# Reconnaissance of the Ground-Water Resources in Parts of Larimer, Logan Morgan, Sedgwick, and Weld Counties, Colorado

By WILLIAM G. WEIST, JR.

*With a section on* THE CHEMICAL QUALITY OF THE WATER

*By* ROBERT BRENNAN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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# RECONNAISSANCE OF THE GROUND-WATER RESOURCES IN PARTS OF LARIMER, LOGAN, MORGAN, SEDGWICK, AND WELD COUNTIES, COLORADO

By William G. Weist, Jr.

## ABSTRACT

The area described in this report includes about 3,600 square miles in parts of Larimer, Logan, Morgan, Sedgwick, and Weld Counties, Colo. It includes the drainage basins of Crow, Cedar, and Pawnee Creeks. Most of the land is flat to gently rolling; in places it is deeply incised by streams. An escarpment across most of the northern part is the boundary between the Colorado Piedmont and the High Plains.

Exposed rocks range in age from Pennsylvanian to Quaternary. The older sedimentary rocks, which are exposed only in the extreme western part, dip steeply eastward and lie at great depths beneath the central and eastern parts and are not generally considered to be sources of potable water. The Upper Cretaceous Pierre Shale is the oldest formation that is considered to be a major source of water in the area. The Pierre Shale, Fox Hills Sandstone, and Laramie Formation yield as much as 300 gpm (gallons per minute) to artesian wells. The White River Group of Oligocene age generally yields about 30 gpm to wells but yields larger amounts in places where it is highly fractured. The Pliocene Ogallala Formation yields as much as 50 gpm to wells across the northern part. As much as 1,500 gpm is available from the unconsolidated Quaternary deposits.

The principal use of ground water is for stock and domestic purposes. Irrigation is practiced chiefly near Hereford and Barnesville, although there are several other small areas of irrigation. Grover, Keota, and Peetz have municipal water systems. The main industrial use of ground water is waterflooding in the oil fields of Logan, Morgan, and Weld Counties.

Water from the Pierre Shale and Laramie Formation has a relatively high concentration of sodium bicarbonate; water from the Fox Hills is high in sodium bicarbonate or sodium sulfate; water from the White River Group is usually high in calcium bicarbonate, although water from the lower part of the formation is usually high in sodium bicarbonate; and water from the Ogallala Formation is high in calcium bicarbonate. Water from the unconsolidated deposits has a wide range in concentration of all constituents. Nearly all the water is suitable for stock and domestic use.

# INTRODUCTION

## PURPOSE OF THE STUDY

A reconnaissance of the ground-water resources of parts of Larimer, Logan, Morgan, Sedgwick, and Weld Counties, Colo., was begun in July 1962, as a part of the program of ground-water investigations being made in Colorado by the U.S. Geological Survey in cooperation with the Colorado Water Conservation Board. The purpose of the study was to determine the present (1962) extent of ground-water development and the chemical quality of the water from the various aquifers, to predict the possibility for future development of large ground-water supplies, and to determine if problems concerning ground water require more detailed investigation.

## PREVIOUS INVESTIGATIONS

One of the earliest reports on the geology and ground-water resources of the region that includes this area was Darton's (1905) report on the central Great Plains. The geology and petroleum prospects of the area were discussed by Mather, Gilluly, and Lusk (1928). A reconnaissance of the ground-water resources of parts of the area was made by Babcock and Bjorklund (1956) and by Bjorklund (1957a). Reports concerning adjacent or nearby areas include those of Rapp, Warner, and Morgan (1953), Bjorklund and Brown (1957), Bjorklund (1957b, 1959), Smith, Schneider, and Petri (1964), and Hershey and Schneider (1964).

## METHODS OF INVESTIGATION

Fieldwork was done in July and August 1962 by F. L. Doyle, T. D. Mundorf, and the writer, and in April and May 1963 by the writer. Locations to the nearest 10-acre tract were determined by odometer for most of the wells that were drilled since 1955 and for which drillers' reports are available. When feasible, the depth to water, yield, and chemical quality of the water were checked. Wells inventoried for earlier reports were also measured, and some wells for which no previous records were available were inventoried.

Subsurface data were collected from records of petroleum company shotholes and from records of test holes drilled for the U.S. Air Force. Records of wells, logs of wells and test holes, and results of chemical analyses were published by the Colorado Water Conservation Board (Weist, 1964).

The geologic map was compiled mainly from other maps. When other maps were not available or where they lack sufficient detail, areas were mapped by means of aerial photographs. Data were compiled on a base at a scale of 1:250,000 and spot checked in the field.

## WELL-NUMBERING SYSTEM

The well-numbering system used in Colorado is based on the U.S. Bureau of Land Management system of land subdivision. The number shows the location of the well or test hole by township, range, section, and position within the section. A graphic illustration of this method of well location is shown on figure 1. 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 meridian—A, indicates the northeast quadrant; B, the northwest quadrant; C, the southwest quadrant; and D, the southeast quadrant. All wells, springs,

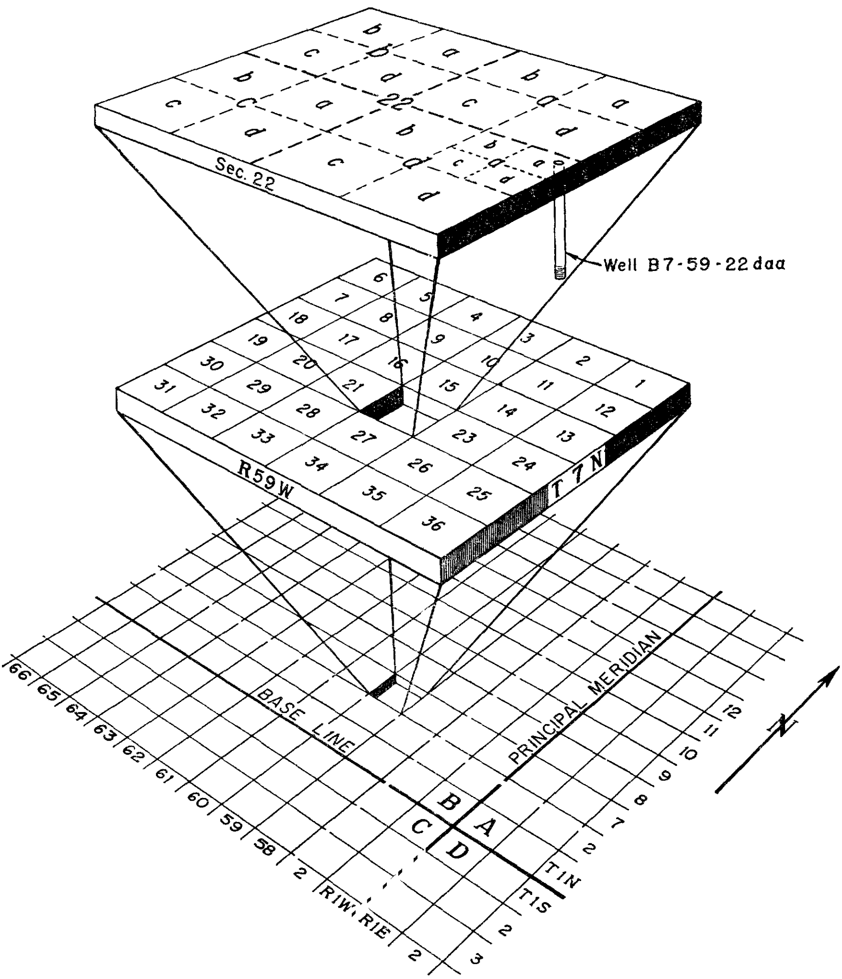


FIGURE 1.—System of numbering wells and test holes in Colorado.

and test holes in this report are located in the northwest or B quadrant. The first numeral indicates the township, the second indicates the range, and the third indicates the section in which the well is situated. Lowercase letters following the section number locate the well within the section. The first letter denotes the quarter section, the second letter denotes the quarter-quarter section, and the third letter denotes the quarter-quarter-quarter section. The letters are assigned in a counterclockwise direction, beginning with (a) in the northeast quarter of the section. Letters are assigned to each quarter-quarter section and each quarter-quarter-quarter section in the same manner. For example, B11–48–22dab indicates a well in the northwest quarter of the northeast quarter of the southeast quarter of sec. 22, T. 11 N., R. 48 W. If more than one well occurs in a quarter-quarter-quarter section, consecutive numbers beginning with 2 are added to the letters.

## ACKNOWLEDGMENTS

The cooperation of the residents, who willingly provided data on their wells, is gratefully acknowledged. Logs of test holes and seismograph shotholes were obtained from the following: U.S. Army Corps of Engineers, British-American Oil Producing Co., California Oil Co., Continental Oil Co., Gulf Oil Corp., Pan American Petroleum Corp., Sinclair Oil and Gas Co., and Superior Oil Co. Shell Oil Co. provided aquifer-test data for several of their water wells.

## GEOGRAPHY

### LOCATION OF THE AREA

The area studied consists of about 3,600 square miles in northeastern Colorado (fig. 2). It includes most of the State north of the South Platte River and east of the Rocky Mountain foothills and the Cache la Poudre River drainage.

### TOPOGRAPHY AND DRAINAGE

The project area lies in the Great Plains physiographic province. Most of it is part of the Colorado Piedmont section, but a narrow strip across the north edge is part of the High Plains section. The land is generally flat to gently rolling. An escarpment across the northern part is the boundary between the Colorado Piedmont and the High Plains. The altitude of the land surface ranges from about 3,600 feet along the South Platte River valley at the east end to more than 7,000 feet in the northwest corner—about 3,400 feet of relief.

Most of the area is drained by tributaries of the South Platte River. The principal streams (Crow, Pawnee, and Cedar Creeks) are generally intermittent. In places, they are deeply cut into the land surface.

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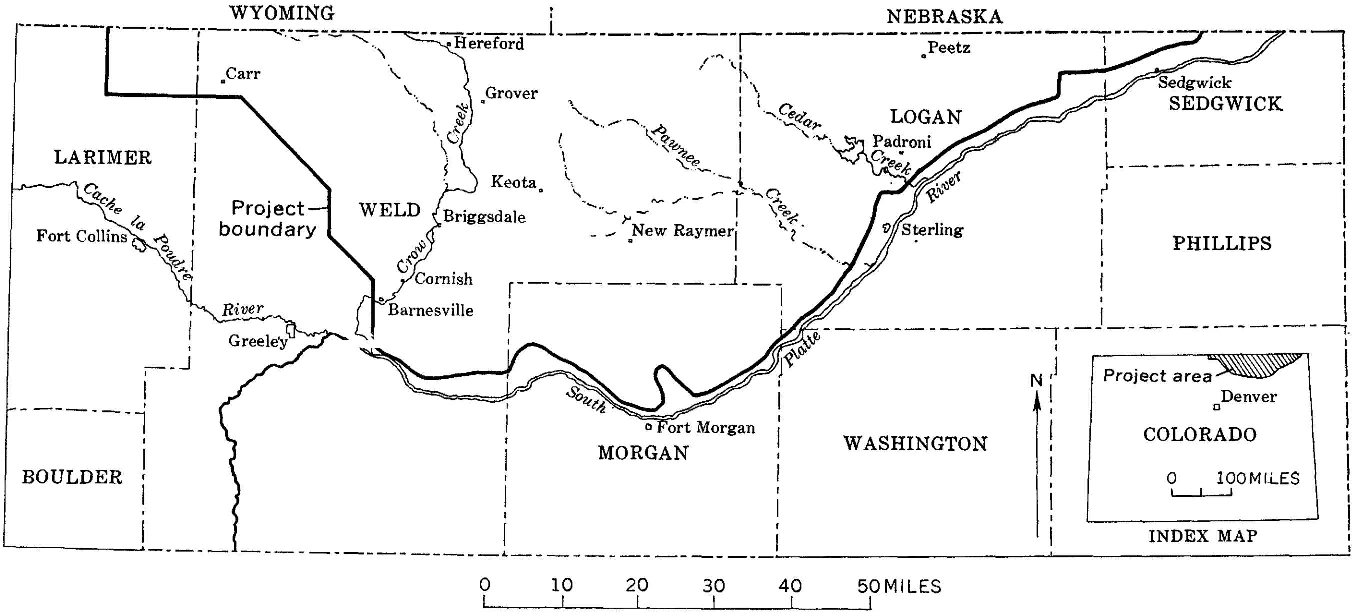


FIGURE 2.—Location of the project area.

## CLIMATE

The climate is semiarid to arid; from 1923 to 1960 the average annual precipitation ranged from 17.18 inches at Sedgwick to 11.12 inches at Greeley. For the same period at both stations the mean annual temperature is about 48° F, the mean maximum annual temperature is about 64° F, and the mean minimum annual temperature is about 33° F. Precipitation and temperature, as measured 10 miles west of Grover, are given in figure 3. The growing season averages 144 days and extends from early May to the end of September.

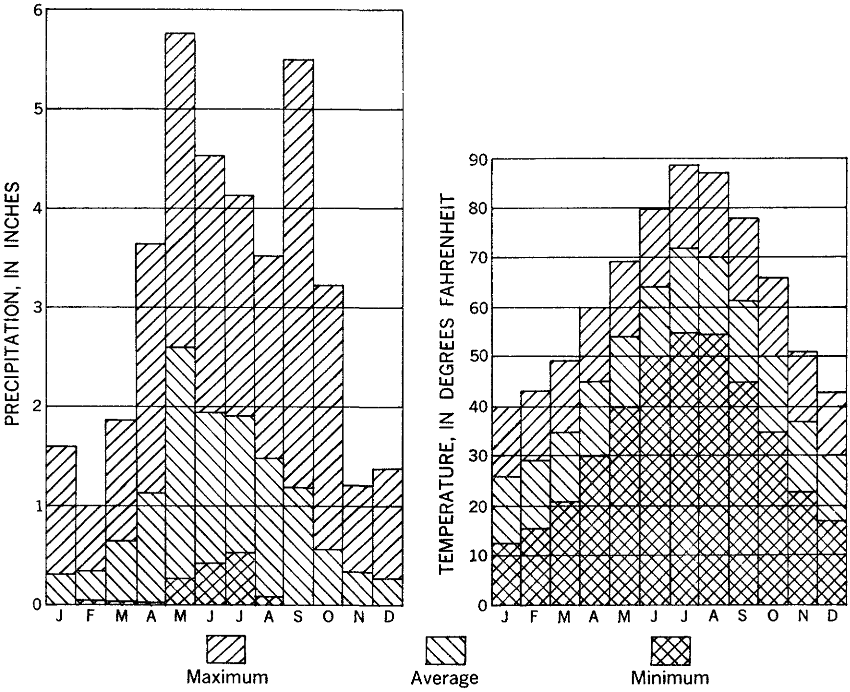


FIGURE 3.—Minimum, average, and maximum monthly precipitation and temperature measured 10 miles west of Grover, Colo., 1931–52.

## ECONOMY

The economy is based chiefly on agriculture. Grazing and dryland farming are practiced throughout most of the area; irrigation farming is concentrated near Hereford and Barnesville, although some pump irrigation is practiced elsewhere.

The petroleum industry is the other large contributor to the economy; numerous wells produce oil in parts of Logan, Morgan, and Weld Counties.

## GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

The properties of the geologic units exposed are summarized in table 1, and their outcrops are shown on the geologic map (plate 1). The Cretaceous deposits in parts of southwestern Logan, northern Morgan, and southeastern Weld Counties are overlain by as much as 70 feet of unmapped unconsolidated deposits. The approximate area of these deposits, as determined from drillers' logs, is shown on plate 1.

The Cretaceous and older rocks generally dip westward. In the western part of the area, however, they dip steeply eastward (Mather, Gilluly, and Lusk, 1928, p. 102). The unconsolidated Tertiary and younger rocks are flat-lying or dip gently eastward.

### UNDIFFERENTIATED PALEOZOIC AND MESOZOIC ROCKS

Rocks older than the Pierre Shale crop out along the west edge of the project area in a strip about 3 miles wide. They include (from oldest to youngest) the Lyons Sandstone, Satanka Shale, Lykins Formation, Jelm Formation, Entrada Sandstone, Morrison Formation, Lytle Formation, South Platte Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, and the Niobrara Formation.

These formations crop out in only a small part of the area and lie at great depths in the rest. Most of the formations are probably not aquifers, and no attempt was made to study their water-bearing properties. The Satanka Shale and the Lytle and South Platte Formations, however, are reported to yield small quantities of water to wells near the outcrop areas (Schneider and Hershey, 1961, p. 5–6).

### CRETACEOUS SYSTEM

#### UPPER CRETACEOUS SERIES

##### PIERRE SHALE

The Pierre Shale consists of a thick sequence of fossiliferous marine shale, silt, and clayey sandstone, which contains numerous calcareous concretions. The shale is generally dark gray to black, and the silt is generally bluish black. In most places, the upper few feet has weathered to yellow-brown clay. The clayey sandstone is tan to yellow brown, is loosely to moderately cemented, and is generally only a few feet thick. The upper part of the formation is transitional with the overlying Fox Hills Sandstone. The Pierre may be as much as 7,000 feet thick. It crops out in Larimer County and along drainages in parts of Logan and Morgan Counties. Much of the outcrop, shown on plate 1, is covered by unconsolidated deposits. Mather, Gilluly, and Lusk (1928, p. 86–92) and Bjorklund and Brown (1957, p. 19–21), among others, discuss the Pierre in more detail.

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

| System | Series | Geologic unit | | Thickness (feet) | Physical character | Water-bearing properties |
|---|---|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | Unconsolidated deposits | Dune sand | 0–50± | Very fine to medium sand and silt. | Not known to yield water to wells. Serves as an infiltration area for recharge. |
| | | | Valley-fill deposits | 0–100± | Gravel, sand, silt, and clay; mixed and interbedded. | Yield adequate quantities of water to stock and domestic wells in most of the area. In places yield as much as 1,500 gpm to irrigation wells. |
| | | | Terrace deposits | 0–120± | Gravel, sand, silt, and clay; mixed and interbedded. Identified only in a small area near Hereford. | Yield as much as 1,200 gpm to irrigation wells. |
| Tertiary | Pliocene | Ogallala Formation | | 0–180± | Clay, silt, sand, and gravel; contains some caliche; poorly to well cemented. In places has a coarse conglomerate at the base. | Yields small to moderate quantities of water to domestic and stock wells and springs. |
| | Miocene | Arikaree Formation | | 0–80± | Fine- to medium-grained, loose to moderately cemented sandstone; contains hard calcareous lenses and pipings. | May yield small quantities of water to stock and domestic wells. |
| | Oligocene | White River Group | | 0–600± | Blocky variegated clay and siltstone; contains loose to moderately cemented sand. In places contains hard channel sandstone. | Yields adequate quantities of water to stock and domestic wells and springs in most of the area. In places yields as much as 1,400 gpm (reported) to irrigation wells. |
| Cretaceous | Upper Cretaceous | Laramie Formation | | 0–600± | Silty to sandy, yellow-brown and gray to olive-gray carbonaceous shale; limonite stained; interbedded with shaly sandstone; contains lignite, and coal. | Yields small to moderate quantities of water to stock and domestic wells and springs. |
| | | Fox Hills Sandstone | | 0–400± | Fine- to medium-grained, yellow-brown sandstone, contains beds of dark-gray to black sandy shale and white massive sandstone. | Do. |
| | | Pierre Shale | | 0–7,000± | Dark-gray to black shale; in places has weathered zone of yellow-brown clay at top; contains lenses and beds of yellow-brown clayey sandstone. | Do. |
| | | Mesozoic and Paleozoic rocks, undifferentiated | | 2,000± | Shale, limestone, and sandstone. | Some units yield small quantities of water to domestic and stock wells and springs in the extreme western part of the area. |

Although the Pierre is usually considered a poor source of water, numerous wells in the project area yield 5 to 30 gpm (gallons per minute) of water from the sandstone and sandy zones. The water is generally under artesian pressure, is soft, and is a sodium bicarbonate solution.

Because of the great thickness of the Pierre, drilling for water below it is not practical.

### FOX HILLS SANDSTONE

The Fox Hills Sandstone is mainly medium yellowish-brown calcareous marine sandstone interbedded with dark-gray to black sandy shale and some massive white sandstone. The sandstone is loosely to moderately cemented and contains concretions. The Fox Hills grades into the underlying Pierre Shale; the contact zone consists of gray sandy shale and shaly sand. The overlying nonmarine Laramie Formation is also transitional, and contains some lignite and other nonmarine beds which occur in the upper part of the Fox Hills. The maximum thickness of the Fox Hills in the project area is about 400 feet. Mather, Gilluly, and Lusk (1928, p. 92–99) and Bjorklund and Brown (1957, p. 21–23), among others, discuss the Fox Hills in more detail.

The Fox Hills crops out in a narrow strip in northeastern Larimer County and along some of the drainageways in eastern Weld and northern Morgan Counties. Much of the outcrop, shown on plate 1, is overlain by unconsolidated deposits.

Although the Fox Hills generally yields less than 15 gpm to wells and springs in the project area, yields as much as 350 gpm from wells have been reported. Except in the outcrop, the water is under artesian pressure. The water is usually hard and is a sodium bicarbonate sulfate solution.

### LARAMIE FORMATION

The Laramie Formation consists mainly of yellow-brown and gray to blue-gray soft carbonaceous shale and clay interbedded with light-gray to yellow-brown sand and shaly sand. It contains some cross-bedded gray to buff sandstone, which is slightly to well cemented, and coal, especially in the lower part. Calcareous limonite concretions occur throughout the formation, and clam shells may be found in the lower part. The Laramie has been partly removed by erosion in much of the area but is as thick as 600 feet. Bjorklund and Brown (1957, p. 23–24) discuss the Laramie in more detail.

The Laramie Formation crops out in eastern Larimer County, across much of western Weld County, and in northwestern Morgan County. Much of the outcrop, shown on plate 1, is covered by unconsolidated deposits.

Throughout most of its extent the Laramie yields 5 to 10 gpm to stock and domestic wells. Where the sandstone beds are thicker, more extensive, and coarser grained, the Laramie yields larger amounts—reportedly as much as 300 gpm—to two irrigation wells in western Weld County. The water is generally under artesian pressure and is a soft sodium bicarbonate solution.

## TERTIARY SYSTEM

### OLIGOCENE SERIES

#### WHITE RIVER GROUP

The White River Group consists predominately of blocky variegated clay and siltstone, which contain beds of loose to moderately cemented fine to coarse sand. In places, the White River contains hard siliceous channel sandstone and conglomerate. In many places the clay is bentonitic. Joints and fissures may penetrate the beds locally, increasing the water-bearing capacity. These fractures may generally be traced on aerial photographs, but they are hard to find on the ground. "Porous zones" in the upper part of the White River that extend under saturated unconsolidated deposits may greatly increase the water-bearing capacity of the beds (McLaughlin, 1948, p. 12–15). Because it is deposited on a highly eroded surface of Cretaceous rocks and has been eroded in turn, the White River differs widely in thickness from place to place. Its maximum thickness in the project area is about 600 feet. It crops out from the foothills eastward to about Sedgwick. A very detailed discussion of the White River Group, including summaries of work by others in nearby areas, may be found in the description of the Frenchman Creek basin by Cardwell and Jenkins (1963, p. 34–40).

The White River Group generally yields as much as 30 gpm to stock and domestic wells and springs. In places where it is either extremely sandy or highly fractured, it reportedly yields as much as 1,400 gpm to irrigation wells. The greatest yields are obtained where fractured White River is overlain by saturated unconsolidated deposits. The water is generally hard and of a calcium bicarbonate solution.

### MIOCENE SERIES

#### ARIKAREE FORMATION

The Arikaree Formation consists of gray to brown fine to medium sandstone that contains hard calcareous lenses and pipings. The sandstone is massive to poorly bedded and loosely to moderately cemented. The Arikaree is exposed only in northwestern Weld County (N. M. Denson, written commun., 1962). It probably does not exceed 80 feet in thickness.

The Arikaree is not known to yield water to wells in the project area; it yields small amounts to wells in adjacent areas, however. (See Babcock and Bjorklund, 1956, and Rapp, Warner, and Morgan, 1953.)

#### PLIOCENE SERIES

##### OGALLALA FORMATION

The Ogallala Formation consists of beds and lenses of stream-deposited gravel, sand, silt, and clay, and contains caliche. In places it contains numerous cobbles, especially in the areas closest to the mountains. The material is loose to well cemented with calcium carbonate; the well-cemented beds are termed "mortar beds" from their resemblance to concrete. The top of the formation is commonly capped by the algal limestone (Elias, 1931, p. 136–141). In places, the formation has a coarse conglomerate at the base. The overall color of the formation ranges from gray to pink.

The Ogallala is exposed across the north edge of the project area. Its southern limit generally forms a prominent escarpment. Because the Ogallala was deposited on an eroded surface, it differs widely in thickness from place to place, but it probably does not exceed 180 feet in the project area.

The Ogallala yields small to moderate quantities of hard water to domestic and stock wells and springs and as much as 50 gpm to wells supplying the town of Peetz. The water is a calcium bicarbonate solution.

### QUATERNARY SYSTEM

#### PLEISTOCENE AND RECENT SERIES

##### UNCONSOLIDATED DEPOSITS

The unconsolidated deposits consist of beds and lenses of gravel, sand, silt, and clay. They generally have an overall gray to brown color. Previous geologists classed some of the deposits as dune sand, alluvium, and terrace deposits (Babcock and Bjorklund, 1956, Bjorklund and Brown, 1957, and Rapp, Warner, and Morgan, 1953). The areas of dune sand and terrace deposits mapped by these men are shown on plate 1. In areas other than those mapped by Babcock and Bjorklund (1956) and Bjorklund and Brown (1957), the unconsolidated deposits have not been differentiated. Deposits they mapped as alluvium are shown as valley-fill deposits on plate 1 and in table 1.

Approximate areas of water-bearing unconsolidated deposits that have not been mapped in detail are shown on plate 1. The deposits shown in Larimer County yield water to two irrigation wells and an industrial well. The unconsolidated deposits in northern Morgan County yield water to numerous stock and domestic wells and in places yield sufficient water for irrigation. According to drillers' reports, these deposits are as thick as 70 feet.

The dune sand is not known to yield water to wells, but it serves as an infiltration area for recharge. The valley-fill deposits generally yield sufficient water for stock and domestic purposes, and in some areas, such as Barnesville and Hereford, they yield as much as 1,500 gpm to irrigation wells. The terrace deposits, which were identified only near Hereford, are reported to yield as much as 1,200 gpm to irrigation wells.

Water from the unconsolidated deposits is usually the hardest in the area. The principal ions in the water are calcium, sodium, bicarbonate, and sulfate.

## HYDROLOGY

### SURFACE WATER

Although maps show numerous streams and water courses in the project area, they are ephemeral or intermittent. The only streamflow records available are those for Crow Creek east Cheyenne, Wyo., and about 72 miles downstream near Barnesville, Colo. The records show an average annual discharge near Cheyenne of 12 cubic feet per second from July 1951 to September 1957. During this period there was not enough flow to measure at the station near Barnesville, the flow having been diverted for irrigation, dammed up, returned to the atmosphere by evapotranspiration, or percolated to the water table.

### GROUND WATER

Ground water in the project area is derived almost entirely from infiltration of precipitation, both directly and from ephemeral streamflow; a minor amount is derived from infiltration of irrigation water. Most precipitation in the project area is evaporated or transpired; occasionally, some leaves as streamflow. The rest percolates down through the soil, replenishing the soil moisture, and eventually reaches the water table. The amount of water reaching the water table depends greatly on the permeability of the surficial materials, the dryness of the soil, the type of crop raised, shape and slope of the land surface, and several other factors. Some of the water in the streams also percolates down through the sand and gravel of the streambeds and reaches the water table. Water is discharged by springs and seeps, by evapotranspiration, by underflow out of the area, and by pumping from wells.

The artesian aquifers are recharged by precipitation on their outcrops in the western part of the area and, in places, by water percolating from streams flowing across the outcrops. The aquifers are discharged by springs and seeps where streams have cut through the water-bearing zones and by pumping from wells.

### WATER LEVELS

Colorado State University Experiment Station measures a few observation wells in the unconsolidated deposits near Hereford and Barnesville. Their latest report on water levels (Skinner, 1963) indicates that the water level in the Hereford area in the spring of 1963 was generally 0.1 to 0.7 foot lower than it was in the spring of 1962, and the water level in the Barnesville area was 0.5 to 1.6 feet lower. These lower levels are probably due to the dry winter and spring of 1962–63. Records for four wells in the Barnesville area, however, show that the water level in November 1962 was the highest it had been in November in the past 10 years.

In general, water levels in wells originally inventoried in 1953 were lower in 1963 for those wells tapping valley-fill deposits and higher for wells tapping the other aquifers.

### AQUIFER TESTS

Data collected from aquifer tests are used to determine the field coefficients of transmissibility, permeability, and storage of an aquifer. The field coefficient of transmissibility is the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of aquifer 1 foot wide extending the height of the aquifer under a unit hydraulic gradient. The field coefficient of permeability is the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a unit hydraulic gradient, at the prevailing water temperature. The average field coefficient of permeability may be determined by dividing the field coefficient of transmissibility by the thickness of the aquifer. The coefficient of storage of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. It is expressed as a percent or as a decimal fraction.

Although no aquifer tests were made during this study, data from tests made by other organizations were analyzed by E. D. Jenkins of the U.S. Geological Survey. The results, summarized in table 2, give an indication of the aquifer characteristics in the immediate vicinity of the well.

The average coefficient of permeability from the tests made of the Laramie Formation in Weld County is 5 gpd per sq ft (gallons per day per square foot), and the average coefficient of transmissibility is about 620 gpd per ft. The coefficient of storage, as determined from two tests for which observation wells were available, was 0.0002. This coefficient is the same as that obtained for the Laramie Formation in Boulder County (E. D. Jenkins, oral commun., 1963).

The average coefficient of transmissibility obtained from tests of the Pierre Shale made by the Shell Oil Co. in western Logan County

TABLE 2.—*Summary of*

| Well | Geologic source | Perforated interval of casing (feet) | Depth of well (feet) | Distance to water level below land surface (feet) | Saturated thickness (feet) |
|---|---|---|---|---|---|
| B8-53-10bca | Pierre Shale | | 710 | 260 | |
| 17dca | do | 145-582 | 585 | 136 | |
| 20bba | do | 150-600 | 614 | 155 | |
| B8-63-24bda | Laramie Formation | 174-446 | 446 | 165 | 160 |
| B10-66-36dda | Laramie Formation | 115-240<br>280-300<br>340-380<br>410-430<br>430-465 | 465 | 120 | 145 |
| B11-61-4cdb | Laramie Formation and White River Group. | 162-415 | 415 | 129 | 85 |

is 500 gpd per ft. Very little is known about the water-bearing properties of the Pierre in this area, which is not usually considered an aquifer, and more testing is needed to allow predictions on the effects of long-term pumping from it.

### SPECIFIC CAPACITY OF WELLS

Because time did not permit making aquifer tests throughout the area, aquifer characteristics can be indicated by the specific capacity of a well. Specific capacity is the yield per unit of drawdown and is generally expressed as gallons per minute per foot of drawdown. For example, if a well yields 100 gpm with a drawdown of 10 feet, it has a specific capacity of 10. It is a function of time of pumping, thickness and hydraulic properties of the aquifer, and well construction. In general, a high specific capacity indicates a high transmissibility.

The yields and drawdowns of many of the inventoried wells are given in table 2 of the basic-data report (Weist, 1964). Specific capacity of these wells ranges from 0.06 for a well in fine unconsolidated material to 70 for a well in coarse gravel. Specific capacity of wells tapping the Ogallala Formation ranges from 0.5 to 17.5; that of wells tapping the White River Group ranges from 0.03 to 700. However, all values of more than two for wells tapping the White River probably indicate that the water is coming from heavily fractured or porous zones rather than from pore space in the rock. Values for wells tapping the Laramie Formation range from 0.01 to 9.0, for wells *the results of aquifer tests*

| Pumping: Duration (hours) | Pumping: Average (gpm) | Draw-down (feet) | Specific capacity (gpm per ft of draw-down) | Field coefficient of— Trans-missi-bility (gpd per ft) | Field coefficient of— Perme-ability (gpd per sq ft) | Apparent coefficient of storage | Date of test | Remarks |
|---|---|---|---|---|---|---|---|---|
| 12 | 94 | 240 | 0. 39 | 200 | ------ | -------- | ---------- | Data from Shell Oil Co. |
| 7½ | 112 | 128 | . 87 | 700 | ------ | -------- | 7–31–58 | Do. |
| 20 | 60 | 124 | . 48 | 600 | ------ | -------- | 6– 6–58 | Do. |
| 40 | 36 | 15 | 2. 40 | 1, 000 | 6 | 0. 0002 | 8–10–59 | Data from Corps of Engineers. |
| 72 | 37 | 87 | . 42 | 500 | 3 | -------- | 11–21–59 | Do. |
| 72 | 41 | 116 | . 35 | 350 | 4 | . 0002 | 8–26–59 | Do. |

tapping the Fox Hills Sandstone from 0.02 to 5.4, and for wells tapping the Pierre Shale from 0.01 to 1.15.

## UTILIZATION

Information was collected for 360 wells and 7 springs (plate 1), including all the public-supply wells and most of the industrial and irrigation wells. Of these, 114 are used for irrigation, 29 are used for industry, 8 are used for public supply, 25 are not used, and the rest are used for domestic or stock purposes.

### DOMESTIC AND STOCK

Most of the residents depend on wells for domestic and stock purposes. These wells are generally 4 to 6 inches in diameter. Most of the domestic wells are equipped with either a submersible or a jet pump driven by an electric motor. Windmills power many of the stock wells. Yields range from 1 gpm from a well that pumps dry in about 45 minutes to more than 20 gpm. Many of the wells could yield more if equipped with larger pumps.

### INDUSTRIAL

Most of the industrial wells were drilled to obtain water for secondary-recovery operations in the oil fields of Logan, Weld, and Morgan Counties. Yields range from 20 to 480 gpm from wells in valley-fill deposits. Other industrial wells include two owned by the Chicago, Burlington, and Quincy Railroad, and one in western Weld County that is supplying water for road construction (1963).

#### IRRIGATION

Most irrigation is confined to two areas along Crow Creek—in the vicinity of Hereford (18 wells) and Barnesville (56 wells). The rest is scattered along Crow Creek and in a few other areas.

Most irrigation wells tap unconsolidated deposits, although several tap the White River Group, and two each tap the Ogallala Formation, the Laramie Formation, and the Fox Hills Sandstone. The wells that tap the White River probably penetrate extensive fractured zones.

In 1961, 46 wells pumped approximately 2,900 acre-feet of water for irrigation in the Barnesville area. No other figures for irrigation pumpage are available.

#### PUBLIC SUPPLY

Grover, Keota, and Peetz have municipal water systems. Residents of other communities depend on private wells. Information on the systems at Grover and Peetz was reported by Gregg and others (1961, p. 62, 84–85).

Grover has two wells, one of which is used only as a standby. The main well is 220 feet deep and is reported to pump 55 gpm from the Laramie Formation. The other well is 250 feet deep and can pump about 30 gpm.

Keota has a well 100 feet deep, which is reported to pump 40 gpm from the White River Group.

Peetz has four wells, ranging in depth from 145 to 375 feet. They yield between 11 and 50 gpm from the Ogallala Formation and the White River Group.

Water from well B8–62–21dcc, owned by Mr. Carl Mays, is used by many of the residents of Briggsdale. The well is 265 feet deep and taps the Laramie Formation.

## CHEMICAL QUALITY OF THE GROUND WATER

By Robert Brennan

Data available to evaluate the chemical quality of the ground water and its suitability for various uses include 52 laboratory analyses of water samples from representative wells and 128 field determinations of specific conductance of ground water. Of the laboratory analyses, 20 represent water from Cretaceous rocks, 15 from Tertiary rocks, 14 from unconsolidated deposits of Quaternary age, and 3 from more than one aquifer. The analytical data are published in the basic-data report by Weist (1964).

TABLE 3.—*Maximum, minimum, and average concentrations of selected constituents in the ground water*

| Water-bearing zone | Bicarbonate ($HCO_3$) | | | Sulfate ($SO_4$) | | | Hardness as $CaCO_3$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Avg. | Max. | Min. | Avg. | Max. | Min. | Avg. |
| Unconsolidated deposits | 477 | 204 | 318 | 1,240 | 21 | 562 | 905 | 185 | 535 |
| Ogallala Formation | 237 | 178 | 205 | 17 | 8.6 | 14 | 184 | 140 | 163 |
| White River Group | 296 | 162 | 210 | 448 | 9.3 | 157 | 306 | 63 | 183 |
| Laramie Formation | 352 | 180 | 250 | 95 | 22 | 44 | 191 | 12 | 76 |
| Fox Hills Sandstone | 540 | 202 | 419 | 1,260 | 40 | 606 | 455 | 30 | 241 |
| Pierre Shale | 788 | 418 | 594 | 426 | 2.7 | 129 | 152 | 10 | 71 |

| Water-bearing zone | Sodium (Na) | | | Percent sodium | | | Specific conductance (micromhos per cm at 25° C) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Avg. | Max. | Min. | Avg. | Max. | Min. | Avg. |
| Unconsolidated deposits | 454 | 12 | 163 | 63 | 12 | 35 | 3,000 | 420 | 1,600 |
| Ogallala Formation | 23 | 9.4 | 15 | 23 | 11 | 16 | 438 | 319 | 386 |
| White River Group | 163 | 12 | 81 | 73 | 16 | 45 | 1,280 | 307 | 567 |
| Laramie Formation | 160 | 21 | 90 | 96 | 21 | 67 | 688 | 414 | 504 |
| Fox Hills Sandstone | 662 | 85 | 374 | 86 | 74 | 79 | 3,520 | 425 | 2,260 |
| Pierre Shale | 515 | 225 | 357 | 99 | 88 | 92 | 4,570 | 1,010 | 1,700 |

## QUALITY OF GROUND WATER IN RELATION TO GEOLOGIC SOURCE

The dissolved constituents in ground water result from solution of chemical compounds from the materials through which the water moves. This process begins with precipitation dissolving the gases of the atmosphere, mainly oxygen and carbon dioxide. When the precipitation reaches the ground, it dissolves more carbon dioxide from decaying organic material in the soil and also soluble salts produced by weathering processes or evaporation. As the water percolates to and through the aquifer, it dissolves more chemical constituents. If the soluble minerals in one aquifer are chemically different from those of another, the chemical quality of the water from each will also be different.

The concentration and type of dissolved minerals in water from various aquifers differ widely. The range and average concentration of the major constituents are given in table 3. Based on the sparse data available, chemical characteristics representative of water from each major aquifer are depicted on figure 4.

### PIERRE SHALE

Analyses of four water samples from the Pierre Shale indicate that the water is generally of the sodium bicarbonate type and has a moderate dissolved-solids content. Except for the sample of water from well B8–53–17dca, which had a specific conductance of 4,570 micromhos, the range of specific conductance was from 1,010 to 1,650

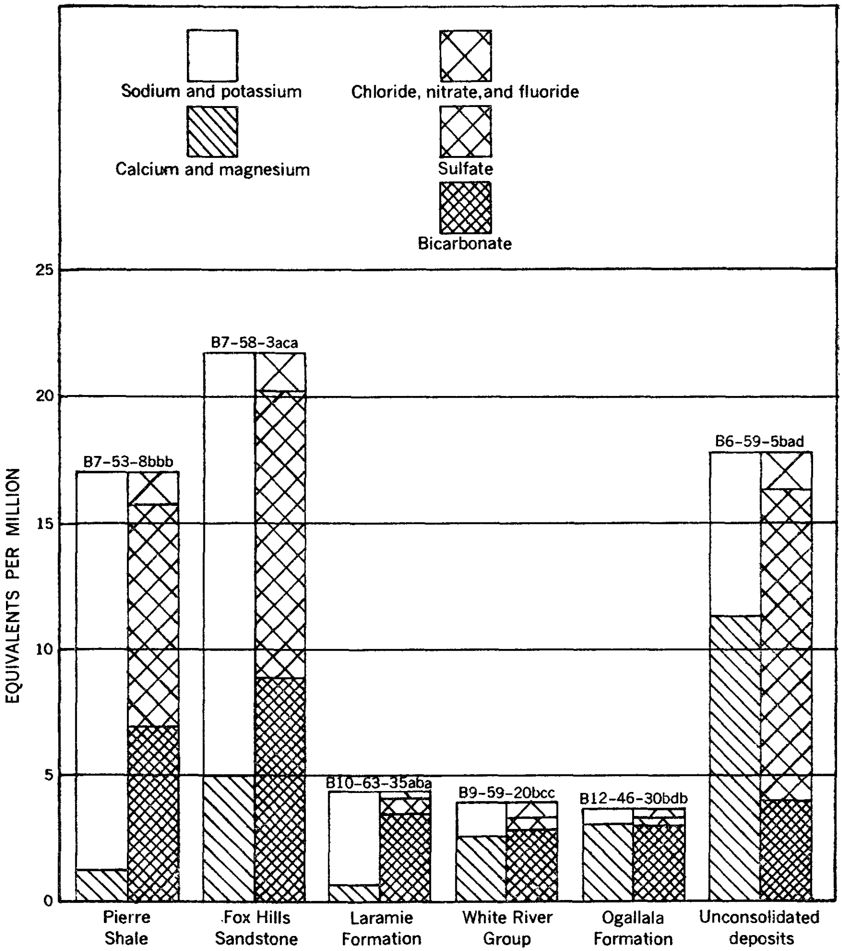


FIGURE 4.—Chemical composition of ground water from various geologic sources.

micromhos. The water from well B8–53–17dca had a chloride content of 508 ppm (parts per million).

The water from well B7–53–8bbb had a sulfate content of 426 ppm. The high sulfate probably comes from gypsum or oxidized sulfide minerals in weathered parts of the shale.

### FOX HILLS SANDSTONE

The chemical quality of water from the Fox Hills Sandstone has been characterized on the basis of analyses of five water samples. These data indicate that in general the water from the Fox Hills is either a sodium bicarbonate or a sodium sulfate type. The dissolved-solids content differs greatly, ranging from less than 425 to more than 2,000 ppm. The water having a high dissolved-solids content is generally of the sodium sulfate type.

### LARAMIE FORMATION

Chemical analyses of water from nine wells that tap the Laramie Formation indicate that generally the water is of the sodium bicarbonate type and that the dissolved-solids content ranges from 235 to 420 ppm.

Water from well B9–62–17dbd had a sulfate content of 955 ppm and a specific conductance of 2,850 micromhos. The high sulfate content could be caused by leakage of sulfate water from a coal seam 6 feet above the perforations in the well casing.

### WHITE RIVER GROUP

Water from nine wells tapping the White River Group was analyzed. The analyses indicate that the water is generally of the calcium bicarbonate type and that the dissolved-solids content is low. Water from seven of the wells had from 225 to 450 ppm dissolved solids.

Water from the lower part of the White River Group, such as that from well B11–54–9ddc, is of the sodium bicarbonate type. Apparently ion-exchange reactions occur as the water percolates to the lower parts of the aquifer. Two wells, B9–60–34adc and B10–58–27aca, yield water high in sulfate. The source of the sulfate could be disseminated gypsum in the White River Group or intermingling of water in contact with ridges of underlying Cretaceous rocks.

### OGALLALA FORMATION

The quality of the water from the Ogallala Formation was more consistent from place to place and with depth of well than that of water from any other geologic source. Analyses of water from five wells tapping the Ogallala Formation indicate that the water is of the calcium bicarbonate type. The specific conductance ranged from 319 to 438 micromhos. Though low in dissolved solids, the water is very hard. The hardness ranges from 140 to 184 ppm.

### UNCONSOLIDATED DEPOSITS OF QUATERNARY AGE

The quality of water from unconsolidated deposits is the most variable from place to place. Water from 14 wells penetrating unconsolidated deposits was analyzed. The range in concentration of all constituents except bicarbonate is large (table 3). The large range may be attributed principally to differential concentration of salts by evapotranspiration.

## SUITABILITY OF THE WATER FOR USE

### MUNICIPAL AND DOMESTIC

Because most residents in the project area depend on ground water for domestic supply, this is the primary use even though it may not be the largest.

The criteria used to determine the suitability of the water for domestic use are given by the U.S. Public Health Service (1962).

Generally, water from the Ogallala Formation, the White River Group, and the Laramie Formation is suitable for domestic use, although softening may be desirable. The high dissolved-solids content and high sulfate content of water from the Fox Hills Sandstone, the Pierre Shale, and the unconsolidated deposits make this water less desirable for use as a domestic supply. Water from the unconsolidated deposits is generally very hard, and softening would probably be required for most uses. Water from some wells in the Laramie, Pierre, Fox Hills, and unconsolidated deposits has too high a dissolved-solids content to be used for a domestic supply, but highly mineralized water probably occurs only locally and is not present in the entire aquifer. High iron content (more than 0.3 ppm) has been noted in water from some wells tapping the Fox Hills Sandstone, the Laramie Formation, and the unconsolidated deposits. Iron removal may be necessary if a more suitable supply cannot be found.

### IRRIGATION AND STOCK WATERING

Irrigation is confined mainly to the Crow Creek valley; however, ground water is used for stock throughout the area.

The criteria used to evaluate the suitability of the water from the various geologic sources for irrigation use are those presented by the U.S. Salinity Laboratory Staff (1954).

Generally, water from the Ogallala Formation, the White River Group, and the Laramie Formation is suitable for most crops on most soils, with only moderate requirements for leaching excess salts from the root zone.

Most of the water from the unconsolidated deposits has a low sodium hazard but a high salinity hazard. This water should be used only on well-drained soil and for plants having a high salt tolerance.

Water from the Pierre Shale, Fox Hills Sandstone, and some from the unconsolidated deposits has a high to very high sodium hazard, which could harm the soil structure. The sodium hazard can be reduced by adding gypsum to the soil before water is applied. If the applied water has a high dissolved-solids content, the added gypsum may increase the dissolved-solids content of the water sufficiently to cause a salinity hazard.

Boron concentrations in the ground water from the area are within suitable limits and do not constitute a hazard to irrigation.

With the exception of the water from well B5–60–12dda, which has dissolved solids in excess of 7,000 ppm, all ground water analyzed is suitable for stock watering.

### INDUSTRIAL

Industrial use of ground water in the area is small. Standards of water quality for industrial use have been established, but are almost as varied as industry. They range from practically pure water for use in high-pressure boilers to water of very poor quality for cooling. In general, industry is concerned with water of adequate supply whose quality does not change appreciably with time, so that treatment may be standardized. In general, the quality of water can usually be changed to fit the intended use. A very general rule is that water that meets the standards for domestic use is suitable for industrial use.

## CONCLUSIONS

Small quantities of water for stock and domestic purposes can be obtained throughout most of the project area, although most of the water from the unconsolidated deposits is very hard. In a few areas the water has too high a dissolved-solids content to be used for domestic purposes, but these areas are small.

Supplies of water for irrigation are obtained chiefly from unconsolidated deposits along the larger stream valleys and from the White River Group. These two aquifers are the only major sources of irrigation water, and only they present possibilities for future development.

More irrigation wells can be drilled in the Hereford and Barnesville areas without seriously affecting the supply of ground water. Irrigation wells can be obtained elsewhere along Crow Creek, where the transmissibility is great enough, but data are lacking to delineate these areas. It is possible to obtain sufficient water for irrigation from some of the other unconsolidated deposits, especially those along the South Platte River valley.

Because irrigation wells in the White River Group probably obtain much of their water from fracture systems not visible on the surface, it is difficult to predict where large supplies of water will be available from this aquifer. Aerial photographs may be used to locate a fracture system, but not to predict its water-bearing properties. The dependability of the water supply depends on the extent of the fracture system and how readily it is recharged. During the fieldwork for this study, several wells were visited that had been inventoried in 1953. At that time they were used for irrigation, but some were no longer in use in 1963, and appeared not to have been in use for several years.

A detailed study of the entire project area does not seem to be warranted at this time. A network of observation wells should be established, however, to provide long-term records of water levels for any future study.

Because considerable ground water is used in the Crow Creek basin, the amount of ground water available and the amount being used should be determined by detailed study. This study should include test drilling to delineate aquifer boundaries, aquifer tests to determine hydraulic characteristics, the determination of annual pumpage, and a more comprehensive water-quality study, especially in the heavily irrigated areas near Hereford and Barnesville.

The hydrologic properties of the Cretaceous aquifers need further study. Although several studies have been made of the ground-water resources of parts of northeastern Colorado, they have been concerned primarily with Tertiary and Quaternary aquifers. Little is known of the quality of water obtainable from the Cretaceous aquifers or even of their extent and water-bearing properties; this information is needed to predict the best well locations and sustained yields in areas where Tertiary and Quaternary rocks are absent. The Pierre Shale, which is not usually considered to be an aquifer, shows potential in parts of the project area. Stratigraphic studies are needed to determine the boundaries or geometry of the water-yielding sandstone beds, and aquifer tests are needed to determine aquifer characteristics. Because of the generally poor quality of water yielded by the Pierre, a more complete definition of the chemical characteristics of water from the Pierre is also needed. After the aquifer's geometry and characteristics have been determined, predictions can be made of the best well locations, maximum yields, and regional water-table declines caused by pumping.

In general, problems relative to the chemical quality of the ground water seem to be negligible. The heavy development in the Crow Creek basin, however, may result in quality-of-water problems in the future. Data on the changes in chemical quality with time are being obtained for key wells in the area as part of a statewide cooperative program. Results of this program will be helpful in detecting water-quality problems before they become severe.

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