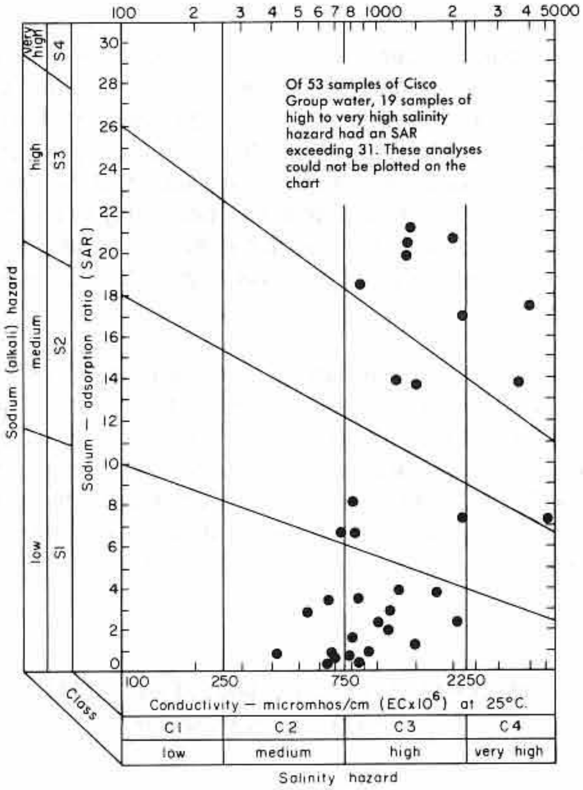
Fluoride content of ground water from the Cisco Group ranged from less than 0.1 to 4.2 mg/l. A total of 29 of 110 wells sampled (26 percent) contained more than the recommended upper limit of 1.6 mg/l. The range in nitrate content was less than 0.04 to 62 mg/l in 105 samples with an average content of 4.5 mg/l. Only 2 percent of the samples contained in excess of the upper recommended limit of 44.3 mg/l.

The dissolved-solids content in the Cisco Group ranged from 108 to 7,558 mg/l, with a mean of 1,431 mg/l. About 44 percent of the samples exceeded the upper recommended limit of 1,000 mg/l for domestic purposes. Figure 14 shows the dissolved-solids content of selected wells in Jack County. Dissolved-solids content of water from the Cisco Group in Jack and adjacent Counties is shown on Figure 28 by the use of colored dots, the different colors representing various ranges of dissolved solids. Areas of poor quality ground-water can be quickly identified, such as the poor-quality area along Lodge Creek in northwest Jack County.

The following discussion on the suitability of ground water for irrigation is geared for those wells used to water lawns and gardens. Using the method previously described and illustrated by Figure 17, values of specific conductance and SAR of water from the Cisco Group were plotted on Figure 29. All but 7 of 53 fall within sodium-hazard classes C3 and C4. The importance of these classes was discussed previously. According to this criteria, water from the Cisco Group is generally not suitable for extensive irrigation practices.

A mean of 434 mg/l sodium was determined from analyses of water from 110 wells sampled from the Cisco Group. An average percent sodium of over 66 was calculated. Generally, when the percentage of sodium to other cations is greater than 60, the sodium hazard becomes progressively greater. The SAR ranged from 0.3 to 206 with a mean ratio of about 23, which would be considered as a high to very high sodium hazard.

Another method of evaluating the suitability of water for irrigation is by calculating the RSC. Water containing 1.25 me/l of RSC are considered marginal and those containing greater than 2.5 me/l are not suitable for irrigation. RSC values of samples from the Cisco Group ranged from 0 to 12.1 me/l with a mean value of 3.7. About 50 percent of the 143 samples contained less than 1.25 me/l and 46 percent exceeded 2.5 me/l.



Of 53 samples of Cisco Group water, 19 samples of high to very high salinity hazard had an SAR exceeding 31. These analyses could not be plotted on the chart

Figure 29.—Diagram for the Classification of Irrigation Waters, Showing Quality of Water From Wells Completed in the Cisco Group

Trinity Group

Extent of Aquifer

Figures 6 and 9 show the areal extent of the Cretaceous outcrop in Jack and adjacent Counties. Ground water is obtained primarily from the Twin Mountains Formation of the Trinity Group in the southeastern part of Jack County. Minor quantities of ground water are obtained from the Antlers Formation along the northeastern boundary of Jack County and extending into Montague and Wise Counties.

Source, Occurrence, and Movement

Primary sources of ground water in the Trinity group are rainfall which falls on the outcrops and infiltration of surface water from unlined earthen ponds, lakes, and streams on or crossing its outcrops. Ground water occurs primarily within sand and sandstone units of the Twin Mountains and Antlers Formations. It exists under water-table conditions along the outcrop and under artesian conditions downdip, where confining beds of limestone, shale, and clay overlie the water-bearing units.

Movement of ground water is primarily down gradient, from high to low elevations, and at right angles to the contours which denote the configuration of the water table. Movement is also to the east and, locally, away from ground-water highs and towards the surface drainage system.

Chemical Quality

Eight samples from 6 wells (3 in Jack County) completed in the Trinity Group were collected as part of this study. All wells were completed in the Twin Mountains Formation.

Due to the lack of samples available in the study area, only general statements can be made concerning the overall quality of Cretaceous ground water. Sulfate content averaged 142 mg/l with 1 of the 8 samples exceeding 300 mg/l. Chloride content averaged 172 mg/l with 2 of the 8 samples greater than 300 mg/l. Fluoride and nitrate content was low. Hardness seems to be the main problem, with an average hardness as $CaCO_3$ of 528 mg/l. All samples would be classed as very hard (greater than 180 mg/l). Dissolved-solids content averaged 883 mg/l. Figure 14 shows sulfate, chloride, and dissolved-solids content for Trinity Group wells in southeast Jack County.

Generally, ground water from the Trinity Group aquifer is suitable for irrigation purposes. SAR and RSC values are low, with an average percent sodium of 35. However, when specific conductance was plotted against SAR on the diagram for classification of irrigation waters, the low sodium hazard plots were offset by salinity hazard plots in the C3 and C4 range. Proper irrigation management practices such as those described prevously for C3 and C4 waters should be adhered to.

The mean value of pH was 8.0, showing the water to be slightly alkaline. Figure 30 shows radial-pattern diagrams of chemical analyses of typical ground-water which contains 2 patterns of analyses from wells completed in the Twin Mountains Formation. The shapes are indicative of hard water with low percent sodium and high bicarbonate content.

Other Aquifers

Strawn Group

Strawn Group units do not crop out in Jack County; however, usable-quality ground water can be obtained in the southeastern part of the county. Even though no water wells were located that were completed in the Strawn Group, a test well drilled southeast of Joplin, state well 19-57-104, did obtain water of usable quality. The 770 foot deep test well was completed in the Turkey Creek Sandstone and the resulting analysis of the sample from this unit tested at 1,453 mg/l dissolved solids. Areas of possible development can be inferred from Figure 7, which shows net-sandstone thicknesses in the Turkey Creek Sandstone. As a result of the data obtained from this test hole, the Turkey Creek will continue to be protected by recommendations made by the Surface Casing, Protection Services Unit of the Texas Water Commission.

Radial-pattern diagrams of three analyses from wells completed in the Strawn Group are depicted on Figure 30. All are of usable-quality ground water but are of two different chemical types. One shape reflects a calcium-sodium-bicarbonate water while the other two patterns show a sodium-bicarbonate-chloride type water.

Alluvium

The Recent alluvium of Quaternary age is a minor source of ground water used primarily in Jack County for livestock purposes. Alluvial deposits are found in the floodplains of the major tributaries of streams which make up the surface drainage system in the county. Figure 6, the geologic map of Jack County, shows the extent of the major deposits of alluvium.

Ground water in the alluvium is generally a calcium bicarbonate water, very hard, normally of neutral pH, and of greatly varying dissolved-solids content. Due to the combination of naturally occurring poor quality water in many areas and the contamination by various activities occurring in the oil and gas industry, the overall quality of ground water obtained from alluvial deposits is poor for domestic purposes.

Figure 30 shows two radial-diagram patterns for the alluvium wells inventoried for this study. The analysis for well UK-31-07-102 shows a typical calcium carbonate water used for domestic purposes in Palo Pinto County. An analysis of an apparently contaminated well, PL-20-46-803, shows a pattern reflecting the high sodium chloride content.

WATER-QUALITY PROTECTION RECOMMENDATIONS

The Texas Water Commission provides recommendations to oil and gas operators and the Railroad Commission of Texas concerning the depth to which usable-quality ground water should be protected during the exploration for and production of oil, gas, and other minerals. The authority for participation by the Commission in this program is derived from rules promulgated by the Railroad Commission under authority given that agency by statutes dealing with the regulation of drilling and production activities of the petroleum industry.

Statewide Rules 13 and 14 of the Railroad Commission of Texas require that operators obtain a letter from the Texas Water Commission recommending the depth to which usable-quality water strata should be protected during drilling, plugging, or production activities related to oil, gas, and other minerals.

In carrying out its duties, the Texas Water Commission maintains technical data files upon which to base ground-water protection recommendations in all areas of the State and for preparing these recommendations for operators contemplating drilling oil, gas, or other exploratory tests. The recommended depth to which ground water of usable quality should be protected is based on all pertinent information available to the program staff at the time the recommendation is given. Recommended depths in any one area may, therefore, be revised from time to time as additional subsurface information becomes available.

Known depths of wells producing usable water, or depths of wells which formerly produced water of usable quality, such as domestic, municipal, industrial, livestock, or irrigation wells, are of primary importance in determining the depth of usable water. Geophysical logs run on oil and gas tests in many areas to determine the depth to which usable-quality ground water should be protected. Surface elevation is given special consideration when a recommendation is given in an area that has moderate to high surface relief, as is common to portions of Jack County.

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