Geology and Ground-Water Resources in Eastern Cheyenne and Kiowa Counties, Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779-N

Prepared in cooperation with the Colorado Water Conservation Board

Geology and Ground-Water Resources in Eastern Cheyenne and Kiowa Counties, Colorado

By ARNOLD J. BOETTCHER

With a section on CHEMICAL QUALITY OF THE GROUND WATER

By C. ALBERT HORR

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779-N

Prepared in cooperation with the Colorado Water Conservation Board

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library catalog card for this publication appears after page 32.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGY AND GROUND-WATER RESOURCES IN EASTERN CHEYENNE AND KIOWA COUNTIES, COLORADO

By Arnold J. Boettcher

ABSTRACT

The principal source of ground water in eastern Cheyenne and Kiowa Counties, Colo., is the Ogallala Formation of Pliocene age. Yields from wells for domestic- or stock-water supplies from the Ogallala Formation are adequate almost anywhere in the area, but yields sufficient for irrigation are obtained only in a few localities. The alluvium of Pleistocene to Recent age occurs only in the valleys, and its yield of water to stock and domestic wells is small.

All the ground water is derived from natural underflow from Kit Carson County and from precipitation. The recharge from precipitation reaching the zone of saturation is estimated at three-fourths of an inch annually. The remainder, about 13.5 inches, either becomes stream runoff, evaporates, or is retained in the soil and subsequently evaporates or is transpired.

The water table slopes generally eastward. Depth to water in the Ogallala Formation ranges from about 15 to 290 feet. Ground water is discharged naturally by underflow to Kansas, Kit Carson County, and Prowers County.

The chemical quality of water in the Ogallala Formation ranges from fair to good. In general the quality of water seems to depend on the thickness of the saturated zone and on the solubility of the minerals in the underlying bedrock. Water obtained from thinly saturated materials overlying the Smoky Hill Marl Member is poor in quality, whereas water from materials overlying the Pierre Shale is better.

INTRODUCTION

PURPOSE OF INVESTIGATION

In eastern Cheyenne and Kiowa Counties, ground water is the only source of potable water for the population and the only means by which the crops can be irrigated.

To determine the availability and occurrence of ground water in this area, a project was started in July 1959 by the U.S. Geological Survey in cooperation with the Colorado Water Conservation Board.

LOCATION

The project area described in this report (fig. 1) includes approximately 1,500 square miles in the eastern half of Cheyenne County and the eastern third of Kiowa County in eastern Colorado. The area is bounded on the east by the Kansas State line, on the west by the Big Sandy Creek valley, on the north by Kit Carson County, and on the south by Prowers County.

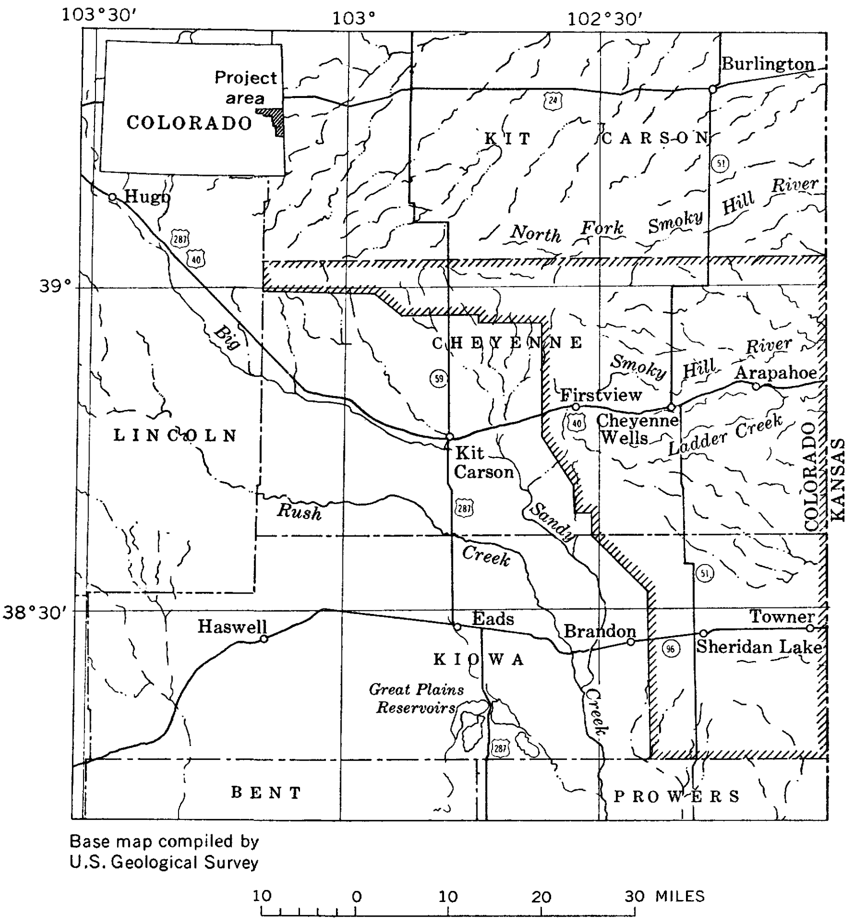

Figure 1.—Map showing area described in this report.

PREVIOUS INVESTIGATIONS

The geology and ground-water resources of eastern Cheyenne and Kiowa Counties were first described by Hay (1895), Johnson (1901, 1902), and Darton (1905) in their studies of the High Plains. The geologic formations were described in detail by Elias (1931) in his report on the adjoining area in Wallace County, Kans. The availability of ground water in the northeastern part of Cheyenne County was discussed by Cardwell (1953) in a report on the irrigation-well development in the Kansas River basin of eastern Colorado. Studies of ground water in Kit Carson County, the lower Big Sandy Creek valley, and Prowers County are in preparation.

METHOD OF INVESTIGATION

Field data for the project were collected by R. O. Smith from July to September 1959 and by the author during the summers of 1960 and 1961. Records of wells, logs, test holes, water-level measurements, and chemical analyses of ground water were collected during this study and were published (Boettcher, 1962). E. A. Moulder, Colorado district engineer of the Ground Water Branch of the U.S. Geological Survey, supervised both the fieldwork and report preparation.

Ground-water information was collected from 257 selected wells. Depth of the well and depth to water were measured with a steel tape. The depth to water in pumping wells was measured with an electric tape. The location of the wells and test holes is shown on plate 1. Altitudes of the wells and test holes were determined by plane-table methods by V. M. Burtis of the Geological Survey. Water samples were collected from 56 wells and analyzed by the Quality of Water Branch of the Geological Survey.

The surficial geology was mapped in the field on aerial photographs (1:20,000 scale) and was later transferred to a special base map prepared by the Topographic Division of the Geological Survey. Information on subsurface geology was obtained from drillers', shothole, and test-hole logs. The test holes were drilled under contract in May and June 1961. Electric logs were made of 20 of the 35 test holes to facilitate the description of the subsurface materials.

WELL-NUMBERING SYSTEM

Wells and test holes referred to in this report have been assigned numbers acording to the Bureau of Land Management's system of land subdivision. The number shows the location of the well or test hole by quadrant, township, range, section, and the position within the section. A graphic illustration of this method of location is shown in figure 2. The capital letter at the beginning of the location number indicates the quadrant in which the well is located. Four quadrants are formed by the intersection of the base line and the principal meridan. The capital letters are assigned in counterclockwise direction beginning with "A" in the northeast quadrant. The first numeral indicates the township, the second the range, and the third the section in which the well is located. The lowercase letters after the last numeral refer to the location within the section. The first letter refers to the quarter section, the second letter refers to the quarter-quarter section, and the third letter refers to the quarter-

quarter-quarter section. The letters are assigned in a counterclockwise direction beginning with "a" in the northeast quarter of the section. If more than one well is within the same quarter-quarter-quarter section, each subsequent well is distinguished by a digit following the lowercase letters.

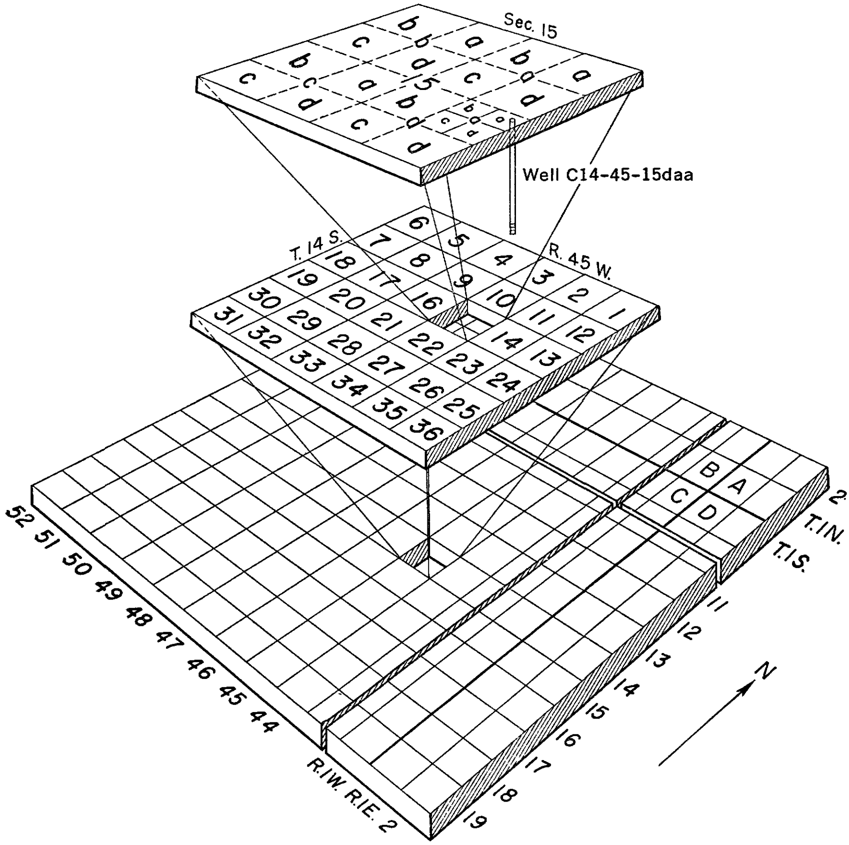

Figure 2.—System used in numbering wells and test holes.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to all the well owners of the area who permitted measurements of their wells and especially to Iley Sexson and Gilbert Lehenbauer for the use of their wells for pumping tests. The author is also grateful to the officials of Cheyenne Wells and Arapahoe for information concerning their municipal well systems and to the Skelly Oil Co. and Texaco, Inc., for the use of their shothole logs.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The project area lies generally within the High Plains section of the Great Plains physiographic province, and it is composed of two distinct topographic units. For the purpose of this report, the area that is part of the Colorado High Plains will be referred to as the High Plains district; the remaining part is within the Big Sandy Creek drainage system and will be referred to as the Big Sandy district, as shown on plate 1.

The High Plains district is a generally flat surface that, in places, has been moderately altered to a gently rolling surface by ephemeral streams and erosion. The topography slopes gently eastward and southeastward from an altitude of 5,150 feet in the northwestern part of Cheyenne County to 3,775 feet in the southeastern part of Kiowa County. This area is drained by intermittent streams which flow generally eastward or southward. The principal streams are the Smoky Hill River and Big Timber, White Woman, and Ladder Creeks, which flow eastward into Kansas, and Wild Horse Creek, which flows southward into the Arkansas River.

The Big Sandy Creek district has a dissected surface that slopes westward and southward into the Big Sandy Creek valley. The principal intermittent streams of this area are Big Spring and Little Spring Creeks.

CLIMATE

Eastern Cheyenne and Kiowa Counties are classed as semiarid. Conditions are generally good for successful dryland farming during years of normal or above-normal precipitation.

Normal precipitation generally is low; most of the rain falls from May to September during the growing season. The mean annual precipitation at Cheyenne Wells is 14.23 inches, as shown in figure 3. Normal or above-normal precipitation does not necessarily guarantee good crop yields because the crops may wilt during a prolonged dry period. Also, many storms are accompanied by hail, an additional crop hazard. The storms in the summer are erratic and do not necessarily cover the entire area.

The following table shows the average monthly precipitation and temperature from 1940 to 1960 at Cheyenne Wells.

Month	*Average temperature (°F)*	*Average precipitation (inches)*
January	29. 3	0. 31
February	32. 9	. 33
March	39. 3	. 77
April	50. 5	1. 37
May	59. 6	2. 15
June	69. 8	2. 29
July	76. 3	1. 91
August	74. 6	2. 62
September	66. 2	1. 09
October	54. 6	. 74
November	40. 0	. 44
December	31. 5	. 21

735-915—64——2

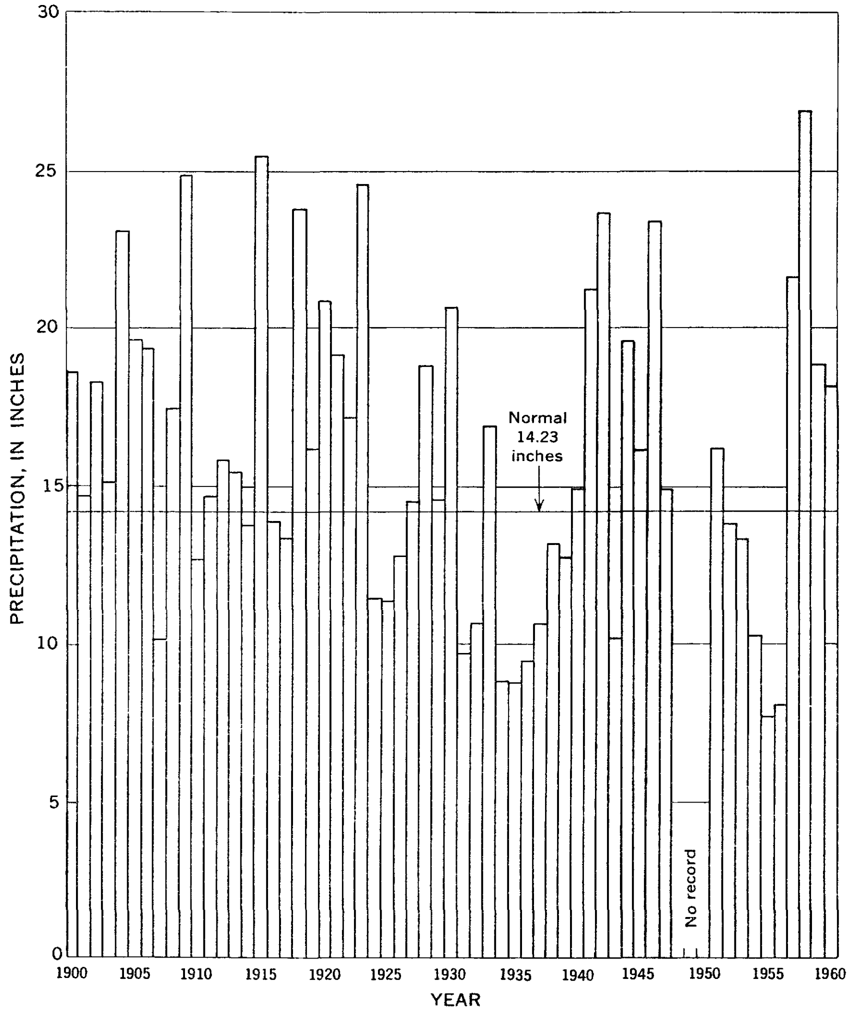

FIGURE 3.—Graph showing annual precipitation at Cheyenne Wells.

Temperatures are usually high during the summer, and they are mild except for short periods of extreme cold in the winter. Occasional blizzards occur in the fall and winter. The mean annual temperature at Cheyenne Wells is 52.1° F. The average growing season is approximately 150 days. Excessive wind in the spring may remove young plants or cover them deep enough with soil to require replanting. Hot dry winds in the summer occasionally remove large quantities of moisture from the soil, and irrigation is necessary for certain crops.

CULTURAL DEVELOPMENT

The economy of eastern Cheyenne and Kiowa Counties depends almost entirely on agriculture, and, consequently, the future economic growth of the project area depends on adequate precipitation and favorable economic trends. Water for stock can be obtained from wells almost everywhere in the High Plains district. Although ground-water irrigation is being practiced in a few small areas, dry-land farming is the predominant farming method in the project area.

According to the 1959–60 Colorado Agricultural Statistics (Colorado Dept. Agriculture, 1961), approximately 185,000 acres of cropland was harvested in the project area, and winter wheat accounted for more than 80 percent of the total harvest. Only about 1,000 acres of the cropland could be irrigated owing to a lack of surface water and to the small amount of ground water now available for use in irrigation. The number of acres of individual crops harvested in 1960 is shown in the following table.

Estimated acres harvested in 1960

	Acres irrigated	*Acres non-irrigated*	*Total acres*
Corn	550	500	1, 050
Winter wheat	--------	155, 000	155, 000
Barley	--------	5, 500	5, 500
Sorghums for grain	430	20, 500	20, 930
Hay	--------	1, 500	1, 500

The 1959–60 Colorado Agricultural Statistics also showed that more than 19,000 cattle and 4,300 sheep grazed within the project area.

The population of the project area is estimated from the 1960 census to have been 2,300 in that year, an average of 1.5 people per square mile. The population of Cheyenne Wells was 1,020 in 1960 and 1,154 in 1950. Sheridan Lake had a population of 90 in 1960. In 1950 the town was not incorporated; consequently, no census figures are available.

Mineral resources in the area other than ground water include extensive sand and gravel deposits, which are used locally both for road and building construction. Oil might be produced in the future; many oil companies are exploring the area at present (1962), but no oil has been produced thus far.

The main line of the Missouri Pacific Railroad Co. runs from Pueblo to Kansas City through the southern part of the project area, and the main line of the Union Pacific Railroad Co. runs east from Denver to Kansas City through the northern part. U.S. Highway 40 parallels the Union Pacific Railroad Co. tracks, and Colorado State Highway 96 parallels the Missouri Pacific Railroad Co. tracks. Colorado State Highway 51 runs north and south through Cheyenne Wells and Sheridan Lake.

GEOLOGY

GENERAL FEATURES

All formations exposed in the project area are of sedimentary origin and range in age from Late Cretaceous to Recent. All exposed formations have a definite effect on the availability of ground water. A generalized geologic section is given in table 1.

TABLE 1.—*Generalized section of the geologic formations*

System	Series	Stratigraphic unit	Thickness (feet)	Physical character	Water supply
Quaternary	Recent and Pleistocene	Alluvium	0-30±	Unconsolidated sand, gravel, and silt.	Yields adequate quantities of water for domestic and stock use.
Tertiary	Pliocene	Ogallala Formaton	0-400±	Buff-colored sand, gravel, clay, and caliche. The algal limestone forms the caprock.	Principal aquifer in the project area. Yields adequate quantities of water for stock and domestic use; yields as much as 2,200 gpm for irrigation in parts of the project area.
Cretaceous	Upper Cretaceous	Pierre Shale	0-1,100±	Black to dark-gray shale. Contains bentonitic clay and calcareous concretions. Occasionally the upper 4-8 ft is a yellow weathered zone.	Not known to yield water to wells in the project area.
		Smoky Hill Marl Member of the Niobrara Formation	700±	Gray shaly marl; usually weathers to orange. Contains thin bentonitic streaks.	Do.

Some formations at depth contain saline water, but they are not included within the scope of this study. The major structural feature in the area is the Las Animas arch, a broad anticline trending northeastward from the northeast corner of Bent County through central Kiowa and Cheyenne Counties and into southeastern Kit Carson County. The project area lies generally on the east flank of the arch except for the northwestern part, which is on the western flank.

The bedrock materials in the northern part of the Big Sandy district are in places overlain by a thin cover of slope-wash material from the Ogallala Formation. Because these deposits are above the water table, they are of no hydrologic significance and were therefore mapped as bedrock.

NIOBRARA FORMATION

The Smoky Hill Marl Member is the upper member of the Niobrara Formation and is the only member exposed in the project area. It is the oldest formation to crop out, and it underlies the entire project area. The stratigraphic thickness of the Smoky Hill is about 700 feet in the project area (Elias, 1931, p. 37). It is exposed in the southern part of the Big Sandy district south of Cheyenne-Kiowa County line (pl. 1). The Smoky Hill is the bedrock on which the Ogallala Formation rests in the southern part of the High Plains district. South of the Cheyenne County line, in the High Plains district, the

Smoky Hill Marl Member has been eroded, and channels have cut since the end of Late Cretaceous time and before the Ogallala was deposited in Pliocene time. Near Lake Albert, the Smoky Hill probably was structually high during Pliocene time. Later it collapsed and formed a basin, which since has been partly filled by windblown material and material eroded from the Ogallala Formation.

The Smoky Hill Marl Member is composed of gray to blue-gray shaly marl. Weathered exposures are usually yellow to light orange. The upper part of the member contains numerous thin beds of bentonite and of gypsum crystals.

PIERRE SHALE

The Pierre Shale of Late Cretaceous age, dipping northward from the Las Animas arch, overlies the Smoky Hill Marl Member and, in the High Plains district, underlies the Ogallala Formation north of the Cheyenne-Kiowa County line. The Pierre Shale is exposed in Cheyenne County in the Big Sandy district. The contact with the Smoky Hill is generally covered with slope wash. As interpreted from logs of oil-test holes, the formation attains a maximum thickness of about 1,100 feet in parts of the project area. After the Pierre was deposited, a drainage pattern was formed on its surface before the Ogallala Formation was deposited. The rolling erosional surface is evident where the Pierre Shale is exposed in the Big Sandy district.

The Pierre is composed of dark-gray to black noncalcareous shale that contains concretions of gray calcareous shale and thin layers of bentonite, gypsum, and limonite. When drilling through the Ogallala Formation into the Pierre Shale, a 2- to 4-foot layer of bright orange to yellow-green dense clay, directly on top of the shale, is sometimes penetrated. This clay is weathered Pierre Shale.

OGALLALA FORMATION

The Ogallala Formation of Pliocene age forms the surface of the High Plains district. The Ogallala is missing in the Big Sandy Creek valley, possibly owing to erosion by Big Sandy Creek. The thickness of the formation ranges from 0 on the west to almost 400 feet near the Kansas State line. The thickness changes greatly throughout the area owing to changes in topography and to the uneven surface of the underlying eroded bedrock.

The Ogallala Formation is a semiconsolidated deposit of sand, silt, clay, gravel, chert, and caliche. Poorly sorted beds of sandy silt, sand, and gravel, usually cemented with calcium carbonate, are common throughout the formation. These cemented materials gave rise to the term “mortar beds.” The mortar beds resemble a poor grade of concrete and are light gray to gray. The clay beds of the Ogallala Formation are usually light brown, brown, or green, and they are occasionally mistaken for bedrock by drillers. The clay is usually dense and discontinuous. The sand, ranging in size from very fine to very coarse, has a characteristic buff color. In some areas the formation is capped by a layer of pink concentrically banded algal limestone that is usually less than 1 foot thick. The algal limestone probably was never continuous but may have been formed in large shallow lakes at the end of Pliocene time (Elias, 1931). This caprock is missing in most parts of the project area.

ALLUVIUM

The alluvium is of Pleistocene to Recent age and has been deposited in the channels cut into the exposed surfaces of the Smoky Hill Marl Member, the Pierre Shale, and the Ogallala Formation. The alluvium generally is less than 50 feet thick. It is an erosional product of the Ogallala Formation and is composed of sand, silt, clay, and gravel.

GROUND WATER

OCCURRENCE

Most potable ground water in the project area is derived from the Ogallala Formation, although the alluvial materials in the Big Sandy district yield small quantities of water to wells. All the ground water in the project area is derived from precipitation and from small amounts of underflow from Kit Carson County.

Precipitation in the area either runs off, is consumed by evapotranspiration, or percolates into the soil. The water that percolates into the soil, although held there by adhesion to the walls of the void spaces and by cohesion to the other particles of water, is subject to evapotranspiration. A large part of the precipitation is absorbed into the soil, but much subsequently is evaporated, if near the surface, or is transpired by plants. Consequently, only a small part of the water absorbed by the soil percolates to the water table.

The average recharge in the High Plains district is estimated to be three-fourths of an inch per year from an average annual precipitation of 14.23 inches, although the amount of recharge differs from place to place because of different types of soil and topography and uneven distribution of precipitation.

The water that reaches the water table in the High Plains district moves as underflow generally eastward and out of the area, as shown by contours on plate 2. Small amounts of water might move from the High Plains district into the alluvium of the Big Sandy district, but the small number of springs or seeps indicates that the amount of water is negligible. Because the depth to water is generally great in the High Plains district, little water is evaporated or transpired after it has reached the water table. Evapotranspiration in the shallow alluvium of the Big Sandy district is higher than it is in the Ogallala Formation in the High Plains district.

HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS

The permeability of the unconsolidated materials of the Ogallala Formation changes greatly in the project area owing to differences in the following characteristics: Grain size, sorting, and degree of cementation.

The Ogallala Formation characteristically is a mixture of lenticular beds of sand, gravel, silt, and clay. The grain size of the sand and gravel generally becomes coarser with depth. Examination of the test-hole cuttings and outcrops indicates that materials generally are coarser in the thicker parts of the Ogallala, which are along the eastern part of the project area.

Three pumping tests were made during the investigation. The lack of adequate test sites made it impossible to determine representative permeabilities throughout the area; however, in two of the three tests, the permeabilities determined probably were as high as those anywhere in the project area. The results of the three tests, as shown in table 2, indicate the hydrologic properties only of that part of the aquifer near the test wells, not the properties of the entire Ogallala Formation.

TABLE 2.—*Summary of the results of pumping tests in the Ogallala Formation*

Well	Date test was started	Depth of well (feet)	Static water level (feet)	Duration of pumping (hours)	Quantity of discharge (gpm)	Total drawdown (feet)	Specific capacity (gpm per ft) [1]	Saturated thickness (feet)	Calculated coefficient of transmissibility (gpd per ft) [2]	Calculated coefficient of permeability (gpd per sq ft) [3]
C17-43-17ccc	4-19-62	48.0	33.1	7.0	9.6	9.4	1.0	11	2,200	200
C20-41-30cdd	8-6-61	[4] 197	92.53	9.1	1,340	25.3	52.9	98	120,000	1,200
C13-43-36baa (Wallace County, Kans.)	8-16-61	255.4	148.48	225	1,445	26.6	54.3	105	170,000	1,600

[1] Specific capacity is the well yield, in gallons per minute per foot of drawdown.
[2] Coefficient of transmissibility is the number of gallons of water per day transmitted through each 1-foot strip extending the height of the aquifer at the existing temperature and under a hydraulic gradient of 100 percent.
[3] Coefficient of permeability is the transmissibility divided by the aquifer thickness, in feet.
[4] Reported value.

The permeability of the materials in the Ogallala Formation in the project area is estimated to range from 200 to 1,600 gpd per sq ft (gallons per day per square foot); the average is about 600 gpd per sq ft. The average permeability is based on three pumping tests, results from other studies in the Ogallala Formation in the Colorado

High Plains, and logs and samples of the test holes drilled in the project area (Boettcher, 1962). The difference in permeability is due to wide variation of grain size within the aquifer, interfingering of the sand and gravel layers, cementation, compaction, and sorting.

The ablity of an aquifer to yield water to wells from storage is expressed as the coefficient of storage.[1] The coefficient of storage could not be determined accurately in three pumping tests, but previous investigations of the Colorado High Plains show the average coefficient of storage of the Ogallala Formation to be about 0.15. This figure is representative of the coefficient of storage used throughout the High Plains district.

CONFIGURATION OF THE WATER TABLE

The water table slopes gently in a general eastward direction, and it is continuous only in the High Plains district. In the Big Sandy district, ground water is obtained in only the alluvial materials. For this reason, the configuration of the water table is shown (pl. 2) only for the High Plains district.

The slope of the water table is influenced by the bedrock surface, permeability of the saturated material, discharging wells, and varying recharge rates. Some of the channels cut into the eroded bedrock, as shown on plate 1, also influence the slope of the water table in the High Plains district.

The shape of the water table, where the Big Sandy district joins the High Plains district, probably is the same as that of the bedrock surface. The lack of control and the possibility of some of the water moving into the Big Sandy district makes interpretation of the data questionable in this area. The water moves generally eastward from 200 to 1,500 feet per year, depending on the local gradient and the permeability.

Altitudes of the water table (pl. 2) are derived from field data collected from 1959 to 1961. Because the fluctuation of the water table is small over an extended period, these altitudes probably are indicative of the water table under normal conditions in the area.

DEPTH TO WATER

Depth to water is a major consideration in the construction and usefulness of a well. Adequate stock and domestic wells can be drilled nearly anywhere in the High Plains district, but large-capacity wells for irrigation are considered by the author to be economically feasible at great depths only if the yields are more than about 500 gpm (gallons per minute).

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

The depth to water in the High Plains district ranges from 15 to 290 feet, as shown on plate 2. The effect of the gently rolling topography on the depth to water is demonstrated by wide changes in the depth to water in the northern part of the High Plains district; in the southern part, the topography is generally flatter, and the depth to water is more uniform.

THICKNESS OF SATURATED MATERIALS

The thickness of the saturated zone is a significant factor in determining potential yields from wells. Generally in the High Plains district, wells penetrating a saturated section 40–50 feet thick can be expected to yield more than 500 gpm. If the material is very coarse and the permeability is high, the same quantity of water can be obtained from a thinner saturated section.

The saturated zone in the High Plains district ranges in thickness from 1 to 175 feet and generally thickens eastward (pl. 3). About 40 percent of the Ogallala Formation in the project area has a saturated thickness of less than 10 feet.

The amount of ground water available to wells—in storage—in the Ogallala Formation within the project area, as shown in the following table, was calculated from the saturated-thickness map (pl. 3); an average storage coefficient of 0.15 was assumed (see p. 12). The total amount of water in storage is estimated to be 2.6 million acre-feet.

Storage in Ogallala Formation in project area

Saturated thickness (feet)	*Average saturated thickness (feet)*	*Total area (square miles)*	*Acre-feet in storage ($\times 10^5$)*
<10	5	547.28	2.63
10–30	20	485.86	9.33
30–60	45	161.39	6.97
60–100	80	63.35	4.87
100–125	115	23.96	2.65

The amount of water that may be withdrawn from an aquifer depends on various physical and economic factors, but recoverable ground water is considerably less than the total amount in storage. About 75 percent of the total amount of water in storage in the Ogallala Formation in the project area would be withdrawn in lowering the overall water level 20 feet.

NATURAL RECHARGE AND DISCHARGE

The amount of water discharged from an aquifer or recharged to an aquifer in the High Plains district depends on the permeability of the formation and on the amount of water available. The practically impermeable clay and shale of the Pierre Shale and of the Smoky Hill Marl Member preclude the downward movement of water, but the

735–915—64——3

unconsolidated materials of the Ogallala Formation and of the alluvium readily permit downward movement of water to the water table.

All the recharge to the Ogallala Formation comes from Kit Carson County and from precipitation, and natural discharge occurs only as underflow out of the area to Kansas, Kit Carson County, and Prowers County. The hydrologic system in the Ogallala Formation has been in operation long enough to reach an equilibrium in which recharge equals discharge. Pumping from large-capacity wells has disturbed the equilibrium only slightly as indicated by the absence of large water-level fluctuations. The amount of water discharge from wells in the project area is insignificant compared with total discharge. The amount of ground-water underflow at the Kansas State line can be calculated from Darcy's law as follows:

$$Q=PIA,$$

when

Q is the discharge by underflow, in gallons per day;

P is the average coefficient of permeability, estimated to be 900 gpd per sq ft at the Kansas State line;

I is the average hydraulic gradient, estimated to be 15 ft per mile or 0.0028;

and

A is the cross-sectional area of saturated materials, determined to be 17 million sq ft.

Therefore, the annual ground-water discharge from the Ogallala Formation in the project area is approximately 52,000 acre-feet. Of the total, about 47,000 acre-feet is discharged from the project area to Kansas, and 5,000 acre-feet is discharged to Kit Carson and Prowers Counties. Because recharge is assumed equal to discharge, the natural recharge of the aquifer in the 1,300-square-mile area of the High Plains district is about three-fourths of an inch per year.

WATER-LEVEL FLUCTUATIONS

Water-level fluctuations in wells are attributed to changes in ground-water storage caused by changes in discharge, recharge, or barometric pressure. Barometric-pressure fluctuations have been noted to cause a water-level change of as much as 1 foot for short periods in wells in the High Plains district. Figure 4 shows a hydrograph of the water level in well C12–48–10abd, as measured by a recording gage, and simultaneous barometric readings taken every 3 hours at Lamar, Colo. The hydrograph indicates that most water-level fluctuations are due to barometric effects.

Observation-well records collected from July 1959 to May 1962 (Boettcher, 1962) indicate no large fluctuation of water levels that are due to heavy pumping of ground water or to changing climate. These data form the basis for a long-term measurement program that should be established to determine regional trends of water levels in the Ogallala Formation.

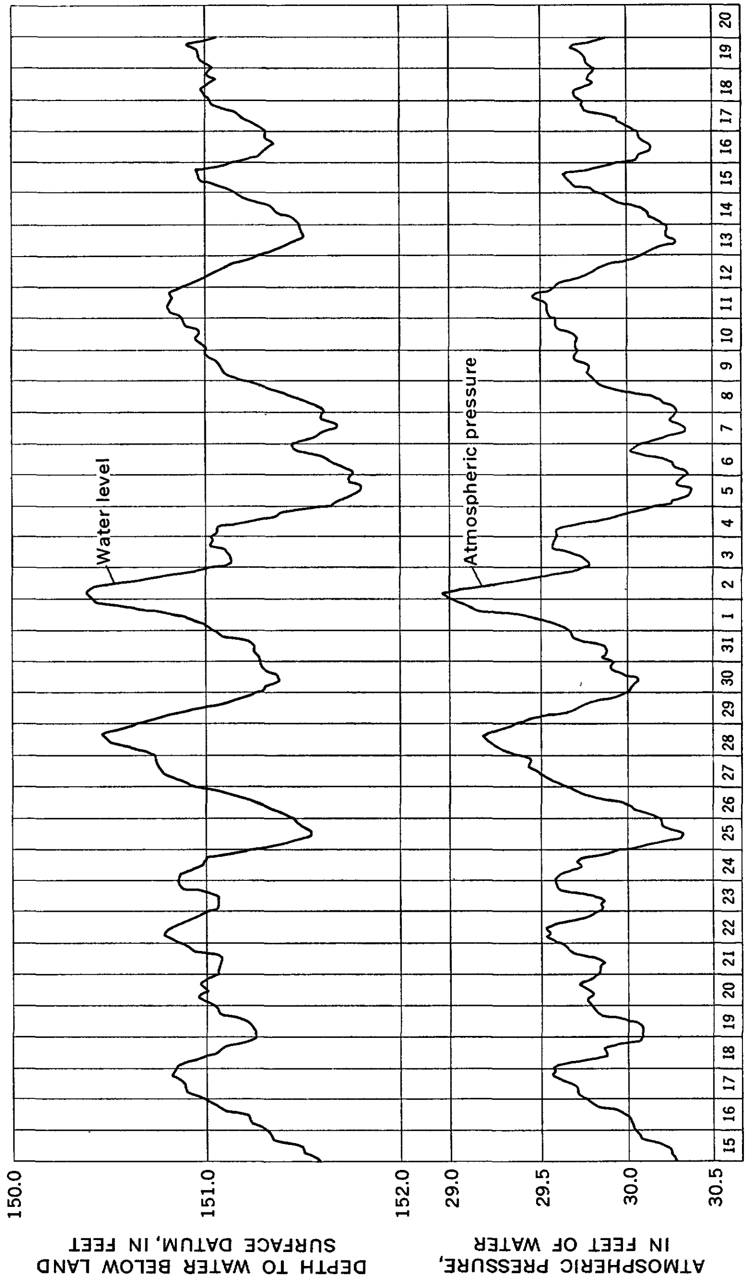

FIGURE 4.—Hydrograph of water-level fluctuations in well C12–48–10abd and barograph of atmospheric-pressure changes from October 15 to November 20, 1961.

UTILIZATION OF WATER

Ground water in eastern Cheyenne and Kiowa Counties was used for municipal, domestic, and stock purposes before 1948. Since that time, irrigation has been the largest single use of ground water.

Data regarding 257 wells in the project area were collected. Of these wells, 223 were used for domestic and stock supplies, 14 for irrigation, and 9 for public supplies. The remaining 11 wells inventoried were not being used. The inventory included all known irrigation and public-supply wells and selected stock and domestic wells.

DOMESTIC AND STOCK

Almost all the water for domestic and stock uses is ground water. Stock supplies in some areas are obtained from runoff, which is collected by dams in small intermittent streams. This water is usually available only in the early summer, when precipitation is sufficient to cause runoff.

Domestic supplies are obtained from small-diameter wells equipped with cylinder pumps powered by windmills. Some of the more modern domestic systems are equipped with electric-powered pumps. Stock wells are equipped with cylinder pumps operated either by windmills or by gasoline or electric motors.

Most of the older stock and domestic wells were completed after penetrating only 5–10 feet of the saturated zone. These wells do not necessarily indicate the total thickness of the saturated zone or the depth to bedrock.

IRRIGATION

Development of irrigation wells in the High Plains district started in 1948 and increased rapidly during the drought from 1952 to 1956. In 1960 about 2,000 acre-feet of ground water was pumped in the project area from 14 irrigation wells, the yields of which were as great as 2,200 gpm. Most pumping is done in the summer, but some hay and pasture crops are irrigated in the spring also.

Ground-water irrigation has increased steadily in the project area, but the increase has been slow in comparison with that in other parts of the Colorado High Plains. Ground-water irrigation probably will continue to increase, but the total growth will be limited to several select areas. These areas will be restricted to locations where the saturated thickness is greater than 50 feet (pl. 3). Only 10 percent of the project area is underlain by a saturated zone more than 50 feet thick; but in the possible irrigation areas, the soils are irrigable (Boettcher, 1963).

MUNICIPAL

Cheyenne Wells and Arapahoe are the only communities that have a municipal water supply. The residents of Towner depend on individual wells. Sheridan Lake is now constructing a municipal water supply (1962), but until its completion, the residents will continue to haul water.

Cheyenne Wells (population 1,020) has 4 wells, whose individual yields range from 130 to 605 gpm. Three of the wells have electrically driven pumps; the other has a liquefied-petroleum gas-engine-driven pump. In the winter the only well pumped yields 405 gpm. The well that has the gas-driven pump serves as a standby to be operated if the electricity is off, and it is used also in the summer when large amounts of water are pumped. The water is stored in a 75,000 gallon elevated tank in the center of town and in a 6,000-gallon tank at the south end of town. Cheyenne Wells uses about 250 acre-feet of ground water annually.

Arapahoe (population 64) uses two wells that have electrically driven submersible pumps. One well is owned by the town, and the other is leased. The leased well is used as a standby when the pump for the other well needs servicing. The water is stored in a 22,000-gallon elevated tank. Each well yields about 25 gpm. The water system was installed in the spring of 1961. Before this time the water supply was obtained from one windmill-operated well, which filled individual cisterns throughout the town. Arapahoe uses about 10 acre-feet of ground water per year.

CHEMICAL QUALITY OF THE GROUND WATER

By C. Albert Horr

The utilization of water is closely related to its chemical quality. Water of suitable quality for one user may not meet the requirements of another. The domestic consumer is concerned with hardness and with contents of iron, manganese, magnesium, chloride, sulfate, nitrate, fluoride, and dissolved solids. Although water-quality criteria for stock use is poorly defined, the stock raiser is concerned with the dissolved-solids content and with the concentration of certain salts such as nitrate, fluoride, and chloride. Content of dissolved solids, boron, and bicarbonate, and the ratio of calcium plus magnesium to sodium are of significance to irrigation.

Samples collected from representative wells in the study area (pl. 1) were analyzed by personnel of the Geological Survey according to previously published methods (Rainwater and Thatcher, 1960). Chemical analyses are shown in table 3. The dissolved-solids content of the ground water, calculated from the chemical analyses, ranges from 123 to 2,560 ppm (parts per million). Eighty percent of the samples analyzed had a dissolved-solids content of less than 500 ppm. On the basis of percentage composition, the ground water may be roughly characterized as a calcium magnesium bicarbonate sulfate type. Calcium and bicarbonate are the predominant dissolved ions and account for more than half the dissolved material in 40 of the 56 samples analyzed. The calcium in the water was derived from cal-

TABLE 3.—*Chemical analyses of ground*

[Analytical results in parts

Well	Depth (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
C12-43-14ddc	130.1	5-17-61	58	----	----	0.18	----	39	20	20
44-13ccd	188.9	10-19-60	61	----	----	----	----	24	19	60
15ccc	44.9	do	57	----	----	----	----	119	82	166
45-16ccc	103.8	5-17-61	55	----	----	----	----	26	11	62
46-7bbb	[3] 132	8-30-60	56	24	----	.00	----	50	9.0	20
47-23aad	91.2	10-20-60	55	----	----	----	----	67	18	13
48-5dac	211.1	do	60	----	----	.03	----	25	17	17
14dcd	110.2	3-22-62	59	30	0.00	.20	0.00	62	11	24
50-9dad [6]	26.4	10-20-60	55	----	----	----	----	50	11	31
C13-42-3ccb	124.3	10-11-60	59	----	----	----	----	35	17	13
6bcc	73.8	8-30-60	59	25	----	.00	----	46	7.5	16
43-36baa [7]	255.4	5-16-61	60	26	----	.02	----	32	8.8	19
44-19aab	74.1	5-17-61	57	----	----	----	----	36	2.9	4.0
21aac	182.5	8-29-60	59	15	----	.00	----	35	6.6	18
45-20aba	53.1	5-17-61	56	----	----	.00	----	102	31	30
C14-43-6cdd	255.1	5-16-61	58	----	----	.35	----	33	9.7	20
12acc2	[3] 265	3-22-62	59	26	.08	.23	.00	40	16	40
12bba	249.2	8-22-60	62	23	----	.93	----	41	12	30
44-18dab	[3] 308	8-13-60	61	----	----	----	----	42	10	14
20bcc	[3] 304	8-22-60	61	26	----	----	----	42	6.6	9.1
45-16ccc	219.4	5-17-61	59	----	----	.02	----	33	8.5	19
46-22dad	223.0	do	58	----	----	2.2	----	96	29	51
C15-42-2aba	185.0	3-22-62	57	27	.22	.33	.00	38	15	20
34aad	211.2	5-16-61	61	28	----	.14	----	29	19	29
44-10bbb	255.2	10-19-60	57	----	----	.26	----	23	18	58
45-11ccb	211.9	3-22-62	----	28	.16	1.3	.00	44	21	40
45-30bbd	199.4	do	58	27	.00	.06	.00	40	14	28
46-12daa	236.4	10-19-60	55	----	----	.20	----	64	43	69
28dba [6]	25.2	3-22-62	58	40	.18	3.4	.39	81	20	18
C16-41-18dcc	241.6	3-23-62	60	44	.11	.71	.00	37	20	20
42-5ccc	259.9	do	59	37	.13	.16	.00	36	16	20
11aaa	215.1	3-22-62	----	----	----	----	----	35	16	17
18cbb	215.2	3-23-62	59	36	.13	.57	.00	33	15	13
43-1cbc	260.0	do	59	25	.00	.08	.00	26	15	18
21bbb	190.0	10-18-60	56	----	----	----	----	38	24	28
26bba	201.9	3-23-62	58	38	.00	.26	.11	34	19	31
44-8bcc	234.2	do	59	29	.00	1.45	.00	33	18	30
C17-42-1bcb	[3] 180	10-17-60	59	----	----	----	----	46	16	38
12dbb	[3] 180	3-23-62	----	26	.00	.10	.00	66	12	41
13cbb	[3] 103	do	57	29	.02	.00	.00	62	14	24
32abb	60.6	5-16-61	58	----	----	.52	----	95	18	48
43-14aad	96.8	10-20-60	58	----	----	.25	----	58	22	33
16cdb	61.0	3-23-62	----	30	.20	4.1	.00	64	17	19
17ccc	48.0	3-21-62	58	41	.10	.54	.00	63	23	59
18bba	72.4	3-23-62	59	30	.00	.10	.00	79	6.3	9.0
44-4cda	125.3	5-16-61	60	----	----	----	----	30	14	21
8ccc	151.1	3-23-62	59	47	.11	.47	.00	126	76	122
12dad	[3] 115	do	59	31	.00	.40	.00	52	7.5	16
26ddd	81.3	10-17-60	58	----	----	.03	----	244	63	132
C18-42-25abd	[3] 83	8-22-60	62	36	----	.05	----	144	85	174
43-25bac	[3] 40	5-16-61	56	----	----	.14	----	378	124	196
C19-42-15baa	99.8	do	58	22	----	.50	----	228	114	222
44-14dda	63.0	10-17-60	57	----	----	.00	----	184	143	424
C20-41-30cdd	[3] 197	8-23-60	60	29	----	.01	----	75	65	127
42-13cbc	105.7	5-16-61	59	----	----	.02	----	82	30	51
36cdc	[3] 187	do	59	----	----	.11	----	76	33	81

[1] Except as indicated, concentration given is sum of determined constituents and does not include silica (SiO_2).

[2] Sodium-adsorption-ratio.

[3] Reported depth.

cium carbonate, which is a cementing material in the Ogallala Formation. Sulfate in ground water in Kiowa County is derived from the Smoky Hill Marl Member; in Cheyenne County it is derived from the Pierre Shale.

water from the Ogallala Formation

per million except as indicated]

Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated) [1]	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	SAR [2]	Specific conductance in micromhos per cm at 25° C	pH
2.4	218	0	20	11	1.0	12	0.10	233	180	1	0.6	434	7.8
7.0	222	8	74	6.0	.8	2.2	-------	310	138	0	2.2	497	8.3
11	198	14	496	216	.8	0	-------	1,190	634	448	2.9	1,950	8.5
1.9	244	0	27	7.0	1.6	15	.19	272	110	0	2.6	473	8.0
3.2	192	0	27	6.5	.4	11	-------	[4] 245	161	4	.7	385	7.7
7.4	160	10	40	20	.0	75	-------	329	241	94	.4	532	8.4
3.4	152	10	20	6.0	.5	5.5	-------	174	132	0	.6	304	8.5
3.6	173	0	56	22	.4	20	-------	[5] 320	200	58	.7	508	7.7
4.8	226	0	11	14	.7	27	-------	261	170	0	1.0	511	8.0
11	198	0	25	3.0	.8	4.6	-------	206	158	0	.4	326	8.0
3.8	176	0	16	5.0	.5	13	-------	[4] 220	145	1	.6	334	7.8
2.2	166	0	12	3.0	.8	8.0	.07	[5] 191	116	0	.8	308	7.6
2.6	122	0	4.7	2.0	.2	10	.05	123	103	3	.2	225	8.1
2.8	154	0	20	3.0	.5	8.6	-------	[4] 186	115	0	.7	298	8.1
4.2	428	0	43	14	.6	45	.14	480	382	31	.7	799	8.0
1.8	163	0	21	3.0	.7	10	.74	180	122	0	.8	332	7.7
4.4	175	0	62	14	.8	21	-------	[5] 294	166	22	1.4	458	7.7
------	162	0	57	12	.7	16	-------	[5] 281	153	20	1.1	423	7.4
3.6	164	10	22	4.0	.3	7.5	-------	193	146	0	.5	337	8.6
------	158	0	13	1.0	.6	9.0	-------	[5] 187	132	2	.3	300	7.3
2.6	168	0	9.7	4.0	.5	9.9	.08	170	118	0	.8	302	8.1
2.5	99	0	316	4.0	.2	60	.14	608	358	278	1.2	928	7.5
5.0	191	0	33	6.2	.8	16	-------	[5] 246	156	0	.7	390	7.7
2.2	196	0	39	5.0	1.0	11	.14	[5] 263	150	0	1.0	423	7.9
6.0	208	0	66	9.0	.2	4.4	-------	287	132	0	2.2	486	7.7
5.2	172	0	101	17	.8	23	-------	[5] 359	196	56	1.2	561	7.8
4.1	190	0	55	7.2	1.0	10	.00	[5] 304	158	2	1.0	430	7.7
8.2	122	4	324	40	.3	16	-------	695	337	230	1.6	958	8.3
3.4	264	0	65	7.6	.3	35	-------	[5] 398	284	68	.5	620	7.4
5.4	173	0	69	2.5	.8	11	-------	[5] 246	174	32	.7	399	7.6
3.6	169	0	45	5.8	.8	10	-------	[5] 249	159	18	.7	383	7.6
------	-------	0	29	5.1	------	------	-------	-------	-------	-------	------	372	------
3.6	164	0	23	3.5	.6	10	-------	[5] 223	144	10	.5	333	7.8
4.6	171	0	10	3.4	.9	9.0	-------	[5] 193	126	0	.6	316	7.8
4.4	154	10	105	4.0	2.4	4.8	-------	297	194	51	.9	347	8.4
4.8	208	0	49	10	1.8	8.0	-------	[5] 273	163	0	.8	335	7.9
3.6	204	0	42	3.0	1.1	8.1	-------	[5] 256	156	0	1.0	421	7.7
6.0	178	0	109	8.0	.5	9.0	-------	320	181	35	1.2	464	8.2
4.0	169	0	136	17	.7	13	-------	[5] 402	214	76	1.2	602	7.6
4.8	212	0	58	16	.8	20	-------	[5] 334	212	39	.5	514	7.7
3.4	238	0	169	24	.6	20	.19	495	311	116	1.2	811	7.7
8.8	230	10	32	25	2.4	44	-------	348	235	30	.9	628	8.4
7.4	226	0	46	10	.5	36	-------	[5] 339	230	44	.5	532	7.7
7.4	319	0	69	17	1.1	42	-------	[5] 469	252	0	1.6	715	7.6
4.0	185	0	45	7.8	.1	46	-------	[5] 326	223	72	.3	484	7.8
1.6	164	6	23	4.0	1.2	4.5	.90	187	132	0	.8	343	8.4
8.0	138	0	625	62	1.2	36	-------	[5] 1,230	627	514	2.1	1,510	7.6
4.0	163	0	50	5.3	.3	22	-------	[5] 256	160	27	.6	388	7.6
4.4	236	0	810	61	.6	95	-------	1,530	868	675	1.9	1,930	7.9
------	174	0	735	108	3.3	20	-------	[4] 1,390	710	567	2.8	1,870	7.3
5.6	193	0	1,440	137	2.4	66	-------	2,440	1,450	1,290	2.2	3,100	7.3
3.6	184	0	1,170	143	4.0	3.9	.63	[5] 2,140	1,040	887	3.0	2,630	7.7
6.8	150	0	1,550	170	.3	9.5	-------	2,560	1,050	924	5.7	3,560	8.1
5.4	198	------	451	66	3.8	13	-------	[4] 932	454	292	2.6	1,330	7.8
4.8	328	------	144	12	2.0	17	.20	504	328	59	1.2	840	7.5
3.5	194	------	287	32	1.6	8.3	.30	618	326	167	2.0	930	8.1

[4] Includes silica (SiO_2).

[5] Residue on evaporation.

[6] Water from alluvium.

[7] Wallace County, Kans.

DEFINITION OF TERMS

Terms used in water chemistry are common ones; however, some have limited usage, and others may convey a variety of meanings. As an aid to clarity, some of the terms used in this report are defined as follows.

Parts per million (ppm).—A unit expressing the concentration of a constituent on a weight-to-weight basis, usually in grams of constituent per million grams of solute. For all practical purposes, it is nearly equal to milligrams of constituent per liter of water.

Equivalents per million (epm).—A unit expressing the concentration of chemical constituents in terms of chemical equivalence; more accurately describes the composition of a water and the relationship of ions in solution. One equivalent of a positively charged ion (cation) will react with one equivalent of a negatively charged ion (anion). Parts per million are converted to equivalents per million by multiplying by the reciprocal of the combining weight of the ion. The following factors are used:

Cation	Factor [1]	Anion	Factor [1]
Calcium (Ca^{+2})	0.04990	Carbonate (CO_3^{-2})	0.03333
Magnesium (Mg^{+2})	.08226	Bicarbonate (HCO_3^{-1})	.01639
Sodium (Na^{+1})	.04350	Sulfate (SO_4^{-2})	.02082
Potassium (K^{+1})	.02557	Chloride (Cl^{-1})	.02821
		Fluoride (F^{-1})	.05264
		Nitrate (NO_3^{-1})	.01613

[1] Based on 1961 atomic weights.

Specific conductance.—A measure of the ability of a water to conduct an electrical current; expressed as micromhos per centimeter at 25° C. Specific conductance is dependent on the concentration of ions in solution and can be used as an emperical measure of the degree of mineralization. The following approximate relations are used:

$$\text{Specific conductance} \times (0.65 \pm .05) = \text{ppm dissolved solids.}$$

$$\frac{\text{Specific conductance}}{100} = \text{epm cations} = \text{epm anions.}$$

Sodium-adsorption-ratio (SAR).—A measure of the quality of irrigation water; related to the adsorption of sodium by a soil from applied water. The ratio is determined by dividing the concentration of sodium by the square root of one-half the concentration of calcium plus magnesium; all concentrations are expressed as equivalents per million.

Leaching requirement (D percent).—A ratio, expressed as a percentage, of the amount of irrigation water that must pass through the root zone to the amount of water applied so that soil productivity for satisfactory crop yields can be maintained.

Salt.—A comprehensive term that includes all ionizable material in solution derived from minerals such as gypsum ($CaSO_4 \cdot 2H_2O$), epsomite ($MgSO_4 \cdot 7H_2O$), and sylvite (KCl). The term does not refer to common table salt ($NaCl$) alone.

FACTORS AFFECTING WATER QUALITY

Rain and snow absorb gases from the atmosphere, thus enabling that part of the precipitation entering the ground-water reservoir to dissolve materials from rocks. Differences from place to place in the chemical quality of the ground water are the result of several interdependent factors. The key factors are the source and amount of recharge and the physical and chemical properties of the material through which the water moves. Regional patterns of chemical quality generally are not as distinct as local patterns.

WATER QUALITY IN RELATION TO GEOLOGY

The Ogallala Formation, of Pliocene age, is the principal aquifer in eastern Cheyenne and Kiowa Counties. It is composed of sand and gravel usually mixed with fine silt, clay, and caliche. In places the sand and gravel are cemented with impure calcium carbonate as in the so-called mortar beds. (See section on "Geology.") The Ogallala Formation is underlain by the Pierre Shale in Cheyenne County and by the Smoky Hill Marl Member in Kiowa County.

The chemical quality of water from the Ogallala Formation reflects the chemical composition of the aquifer in that the predominant calcium and bicarbonate content is derived by solution of the calcium carbonate cementing the sand and gravel. The sharp change in quality along the Cheyenne-Kiowa County line is associated with the contact of the Pierre Shale overlying the Smoky Hill Marl Member. A bedrock high, hence a thinly saturated layer, is indicated by the quality of water from well C12–44–15ccc in northern Cheyenne County. The high sulfate content of the water in Kiowa County can be attributed to the Smoky Hill Marl Member.

Figure 5 shows the relation of chemical quality to saturated thickness. In general the quality of the ground water, as indicated by specific conductance, improves with an increase in saturated thickness.

RELATION OF WATER QUALITY AND USE

Water from the Ogallala Formation in eastern Cheyenne and Kiowa Counties is of generally fair to good quality for most uses. Water-quality criteria vary according to use and are presented below.

DOMESTIC

Water for domestic use should be clear; colorless; free of objectionable odors, tastes, and disease-causing micro-organisms; at a reasonable temperature. Several of the State health departments have established quality standards, but the only nationwide standards for potable water are those established by the U.S. Public Health Service (1962). These standards, first enacted in 1914 and revised in 1925,

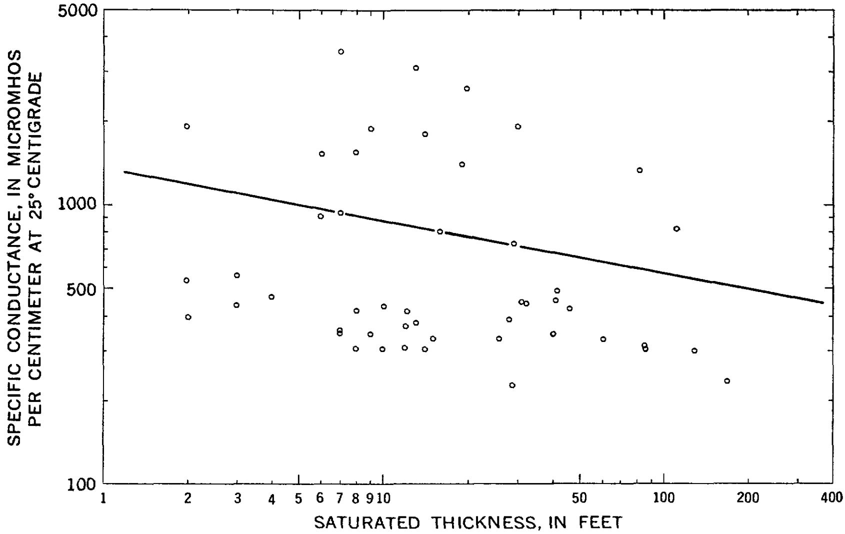

FIGURE 5.—Relation of chemical quality of water, as indicated by specific conductance, to the saturated thickness of the Ogallala Formation.

1942, 1946, and 1962, apply strictly to culinary water used in vehicles engaged in interstate commerce. The American Water Works Association has adopted these standards as recommended limits for all public water supplies. Standards for some of the chemical constituents are listed below:

Allowable limits for public water supply

Constituent	*Concentration (ppm)*
Iron (Fe)	0.3
Manganese (Mn)	.05
Chloride (Cl)	250
Sulfate (SO_4)	250
Fluoride (F)	[1] 1.5
Dissolved solids	[2] 500

[1] Latest recommendations (1962) give lower, optimum, and upper control limits for fluoride based on the annual average of maximum daily air temperatures. For the study area, these limits are 0.7 ppm (lower), 0.9 ppm (optimum), and 1.2 ppm (upper). Fluoride concentrations greater than twice the optimum limit constitute grounds for rejection of the supply.

[2] If no other supply is available, 1,000 ppm is permitted.

Whereas few permanently disabling diseases other than diseases of bacterial origin are attributable to water, concentrations of chemical constituents that exceed the recommended limits are undesirable for domestic use. High magnesium concentrations in combination with sulfate (epsom salts) have laxative effects. Excess chloride imparts a characteristic salty taste to water. Although fluoride in water at concentration of about 1.0 ppm has been shown to prevent dental caries (Dean, 1936), greater concentrations give rise to chronic fluorosis of bone tissue and teeth. The condition appears as mottled enamel in the teeth. Nitrate in excess of 45 ppm (U.S. Public Health

Service, 1962) is particularly hazardous in infants causing methemogolbinemia or cyanosis. Excessive nitrate may be an indication of contamination from sewage, decaying vegetation, or fertilizers.

Hardness in water which is manifiested by the formation of soap curd or scum, is caused principally by calcium and magnesium. Other constituents such as boron, strontium, aluminum, iron, and free acid, if present, also contribute to hardness. The ratings of hardness are subject to variation, and the following table establishes the U.S. Geological Survey's (S. K. Love, written commun., 1962) hardness classification of water.

Hardness (ppm)	*Rating*
<60	Soft.
61–120	Moderately hard.
121–180	Hard.
>181	Very hard.

The hardness of ground water sampled in the study area ranges from moderately hard to very hard.

STOCK

An intensive literature search has revealed very little data on which to establish criteria for rating water for stock use. Although animals are able to tolerate water having higher dissolved-solids concentrations than man, water that meets the standards for domestic use should be used for maximum production. Drinking highly mineralized water for prolonged periods may result in physiological disturbances such as wasting, gastrointestinal disturbances, and disease, and may eventually cause the death of the animal. Other effects are reduction in lactation and in rate of reproduction.

The Department of Agriculture and Government chemical laboratories in Western Australia (1950) listed the following threshold salinity (dissolved solids) concentrations:

	Threshold salinity (ppm)
Poultry	2, 860
Swine	4, 290
Horses	6, 440
Cattle, dairy	7, 150
beef	10, 000
Sheep, adult dry	12, 900

The State of Colorado (Storey, oral commun., 1961) recommends that water containing no more than 2,500 ppm of dissolved solids is acceptable for stock. Montana (Storey, oral commun., 1961) rates water containing less than 2,500 ppm of salts as good, 2,500–3,500 ppm as fair, 3,500–4,500 ppm as poor, and more than 4,500 ppm as unfit. Apart from total salt concentrations, certain salts—particularly the nitrates, fluorides, and salts of selenium and molybdenum—are specifically toxic to animals even in low concentrations.

The critical factor in the animal's metabolism, however, is the total quantity of salts ingested. Salt intake depends on the daily water consumption which, in turn, depends on the water content of feed, the temperature and humidity, and the degree of exertion of the animal. Using Colorado's limit of 2,500 ppm of dissolved solids, ground water in the area would be rated as acceptable for stock use.

IRRIGATION

Although eastern Cheyenne and Kiowa Counties are primarily a dryland-farming area, some irrigation with ground water is possible in parts of the area.

The success or failure of any irrigation project depends on the quality of the water applied. Interpretation of water quality in relation to irrigation has been largely based on field observations and studies of plant tolerances. However, recent investigations by Eaton (1954), the U.S. Salinity Laboratory Staff (1954), and others are providing better understanding of the subject.

The suitability of water for irrigation is determined by the total salt concentration, the concentration ratios of certain salts, the chemical reactions between the salts in the applied water and the soil, and the increase in soil-salt concentration after application of the water. Water rated as good for irrigation may, with poor irrigation practices, cause deterioration and eventual destruction of the soil. Conversely, poor water applied in sufficient quantity on well-drained soil—so that injurious concentrations of salt are leached beyond the root zone—and the use of soil amendments may maintain good productivity and cause little damage to the soil.

The calcium to sodium ratio in irrigation water must be considered because of ion-exchange reactions in the soil. Water that is high in sodium in relation to calcium, if applied to soils that contain silt, fine clay, or organic fractions, may cause alkalinization of the soil, which would result in poor tilth. In general, however, the sodium concentration must be over half the soluble cations before exchange is significant. Because the exchange equilibrium favors calcium in the reaction, water that is high in calcium relative to sodium will maintain soil permeability and texture.

The U.S. Salinity Laboratory Staff (1954) made a diagram for rating irrigation water on the basis of salinity and sodium (alkali) hazards. The diagram, figure 6, is interpreted by the U.S. Salinity Laboratory Staff (p. 75–81) as follows:

Salinity hazard

* * * * * * *

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-Salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium [*hazard*]

The classification of irrigation waters with respect to *SAR* is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

* * * * * * *

In the classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of crop. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality.

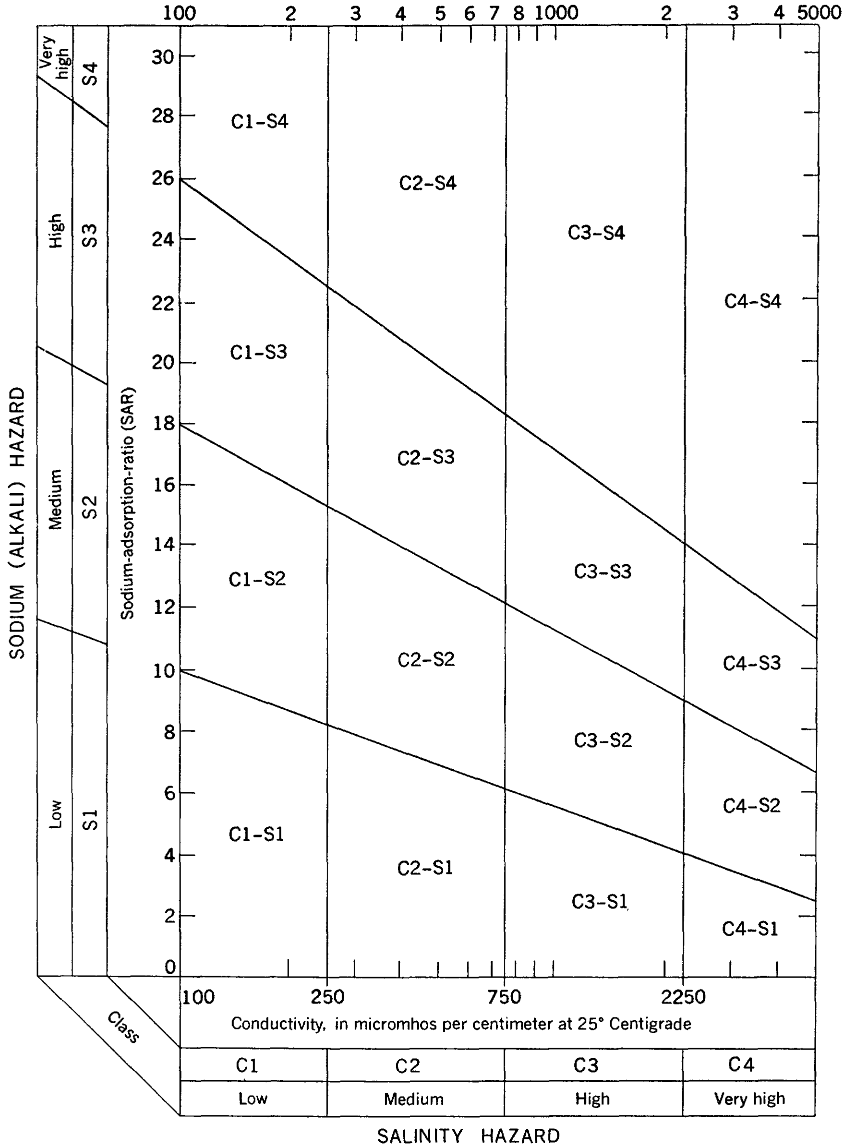

Figure 6.—Diagram by U.S. Salinity Laboratory Staff for classification of irrigation water.

The suitability, for irrigation, of ground water in eastern Cheyenne and Kiowa Counties is summarized in table 4. Most of the waters are classified as having a medium salinity hazard and a low sodium (alkali) hazard.

Evapotranspiration, percentage of water drained from the root zone, and harvesting practice result in a soil solution that is many times more concentrated than the applied irrigation water. To keep irrigation agriculture productive, salts must be prevented from accumulating in the soil by the application of sufficient quantities of water so that leaching of the soil carries excess salts beyond the root zone. However, application of excessive amounts of water results in waste, in leaching of required plant nutrients, and possibly in drainage problems.

TABLE 4.—*Suitability, for irrigation, of ground water from the Ogallala Formation*

Well	Specific conductance micro (mhos per cm at 25°C)	Sodium-adsorption ratio	Classification	Residual sodium carbonate (epm)	Boron (ppm)
C12-43-14ddc	434	0.6	C2-S1	0.0	0.10
44-13ccc	497	2.2	C2-S1	.88	---
44-15ccc	1,950	2.9	C3-S1	.0	---
45-16ccc	473	2.6	C2-S1	1.79	.19
46-7bbb	385	.7	C2-S1	.0	---
47-23aad	532	.4	C2-S1	.0	---
48-5dac	304	.6	C2-S1	.0	---
48-14dcd	508	.7	C2-S1	.0	---
50-9dad	511	1.0	C2-S1	.30	---
C13-42-3ccb	326	.4	C2-S1	.10	---
42-6bcc	334	.6	C2-S1	.0	---
43-36baa	308	.8	C2-S1	.40	.07
44-19aab	225	.2	C1-S1	.0	.05
44-21aac	298	.7	C2-S1	.22	---
45-20aba	799	.7	C3-S1	.0	.14
C14-43-6cdd	332	.8	C2-S1	.22	.74
43-12acc2	458	1.4	C2-S1	.0	---
43-12bba	423	1.1	C2-S1	.0	---
44-18dab	337	.5	C2-S1	.0	---
44-20bcc	312	.3	C2-S1	.0	---
45-16ccc	302	.8	C2-S1	.39	.08
46-22dad	928	1.2	C3-S1	.0	.14
C15-42-2aba	390	.7	C2-S1	.0	.14
42-34aad	423	1.0	C2-S1	.20	---
44-10bbb	486	2.2	C2-S1	.78	---
45-11ccb	561	1.2	C2-S1	.0	---
45-30bbd	430	1.0	C2-S1	.0	---
46-12daa	958	1.6	C3-S1	.0	---
46-28dba	620	.5	C2-S1	.0	---
C16-41-18ddc	399	.7	C2-S1	.0	---
42-5ccc	383	.7	C2-S1	.0	---
42-18cbb	333	.5	C2-S1	.0	---
43-1cbc	316	.6	C2-S1	.27	---
43-21bbb	347	.9	C2-S1	.0	---
43-26bba	335	.8	C2-S1	.15	---
44-8bcc	421	1.0	C2-S1	.22	---
C17-42-1bcb	464	1.2	C2-S1	.0	---
42-12dbb	602	1.2	C2-S1	.0	---
42-13cbb	514	.5	C2-S1	.0	---
42-32abb	811	1.2	C3-S1	.0	.19
43-14aad	628	.9	C2-S1	.0	---
43-16cdb	532	.5	C2-S1	.0	---
43-17ccc	715	1.6	C2-S1	.20	---
43-18bba	484	.3	C2-S1	.0	---
44-4cda	343	.8	C2-S1	.04	.90
44-8ccc	1,510	2.1	C3-S1	.0	---
44-12dad	388	.6	C2-S1	.0	---
44-26ddd	1,930	1.9	C3-S1	.0	---
C18-42-25abd	1,870	2.8	C3-S1	.0	---
43-25abb	3,100	2.2	C4-S1	.0	---
C19-42-15baa	2,630	3.0	C4-S1	.0	.63
44-14dda	3,560	5.7	C4-S2	.0	---
C20-41-30add	1,330	2.6	C3-S1	.0	---
42-13cbc	840	1.2	C3-S1	.0	.20
42-36cdc	930	2.0	C3-S1	.0	30

Eaton (1954) proposed a method for calculating (1) the percentage of irrigation water that should be applied in excess of plant requirements to leach salts so that reasonable crop yields (70–80 percent of the yields on nonsaline land) are attained and (2) the amount of calcium, as gypsum, that should be added to irrigation water or applied to the land to keep the sodium concentration at not more than 70 percent of the soil solution leaving the root zone.

Estimations both of the leaching percentages for reasonable and good yields and of the required calcium have been made, by use of Eaton's formulas shown below, for ground water in the study area.

Formulas for estimating leaching and gypsum requirements of irrigation waters

[After Eaton, 1954]

The designations used in the formulas are as follows:

Sw, Salinity of irrigation waters expressed as milliequivalents per liter (or equivalents per million) of Cl plus $\frac{1}{2}SO_4$.

d percent and *D* percent, Tentative (*d*) and final (*D*) percentage of applied irrigation water passed through the root zone as drainage.

Mss, Salinity of mean soil solution measured as milliequivalents per liter of Cl plus $\frac{1}{2}SO_4$. The value 40 is taken as an *Mss* concentration that is expected to produce reasonable yields, and 20 should produce good yields of crops that are of intermediate salt tolerance and that are grown in a semiarid climate, such as Riverside, Calif.

Required leaching—tentative:

$$\frac{Sw \times 100}{(2 \times Mss) - Sw} = d \text{ percent or } \frac{Sw \times 100}{(2 \times 40) - Sw} = d \text{ percent}$$

Calcium requirements—Ca, in milliequivalents per liter:

To adjust water to 70 percent Na:

$(Na \times 0.429) - (Ca + Mg) = Ca$ (retain plus or minus sign when carried to equation 4)

To offset HCO_3 precipitation: (1)

$$\frac{HCO_3(100 - d \text{ percent})}{100} = Ca \qquad (2)$$

$$\frac{0.30(100 - d \text{ percent})}{(100)} = Ca \qquad (3)$$

Total Ca: (1) + (2) + (3) (4)

Multiply total Ca by 234 to get pounds of gypsum per acre-foot of irrigation water.

Required leaching—final:

$$\frac{Sw \times 1/2 \text{ total Ca} \times 100}{(2 \times Mss) - (Sw + 1/2 \text{ total Ca})} = D \text{ percent}$$

These values, shown in table 5, are tentative because an assumed value for mean soil-solution salinity was used in the calculations. Measurements in the field should be made to arrive at final values of leaching percentage and calcium requirements.

Eaton (1950), in a study of black alkali soils, defined the concept of residual sodium carbonate as the excess of bicarbonate over calcium plus magnesium, expressed in milliequivalents per liter (meq per l).

He pointed out that when water contains residual sodium carbonate, calcium and magnesium are precipitated in the soil and there is a corresponding increase in the SAR of the water. Therefore, even though sodium is originally not the predominant cation, it becomes so, and an increase in the sodium hazard of irrigation water results. Water that contains residual sodium carbonate in excess of 2.5 meq per l is classified as unfit for irrigation. Water having from 2.5 to 1.3 meq per l is marginal, and water having less than 1.3 meq per l is safe. Marginal water may be safely used with proper use of soil amendments and good management practices.

TABLE 5.—*Leaching and gypsum requirements of ground water from the Ogallala Formation*

[E indicates excess of gypsum present; N indicates none]

Well	Reasonable yields		Good yields	
	Leaching requirement (D percent)	Gypsum requirement (lb per acre-ft)	Leaching requirement (D percent)	Gypsum requirement (lb per acre-ft)
C12-43-14ddc	1.1	147	2.1	143
44-13ccd	2.5	529	5.7	576
44-15ccc	16	E	24	E
45-16ccc	2.7	756	5.5	751
46-7bbb	1.0	136	1.9	129
47-23aad	1.2	E	2.5	E
48-5dac	.8	105	1.9	180
48-14dcd	1.5	E	3.1	E
50-9dad	1.4	271	2.8	267
C13-42-3ccb	.8	147	1.7	145
42-6bcc	.8	133	1.5	129
43-36baa	.9	246	1.9	243
44-19aab	.3	73	.7	77
44-21aac	.9	197	1.8	201
45-20aba	1.2	37	2.3	19
C14-43-6cdd	.9	206	1.9	206
43-12acc2	1.7	133	3.4	122
43-12bba	1.5	105	2.9	96
44-18dab	.6	75	1.7	150
44-20bcc	.5	96	.9	97
45-16ccc	.9	243	1.9	246
46-22dad	4.4	E	9.3	E
C15-42-2aba	1.1	152	2.1	147
42-34aad	1.3	238	2.7	234
44-10bbb	3.2	735	5.2	487
45-11ccb	1.9	E	4.0	E
45-30bbd	1.4	176	2.9	166
46-12daa	6.0	E	13	E
46-28dba	1.1	E	3.1	E
C16-41-18ddc	1.0	N	2.0	E
42-5ccc	1.0	73	2.0	66
42-18cbb	.6	80	1.3	77
43-1cbc	.8	208	1.7	208
43-21bbb	1.5	E	2.7	E
43-26bba	1.6	234	3.3	222
44-8bcc	1.3	248	2.7	243
C17-42-1bcb	1.9	58	3.8	47
42-12dbb	2.4	E	5.0	E
42-13cbb	1.3	E	2.7	E
42-32abb	3.2	E	6.4	E
43-14aad	.6	E	2.7	E
43-16cdb	1.0	E	2.0	E
43-17ccc	2.5	356	5.0	335
43-18bba	.9	E	1.8	E
44-4cda	.9	168	1.8	164
44-8ccc	10	E	26	E
44-12dad	.9	94	1.7	N
44-26ddd	14	E	34	E
C18-42-25abd	15	E	36	E
43-25abb	17	E	89	E
C19-42-15baa	25	E	74	E
44-14dda	35	E	110	E
C20-41-30add	8.9	E	20	E
42-13cbc	2.4	E	4.8	E
42-36cdc	5.1	E	11	E

Class limits for boron concentrations in water are shown below:

Limits, in parts per million

Class	Sensitive crops	Semitolerant crops	Tolerant crops	Description
1	0. 33	0. 67	1. 00	Very low. No effect on crops.
2	0. 33–0. 67	0. 67–1. 33	1. 00–2. 00	Low. Very slight effect on crops.
3	0. 67–1. 00	1. 33–2. 00	2. 00–3. 00	Moderate. Significant yield depression.
4	1. 00–1. 25	2. 00–2. 50	3. 00–3. 75	High. Large yield depression anticipated.
5	1. 25	2. 50	3. 75	Very high. Nonusable.

Boron concentrations in ground water from several wells in the study area shown in table 4, indicate no effect to very slight effect on crops grown in the area.

WATER-BEARING PROPERTIES OF THE GEOLOGIC FORMATIONS

The water-bearing properties of the different geologic formations vary widely in the project area. The principal source of water is the Ogallala Formation. The water-bearing properties of each of the exposed geologic formations in the project area are discussed below.

SMOKY HILL MARL MEMBER OF THE NIOBRARA FORMATION

Because it is practically impermeable, the Smoky Hill Marl Member prevents downward movement of ground water. The Smoky Hill imparts fair quality to the water that overlies it; as shown in the "Quality of water" section, it contributes to the water a high sulfate content. The Smoky Hill is not known to yield water to wells in the project area.

PIERRE SHALE

The Pierre Shale is practically impermeable and does not allow downward movement of water. The quality of water that moves laterally over the Pierre is generally fair to good. In comparison to the Smoky Hill, the Pierre does not contribute as much mineral content to the overlying water, and the quality of the water therefore is better. The Pierre is not known to yield water to wells in the project area. The weathered material at the top of the Pierre, where it is exposed, probably contains small quantities of water.

OGALLALA FORMATION

The Ogallala Formation acts as a reservoir for ground water in the High Plains district, and it is the principal source of water in the project area. The aquifer contains water of fair to good quality, depending on the saturated thickness. Well C12–44–15ccc penetrates a thin saturated zone and is underlain by the Pierre Shale, and the water yielded by this well is poorer in quality than that in the area where the saturated material is thicker. The Ogallala yields water to stock and domestic wells almost everywhere in the High Plains district. Yields of as much as 2,200 gpm are possible in the Ogallala Formation in areas of high permeability and thick sections of saturated materials. Areas of thick saturated material, as shown on plate 3, are logical places to drill irrigation or large-capacity wells, as high permeability usually correlates with thick saturated sections in the project area.

ALLUVIUM

The alluvium receives and transmits water readily; it does not contain much water in storage, however, and water levels usually decline after extended dry periods. The quality of the water ranges from fair to poor and depends on the type of underlying bedrock and the thickness of saturation. The alluvium is generally above the water table in the High Plains district and does not yield water to wells. In the Big Sandy district, the alluvium overlies bedrock, and wells yield small quantities of water for stock and domestic use.

REFERENCES CITED

Boettcher, A. J., 1962, Records, logs, and water-level measurements of selected wells and test holes and chemical analyses of ground water in eastern Cheyenne and Kiowa Counties, Colorado: Colorado Water Conserv. Board Basic-Data Rept. 13, Ground-Water Ser.

——— 1963, Prospects for irrigation in eastern Cheyenne and Kiowa Counties, Colorado: Colorado Water Conserv. Board Circ. 7, Ground-Water Ser., 12 p.

Cardwell, W. D. E., 1953, Irrigation-well development in the Kansas River basin of eastern Colorado: U.S. Geol. Survey Circ. 295, 72 p.

Colorado Department of Agriculture in cooperation with the U.S. Department of Agriculture, 1961, Colorado agricultural statistics 1959–1960: v. 3, no. 1, 119 p.

Darton, N. H., 1905, Preliminary report on the geology and underground water resources of the central Great Plains: U.S. Geol. Survey Prof. Paper 32, 433 p.

Dean, H. T., 1936, Chronic endemic dental fluorosis: Am. Med. Assoc. Jour., v. 107, p. 1269–1272.

Eaton, F. M., 1950, Significance of carbonates in irrigation waters: Soil Science, v. 69, p. 123–133.

——— 1954, Formulas for estimating leaching and gypsum requirements of irrigation waters: Texas Agr. Expt. Sta. Misc. Pub. 111.

Elias, M. K., 1931, The geology of Wallace County, Kansas: Kansas Geol. Survey Bull. 18, 254 p.

Hay, Robert, 1895, Water resources of a portion of the Great Plains: U.S. Geol. Survey 16th Ann. Rept., pt. 2, p. 535–588.

Johnson, W. D., 1901, The High Plains and their utilization: U.S. Geol. Survey 21st Ann. Rept., pt. 4, p. 601–741.

——— 1902, The High Plains and their utilization [sequel]: U.S. Geol. Survey 22d Ann. Rept., pt. 4, p. 631–669.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p.

U.S. Public Health Service, 1962, Drinking water standards: U.S. Public Health Service Pamph. 956.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agriculture Handb. 60, 160 p.

Western Australia Department of Agriculture, 1950, Waters for agricultural purposes in Western Australia: Perth, Western Australia, Western Australia Jour. Agriculture, v. 27, ser. 2, p. 156.

○

The U.S. Geological Survey Library has cataloged this publication as follows:

Boettcher, Arnold J 1933–

Geology and ground-water resources in eastern Cheyenne and Kiowa Counties, Colorado. With a section on Chemical quality of the ground water, by C. Albert Horr. Washington, U.S. Govt. Print. Off., 1964.

iv, 32 p. maps (3 folds. in pocket) diagrs., tables. 24 cm. (U.S. Geological Survey. Water-supply paper 1779–N)

Contributions to the hydrology of the United States.

Prepared in cooperation with the Colorado Water Conservation Board.

(Continued on next card)

Boettcher, Arnold J 1933– Geology and ground-water resources in eastern Cheyenne and Kiowa Counties, Colorado. 1964. (Card 2)

Bibliography: p. 31–32.

1. Geology—Colorado. 2. Water-supply—Colorado. 3. Water, Underground—Colorado. 4. Water—Composition. I. Colorado. Water Conservation Board. II. Horr, Clarence Albert, 1922– Chemical quality of the ground water. III. Title. (Series)