

# Ground-Water Investigations in the Lower Cache la Poudre River Basin, Colorado

By LLOYD A. HERSHEY and PAUL A. SCHNEIDER, JR.

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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**UNITED STATES DEPARTMENT OF THE INTERIOR**

**STEWART L. UDALL, *Secretary***

**GEOLOGICAL SURVEY**

**Thomas B. Nolan, *Director***

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ABSTRACT

Ground water is a major natural resource in the lower Cache la Poudre River basin. During periods of low precipitation and short surface-water supply, supplemental irrigation water from ground-water sources provides the needed moisture to sustain crops in this predominantly agricultural area. The lower Cache la Poudre River basin lies in northwestern Weld and northeastern Larimer Counties, Colo., and contains about 800 square miles of irrigated, dry-farmed, and grazing land.

Alluvial deposits overlying rocks of Late Cretaceous age constitute the principal aquifers in the area. Yield from the alluvium ranges from a few gallons to 2,000 gallons per minute. Because of the availability of surface water, ground water is used principally as a supplemental irrigation supply. During periods of low surface-water supply, heavy pumping of wells substantially lowers the water table in parts of the area, but the ground-water reservoir recovers after normal precipitation has resumed.

Principal sources of recharge to the aquifers are seepage from ditches and storage reservoirs, downward percolation of applied surface water, and precipitation.

About 86,000 acre-feet of ground water was pumped for irrigation in the lower Cache la Poudre River basin in 1959; an average of 78 acre-feet per well was applied to irrigation during the same year.

The chemical quality of ground water used for irrigation in the lower Cache la Poudre River basin has been evaluated from the analyses of 88 water samples collected during the study. Dissolved-solids content is the principal factor of evaluation for these samples. High concentrations of calcium and sulfate cause some of the water to be undesirable for irrigation use under average soil and drainage conditions. Good soil and drainage conditions and the use of surface-water reduce the hazard of applying the locally highly mineralized water to crops.

INTRODUCTION

Ground water is a major natural resource and the principal source of supplementary irrigation water in the lower Cache la Poudre River basin, especially during periods of low precipitation and short sur-

face-water supply. Ground water has also been developed for stock and domestic supplies from alluvial and bedrock aquifers. The principal source of ground water for irrigation is the alluvium of the flood plain and the terrace deposits of the Cache la Poudre River and its tributaries.

Water supply for agriculture in the project area is largely dependent on surface water. Surface water is distributed to the area by more than 30 major canal systems and from about 75 storage reservoirs. The canals divert water from the Cache la Poudre River northwest of Fort Collins, Colo., and from various points along the stream valley. Irrigation supplies are drawn directly from the diversion canals as needed, and some of the water is diverted to storage reservoirs.

#### LOCATION AND EXTENT OF THE AREA

The lower Cache la Poudre River basin, as defined in this report, is an area of about 800 square miles and includes parts of northwestern Weld and northeastern Larimer Counties, Colo. (fig. 1). Most of the area lies north of the lower Cache la Poudre River between La Porte, Colo., and the junction of the Cache la Poudre River with the South Platte River east of Greeley, Colo.

#### PURPOSE AND SCOPE OF THE INVESTIGATION

This investigation is one of a series of studies being made by the U.S. Geological Survey for the U.S. Bureau of Reclamation as a part of the program of the Department of the Interior for the development of the Missouri River basin.

Ground water has been extensively developed for irrigation in the lower Cache la Poudre River valley during the past 30 years. This study is to evaluate the present state of development and to determine hydrologic relationships within the project area. In addition, the chemical quality of the ground water is evaluated in terms of its suitability for crop irrigation. This report presents preliminary data on the relative availability of ground water, the extent of present development, the chemical quality of water, the hydrologic relationships, and the critically overdeveloped areas.

Ground-water investigations in Colorado are under the direct supervision of E. A. Moulder, district engineer for Colorado. The quality-of-water investigations are under the direction of D. M. Culbertson, district engineer in charge of quality-of-water studies in the Missouri River basin.

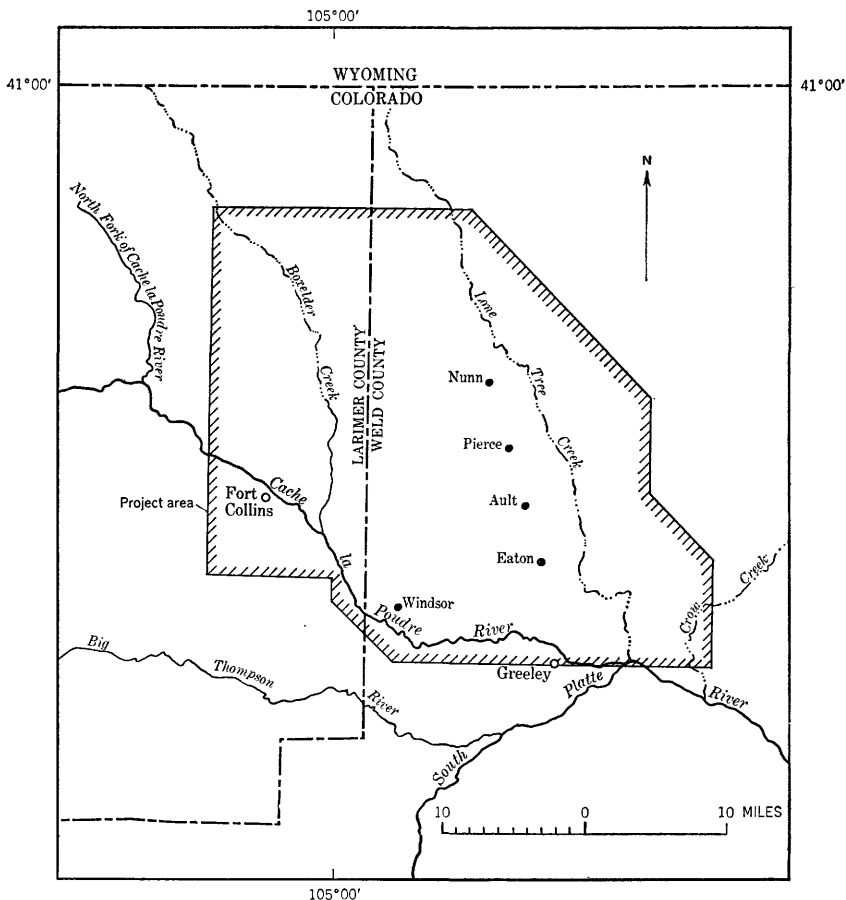


FIGURE 1.—Map showing the location of the project area in Larimer and Weld Counties, Colo.

### WELL-NUMBERING SYSTEM

The well numbers in the text and on the illustrations indicate well locations. The numbering system is based on the U.S. Bureau of Land Management system of land subdivision. The number shows the location of the well by quadrant, township, range, section, and position within the section. A diagram showing the method of well 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 meridian—A indicates the northeast quadrant, B the northwest quadrant, C the southwest quadrant, and D the southeast quadrant. The first numeral indicates the township, the second indicates the range, and the third indicates the section in which the well is located.

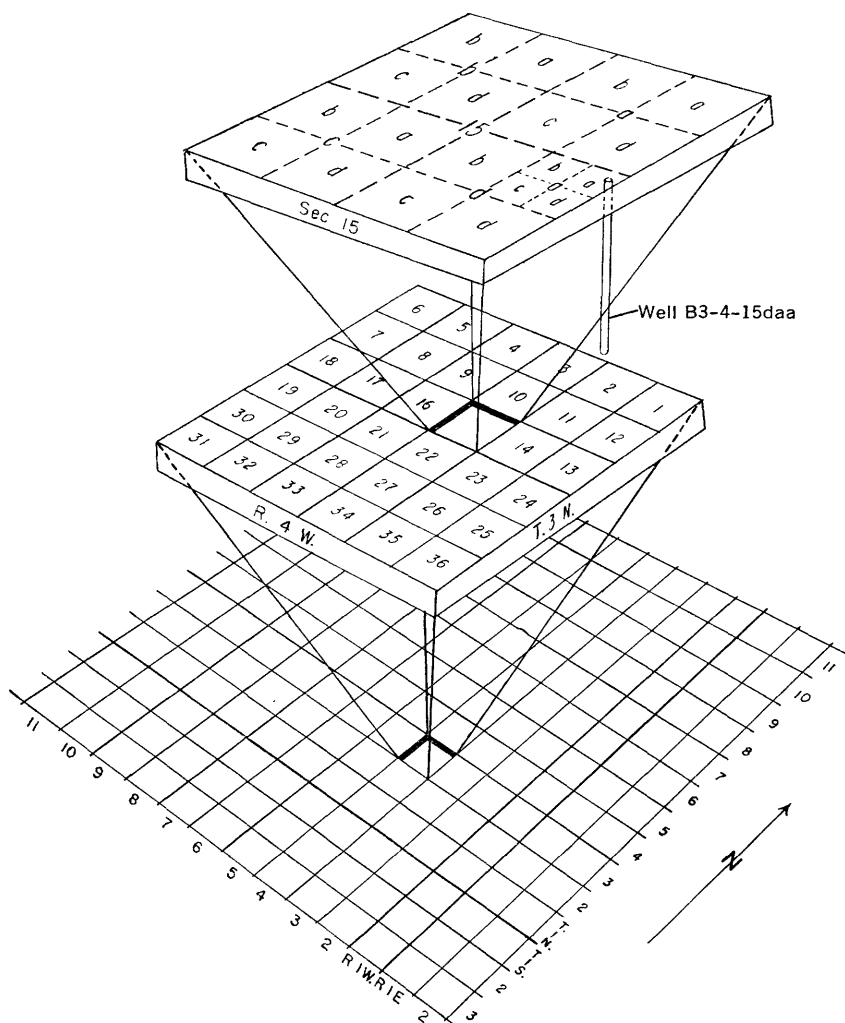


FIGURE 2.—System of numbering wells and test holes in Colorado.

Lowercase letters following the section number locate the well within the section. The first letter denotes the quarter section, the second denotes the quarter-quarter section, and the third denotes the quarter-quarter-quarter section. The letters are assigned within the section in a counterclockwise direction, beginning with "a" in the northeast quarter of the section. Letters are assigned within each quarter section and within each quarter-quarter section in the same manner. Where two or more wells are located within the smallest subdivision, consecutive numbers beginning with 1 are added after the letters in the order in which the wells or test holes were inventoried. For example,



B6-66-29cba2 indicates a well in the northeast quarter of the northwest quarter of the southwest quarter of sec. 29, T. 6 N., R. 66 W., and shows that this is the second well inventoried in the quarter-quarter-quarter section. The capital letter B indicates the township is north of the base line and that the range is west of the principal meridian.

### ACKNOWLEDGMENTS

Data on water-table fluctuation were obtained from the Colorado State University Experiment Station. Records of power consumption for wells were made available by private and public utilities operating in the report area. Well owners supplied much valuable data on well performance and general information on water development. Records of the Colorado Water Conservation Board were very helpful in supplementing the well inventory. Information on soil conditions and irrigated acreage was supplied by the Soil Conservation Service, U.S. Department of Agriculture.

### GEOGRAPHY

#### PHYSIOGRAPHY AND DRAINAGE

The report area is a part of the Colorado Piedmont section of the Great Plains physiographic province. The area ranges in altitude from about 4,600 feet where the Cache la Poudre River joins the South Platte River in the extreme southeastern part of the area to about 5,700 feet along the western and northern uplands. The area includes three general types of topography: (1) dissected uplands, which are broadly rolling and in places are scarped; (2) relatively flat discontinuous uplands; and (3) valleys having nearly flat profiles.

The Cache la Poudre River is the largest tributary of the South Platte River. The lower Cache la Poudre River is the reach of the stream that flows southeastward for a distance of 32 miles from its entry of the report area at Laporte, Colo., to the confluence with the South Platte River east of Greeley, Colo. Drainage tributary to the Cache la Poudre River is principally from the north and west. Most of the minor drainages that were formerly tributary to the mainstem now terminate in irrigation canals north of the river.

Boxelder Creek is the principal tributary of the lower Cache la Poudre River; it flows southward through the project area from its point of emergence from the foothills in the northwestern part of the area for about 20 miles to the mainstem. Lower Boxelder Creek is principally an intermittent stream in its upper reaches but becomes perennial southeast of Wellington.

Lower Lone Tree, Spring, and Owl Creeks are intermittent streams that provide the principal drainage for the area north of

Greeley. These creeks form a complex drainage system that occupies a relatively broad valley that contains discontinuous remnants of former stream divides. Lone Tree Creek drains southeastward for about 35 miles from the point where it enters the northern project boundary to the South Platte River half a mile east of the mouth of the Cache la Poudre River. Spring Creek heads north of the project boundary and drains southeastward for about 16 miles in the report area; its drainage becomes discontinuous south and east of Pierce. Owl Creek also heads north of the report area and drains southeastward along the east margin of the tributary valley for a distance of 9 miles into Owl Creek Reservoir.

#### CLIMATE

The climate from the foothills west of Fort Collins to the Greeley area is characterized by low relative humidity, annual precipitation of less than 15 inches, cold winters, and warm summers. The mean annual temperature recorded at Greeley and Fort Collins is 48 °F. The first killing frost occurs about September 30 and the last killing frost about May 9. The highest recorded temperature in the area was 107 °F at Greeley in July 1936; the lowest temperature of record was -45° F at Greeley in February 1899.

Most of the precipitation in the report area occurs from April through September, but its distribution is often erratic; prolonged dry spells often occur during the growing season.

#### AGRICULTURE

Irrigated farming is common in the uplands and valleys served by irrigation canals. In the valley lands, north of the irrigation canals, limited irrigation is carried on with water obtained from wells. The principal crops raised on the irrigated farms are sugar beets, corn, and alfalfa. Cattle feeding also is commonly practiced in the irrigated area. North of the irrigated lands, dryland farming is practiced, and the principal crop is wheat. Livestock grazing is the predominant type of agriculture in the extreme northern part of the project area.

#### GENERAL GEOLOGY

##### BEDROCK

The bedrock formations consist chiefly of sandstone, limestone, shale, and coal of Late Cretaceous age.

The formations dip generally eastward from the foothills at the western margin of the area. Dips along the foothills range from 25° to 35°; farther east along the Larimer County line, the dips range

from  $3^{\circ}$  to  $6^{\circ}$ . A reversal of dip occurs in the area north of Fort Collins, where the formations have been folded into a series of northward-trending anticlines. The Fort Collins and Wellington oil fields are situated on these structural features. Black Hollow Field, which is located several miles east of Black Hollow Reservoir, is underlain by an anticlinal structural feature of low relief. (See Rocky Mountain Association of Geologists, 1954, p. 102-103.) Similar low-relief structural features probably underlie the Pierce and New Windsor oil fields but are difficult to recognize because of the mantle of slope wash and alluvial deposits.

Lithology and water-bearing characteristics of the bedrock formations are summarized in table 1.

Sandstones of the South Platte and Lytle Formations dip steeply eastward from the mountain front and form prominent hogbacks along the western margin of the project area. These formations compose the Dakota Group and consist of massive and lenticular sandstone, varicolored claystone, and dark-gray to black clay shale.

The Mowry Shale, Greenhorn Limestone, and the Carlile Shale overlie the Dakota Group. The thin-bedded shales and chalky limestones of these formations are less resistant to erosion than either the Dakota Group or the overlying Niobrara Formation, and thus, their area of outcrop is a valleylike depression.

The Niobrara Formation consists of chalky shales and thin-bedded chalky limestones. The basal limestone unit forms a persistent low hogback along the eastern margin of the foothills. North of Fort Collins, limestone from the Niobrara is quarried extensively for use in the manufacture of cement.

Overlying the Niobrara Formation is the Pierre Shale, which consists of a sequence of interbedded sandy shale, mudstone, and massive to lenticular sandstone. Pediment deposits, slope wash, and alluvium cover much of the Pierre Shale in the area under study; however, sandstone members are conspicuously exposed on the Wellington and Fort Collins anticlines and for several miles south of Fort Collins along U.S. Highway 287. The Pierre Shale becomes increasingly sandy in its upper part and grades into the Fox Hills Sandstone. Exposures of this transition zone occur locally between U.S. Highway 87 and the low escarpment along the east side of Boxelder Creek valley.

The low escarpment that forms the east valley wall of the Boxelder Creek drainage is composed of fine- to medium-grained friable silty sandstone of the Fox Hills Sandstone. The sandstone is decomposed rapidly by weathering and, therefore, is poorly exposed, except where the formation has been sharply breached by artificial cuts or stream channels.

TABLE 1.—*Generalized section of the geologic formations in the lower Cache la Poudre River basin, Colorado*

Era	System or period	Series	Formation	Member	Approximate thickness (feet)	Physical character	Water supply
Cenozoic	Quaternary	Recent	Slope wash		0-25	Sand, gravel, and bedrock debris. Forms thin veneer on pediment slopes.	Yields small quantities of water that is generally of poor chemical quality to stock wells in some parts of the report area.
			Alluvium		0-100	Arkosic gravel and sand; locally contained sandy clay. Commonly cemented at the base with calcium carbonate. Occupies the flood plain and includes undifferentiated terrace deposits of the tributary valleys.	Yields moderate to large quantities of water to irrigation, municipal, industrial, domestic, and stock wells. Chemical quality of the water is generally poorer in the southern and eastern limits of the Cache la Poudre and tributary valleys.
		Pleistocene	Terrace deposits		0-130	Arkosic gravel and sand; contain some zones cemented with calcium carbonate, caliche, and limonite. Range from 25 to 100 feet above the flood plain of the Cache la Poudre River.	Yield moderate to large quantities of water that is of fair to poor chemical quality, to irrigation, stock, and domestic wells.
			Pediment deposits		0-100	Arkosic gravel, sand, and red clay; contain cemented intervals. Occur in dissected upland areas above the alluvium and terrace deposits.	Yield small to moderate quantities of generally hard water to stock, irrigation, and domestic wells.
			Laramie Formation		60-400	Silty to sandy blue to gray shale; contains silty and carbonaceous sandstone, lignite, coal seams, ironstone, and clay. Lower part contains fine- to medium-grained sandstone, which has "salt-and-pepper" texture, and interbedded sandstone and sandy shale.	Yields small to moderate quantities of soft alkaline water to stock and domestic wells in the eastern part of the report area. Chemical quality varies with depth; yields are also reported from fractured coal beds.
			Fox Hills Sandstone	Milliken Sandstone	60±	Very fine angular silty yellowish-gray sandstone, massive; locally fossiliferous.	Yields small quantities of soft alkaline bicarbonate water to stock and domestic wells. Chemical quality varies in the report area; better quality water is obtained near the outcrop area, but quality becomes poorer with depth and distance from recharge area.
					130±	Fine- to very fine-grained, massive sandstone, grayish-yellow to yellowish-gray; contains discontinuous black shale lenses. Lower 65 ft contains massive sandstone separated by shale units.	
					2,000±	Transition zone. Yellowish-gray sandstone and sandy shale; locally contains dark iron-stained limestone concretions.	Yields small quantities of water to stock and domestic wells. Chemical quality is similar to that of the Milliken Sandstone Member.

## Cretaceous

## Upper Cretaceous

## Pierre Shale

Shale No. 4	3,000-5,000	Dark-gray shale.	Yields small quantities of water of poor chemical quality to stock and domestic wells. Production is principally from fracture zones near the outcrop area in the western part of the report area. Water produced from this formation is high in sulfate content.
Richard Sandstone	60-70	Fine olive-gray sandstone, massive; contains large orange-brown calcareous concretions.	Yields small quantities of water that is generally of poor chemical quality to stock and domestic wells in the Fort Collins-Wellington area. Water has a high dissolved-solids content and is particularly high in sulfate.
Upper sandstone and shale.	0-170	Sandy shale and thin silty sandstone.	Do.
Larimer Sandstone	0-150	Fine olive-gray sandstone, massive; contains brown sandy calcareous concretions and several ledge-forming sandstones.	Do.
Lower sandstone and shale	0-170	Sandstone and shale.	Do.
Rocky Ridge Sandstone	0-165	Fine olive-gray sandstone, massive; contains large calcareous sandstone concretions that weather to dark-brown.	Do.
Shale No. 3	300-600	Sandy shale.	Do.
Terry Sandstone	10-20	Medium yellowish-gray sandstone, thin-bedded to massive; contains fossiliferous calcareous concretions that range from 6 to 18 inches in diameter.	Do.
Shale No. 2	200-400	Shale.	Do.
Hygiene Sandstone	50-100	Medium-grained yellowish-gray sandstone, thin-bedded to massive; contains glauconite and carbonaceous material and has "salt-and-pepper" texture.	Do.
Shale No. 1	2,400-3,100	Dark-gray shale, bentonitic; contains concretions.	Not known to yield water to wells in the report area. May yield small quantities of water from fractures near the area of outcrop.
Smoky Hill Marl	280±	Calcareous medium- to dark-gray shale, fossiliferous, speckled; contains thin bentonite streaks and marlstone.	Do.

## Niobrara Formation

TABLE 1.—Generalized section of the geologic formations in the lower Cache la Poudre River basin, Colorado—Continued

Era	System or period	Series	Formation	Member	Approximate thickness (feet)	Physical character	Water supply
Mesozoic	Cretaceous	Upper Cretaceous	Niobrara formation	Fort Hays Limestone	30±	Limestone, massive, chalky, fossiliferous; contains large fossil mollusks, <i>Inoceramus deformus</i> .	Do.
			Carlile Shale	Codell Sandstone	20	Fine- to very fine-grained clayey sandstone. Generally capped by thin brown sandy limestone.	Not known to yield water to wells in the report area. May yield small quantities of water to wells where the sandstone is clean. Water becomes more mineralized with distance from the area of recharge.
					200±	Calcareous, black to brownish-gray, micaceous shale.	
			Greenhorn Limestone		85±	Chalky shaly limestone and slightly calcareous dark-gray shale.	Not known to yield water to wells in the report area.
		Lower Cretaceous	Mowry Shale		190±	Dense noncalcareous black shale; contains fish remains.	Do.
			South Platte Formation	Upper	240±	Silty gray to black shale and siltstone, locally calcareous and gypsiferous; contains scattered fossiliferous zones and fine-grained well-sorted quartzose sandstones, which form persistent cap rocks.	Do.
				Plainview Sandstone	35	Medium- to coarse-grained sandstone, locally conglomeratic; contains an interbedded sandstone and siltstone interval and a coarse-grained, in places conglomeratic, basal unit.	Reported to yield small quantities of water to domestic wells and springs near the hogbacks along the western boundary of the project area.
			Lytile Formation		80	Sandstone, varying in grain size and degree of sorting, porous, light-gray to white, locally conglomeratic (most commonly at the base); contains variegated claystone.	Do.
	Jurassic	Upper Jurassic	Morrison Formation		250±	Variegated shale and siltstone; contains grayish-white to white massive to interbedded limestone. Algal structure and mud cracks are common in the lower limestones.	Not known to yield water to wells in report area.
			Entrada Sandstone		40±	Fine- to medium-grained gray to pink sandstone, massive, crossbedded, porous; locally contains thin red sandy shale at base.	Not known to yield water to wells in report area. Wells could be developed where this sandstone is not drained in the western part of the report area.

	Paleozoic						
	Penn- sylvan- ian	Permian					
Prote- rozoic		Triassic			70±	Fine- to medium-grained orange to red sandstone, [massive, crossbedded, hard.	Yields small quantities of water having good chemical quality to domestic wells west of Laporte, Colo.
					500±	Thin-bedded dark-red sandstone and sandy shale; becomes massive toward the top.	Not known to yield water to wells in the report area.
				Upper	130±	Sandy red shale, sandstone, and siltstone; contains anhydrite and gypsiferous shale in the basal section.	Do.
					65±	Quartzose light-gray to yellowish-gray sandstone, crossbedded.	Do.
				Lower	225±	Sandy brick-red shale; contains massive and thin interbedded fine-grained pink sandstone in the lower part.	Do.
					250±	Fine-grained sandstone, massive, crossbedded; con- tains some fossiliferous zones and white to gray oolitic limestone units in the upper part of the sequence.	Do.
					300-800	Sandstone, arkosic conglomerate, and sandy limestone interbedded with sandy red shale; becomes more conglomeratic in the basal section.	Do.
						Granite, schist, and gneiss.	Do.
						Crystalline rocks	

Overlying the Fox Hills Sandstone are the silty lenticular sands, varicolored carbonaceous and often gypsiferous shales, and coals of the Laramie Formation. Because of its character, the formation is relatively nonresistant to erosion and is poorly exposed in the project area. Much of the Laramie Formation is covered by alluvium, slope wash, and pediment deposits.

#### **PEDIMENT DEPOSITS**

Several pediment surfaces underlie the uplands of the report area. These pediment surfaces were probably continuous over the entire area in the past, but only remnants now remain as gravel-capped benches or gently rolling hills. In places, the pediment deposits have been firmly cemented and form a resistant caprock. Dips of the remnants indicate that the slope of the pediment was southward from the northern boundary of the report area and eastward from the foothills of the front range.

In the Fort Collins area, the pediment deposits consist of dark-red bentonitic clay, sand, and gravel. These deposits range in thickness from 0 to 50 feet and average about 35 feet. The water-bearing gravels are generally overlain by 1 to 30 feet of clay. Drillers' logs indicate that one gravel bed ranging in thickness from 3 to 35 feet underlies much of the area, but—locally—thicknesses greater than 35 feet are found.

North of Waverly, pediment deposits consist of dark-red bentonitic clay and arkosic sand and gravel. The thickness of these deposits ranges from a few feet to more than 90 feet, and the average thickness probably does not exceed 30 feet.

Pediment deposits east of Boxelder Creek generally do not exceed 15 feet in thickness and, in many places, consist of a thin cover of coarse gravel that contains many rounded cobbles and small boulders.

#### **ALLUVIUM AND TERRACE DEPOSITS**

The alluvium and terrace deposits of the Cache la Poudre River and its tributaries consist of clay, sand, and gravel, which were derived partly from the local bedrock but mostly from the formations of the Front Range. Most of the material in the alluvium of the tributary streams has been derived from deposits of Tertiary and Pleistocene age that overlie the Upper Cretaceous bedrock north of the area.

The alluvium of the Cache la Poudre River probably does not exceed 80 feet in thickness and averages about 30 feet between Fort Collins and Greeley. The alluvium consists of sand, gravel, silt, and minor amounts of clay. Most of the samples of cuttings from test



holes drilled in the alluvium contained poorly sorted sand, arkosic gravel, and scattered cobbles. Coarse gravel and boulders have been reported by drillers, who have drilled wells in the alluvium of the Cache la Poudre west of Laporte.

The terrace deposits of the Cache la Poudre River consist of beds of sand, gravel, and clay and commonly contain intercalated lenses of sandy clay. In the area between Fort Collins and Greeley, the terrace deposits rarely exceed 35 feet in thickness. The Pleasant Valley terrace, north of Greeley, averages 60 feet in thickness but locally exceeds 100 feet.

The surface of the alluvium of lower Boxelder Creek forms a relatively flat alluvial plain ranging in width from less than half a mile in the upper reaches of the creek to about 3 miles at the mouth of the valley. The alluvium consists of sand and fairly well sorted fine to coarse arkosic gravel; it contains clay layers of variable thickness. Near the mouth of Boxelder Creek, the deposits are poorly sorted and contain much fine sediment. The average thickness of the alluvium is 50 feet; however, the deposits are generally thinner along the margins of the valley. A channel ranging from 70 to 100 feet in depth and about a quarter of a mile wide underlies the alluvium along the western side of the valley south of Wellington. Another segment of this channel is found several miles northwest of Wellington. The location of these channel segments is shown graphically on plate 2, where the pattern for yields of over 1,000 gpm (gallons per minute) indicates areas of greater saturated thickness.

Scattered thin terrace remnants are distributed along the upper reaches of the Boxelder Creek in the report area; south of Wellington, the terrace deposits are restricted to the west side of the valley. They are lithologically similar to the alluvium and generally do not exceed 25 feet in thickness.

The alluvium of Spring, Lone Tree, and Owl Creeks forms a broad, relatively flat plain north of Pierce. Southward, a bedrock divide separates the alluvium of Lone Tree Creek from that of Spring Creek. The alluvium of the two drainages averages 40 feet in thickness and consists of sand, very fine to medium arkosic gravel, and scattered cobbles.

Terraces are not extensive on the minor tributaries of the report area. Bryan and Ray (1940, p. 25) reported, "The stages appear to have been of short duration, and the streams were too feeble to accomplish complete gradation to the main streams at each successive change in grade level."

## AVAILABILITY OF GROUND WATER

Ground water is readily available throughout most of the report area; but because of poor chemical quality, some of the water from the bedrock aquifers is unfit for consumption by humans or stock. Most irrigation wells are in and near the principal stream valleys of the area (pl. 1).

Yields from irrigation wells in the report area range from less than 50 to as much as 2,000 gpm. The approximate yield that may be expected from aquifers in different parts of the area is shown on plate 2.

Wells in the immediate vicinity of Fort Collins are reported to yield an average of 15 gpm from the pediment deposits. Maximum reported yield in this area is 200 gpm from irrigation well B7-69-3cbc. The pediment deposits of the Fort Collins area are recharged principally by seepage from canals and by percolation from city water applied to lawns and small gardens. Wells drilled in remnants of the pediment that are isolated from sources of recharge are generally dry.

North of Waverly, the pediment deposits yield an average of 300 gpm to irrigation wells. Locally, where the pediment deposits are thicker, yields of 400 to 800 gpm have been obtained. Where the water table is shallow and the pediment deposits are thin, sumps have been dug to bedrock and are used as a source for irrigation water. These deposits are recharged by percolation of applied irrigation water, seepage from canals and storage reservoirs, and precipitation. During years of low precipitation and short surface-water supply, most of the wells that tap the pediment gravels yield appreciably less water.

Relatively few irrigation wells have been drilled in the alluvium of the flood plain in the lower Cache la Poudre Valley, because much of the area is subject to waterlogging.

The terrace deposits of the Cache la Poudre River occur principally along the north side of the valley. The average yield of wells tapping the terrace deposits is about 300 gpm. Ground water for irrigation has been intensively developed in the Pleasant Valley area north and east of Greeley, where wells penetrate as much as 90 feet of water-bearing material above the bedrock. The average yield of wells on the Pleasant Valley terrace is 700 gpm; yields of 1,300 gpm have been measured from wells located where the deposits are the thickest.

Ground water in the alluvium of Boxelder Creek valley has been intensively developed for irrigation. The average yield from irrigation wells tapping the alluvium of this valley is about 600 gpm. Yields greater than 1,000 gpm are obtained southwest and northwest of Wellington (pl. 2). The abrupt change in yield along the west

side of Boxelder Creek valley (pl. 2) is caused by a deep asymmetrical channel having a steep west wall.

Recharge of the Boxelder alluvium occurs by seepage from canals and reservoirs, percolation of surface water, and precipitation. Water-level fluctuations in well B9-68-27bab (fig. 3) show the influence of the availability of surface water on the stability of the water table.

Yields from irrigation wells in the alluvium of Spring Creek average 500 gpm. Somewhat smaller yields are obtained from the alluvium of Lone Tree Creek. The higher yields in the Spring Creek drainage may be attributed to the thicker deposits of saturated material.

North of Pierce, the alluvium is relatively thin, and yields to irrigation wells are generally less than 200 gpm. Code (1943, p. 25-26) stated:

A number of attempts were made to obtain wells north of the Pierce Lateral and below the Laramie-Poudre Canal. Water ran through this canal discontinuously for a few years previous to 1928, but none has run since. The plants were operated a few years and then abandoned when the water table dropped 5 to 10 feet.

The four irrigation canals that cross the alluvium of Spring and Lone Tree Creeks are probably the principal source of recharge for these alluvial aquifers. Percolation of applied surface water and precipitation also recharge the alluvium. The influence of recharge from surface water on the water table is shown by the fluctuation of the water level in well B7-66-14aba (fig. 3).

Ground water is available also from the alluvium of lower Crow Creek. Yields from irrigation wells tapping the alluvium of Crow Creek range from 100 to 700 gpm.

## EXTENT OF DEVELOPMENT OF GROUND WATER FOR IRRIGATION

### HISTORY OF DEVELOPMENT

The first irrigation well on record in the lower Cache la Poudre River basin was dug reportedly east of Eaton, Colo., in 1885 by E. F. Hurdle, who later dug two other irrigation wells in the same area.<sup>1</sup> The measured yield of one of the wells was reported to be 600 gpm. One of the wells was still in use in 1917.

A survey made during 1911-12 and reported in the "Sixteenth Biennial Report of the State Engineer" (Comstock, 1913) indicated that 27 wells were used for irrigation in the report area.

<sup>1</sup> Rohwer, Carl, 1953, History of irrigation by pumping from wells in Colorado: U.S. Dept. Agriculture unpublished report, 9 p.

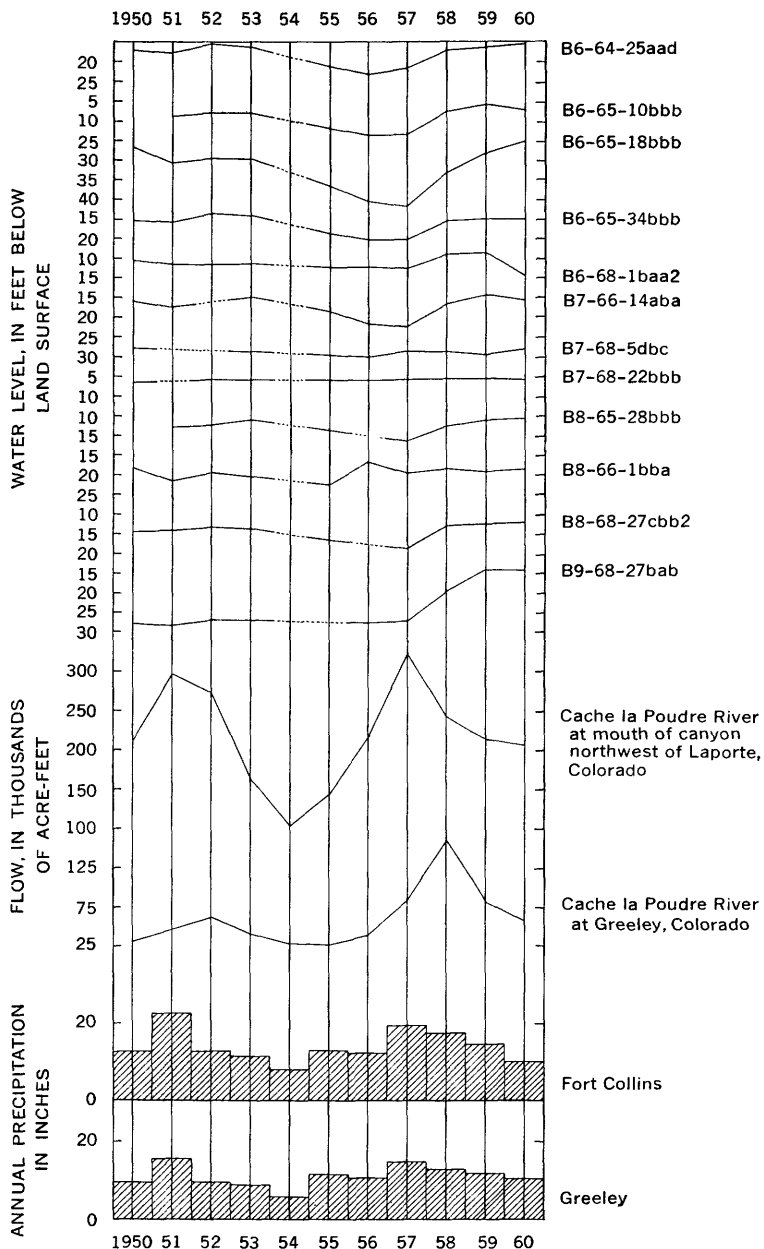


FIGURE 3.—Graphs showing the annual precipitation, streamflow, and water-table fluctuations for a 10-year period in lower Cache la Poudre River basin, Colorado.

A later study designed to show the extent of development of pumped irrigation wells in the south Platte River basin was made in 1940 (Code, 1943). This survey, under the direction of W. E. Code, was made by the Colorado Agricultural Experiment Station in cooperation with the Division of Irrigation, the Soil Conservation Service, the U.S. Department of Agriculture, and the Colorado Water Conservation Board. The survey included the lower Cache la Poudre River basin and disclosed that there were 593 irrigation wells in this basin.

The present study indicates that there were about 1,300 irrigation wells in the report area in 1959. Irrigation by pumping from wells received impetus during the drought period in the early 1930's. Also during this period, more efficient engines were developed, and electrical-power rates were reduced. The rapid increase in ground-water irrigation wells constructed in the report area from the mid-1930's to World War II is illustrated on figure 4.

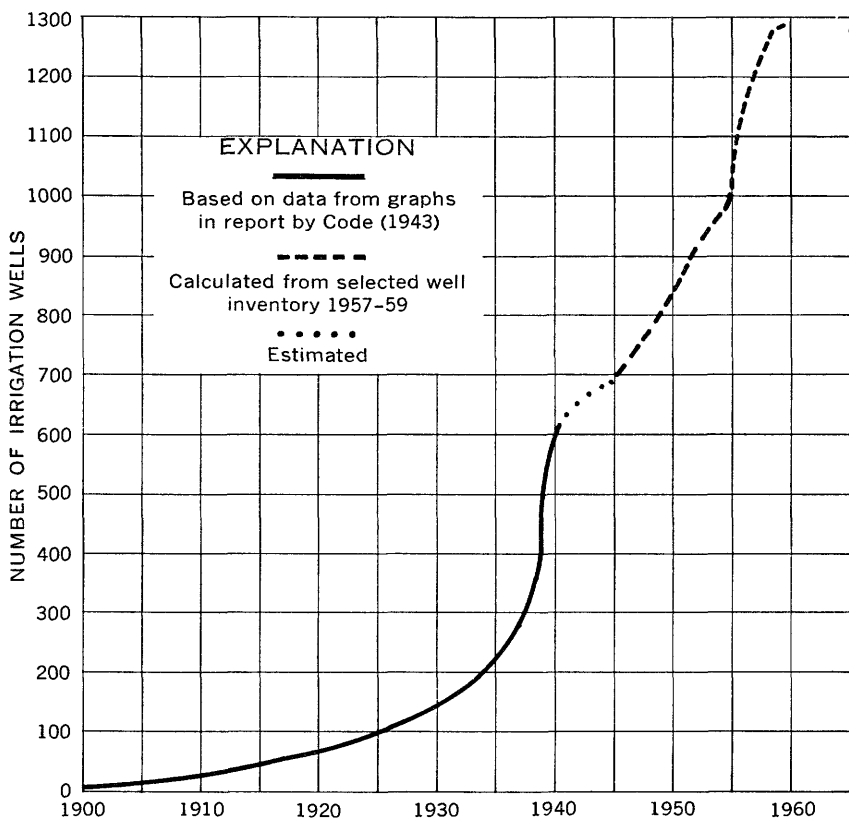


FIGURE 4.—Graph showing the rate of irrigation-well installation in the lower Cache la Poudre River basin, Colorado.

The latest well inventory indicated that fewer than 100 wells were drilled in the report area between 1941 and 1945. After World War II, the installation of irrigation wells continued at a constant rate until the dry spell of 1954-56; during this period, the rate of drilling and installation of irrigation wells increased markedly. By 1958, the rate of installation of new wells had leveled off, and the drilling of replacement wells was the principal activity in the report area through 1958 and 1959.

A comparison of the number of irrigation wells and the amount of water pumped in the report area for the years 1940 and 1959 is shown in table 2. The data in table 2 for 1940 are based on a report by Code (1943). Several areas that presently supply ground water for irrigation in the report area were not developed at the time of Code's investigation, or their data were included under the larger drainage areas in the report.

The amount pumped, in acre-feet, during 1940 and 1959 was estimated from measured discharges and records of electrical-power consumption. The average kilowatt-hours required to pump an acre-foot was applied to the power-consumption records of wells where conditions for measuring discharges were poor. Code (1943) also used measurements furnished by other agencies and estimates of fuel consumption of pumps that were powered by combustion engines. Nearly all pumps in the report area are now powered by electricity.

The decrease in the withdrawal rate per well between 1940 and 1959 indicated in table 2 may be attributed to (1) increased amounts of surface water available for diversion because of the completion of the Colorado-Big Thompson Project and (2) to a lesser extent to the increased number of wells that have been drilled in areas where the average yields are less than those of wells drilled prior to 1940.

TABLE 2.—*Irrigation from ground-water sources in the lower Cache la Poudre River basin in 1940 and 1959*

Area	Number of pumps in—		Estimated acre-feet pumped in—		Acre-feet per well in—	
	1940	1959	1940	1959	1940	1959
Cache la Poudre.....	188	360	16,000	29,000	85	80
Boxelder.....	59	200	6,000	19,000	101	95
Lone Tree and Spring Creeks.....	336	480	39,000	36,000	107	81
Crow Creek.....	10	20	( <sup>1</sup> )	400	( <sup>1</sup> )	20
Pediment.....	0	40	0	1,400	0	35
Totals.....	593	1,100	61,000	85,800	102	78
Average acre-feet per well pumped.....						

<sup>1</sup>No data available.

Although there may be some minor discrepancies between the definitions of areas of the 1940 and 1959 surveys, most of the figures in table 2 are directly comparable. Figure 5 shows the area boundaries and the pumpage data as applied within these areas.

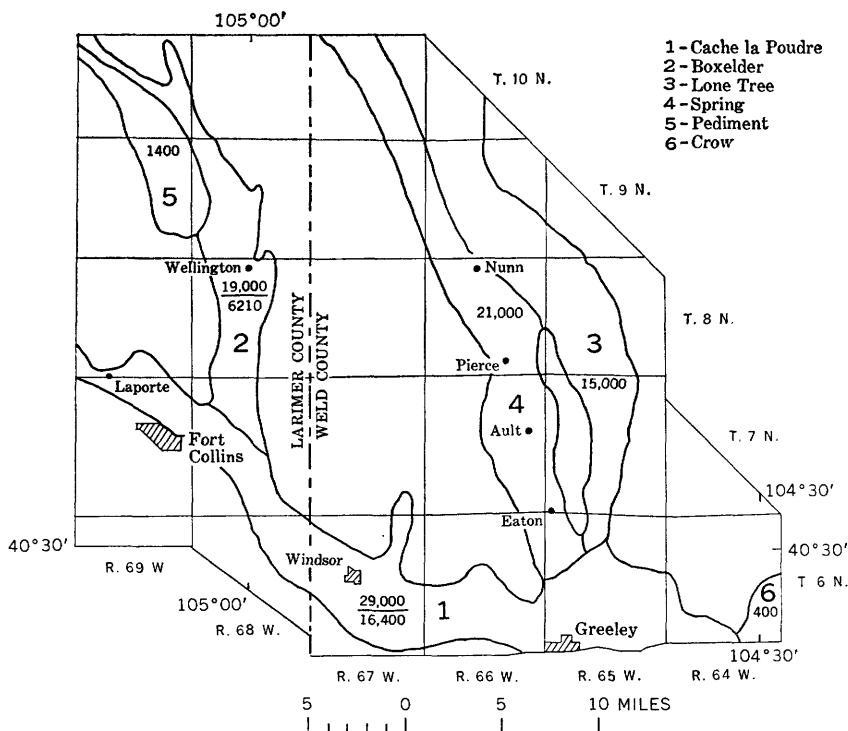


FIGURE 5.—Map of the lower Cache la Poudre River basin, Colorado, showing the approximate boundaries of the alluvial aquifers and pumpage by area for 1940 and 1959. Upper or single numbers indicate quantity pumped in 1959. Lower numbers indicate quantity pumped in 1940 in acre-feet.

### EFFECTS OF PUMPING

Fluctuations of the water table in the lower Cache la Poudre River basin have been observed by the Colorado Experiment Station since 1929. (See Code, 1958, p. 1.) Records for selected observation wells in the report area as reported by the Experiment Station for the period 1950-60 are illustrated on figure 3.

The water table in the lower Cache la Poudre Valley (fig. 5, area 1) is, in general, stable in the area between Fort Collins and Greeley. Recharge is available from surface-water sources or from applied ground water.

The greatest concentration of irrigation wells in the Boxelder Creek valley (fig. 5, area 2) is south of Wellington, where wells range in number from 3 to 11 per section. The heavy concentration of withdrawals has caused a lowering of the water table locally and a substantial decline in yields. The water table near Wellington has fluctuated considerably; Code (1958, p. 13) reported that "the lands in this area are under a canal that has suffered from short water supplies for some time. In consequence, there have been many wells drilled in the past 20 years, and the draft has exceeded replenishment much of the time." Abundant surface water during 1957 and 1958 has recharged the ground-water reservoir effectively in this area. However, during an extensive drought that requires total dependency on ground water for irrigation, lowering of the water table would spread southward toward the mainstem. South of Wellington, where other canals with perennially large supplies of surface water cross the valley, the water table is subject to less fluctuation.

In the Lone Tree and Spring Creek valleys (fig. 5, areas 3 and 4), the water-table fluctuations can generally be correlated with the amounts of surface water south of the Pierce Lateral. The water table in these valleys has declined locally as much as 15 feet because of increased pumping during periods of short surface-water supply, but it has recovered when surface-water supplies were restored to normal and pumping was reduced.

### SUMMARY OF CHEMICAL QUALITY

The chemical quality of ground water used for irrigation in the lower Cache la Poudre River basin is evaluated from analyses of 88 water samples collected during the study. The location and principal chemical constituents of representative samples are shown by the use of Stiff diagrams (Stiff, 1951) in plate 3. The Stiff diagrams show relative concentrations (in equivalents per million) of calcium, magnesium, and sodium, which are plotted to the left of an ordinate on three separate abscissas; concentrations of bicarbonate, sulfate, and chloride are similarly plotted to the right of the ordinate. The diagrams have a distinctive shape that depends on the type of water. The size of the area enclosed indicates the concentration of dissolved solids. By comparing the area of diagrams in the upper and lower parts of the drainages in plate 3, it becomes readily apparent that the dissolved-solids content generally increases downgradient and that the chemical character of the water changes markedly.

The chemical analyses of water samples collected from aquifers in the report area are given in table 5 of Colorado ground water basic-data report No. 8 (Schneider and Hershey, 1961). Chemical constit-



units in the basic-data report are reported in parts per million. A part per million is a unit weight of a constituent in a million unit weights of water. An equivalent per million is a unit chemical combining weight of a constituent in a million unit weights of water and is calculated by dividing the concentration in parts per million by the chemical combining weights of the constituent. For convenience in making this conversion, the reciprocals of chemical combining weights of the most commonly reported constituents are given in the following list:

<i>Constituent</i>	<i>Factor</i>	<i>Constituent</i>	<i>Factor</i>
Calcium ( $\text{Ca}^{++}$ )-----	0.04990	Bicarbonate ( $\text{HCO}_3^{--}$ )-----	0.01639
Magnesium ( $\text{Mg}^{++}$ )-----	.08226	Sulfate ( $\text{SO}_4^{--}$ )-----	.02082
Sodium ( $\text{Na}^+$ )-----	.04350	Chloride ( $\text{Cl}^-$ )-----	.02821
Potassium ( $\text{K}^+$ )-----	.02557	Fluoride ( $\text{F}^-$ )-----	.05264
Carbonate ( $\text{CO}_3^{--}$ )-----	.03333	Nitrate ( $\text{NO}_3^-$ )-----	.01613

Much of the ground water, particularly in the lower reaches of the tributary valleys, contains dissolved solids in amounts prohibitive to irrigation under normal conditions (U.S. Salinity Lab. Staff, 1954, p. 69-82). However, on well-drained sandy soils alternate heavy applications of good-quality surface water and applications of poorer quality ground water prevent concentration of the salts in the soils.

In times of deficient supplies of surface water and increased dependency on ground water, the high salinity hazard (U.S. Salinity Lab. Staff, 1954, p. 29) of the applied ground water may be expected to cause the soils to become saline and crop yields to decline. A pronounced increase in calcium and sulfate salts is a principal cause for the increase in the dissolved-solids content. Slope washing of the bedrock that contains gypsiferous shales or local concentrations of gypsum and reuse of ground water probably are the principal factors contributing to the increase in dissolved solids in the ground water. Locally, high concentrations of magnesium also occur.

The quality of water, for use in irrigation, is based principally on three characteristics: (1) dissolved solids, (2) sodium-adsorption-ratio (SAR), and (3) concentration of boron (U.S. Salinity Lab. Staff, 1954, p. 75). Classification of irrigation waters in this report is based on the assumption that conditions are normal in relation to soil texture, infiltration rate, drainage, quantity of water applied, climate, and tolerance of crop.

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