

2115-5574

GROUND-WATER QUALITY
OF THE ABILENE AREA, KANSAS

by

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B. S., Kansas State University, 1972

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

Approved by:


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INTRODUCTION

Purpose of Investigation

Ground water in the Smoky Hill River Valley near Abilene has a past history of low-quality water. The city of Abilene has recently begun to search for additional water supplies to meet increasing demands and Abilene has no good source of information to guide them in their search. This investigation of the geology and ground-water quality of the Smoky Hill River Valley near Abilene was made to obtain a better understanding of the water quality of the area and its relation to the geology and to determine the source of any pollution.

No detailed or extensive study of the water quality or geology had been done before this investigation, although Latta (1949) made a water resource study that reported water quality for three wells and defined the general geology in the area. Abilene and surrounding townships presently have adequate water supplies, but this study should be useful in locating future water supplies for agricultural, municipal, and industrial purposes.

Location of Area

Approximately 45 square miles were investigated in the Smoky Hill River Valley in northern Dickinson County, Kansas (Fig. 1). The area is 10 miles long, 4 to $4\frac{1}{2}$ miles wide, bounded on the west by Sand Springs and on the east by Enterprise (Fig. 2); Abilene is in the north-central part of the area.

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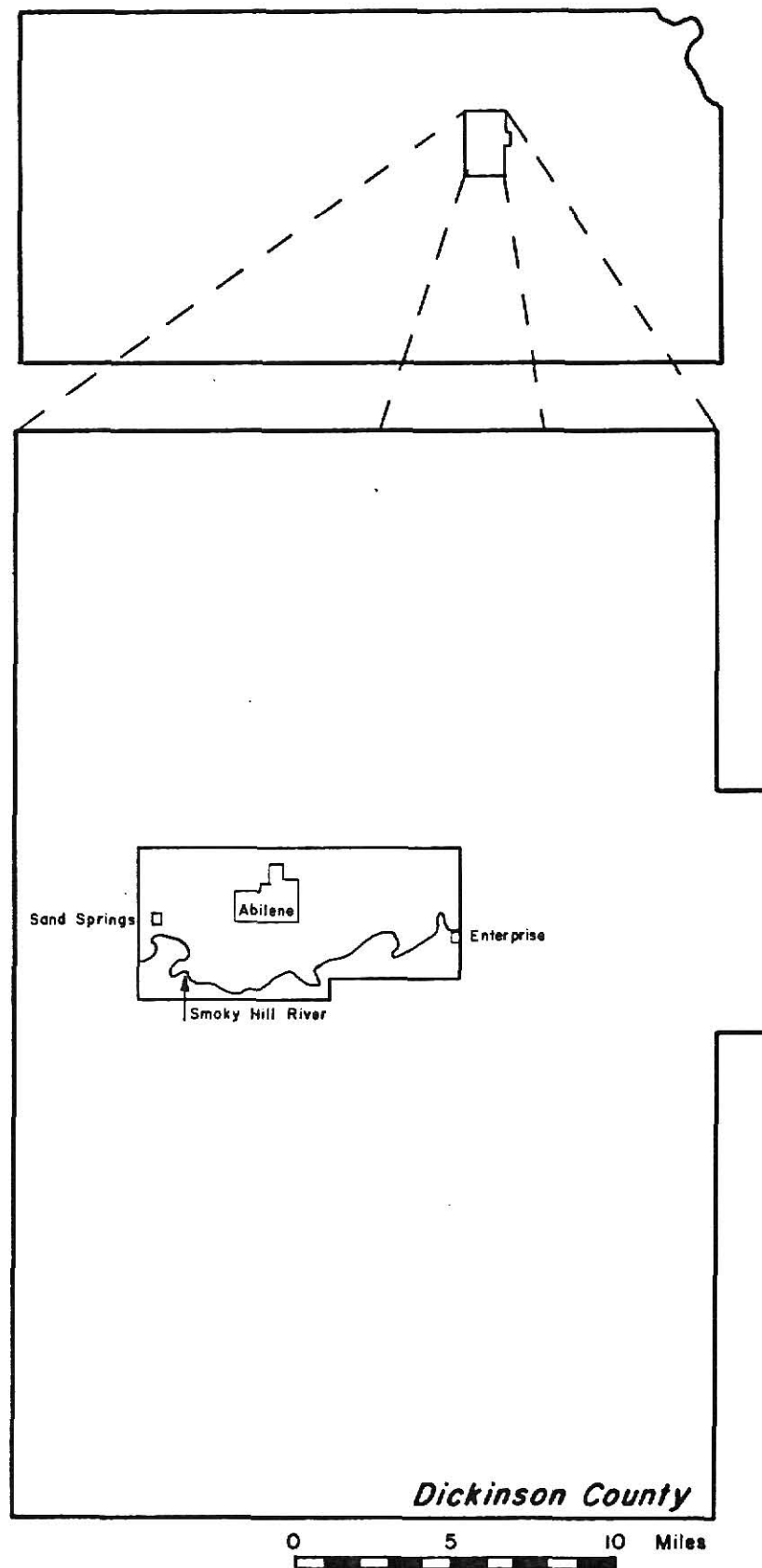
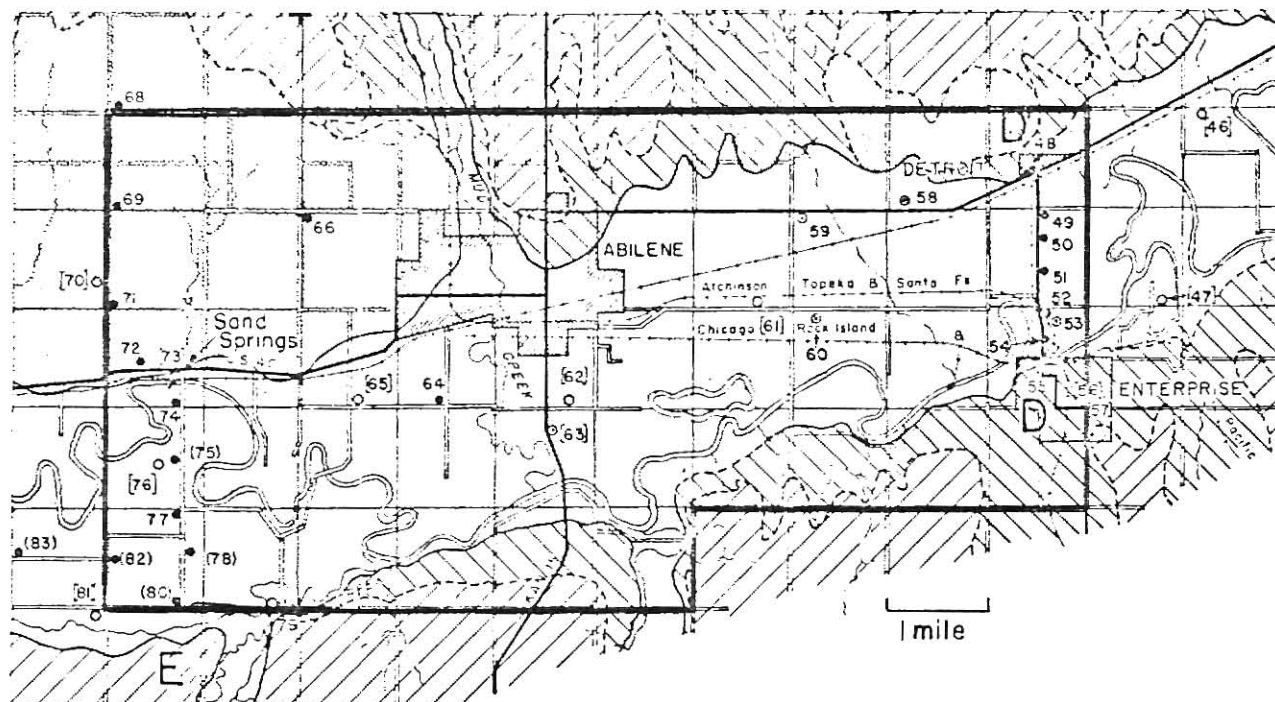


Fig. 1. Location of study in Dickinson Co., Kansas.



Legend

Quaternary System Pleistocene Series

Recent Stage

Alluvium &
Terrace Deposits

Dune sand

Permian System Lower Permian Series

Cimarronian Stage

Sumner Group
Wellington Formation

Gearyan Stage

Chase Group
Odell shale,
Nolans Limestone Fm.

Fig. 2. Geologic map of study area. (Adapted from Latta, 1949)

Previous Investigations

Only one investigation (Latta, 1949) dealing primarily with the geology and ground-water resources of the Smoky Hill Valley, including Abilene, has been made. Brief references to geology or ground water in parts of the area have been made in several reports listed below.

Haworth (1897) included a brief description of the Smoky Hill Valley in a report on the physiography of western Kansas. Bailey (1902) discussed briefly the quality of water from Sand Springs, which is one source of Abilene's municipal water supply. Parker (1911) reported the analyses of water from wells at Enterprise. Moore (1940) described the ground-water resources of Kansas. Lohman, et al. (1942) reported ground-water supplies in Kansas that were available for national defense industries and included a description of supplies in the Smoky Hill River Valley. Part of a report by Latta (1949) described the geology and ground-water resources of Dickinson County in the Smoky Hill Valley, and Shenkel (1959) discussed the geology of the Abilene Anticline. The Kansas Water Resources Board (1967) published a generalized report on irrigation in Dickinson County.

Well Location and Numbering System

Wells and test holes are located according to General Land Office surveys, in the following order: township, range, section, quarter section, quarter-quarter section, quarter-quarter-quarter section (10-acre tract). Where two or more wells are within the same 10-acre tract, the wells' locations are numbered serially according to the order in which they were inventoried. The quarter sections, quarter-quarter sections

and 10-acre tracts are designated a, b, c, and d in a counter-clockwise direction, beginning in the northeast quarter. For example, well number 1 has a location of 13 1E 13ddd and is in the $SE\frac{1}{4}$, $SE\frac{1}{4}$, $SE\frac{1}{4}$, Sec. 13, T.13S., R.1E.

Wells and samples are numbered in the order in which samples were collected from the wells. Where two samples were collected from the same well the samples are lettered in the order in which they were collected. For example, two samples were collected from well #1, sample 1a and sample 1b; only one sample was collected from well #2. The sample with the lowest percent error of analyses (p. 45-47) is always cited where water quality in wells with duplicate analyses is discussed.

Acknowledgments

Thanks and appreciation are expressed to the many residents of the Abilene area who supplied logs and information about their wells and permitted sampling of their wells; to the city officials of Abilene and Enterprise for information and access to municipal water supplies; and to O. S. "Nick" Fent for logs of wells and test holes in the area. Special acknowledgment is made to Mr. Melvin Leckron, and to Mr. Randy Leckron, for assistance in obtaining initial contacts with well owners, water-level measurements, and well elevations. Finally, thanks are expressed to Mr. Robert Harris for writing the computer program and advising on surveying techniques, to Dr. Donald Whittemore for invaluable guidance and assistance with analyses of water samples, and to Dr. Henry Beck for overall guidance on the entire project.

The manuscript has been reviewed by Professors Henry V. Beck, Page C. Twiss, and Donald O. Whittemore, Department of Geology, and Professor Jerome J. Zovne, Department of Civil Engineering, of Kansas State University.

GEOLOGY IN RELATION TO GROUND WATER

The area is underlain, in part, by beds of shale, limestone, and gypsum of the Permian Period and, in part, by clay, silt, sand, and gravel of terrace, dune, and alluvial deposits of Pleistocene to Recent age (Fig. 2). The Ancestral Smoky Hill River cut a deep valley in Post-Kansan - Pre-Wisconsinan time which was later partly filled with clay, silt, sand, and gravel of Wisconsinan (Late Pleistocene) aggradation. This report is concerned mainly with alluvial deposits, and more specifically with the sands and gravels, which are the principal source of ground water used in the area.

Four cross sections of the valley were drawn from logs of test holes and wells obtained from Latta (1949) and O. S. Fent (Fig. 4-7). The location of wells and test holes used in construction of the cross sections and lines of cross sections are in Figure 3.

Bedrock

The alluvium in the valley is underlain by the upper part of the Doyle Shale, the Winfield Limestone, the Odell Shale, and the Nolans Limestone of the Chase Group (Fent, 1974) (Plate 1). The upland surface on either side of the Smoky Hill Valley is underlain by the upper part of the Chase Group, Gearyan Stage and the lower part of the

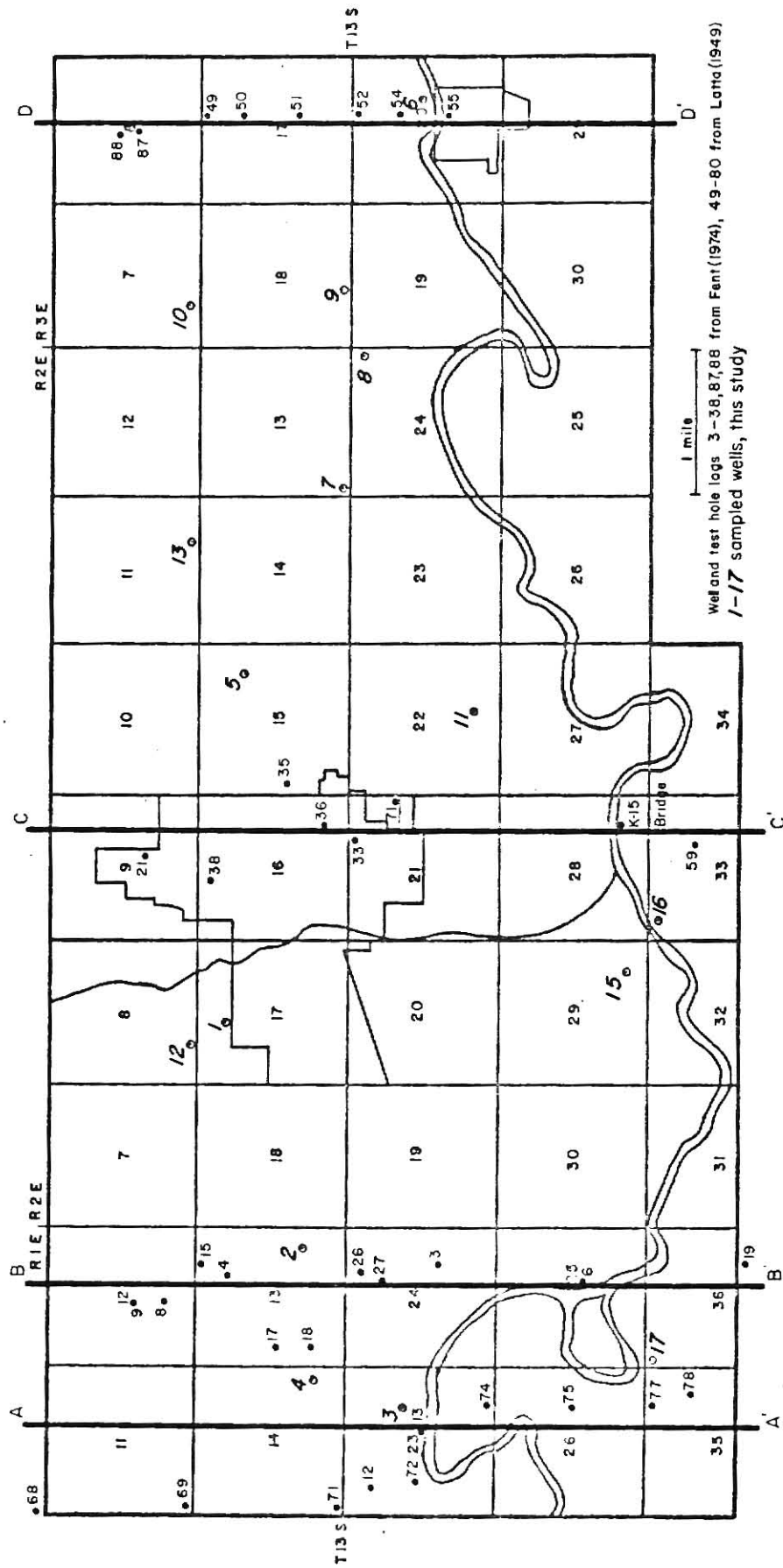


Fig. 3. Location of cross sections, wells and test holes used to construct cross sections, and sampled wells.

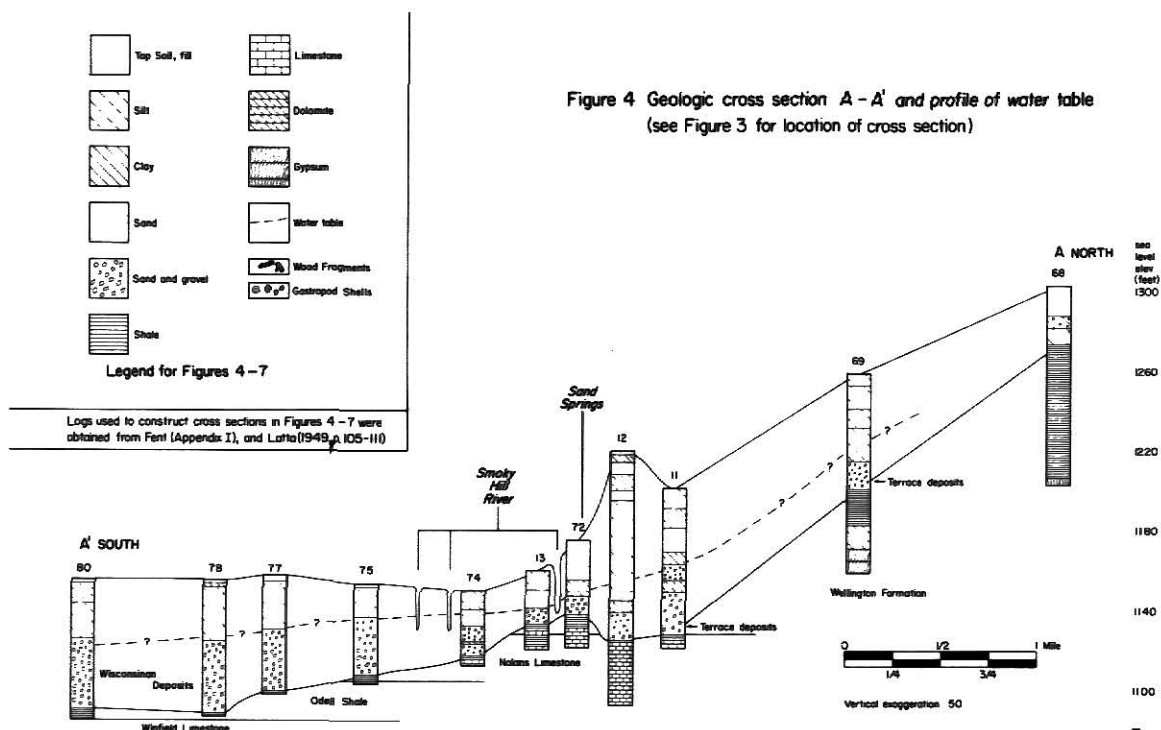


Figure 5 Geologic cross section B-B' and profile of water table (see Figure 3 for location of cross section)

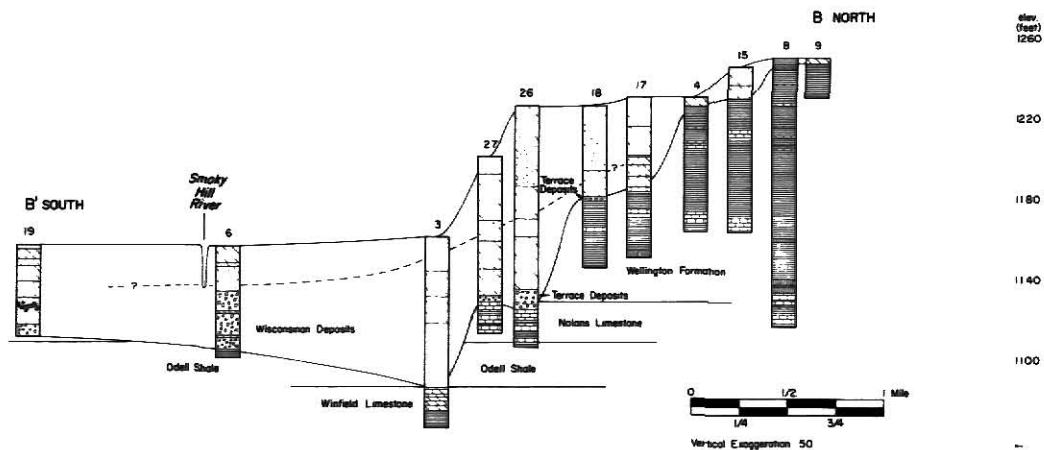


Figure 6 Geologic cross section C—C' and profile of water table
(see Figure 3 for location of cross section)

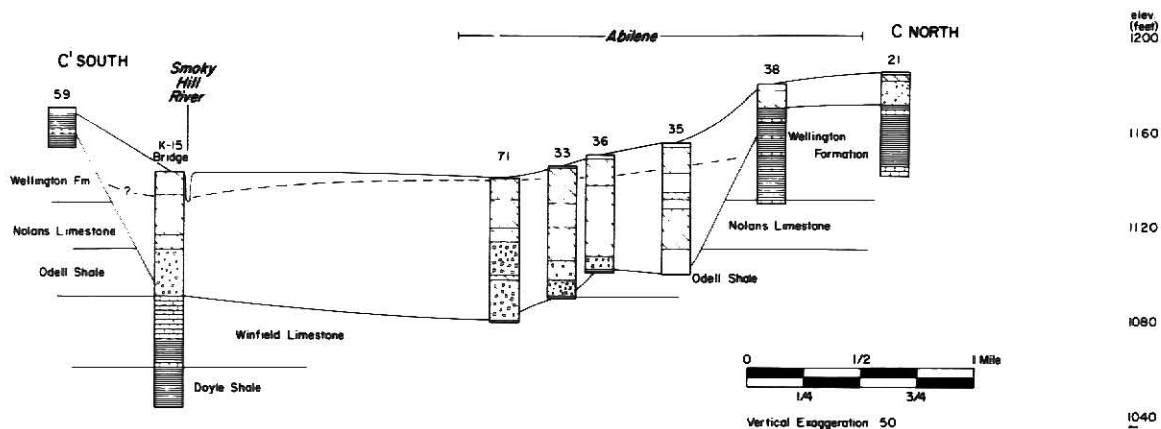


Figure 7 Geologic cross section D—D' and profile of water table
(see Figure 3 for location of cross section)

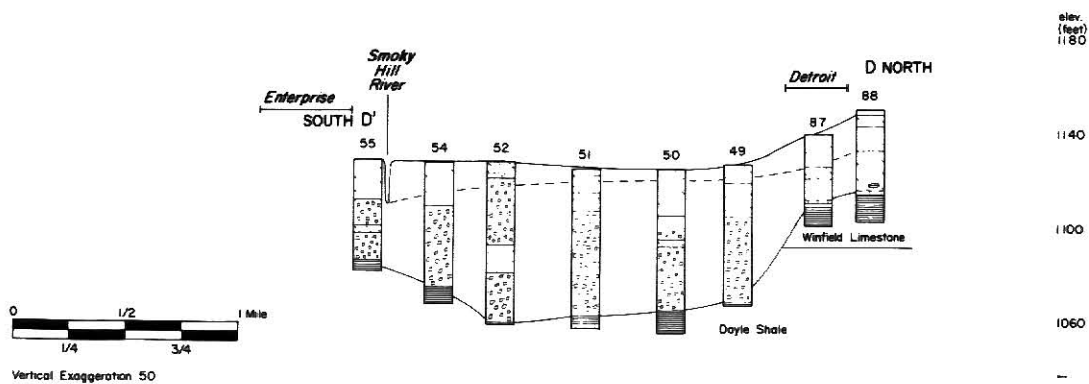


PLATE I

GENERALIZED STRATIGRAPHIC SECTION
ABILENE AREA, KANSAS

System	Series	Stage	Group	Formation	Member	Graphic Section	Description and Remarks	Thickness (ft)
QUATERNARY	PLEISTOCENE	KANSAS WISCONSINAN ILLINOIAN RECENT			alluvium		grayish-orange, gray, green, yellow, white, brown, and black gray silt and clay from 1 to 55 ft thick, and sand and gravel from 2 to 56 ft thick	1-80
					dune sand		grayish-orange to light-gray, fine to medium quartz sand locally containing light-gray, dark-gray, brown, and black silt	0-20
					Terrace deposits		unconsolidated and poorly sorted silts, sands, and gravels	3-21
PERMIAN	LOWER PERMIAN	CIMARRONIAN	SUMNER	Wellington Formation			yellow, brown, red, blue, gray, and green shale with limestone beds ranging from 0 to 6 ft thick, primary gypsum ranging from 0 to 12 ft thick in lower part, usually immediately above the Herington Limestone Member of the Neocom Limestone	0-123
				Nolans Limestone	Herington Limestone		grayish-orange to yellow to light-gray to gray dolomite and dolomitic limestone	5-7
					Paddock Shale		yellow to gray-green to bluish-gray to gray shale	9-12
					Krider Limestone		an upper and lower dolomitic limestone bed separated by a pelagic to bluish-gray to dark-gray shale, each bed is slightly more than one foot thick	3 1/2 - 5
				Odell Shale			gray-green, bluish-gray, dusty-red mottled bluish-gray, and purple shale	17-20
				Winfield Limestone	Cresswell Limestone		olive to dark-gray to white limestone, locally fossiliferous, locally stony in lower part	17-25
					Grant Shale		light gray to yellow to dark gray in upper part and dark gray in lower part	10-12
					Stovall Limestone		gray limestone with abundant dark gray chert	2-3 1/2
				Doyle Shale	Gage Shale		lower part reddish-brown to gray to green, middle part red and gray-green, upper part light gray and gray-green; primary gypsum from 0 to 5 ft thick occurs in the lower half	40-50

Wellington Formation, Sumner Group, Cimarronian Stage, Lower Permian Series, Permian System (Fig. 2) (Plate 1). Wells for part of Abilene's municipal water supply at Sand Springs produce water from solution cavities in the Herington Limestone Member of the Nolans Limestone (Latta, 1949 p. 46).

No salt beds exist in the Abilene area, but the Hutchinson Salt Member of the Wellington Formation, Sumner Group, is in the subsurface 25 miles west of the study area in Saline County (Lee, 1956 p. 117). The Hutchinson Salt is mentioned here because it may be a possible source of ground-water contamination in the Abilene area. The Gage Shale and the lower part of the Wellington Formation contain beds of gypsum (Fent, 1974) which also may affect the ground-water quality (Plate 1).

Terrace and Dune Sand Deposits

Pleistocene terrace deposits underlie dune sand in the northwest corner of the area, north of Sand Springs (Figs. 4-5). The terrace deposits may be Kansan and Illinoian in age because elevations at which they occur conform to Pleistocene stream profiles of the area that were postulated by Bayne and Fent (1963 p. 370). The Kansan age terrace is topographically below the Illinoian terrace in the Upper Smoky Hill Valley at Salina, west of the investigation area, whereas the Kansan terrace is higher than the Illinoian terrace east of Abilene (Bayne and Fent, 1963 p. 374). At what point the Kansan and Illinoian terraces reverse positions is unknown but the change seems to occur west of Abilene in the investigation area (Bayne and Fent, 1963 p. 374). Therefore, the age of these terraces is unknown.

The lower terrace deposit is 10 to 21 feet thick whereas the upper terrace deposit is 3 to 14 feet thick, and thins to a feathered edge at the northern valley boundary. Both terrace deposits consist principally of unconsolidated and poorly sorted silts, sands, and gravels which overlap one another irregularly (Latta, 1949 p. 30).

Dune sand is on top of the terrace deposits north of Sand Springs in the northwest corner of the area and in a smaller area north of Detroit in the northeast corner (Fig. 2). The dune sand consists of grayish-orange to light gray (as reported in drillers' logs), fine to medium quartz sand that in a few places contains much silt. It ranges in thickness from 3 to 20 feet north of Sand Springs, but is much thinner and probably not more than 15 feet thick north of Detroit (Latta, 1949 p. 31).

The dune sand is above the water table and, therefore, does not supply water to wells, but the sand is loose, very permeable, and provides excellent recharge for underlying water-bearing beds (Latta, 1949 p. 31).

Alluvium

Alluvium of Wisconsinan (Late Pleistocene) and Recent age occurs in the Smoky Hill Valley (Fig. 2) and is the most important source of water for stock, domestic, irrigation, industrial, and municipal supplies. All large wells in the area derive water from sand and gravel beds of the alluvium.

Alluvium is composed of clay and silt in the upper part, and sand and gravel in the lower part. At some places, silt and clay lenses

occur within the gravels and fine sand may be interbedded with silt and clay. Sandy and silty clay ranging in thickness from 1 to 55 feet and from yellow to grayish-orange to light-gray to dark-gray to blue-gray (as reported in drillers' logs) mostly occurs on top of the gravels. Fine to coarse sand and some gravel occur at a few places rarely, immediately above the gravel. Gravel ranges in thickness from 2 to 56 feet. Figure 8 is an isopach map of the saturated thickness (rock or soil in which all the interstices are filled with water) in the area.

METHODS OF INVESTIGATION

Field Procedure

Selection of Wells.--Locations of wells for water-table measurements were obtained from the Division of Water Resources of the Kansas State Board of Agriculture and through personal contact with residents in the area. Permission for use of wells and well information was obtained by letter and personal contact. Wells were selected for water analyses because of location and accessibility within the area of investigation.

Water-Table Measurements.--Depth-to-water measurements were made to the nearest 0.05 foot with a steel tape. Elevations of measuring points at the wells were surveyed to the nearest 0.1 foot using an automatic level (borrowed from the Department of Civil Engineering, Kansas State University) and United States Coast and Geodetic Survey first-order benchmarks. Locations and elevations of the benchmarks were provided by Kansas State Highway Commission.

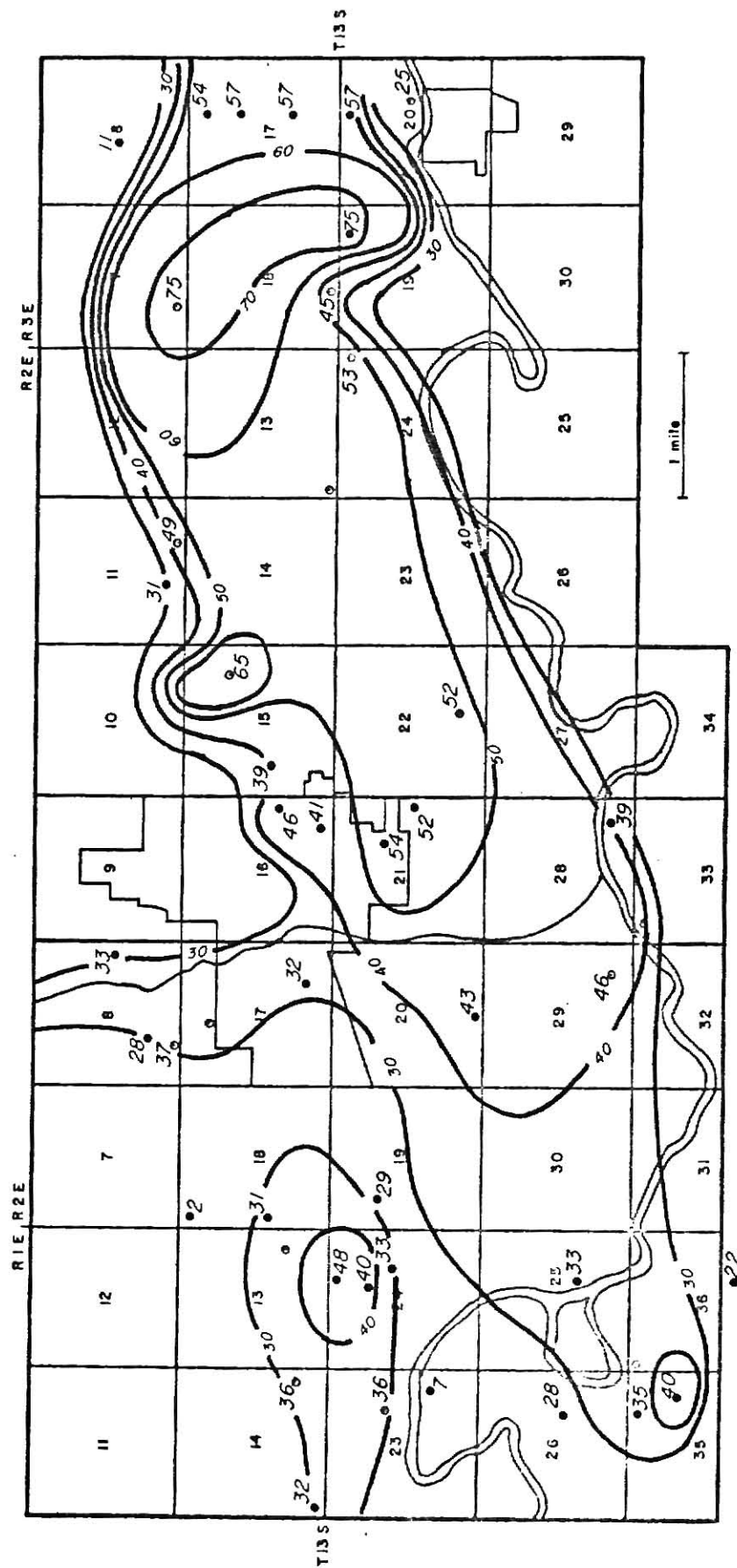


Fig. 8. Isopach map of saturated thickness (ft.). Contour interval 10 feet.

Maps and Cross Sections.--Base maps were constructed from Solomon, Kans., Abilene, Kans., and Chapman, Kans. quadrangles of the U. S. Geological Survey, 7.5 minute series; aerial photographs were examined to aid in establishing the locations of wells. Elevations of wells and test holes drilled by the Kansas Geological Survey were taken from Latta (1949), while elevations of wells and test holes provided by O. S. Fent were measured to the nearest five feet from the quadrangles. Isocon maps indicate concentrations of dissolved constituents in the ground water at the depth from which the water samples were drawn.

Collection of Water Samples.--The well system was thoroughly flushed and pressure tanks were drained before representative ground-water samples were collected. One-liter polyethylene sample bottles, rinsed three times with water from the well, were filled to eliminate air spaces, capped tightly, and immediately iced until they were analyzed for bicarbonate, calcium, magnesium, sodium, potassium, and nitrate. From seven wells two ml of concentrated HCl were added to the liter bottles to aid in analysis for iron.

Temperature of Ground Water.--Ground water was collected in a two-gallon plastic container to minimize temperature change and the temperature recorded to the nearest 0.1° C. The thermometer was immersed in the water to a uniform depth for each measurement.

Laboratory Procedure

This investigation does not consider all the dissolved constituents of natural waters, but only those constituting the major part of the dissolved-solids content which govern the use of ground water.

The cations analyzed were calcium, magnesium, sodium, potassium, and for some samples, iron. The anions analyzed included chloride, nitrate, sulfate, and bicarbonate. The specific conductivity and total dissolved solids of the water samples were determined also. The methods of analysis included titrimetric, turbidimetric, specific ion electrolysis, and atomic absorption/flame emission spectrophotometry. General descriptions of the analysis are given in Table 1 whereas detailed procedures for analysis of each ion or radical and the specific conductance are in Appendix II.

DISCUSSION AND INTERPRETATION OF DATA

Water Table

The upper surface of the zone of saturation in permeable rock or soil is called the water table and is at atmospheric pressure as if it were in an open tank. Under this unconfined or free condition the aquifer (a permeable material through which water moves) is referred to as a water-table aquifer or unconfined aquifer.

The zone of saturation may include both permeable and impermeable layers of sediment or rock. Where an aquifer is between impermeable layers, both the aquifer and its water are confined, and the water within the pores of the aquifer is at pressures greater than atmospheric (Johnson Div., 1972 p. 21-22). In the investigation area, the aquifer is almost totally unconfined, except at a few places.

The water table is not a stationary surface but fluctuates up and down in response to additions or withdrawals from the ground-water reservoir. It rises when more water is added to the zone of saturation

Table 1. Laboratory methods, instruments, and precision of analyses.

Disolved Constituent	Method	Instrument	Electrodes	Precision	Time After Collection of Sample Until Analyses Performed
Total dis- solved sol- ids	residue on evaporation (Rainwater & Thatcher, 1960) using borosili- cate glass evaporating dishes.	Sargent Electric Drying Oven (low temp.)-Blue M Electric Co. Lab- Heat Muffle Furn- ace (high temp.)		$\pm 2\%$	1 week
Calcium, Magnesium, Sodium, and Iron	atomic absorption spectrophotometry	Perkin-Elmer 305B atomic absorption/ flame emission spectrophotometer		$\pm 0.8\%$	1 day
Potassium	flame emission spectrophotometry	"	"	"	"
Chloride	specific ion electrolysis	Corning Model 12 Research pH-milli- volt meter	Orion solid state chloride specific ion electrode, double-junction reference electrode containing silver- silver chloride in the inner electrode and a LM potassium nitrate outer salt bridge	$\pm 3.2\%$	4 days
Nitrate	"	"	Orion nitrate specific ion electrode, calomel reference electrode	$\pm 1.8\%$	2 days
Sulfate	turbidimetry (mod- ified from Ewing, 1960)	Coleman Universal Spectrophotometer Model 14		$\pm 0.9\%$	5 days
Bicarbonate	titration	Corning Model 12 Research pH-milli- volt meter		$\pm 4.3\%$	12 hours
Specific conductivity		Lab-Line Lectro Mho- meter, Model MC-1, Mark IV and a Lab- Line epoxy conduc- tivity cell		$\pm 2\%$	4 days

by vertical percolation and drops during drought periods when previously stored water flows laterally toward springs, streams, wells, and other points of ground-water discharge, or is evapotranspired.

Water-level measurements were made during the winter (Table 2) within a three-day period to insure an essentially instantaneous overview of the water table. Winter is the most stable time to measure water levels because the aquifer has adjusted to recharge following the previous growing season and has not been affected by withdrawals from irrigation wells and plants during the spring growing season.

Shape and Slope of Water Table.--The water table is not a flat surface but has irregularities that are related to topography, geology, and hydrology. The shape and slope of the water table in the area is shown with contour lines (lines connecting points of equal elevation) drawn on the water table (Fig. 9). In this area the shape of the water table conforms closely to the surface topography.

Ground Water Movement.--Ground water can move only toward an area of discharge in response to a hydraulic gradient. The direction of movement is always down-slope and at right angles to a water-table contour. The ground-water movement in the study area is generally from northwest to southeast (Fig. 9).

The shape and slope of the water table indicate that the recharge area for the aquifer is in the hills north of Sand Springs. A great deal of recharge occurs by vertical percolation of water through the loose and highly permeable dune sand (Latta, 1949 p. 31). In many river valleys, the source of appreciable recharge is underflow from up-valley. This is seemingly not so in the study area because 1) water-table does

Table 2. Records of wells in a part of Dickinson Co., Kansas

Well Location ^a	Owner	Depth of Well Below Land Surface (ft.)	Use of Water ^b	Measuring Point				Date of Measurement 1974
				Height Above Ground (ft.)	Depth to Water from Measuring Point (ft.)	Depth to Ground Surface (ft.)	Elevation of Ground Surface	Elevation of Water ^c Table
13 1E 13ddd	Frank Garten	UNK	D, S	0.00	6.2	6.2	1197.71	1191.51
13 1E 14dd	Red Bud Lake Assoc.	UNK	P	0.75	15.0	14.25	1177.8	1163.55
13 1E 23acd	City of Abilene	54	P	1.50	19.15	17.65	1166.94	1149.29
13 1E 23dac	Rural Water District #2	UNK	N	1.25	16.10	14.8	1154.59	1139.79
13 2E 8cab1	Abilene Country Club	UNK	I	1.50	24.0	22.5	1186.89	1164.39
13 2E 8cab2	Abilene Country Club	UNK	I	0.00	36.8	36.8	1199.71	1162.91
13 2E 8cac	Abilene Country Club	UNK	I	1.2	10.5	9.3	1171.09	1161.79
13 2E 8cdc	Abilene Country Club	50	I	0.00	11.2	11.2	1168.33	1157.13
13 2E 13cca	Charles Wood	UNK	I	0.00	8.9	8.9	1138.88	1129.98
13 2E 15adb	Melvin Leckron	70	I	0.00	8.2	8.2	1145.89	1137.69
13 2E 17dbc	City of Abilene	UNK	N	0.00	4.2	4.2	1154.61	1150.41
13 2E 19acb	City of Abilene	UNK	P	1.83	11.95	10.12	1160.48	1150.36
13 2E 19cab	City of Abilene	UNK	P	1.3	11.0	9.7	1158.51	1148.81
13 2E 20ccc	Raymond Whitehair	UNK	I	0.00	7.2	7.2	1149.23	1142.03
13 2E 20idd	Bruce Sexton	UNK	I	1.5	15.9	14.4	1147.42	1133.02
13 2E 21bdc	Dautel	UNK	I	3.0	16.3	13.3	1145.62	1132.32
13 2E 22c	Charles Wilson	UNK	I	1.6	11.6	10.0	1141.46	1131.46
13 2E 24aab	Charles Wood	UNK	I	2.9	8.15	5.23	1134.75	1129.52
13 2E 24btd	Virginia Kean	UNK	I	0.00	10.5	10.5	1139.52	1129.02
13 2E 27beb	Ray Wilson	UNK	I	0.9	13.7	12.8	1144.46	1131.66
13 2E 28abd	Charles Wilson	UNK	I	1.0	11.4	10.4	1147.62	1137.22
13 2E 28baa	Wise	UNK	N	1.75	11.85	10.1	1144.45	1134.35

Table 2. Continued

Well Location ^a	Owner	Depth of Well Below Land Surface (ft.)	Use of Water ^b	Measuring Point		Elevation of Ground Surface	Elevation of Water Table ^c	Date of Measurement 1974
				Height Above Ground (ft.)	Depth to Water from Measuring Point (ft.)			
13 2E 29adc	Ray Wilson	UNK	I	0.00	16.6	1152.63	1136.03	2/15
13 2E 29bdc	Paul Nemecheck	UNK	I	0.9	14.3	1150.71	1137.31	2/15
13 2E 29ddb	Bruce Sexton	55	I	1.6	13.0	1146.96	1135.56	2/15
13 3E 7ecd	Wayne Mills	83	I	0.8	8.2	1137.75	1130.35	2/15
13 3E 17ddb	Ruth Glatt	UNK	I	1.1	12.1	1128.48	1117.48	2/15
13 3E 18cdd	Charles Wood	48	S	1.25	6.6	1132.44	1127.09	2/15
13 3E 19aab	Carl Stirtz	UNK	I	0.00	3.7	1128.27	1124.57	2/15
13 2E 17bad	City of Abilene	50	P	1.79	23.8	1163.77	1141.87*	2/15
13 3E 19bdc	Charles Wood	UNK	I	3.83	15.3	1132.31	1120.89	2/15
13 3E 20abc	7th Day Advents	UNK	I	1.8	12.3	1126.73	1116.23	2/15
13 3E 20acd	City of Enterprise	53	P	1.9	20.1	1132.27	1114.07	2/15

^aWell location: see p. 4 for description of well numbering system^bDepth of well below land surface: UNK, unknown.^cUse of water: P, public; D, domestic; S, stock; I, irrigation; N, not used.

*Well was pumping when depth to water was measured.

not slope in the valley direction, and 2) there is a lack of correlation of depth versus concentration (p. 87). Underflow derived from an up-valley source would be expected to contain more dissolved constituents because it has had greater residence time (see p. 42 for explanation of residence time) in the aquifer.

Ground-water discharge (return to the surface) may be by natural springs or seeps, by flow into surface streams, through water wells drilled into an aquifer, and by evapotranspiration. Two of the more obvious methods of discharge in the area are through wells and from the spring in the Herington Limestone Member of the Nolans Limestone at Sand Springs. Water-table contours near Mud Creek (Fig. 9) indicate water flows into or contributes to the flow of Mud Creek. Finally, if ground water is not discharged before reaching the southern edge of the area, it either discharges into the river, leaves the area as subsurface flow, is evapotranspired through plants, or evaporates from the soil.

Quality of Ground Water Related to Use

Total Dissolved Solids.--The concentration of total dissolved solids (TDS) in water includes ionized and nonionized rock, mineral, and sediment in solution. It does not include suspended sediments, colloids, or dissolved gases. The TDS concentration is therefore the numerical sum of all concentrations of dissolved solids as determined accurately by chemical tests. The residue left after evaporation does not equal the TDS because gases are driven off, bicarbonate converts to carbonate, sulfate deposited as gypsum traps some of the water, and small amounts of magnesium, chloride, and nitrate may be volatilized (Davis and

DeWiest, 1966 p. 100). However, the residue after evaporation and specific conductance (see p. 23) provide a verification of the accuracy of determinations of total dissolved solids.

The recommended maximum TDS for drinking water is 500 ppm (USPHS, 1962); water with higher concentrations may have a disagreeable taste. Water for most domestic and industrial uses should be less than 1000 ppm and water for most agricultural uses should be below 3000 ppm (Davis and DeWiest, 1966 p. 100). Total dissolved solids in drinking water in the U. S. range from 100 to 900 with a typical value from 300 to 400 ppm. The total dissolved solids of water analyzed in this project ranged from 211 to 2458 ppm (Table 3) and 10 of the 16 wells analyzed had TDS concentrations greater than 500 ppm.

Specific Conductivity.--The specific conductance of natural waters is given in micromhos (μ mhos), and measures the ability of water to conduct an electric current. Specific conductivity usually increases as total dissolved solids increase because most dissolved solids are largely ionized (the ions carry the electric current). The specific conductivity of a particular sample of water depends on the number, type, and charge of ions, their mobility or rate of movement, and the temperature.

Relation of TDS to Specific Conductance.--Total dissolved solids (ppm) divided by specific conductivity (μ mhos) can be determined for each sample and an average made of all samples. An estimate of the total dissolved solids in a water sample from an area can be made by using the following formula:

Table 3. - Analyses of water from wells in 1974. Dissolved constituents given in parts per million.

Sample ^a Well #	Location ^b	Geologic ^c Source	Owner	Date of Collection, 1974	Depth (ft)	Temp ^d (°C)	Dissolved Solids ^e (mg/l)	Iron (mg/l)	Calc. (mg/l)	Magn. (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Bicarbonate (mg/l)	Hardness as CaCO ₃ Total	Calcium Carbonate	Specific Conductivity	TDS Spec. Cond.	pH (lab)	pH (field)																				
1a	13 2E 17nd	A	City of Abilene	3/21	50	14.7	492	—	101	24	21	1.9	32	65	67	305	352	250	747	0.66	7.30	7.30																				
1b	13 2E 17nd	T	—	4/22	50	15.1	400	0.01	97	22	20	1.8	32	60	57	281	341	230	112	679	0.59	7.80	7.14																			
2	13 1E 13ccc	T	City of Abilene	3/21	35	14.6	339	—	78	15	10	1.2	10	53	27	290	257	205	52	538	0.56	7.48	7.35																			
3	13 1E 24nd	H	City of Abilene	3/21	54	14.6	211	—	46	9.9	9.6	1.8	19	34	33	134	161	110	51	378	0.36	7.35	7.05																			
4	13 1E 24dd	T	Red Bud Lake Assoc.	3/21	50	13.7	282	—	75	14	11	1.9	17	2.6	42	296	246	210	36	502	0.56	7.05	7.34																			
5a	13 2E 14db	A	Malvin Leckron	3/21	70	13.1	478	—	118	28	45	3.2	26	53	51	500	410	410	0	928	0.52	7.34	7.31																			
5b	13 2E 14db	—	—	5/22	70	13.2	591	0.5	132	29	51	3.1	19	46	55	549	450	450	0	964	0.61	7.45	7.31																			
6a	13 3E 2nd	A	City of Enterprise	5/22	53	14.2	706	—	153	28	55	6.1	91	3.2	218	433	498	355	143	1139	0.62	7.21	7.30																			
6b	13 3E 2nd	—	—	3/21	53	14.9	765	7.1	172	28	51	5.9	90	1.8	230	409	558	335	223	1117	0.69	7.28	7.30																			
7	13 2E 13ccc	A	Charles Wood	4/11	40	(14.6)	556	—	177	21	33	9.9	50	14	60	476	430	390	40	881	0.53	7.61	7.50																			
8	13 2E 24aaa	A	Charles Wood	4/11	58	(15.1)	851	—	203	30	55	6.6	41	61	198	561	632	460	172	1231	0.70	7.69	7.50																			
9a	13 3E 18ddd	A	Charles Wood	4/11	48	14.2	1626	—	287	60	54	11.9	105	57	784	537	965	440	525	2029	0.80	7.98	7.98																			
9b	13 3E 18ddd	—	—	5/22	48	14.9	1855	0.9	378	61	58	74	123	30	880	484	1198	395	803	3256	0.82	7.30	6.99																			
10	13 3E 7ccc	A	Wayne Mills	4/11	83	14.7	625	—	123	37	24	2.2	43	25	165	360	460	295	165	894	0.70	7.65	7.65																			
11	13 2E 22dbb	A	Charles Wilson	4/11	60	14.0	809	—	181	38	38	6.0	105	3.0	264	464	610	380	230	1258	0.64	7.56	7.56																			
12	13 2E 8ccc	A	Abilene Country Club	4/11	90	13.8	249	—	64	14	15	1.6	16	21	29	232	218	290	28	467	0.53	7.51	7.51																			
13	13 2E 11ccc	A	Charles Wood	4/11	53	[14.4]	464	—	102	26	33	2.8	33	17	73	604	452	455	0	1361	0.61	7.51	7.51																			
14	13 2E 24db	A	Bruce Seron	5/22	55	14.3	747	4.1	227	34	36	6.1	240	3.7	103	444	474	380	42	1304	0.57	7.37	7.10																			
15	13 2E 24db	A	Albert Nollig	5/22	20	14.6	2458	0.05	175	24	69	8.3	120	24	205	519	537	426	287	1427	0.63	7.36	7.21																			
16	13 2E 24db	A	Joe Clumance	5/22	20	14.3	2458	0.05	175	24	69	8.3	120	24	172	410	474	376	147	1173	0.63	7.36	7.21																			
17	13 1E 26bbs	A	—	mean	50	14.5	602	—	80.7	12.4	166	17.1	298	20.8	20.8	140	249	115	196	911	0.074	0.177	0.177																			
Standard Deviation																						13.8	0.692																			

^aSample of Well #: (a,b) indicates duplicate sample from that well.^bLocation: see p. for description of well locations.^cGeologic Source: A, alluvium; T, terrace; H, Herlington ls.^dTemp: () indicated questionable ground-water temperature because water passed through pressure tank before temperature was measured, [] indicated mean value of ground-water temperatures because no temp. was measured.

$$\text{SpC (A)} = \text{TDS}$$

where SpC = specific conductance measured in μ mhos at 25° C.

(A) = the average of $\frac{\text{TDS}}{\text{SpC}}$ for all the samples

TDS = total dissolved solids

In the formula above, (A) has an average value of 0.65 ppm/ μ mho and a range from 0.55 to 0.75 ppm/ μ mho in natural waters in the United States. The higher values are generally associated with waters high in sulfate (Hem, 1971 p. 99). Ground water in the area had a range of 0.53 to 0.82 ppm/ μ mho and an average of 0.63 ppm/ μ mho. Well #9 (sample b) had a value of 0.82 ppm/ μ mho (Table 3) which probably can be attributed to high sulfate content from dissolution of gypsum in the Gage Shale (Plate 1).

The equation for a linear regression of total dissolved solids versus specific conductance of samples in the investigation was computed (Graph 1) (Appendix III). The specific conductance of ground water in the Abilene area can be related to total dissolved solids through the expression:

$$\text{TDS} = 0.65(\text{SpC}) + 6$$

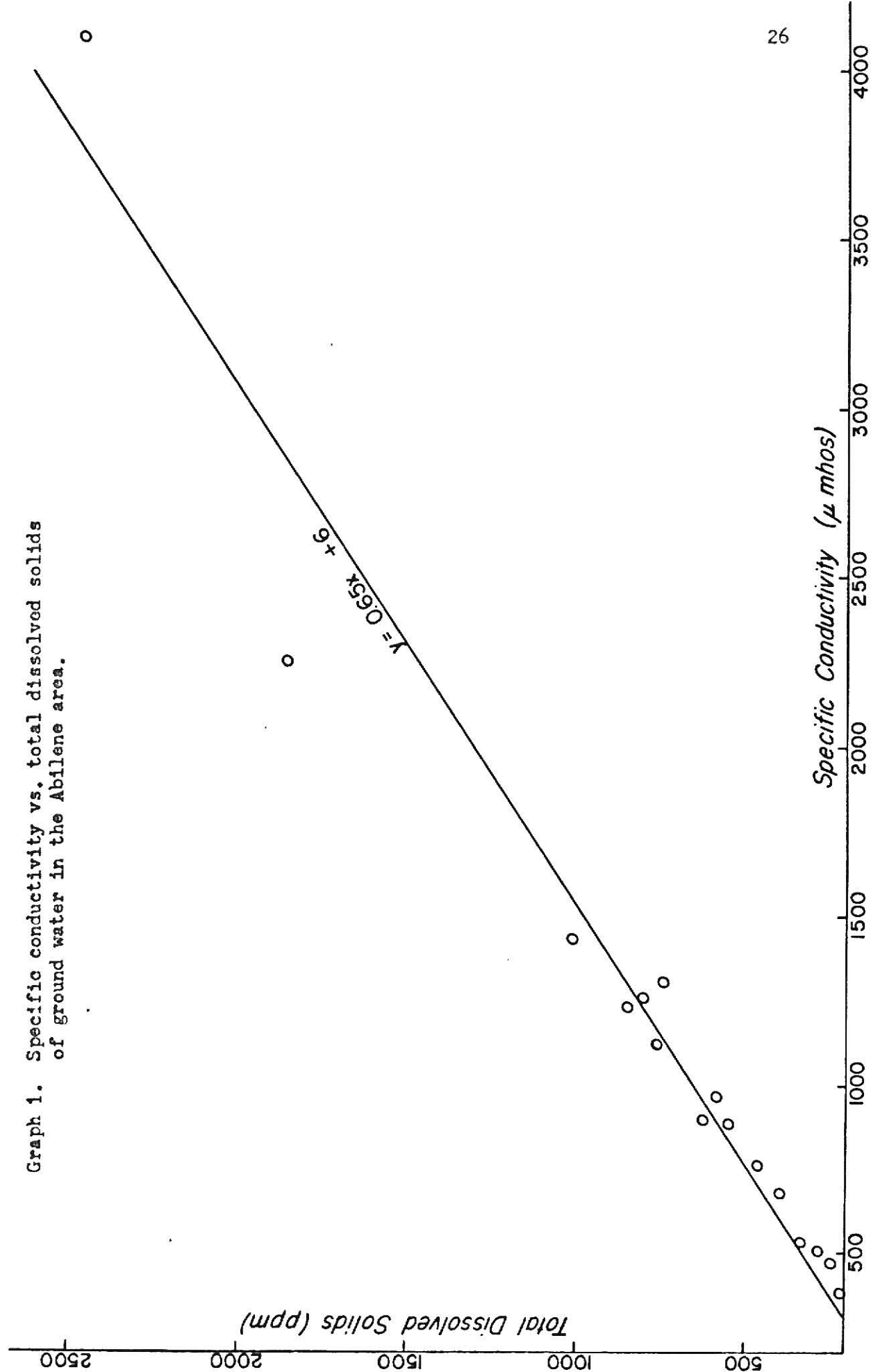
where TDS = total dissolved solids

and SpC = specific conductance measured in μ mhos at 25° C.

Using this expression an estimate of the total dissolved solids in a particular water in the investigation area can be made if specific conductance for the water is known.

Hardness.--Hardness of water is that quality that prevents lathering because calcium and magnesium salts form insoluble soaps

Graph 1. Specific conductivity vs. total dissolved solids of ground water in the Abilene area.



(Johnson Div., 1972 p. 66). The total hardness of water may be divided into carbonate and non-carbonate hardness. Carbonate hardness (formerly called "temporary hardness") is calcium and magnesium that would combine with bicarbonate and the small amount of carbonate; it can be removed by boiling. Non-carbonate hardness is caused by calcium and magnesium that normally combines with sulfate, chloride, and nitrate ions and it cannot be removed by boiling (Johnson Div., 1972 p. 67).

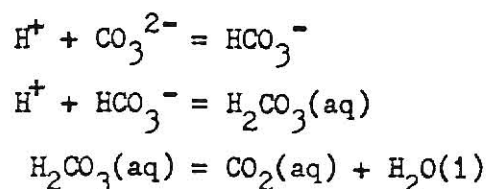
The U. S. Public Health Standards (1962) do not specify any value for hardness. The adjectives "hard" and "soft" as applied to water are inexact, and some writers have tried to improve this situation by adding qualifying adverbs. Durfor and Becher (1964) suggested the following hardness scale:

Hardness Range (mg/l of CaCO_3)	Description
0- 60 -----	Soft.
61-120 -----	Moderately hard.
121-180 -----	Hard.
More than 180 -----	Very hard.

Total hardness in the area ranged from 161 to 1198 ppm with typical values from 300 to 500 ppm (Table 3). Carbonate hardness ranged from 110 to 495 ppm with typical values from 300 to 400 ppm (Table 3) and noncarbonate hardness ranged from 0 to 803 ppm with typical values from 50 to 200 ppm (Table 3). According to the hardness classification, the water ranged from hard to very hard. Fig. 10 is a map of hardness values in the Abilene area.

Hydrogen-Ion Activity (pH).--The pH is a measure of the hydrogen-ion activity and is the negative log to the base-10 of the hydrogen-ion activity in moles per liter. The pH values were measured in the

water samples after they were brought into the laboratory, and seven pH measurements were also made at the well sites. Laboratory pH measurements ranged from 7.05 to 7.80 with an average of 7.44 (Table 3) and field measurements, made by Whittemore, 1974, ranged from 6.99 to 7.31 with an average of 7.17 (Table 3). The average difference between laboratory measurement and field measurement was 0.27; pH measured in the lab was higher because CO_2 came out of solution which had the effect of reducing hydrogen-ion activity and raising pH between time of collection and time of measurement. Reactions are as follows (Hem, 1971 p. 89):



Iron.--The principal sources of dissolved iron in ground water are the oxide and sulfide species of iron minerals. Weathering or solution of iron-bearing silicates can produce an accumulation of ferric oxyhydroxides, commonly responsible for the red or yellow color of rocks and soils (Hem, 1971 p. 114-116).

Water with greater than 0.3 ppm iron is considered undesirable (USPHS, 1962). Greater concentrations of iron stain plumbing fixtures and clothes during laundering, encrust well screens, and plug pipes (Johnson Div., 1972 p. 71). When water with a high concentration of iron is exposed to air, iron may precipitate, turning the water reddish-brown. Concentrations of iron in the area ranged from 0.01 to 7.1 ppm (Whittemore, 1974) (Table 3).

Calcium.--Subsurface waters in contact with sedimentary rocks derive most calcium from solution of calcite, aragonite, dolomite, anhydrite, and gypsum (Davis and DeWiest, 1966 p. 102). Ground water associated with limestone would commonly be saturated with calcite (Hem, 1971 p. 140). If sulfate is the major anion in the water and the concentration of bicarbonate is low, the solubility of calcium sulfate (gypsum) will tend to control the final calcium concentration in the water (Davis and DeWiest, 1966 p. 103).

Typical values of calcium in ground waters in carbonate rocks are 4 to 120 ppm and, with gypsum, are 600 ppm (Langmuir, 1970 p. 7). Concentrations of calcium in the area range from 46 to 378 ppm with a typical range from 100 to 200 ppm (Table 3). Fig. 11 is an isocon map of calcium concentrations in the area.

Magnesium.--The most common source of magnesium in sedimentary rocks is dolomite. In addition, most calcite contains a small amount of magnesium, so dissolution of limestone commonly yields magnesium also. Magnesium is in lower concentrations than calcium in natural waters, despite magnesium's higher solubility, because dolomite dissolves slowly and calcium is more abundant in the earth's crust (Davis and DeWiest, 1966 p. 104).

Magnesium concentrations were from 9.9 to 61 ppm with a typical range from 20 to 40 ppm (Table 3) and are on the isocon map (Fig. 12).

Sodium.--The primary source of most sodium in natural water is the release of soluble products during weathering of plagioclase feldspars (Davis and DeWiest, 1966 p. 104), and from evaporites such as

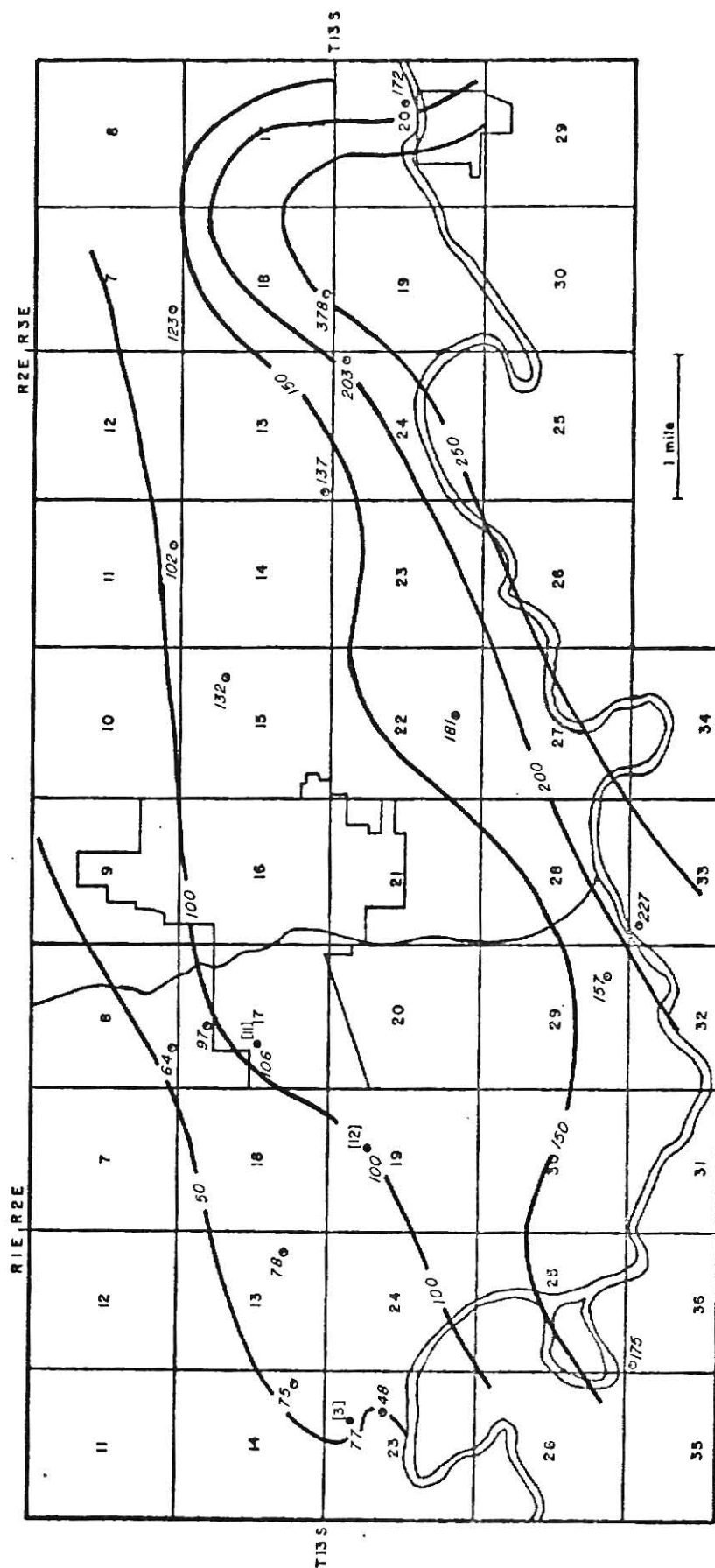


Fig. 11. Calcium concentration (ppm) of ground water in Abilene area. Contour interval 50 ppm.

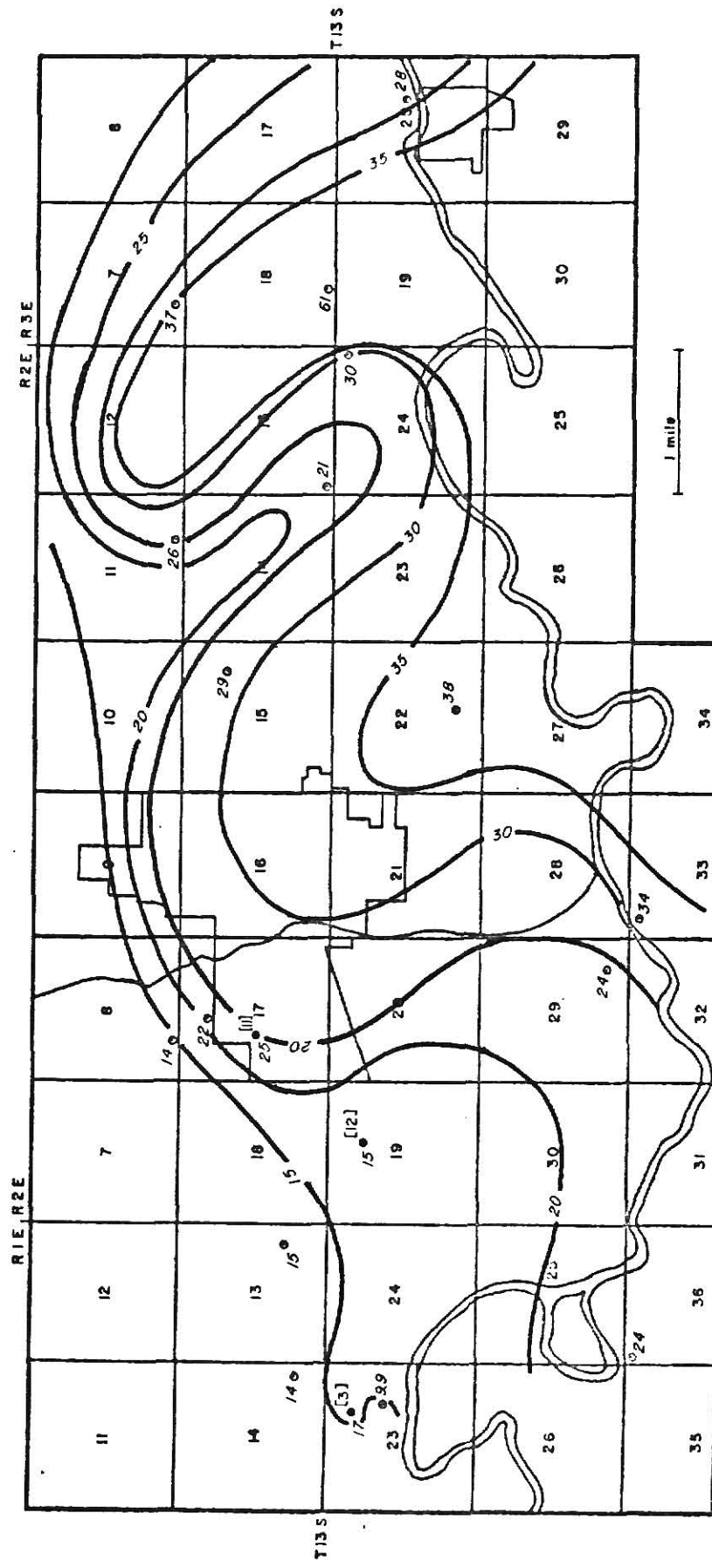


Fig. 12. Magnesium concentration (ppm) of ground water in Abilene area. Contour interval 5 ppm.

halite or rock salt. Ground water in limestone formations may have only a few parts per million out of several hundred ppm dissolved solids (Johnson Div., 1972 p. 73). All natural water contains measurable amounts of sodium (Davis and DeWiest, 1966 p. 105). Typical ground-water sodium concentrations range from 10 to 90 ppm and most ground water contains 50 ppm sodium (Davis and DeWiest, 1966 p. 98).

Ground water analyzed had sodium concentrations ranging from 9.6 to 695 ppm, but only two wells had greater than 100 ppm (Table 3). Fig. 13 is a map of sodium concentration in the Abilene area.

Potassium.--Although potassium in the earth's crust is about as abundant as sodium, potassium is commonly less than one-tenth the concentration of sodium in natural water. Potassium enters into the structure of illite during weathering and potassium-rich minerals are more resistant to weathering (less soluble) than sodium minerals (Davis and DeWiest, 1966 p. 106).

Most ground water in the U. S. contains less than 10 ppm potassium and commonly ranges between 1.0 and 5.0 ppm (Davis and DeWiest, 1966). Ground waters in the area had concentrations ranging from 1.2 to 9.9 (Table 3) except well #9 which had a concentration of 74 ppm. Figure 14 is a map of potassium concentrations in the study area.

Nitrate.--Most nitrate in water comes from organic sources or from industrial and agricultural chemicals (Davis and DeWiest, 1966 p. 110). Range of nitrate content for different waters is great and seems to be unrelated to any geologic formation.

Nitrate content of soil can accumulate from plant debris, animal wastes, and nitrate fertilizers and additional amounts emanate from the

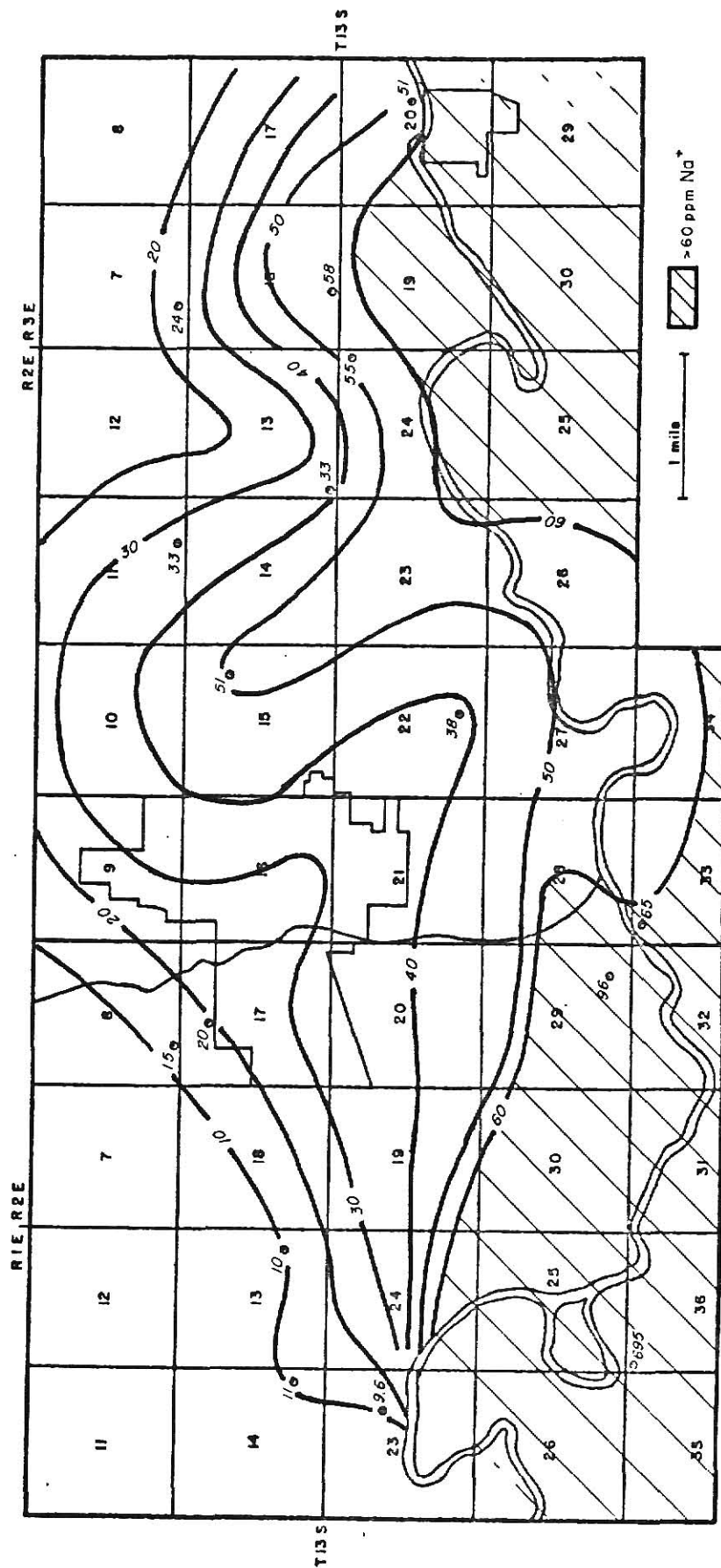


Fig. 13. Sodium concentration (ppm) of ground water in Abilene area. Contour interval 10 ppm.

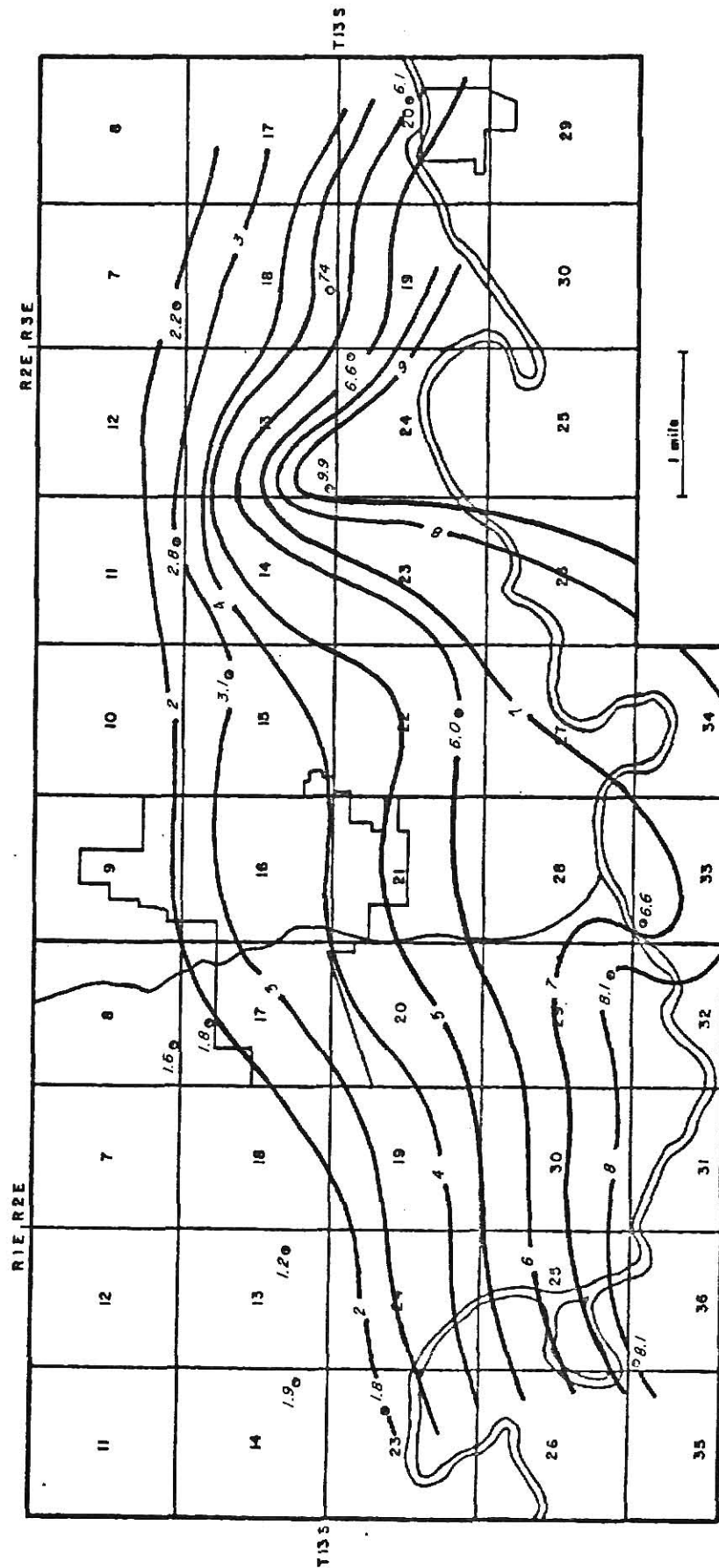


Fig. 14. Potassium concentration (ppm) of ground water in Abilene area. Contour interval 1 ppm.

discharge of sewage wastes. High nitrate concentrations in water from a well may be caused by direct flow of surface water into the well, or by percolation of contaminated water into the aquifer from overlying soil zones. Large amounts of nitrate in well water may indicate pollution from such sources as cesspools, barnyards, and feedlots. A high nitrate content indicates pollution and is a warning that the water should be tested for harmful bacteria which also may be carried into the aquifer from sources of pollution mentioned above (Johnson Div., 1972 p. 75).

The United States Public Health Service has stated that concentrations of nitrate greater than 45 ppm is undesirable in water for public use because it may cause cyanosis or methaglobinemia in infants (USPHS, 1962). Cyanosis causes the baby to become listless, drowsy, and the skin turns blue; the condition may result when water containing excessive nitrate is used in preparing the baby's formula. Nitrate in drinking water does not cause cyanosis in adults or older children (Johnson Div., 1972 p. 75).

Nitrate concentrations ranged from 1.8 to 65 ppm with typical values of 20-40 ppm (Table 4). Because nitrate had no trends when plotted on the map, no contours of nitrate values were made. However, five wells had nitrate concentrations greater than 45 ppm (Fig. 15). Three wells (#1, #2, and #5) were analyzed for this study and two additional wells ([11] and [12]) were analyzed by the Kansas Geological Survey. Well [11] lists an average value of analyses made in 1961, 1963, and 1967 of 53 ppm. Well [12] was analyzed in 1968 and had a concentration of 53 ppm.

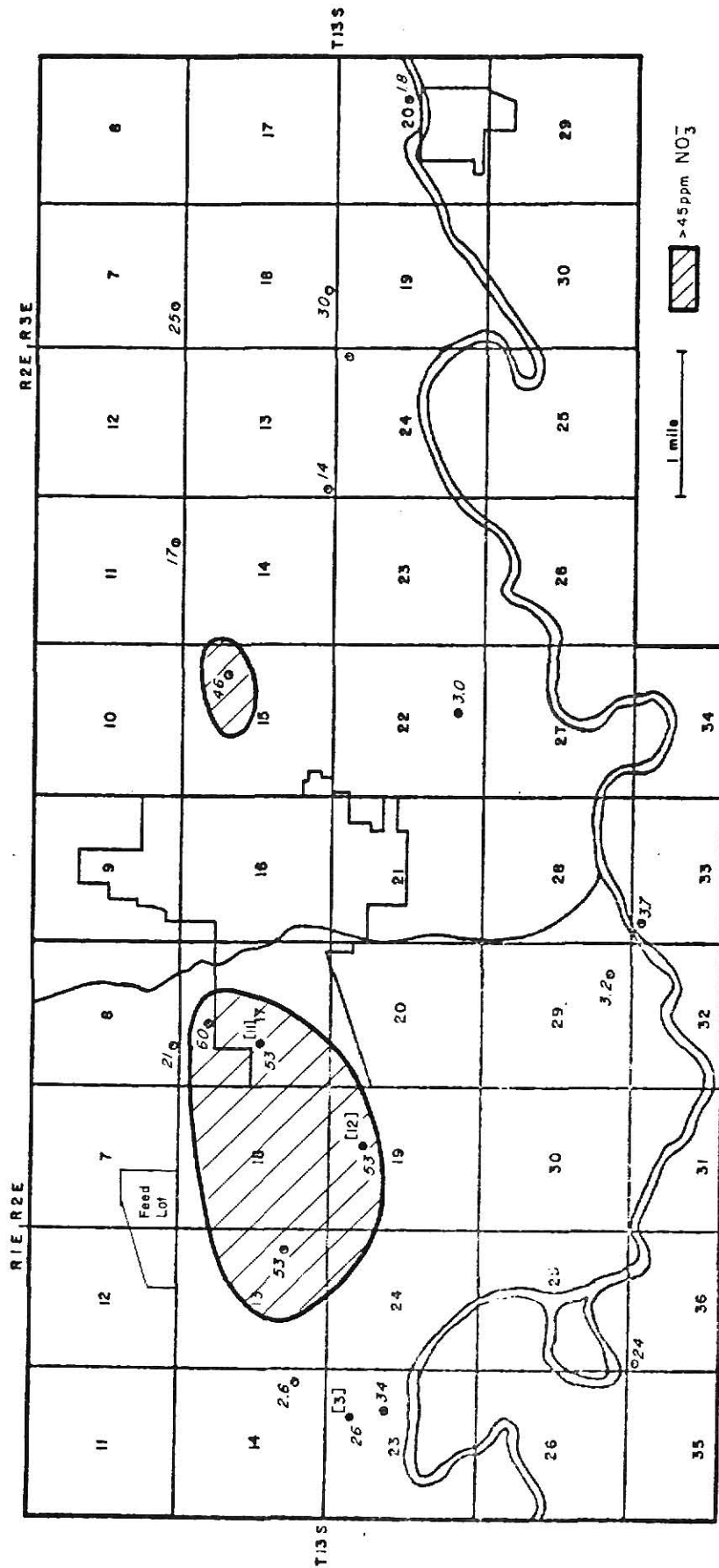


Fig. 15. Nitrate concentration (ppm) of ground water in Abilene area. [] indicate well analyzed by Kansas Geological Survey.

Table 4. Nitrate concentrations in wells in the Abilene area.

Sample or Well #	Nitrate (NO ₃)	Sample or Well #	Nitrate (NO ₃)	Sample or Well #	Nitrate (NO ₃)
1a	65	6a	3.2	11	3.0
1b	60	6b	1.8	12	21
2	53	7	14	13	17
3	34	8	61	15	3.2
4	2.6	9a	57	16	3.7
5a	53	9b	30	17	24
5b	46	10	25	[11] KGS	53
				[12] KGS	53

Sulfate.--In areas of sedimentary rocks, sulfate in ground water is derived principally from dissolution of gypsum (CaSO₄) (Johnson Div., 1972). The recommended maximum sulfate concentration of drinking water is 250 ppm (USPHS, 1962). Water with sulfate concentrations in excess of 250 ppm may have a bitter taste and a laxative effect on those not accustomed to it. Concentrations of ground water in the U. S. range from 5 to 100 ppm with a typical value of 30 ppm (Davis and DeWiest, 1966 p. 98). Concentrations of sulfate ranged from 27 to 880 ppm with a typical range from 50 to 250 ppm (Table 3) in ground water in the Abilene area. Four wells analyzed had sulfate concentrations greater than the limit set by the U. S. Public Health Service; three are domestic wells and one is a stock well. Figure 16 is a map of sulfate concentrations.

Chloride.--Most chloride in ground water is derived from (1) chloride from ancient sea water entrapped in sediments; (2) solution of halite and related minerals in evaporite deposits; (3) concentration by evaporation of chloride contributed by rain or snow; and (4) solution

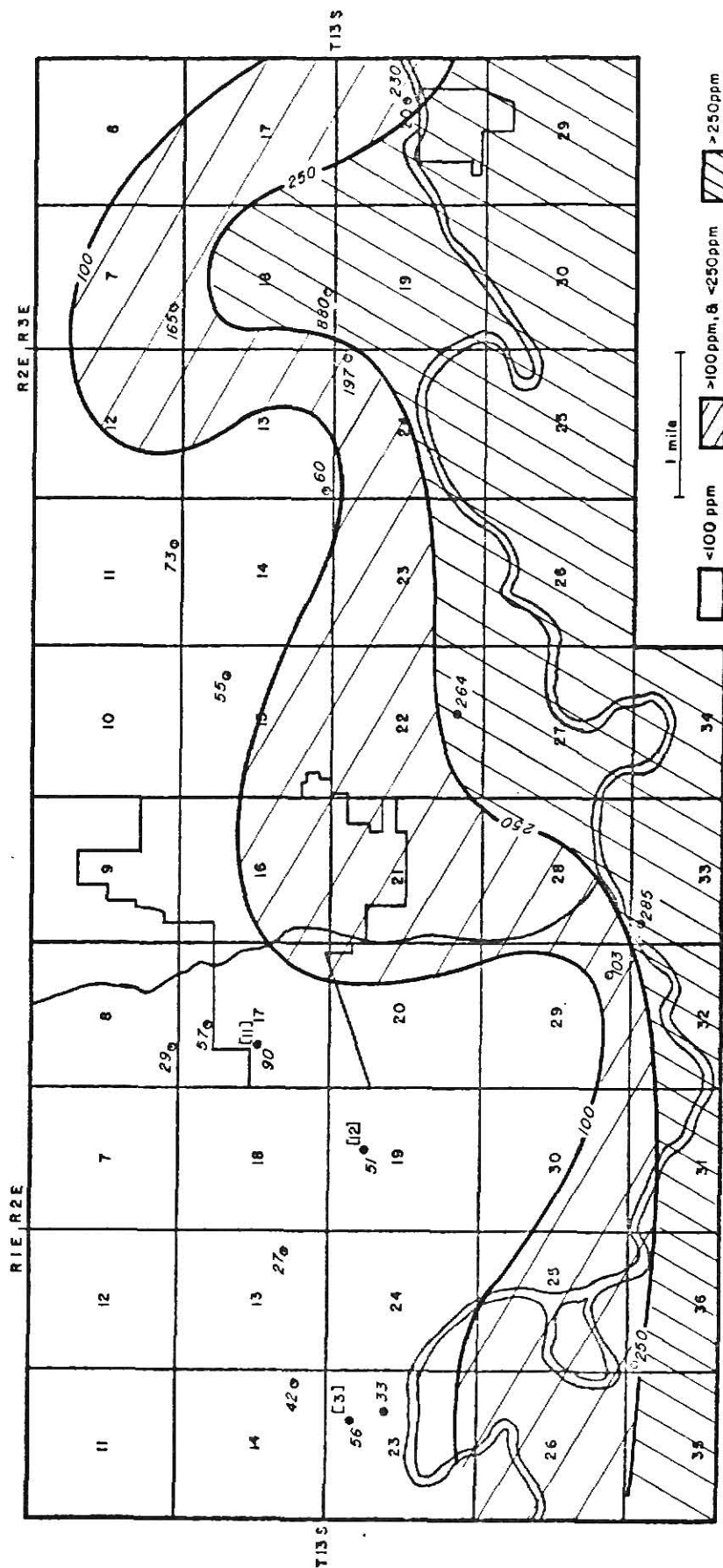


Fig. 16. Sulfate concentration (ppm) of ground water in Abilene area.

of dry fallout from the atmosphere, particularly in arid regions (Davis and DeWiest, 1966 p. 109).

Maximum concentration of chloride in drinking water is 250 ppm (USPHS, 1962). Water with excessive chloride is very corrosive and can cause a disagreeable taste, and if greater than 350 ppm, is undesirable for most irrigation or industrial uses (Johnson Div., 1972 p. 74). Concentrations of chloride in ground water in the United States range from 5 to 100 ppm with a typical value of 20 ppm (Langmuir, 1970 p. 2). Chloride concentrations in water analyzed here ranged from 10 to 1230 ppm with typical values from 20-120 ppm (Table 3). Only well #17 (1230 ppm) had a concentration greater than 350 ppm. Figure 17 is a map of chloride concentrations in the Abilene area.

Bicarbonate (HCO_3^-) (Alkalinity).--The amount of a standard concentration of sulfuric acid needed to titrate a water sample to an endpoint of pH 4.5 is a measure of the alkalinity of the water. Alkalinity is a reliable measure of carbonate and bicarbonate ions for most natural water because alkalinity is caused largely by bicarbonate and carbonate ions, although hydroxide, iron, silicate, and phosphate will have a small effect on alkalinity (Davis and DeWiest, 1966 p. 106).

Dissociation of bicarbonate to carbonate ions is effective largely above a pH of 8.2. Below 8.2 most carbonate ions add hydrogen to become bicarbonate ions ($\text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{HCO}_3^-$), and the ratio of bicarbonate to carbonate increases to more than 100 to 1. The alkalinity titration above a pH of 8.2, therefore, measures carbonate ions and below 8.2 measures bicarbonate ions (Davis and DeWiest, 1966 p. 107). Because the pH values of the waters in the study area are below 8.2

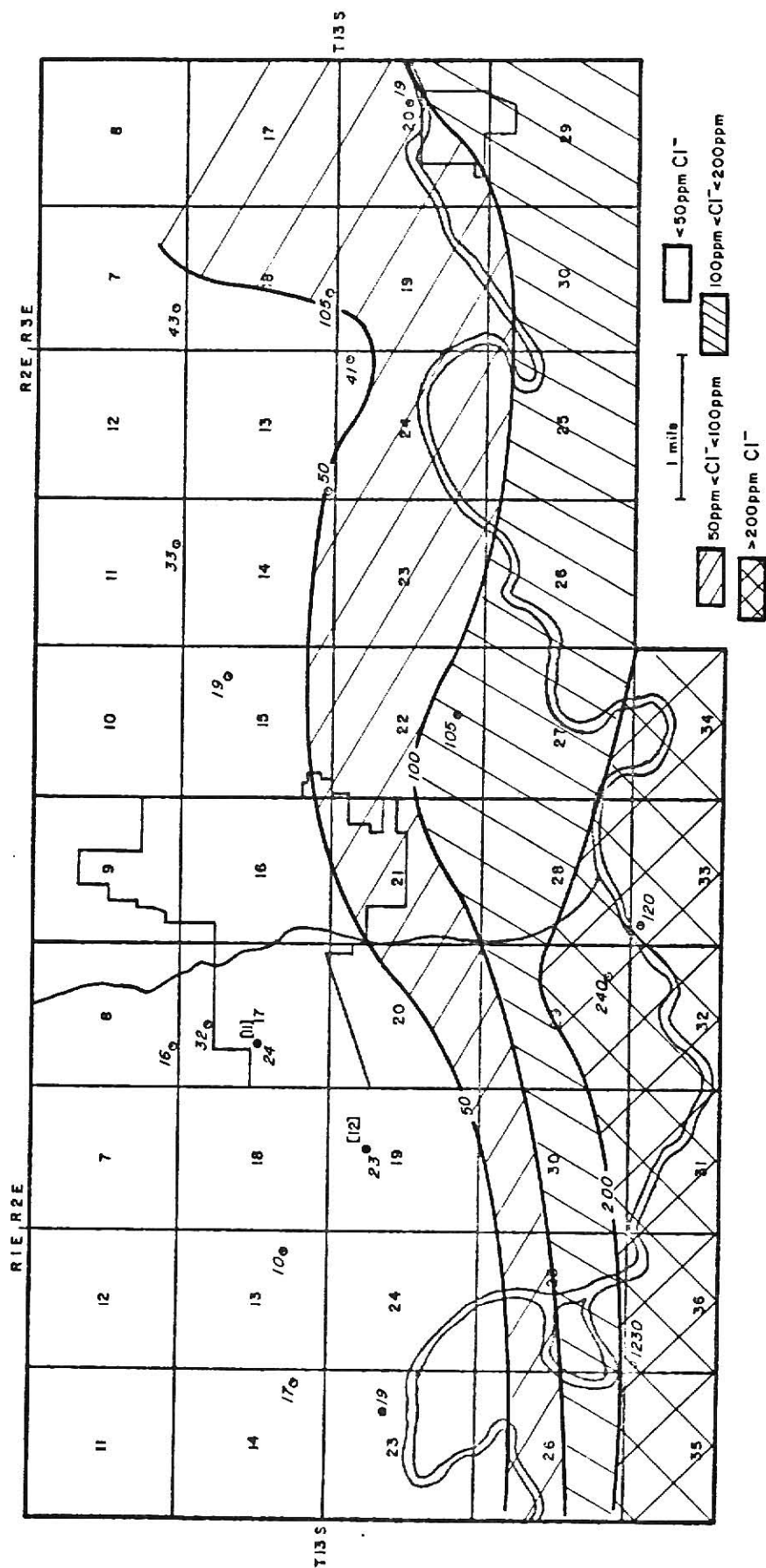


Fig. 17. Chloride concentration (ppm) of ground water in Abilene area.

(Table 3), alkalinity of the water is listed as bicarbonate (HCO_3^-) values.

Most carbonate and bicarbonate ions in ground water are derived from carbon dioxide in the atmosphere, carbon dioxide and calcium carbonate in the soil, and solution of carbonate rocks. These factors probably contribute to the bicarbonate of ground water in the Abilene area but possibly the solution of calcium carbonate in the sand and silt fractions of the aquifer contributes the most (Beck, 1974).

Ground water generally contains more than 10 ppm but less than 800 ppm bicarbonate. Concentrations between 50 and 400 ppm are most common (Davis and DeWiest, 1966 p. 107). Bicarbonate values in this area range from 134 to 604 ppm with typical values from 350 to 520 ppm. Concentrations of bicarbonate in the area are in Figure 18.

Interpretation of Data

Isocon (equal concentration) maps of dissolved constituents in the Abilene area indicate that concentrations of calcium (Fig. 11), magnesium (Fig. 12), sodium (Fig. 13), potassium (Fig. 14), chloride (Fig. 17), sulfate (Fig. 16), and bicarbonate (Fig. 18) increase from north to south. This can be explained as a function of the residence time of ground water in the aquifer. As water flows from north to south through the aquifer (Fig. 9), ground water in the southern part of the area has been in, or has resided in, the aquifer for a longer time than water to the north. Therefore, water in the southern part of the aquifer will have more dissolved constituents than in the northern part because 1) it has been in the aquifer longer and, thus, has had

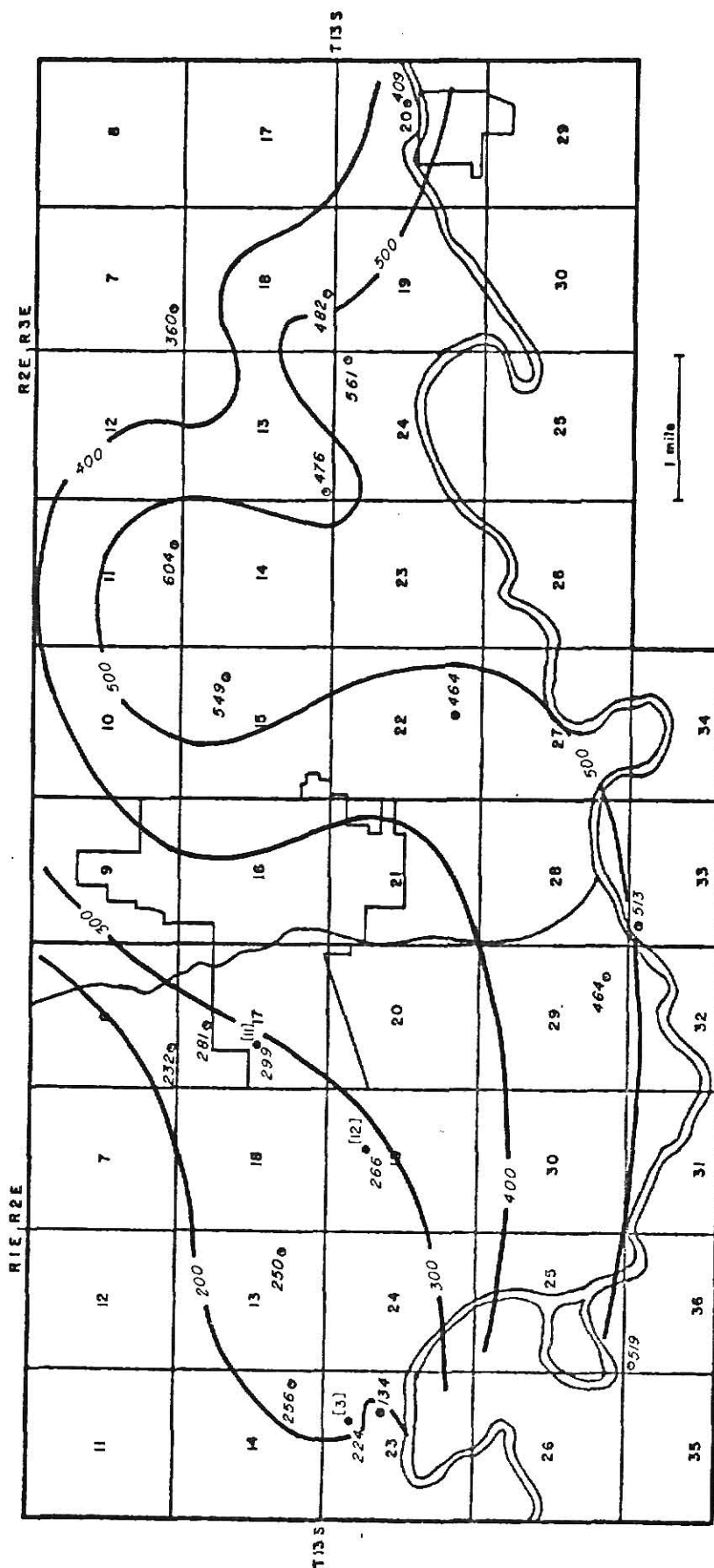


Fig. 18. Bicarbonate concentration (ppm) of ground water in Abilene area. Contour interval 100 ppm.

more time to dissolve rock and sediment and 2) it has come in contact with more dissolvable rock and sediment by flowing through the aquifer.

Most calcium in the area is probably derived from the dissolution of primary calcium carbonate in the sand and silt fractions of the aquifer (Beck, 1974), limestone (CaCO_3), and gypsum, because all are in the area (Plate 1) (Logs of Wells, App. I). A high concentration of calcium in the eastern part of the area, just north of the river (Fig. 11), coupled with an extremely high concentration of sulfate (784 ppm) for the same area (Fig. 16) is caused by well #9 (13 3E 18cdd) which is in or close to gypsum. Perhaps salt (NaCl) has been dissolved by ground water because the sodium concentration in well #17 (13 1E 36bbb) is 695 ppm and is associated with a high concentration of chloride (1230 ppm). The contamination is not derived locally because no salt beds are in the area and the Smoky Hill River lacks high enough sodium and chloride concentrations to affect the well (USGS, 1973 p. 297). The source of contamination is probably salt brine from the Hutchinson Salt Member of the Wellington Formation moving up dip from the west.

Wells #1, #2, [11], and [12] have concentrations of nitrate greater than 45 ppm (Table 4). A feedlot was operated from 1960 to 1968 in the $\text{SW}\frac{1}{4}$ of Sec. 7, T.13S., R2E., and a feedlot has operated in the $\text{SE}\frac{1}{4}$ of Sec. 12, T.13S., R.1E. since 1955. Runoff from the feedlots percolating through the loose and permeable dune sands may explain the high nitrate content in the four wells. The ground-water flow (Fig. 9) indicates the feedlots could be the source of high nitrates. Wells #1 and #2 which are used by Abilene, should be monitored in the future to

determine if the nitrate concentration increases. The high value of nitrate in well #9 is caused by its proximity to a livestock pen, while the source of pollution for well #5 is unknown.

Dissolved iron in the ground water is probably derived from solution of iron-bearing silicates in the alluvium. Iron concentrations seem to increase toward the southern and southeastern parts of the area, possibly because the iron concentration increases with increasing depth or increasing saturated thickness.

Accuracy of Water Analyses

According to Rainwater and Thatcher (1960):

Some errors are practically unavoidable in analytical work. Errors may result from the reagents, from the limitation of the method or instruments employed, or even from impurities in distilled water. The analyst's skill and general judgment have a direct bearing on the accuracy of the analytical statement. After the chemical analysis of the water sample has been completed, there are several ways by which the validity of the results can be evaluated. No one method gives conclusive proof of the accuracy of the determinations, but the process of checking may bring to light some dubious results or may suggest some additional constituents of the sample that were not considered in the analysis.

A common method for validating the accuracy of a water analysis is balancing the chemical equivalents of the major ions; the sum of the equivalents of cations should equal the sum of the anions. The equivalents per million (epm) of the anions and the epm of the cations should balance to within one or two percent (see equation p.) for waters of more than 150 ppm total dissolve solids, if all major ions have been determined accurately (Rainwater and Thatcher, 1960 p. 83). Equivalents per million is determined by using the following expression:

$$\text{epm} = \frac{\text{concentration (ppm) of ion}}{\frac{\text{formula weight of the ion}}{\text{charge of the ion}}}$$

Table 5 lists errors for 20 water analyses which were calculated using the following expression:

$$\text{Percent error} = \frac{\text{Anion epm} - \text{Cation epm}}{\text{Anion epm} + \text{Cation epm}} \times 100$$

Table 5. Percent Error for Water Analyses

Sample #	Percent Error	Sample #	Percent Error
1a _____	2.3	8 _____	1.0
1b _____	0.6	9a _____	8.1
2 _____	1.8	9b _____	3.2
3 _____	3.9	10 _____	3.1
4 _____	1.6	11 _____	7.1
5a _____	2.9	12 _____	1.5
5b _____	0.6	13 _____	18.2
6a _____	6.6	15 _____	7.2
6b _____	2.0	16 _____	1.8
7 _____	2.1	17 _____	8.5

The total anion equivalents ranged from 0.6% to 8.4% higher than cation, although sample 13 lists an 18.2% error; most errors were between 1 to 3 percent. Calcium determinations were low in the first 13 samples possibly because calcium was complexing with sulfate or because calcium and sulfate precipitated during the 2 to 5 weeks after bicarbonate had been analyzed and before concentrations of calcium and sulfate were determined, causing erroneous calcium and sulfate values and introducing the error.

To check the error for calcium and the stability of the ionic concentrations, four duplicate samples (1b, 5b, 9b, 6b) were taken

(duplicates of 1a, 5a, 9a, and 6a respectively) and calcium was analyzed within 1 day after bicarbonate. A lanthanum solution (see calcium procedure App. II) was added to the samples to break up complexes of the calcium ion. Samples 15, 16, and 17 were also analyzed at this time following the same procedure. In the four duplicate samples errors were reduced from the first analyses from 2.3 percent (1a) to 0.6 percent (1b), 2.9 percent (5a) to 0.6 percent (5b), 6.6 percent (6a) to 2.0 percent (6b), and 8.1 percent (9a) to 3.2 percent (9b).

However, during these analyses, samples 15 and 17 (not duplicate samples) recorded 7.2 percent and 8.1 percent errors respectively. No reason for this error has been determined but it may have been caused by interferences from high concentrations of Na^+ and Cl^- in both samples.

Except for the calcium concentration, the values of the dissolved constituents did not change appreciably, indicating the chemical composition of ground water in the area is stable.

Possible Utilization of Ground Water

Most interpretations of quality of ground-water data are made to determine if the water is satisfactory for a proposed use. All classifications of water according to possible uses, should be used with caution and should not be rigidly applied because for economic or availability reasons an area may be forced to use a water supply, even though it doesn't meet USPHS recommendations.

Public Use.--Standards for drinking water are based on 1) objectionable tastes, odors, or colors, and 2) substances with adverse physiological effects. Iron and hardness are the two constituents analyzed in

this report that may produce undesirable tastes, odors, or colors; sulfate, chloride, and nitrate may have adverse physiological effects (Davis and DeWiest, 1966 p. 120).

Wells #9, #11, and #16 had sulfate concentrations above the USPHS standard of 250 ppm (Table 3) (Fig. 16) and well #17, south of the river, has a chloride concentration above the USPHS standard of 250 ppm (Table 3) (Fig. 17). High concentrations of nitrate in wells #5 and #9 are probably caused by local effects, such as feed lots.

Considering only the chemical quality of ground water, future public water supplies should be obtained in the northern half of the study area where concentration of the dissolved constituents is lowest and the water is least hard. Areas in the southern part of the study area near the river, especially south of the river, should be avoided. The area northwest of Abilene with the high nitrate content should also be avoided until the problem has been resolved and the nitrate content drops below the USPHS standard of 45 ppm.

Agricultural Use.--Water required for nondomestic purposes on farms and ranches includes that consumed by livestock and that used for irrigation. Water used by stock is subject to quality limitations of the same type relating to quality of drinking water for human consumption. Most animals, however, are able to use water considerably higher in total dissolved solids than water considered satisfactory for humans. McKee and Wolf (1963) reported the concentration limits of total dissolved solids for stock water as follows:

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

The chemical quality of water is an important factor in evaluating its usefulness for irrigation. Total concentration of dissolved solids and relative proportions of calcium, magnesium, and sodium must be known. The calcium and magnesium content of the soil and subsoil, topography, position of the water table, amounts of ground water used and the method of application, kinds of crop grown, and climate of the area also need to be considered (Walton, 1970 p. 459).

If salinity of irrigation water is high, excess soluble matter left in the soil from irrigation must be removed by leaching the topsoil and allowing the resulting solution to percolate to the water table. If the water table rises excessively, this process of drainage disposal of salts may not be effective.

Besides potential dangers from high salinity, a sodium hazard sometimes exists. The two principal effects of sodium are a reduction in soil permeability and a hardening of the soil. Both effects are caused by replacement of calcium and magnesium ions by sodium ions on soil clays and colloids (Davis and DeWiest, 1966), and can be estimated by the sodium adsorption ratio (SAR) expressed as:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where: Na, Ca, and Mg represent concentrations in milliequivalents per liter.

Table 6 lists the SAR values for wells in the investigation area which are plotted on the standard SAR diagram (Fig. 19).

Table 6. Sodium Adsorption Ratios for wells in the study area

<u>Well No.</u>	<u>SAR</u>	<u>Well No.</u>	<u>SAR</u>
1a	0.5	8	1.0
1b	0.5	9a	0.8
2	0.3	9b	0.7
3	0.3	10	0.5
4	0.3	11	0.7
5a	1.0	12	0.4
5b	1.0	13	0.8
6a	1.1	15	1.9
6b	1.0	16	1.1
7	0.7	17	13.1

All wells in the area are suitable for use by stock and, all but one (#17), for irrigation. Because many wells have a high salinity hazard, proper leaching of the soil should be maintained to insure that salts in irrigation water are not being deposited in the soil, but are percolating down through the soil layer (Fig. 19).

Industrial Uses.--The water requirements for industrial water supplies range widely and almost every industrial application has its own standard. Ground water in the northern part of the investigation area probably would be suitable for most industries, however, no attempt to discuss the application of water for industrial use will be made because industrial requirements have such a wide range.

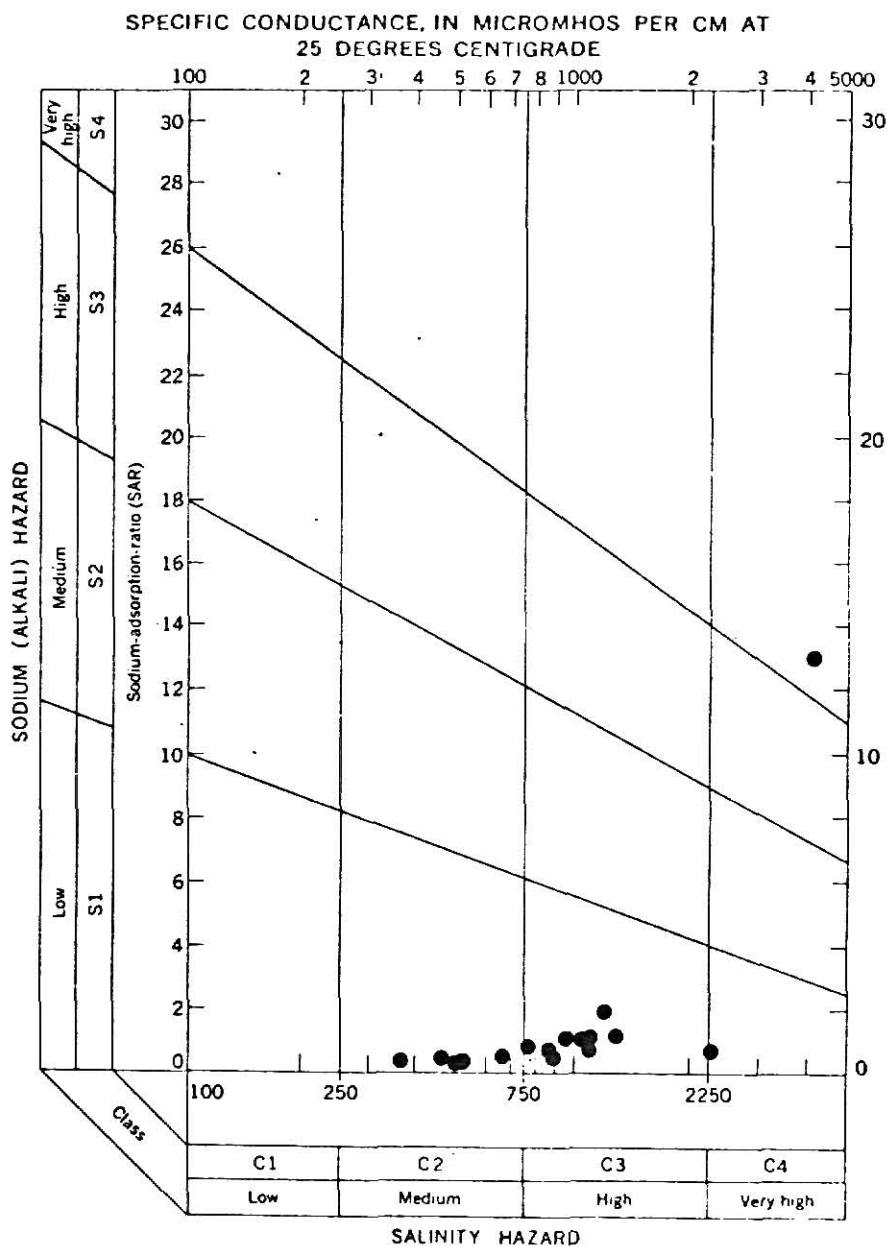


Fig. 19. Classification of irrigation water in the Abilene area. Adapted from U. S. Salinity Laboratory Staff (1954).

Linear Regression Between Dissolved Constituents

A linear regression of several points on a graph is made to find the equation of the line that best fits the plotted points. By determining this line one can find how y is dependent on x or how y changes as x changes. The general equation of the linear regression is:

$$y = mx + b$$

where x and y are variables and m and b are constants and

m = slope of the line

b = y -intercept of the line (value of y when $x = 0$)

A correlation coefficient (r) can be calculated to determine how well x correlates with y . Values of r range from -1 to $+1$; an r value of 0 indicates no correlation while $+1$ and -1 indicate perfect correlation (all plotted points are on the regression line). A $+1$ r value occurs when x and y increase together and a -1 r value indicates that large values of x are associated with small values of y .

A t -test can be used to determine if r is significantly different from 0 , that is, that a correlation does indeed exist. If a calculated " t " value is greater than a table " t " value, then r is statistically significantly different from 0 and a correlation between x and y does exist. The " t " value can be calculated without actually calculating the regression coefficient, as was done in this study.

A computer program (App. III) was used to calculate the linear regression of each analysis in Table 3 against all other analyses in the table (Harris, 1974). The program calculated the equation for each of 120 linear regressions and made a t -test of each linear regression

to determine if the correlation coefficient was statistically significantly different from zero at the 95 percent level or the 90 percent level. The equations for the linear regressions and results of the t-tests are given in Appendix IV. Some correlations that were significantly different from zero at the 99.9 percent level will be briefly discussed.

The nitrate analyses did not correlate with any of the other analyses, indicating nitrate occurrence is not geologically dependent, but is a result of man's activities (possible feed lot contamination). Sodium and chloride were significant indicating salt is definitely contaminating the ground water in the area. Calcium and sulfate correlation is significant at the 99.9 percent level and supports the theory that gypsum is in the area. Sulfate and non-carbonate hardness are significant at the 99.9 percent level indicating that sulfate composes the largest percentage of non-carbonate hardness. Equations of linear regressions that may be useful are given below:

<u>X</u>	<u>Y</u>	<u>Linear Regression</u>	<u>% Level</u>
calcium	magnesium	$y = 0.14x + 6$	99.9
"	total hardness	$y = 3.07x + 24$	"
"	sulfate	$y = 2.44x - 187$	"
sodium	chloride	$y = 1.78x - 4$	"
specific conductivity	total dissolved solids	$y = 0.65x + 6$	"

CONCLUSIONS

Ground water in the area near Abilene, Kansas, generally flows from northwest to southeast as inferred from the contour map of the water table and isocon maps (equal concentration). Recharge occurs in the northern part of the area and discharge is into Mud Creek and Smoky Hill River, through domestic, public, and municipal wells, and through evapotranspiration.

Ionic concentrations of the water are generally lower in the northern part of the area and higher in the southern part. This can be attributed to residence time of the water in the aquifer because as the water flows south, it continues to dissolve rocks and minerals of the aquifer. Ground water is also harder in the southern part of the area than in the northern part.

High concentrations of calcium and magnesium are caused by dissolution of limestone and high concentrations of calcium and sulfate, by solution of gypsum in the Wellington Formation and Doyle Shale. High sodium and chloride concentrations are attributed to evaporites or salt brine moving up dip from the west from the Hutchinson Salt Member of the Wellington Formation. High iron concentrations are the result of dissolution of iron oxyhydroxides in the alluvium.

High nitrate concentrations are probably caused by pollution from livestock waste. The area northwest of Abilene may have unusually high nitrate concentrations because of infiltration of runoff from feedlots into loose and highly permeable dune sand in the area. This would facilitate movement of nitrate into the ground-water system where it

would flow southeast. The wells northwest of Abilene, particularly public water supply wells for the city, should be monitored for nitrate concentrations and colloform bacteria. Nitrate concentrations in those municipal wells (#1 and #2) are above U. S. Public Health Standards and further increases would warrant discontinued use of those wells as a public water supply.

Most ground water in the Abilene area is chemically qualified for both public and agricultural use. Future municipal wells should be placed north of the river where dissolved constituents are lower and the water is softer. The area just northwest of the city should be avoided until nitrate concentrations have dropped below the limit set by the U. S. Public Health Service. The ground water is good for both watering livestock and irrigation (with the exception of well #17). However, care should be taken to insure that all dissolved solids in the ground water are leached from the soil and infiltrate to the water table. Otherwise, salts will build on the surface and decrease permeability of the soil, causing drainage problems.

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APPENDIX I

LOGS OF WELLS AND TEST HOLES

The following pages contain logs of 21 test holes and wells drilled by O. S. Fent (Hydraulic Drilling Co.) and 1 test hole drilled by the Kansas Highway Commission. The numbers assigned to the logs are the same as well and test hole numbers used in Figures 3-7. Logs of test holes 3-38, 87 and 88 and 49 are in Latta (1949, p. 105-111). Logs are listed by occurrence from north to south in cross sections A-A' through D-D' and elevations of wells and test holes were determined to the nearest five feet from the Solomon, Kans., Abilene, Kans., and Chapman, Kans. 7.5 minute quadrangles of the U. S. Geological Survey.

12. Log of test hole in the SE $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 23, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1950. Surface altitude 1,220 feet.

Description of Material	Thickness (feet)	Depth (feet)
Dune sand:		
Sand, medium to fine.	2.5	2.5
Silt and clay, light gray-green, mottled yellow.	3.5	6
Sand, medium to fine.	5.5	11.5
Terrace alluvium:		
Silt, dark gray-brown downward to light gray and red tan, sandy.	7.5	19
Sand, fine to coarse.	5	24
Silt, sandy light gray.	5	29
Silt, light gray and sand fine to coarse.	11	40
Silt, sandy tan and light gray.	8	48
Silt, sandy, tan and yellow.	25	73
Silt, compact, light gray and yellow tan; contains much sand, fine.	6.5	79.5
Gravel, fine and sand, some gravel, medium; contains many thin zones of clay and silt, yellow and gray-green.	13.5	93
Permian:		
Shale, blue-gray and white, some gypsum.	1	94

Description of Material	Thickness (feet)	Depth (feet)
Limestone, argillaceous, gray-white.	9	103
Limestone, argillaceous, blue-gray.	25	128
Limestone, cherty, blue-gray.		
13. Log of test hole in the NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 23, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1950. Surface altitude 1,160 feet.		
Dune sand and silt, light brown.	8	8
Sand, fine to coarse.	11	19
Gravel, medium to fine and sand.	8	27
Permian:		
Shale, gray.	2	29
Shale, calcareous, hard, white.	1	30
Limestone, hard, white.	1	31
Shale, calcareous, white.	3	34
Porous limestone.	1	35
Shale, calcareous, white interbedded with limestone gray.	3	38
Limestone gray and shale, dark gray.	2	40
9. Log of test hole in NE $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 12, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,250 feet.		
	Depth Range (ft.)	
Clay, tan.	0	3
Shale, yellow-gray (much fluid loss 8 to 30).	3	36
Shale, very soft, yellow-gray (Total fluid loss at 37 ft. Dry).	36	40
Reamed and cased to 40 ft.		
Limestone, hard, silty, broken and shale, hard, calcareous (many temporary fluid losses).	40	46
Shale, gray-green and yellow.	46	52
Shale, red and green.	52	74
Shale, very soft, blue and dull red.	74	80
Shale, dark gray; contains many thin gypsum zones.	80	84
Limestone, gray (temporary loss of circulation).	84	84.5
Shale, soft (lost balance of fluid).	84.5	85
Shale and gypsum (no sample of formation).	85	88
Pumped water sample with intake at 84 ft.		
Started pumping 1:30 pm.		
Water at 2:15 pm 24 grains per gallon hardness.		
Water at 2:35 pm 45 grains per gallon hardness.		

8. Log of test hole in NE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 12, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,250 feet.

Description of Material	Depth Range (ft.)	
Shale, yellow-gray; contains many thin limestones. Fluid loss 50 gpm between 10 and 20. Cased to 21 ft.	0	39
Limestone, hard, white.	39	39.5
Limestone, hard, brown (fluid loss 10 gpm at 39.5 and 5 at 40').	39.5	40.5
Shale, yellow-gray, many thin limestones.	40.5	53
Shale, red and green, grades downward to light blue-gray and lt. red.	53	78.5
Limestone, hard, brown and light gray	78.5	79.5
Shale, brittle, gray, interbedded with limestone, silty, soft, light gray flecked black.	79.5	82
Shale, black to dark gray, clayey, firm, contains thin gypsum zones at 91 and 94	82	96
Shale, light green	96	99
Shale, green and red	99	102
Shale, dull red-brown, silty, firm	102	113
Gypsum, white and shale, gray-green	113	123
Limestone, fairly hard, light gray; contains interbedded gypsum and hard calcareous shale, light gray	123	141
Shale, hard, black and gray, contains thin limestone	141	143

15. Log of test hole in NE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 13, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,245.

Sand, fine and silt	0	9
Silt, sandy, buff	9	13
Silt, sandy, tan	13	16
Shale, yellow and light gray-green, fractured and stained on fragments. Fluid loss 5 gpm. 20 to 32 ft.	16	32
Limestone, fairly hard	32	32.5
Limestone hard; contains soft porous zones at 33 and 34.5	32.5	36
Shale, green, contains thin limestone zones. Reamed and cased to 38 ft. to regain partial circulation depth from 20 to 34.5	36	42
Shale, red and green	42	66
Shale, blue-gray and light gray	66	75
Limestone, silty, gray, coarse grained, fairly friable	75	81
Shale, dark gray	81	82

4. Log of test hole in SW $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 13, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,230 feet.

	Depth Range (ft.)	
Clay, sandy, tan	0	5
Shale, yellow and green, contains thin limestones	5	13
Shale, green, contains thin limestones	13	23
Limestone, hard, brown, porous (5 gpm fluid loss)	23	25.5
Shale, yellow and green	25.5	32.5
Shale, red and green	32.5	57
Limestone, hard, brown and white	57	63
Shale, dark gray	63	67

17. Log of test hole in NE $\frac{1}{4}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$, sec. 13, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,230 feet.

Dune and Terrace Deposits:

Sand, fine to medium and silt, tan	0	15
Silt, slightly clayey, sandy, tan and light gray	15	29
Sand, silty, slightly iron-cemented	29	29.5
Clay, light green	29.5	34
Clay, gray-white and white, contains some interbedded sand, iron cemented and caliche nodules	34	39.5
Clay, green, contains few thin caliche beds and nodules	39.5	44.5
Loss of all fluid at 44.5 0.25 ft. open cavity	44.5	46
Limestone, hard	46	47
Shale, hard, blue-gray. Reamed and cased hole to 47.5 ft.	47	57
Limestone, very hard, light gray	57	61.5
Shale, bright green	61.5	64
Shale, red and green	64	77
Gypsum, white, unweathered	77	80

18. Log of test hole in NE $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 13, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,225 feet.

Dune sand and Terrace deposits:

Silt, buff, and sand, fine to medium	0	32
Clay, light greenish-gray and yellow	32	45
Gravel, cemented with calcite	45	47.5

Permian:

Shale, yellow; grades downward to dark blue-gray	47.5	50
Shale	50	57

	Depth Range (ft.)	
Limestone, hard, dark gray	57	58
Shale, light gray	58	60
Limestone, dark and light gray speckled darker gray	60	61.5
Shale, bright green	61.5	64
Shale, red and green	64	79.5
Gypsum, unweathered	79.5	80
27. Log of test hole in SW $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 24, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,200 feet.		
Dune and terrace deposits:		
Sand, fine	0	9
Silt and clay	9	32
Sand, fine and silt	32	42
Silt and clay	42	57
Sand, fine and silt	57	72
Sand and gravel	72	75
Permian (Winfield limestone, Cresswell member)		
Limestone, light gray, contains thin shale zones 81 to 82 and 85 to 86.5 ft.	75	90
3. Log of test hole in NE $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 24, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1971. Surface altitude 1,160 feet.		
Dune and terrace deposits:		
Sand, fine to medium	0	17
Sand, fine to medium and silt, buff	17	30
Silt, clayey, tan and light gray	30	43
Sand, fine to medium, interbedded with clay, light gray	43	79.5
Winfield Limestone: (Cresswell member)		
Limestone, shaley, dolomitic, alternating fairly firm and soft, buff and light gray	79.5	85
Dolomite, hard, unweathered, dark gray; contains chert-calcite nodules and echinoid spines	85	90.5
Grant shale member		
Shale, dark gray	90.5	95
6. Log of test hole in NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 25, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1966. Surface altitude 1,155 feet.		
Alluvium:		
Clay, fairly firm, dark gray and brown	0	8
Silt, fairly soft, light brown (will pump slowly)	8	10
Silt, soft, buff, sandy (will pump)	10	14

	Depth Range (ft.)	
Silt, soft, sandy, dark gray (will pump)	14	20
Sand, fine to coarse	20	22
Gravel, medium to fine and sand	22	32.5
Clay, soft, gray (will pump)	32.5	33
Gravel, coarse to fine and sand	33	44
Clay, fairly soft, gray	44	45
Gravel, coarse to fine and sand	45	51
Permian:		
Shale, yellow	51 plus	

19. Log of well in SE $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 36, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1948. Surface altitude 1,155 feet.

Description of Material	Thickness (ft.)	Depth (ft.)
Soil	2	2
Clay, gray	5	7
Silt, light yellow-gray	3	10
Clay, silty, dark gray	8	18
Silt, yellow-gray; contains much sand, fine to medium	8	26
Sand, medium to fine and silt, gray; con- tains wood at 30 and many snail shells	4	30
Sand, coarse to fine	9	39
Gravel, medium to fine and sand	6	45

21. Log of well in the NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 9, T.13S., R.2E., Dickinson Co., drilled by O. S. Fent, 1953. Surface altitude 1,185.

Top soil, silty, black	1.5	1.5
Silt, sandy, soft, dark tan	3	4.5
Silt, soft, sand fine to coarse and some gravel	8.5	13
Permian:		
Shale, clayey, gray-green	2	15
Limestone, hard, tan-gray	1.5	16.5
Shale, clayey, fairly hard, maroon and gray- green to 23'. Dark red below 23'.	16.5	33
Shale, clayey, fairly hard. Green to gray- green	5	38
Limestone, hard	6	44

38. Log of well in the NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 16, T.13S., R.2E., Dickinson Co., drilled by O. S. Fent, 1953. Surface altitude 1,180 feet.

Fill	3	3
Silt, sandy, red-brown	7.5	10.5

Description of Material	Thickness (ft.)	Depth (ft.)
Permian:		
Shale, yellow-gray, silty	8.5	19
Shale, silty, gray	2	21
Limestone, fairly hard, cream	0.5	21.5
Shale, silty, gray-green and maroon; contains thin interbedded limestones	27.5	49
Limestone, hard, cream	2	51
Cavity, open	0.3	51.3
35. Log of well in the NW $\frac{1}{4}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 15, T.13S., R.2E., Dickinson Co., drilled by O. S. Fent, 1953. Surface altitude 1,155 feet.		
Top soil	2	2
Clay, silty, dark gray	2	4
Clay, silty, tan	9	13
Sand, fine to medium and interbedded clay	3	16
Sand, fine to medium	5	21
Clay, tan	3	24
Sand, fine to coarse and interbedded clay, tan	4.5	28.5
Clay, light tan to gray	13.5	42
Clay, silty, dark gray to gray-green	3	45
Sand (no sample)	10.5	55.5
Permian:		
Shale	0.5	56
36. Log of well in NW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 16, T.13S., R.2E., Dickinson Co., drilled by O. S. Fent, 1954. Surface altitude 1,150 feet.		
Top soil	2.5	2.5
Silt, light brown	10.5	13
Clay, light brown	24	37
Clay, dark blue	6	43
Sand and gravel	5	48
Wellington fm.		
Shale		48 plus
33. Log of well in NE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 21, T.13S., R.2E., Dickinson Co., drilled by O. S. Fent, 1953. Surface altitude 1,145 feet.		
Top soil, silty, black	1	1
Clay, dark gray	3	4
Clay, light tan	12	16
Sand, fine to medium and interbedded clay, tan	10	26
Clay, tan	14	40

Description of Material	Thickness (ft.)	Depth (ft.)
Sand, fine to coarse and gravel, fine	8	48
Gravel, fine to medium and sand	7	55
Permian:		
Shale, calcareous, cream	0.5	55.5
71. Log of test hole in NE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 21, T.13S., R.2E., Dickinson Co., drilled by O. S. Fent, 1971. Surface altitude 1,140 feet.		
Alluvium:	Depth Range (ft.)	
Clay, compact, dark gray grading downward to buff; becomes softer and silty downward	0	9
Silt, clayey, buff; becoming fine sandy and very soft downward	9	21
Sand, very fine and silt, soft, buff	21	26.5
Gravel, fine and sand	26.5	29
Gravel, fine to medium and sand, silty	29	40
Silt, clayey, light gray	40	42
Gravel, medium to fine and sand	42	60
Permian:		
Limestone, fairly hard, silty, light greenish-gray	60	61
59. Log of test hole in NE $\frac{1}{4}$ SW $\frac{1}{4}$ NE $\frac{1}{4}$, T.13S., R.2E., Dickinson Co., drilled by O. S. Fent, 1963. Surface elevation 1,170 feet.		
	Thickness	Depth
Fill:		
Shale rubble	3.5	3.5
Permian:		
Shale, gray-green	1	4.5
Shale, gray-green and porous boxwork limestone	2.5	7
Shale, yellow and gray-green, soft; calcite seams 8.5 to 9.5 ft.	2.5	9.5
Limestone, porous, hard, brown and yellow, cavernous	1.5	11
Shale, very soft, weathered, becoming more firm downward	6	17
87. Log of well in NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 8, T.13S., R.3E., Dickinson Co., drilled by O. S. Fent, 1954. Surface altitude 1,140 feet.		
Top soil, sandy	1.0	1.0
Sand, very fine, and silt	13.0	14.0
Silt and clay	5.0	19.0
Sand, very fine	9.0	28.5
Permian:		
Limestone	2.5	31.0
Shale	8.0	39.0

88. Log of well in SE $\frac{1}{4}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 8, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1948. Surface altitude 1,150 feet.

Description of Material	Thickness (ft.)	Depth (ft.)
Soil	2	2
Silt, buff	5	7
Sand, fine to medium and silt, buff and gray	10	17
Silt, buff, gray and brown; contains much sand and many fragments of limestone	29-34.5	34.5
Permian:		
Limestone, buff, contains crystals of clear calcite and some chert	1.5	36
Shale, yellow and gray; contains calcite veins	10	46
Limestone, very hard, dark gray	0.7	46.7

26. Log of test hole in NE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 24, T.13S., R.1E., Dickinson Co., drilled by O. S. Fent, 1967. Surface altitude 1,225 feet.

Dune and terrace deposits:		
Sand, fine and silt	0	40
Silt and clay	40	56
Sand, fine	56	65
Silt and clay	65	91
Sand and gravel, fine to coarse	91	101
Permian (Winfield, Cresswell member)		
Limestone, gray	101	106
Shale, gray and yellow	106	108
Limestone, gray	108	111
Limestone and shale, light gray (No fluid loss in hole)	111	120

APPENDIX II

Procedures of Chemical Analysis

General.--All beakers, electrodes, and thermometer were rinsed between analyses several times with distilled water followed by distilled deionized water and then dried. Pipets and cuvettes were either rinsed and dried or rinsed twice with sample water before use between analyses. Reagent grade or primary standard chemicals were used for all analyses.

Bicarbonate (HCO_3^-) Analysis

Method: titration.

Apparatus: Buret Corning Model 12 pH meter, magnetic stirrer, 0.1N H_2SO_4 , thermometer graduated in 0.1°C .

Procedure:

- 1) Prepare 0.1N H_2SO_4 solution by diluting 2.7 ml. conc. H_2SO_4 to 1 liter with distilled-deionized water.
- 2) Standardize by titrating to the endpoint a weighed quantity of Na_2CO_3 dried at 150°C for two hours.
- 3) Prepare 0.01N H_2SO_4 from standard by dilution.
- 4) Pipette 25 ml. (or 50 ml.) of sample into a plastic beaker containing a teflon coated magnetic stirring bar.
- 5) Rinse the pH electrode with distilled-deionized water (henceforth referred to as D-D water) and dry. Measure initial pH of sample. While the pH is stabilizing, measure the temperature of a similar quantity of the sample in another plastic beaker to the nearest 0.1°C .
- 6) Turn on magnetic stirrer (this should not be on for the initial pH reading).

- 7) Titrate the sample with 0.01N H_2SO_4 and record the ml. and pH values from a pH of 5.0 to pH 3.0 using 12 to 15 readings (6 or 7 readings on either side of the 4.5 endpoint).

Calculations: Prepare a Gran¹ plot of the data to determine exactly the ml. of 0.01N H_2SO_4 used to reach the endpoint by plotting ml. values on the abscissa and $(V_o + V)10^{-\text{pH}}$ on the ordinate where:

V = ml. of original sample volume

V^o = ml. of 0.01N H_2SO_4 titrated

pH = pH reading corresponding to V value

Then:

$$\text{Normality of sample water} = \frac{\text{ml. of titrant at endpoints}(\text{N of titrant})}{\text{ml. of sample volume}}$$

$$\text{Conc. of } \text{HCO}_3 \text{ in ppm} = \text{N of sample water} (61.02) 1000$$

Note: Because alkalinity tends to change after the sample has been collected, the titrations were performed within 12 hours after collection.

Nitrate (NO_3^-) Analysis

Method: specific ion electrode.

Apparatus and Reagents: Orion nitrate specific ion electrode, calomel reference electrode, Corning Model 12 pH-mv meter, magnetic stirrer, 500 mg/l NO_3 standard.

Procedure:

- 1) Prepare a 500 mg/l NO_3 solution by diluting 0.8153 g. of KNO_3 dried at 105°C for 2 hours to 1 liter with distilled-deionized water. From this 500 mg/l solution prepare standards of 2, 10, 25, 50, and 75 mg/l.

¹For a description of Gran plots see Stum and Morgan (1970 p. 155-158).

- 2) Place electrodes in standard solution and turn on stirrer for 1 minute.
 - 3) After stirring has stopped record a (+) mv reading to the nearest 0.5 mv at 30 sec. and again at 1 min.
 - 4) After all standards have been analyzed, starting with the least concentrated and proceeding to the most concentrated, analyze all the samples following the procedure outlined above. After the samples have been measured, analyze a few more standards that are close to the concentrations of the samples.
- Calculations: Plot the standard curve on semi-log paper plotting concentration of standards in mg/l on the logarithmic scale and +mv on the arithmetic scale. Read mg/l concentration of NO_3 for the samples from standard curve. Calculate corrections for Cl and HCO_3 using procedure in Langmuir and Jacobson (1970). Approximate anion selectivity constants for Cl^- and HCO_3^- ions were taken from Orion Research Inc., p. 10.
- Note: nitrate should be analyzed within a few days after the sample has been collected to insure that nitrate consuming bacteria do not alter the values.

Chloride (Cl^-) Analysis

Method: specific ion electrode.

Apparatus and Reagents: Orion solid state chloride specific ion electrode, double junction reference electrode containing Ag-AgCl inner electrode and 1M KNO_3 outer salt bridge solution, Corning Model 12 pH-mv meter, 500 mg/l Cl^- standard.

Procedure:

- 1) Prepare a 500 mg/l Cl^- standard by dissolving in distilled-deionized water 0.8243 g. of NaCl dried at 105°C for 2 hours and diluting to 1 liter. From this 500 mg/l solution prepare standards of 5, 10, 25, 50, 75, 100, and 125 mg/l.
- 2) Follow steps 2-4 in the procedure for analyses of nitrate.
Calculations: Follow the procedure for the determination of nitrate. No interferences need be calculated.

Sulfate (SO_4^{--}) Analysis

Method: turbidimetry. (Modified from Ewing, 1960 p. 410).

Apparatus and Reagents: magnetic stirrer, Coleman Universal spectrophotometer, 500 mg/l SO_4^{--} solution, 30-40 mesh BaCl_2 crystals, salt-acid glycerol solution.

Procedure:

- 1) Prepare 500 mg/l SO_4^{--} solution by dissolving in distilled-deionized water 0.7393 g. of Na_2SO_4 , dried at 105°C for 2 hours, and diluting to 1 liter of solution. From this 500 mg/l standard prepare standards of 25, 35, 50, 65, 75, 85, and 100 mg/l.
- 2) Prepare a salt-acid glycerol solution dissolving 120 g. NaCl in about 400 ml D-D water, add 10 ml. conc. HCl and 500 ml. glycerol and dilute to 1 liter.
- 3) Pipette 50 ml. of standard (or sample) into a small beaker and add 10 ml. of salt-acid glycerol solution. Put in magnetic stirrer and begin stirring.
- 4) Add 0.3 g. of 30-40 mesh BaCl_2 crystals and continue stirring for 1 minute.

- 5) Stop stirrer for $3\frac{1}{2}$ minutes then stir for $\frac{1}{2}$ minute.
- 6) Take magnetic stirring bar out of the beaker and pour sample into a 19 x 105 mm Coleman round cuvette (make sure cuvette is absolutely clean and oriented in the same position for all analyses; see Notes on Spectrophotometer, p. 74.
- 7) Within 5 min. read percent Transmittance on the spectrophotometer by comparing aliquot against a blank solution of 50 ml. D-D water and 10 ml. salt-acid glycerol solution. Analyze samples using the Null Method. (Coleman spectrophotometer instructions)

Calculations: On semi-log paper plot a standard curve with SO_4^{2-} concentration in mg/l on the abscissa (arithmetic scale) and percent Transmittance on the ordinate (logarithmic scale). Sulfate concentrations in the samples are in mg/l from the standard curve.

Notes on Spectrophotometer

Find two cuvettes that are matched. Use square cuvettes, if possible, but if round cuvettes are used match them to their maximum Transmittance reading by placing the cuvettes in the well with the word "Coleman" toward the top of the instrument. Then turn the cuvettes slightly (within 45° of center either way) until the maximum transmittance is obtained.

Each time a sample reading is taken the blank cuvette must be first maximized and then set at 0% T. After sliding the sample cuvette into the beam it also must be maximized. Note: there will be much

less deviation in the sample cuvette reading when it is turned than when the blank cuvette is turned.

All samples were analyzed using the Null Method.

After each sample is analyzed the sample cuvette must be thoroughly cleaned by brushing to prevent the buildup of residue on the sides of the cuvette.

Allow the spectrophotometer to warm up for at least $\frac{1}{2}$ hour before using.

Atomic Absorption and Flame Emission Analyses.--Because calcium, magnesium, sodium, potassium, and iron were all analyzed using an atomic absorption/flame emission spectrophotometer and because procedures for their determinations are quite similar, they are discussed under one heading. Calcium, magnesium, sodium, and iron were determined by absorption whereas potassium was determined by flame emission.

Method: Ca - Mg - Na - Fe absorption, K emission.

Apparatus and Reagents: Perkin-Elmer 305B atomic absorption/flame emission spectrophotometer, 500 mg/l Ca standard, 500 mg/l Mg standard, 500 mg/l Na standard, 500 mg/l K standard, 1000 mg/l Rb standard, 10,000 mg/l La - 800 mg/l Rb solution.

Procedure:

- 1) Prepare 500 mg/l Ca standard with 1.2486 g. primary standard CaCO_3 (dried at 105°C . for 2-3 hrs.) in 50 ml. H_2O . Add about 10 ml. HCl until CaCO_3 is totally dissolved and dilute to 1 liter with distilled-deionized water.

- 2) Prepare 500 mg/l Na standard by dissolving and diluting 1.2710 g. NaCl (dried at 105° C. for 2-3 hrs.) to 1 liter with distilled-deionized water.
- 3) Prepare 500 mg/l K standard by dissolving and diluting 0.9533 g. KCl (dried at 105° C. for 2-3 hrs.) to 1 liter with distilled-deionized water.
- 4) Prepare 500 mg/l Mg standard by dissolving and diluting 4.1820 g. $\text{Mg}_2\text{Cl} \cdot 6 \text{H}_2\text{O}$ to 1 liter with distilled-deionized water. Standardize using a prepared Mg standard (Instrumentation Laboratory Inc.).
- 5) Using the above standards prepare six "Universal Standards" containing the following concentrations in mg/l:

<u>Ion</u>	<u>Std A</u>	<u>Std B</u>	<u>Std C</u>	<u>Std D</u>	<u>Std E</u>	<u>Std F</u>
Ca^{2+}	25	50	75	100	125	175
Mg^{2+}	5	10	20	30	50	60
Na^+	5	10	20	30	50	75
K^+	1	5	10	15	25	30

- 6) Prepare 1000 mg/l Rb solution in dilute HCl by dissolving 2.7021 g. Rb_2CO_3 in 5-10 ml. HCl and diluting to 1 liter.
- 7) Prepare 10,000 mg/l La - 800 mg/l Rb^+ solution by first adding 40 ml of water to 11.7 g. La_2O_3 . Slowly and carefully add 50 ml concentrated HCl to dissolve the La_2O_3 and dilute to 100 ml. Dilute 100 ml La_2O_3 solution to 500 ml with the 1000 mg/l Rb solution. The La is a chemical releasing agent for Ca and Mg analysis while Rb was used to decrease Na and K ionization.

- 8) Prepare the water samples for analyses by combining 10 ml. of sample with 10 ml. of La - Rb solution. Prepare the "Universal Standards" by combining 10 ml. of standard with 10 ml. of La - Rb Solution.
- 9) Analyze the calcium, magnesium, and sodium using absorbance and potassium by emission of the atomic absorption unit following the procedures in the Perkin-Elmer Analytical Methods for Atomic Absorption Spectrophotometry (integrating each reading over 10 seconds). Readings were taken using absorbance mode and integration over 10 seconds.

Calculations: On arithmetic graph paper plot the standard curves for each element using mg/l concentration on the abscissa and absorbance on the ordinate. Absorbance values are plotted and concentration of the particular element in each sample is read from the standard curve.

Iron Analysis.--Concentrations of iron were determined by absorption by Whittemore (1974) from separate samples that were acidified upon collection with 2 ml concentrated HCl. Standard procedures as outlined in Perkin-Elmer (1973) were followed in their analyses.

Specific Conductivity.--

Method: specific conductivity electrode and meter.

Apparatus: Lab-Line Lectro Mho-Meter, Model MC-1, Mark IV conductivity meter Lab-Line epoxy conductivity cell with cell constant at 1.03, thermometer graduated in 0.1° C.

Procedure:

- 1) Put selector switch on 10^3 and temperature selector on 25° C.
- 2) Place electrode in sample and read micromhos/cm conductance.
- 3) Read temperature of water to nearest 0.1° C.
- 4) Correct specific conductivity values to 25° C using the fol-

lowing formula:

$$\text{Spec. Cond.} = (\text{measured conductance})(\text{cell constant})[1 + 0.02(25 - \text{temp. of sample})]$$

APPENDIX III

Appendix III. Computer Program for Equations and T-test of Linear Regressions of Ionic Concentration

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A STATISTICAL ANALYSIS OF VARIOUS ION CONCENTRATIONS IN GROUNDWATER
  NEAR ABILENE, KANSAS
REAL*8 LABEL, SIGNF, SGNFM, NOWEL, BLNK
DIMENSION DATAM(99,16), SUMX(16), SMSQX(16), SUMXY(16,16), B(16,16)
DIMENSION T(16,16), SGNFM(16,16), SIGNF(2), LABEL(16), NOWEL(99)
DIMENSION XMEAN(16), SDEV(16)
1 FORMAT(1X,A4,15F5.0/5X,F5.0)
2 FORMAT(1X,19A4)
3 FORMAT(1H1,8HDATA SET)
4 FORMAT(1H0,4HMEAN,16F8.3)
5 FORMAT(1H0,4HSDEV,16F8.3)
6 FORMAT(15,2F6.4)
80 FORMAT (1H1,5HYHAT= )
81 FORMAT(1H ,A4,8(F9.2,F6.2,1HX))
82 FORMAT(11X,7(A4,12X),A4)
83 FORMAT (1H--)
84 FORMAT(1H ,8(F9.2,F6.2,1HX))
85 FORMAT(6X,7(A4,12X),A4)
86 FORMAT(1H1,13HT TEST VALUES )
87 FORMAT(1H ,A4,16F8.2)
88 FORMAT(8X,15(A4,4X),A4)
89 FORMAT(1H--,42HSIGNIFICANT AT 95 PERCENT CONFIDENCE LEVEL )
90 FORMAT(1H--, 37HSIGNIFICANT BETWEEN 90 AND 95 PERCENT )
91 FORMAT(1H , 19(1X,A4))
DO 7 I=1,16
  SMSQX(I)=0.0
7 SUMX(I)=0.0
DO 8 I=1,16
  DO 8 J=1,16
8 SUMXY(I,J)=0.0
READ(5,2) (LABEL(I),I=1,16),(SIGNF(I),I=1,2),BLNK
9 READ(5,6,END=100) NWELL, T95,T90
  WRITE (6,3)
  WRITE(6,88) (LABEL(I),I=1,16)
  ANW=NWELL

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App. III. Continued

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34 AMU=ANW-2.
35 DO 10 I=1,NWELL
36 10 READ(5,1) NOWEL(I),(DATAM(I,J),J=1,16)
37 DO 20 I=1,16
38 DO 20 J=1,NWELL
39 SUMX(I)=SUMX(I) + DATAM(J,I)
40 20 SMSQX(I)=SMSQX(I)+ DATAM(J,I)**2
41 DO 21 I=1,NWELL
42 21 WRITE(6,87) NOWEL(I),(DATAM(I,J),J=1,16)
43 DO 22 I=1,16
44 SDEV(I)=SQRT((SMSQX(I)-SUMX(I)**2/ANW)/(ANW-1.))
45 22 XMEAN(I)=SUMX(I)/ANW
46 WRITE(6,4) (XMEAN(I),I=1,16)
47 WRITE(6,5) (SDEV(I),I=1,16)
48 DO 25 I=1,15
49 I1=I+1
50 DO 25 J= I1,16
51 DO 25 K=1,NWELL
52 25 SUMXY(I,J)=SUMXY(I,J) + DATAM(K,I)*DATAM(K,J)
53 DO 30 I=1,15
54 I1=I+1
55 DO 30 J=I1,16
56 SLXY=SUMXY(I,J)-(SUMX(I)*SUMX(J)/ANW)
57 SLXS=SMSQX(I)-(SUMX(I)**2 /ANW)
58 SLYS=SMSQX(J)-(SUMX(J)**2/ANW)
59 B(I,J)=SLXY/SLXS
60 B(J,I)=SUMX(J)/ANW -(B(I,J)*SUMX(I))/ANW
61 T(I,J)=ARS(R(I,J))/(SQRT((SLYS-SLXY**2/SLXS)/AMU))/(SQRT(SLXS)))
62 IF(T(I,J).GE.T95) GO TO 28
63 IF(T(I,J).GE.T90) GO TO 29
64 SGNFM(I,J)=SIGNF(1)
65 SGNFM(J,I)=SIGNF(1)
66 GO TO 30
67 28 SGNFM(I,J)=SIGNF(2)
68 SGNFM(J,I)=SIGNF(1)
69 GO TO 30

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App. III. Continued

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70 SGNFM(J,I )=SIGNF(2)
71 SGNFM(I,J)=SIGNF(1)
72 CONTINUE
73 WRITE (6,80)
74 DO 35 I=2,9
75 IM1=I-1
76 WRITE(6,81) LABEL(I),(R(I,J),B(J,I),J=1, IM1)
77 DO 40 I=10,16
78 WRITE (6,81) LABEL(I), (R(I,J),B(J,I),J=1,8)
79 WRITE(6,82) (LABEL(I),I=1,8)
80 WRITE (6,83)
81 DO 45 I=10,16
82 IM1=I-1
83 WRITE(6,84) (R(I,J),B(J,I),J=9,IM1)
84 WRITE(6,85) (LABEL(I),I=9,15)
85 WRITE (6,86)
86 DO 50 I=2,16
87 IM1=I-1
88 WRITE (6,87) LABEL(I),(T(J,I),J=1,IM1)
89 WRITE(6,88) (LABEL(I),I=1,15)
90 WRITE (6,89)
91 DO 55 I=2,16
92 IM1=I-1
93 WRITE(6,91) LABEL(I),(SGNFM(J,I),J=1,IM1)
94 WRITE(6,91)BLNK, (LABEL(I),I=1,15)
95 WRITE (6,90)
96 DO 60 I=2,16
97 IM1=I-1
98 WRITE (6,91) LABEL (I), (SGNFM(I,J),J=1,IM1)
99 WRITE (6,91)BLNK, (LABEL(I),I=1,15)
100 GO TO 9
101 CONTINUE
102 STOP
103 END

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APPENDIX IV

Appendix IV. Equations and T-test Values for Linear Regressions of Dissolved Constituents

Table 7. Equations of linear regressions of dissolved constituents

CALC	$y = -404.35 + 37.91X$		
MAGN	$-15.09 + 2.87X$	$6.40 + 0.14X$	
SODI	$-2156.97 + 153.81X$	$23.29 + 0.38X$	$73.45 + 0.21X$
POTA	$-67.22 + 5.23X$	$-17.82 + 0.18X$	$-20.44 + 1.10X$
CHLO	$-3916.78 + 278.83X$	$26.43 + 0.75X$	$116.05 + 0.78X$
NITR	$-68.96 + 6.46X$	$28.84 - 0.03X$	$28.14 - 0.12X$
SULF	$-1290.72 + 100.61X$	$-186.53 + 2.44X$	$-231.77 + 15.13X$
BCAR	$3.64 + 27.93X$	$260.54 + 1.02X$	$240.74 + 6.33X$
TOTL	$-1130.42 + 110.39X$	$24.37 + 3.07X$	$-30.42 + 18.92X$
CARB	$0.93 + 23.03X$	$213.51 + 0.83X$	$197.38 + 5.19X$
NCAR	$-1083.68 + 84.65X$	$-171.86 + 2.17X$	$-218.43 + 13.69X$
SPCO	$-11501.65 + 871.83X$	$204.00 + 6.60X$	$346.17 + 30.97X$
TDS	$-7474.83 + 566.67X$	$-28.67 + 5.39X$	$22.14 + 27.77X$
PH	$6.93 + 0.04X$	$7.51 - 0.00X$	$7.44 + 0.00X$
DPTH	$207.56 - 10.83X$	$54.75 - 0.03X$	$44.40 + 0.21X$
	TEMP	CALC	MAGN
POTA	$8.55 + 0.00X$		
CHLO	$-4.17 + 1.78X$	$127.66 + 1.03X$	
NITR	$25.47 - 0.01X$	$24.92 + 0.00X$	$26.04 - 0.01X$
SULF	$156.22 + 0.20X$	$74.01 + 11.07X$	$154.20 + 0.13X$
BCAR	$389.38 + 0.26X$	$393.03 + 1.88X$	$391.57 + 0.13X$
TOTL	$456.63 + 0.22X$	$370.09 + 11.78X$	$455.62 + 0.14X$
CARB	$319.08 + 0.21X$	$322.15 + 1.54X$	$320.96 + 0.11X$
NCAR	$147.04 - 0.00X$	$57.79 + 10.07X$	$144.39 + 0.02X$
SPCO	$780.41 + 4.96X$	$988.79 + 20.76X$	$791.68 + 2.78X$
TDS	$532.97 + 2.91X$	$593.18 + 19.21X$	$538.86 + 1.64X$
PH	$7.46 - 0.00X$	$7.46 - 0.00X$	$7.46 - 0.00X$
DPTH	$53.88 - 0.05X$	$50.79 - 0.08X$	$53.81 - 0.03X$
	SODI	POTA	CHLO
SULF	$195.56 - 0.95X$		
BCAR	$430.82 - 0.85X$	$396.36 + 0.23X$	
TOTL	$497.72 - 0.94X$	$281.71 + 1.12X$	$52.00 + 1.03X$
CARB	$353.10 - 0.70X$	$302.73 + 0.19X$	$-0.10 + 0.82X$
NCAR	$156.99 - 0.40X$	$-9.30 + 0.91X$	$24.38 + 0.30X$
SPCO	$1274.20 - 4.07X$	$766.58 + 2.36X$	$-142.25 + 3.21X$
TDS	$819.47 - 2.26X$	$418.80 + 2.00X$	$-139.21 + 2.20X$
PH	$7.34 + 0.00X$	$7.48 - 0.00X$	$7.42 + 0.00X$
DPTH	$47.65 + 0.10X$	$51.64 - 0.01X$	$52.76 - 0.01X$
	NITR	SULF	BCAR

Table 7. Continued

CARB	209.22 + 0.27X		
NCAR	-193.29 + 0.72X	24.44 + 0.36X	
SPCO	209.48 + 2.03X	-144.57 + 3.92X	901.98 + 1.94X
TDS	-40.86 + 1.69X	-140.57 + 2.69X	506.44 + 1.75X
PH	7.49 - 0.00X	7.42 + 0.00X	7.47 - 0.00X
DPTH	53.17 - 0.01X	52.82 - 0.01X	51.11 - 0.01X
	TOTL	CAR3	NCAR
TDS	5.59 + 0.65X		
PH	7.49 - 0.00X	7.49 - 0.00X	
DPTH	59.54 - 0.01X	58.71 - 0.01X	-142.55 + 25.88X
	SPCO	TDS	PH

Table 8. T-test values* for linear regressions of dissolved constituents

CALC	1.25							
MAGN	0.59	7.79						
SODI	2.98	0.70	0.06					
POTA	0.76	5.62	4.53	0.13				
CHLO	3.03	0.78	0.12	34.22	0.23			
NITR	0.80	0.39	0.27	0.19	0.01	0.43		
SULF	1.27	9.94	7.26	0.59	9.13	0.70	0.35	
BCAR	0.51	2.70	2.52	1.19	0.91	1.09	0.48	
TOTL	1.17	29.83	10.18	0.57	5.61	0.62	0.29	
CARB	0.51	2.70	2.52	1.20	0.91	1.09	0.48	
NCAR	1.13	7.45	6.41	0.00	7.93	0.11	0.16	
SPCO	3.14	2.69	1.73	7.89	1.64	8.20	0.35	
TDS	3.06	3.92	2.60	5.05	2.54	5.20	0.29	
PH	0.51	0.76	0.06	0.57	0.86	0.62	2.02	
DPTH	1.95	0.62	0.63	2.21	0.34	2.27	0.48	
	TEMP	CALC	MAGN	SODI	POTA	CHLO	NITR	
BCAR	1.41							
TOTL	10.95	2.66						
CARB	1.41	2352.15	2.66					
NCAR	16.57	0.82	8.30	0.82				
SPCO	2.43	2.12	2.50	2.13	1.61			
TDS	3.67	2.23	3.69	2.24	2.59	17.88		
PH	0.94	0.14	0.57	0.14	0.74	0.74	0.83	
DPTH	0.46	0.22	0.39	0.22	0.33	1.98	1.79	1.13
	SULF	BCAR	TOTL	CARB	NCAR	SPCO	TDS	PH

*A t-test value is a calculated number that is compared with a t value from a table to determine at what level the linear regression is significant.

Table 9. Dissolved constituents with linear regressions significant at 95 percent confidence level

	TEMP	CALC	MAGN	SODI	POTA	CHLO	NITR	SULF	BCAR	TOTL	CARB	NCAR	SPCO	TDS	PH
CALC	NO														
MAEN	NO	YES													
SODI	YES	NO	NO												
POTA	NO	YES	NO	YES											
CHLO	YES	NO	NO	YES	NO										
NITR	NO	NO	NO	NO	YES	NO	NO								
SULF	NO	YES	YES	NO	NO	NO	NO								
BCAR	NO	YES	YES	NO	NO	NO	NO	NO							
TOTL	NO	YES	YES	NO	YES	NO	NO	YES	YES						
CARB	NO	YES	YES	NO	NO	NO	NO	NO	YES	YES					
NCAR	NO	YES	YES	NO	YES	NO	NO	YES	NO	YES	NO				
SPCO	YES	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO			
TDS	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES		
PH	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
DPTH	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 10. Dissolved constituents with linear regressions significant between 90 and 95 percent confidence level

	TEMP	CALC	MAGN	SODI	POTA	CHLO	NITR	SULF	BCAR	TOTL	CARB	NCAR	SPCO	TDS	PH
CALC	NO														
MAGN	NO	NO													
SODI	NO	NO	NO												
POTA	NO	NO	NO	NO											
CHLO	NO	NO	NO	NO	NO										
NITR	NO	NO	NO	NO	NO	NO	NO								
SULF	NO	NO	NO	NO	NO	NO	NO								
BCAR	NO	NO	NO	NO	NO	NO	NO	NO							
TOTL	NO	NO	NO	NO	NO	NO	NO	NO	NO						
CARB	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO					
NCAR	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO				
SPCO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO		
TDS	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	
PH	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	
DPTH	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO

GROUND-WATER QUALITY
OF THE ABILENE AREA, KANSAS

by

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B. S., Kansas State University, 1972

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

The quality of ground water in a 45 square-mile area of the Smoky Hill River Valley near Abilene, Kansas, was studied to measure the influence of geology on quantity of dissolved solids, to determine the source of any pollution, and to suggest possible uses for the water. Post-Kansan, pre-Wisconsinian dune sand, Kansan and Illinoian terrace deposits, and Wisconsinian and Recent alluvium in the area are underlain by the Winfield Limestone, Odell Shale, and Nolans Limestone of the Chase Group, Gearyan Stage, and the Wellington Formation, Sumner Group, Cimarronian Stage, all of the Lower Permian Series, Permian System.

Elevations of the water table were measured in 33 wells and ground-water samples were collected in 16 wells. Concentrations of total dissolved solids in the ground water have a range from 211 to 2458 ppm and can be related to specific conductivity by the expression $TDS = 0.65(SpC) + 5.59$; pH of the ground water ranged from 7.05 to 7.8 when measured in the lab and from 6.99 to 7.31 when measured in the field. Iron concentrations range from 0.01 to 7.1 ppm; calcium concentrations range from 46 to 378 ppm with a typical range from 100 to 200 ppm; magnesium concentrations range from 9.9 to 61 ppm with a typical range from 20 to 40 ppm; sodium concentrations range from 9.6 to 695 ppm but only two samples had concentrations greater than 100 ppm; potassium concentrations range from 1.2 to 74 ppm and all wells but one had concentrations less than 10 ppm. Nitrate concentrations range from 1.8 to 61 ppm with a typical range from 20 to 40 ppm; sulfate concentrations range from 27 to 880 ppm with a typical range from 50 to 100 ppm; chloride concentrations range from 10 to 1230 ppm with a typical range from

20 to 120 ppm; bicarbonate concentrations range from 134 to 604 ppm with a typical range from 350 to 520 ppm; and total hardness ranges from 161 to 1198 with a typical range from 300 to 500 ppm.

Ground water is derived from alluvium and terrace deposits and generally flows from northwest to southeast. The aquifer is recharged from the north and discharge occurs through springs, wells, and evapotranspiration, and into Mud Creek and Smoky Hill River. Concentrations of dissolved constituents increase from north to south. Nitrate concentrations range from 53 to 60 ppm in an area northwest of Abilene which may be caused by percolation of feedlot runoff in that area. The ground water is suitable for irrigation and stock and the chemical quality indicates that future municipal supplies should be obtained in the northern part of the area.