# Water in the Dakota and Purgatoire Formations in Otero County and the Southern Part of Crowley County, Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1669-P

*Prepared in cooperation with the Colorado Water Conservation Board*

# Water in the Dakota and Purgatoire Formations in Otero County and the Southern Part of Crowley County, Colorado

*By* WILLIAM G. WEIST, JR.

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

---

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1669-P

*Prepared in cooperation with the Colorado Water Conservation Board*

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

# CONTENTS



# ILLUSTRATIONS



# TABLE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

# WATER IN DAKOTA AND PURGATOIRE FORMATIONS IN OTERO COUNTY AND THE SOUTHERN PART OF CROWLEY COUNTY, COLORADO

By William G. Weist, Jr.


## ABSTRACT

The hardness of available shallow ground water in Otero County and in the southern part of Crowley County generally exceeds 1,000 parts per million, and the water requires treatment for most uses. To obtain a supply of softer water, wells have been drilled into the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation, both Early Cretaceous in age. These aquifers underlie most of the area at depths from 0 to 2,000 feet and have a general regional dip northward into the Denver Basin. More than 150 wells have been drilled into the aquifers in this area to obtain water for stock, domestic, and industrial purposes and for public supply.

The aquifers are recharged in areas where they crop out or are overlain by sand, principally to the south and west of Otero County. Because water in the aquifers is generally under pressure, it rises above the top of the aquifer in wells penetrating it; at least 20 wells in the area flow. Yields from wells tapping the aquifers range from 4 to 75 gpm (gallons per minute). Flows as great as 50 gpm have been obtained.

Water in the aquifers is commonly soft and of good chemical quality. There appears to be little difference in quality of water from the two aquifers.

Most residents and drillers know that soft water can be obtained from wells throughout most of the area described in this report, but many are not aware of certain factors related to the development of this water. This report should be of value in further developing the sources of soft water by showing: (a) The approximate depth of a well needed to tap these supplies, (b) the range in yields that may be expected, (c) the range in chemical quality that may be expected, (d) the depth to which water will rise in wells, and (e) information on the factors affecting the durability of the supply.


## INTRODUCTION

This report discusses present knowledge of the occurrence, quality, and development of soft-water supplies in Otero County and southern Crowley County, Colo. The investigation was begun in July 1959 by the U.S. Geological Survey in cooperation with the Colorado Water Conservation Board, and was done under the supervision of E. A. Moulder, district engineer in charge of the Survey's ground-water investigations in Colorado.

The area of 1,500 square miles covered by this investigation is in southeastern Colorado (fig. 1), and comprises all of Tps. 21–27 S.,

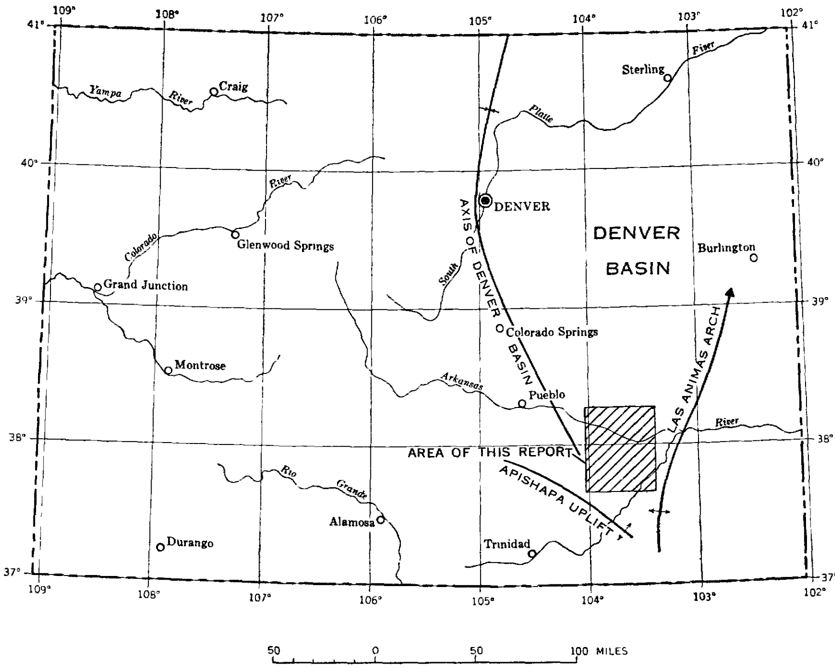



*FIGURE 1.—Map of Colorado showing the location of the report area and the major geologic structural features.*

Rs. 54–59 W. It is part of the Colorado Piedmont section of the Great Plains physiographic province. Altitudes range from about 5,200 feet along the western boundary of the report area to about 4,000 feet in the valley of the Arkansas River at the eastern boundary of the area. The Arkansas River and its tributaries drain the region and, in general, the land surface slopes toward the river. The mean annual precipitation is 11 to 14 inches. Irrigation with surface water is practiced extensively in the Arkansas Valley, and ranches occupy most of the remainder of the area. The population of the two counties according to the 1960 census was 28,106. Most of the industries are related to agriculture and are in La Junta, Fowler, Rocky Ford, and Cheraw.

Ground water is available from surficial deposits at depths less than 100 feet throughout most of the area. Yields from wells are generally small except along the Arkansas River and some of its tributaries where large supplies can be obtained from the alluvium and low terraces along the river. However, most of this water is very hard and has a high sulfate content that makes it undesirable for most domestic, municipal, and industrial uses.

There is considerable interest in the availability of soft water, because shallow water is not available in some places and, where present, is generally very hard.

Water that generally is soft or softer than other available supplies and is better suited for domestic and industrial uses can be obtained from wells tapping the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation of Early Cretaceous age, which underlie most of this area.

## GEOLOGY

### STRATIGRAPHY

The geologic units exposed in Otero County and the southern part of Crowley County range from the Morrison Formation of Late Jurassic age to dune sand and alluvium of Recent age. This report, however, is concerned only with the principal artesian aquifers, the Cheyenne Sandstone Member of the Purgatoire Formation, the Dakota Sandstone, and the formations immediately above and below them. The thickness of these formations, their physical characteristics, and their water-bearing properties are described in table 1.

### STRUCTURE

The relation of the report area to three major geologic structural features of southeastern Colorado is shown on figure 1. To the east is the Las Animas arch; to the southwest is the Apishapa uplift; to the northwest is the axis of the Denver Basin; and to the north is the main part of the Denver Basin. Consequently, throughout most of the area the consolidated beds dip to the north or northwest into the Denver Basin. The southwestern part of Otero County is close to the Apishapa uplift and, in this area, the consolidated beds, in general, dip northeast away from the uplift. The dips are generally very slight, but local structural features cause very abrupt steepening or change in the direction of the dip.

686-165—63——2

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

| System | Series | Formation | Member | Thickness (feet) | Physical character | Water-bearing properties |
|---|---|---|---|---|---|---|
| Cretaceous | Upper Cretaceous | Graneros Shale | | 90–200 | Gray to black platy and fissile shale containing thin beds of bentonite; thin limestone beds in lower part. Transition zone of several feet of alternating sandstone and shale at base. | Relatively impermeable. Not known to yield water to wells in area. Acts as confining bed for Dakota Sandstone. |
| | Lower Cretaceous | Dakota Sandstone | | 75–140 | White to brown fine-grained thin-bedded to massive sandstone; contains beds of gray to black sandy shale. Mostly quartz sand and limonite, calcite, or silica cement in varied amounts; hard to friable; forms cliffs and ledges; some lenticular beds and crossbedding; locally conglomeratic. | Moderately porous; yields adequate water for stock and domestic use. In some areas yields enough water for municipal and industrial supplies. Water is soft but contains iron and sulfur. |
| | | Purgatoire Formation | Kiowa Shale | 50–130 | Gray to black platy calcareous shale; in places very sandy; contains some beds of brown fine-grained sandstone. | Relatively impermeable. Not known to yield water to wells in area. Acts as confining bed between Dakota and Cheyenne Sandstone Member. |
| | | | Cheyenne Sandstone | 70–110 | Massive white to buff fine- to coarse-grained sandstone; poorly cemented and friable; some lenses of conglomerate in lower part. | Yields adequate water for stock and domestic use. In some areas yields enough water for municipal and industrial supplies. |
| Jurassic | Upper Jurassic | Morrison Formation | | 125–300 | Red, green, gray, and brown shale containing thin beds of sandstone and limestone; thin layers of chert at base. | Shales are relatively impermeable. Some sandstone layers yield small amounts of water for stock and domestic use. |

Numerous small, nearly vertical faults are found in the more resistant beds. A few faults can be traced for a mile or more, but most lose their identity in beds of shale. Displacement along the faults is usually only a few feet.

## OCCURRENCE OF SOFT WATER

### SOFT AND HARD WATER

The adjectives "hard" and "soft" are often used to describe water, but they lack exactness and may have different connotations to different people. In an area such as New England, where the water is commonly low in dissolved solids, water having a hardness of 100 ppm (parts per million) might be considered "very hard," whereas the same water in an area such as Arizona, where the water is generally high in dissolved solids, might be considered "soft."

The hardness of water classification of Collins, Lamar, and Lohr (1934, p. 17–18) has been generally accepted. Under this classification, water having a hardness of 60 ppm or less is considered "soft." However, water with a hardness near 60 ppm may have to be softened for some industrial uses. Water containing 61 to 120 ppm of hardness is "moderately hard" and will have to be softened for many industrial uses; it may be softened for household use. Collins, Lamar, and Lohr report that it is customary to reduce the hardness of municipal supplies to less than 120 ppm. Water having a hardness of 121 to 180 ppm is considered "hard" and generally is softened for most uses. Water having a hardness of more than 180 ppm is considered "very hard."

The alkaline-earth metals, calcium and magnesium, are the principal constituents that cause hardness of water. Hardness also is caused by aluminum, iron, manganese, strontium, zinc, and free acid, but these generally are present in water only in very small amounts. It follows, therefore, that hard water will have a much higher calcium and magnesium content than soft water.

Most of the readily available shallow water in Otero County and in the southern part of Crowley County has a hardness of 1,000 ppm or more. Thus, water from the Dakota Sandstone is soft by comparison even though it may have a hardness as great as 400 ppm.

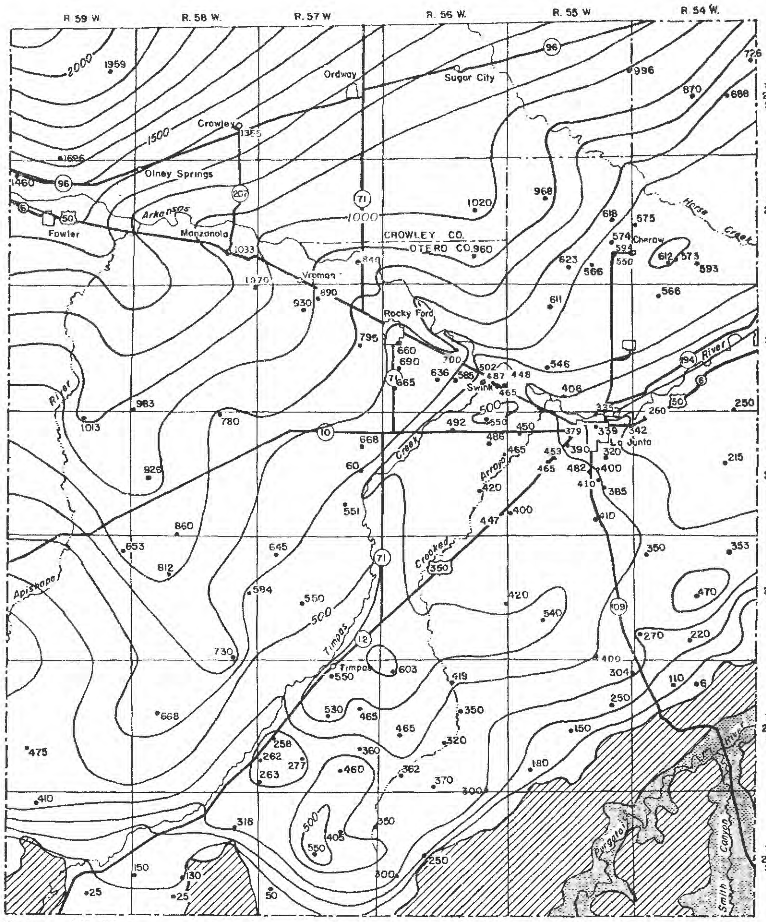
## PRINCIPAL AQUIFERS

The Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation are the principal formations in Otero and Crowley Counties known to contain soft water. These units consist of sandstone, which in most areas is interbedded with shale. The Dakota Sandstone ranges in thickness from 75 to 140 feet, and the Cheyenne Sandstone Member ranges in thickness from 70 to 110 feet. The two sandstone units are separated by the Kiowa Shale Member, a black shale that in places is very sandy and that ranges in thickness from 50 to 130 feet.

These formations underlie all of Otero and southern Crowley Counties except parts of the southeast corner of Otero County where the Purgatoire River and its tributaries have cut through to the Morrison Formation, which underlies the Cheyenne Sandstone Member. Figure 2 shows the general area of outcrops of the Purgatoire Formation and the Dakota Sandstone and the approximate depth to the top of the Dakota Sandstone elsewhere in the area.

Below the Cheyenne Sandstone Member in this area are beds of sandstone of Triassic and Jurassic age that may contain potable water.

686-165—2——63




Base modified from maps prepared by the Army Map Service

Hydrology by William G. Weist, Jr., 1960. Geology from geologic map of Colorado (U.S. Geological Survey)

EXPLANATION

• 566

**Well**

*Number indicates depth, in feet, to the top of the Dakota Sandstone*

Approximate areas of outcrop of the Dakota Sandstone and the Purgatoire Formation

Approximate areas where the Dakota Sandstone and the Purgatoire Formation have been eroded away

5 0 5 10 MILES

CONTOUR INTERVAL 100 FEET

FIGURE 2.—Map of report area showing approximate depth to the top of the Dakota Sandstone.

These beds are known to contain soft water in other parts of Colorado and New Mexico. Potable supplies of hard water are sometimes obtained from lenses of sandstone in the Morrison Formation, but this is the only known source of potable water below the Cheyenne Sandstone Member in the area.

Water obtained from beds below the Morrison Formation probably would not be potable. Because the beds lie at fairly great depths, the water is very likely to be highly mineralized. Darton (1906, p. 53–54) reports that a well drilled at Manzanola penetrated several beds containing water in a zone 1,655 to 2,110 feet deep, which is 280 to 735 feet below the base of the Cheyenne Sandstone Member. Darton reports the water was "too impure for use." Another well at Bloom reached water 600 feet below the base of the Cheyenne Sandstone Member. This water also was of poor quality. In 1961 a deep well was drilled at Las Animas, Colo., (19 miles east of La Junta) to test the deeper formation. Samples of water from various beds below the Morrison Formation were too highly mineralized for most uses.

Because the two water-bearing units are confined by underlying and overlying beds of fairly impermeable shale, the water in the two sandstones is under artesian pressure nearly everywhere, and rises above the level at which it is found, and in some places wells flow at the surface. The imaginary surface to which the water will rise under artesian pressure is called the "piezometric surface." This surface does not remain fixed but moves up and down in response to fluctuation of the artesian pressure, as is shown by changes in the water level in a well. Figure 3 shows the approximate depth to the piezometric surface of water in the Dakota Sandstone in the area as it was measured or reported during the summers of 1959 and 1960.

The level of the piezometric surface is gradually declining, especially in areas such as La Junta and Cheraw where many wells tap the artesian aquifers. The flow of many wells has decreased or even stopped. A few well owners have reported that they have had to lower their pumps to get an adequate supply of water. This decline of the piezometric surface probably is due to the reduction in artesian head caused by the withdrawal of water from the increasing number of wells tapping these aquifers. Figure 4 shows the fluctuations of the water level in an observation well tapping the Dakota Sandstone south of La Junta.

Although the piezometric surface is slowly declining, the aquifers are not necessarily overdeveloped. The water level in most of the wells is still considerably above the top of the Dakota Sandstone and, with the present rate of development, a rapid decline would not be expected. Because it is deeper than the Dakota Sandstone, the

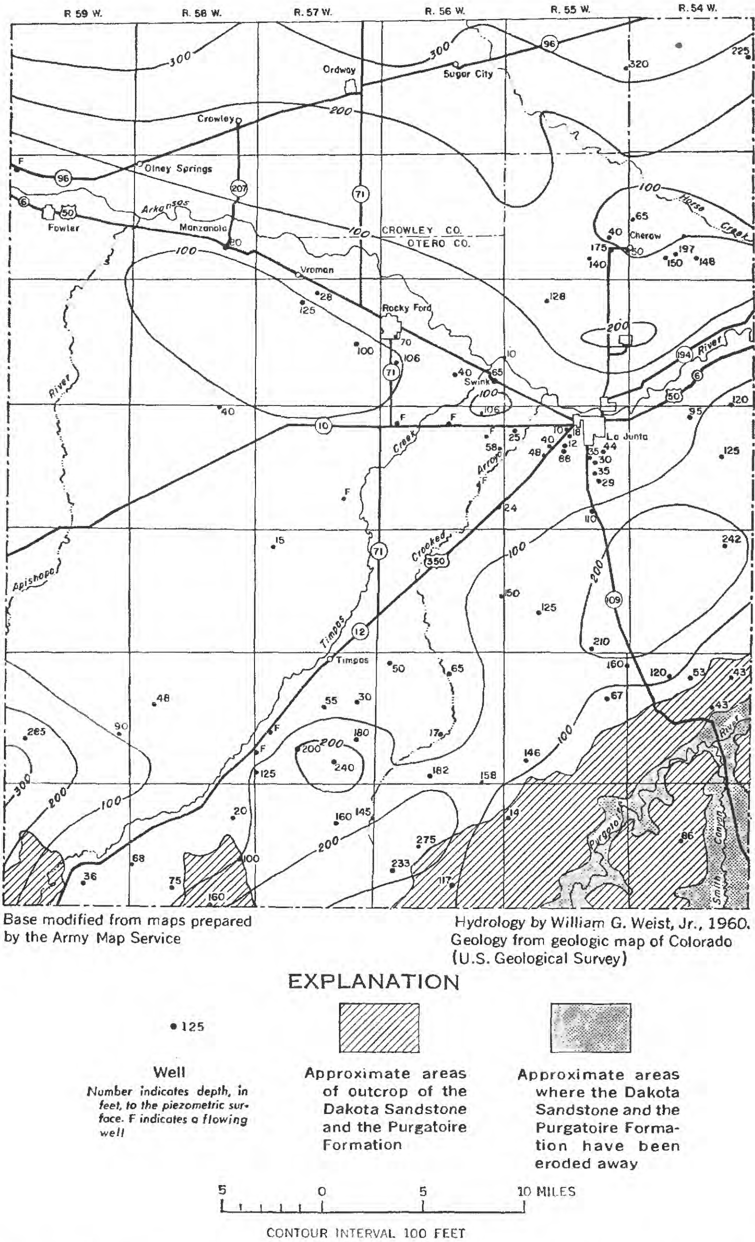



FIGURE 3.—Map of report area showing approximate depth to piezometric surface of water in the Dakota Sandstone, 1959–60.

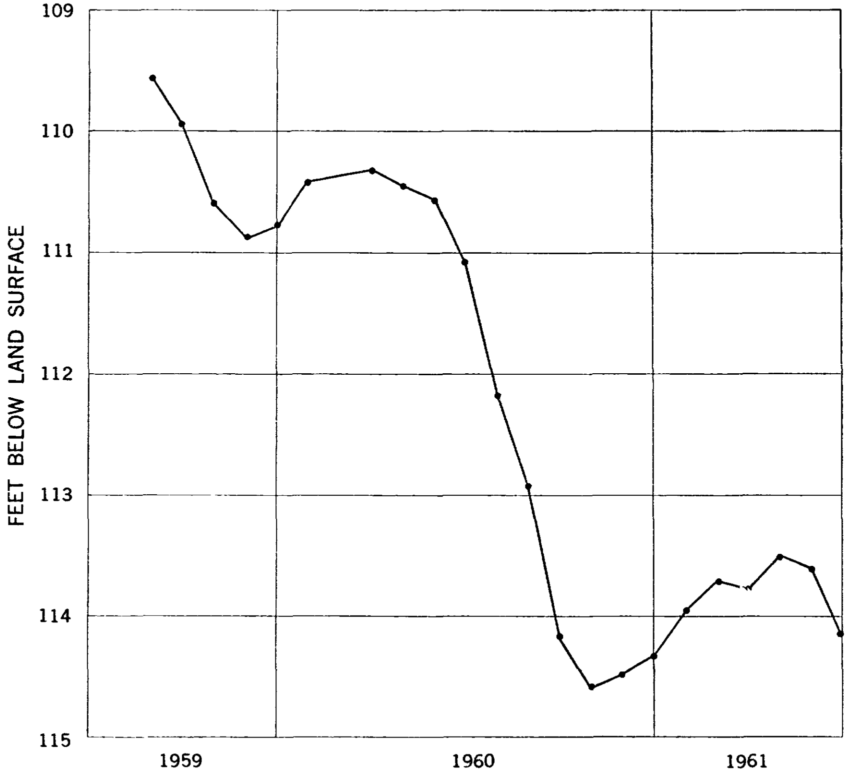



FIGURE 4.—Fluctuations of the water level in a 510-foot well tapping the Dakota Sandstone south of La Junta, Colo.

Cheyenne Sandstone Member of the Purgatoire Formation is much less developed. Of the wells inventoried in the area, 27 are reported to tap only the Cheyenne Sandstone Member, 102 are reported to tap only the Dakota Sandstone, and 42 are reported to tap both sandstones.

## RECHARGE AREAS

The aquifers are recharged mainly in their areas of outcrop to the south and west of Otero County. The water for recharge comes principally from direct precipitation, although some water percolates into the aquifers from streams that cross the outcrops.

Conditions are most favorable for recharge where the outcrop areas are flat-lying. The outcrops of the aquifers along the foot of the Front Range west of Otero County are very narrow owing to their steep dip to the east. Most of the precipitation on them runs off the steep slope, and only a small amount recharges the aquifers. In outcrop areas east of the foothills, such as the plateaus along the Purgatoire River and the area northwest of Thatcher extending from the Apishapa River to the Huerfano River, the aquifers are nearly flat-lying. However, the deep canyons in the area along the Purgatoire River drain off some of the water that would otherwise recharge the aquifers. Some recharge also occurs in areas where the aquifers are overlain by unconsolidated upland deposits.

At this writing, no information is available on the amount of recharge received by the aquifers.

## DEVELOPMENT AND UTILIZATION

### HISTORY OF DEVELOPMENT

The earliest study of the geology and ground-water resources of this area was made by Gilbert (1896) who reported the existence of six artesian wells at Rocky Ford and La Junta, but did not record the year when the first well tapping the Dakota Sandstone was drilled in this area. In a footnote to page 584, Gilbert noted that the first two wells at La Junta that penetrated the Cheyenne Sandstone Member of the Purgatoire Formation were drilled in 1896. It appears that these were the first wells in the area to penetrate this aquifer.

Several more wells were drilled in the area during the next 10 years. Darton (1906, p. 52–57, 62–63) reported "several" artesian wells at Rocky Ford and La Junta, at least four each at Timpas and Ayers, two each at Bloom and Cheraw (Holbrook), and one each at Sugar City, Ordway, Fowler, and Manzanola. By 1903 the drop in artesian pressure at La Junta was great enough to require that most of the wells there be pumped. The towns of Ayers and Bloom no longer exist.

The aquifers were developed slowly during the next few years. Patton (1923) in his study of the ground-water possibilities of the La Junta area, reported at least 50 artesian wells, including 10 that tapped only the Cheyenne Sandstone Member and 6 that tapped both aquifers. The greatest development took place between 1949 and 1959, when at least 60 artesian wells were drilled as compared to 30 during the previous decade.

### PRESENT UTILIZATION

The following table summarizes the use in 1960 of water from the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation in the area:

| Use | Wells | Source | Range of yield (gpm) | Approximate amount used (millions of gallons) |
|---|---|---|---|---|
| Stock and domestic (includes hauled water). | 124 | Pump<br>Flow | 4–60<br>Trace–50 | 350 |
| Municipal | 7 | Pump | 4–85 | 45 |
| Water associations | 17 | Pump<br>Flow | 7–65<br>1–7 | 50 |
| Industrial | 10 | Pump<br>Flow | 10–75<br>1.5 | 40 |
| Wells not in use | 13 | | 10 | 0 |
| Total | 171 | | | 485 |

### STOCK AND DOMESTIC SUPPLIES

Of the artesian wells in Otero County and the southern part of Crowley County, 120, or more than two-thirds, are privately owned stock and domestic wells. Of these, 79 are used solely for watering livestock, 32 are used for both livestock and domestic purposes, and 9 are used for domestic purposes only. Yields range generally from 10 to 25 gpm (gallons per minute), and some wells are reported to pump as much as 60 gpm. One well is reported to flow 50 gpm.

### MUNICIPAL SUPPLIES

Four towns in the area obtain all or part of their water supply from wells tapping one or both of the Cretaceous aquifers.

*Cheraw.*—The town of Cheraw uses an average of 12 mgy (million gallons per year) from a well tapping the Cheyenne Sandstone Member. The well, drilled in 1927 to a depth of 850 feet, is pumped at 65 gpm. The water rises in the well to 60 feet below the land surface. In 1961, the town had a second well drilled. This well is 735 feet deep and yields a reported 85 gpm from the Dakota Sandstone.

*Crowley.*—The town of Crowley uses more than 1 mgy from a well that is reported to tap the Cheyenne Sandstone Member of the Purgatoire Formation. The well was drilled to a depth of 1,432 feet and yields 4 gpm. The water rises in the well to 175 feet below the land surface. The town also has a supply of hard surface water for uses other than cooking and washing.

*Manzanola.*—The town of Manzonola uses about 22 mgy from 2 artesian wells. The older well was drilled in 1909 to a depth of 1,113 feet penetrating 80 feet into the Dakota Sandstone. It is pumped at 50 gpm. The other well was drilled about 1924 to a depth of 1,365 feet penetrating both aquifiers, and is pumped at 45 gpm. Both wells flowed until about 1944, but the pressure has declined and the water level is now about 80 feet below the land surface. Hard water from a well 37 feet deep is used for watering lawns.

*Swink.*—The town of Swink uses about 10 mgy from two artesian wells. The older well, drilled in 1908 to a depth of 769 feet, taps both aquifers. The other well was drilled in 1920 to 555 feet and taps just the Dakota Sandstone. Both wells are pumped at 30 gpm. The water level in both wells has declined and now stands at about 65 feet below the land surface. Water for watering lawns is obtained from three shallow wells, each about 50 feet deep.

### PRIVATE WATER ASSOCIATIONS

In 1954 a group of farmers near Cheraw organized the West Holbrook Pipeline Co. They had a well drilled 886 feet through both artesian aquifers, and a pipeline was laid to distribute water to their farms for domestic and stock uses. Since then, at least 10 other water associations have been formed in Otero County and have either drilled new wells or utilized deep wells at abandoned schools. The 10 associations in existence in 1959 used approximately 43 million gallons to serve more than 1,300 people.

Of the 17 wells presently in use by these organizations, 9 tap only the Dakota Sandstone. Yields are generally from 20 to 40 gpm, but one well yields only 10 gpm, 2 wells yield 50 gpm, and one well yields 65 gpm.

### WATER HAULING

In addition to distributing water through pipelines, several towns and water associations sell water to be hauled to other residences. Water hauled from Manzanola's wells serves nearly as many people as the town's municipal system. A water hauler in Rocky Ford, who obtains water from five different wells, averages eight deliveries of 1,000 gallons each day.

Some water haulers have their own wells. One in La Junta withdraws about 5 mgy from a well 700 feet deep tapping the Cheyenne Sandstone Member. The water rises to about 60 feet below the land surface and is pumped at 25 gpm. Others haul water from deep wells at schools in the area.

### INDUSTRIAL SUPPLIES

Ten artesian wells in the area are used for industrial purposes; they withdraw about 40 mgy from the two aquifers.

The processing plant of the Holbrook Turkey Growers Association in Cheraw uses about 6 mgy from a Dakota well 702 feet deep. In Rocky Ford, the Southern Colorado Power Co. has three wells that pump 40 to 50 gpm each from the two aquifers. The La Junta

Rendering Co. uses about 22 mgy from a 624-foot well that taps both aquifers. The Best Laundry of La Junta uses more than 7 mgy from a 703-foot well.

## CHEMICAL QUALITY OF WATER SAMPLES

The mineral content of a water determines its suitability for various uses. Water that is suitable for one use may not be suitable for another. The following discussion of water-quality criteria for various uses is taken largely from California Water Pollution Control Board (1952) and Hem (1959), and the reader is referred to these references for a more detailed discussion.

The quality of water considered suitable for domestic use varies widely from place to place. The following table presents some of the standards set by the U.S. Public Health Service (1946) for drinking water used in interstate commerce:

Iron and manganese combined should not exceed 0.3 ppm.
Magnesium should not exceed 125 ppm.
Sulfate should not exceed 250 ppm.
Fluoride must not exceed 1.5 ppm.
Dissolved solids, recommended 500 ppm.
Dissolved solids, permissible 1,000 ppm.

Water containing minerals far in excess of the suggested concentrations is being used where better water is not available. People using such water become accustomed to it and apparently suffer no serious ill effects, except from water high in fluoride, which causes mottling of the teeth in young children.

Little has been written about quality of water desirable for livestock. Most animals seem to be able to tolerate water poorer in quality than that which can be used by humans. The upper limit of dissolved solids seems to range from 2,860 ppm for poultry to 12,900 ppm for adult sheep (Hem, 1959, p. 241).

Water-quality requirements for industrial use vary greatly. For some uses, such as cooling or concentrating ores, almost any water can be used, whereas water of high quality is needed for making drugs, high-grade paper, and some other products. The report of the California State Water Pollution Control Board (1952) gives detailed information on industrial requirements.

Water from the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation is generally soft and of the sodium sulfate type. In general, water in the two aquifers in the northern half of the area is much softer than that in the southern half. Locally, the water may be harder owing to local conditions such as leakage from other formations through faulty casing or improper plugging of abandoned wells. Hardness of water samples collected from 23 wells tapping these two aquifers ranged from 8 to 906 ppm. This can be broken down as follows: less than 60 ppm (9 wells), 60 to 120 ppm (2 wells), 120 to 180 ppm (1 well), more than 180 ppm (11 wells). Noncarbonate hardness constituted a major part of the hardness of the last 11 samples; it constituted more than 50 percent of the hardness of the 8 samples having a hardness greater than 400 ppm.

Water from these two aquifers is within the standard limits suggested by the U.S. Public Health Service (1946) for magnesium and chloride content, but commonly exceeds the standard limits for iron and manganese combined, sulfate, and fluoride. The following table summarizes the analyses (Weist, 1962).

| Constituent | Range (ppm) | Suggested limit (ppm) | Samples exceeding limit |
|---|---|---|---|
| Silica | 6. 7–12 | | |
| Iron and manganese | 0–51 | 0. 3 | 14 |
| Calcium | 0–182 | | |
| Magnesium | 1. 2–110 | 125 | 0 |
| Sodium | 116–670 | | |
| Potassium | 2. 7–24 | | |
| Bicarbonate | 79–1, 030 | | |
| Sulfate | 211–1, 430 | 250 | 22 |
| Chloride | 12–110 | 250 | 0 |
| Fluoride | .4–3. 2 | 1. 5 | 8 |
| Total dissolved solids | 750–2, 360 | 1, 000 | 17 |

Available chemical data are insufficient to differentiate between water from the Dakota Sandstone and water from the Cheyenne Sandstone Member of the Purgatoire Formation. Residents of the area report that the iron and hydrogen sulfide contents of water from the Cheyenne Sandstone Member generally are less than those of water from the Dakota Sandstone. Observations in the field indicate that this report may be true locally. Water in stock tanks filled from wells tapping the Cheyenne Sandstone Member is usually much clearer than water in tanks filled from wells tapping the Dakota Sandstone. Water from the Dakota is apt to be reddish brown and leaves a deposit in the stock tanks. This probably is due to local conditions within the formations because it is not found everywhere.

Darton (1906, p. 80–81) gives the results of analyses of water from 15 wells in this area. A comparison of the results of analyses done for this report with those reported by Darton shows no significant change in mineral content of the water. Figure 5 compares

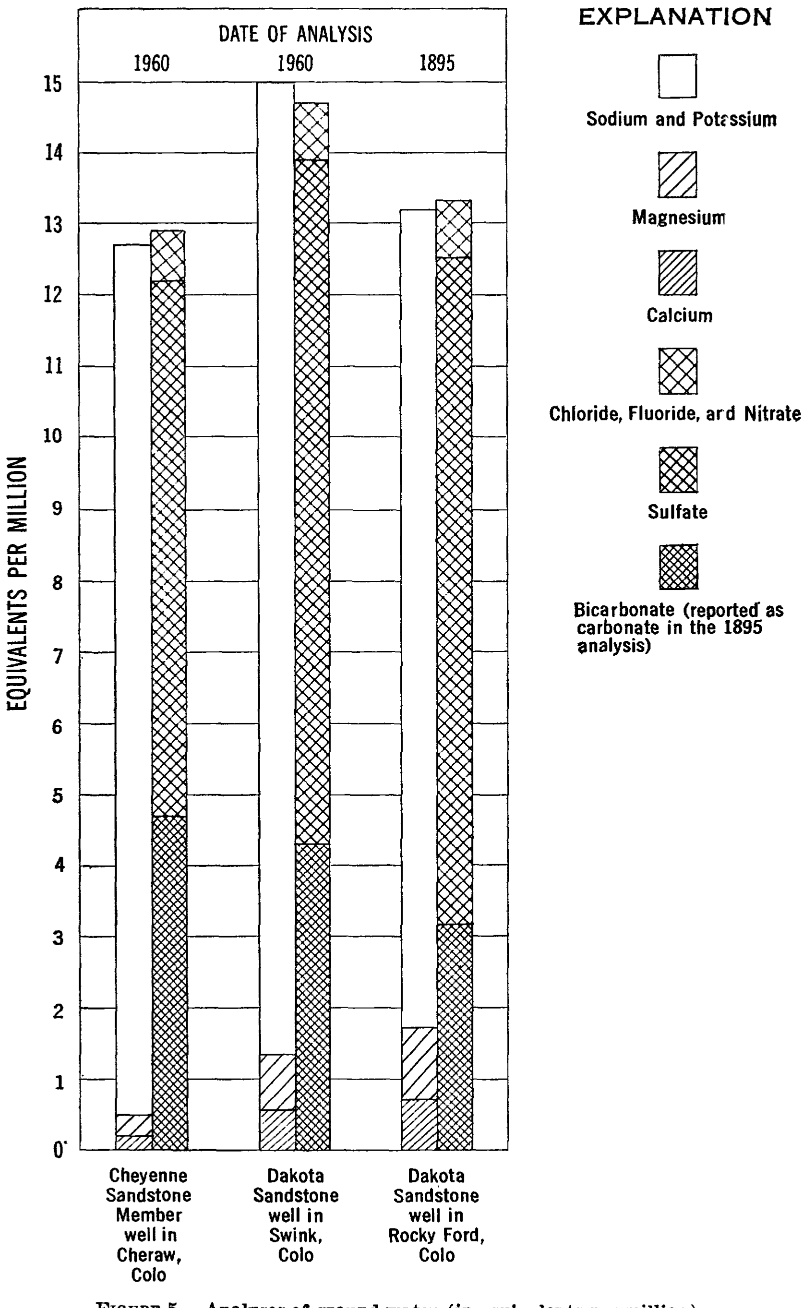



FIGURE 5.—Analyses of ground water (in equivalents per million).

analyses of water from the Cheyenne Sandstone Member and the Dakota Sandstone made in 1960 with an analysis made in 1895 of water from the Dakota Sandstone.

## CONCLUSIONS

Supplies of comparatively soft water for domestic and stock use are available nearly everywhere in Otero County and in the southern part of Crowley County. These supplies are available from the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation, which underlie nearly all of the area at depths ranging from 0 to 2,000 feet. In most places, supplies of water adequate for public supply and industrial use can be obtained. Water cannot always be obtained from these two aquifers in parts of the southeast corner of Otero County where the Purgatoire River and its tributaries have cut through and partially drained the aquifers. The aquifers may be too deep in the northwestern part of the area to be economically feasible for developing water supplies at the present time.

Water in the aquifers is generally under artesian pressure and rises in the wells for a considerable distance above the top of the aquifer. In several places, water flows from the wells. In certain areas, such as around Cheraw and La Junta, the pressure on the water has declined because of the withdrawals by the large number of wells penetrating the aquifers.

Pumped wells yield from 4 to 75 gpm; some flowing wells yield as much as 50 gpm.

The chemical quality of the water is generally good except in some places where it has a rather high iron and sulfur content. There is no noticeable difference in mineral content or character of water from the two aquifers.

## REFERENCES CITED

California State Water Pollution Control Board, 1952, Water-quality criteria: California State Water Pollution Control Board Pub. 3., 512 p., 4 figs.

Collins, W. D., Lamar, W. L., and Lohr, E. W., 1934, The industrial utility of public water supplies in the United States, 1932: U.S. Geol. Survey Water-Supply Paper 658, 135 p., 1 pl., 1 fig.

Darton, N. H., 1906, Geology and underground waters of the Arkansas Valley in eastern Colorado: U.S. Geol. Survey Prof. Paper 52, 90 p., 28 pls.

Gilbert, G. K., 1896, The underground water of the Arkansas Valley in eastern Colorado: U.S. Geol. Survey 17th Ann. Rept., pt. 2, p. 551–601, 13 pls., 5 figs.

Hem. J. D. 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p., 2 pls., 40 figs.

Patton, H. B., 1923, Underground water possibilities for stock and domestic purposes in the La Junta area, Colorado: Colo. Geol. Survey Bull. 27, pt. 1, p. 1–58, 2 pls., 4 figs. [1924].

U.S. Public Health Service, 1946, Drinking water standards: Public Health Reports, v. 61, p. 11. [Repr. 2697.]

Weist, W. G., Jr., 1962, Records, logs, and water-level measurements of selected wells, springs, and test holes, and chemical analyses of ground water in Otero and the southern part of Crowley Counties, Colorado: Colo. Water Conserv. Board, Basic Data Rept. 11, Ground-Water Ser., 54 p., 1 pl., 1 fig.

U.S. GOVERNMENT PRINTING OFFICE: 1963