Geology and Ground-Water Resources of Laramie County Wyoming

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1834

Prepared in cooperation with the Wyoming State Engineer

Geology and Ground-Water Resources of Laramie County Wyoming

By MARLIN E. LOWRY *and* MARVIN A. CRIST

With a section on

CHEMICAL QUALITY OF GROUND WATER AND OF SURFACE WATER

By JOHN R. TILSTRA

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS66-309

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

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By MARLIN E. LOWRY and MARVIN A. CRIST

ABSTRACT

Laramie County, an area of 2,709 square miles, is in the southeast corner of Wyoming. Rocks exposed there range in age from Precambrian to Recent. The most extensive aquifers in the county are the White River Formation of Oligocene age, which is as much as 500 feet thick and consists predominantly of siltstone; the Arikaree Formation of Miocene age, which consists of as much as 450 feet of very fine grained to fine-grained sandstone; and the Ogallala Formation of Miocene and Pliocene age, which consists of as much as 330 feet of gravel, sand, silt, and some cobbles and boulders. These formations are capable of yielding large supplies of water locally. Terrace deposits of Quaternary age yield moderate to large supplies of water in the southeastern and northeastern parts of the county.

In the Federal well field, large yields of water from the White River Formation are obtained from gravel lenses. In the eastern part of the county near Pine Bluffs, large yields are obtained from openings in the siltstone of the White River. Previous investigators reported that the large yields were obtained in areas where the formation is fractured and fissured. The authors of this report believe that the large yields from siltstone in the White River Formation are from pipes, sometimes called natural tunnels, rather than from fractures or fissures.

Little is known about the water-bearing properties of the pre-Tertiary aquifers in the county, but water derived from the pre-Tertiary formations would probably be of poor quality, except in the vicinity of the outcrop near the western edge of the county.

Precipitation is the principal source of recharge to the ground-water reservoirs. About 5 percent of the annual precipitation, or about 108,400 acre-feet per year, is estimated to be recharge. Only a small amount of additional recharge is from streams. The general movement of ground water is eastward, and the average gradient of the water table is about 40 feet per mile.

The total amount of ground water pumped from wells in Laramie County during 1964 is estimated to be 28,000 acre-feet; about 6,000 acre-feet was used for municipal and industrial supplies, about 17,000 acre-feet was used for irrigation in the Pine Bluffs–Carpenter area, and about 5,000 acre-feet was used for other purposes. The balance of the recharge (80,400 acre-feet) is estimated to be discharged by the following means: 20 percent by underflow, 20 percent by streamflow, and 60 percent by evapotranspiration.

The coefficient of transmissibility of the Ogallala Formation, determined by averaging data from 28 pumping tests made in the Cheyenne municipal well

field, is about 16,000 gallons per day per foot. However, this figure is an average of the more permeable zones, and the average coefficient of transmissibility of the Ogallala in the county is probably much less because of the heterogeneous character of the formation. A coefficient of transmissibility of 3,800 gallons per day per foot was calculated for the Ogallala, in the same vicinity that the pumping tests were made, by using a regional method of analysis. Although the average transmissibility of the Ogallala is considered to be low, large yields are obtained from gravel stringers and lenses in the formation. The maximum perennial yield from the Cheyenne well field is estimated to be about 1.6 billion gallons per year.

Moderate to large yields of water can be obtained in the north-central part of the county where the saturated thickness of the Arikaree Formation, or combined Arikaree and Ogallala Formations, is 200 feet or more.

Ground water has been developed throughout the county, but development has been intensive only in the Cheyenne municipal well fields near Cheyenne and Federal and in the Pine Bluffs lowland. The water level has been lowered as much as 40 feet in the Cheyenne well field and somewhat less in the Federal well field.

Interference between wells occurs in the Pine Bluffs lowland during the summer, when pumping is at a maximum, and additional development will aggravate the interference. At the present rate of development, no permanent lowering of the water table is likely to occur in this area in the near future; however, a great amount of additional development could possibly cause permanent lowering of the water table.

The chemical quality of water from the principal aquifers and streams is generally suitable for domestic, irrigation, and industrial uses. The water is predominantly of a calcium bicarbonate type and is very hard; its dissolved-solids concentration ranges from 167 to 688 parts per million. The chemical composition of water from the White River, Arikaree, and Ogallala Formations, and from the alluvium is generally similar, although small local differences are apparent within the formation. Comparison of older data with recent data indicates that water from the alluvium in the Pine Bluffs vicinity has increased in mineralization as a result of irrigation.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

Laramie County is one of the principal areas of ground-water development in the State, and many reports on ground-water conditions in the area have been written. The purposes of this investigation were to consolidate and update existing data, to determine the effect of the development of ground water on the hydrology of the area, and to study the hydraulic properties of the aquifers in order to better understand the relation between aquifers and the extent to which additional water can be developed from them.

The investigation was started in the winter of 1964 as part of the program of the U.S. Geological Survey in cooperation with the Wyoming State Engineer. The ground-water study was under the supervision of E. D. Gordon, district geologist of the Ground Water

Branch of the Geological Survey. The quality-of-water study was under the supervision of T. F. Hanly, district engineer of the Quality of Water Branch of the Geological Survey.

LOCATION AND EXTENT OF THE AREA

Laramie County occupies the southeast corner of Wyoming (fig. 1). Almost rectangular, it covers 2,709 square miles.

WELL-NUMBERING SYSTEM

Water wells, springs, and test holes cited in this report are numbered according to the Federal system of land subdivision (fig. 2). The first numeral of the number indicates the township, the second the range, and the third the section in which the well, spring, or test hole is located. The lowercase letters following the section number indicate the position of the well in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, and the third letter the quarter-quarter-quarter section (10-acre tract). The subdivisions of a section are lettered a, b, c, and d in a counterclockwise direction, starting in the northeast quarter. If more than one well is listed in a 10-acre tract, consecutive numbers starting with 1 are added to the well numbers.

PREVIOUS INVESTIGATIONS

Darton, Blackwelder, and Siebenthal (1910) mapped in detail the geology of the western part of the county as far north as lat 41°30′. Newhouse and Hagner (1957) mapped the Precambrian rocks in the northern part of the county, and Denson and Banks (written commun., 1965) mapped the Tertiary formations throughout the county. Master's theses by Gray (1946), Haun (1948), Brady (1949), Hammond (1949), and McGookey (1952) describe the geology along the east flank of the Laramie Range.

Several water-supply papers and circulars that cover parts of the area have been published by the U.S. Geological Survey. These are by Adams (1902), Meinzer (1917), Babcock and Rapp (1952), Rapp, Warner, and Morgan (1953), Babcock and Bjorklund (1956), and Bjorklund (1959). In addition, reports by Cady (1935), Theis (1941), Foley (1943), and Morgan (1946) have been placed on open file by the U.S. Geological Survey.

Other reports on ground-water conditions in the county include reports by the Wyoming Geological Survey (Knight and Morgan, unpub. data, 1936, 1937; Dockery, 1940) and reports by the U.S. Department of Agriculture (Burleigh and others, 1938; U.S. Dept. Agriculture, 1940).

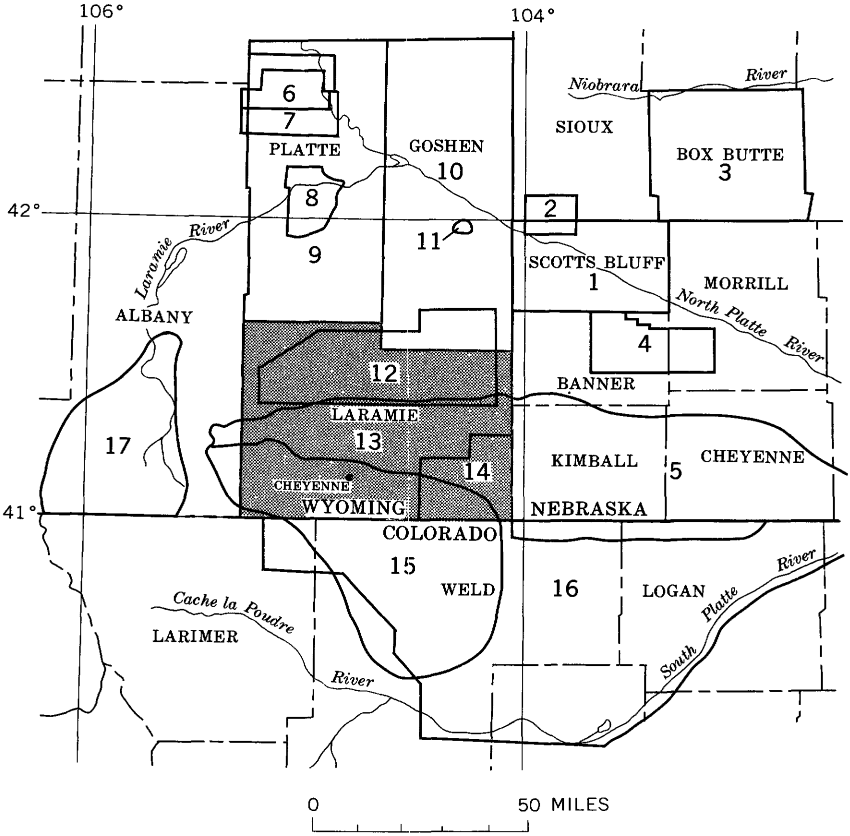

FIGURE 1.—Areas described in this report and in earlier ground-water reports on Laramie and nearby counties. Numbers on map refer to U.S. Geological Survey reports listed below. Type of publication identified as follows: WSP, water-supply paper; Circ., circular.

1	WSP 943	Wenzel, L. K., Cady, R. C., and Waite, H. W.	1946
2	Circ. 126	Babcock, H. M., and Visher, F. N.	1951
3	WSP 969	Cady, R. C., and Scherer, O. J.	1946
4	Circ. 156	Babcock, H. M., and Visher, F. N.	1952
5	WSP 1410	Bjorklund, L. J.	1957
6	WSP 1791	Welder, G. E., and Weeks, E. P.	1965
7	Circ. 163	Rapp, J. R., and Babcock, H. M.	1953
8	WSP 1783	Weeks, E. P.	1964
	Circ. 70	Littleton, R. T.	1950
9	WSP 1490	Babcock, H. M., and Morris, D. A.	1960
10	WSP 1377	Rapp, J. R., Visher, F. N., and Littleton, R. T.	1957
11	Circ. 238	Visher, F. N., and Babcock, H. M.	1953
12	Circ. 162	Babcock, H. M., and Rapp, J. R.	1952
13	WSP 1483	Bjorklund, L. J.	1959
14	WSP 1140	Rapp, J. R., Warner, D. A., and Morgan, A. M.	1953
15	WSP 1367	Babcock, H. M., and Bjorklund, L. J.	1956
16	WSP 1809–L	Weist, W. G., Jr.	1965
17	Circ. 80	Littleton, R. T.	1950

ACKNOWLEDGMENTS

The writers appreciate the cooperation of Pure Oil Co., Shell Oil Co., and local water-well drillers who furnished logs of holes drilled in

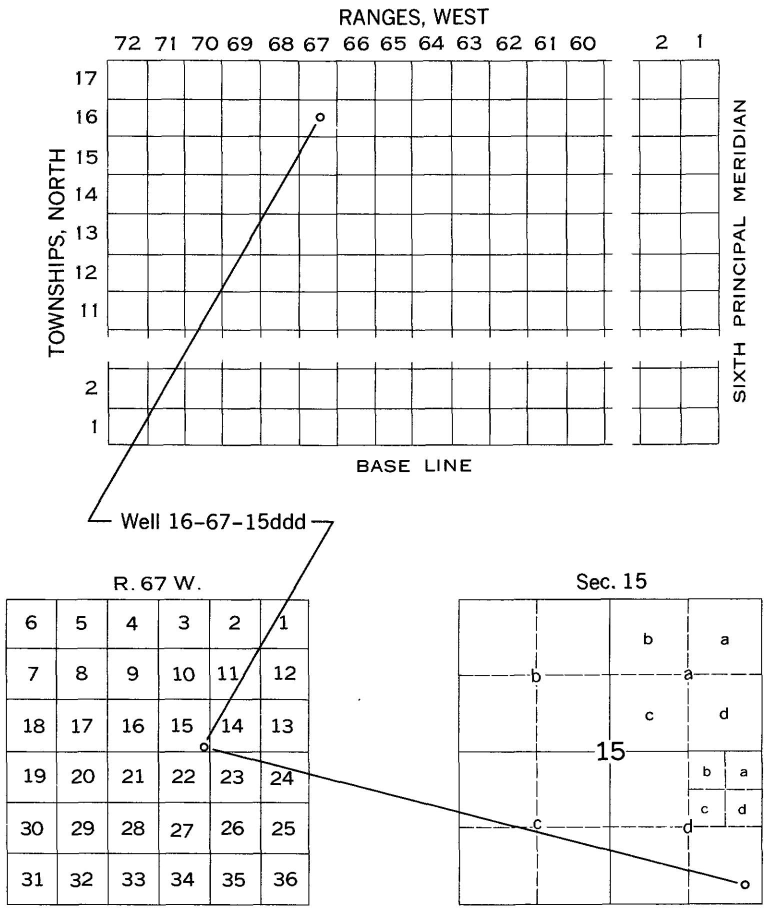

FIGURE 2.—Well-numbering system.

the area. Many well owners in Laramie County supplied information on their wells and gave permission for various measurements and tests. The writers are especially indebted to Mr. Ray Sherard, superintendent of the Cheyenne Water Department, for his cooperation during the pumping tests in the municipal well fields; to Adolpho K. Hanke, trainee from Brazil, who assisted during the pumping tests; and to L. J. McGreevy, of the U.S. Geological Survey, whose assistance in this study is greatly appreciated.

LANDFORMS AND DRAINAGE

Laramie County includes parts of the Southern Rocky Mountains and Great Plains physiographic provinces. The Laramie Range, which extends along the western edge of the county, is part of the

Southern Rocky Mountains. The mountain surface in many localities has been reduced to a relatively uniform plain that slopes gently eastward and is nearly smooth in gross appearance. The surface in other localities, however, is rough and irregular, and is broken by steep-sided valleys several hundred feet deep and by rugged mountain peaks.

North of Crow Creek, ridges of resistant sandstone and limestone form a line of foothills along the mountain front. South of Crow Creek, Tertiary deposits form a gradual slope from the mountains to the plains. This gradual slope, the "gangplank," is utilized by U.S. Highway 30 and the Union Pacific Railroad to gain access to the mountain uplands with the least possible grade.

The area east of the mountains lies in the High Plains section of the Great Plains physiographic province. The central part of the area is a high eastward-sloping surface underlain by Tertiary sediments. Gradients range from 100 feet per mile on the "gangplank" to 20 feet per mile near Albin, Wyo., at the eastern edge of the county. This surface has a gently rolling topography of only moderate relief and is marked by ephemeral and intermittent streams.

The high central area is nearly surrounded by escarpments. An escarpment extends northward from Granite Canyon along the east side of Federal and Chugwater Creek valleys; the Goshen Hole and related escarpments bound the north side of the area; and to the south, in Colorado, an escarpment that nearly parallels the Wyoming-Colorado State line extends eastward from the mountains. Two embayments extend into Wyoming from Colorado, one at Warrenton and a more extensive one in the Pine Bluffs-Carpenter area.

The county is drained by small eastward-flowing streams. Chugwater, Bear, and Horse Creeks are part of the North Platte River drainage, and Lodgepole, Crow, and Lone Tree Creeks are part of the South Platte River drainage. Horse and Chugwater Creeks are the only streams that are perennial throughout their course in the county. Crow Creek at one time was perennial from the mountains to the vicinity of Arcola, Wyo. (Foley, 1943, p. 9; Babcock and Bjorklund, 1956, p. 8), but the channel through the city well field is now dry. Other streams in the area are intermittent, alternately gaining water from and losing water to the ground-water reservoir.

CLIMATE

The climate of the area is characterized by high evaporation, wide temperature range, cold winters, and low precipitation. Strong winds are frequent during the winter and spring. Summer temperatures are relatively cool; on only 8 percent of the days in an average year are temperatures in the nineties. January is the coldest month; on 13 percent of the days in an average January temperatures are zero or below. The growing season in Laramie County averages between 130 and 140 days; and, at Cheyenne, the mean precipitation from 1871 to 1964 was 14.67 inches, about 70 percent of which fell during the growing season.

GEOLOGY

Rocks ranging in age from Precambrian to Recent are present in Laramie County. The sedimentary rocks are predominantly shale with smaller amounts of sandstone, siltstone, and limestone. Physical characteristics, thickness, and water-bearing properties of the formations are summarized in table 1. The geologic map (pl. 1) was compiled principally from existing maps. Because of the small scale of the map and the relative unimportance of the older formations as aquifers, many formations have been mapped together.

ROCKS OF PRE-TERTIARY AGE

Pre-Tertiary rocks have not been considered to be major aquifers in Laramie County, because other supplies are generally more readily available. There is, however, increasing need for an understanding of the total water resources of the area. For this reason, information on water-bearing properties is given for formations for which well data are not available. Much of the following discussion is inferred from data obtained in nearby areas.

The oldest rocks in the area are of Precambrian age and are exposed in the Laramie Range in the western part of the county. They have been mapped in some detail by Darton, Blackwelder, and Siebenthal (1910), and more recently part of the area was mapped by Newhouse and Hagner (1957). The rocks are principally granite, gneiss, and schist. Of these the most widespread is granite, which is normally massive and coarse grained, although locally it may be either fine grained or porphyritic (Darton and others, 1910, p. 5). The granite is weathered to depths of as much as 40–50 feet (Darton and others, 1910, p. 5), and it forms rounded hills. Where the granite is firm, weathering occurs principally along joints, and the rock has the appearance of stacks of rounded boulders.

Pre-Tertiary sedimentary rocks, which may have an aggregate thickness of as much as 12,000 feet, are exposed only in a narrow belt along the eastern mountain front, where the formations have been upturned and faulted. The dips of the beds range from 5° to vertical, and some beds are overturned. Anticlines east of the mountains cause reversals in dip in some areas. Horse Creek and Borie oil fields are on anticlines, and similar folds probably occur elsewhere.

TABLE 1.—*Summary of stratigraphic units and their water-bearing characteristics*

Era	System	Series	Subdivision	Thickness (feet)	Physical characteristics	Water supply
Cenozoic	Quaternary	Recent	Flood-plain deposits	0–85	Lenticular beds of fine to very coarse sand, gravel, silt, and clay; some cobbles and boulders.	Yield small to moderate supplies to wells.
		?—Pleistocene	Terrace deposits	0–200	Lenticular beds of coarse sand, gravel, silt, fine sand, and clay; some cobbles and boulders.	Yield large supplies to some wells.
	Tertiary	Pliocene	Ogallala Formation	0–330	Heterogeneous deposits of gravel, sand, and silt, containing some cobbles and boulders. May be either unconsolidated or well cemented.	Yields small to large supplies to wells.
		Miocene	Arikaree Formation	0–450	Loose to well cemented very fine grained to fine-grained gray to white sandstone and silt, containing hard concretionary zones. May be a coarse channel conglomerate at base in some areas.	Yields small to moderate supplies to most wells; large supplies could be obtained under optimum conditions.
		Oligocene	White River Formation	0–500	Predominantly a uniform brittle pinkish-brown siltstone. Contains beds of sandstone and conglomerate, principally near the mountains. Basal part of formation contains red and green clay with conspicuous iron staining.	Yields large supplies from conglomerate and openings in siltstone; however, will probably yield only small supplies in most areas.
			Lance Formation	200–1500	Light-gray to yellow-brown sandstone; contains beds of soft shale and coal.	Yields small supplies. Deeper wells would probably obtain moderate yields; however, the water may be unfit for some uses.

Mesozoic	Cretaceous	Upper Cretaceous	Fox Hills Sandstone	250±	Medium-grained gray to yellow-brown friable silty sandstone interbedded with dark shale.	Not known to yield water to wells in the area. Yields small to moderate supplies of water to wells south of the area, in Colorado. The water is of the sodium bicarbonate type (Babcock and Bjorklund, 1956).
			Pierre Shale	5700±	Predominantly dark-gray shale but has a thick persistant sandstone bed near the middle of the formation.	Yields small supplies of water, generally poor in quality, from sandstone and fractured shale. The formation is not considered to be a good source of water.
			Niobrara Formation	325–400	Limestone and calcareous shale.	Not known to yield water to wells in Laramie County. May yield small quantities from fractures near the outcrop, but the formations are not considered to be a potential source of water.
			Frontier Formation	550–600	Black and gray shale containing thin sandstone beds.	
		Lower Cretaceous	Mowry Shale	80	Upper part is dark-gray siliceous shale that weathers light gray; lower part is dark-gray shale.	
			Newcastle Sandstone	75–100	Coarse-grained massive sandstone.	Not known to yield water to wells in Laramie County but would probably yield small to moderate supplies. Two samples of water from the Horse Creek oil field were of the sodium chloride type and contained slightly more than 20,000 parts per million dissolved solids. The water is probably of better quality nearer the outcrop.
			Skull Creek Shale	70–150	Dark-gray fissile shale.	Not known to yield water to wells in the county, nor is it considered to be a potential source of water.
			Cloverly Formation	100–200	Flaggy tan sandstone, conglomerate, quartzite, siltstone, and shale. Outcrops consist of an upper and lower sandstone separated by shale.	Not known to yield water to wells in the county but might yield small to moderate supplies. A sample of water from the Horse Creek oil field was of the sodium bicarbonate type and contained 1,290 ppm dissolved solids.

TABLE 1.—*Summary of stratigraphic units and their water-bearing characteristics*—Continued

Era	System	Series	Subdivision	Thickness (feet)	Physical characteristics	Water supply
	Jurassic	Upper Jurassic	Morrison Formation	200–230	Variegated shale, thin sandstone, and limestone beds.	Not known to yield water to wells in the county. It is not considered to be a potential source of water.
	Jurassic	Upper Jurassic	Sundance Formation	40–100	Predominantly light-tan sandstone and greenish sandy shale.	Not known to yield water to wells in the county. Sandstone classed as a potential aquifer in Albany County (Littleton, 1950, p. 14) probably has similar water-bearing characteristics in Laramie County.
	Triassic		Chugwater Formation	430–500	Reddish-orange siltstone and very fine grained sandstone.	No wells known to penetrate these formations in the county. Not considered to be a potential source of water.
	Triassic	Lower Triassic	Goose Egg Formation	200–250	Reddish siltstone and sandstone interstratified with limestone, dolomite, and gypsum.	
Paleozoic	Permian					
Paleozoic	Carboniferous: Pennsylvanian		Casper Formation	800–900	Upper 600–700 feet consists of limestone and sandstone; lower part is reddish to reddish-yellow sandstone, quartzite, and arkose.	Yields large quantities of water to spring 13-69-8dbb. Would yield moderate to large supplies to wells.
Precambrian				(?)	Predominantly granite, gneiss, and schist.	Will yield small quantities of water from fractures or weathered zones at favorable locations.

The oldest known sedimentary rocks in Laramie County are equivalent to the Madison Limestone of Early and Late Mississippian age. The rocks, which consist of sandstone, siltstone, and limestone, are 45 feet thick at Farthing, Wyo., but wedge out near the Middle Fork of Crow Creek (Maughan, 1963, fig. 66.2). The formation is not differentiated in this report but is included with beds assigned to the Casper Formation.

The Casper Formation of Pennsylvanian and Permian age is divisible into two units. The lower unit, which correlates with the Fountain Formation of Pennsylvanian and Permian age, consists of about 200 feet of reddish-yellow sandstone, quartzite, and arkose. The upper unit, which correlates with the Ingleside Formation of Permian age, consists of 600–700 feet of limestone. The limestone forms the dominant hogback along much of the mountain front.

Overlying the Casper Formation is a red-bed sequence of Permian and Triassic age. As redefined by Maughan (1964), the Goose Egg Formation of Permian and Early Triassic age consists of about 200 feet of red beds interstratified with gypsum, limestone, and dolomite. The Chugwater Formation of Triassic age consists of about 500 feet of moderate-reddish-orange siltstone and very fine grained sandstone.

The Sundance and Morrison Formations, of Late Jurassic age, overlie the Chugwater Formation. They consist of about 300 feet of sandstone, greenish and variegated blue and olive-green shale, and thin beds of limestone. The rocks are generally soft and friable and weather to form slopes beneath the overlying Cloverly Formation.

Rocks of Early Cretaceous age include, in ascending order, the Cloverly Formation, Skull Creek Shale, Newcastle Sandstone, and Mowry Shale. The Cloverly Formation consists of two prominent sandstone units separated by soft shale. The thickness of the sandstone outcrops is highly variable locally. In sections measured by Lee (1927), the lower sand is 54 feet thick at Mill Creek and 25–45 feet thick at Chugwater Creek. The upper sandstone, at the same locations, is 12 and 30–40 feet thick, respectively. Where the sandstone outcrops are more resistant than adjacent strata, they form prominent ridges along the mountain front; elsewhere such surficial expression may be entirely absent.

The Skull Creek Shale consists of as much as 150 feet of dark soft fissile shale that often forms a narrow valley between steeply dipping strata of the underlying Cloverly Formation and the overlying Newcastle Sandstone. The Newcastle Sandstone is a coarse-grained massive sandstone that is as much as 100 feet thick, but the thickness varies considerably throughout the area. The overlying Mowry Shale consists principally of dark-gray siliceous shale and is about 80 feet thick.

Rocks of Late Cretaceous age include, in ascending order, the Frontier and Niobrara Formations, Pierre Shale, Fox Hills Sandstone, and Lance Formation. The Frontier Formation is about 600 feet thick and consists principally of nonresistant shale. The overlying Niobrara Formation is about 400 feet thick near the North Fork of Horse Creek (Darton, 1910, p. 9). The formation in that locality consists of light-orange calcareous shale and limestone, which are more resistant to erosion than adjacent formations.

Overlying the Niobrara Formation is the Pierre Shale. It is present in large areas north of Crow Creek, where it is exposed in many stream valleys. Elsewhere the formation is generally concealed by overlying thin pediment and terrace deposits. The Pierre consists of more than 5,000 feet of interbedded shale, sandy shale, and lenticular sandstone. The Pierre becomes increasingly sandy in its upper part and grades upward into the Fox Hills Sandstone.

The Fox Hills Sandstone, which consists of gray to yellowish-brown sandstone beds interbedded with sandy shale, was mapped by Darton (1910) principally along Horse Creek and in the Crow Creek drainage. Bergstrom (1953) (correlated the rocks along Horse Creek with the Mesaverde Formation of the Laramie Basin, and the youngest Cretaceous unit shown in the county on the State geologic map (Love and others, 1955) is the Mesaverde Formation. The Mesaverde is equivalent to a part of the Pierre Shale of this report. Fossils collected from SE¼ sec. 16, T. 14 N., R. 69 W. (USGS Mesozoic loc. D4865) are *Ostrea glabra* Meek and Hayden. A few specimens have faint radial ribs, which are common on the very late forms of the species, and may be from Fox Hills or Lance strata (W. A. Cobban, written commun. 1965). Time was not available for detailed mapping, and consequently the Pierre and the younger Cretaceous strata are not differentiated on the geologic map (pl. 1).

The Lance Formation, which overlies the Fox Hills, may be as much as 1,500 feet thick in the western part of the county, but it was beveled by erosion before deposition of the White River Formation and is only about 200 feet thick in the northeastern part. Exposures in Colorado were described by Babcock and Bjorklund (1956, p. 12) as light-gray to yellowish-brown sandstone and gray to bluish-gray soft shale and clay containing lenses of crossbedded sandstone and beds of coal. Sandstone concretions, which are cemented by limonite or calcium carbonate, occur throughout much of the formation. Beds of calcareous shale, coal, and sandstone are abundant in the lower part of the formation.

ROCKS OF TERTIARY AGE

WHITE RIVER FORMATION

The White River Formation of Oligocene age has been given group rank in nearby areas and divided into the Chadron and Brule Formations. In this report the Chadron and Brule are not differentiated. The White River overlies the truncated edges of older rocks, and it is as much as 500 feet thick. It is of remarkably uniform composition throughout Laramie County and adjacent areas, consisting predominantly of massive brittle argillaceous siltstone containing a few beds of sandstone, conglomerate, and volcanic ash. The siltstone is pinkish gray on fresh exposures. Near the base of the formation, red and green shale and coarse channel deposits are present. Denson and Bergendahl (1961, p. C170) described the White River Formation in southeastern Wyoming and adjacent areas as follows:

> In general, these rocks consist of 65 to 85 percent silt and 5 to 25 percent very fine grained sand imbedded in a matrix of clay-size particles. The silt and very fine grained sand fractions consist of glass shards and angular to subrounded fragments of quartz, potassium feldspar (microcline and orthoclase), plagioclase, and small amounts of detrital minerals. The clay-size fraction consists of montmorillonitic clay, clay size carbonate flakes, and fine volcanic ash.

Where the White River Formation has been extensively fractured, weathered outcrops often appear as assemblages of loose blocks that are only inches in size, but the fractures are less pronounced on fresh exposures. (See fig. 3.) The smooth, nearly vertical walls of the White River Formation are the result of weathering along clastic dikes similar to the one shown in figure 4.

The clastic dikes observed during the investigation are composed of material derived mainly from the White River Formation. All are nearly vertical, and they have no apparent preferred orientation. The dikes range from a fraction of an inch to 1½ feet in width, and many can be traced on the surface for several hundred feet.

ARIKAREE FORMATION

The Arikaree Formation of Miocene age is generally homogeneous and is considered to be a single hydrologic unit.

The formation is predominantly a very fine grained to fine-grained massive sandstone that contains beds of siltstone, layers of hard concretionary sandstone, and thin beds of volcanic ash. A basal conglomerate is present in many localities.

The following logs of test holes illustrate the composition of the formation. The terminology used is that of the driller with minor modifications by the authors.

FIGURE 3.—Fractured siltstone of the White River Formation, sec. 2, T. 14 N., R. 69 W. Fractures are much more pronounced on weathered surfaces, right and left background, than on freshly exposed surfaces, center.

Test hole (partial log) 19–67–5cdd

	Thickness (feet)	*Depth (feet)*
Arikaree Formation:		
Siltstone, clayey, sandy, organic, calcareous, brown	2. 5	2. 5
Sandstone, medium- to coarse-grained, trace of silt and clay, gravelly, micaceous, grayish-brown	5. 5	8
Sandstone, fine- to coarse-grained, silty, clayey, micaceous, grayish-brown	4. 5	12. 5
Conglomerate, well-cemented, brown and mottled grayish-brown; consists of ¼–1 in. subrounded igneous rock pebbles in a calcareous silstone matrix	9. 5	22
White River Formation.		

FIGURE 4.—Clastic dike in the White River Formation, NW¼ sec. 9, T. 12 N., R. 63 W.

Test hole (partial log) 16–63–30aaa

	Thickness (feet)	*Depth (feet)*
Ogallala Formation:		
Siltstone, sandy, clayey, reddish-brown	9. 5	97
Arikaree Formation:		
Sandstone, fine- to medium-grained, gravelly, tan; contains trace of silt	19	116
Siltstone, sandy, gravelly, tan	2	118
Siltstone and fine-grained sandstone, tan	5. 5	123. 5
Siltstone, massive, shaly, micaceous, moderately cemented, brown. Bottom 1 ft well cemented	7	130. 5
Sandstone, fine-grained, silty, pale-reddish-brown	36. 5	167

Test hole (partial log) 16–63–30aaa—Continued

	Thickness (feet)	*Depth (feet)*
Ogallala Formation—Continued		
Sandstone, fine- to coarse-grained, well-cemented, calcareous, dark-brown	5	172
Siltstone, well-cemented, calcareous, gray	2. 5	174. 5
Sandstone, fine-grained, silty, reddish-brown	17	191. 5
Sandstone, fine-grained, well-cemented, calcareous, brown	2. 5	194
Siltstone, sandy, reddish-brown	7	211
Sandstone, fine-grained, silty, well-cemented, calcareous, grayish-brown	11. 5	222. 5
Sandstone, fine-grained, silty, brown	22. 5	245
Sandstone, fine-grained, brown; contains trace of silt	26	271
Sandstone, fine- to medium-grained, very dense, brown; contains trace of silt, sandstone lenses	11. 5	282. 5
Sandstone, fine-grained, thin-bedded, well-cemented, calcareous, grayish-brown	15. 5	298
Sandstone, fine-grained, brown; contains trace of silt	27	325
Sand, fine, silty, slightly cemented, tan	19	344
Sand, fine, silty, tan; calcareous in part	10	354
Sand, fine to medium, brown; contains trace of silt	11	365
Sand, fine, brown; contains trace of silt	35	400

Erosion has removed the Arikaree in the southern and western parts of the county. The formation thickens rapidly to the north and northeast and it is about 500 feet thick along the Goshen Hole escarpment.

Numerous white resistant ledges occur in outcrops of the Arikaree Formation, in sharp contrast with outcrops of the less resistant overlying Ogallala Formation.

OGALLALA FORMATION

The Ogallala Formation of Miocene and Pliocene age unconformably overlies rocks that range from Miocene to Precambrian in age. The Ogallala consists of lenticular beds of sand and gravel deposited by braided streams and of silt, clay, and thin limestone beds deposited in temporary lakes. The gravel in the Ogallala was derived from the mountains to the west and consists mainly of quartz, quartzite, feldspar, gneiss, and schist.

The following logs of test holes show the heterogeneous character of the material and the change from predominantly coarse material near the mountains to finer material in the eastern part of the county. The terminology used is that of the driller with minor modification by the authors.

Test hole 17–68–28bca

	Thickness (feet)	Depth (feet)
Ogallala Formation:		
Clay, sandy, slightly organic, brown	3	3
Sand, fine to coarse, gravelly, slightly cemented, calcareous, grayish-brown	6	9
Conglomerate; consists of angular to subangular pebbles of granitic rocks in a tan silty sandstone matrix; poorly cemented in upper part, last 3 ft moderately cemented	21	30
Conglomerate; consists of 50–60 percent angular to subangular pink and gray pebbles of granitic rocks in a tan calcareous fine-grained sandstone matrix; slightly porous, moderately cemented, hard	34	64
Conglomerate; consists of 60–80 percent pebbles of granitic rocks in a fine-grained calcareous sandstone matrix	11	75
Conglomerate; consists of 60–80 percent angular to subangular pink and gray pebbles of granitic rocks in a tan calcareous fine-grained sandstone matrix, slightly porous, moderately hard. Occasional pebbles of buff very hard limestone from 101 to 109 ft. Occasional thin zones with sandy limestone matrix from 109 to 113 ft	41	116
Sandstone, medium- to coarse-grained, moderately cemented, calcareous, conglomeratic, hard, pink and tan	5	121
Conglomerate; consists of 60–80 percent angular to subangular pink and gray pebbles of granitic rocks in a calcareous medium-grained sandstone matrix, slightly porous, hard to very hard	9	130

Test hole (partial log) 16–63–30aaa

	Thickness (feet)	Depth (feet)
Ogallala Formation:		
Sand, fine to medium, clayey, slightly organic, brown	3	3
Sand, fine to coarse, very dense, tan; contains trace of silt and gravel	6	9
Gravel, fine to coarse, sandy, silty, tan	9	18
Sand, fine to coarse, silty, gravelly, pale-reddish-brown	9	37
Silt and fine sand, clayey, brown	6	43
Clay, silty, reddish-brown; contains trace of sand	9. 5	52. 5
Sand, fine to medium, tan; contains trace of silt	11. 5	64
Sand, fine to coarse, silty, pale-reddish-brown	13	77
Silt, sandy, micaceous, tan-brown; contains trace of clay	8	85
Sand, fine to medium, pale-reddish-brown; contains trace of silt	2. 5	87. 5
Silt, sandy, clayey, reddish-brown	9. 5	97
Arikaree Formation.		

Test well 16–60–3bbb

	Thickness (feet)	Depth (feet)
Ogallala Formation:		
Sand, fine to medium, silty, slightly organic, dark-brown	1.5	1.5
Sand, fine to coarse, gravelly, brown, contains trace of silt	16.5	18
Sandstone, fine-grained, well-cemented, calcareous, light-brown	7	25
Sand, fine to medium, silty, brown; contains occasional cemented nodules	6	31
Sandstone, fine-grained, well-cemented, calcareous, reddish-brown	4	35
Sand, fine, silty, brown; contains occasional cemented nodules	2	37
Sandstone, fine-grained, well-cemented, calcareous, reddish-brown	4.5	41.5
Silt, sandy, calcareous, reddish-brown	6.5	48
Sandstone, fine-grained, massive, slightly cemented, silty, reddish-brown	10.5	58.5
Sand, fine, silty, brown	6.5	65
Sand, fine to coarse, tan; contains trace of silt and gravel	13	78
Sand, fine to coarse, gravelly, tan; contains trace of silt	6	84
Sand, fine to coarse, tan; contains trace of silt and fine gravel	14	98
Sand, medium to coarse, and fine gravel, silty, reddish-brown	10	108
Sand, fine, silty, reddish-brown	12	120
Arikaree Formation:		
Sandstone, fine, silty, grayish-brown	10	130

The Ogallala is thickest in the western part of Laramie County, where 330 feet of the formation has been logged. It thins eastward to the State line, where 150 feet is exposed near Pine Bluffs (Rapp and others, 1953). The thickness elsewhere in the eastern part of the county is much less, and the exposure near Pine Bluffs is probably about the maximum thickness of Ogallala present near the Wyoming-Nebraska border.

Some resistant beds in the Ogallala, such as the one capping the escarpment at Pine Bluffs, are cemented by calcium carbonate. The topography where the Ogallala is exposed, however, generally consists of rounded hills and shallow valleys.

ROCKS OF QUATERNARY AGE

ALLUVIUM

Alluvium underlies terraces and flood plains throughout the county. It consists of lenticular beds of poorly sorted clay, silt, sand, gravel, and boulders that were derived from all the older rocks in the area. The coarse fraction is predominantly igneous rock derived from Tertiary formations and from Precambrian rocks of the Laramie Range. Thick deposits of alluvium are known only in areas immediately underlain by the White River Formation.

Logs of many wells show little difference between the composition of alluvium derived from the White River Formation and the White River Formation in place. Many of the reported fractured or porous zones in the White River are probably permeable alluvial deposits. Babcock and Bjorklund (1956, p. 14) stated that "In some places, a zone of loose material is present at the top of the formation [White River] where it is protected by a cover of younger deposits. This zone, which is as much as 15 feet thick, contains rounded pebbles of siltstone derived from the Brule Formation."

McLaughlin (1948, p. 12) noted that along Lodgepole Creek in Nebraska the "porous" zone in the White River was confined to the valley and did not extend beneath the bordering uplands. He stated (p. 13): "During the test drilling done by the town of Julesburg [Colo.], it was found that the 'porous' zone consists of moderately well rounded pebbles of reworked Brule clay [White River], the pebbles ranging in diameter from less than half an inch to more than 2 inches. Inasmuch as the so-called 'porous' zone is actually a deposit of coarse gravel that is confined to the zone underlying the alluvium, it perhaps should be considered a part of the alluvium."

The difficulty in distinguishing between the alluvium and the formation from which it was derived, whether White River or Ogallala, is probably why Bjorklund (1959, p. 15) found that the alluvium of Lodgepole Creek valley between the Wyoming State line and Chappell, Nebr., is relatively thin, averaging about 25 feet, whereas Rapp, Warner, and Morgan (1953, p. 47) stated that the alluvium along Lodgepole Creek in Wyoming is generally thin but is as much as 85 feet thick at some places.

TERRACE DEPOSITS

Terraces are widely distributed in the county but are generally topographically high and drained of water. The only terraces shown on the geologic map (pl. 1), however, are those in the Pine Bluffs lowland in the southeast corner of Laramie County and along Horse Creek in the northeast corner of the county. These are the areas where terraces are underlain by significant thicknesses of saturated alluvium.

Pine Bluffs lowland.—Terraces in the Pine Bluffs lowland have been discussed in detail by Rapp, Warner, and Morgan (1953), who divided them into older and younger terrace deposits. The older terraces include the surfaces that extend from about 4 miles south of the Colorado State line (Weist, 1965) in Rs. 61 and 62 W. northward to the valley of Lodgepole Creek. This terrace is a nearly continuous surface in Wyoming, cut only by Muddy Creek and its tributaries and

Crow Creek. A generalized map of the saturated thickness of the alluvium underlying the main part of the terrace is shown in figure 12.

The alluvium underlying one of the younger terraces along Lodgepole Creek was found to be 107 feet thick during a test drilling program in 1943. Drilling during this program provided data incorporated in the geologic sections shown in figure 5. The thickness of the alluvium underlying the other younger terraces is not known, mainly because of the difficulty in recognizing the White River Formation in the logs available. However, the level to which erosion occurs in tributaries is accordant with that in the main stream—Lodgepole Creek. Therefore, thick deposits of alluvium probably underlie the other younger terraces as well.

Horse Creek.—The terrace along Horse Creek in the northeast corner of the county is only about 8 miles long and, in most places, less than 1 mile wide. The alluvium underlying the terrace was deposited in a former course of Horse Creek, and the terrace surface is 40–60 feet above the present (1965) level of Horse Creek. Little is known about the thickness of the deposits. Well 18–62–12acd penetrated 65 feet of saturated terrace deposits, and test drilling would probably locate comparable thicknesses in other parts of the deposits.

FLOOD-PLAIN DEPOSITS

Most of the streams and dry washes are underlain by flood-plain deposits, but only the deposits along the major drainages are shown on plate 1. In most of the tributary valleys and some reaches of Horse and Lodgepole Creeks, the alluvium is very thin. In many of the tributary valleys, the alluvium may be above the water table. The thickest flood-plain deposits are in the Pine Bluffs lowland, where they are as much as 85 feet thick; known thicknesses elsewhere are less than 50 feet.

GROUND WATER

HISTORY OF DEVELOPMENT

Cheyenne and Pine Bluffs were established in conjunction with the building of the Union Pacific Railroad in 1867. Other than the railroad, there was little economic development in Laramie County until 1875. Cattle raising was the principal industry from 1875 to about 1893.

In 1909 farmers began to move into the eastern part of the county after methods had been developed for producing dryland crops. The communities of Burns and Carpenter were established at about this time. Since 1930 the rural population has decreased, but the county has experienced a rapid growth in population that is primarily attributable to the expansion of Cheyenne and its suburbs. The population of

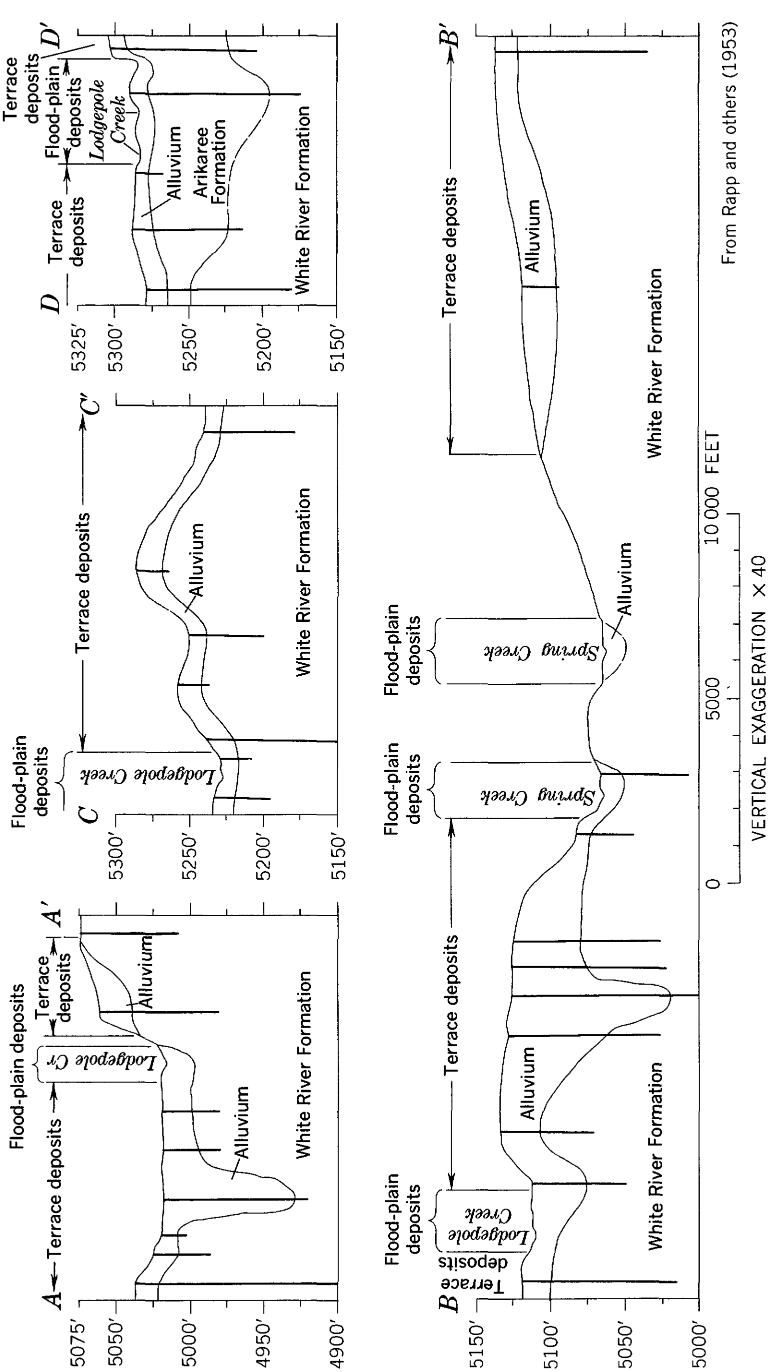

FIGURE 5.—Sections across Lodgepole Creek valley, looking upstream. (Location of sections shown on pl. 1.)

Laramie County in 1960 was 60,149, with about 87 percent of the people residing in the Cheyenne area.

Use of ground water for irrigation was started in the Pine Bluffs–Carpenter area during the drought years of the middle 1930's and by 1942 about 75 irrigation wells were in use. The number of wells increased to about 125 by the end of 1946, and by 1950 an estimated 210 wells were in operation (Rapp and others, 1953, p. 30). As of October 1964, there were about 220 irrigation wells in the Pine Bluffs–Carpenter area. However, many of these wells are not pumped every year. Nearly all the large wells in this area are equipped with electric motors, and records of the Rural Electric Co. at Pine Bluffs showed that 148 wells were in operation during 1964. A few wells were pumped during the year with some other type of power. Use of ground water for irrigation in this area has increased from an estimated 1,500 acre-feet in 1936 to an estimated 17,000 acre-feet in 1964.

The municipal water supply for Cheyenne (1960 population, 43,505) is about one-third ground water and about two-thirds surface water. The ground water is obtained from 44 wells in the municipal well fields west and northwest of Cheyenne, and from 2 collection galleries in the alluvium of Crow Creek, one in sec. 20, T. 14 N., R. 67 W., and another in sec. 27, T. 14 N., R. 67 W. Part of the surface water is obtained from the headwaters of Crow Creek, and since January 1964 an additional amount has been piped from Douglas Creek in the Medicine Bow Mountains about 50 miles west of Laramie County. The amount of water used annually by Cheyenne since 1941 is shown in figure 6. Included in the total is water supplied to F. E. Warren Air Force Base, the Frontier Gasoline Refinery, and the Union Pacific Railroad. In 1964, these three consumers used about 22 percent of the total water pumped to Cheyenne. A fertilizer plant that moved to the vicinity of Cheyenne in 1964 is expected to pump about 100 million gallons of ground water per year.

PRINCIPLES OF OCCURRENCE

Meinzer (1923a), Wenzel (1942), and several others have fully discussed the principles of the occurrence and movement of ground water. Only a few definitions and principles will be discussed in this report.

Porous rocks contain interstices, which are open spaces that form the receptacles for ground water. The size of the interstices in a sedimentary rock depends on the size of the particles, the degree of sorting, and the amount of compaction and cementation. Hard massive formations may have voids that result from deformation or solution that occurred after the rocks were laid down. Interconnected interstices form the conduits through which water may move in the rocks.

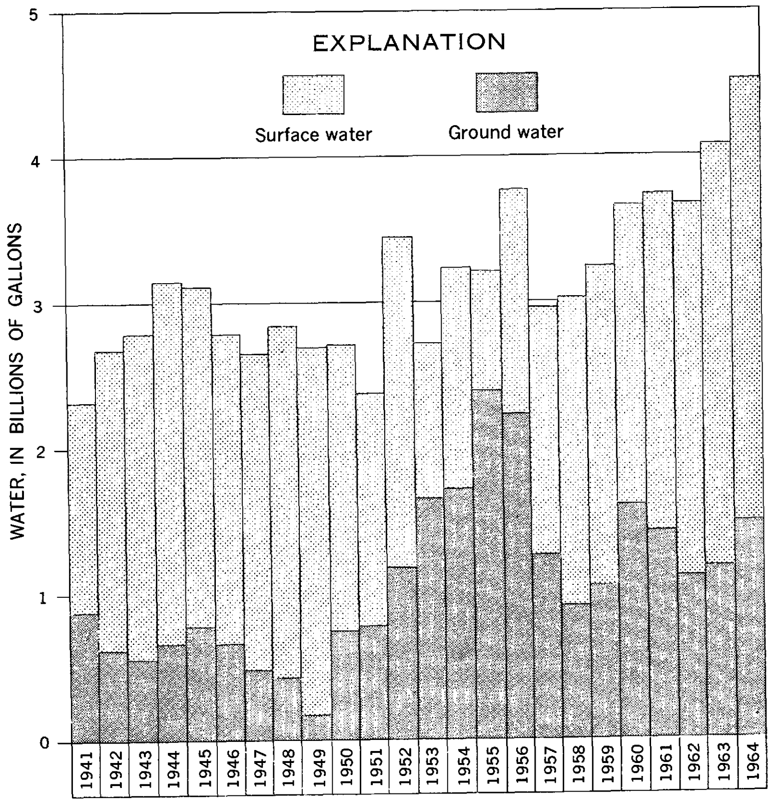

FIGURE 6.—Sources of Cheyenne municipal water supply and annual usage.

Permeability is the property of a porous material that permits it to transmit water through its interstices under a hydraulic gradient. In the more permeable rocks, such as deposits of unconsolidated sand and gravel, the interstices are relatively large and will permit free movement of water. Rocks such as claystone, siltstone, and fine sandstone are less permeable, so movement through them is much slower. Rocks that are capable of yielding recoverable quantities of water to wells are called aquifers.

The water table has been defined by Meinzer (1923b, p. 22) as "the upper surface of a zone of saturation except where that surface is formed by an impermeable body." The zone of saturation is that zone in which permeable rocks are generally saturated with water under hydrostatic pressure. The water table, which is not a flat surface, has irregularities related to those of the land surface, although smoother. It is not stationary; instead it fluctuates as water is added to or removed from the underground reservoir.

An artesian aquifer is one in which water will rise in a well to some level higher than the top of the aquifer. For this to occur, a relatively impermeable rock must overlie the aquifer and confine the water under pressure.

The piezometric surface of an aquifer is an imaginary surface that everywhere coincides with the static level of the water in the aquifer. It is the surface to which the water from a given aquifer will rise under its full head. If the piezometric surface is above the land surface, water in wells that penetrate the aquifer will flow. The piezometric surface is also irregular, but its irregularities may not be comparable to those of the land surface.

HYDRAULIC PROPERTIES OF THE PRINCIPAL AQUIFERS

The ability of an aquifer to transmit water and to yield water to wells depends on its hydraulic properties. The gross rate of movement of the water is proportional to the hydraulic gradient and to the permeability of the aquifer. The hydraulic gradient of an aquifer at a given place is the rate of change of pressure head per unit of distance at that place in that direction (Meinzer, 1923b, p. 38). Generally, for horizontal aquifers the hydraulic gradient is expressed as the ratio of the difference in static water level between two points to the horizontal distance between them.

The field coefficient of permeability, P, is a measure of the material's capacity to transmit water. It is defined as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at the prevailing water temperature and is expressed in gallons per day per square foot. The coefficient of transmissibility, T, is the rate of flow of water, in gallons per day, at the prevailing temperature through a vertical strip of the aquifer 1 foot wide extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 percent. The coefficient of transmissibility is equal to the average field coefficient of permeability times the saturated thickness of the aquifer and is expressed in gallons per day per foot.

The specific capacity of a well is the yield per unit of drawdown of the water level in the well and is generally expressed in gallons per minute per foot of drawdown. It is not a constant; it may decrease with increased pumping rates because of partial dewatering of the aquifer. The specific capacity will also decrease with time if the well is pumped continuously because the drawdown increases as the cone of influence of the well expands.

The coefficient of storage, S, of an aquifer is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component head normal to the surface. In unconfined aquifers the coefficient of storage is approximately equal to the specific yield, which is the quantity of water that a given saturated volume of the aquifer will yield by gravity drainage. The specific yield is the ratio of the volume of water given up by gravity drainage to the total volume of the aquifer that is drained.

WHITE RIVER FORMATION

The White River Formation yields small to large supplies of water to wells in Laramie County. Large yields,[1] over 350 gpm (gallons per minute), are obtained only in the Federal well field and in the Pine Bluffs lowland; however, well 19–66–17cda near Bear Creek and well 18–62–15ddb near Horse Creek are exceptions.

Logs of wells in the Federal well field show that the large yields of water are obtained from gravel channels in the White River Formation. These deposits are apparently limited to the lower part of the formation. No large gravel channels have been found in the upper part of the White River exposed along the escarpment between Granite and Federal. Two pumping tests were made in the Federal well field. However, conditions in the aquifer do not approximate those assumed in the available mathematical derivation of theoretical aquifer response, and coefficients of transmissibility and storage could not be computed. Specific capacities, which are available from 7 of the 10 Cheyenne municipal wells which tap the White River Formation, range from 2.8 to 8.1 gpm per foot of drawdown. More than half of the test wells drilled in the area by the city were abandoned because of low yields; therefore, these specific capacities are probably the largest that might be expected in the area.

The White River Formation is reportedly the principal aquifer in the Pine Bluffs lowland. Yields of the irrigation wells are as much as 2,000 gpm; the reported specific capacity of one well is 257 gpm per foot of drawdown. Because of the difficulty in differentiating the White River that is in place from that which has been reworked and deposited as alluvium, many of the wells reported to be in the White River may be in alluvium.

Siltstone of the White River Formation is not sufficiently permeable to yield significant quantities of water to wells. Three samples of siltstone from Goshen County were tested in the U.S. Geological Survey's Hydrologic Laboratory, Denver, Colo., in order to determine their coefficients of permeability. The results ranged from "too small to be measured accurately" to 0.2 gpd per sq ft (gallons per day per

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[1] In this report 3 yield categories are used. The range of yields in each category is as follows: Small, 0–50 gpm; moderate, 50–350 gpm; and large, more than 350 gpm.

square foot) (Rapp and others, 1957). The permeability of the siltstone in Laramie County is probably very similar. Large yields of water from the White River Formation have been attributed to joints, fissures, and fractures formed after deposition of the formation. Babcock and Bjorklund (1956, p. 14) described the formation as follows:

> Surficially, the Brule Formation [White River] is cut by systems of joints. The joints are either horizontal (along bedding planes) or vertical and, although they are most prominently developed where the formation is exposed, they occur also at the top of the formation where the Brule [White River] is mantled by younger stream deposits. In some places, nearly vertical fractures, or fissures, penetrate to unknown depths within the formation and possibly penetrate completely through it. Surface traces of these fractures, some of which are at least 1 foot wide and 1 mile long, are seen easily on aerial photographs, but they are difficult to detect and follow on the ground.[2]

Other investigators have similarly described the White River.

It is assumed that the vertical fractures (or fissures) in outcrops referred to in previous reports are clastic dikes such as shown in figure 4. Because these dikes are often truncated within the White River Formation and the filling material is generally similar to the surrounding formation, it is doubtful whether they are sufficiently permeable to yield even moderate quantities of water to wells.

Fractures undoubtedly transmit water to many small-yield wells that tap the White River Formation. However, fracturing alone does not adequately explain the large variation in permeability that occurs within a few tens of feet—a battery of wells connected below the water level is often drilled to locate permeable sites—or explain the concentration of large-yield wells in areas underlain by alluvium. Permeability resulting from fractures, such as those shown in figure 3, would not vary significantly in short distances. Furthermore, if fractures were the principal cause of zones of large permeability, it would be expected that large-yield wells would be closely related to faulting; however, only one such well is known to the authors. Welder and Weeks (1965, p. 49) reported that the relatively large yield of a well (29–69–33bac) in the Horseshoe Creek valley, Platte County, Wyo., may be the result of increased permeabiilty near the Elkhorn fault.

Piping, which is the process by which subterranean channels form as a consequence of the movement of water in relatively insoluble and incoherent clastic rocks, occurs in the White River (fig. 7) and is widespread in alluvium derived from the formation. Piping occurs where there are large hydraulic head differences in short distances, an example of which is the "gully-wall" type of piping so widespread in the

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[2] The authors of this report believe that the features previously identified on aerial photographs as fractures are traces of animal and vehicle trails.

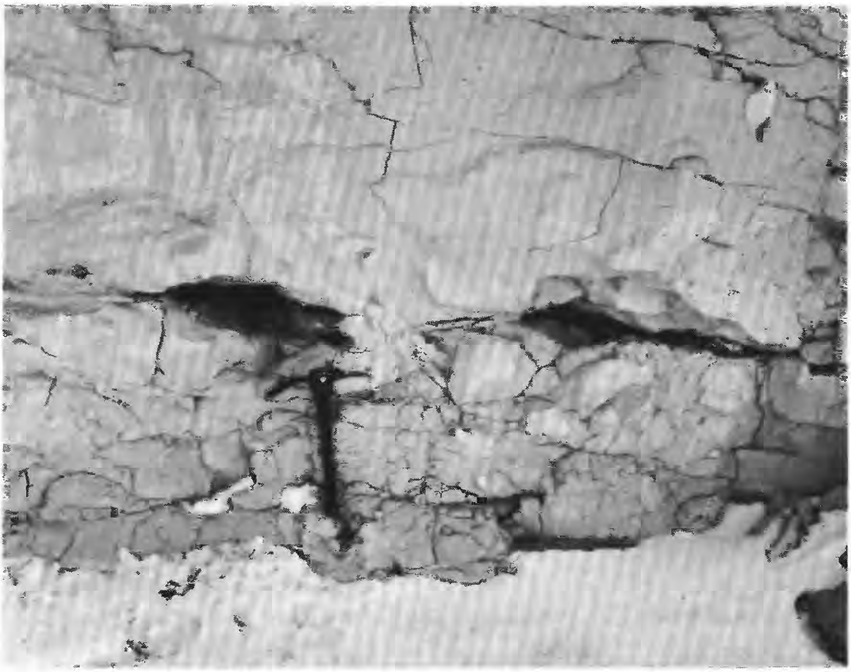

FIGURE 7.—Pipe in White River Formation, sec. 15, T. 15 N., R. 69 W.

Western States (Parker, 1963, p. 104). Parker (1963, p. 106) listed the conditions necessary for piping to occur as follows: (1) Sufficient water to saturate some part of the soil or bedrock above base level, (2) hydraulic head to move the water through a subterranean route, (3) presence of a permeable erosible soil or bedrock above base level, and (4) an outlet for flow. Parker listed siltstone, volcanic ash, and swelling clays as materials favorable to piping. Some of the permeability in the White River Formation is very likely the result of piping.

Conditions related to piping have been described in part of the White River in Scotts Bluff County, Nebr., by Wenzel, Cady, and Waite (1946, p. 85), who stated, "The Brule is eroded very easily and, hence, in irrigated parts of the county, the openings have been enlarged by circulation through them. Thus, the permeability of the formation is probably greater in those areas than it is where the source of ground water is precipitation."

In the Pine Bluffs lowland, an erosion surface with a local relief of 100 feet formed on the White River before deposition of the alluvium, and conditions were created that were suitable for the formation of pipes. The position of the pipes may have been controlled by fractures or other zones of weakness in the formation; however, pipes, not fractures, are believed to be the cause of increased permeability in areas where large yields are obtained. The large-yield wells near Horse Creek (18–62–15ddb) and Bear Creek (19–66–17cda) may be in areas of increased permeability resulting from piping near the streams. However, well 19–66–17cda may derive part of its water from alluvium.

ARIKAREE FORMATION

Previous investigators have not considered the Arikaree Formation to be a source of large supplies of water in Laramie County; however, the Arikaree is believed to contribute a large part of the yield of several irrigation wells in the county. Although the permeability of the formation is generally low, the saturated thickness of the formation is great enough in the central part of the county that sufficiently deep wells yield large quantities of water.

Because the Ogallala Formation consists, in part, of reworked material from the Arikaree Formation, it is difficult to distinguish the contact between the two formations in many wells. Where the formations are so similar in appearance that they are not easily distinguished, the water-bearing properties of the Ogallala and of the Arikaree are similar enough that the two formations may be considered as a hydrologic unit.

The yields of wells 16–65–3bbb and 16–65–3cca, open to both the Ogallala and Arikaree Formations, are reported to be in excess of 300 gpm. Specific capacities of these two wells were reported to be 4.5 and 7.4 gpm per foot of drawdown, respectively. Well 17–63–6dc, which taps only the Arikaree, has a reported specific capacity of 3.6 gpm per foot of drawdown with a pumping level 92 feet below land surface.

Data from wells producing from the Arikaree, or Arikaree and Ogallala, have been used to prepare a specific capacity frequency graph. Specific capacities per foot of penetration were plotted against the percentage of wells, as shown in figure 8. The Arikaree is fairly homogeneous over a large area; therefore, data from Arikaree wells in Platte County were used to support the data obtained from Arikaree wells in Laramie County. By fitting a straight line to the plotted data, the specific capacity is shown to average 0.016 gpm per foot of penetration in the Arikaree.

Small yields can be obtained at most locations where the Arikaree is saturated. However, based on existing data, the chances are good of obtaining large yields from wells in areas where at least 200 feet of saturated material overlies the White River Formation, as shown on plate 2. Pumping lifts would probably range from 100 to 300 feet.

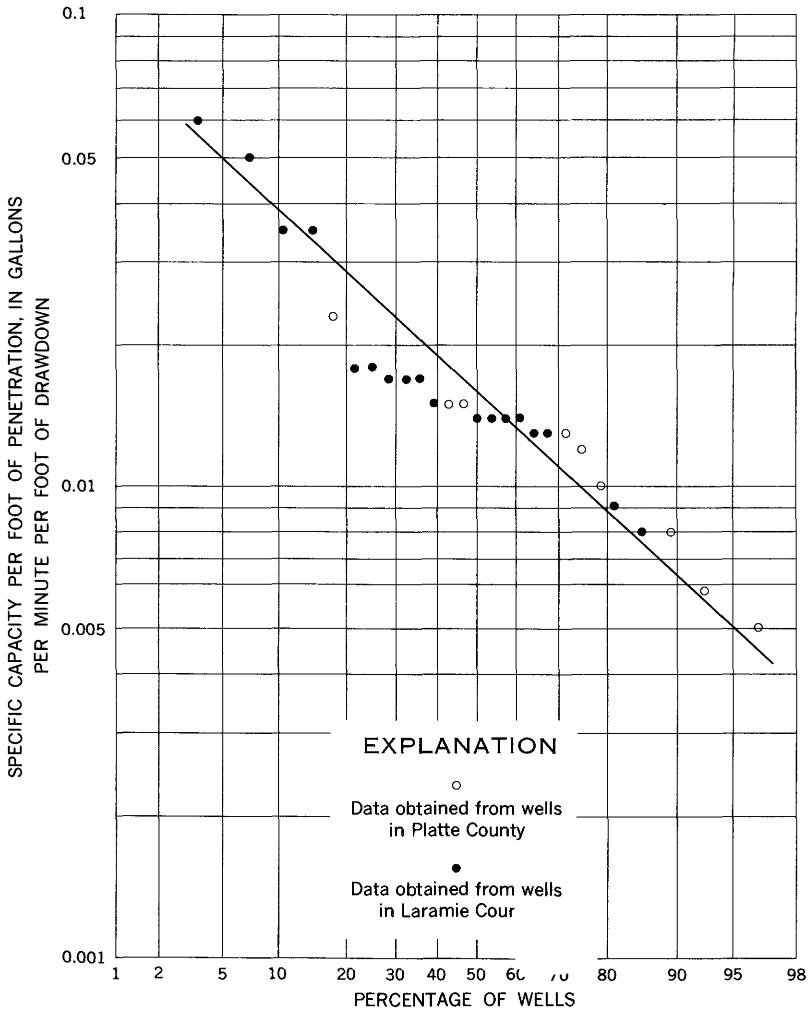

FIGURE 8.—Specific capacity frequency of wells in the Arikaree Formation, in Platte and Laramie Counties.

An example of using these data for predicting yields of wells is illustrated as follows. In an area where 200 feet of saturated material can be penetrated, the specific capacity would probably be greater than 3.2 (0.016×200) gpm per foot of drawdown in 50 percent of the wells.

To obtain maximum yields with minimum lift, wells should be drilled completely through the Ogallala and Arikaree Formations and should be finished so that as much of the aquifer as possible contributes water to the well.

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OGALLALA FORMATION

PUMPING TESTS

The Ogallala Formation is the most extensively developed aquifer in Laramie County. The area of largest ground-water withdrawal from the Ogallala is in the Cheyenne well field, about 6 miles west of Cheyenne. Of 36 municipal wells drilled in this area, 35 are considered to obtain water primarily from the Ogallala.

Theis (1941, p. 15) analyzed pumping tests at six of the wells in the Cheyenne well field in 1940. In 1942, Foley (1943, p. 69) made a pumping test at one of the same wells as Theis and obtained similar results. Pumping tests were made on four more wells in the period 1942–46 (Morgan, 1946, p. 21). D. A. Morris made 12 pumping tests when the Cheyenne well field was expanded in 1955 and 1956; 5 pumping tests were made in 1964: 3 in the Cheyenne well field, 1 at an industrial plant, and 1 at a privately owned irrigation well. These tests were analyzed by the Theis nonequilibrium formula (Jacob, 1950, p. 368) and the Theis recovery formula (Theis, 1935).

Results of all the pumping tests are shown in table 2. The wide range of the coefficients of transmissibility is expected, owing to the heterogeneity of the Ogallala Formation. Theis (1941, p. 15) stated, "The recovery curves of all the wells, except the Eddy well [14–68–23ddc] showed anomalies that are doubtless to be ascribed to irregularities of the aquifer." One of the basic assumptions made in analyzing aquifer tests is that the aquifer is homogeneous and isotropic. However, the water-bearing beds in the Ogallala consist of lenses, stringers, and irregular masses of sand and gravel which are interbedded with silt and clay. Two of the pumping tests made in 1964 were continued for 7 days to determine if, with a longer pumping period, the Ogallala would respond as a homogeneous aquifer. The indicated boundary conditions showed that even prolonged pumping tests were not reliable for computing the aquifer characteristics of the formation. Although the data obtained from the individual pumping tests are not significant by themselves, they can be used for comparison of the aquifers within the formation tapped by the different wells and add to the geologic knowledge of the aquifers. Morgan (1946, p. 12) noted that, in the older parts of the Cheyenne well field, the wells appear to tap two or more locally separate lenses, or groups of lenses, of sand and gravel. Wells that are in a belt extending from wells 13–68–4acd and 13–68–4dcc northeast to well 14–68–25dda mutually interfere but do not appreciably affect other wells.

Adjacent to this belt, four other wells, 14–68–26bdd, 14–68–26cbc, 14–68–27dcc, and 14–68–34abb, appear to be in a separate lens, and apparently there is slight hydrologic connection between these two

TABLE 2.—*Aquifer coefficients of the Ogallala Formation as determined from pumping tests*

Date	Location of pumped well	Name	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Specific capacity (gpm per foot of drawdown)	Length of test (hr)	Length of test (min)	Remarks
1940	14-68-25bcb	Elkar 1	16,750					
1940	34aab	Koppes 1	16,400					
1940	27dcc	Koppes 2	17,000					
1940	26cbc	Bailey 3	26,900					
1940	23ddc	Eddy 1	4,750					
1940	26bdd	Bailey 1	1,065					
1942	26cbc	Bailey 3	24,954					
1945	13-68-14bbb	Elkar 7	31,700					
1945	14cbd	Finerty 2	23,392					
1945	14-68-33dcc	Koppes 5	34,316					
1945	35cac	King 4	12,278					
May 1956	14-67-24acb	Riser 1	1,670			7		
December 1955	14-68-13dad	Bell 5	10,824		2.9	45	40	
Do	14-67-18cbd	Bell 6	6,900		4.7	46		
			13,600	5.6×10^{-4}		46		Observation well 1,700 ft west of pumped well.
January 1956	14-68-14ada	Bell 7	7,200		2.6	48		
Do	14cad	Bell 8	32,000		14.0	25	50	
Do	24bdd	Bell 10	6,200		5.5	46		
October 1955	13acb	Bell 11	23,000		15.3	73		
February 1956	14dcd	Bell 12	19,200			24		
			31,000	5.9×10^{-5}		24		Observation well 2,140 ft north of pumped well.
January 1956	14-67-18ddc	Bell 14	4,300		1.5	12		
			16,400	1.8×10^{-4}		12		Observation well 1,320 ft west of pumped well.
March 1956	19bbd	Bell 15	3,000		1.5	27	20	
October 1956	7ccb	Bell 16	5,580			7		
1956	14-68-13ccd	Bell 17	27,000		13.5	24	55	
March 1964	26cbc	Bailey 3	26,400		5.2	168		
			28,200	3.11×10^{-4}		168		Do.
February 1964	24ddd	Holman				168		
			[1] 38,300	1.95×10^{-4}		168		Observation well 1,730 ft west of pumped well.
			[2] 5,300	7.85×10^{-6}		168		Observation well 2,950 ft east of pumped well.
Do	36acc	Happy Jack 2.				4		
			15,000	1.4×10^{-4}		4		Observation well 2,000 ft west of pumped well.
August 1964	15-67-2dba		39,200			232	30	
September 1964	16bca	Wycon 7			.3	55	40	
			1,730	4.95×10^{-5}		55	40	Observation well 1,981 ft southeast of pumped well.
			1,835	6.74×10^{-5}		55	40	Observation well 835 ft west of pumped well.
			1,870	3.19×10^{-5}		55	40	Observation well 1,200 ft southwest of pumped well.

[1] Coefficients of transmissibility and storage were calculated from early test data. At least 4 boundary conditions were indicated; therefore, interpretation is doubtful. The coefficient of transmissibility will probably range from 4,900 to 38,300 gpd per ft (gallons per day per foot), and the coefficient of storage will probably range from 3.04×10^{-5} to 1.95×10^{-4}.

[2] Aquifer characteristics calculated from the first 24 hours of data; later data indicate boundary conditions.

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groups of wells. Two other wells, 13–68–14bbb and 13–68–14cbd, appear to tap a lens isolated from the two previously mentioned groups of wells. Morgan also stated that wells 14–68–23ddc and 14–68–24dd may be in another separate lens. This was verified in 1964 by the authors during a 7-day pumping test of well 14–68–24ddd. In addition, the well yielded water from the same zone as 14–67–30abb and 14–68–24bdd, but the water level in well 14–68–25dda was not affected. Morgan (1946, p. 12) stated, "The alignment of the various identified beds suggests that the mass of sand and gravel furnishing water to the well field is part of an alluvial fan built up by Lone Tree Creek with the apex of the fan near the mouth of Lone Tree Canyon where the stream emerges from the mountains."

IDEALIZED AQUIFER

The Ogallala Formation in the vicinity of the Cheyenne well field has been represented as an idealized aquifer for the purpose of estimating a coefficient of transmissibility that might be representative of the formation. Figure 9 shows the depression in the piezometric surface caused by pumping in the Cheyenne well field. The contours represent the drawdown of the piezometric surface during the period 1942–64. The zero contour represents the boundary of the area influenced by pumping in 1964. Section A–A′ in figure 9 shows a marked change in gradient from 1942 to 1964, but the direction of ground-water movement continues to be from west to east.

Pickup of ground water in Crow Creek between Silver Crown and Cheyenne was reported to be 4,324,000 gpd (13.27 acre-feet per day) in November 1942 (Morgan, 1946, p. 30). However, during the period 1961–64, Crow Creek was dry between Silver Crown and the eastern edge of the Cheyenne well field. Also, progressive drying of the higher springs has caused an eastward movement of the spring line (pl. 2). The ground water formerly discharged to the surface is now being diverted to the well field, and near-equilibrium conditions have been established in the aquifer.

Water-level fluctuations and annual pumpage in the Cheyenne well field are graphed in figure 10. The hydrograph was compiled from the monthly average nonpumping water levels in the wells and is believed to be representative of the average water-level trend in the Cheyenne well field.

The water level declined only slightly during the years 1945–49 and 1961–64. It is assumed that the recharge-discharge relation in the area had reached near equilibrium during these periods. Therefore, the depression shown in figure 9 is assumed to be almost entirely the result of the increased pumping rate between the two periods. The

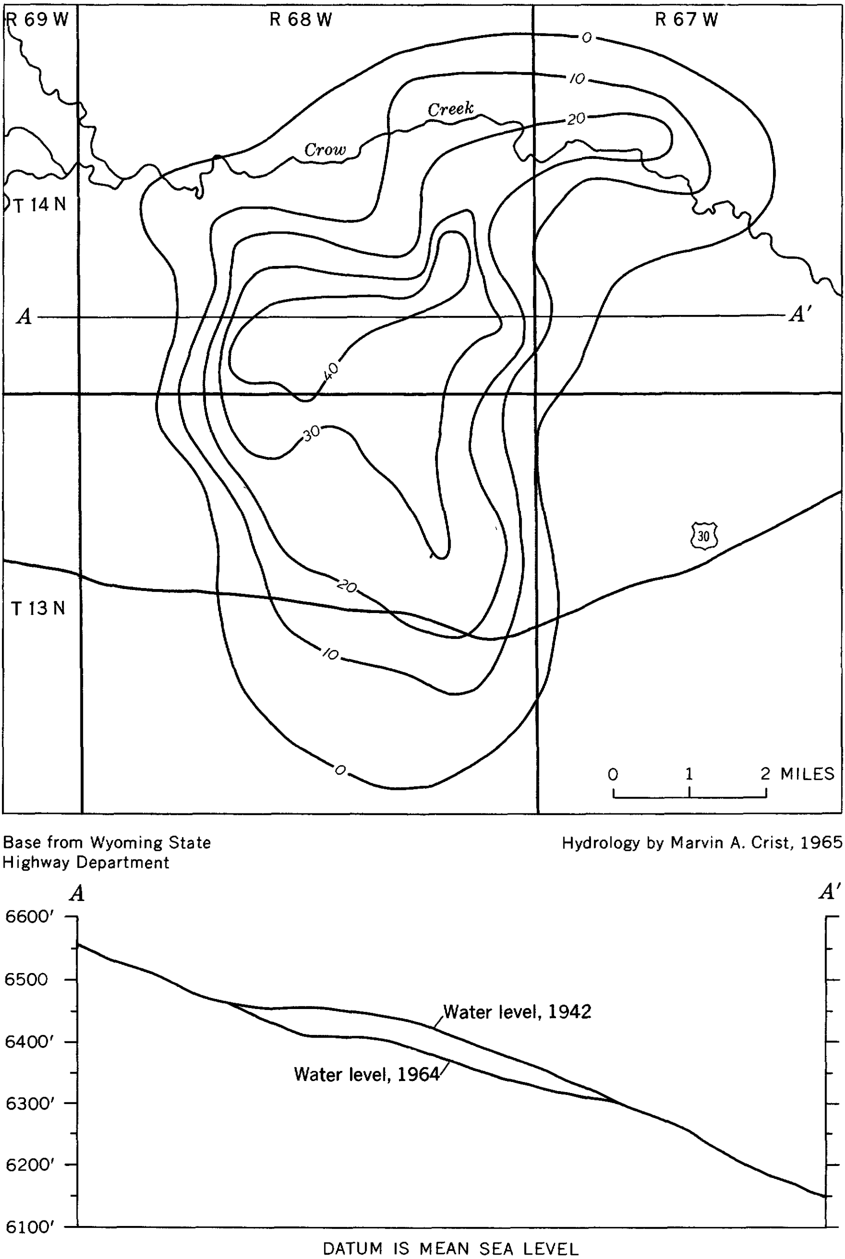

FIGURE 9.—Area affected by pumping and changes in the piezometric surface, 1942–64, in Cheyenne well field.

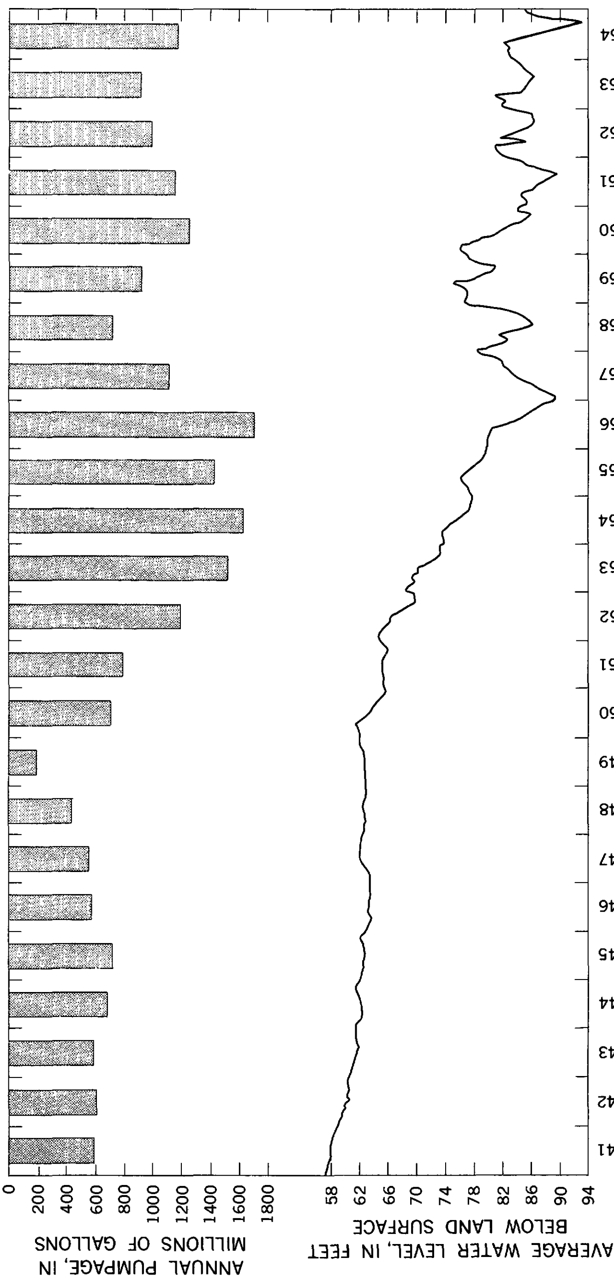

FIGURE 10.—Relation of water levels to annual pumpage in Cheyenne well field. Pumpage from collection galleries not included.

difference between the average yearly pumping rates during the two periods of equilibrium is considered to be the average yearly inflow to the area of depression. This is about 1,800 acre-feet per year or a minimum inflow of about 27,000 acre-feet from 1950 to 1964, inclusive.

The total amount of water pumped from the area from 1950 to 1964 is estimated to be about 31,000 acre-feet. Subtracting the inflow from the amount pumped indicates 4,000 acre-feet of water was removed from storage within the area. The volume of the aquifer dewatered is estimated from figure 9 to be 22.3 billion cubic feet. This was determined by multiplying the planimetered area between the contours by the estimated average thickness of the dewatered zone within each area. A specific yield of about 0.7 percent was calculated by dividing the amount of water removed from storage by the volume of the aquifer dewatered.

The Theissen-mean method (Theissen, 1911) was used to estimate the changes in saturated volume within the area. In this method a system of polygons is constructed around each well in which water-level measurements are made. It is assumed that the change in water level observed in a well is the change in water level throughout the area of the polygon surrounding that well and that the change in saturated volume can be attributed mainly to ground-water inflow into the area and does not reflect solely the recovery of the wells from a pumped-down condition. The polygon network used for the determination of the change in saturated volume is shown in figure 11. The changes in saturated volume were calculated by multiplying the change in water level by the area of the polygon. Water-level changes were measured January 28 and February 28, 1964, because during the intervening period the least number of wells was pumped. Interference occurs between many of the wells in the Cheyenne well field; however, computation of the change in saturated volume during February 1964 would probably be more reliable because less water was pumped during that month than during any other that year. If a well was pumping during Februray, the change in water level was estimated from the change in water levels observed during the months of November and December 1963.

If a part of the area shown in figure 11 is considered to be an aquifer bounded on one side by a fully penetrating stream and on the other side by a parallel ground-water divide, both of infinite length, and if it is assumed that the aquifer is regionally homogeneous and isotropic, then the coefficient of transmissibility for the area can be calculated using the equation of the steady-state profile (Jacob, 1943, p. 566):

$$h_0=\left(\frac{a^2W}{2T}\right)\left(\frac{2x}{a}-\frac{x^2}{a^2}\right)$$

where

W=constant rate of recharge to the water table. Recharge to the area of depression between Crow Creek and the water-table divide is assumed to be approximately equal to the yearly inflow to that area.

a=distance from the stream to the ground-water divide.

x=distance from the stream to a point where the altitude of the water table is measured.

h_0=altitude of the water table at point x, with respect to the mean stream level.

If the altitude of the water table with respect to the mean stream level is measured at the ground-water divide, then $x=a$, and the foregoing equation becomes

$$T=\frac{a^2W}{2h_0}.$$

The planimetered area of the polygons between the ground-water divide and Crow Creek was multiplied by the respective change in water level of each polygon to obtain the increase in saturated volume. During February 1964, the saturated volume increased about 16,900 acre-feet. The change in saturated volume multiplied by the specific yield of 0.7 percent is about 118 acre-feet. This is the estimated quantity returned to storage during February in the part of the area between the ground-water divide and Crow Creek. Assuming that the inflow is constant, the yearly inflow to this part of the area is estimated to be about 1,400 acre-feet.

The coefficient of transmissibility calculated with the above equation is about 3,800 gpd per ft. This is somewhat lower than the average coefficient of transmissibility of 16,000 gpd per ft determined from pumping tests. It is realized that many assumptions were based on meager data and that possibly some error may be induced by assuming that steady-state conditions exist during any one month. However, the coefficient of transmissibility (3,800 gpd per ft) calculated by the regional method appears to be a reasonable value for the formation. It would be expected to be lower than an average coefficient of transmissibility determined from pumping tests made on wells producing principally from highly permeable gravel zones. The large-yield wells were located by drilling many test holes and therefore are located in areas of relatively high permeability.

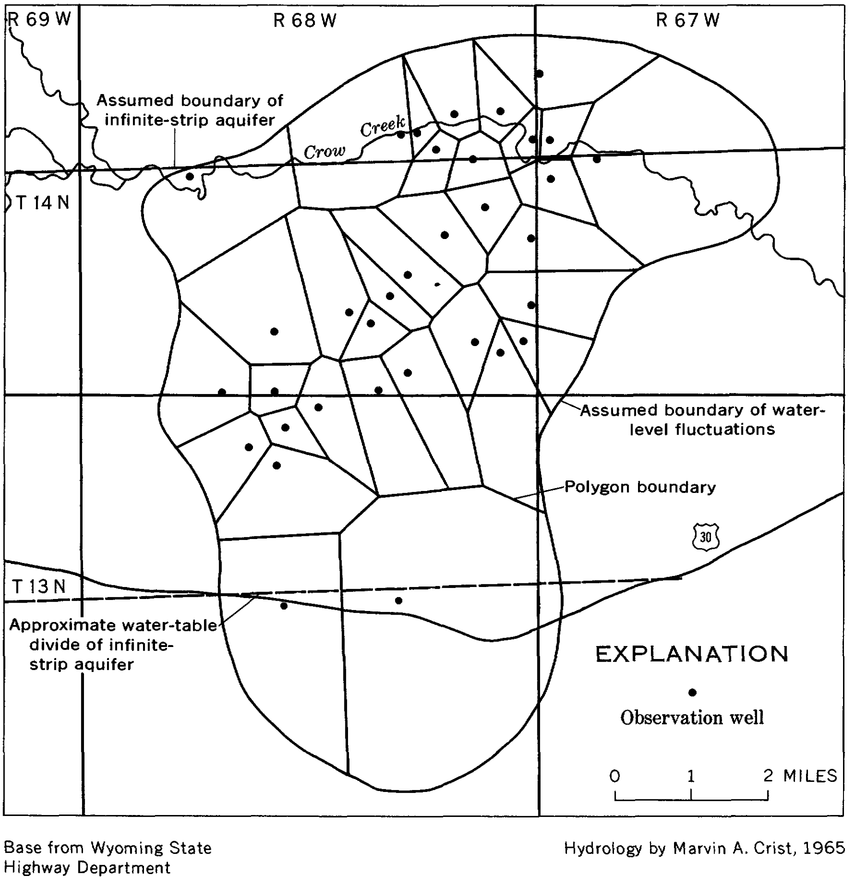

FIGURE 11.—Polygon network used to estimate change in ground-water storage in vicinity of Cheyenne well field.

The steady-state profile method was used to determine an average coefficient of transmissibility of about 3,800 gpd per ft in the vicinity of the Cheyenne well field where 27 of the 28 pumping tests were made. Considering 3,800 gpd per ft as a conservative estimate of the average coefficient of transmissibility in the Cheyenne well field, a strip of the aquifer 10 miles wide is capable of transmitting 830 million gallons per year under a hydraulic gradient of 60 feet per mile. Pumpage at this rate should not lower the water table below its present level. An estimated 100 feet of saturation exists below the present drawdown. Assuming that the gradient of 60 feet per mile and the calculated premeability of 0.86 gpd per sq ft remain constant, an additional 830 million gallons per year could be pumped from a 10-mile-wide strip of aquifer by lowering the water table 50 feet. Interception of this additional water would reduce the amount of discharge from springs east of the well field, and the spring line would migrate farther eastward. Maximum yield from the Cheyenne well field is estimated to be about 1.6 billion gallons per year, which is probably a conservative estimate. This value approximates the maximum yield of 1.8 billion gallons per year estimated by a consulting firm in 1950, although the areas and permeabilities used in the methods of calculation were considerably different.

At least three irrigation wells east of Cheyenne and two north of Cheyenne are believed to derive water principally from the Ogallala Formation. Reported yields range from 150 to about 1,000 gpm. Undoubtedly, such yields can be obtained only from sand and gravel lenses because the indicated average coefficient of transmissibility of the Ogallala is small. Stock and domestic wells yielding as much as 50 gpm can probably be drilled in the Ogallala at most locations, except in the eastern part of Laramie County near the Nebraska border and near the edge of escarpments where the formation is drained.

Conclusions.—Coefficients of transmissibility for the Ogallala Formation, determined by 28 pumping tests, ranged from 1,730 to 38,300 gpd per ft and averaged about 16,000 gpd per ft. All the tests except one were made using moderate- to large-yield wells that produce from sand and gravel stringers and lenses. The average coefficient of transmissibility as stated above, may be too high if applied to all the Ogallala in Laramie County, because only a very small percentage of the wells drilled in this formation penetrates the highly productive zones.

It is believed that the coefficient of transmissibility determined by the regional method is better than the average obtained from pumping tests for the Ogallala in Laramie County for the reasons listed below.

1. Data obtained from pumping tests in the Ogallala are difficult to interpret, and the results of the interpretation may be misleading.
2. All but one of the pumping tests were made at large-capacity wells completed in sand and gravel lenses. Many unsuccessful test holes were drilled to find the highly productive zones.
3. The assumption that the aquifer is regionally homogeneous and isotropic is more valid than similar assumptions made to permit use of pumping-test data to determine aquifer characteristics in the Ogallala. Local heterogeneity was revealed by pumping tests made by Theis (1941, p. 15) and by the 7-day tests made by the authors in 1964.

ALLUVIUM

The lithologic characteristics of the alluvium are similar throughout Laramie County, and the permeability of the alluvium is of the same order as that of the older terrace deposits. The Pine Bluffs lowland is the principal area where the alluvium will yield large supplies of water to wells. In most other areas the alluvium is thin and may not be saturated. Large yields have been obtained from wells in the terrace deposits along Horse Creek and from collection galleries in the flood-plain deposits of Crow Creek. A yield of 450 gpm has been obtained from well 13–70–15cba in wet years. This well probably produces from both alluvium and weathered granite.

Aquifer characteristics of the older terrace deposits near Carpenter, Wyo., determined from three pumping tests, are shown in the following table.

Location of pumped well	Distance of observation well from pumped well	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Specific capacity (gpm per ft of drawdown)	Length of test		Date of test
					hr	*min*	*1964*
12-62-2bcb		105,000		58.0	97	15	April 29.
	745 ft west	146,000	5.43×10^{-2}		97	15	Do.
3bcc		53,300		37.4	7	35	April 28.
22abb		59,000		13.9	84	15	May 21.
	305 ft east	44,800	4.65×10^{-3}		84	15	Do.

The saturated thickness of the terrace deposits in the three wells tested ranges from about 33 feet at well 12–62–2bcb to about 85 feet at well 12–62–22abb. The coefficient of permeability ranges from 3,180 to 694 gpd per sq ft, respectively. Figure 12 is a generalized saturated-thickness map of the terrace deposits in the vicinity of Carpenter, Wyo. Many large-yield irrigation wells in the area tap more than 40 feet of saturated material, and at least seven wells, with reported yields of 400–700 gpm, penetrate 30–40 feet of saturated material. Additional large-yield wells tapping more than 30 feet of saturated material could possibly be developed within the area.

THE WATER TABLE

CONFIGURATION

Plate 2 is a contour map of the piezometric surface in Laramie County showing the location of wells and springs used for control in drawing the contours. Pertinent data regarding most of the wells and springs are given in the section "Records of Selected Wells and Springs"; data on some wells have been published previously and are therefore omitted. Most of the water-level measurements were made during 1963 and 1964. In some areas, control was supplemented by older measurements that were assumed to be representative of that area.

Hydraulic connection between the Tertiary formations is sufficient to permit contouring a common water table. On the western edge of

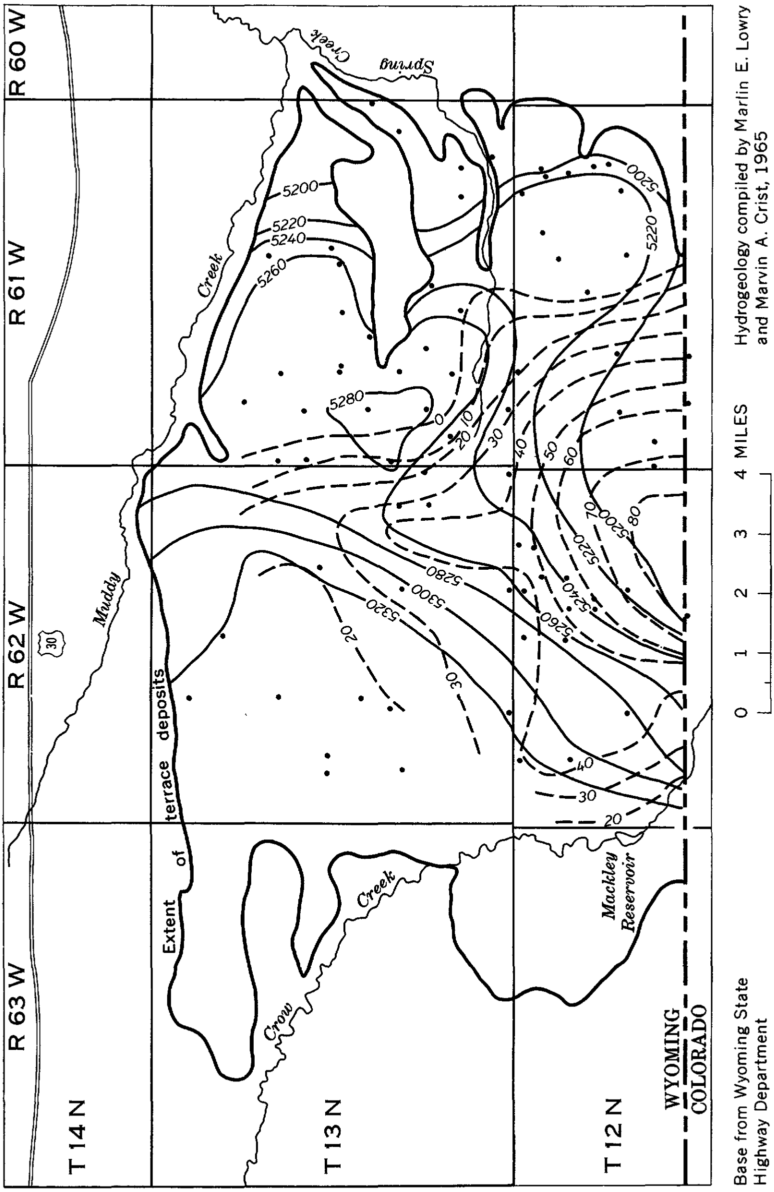

FIGURE 12.—Configuration of top of White River Formation (solid contours) and saturated thickness of terrace deposits (dashed contours). Dots are control points.

the county the piezometric surface has been extended, particularly in the southwestern corner, to include the water level in pre-Tertiary rocks where there was control.

Ground water moves in the general direction of the slope of the piezometric surface, and the rate of movement is dependent on the slope (hydraulic gradient) and the permeability of the aquifer. The slope of the piezometric surface averages about 40 feet per mile, but it is considerably different in some areas in Laramie County owing to the difference in permeability, thickness of the water-bearing materials, and amount of water moving through the beds.

Drainage systems influence the configuration of the water table. This is particularly noticeable along Chugwater Creek, Horse Creek, and the upper reaches of Crow Creek. The contour lines along Crow Creek (pl. 2) show the stream is effluent (receives water from the formation) west of Cheyenne and is influent (discharges water to the formations) in the lower reaches. Pumping in the Cheyenne well field has lowered the water table so that Crow Creek is dry between Silver Crown and sec. 18, T. 14 N., R. 67 W. This, however, has not changed the regional drainage pattern of ground water in this area. The change in the piezometric surface due to pumping (discussed in section on hydraulic properties of the Ogallala Formation) in the Cheyenne well field was less than 50 feet; therefore, because the contour interval of plate 2 is 50 feet, the map does not reflect the influence of pumping.

East of Cheyenne, Crow Creek is perennial nearly to Carpenter except when the flow is diverted for irrigation. Surface flow ceases in sec. 36, T. 13 N., R. 63 W., where all the flow seeps into the terrace deposits. Chugwater and Horse Creeks are effluent streams and are the only perennial streams crossing the county; all others are intermittent.

The water level in the terrace deposit north of Horse Creek in T. 18 N., Rs. 61 and 62 W., is higher than that in the adjacent White River Formation because of recharge received from surface-water irrigation. Some of the water may percolate downward to contribute recharge to the White River Formation.

FLUCTUATION

Fluctuations of the water level in an aquifer are attributed mainly to recharge and discharge. Only the more significant water-level trends in Laramie County are discussed in this report. Additional information is available in other ground-water reports on various parts of the area and in the annual water-level reports of the Geological Survey.

A graph of the water level in well 18–66–31ccc, which taps the Arikaree Formation, is shown in figure 13. The water-level fluctuations in this well are slight; they are caused by changes in atmospheric pressure. Barometric-pressure readings at the Cheyenne Airport, taken at the same time as the water-level measurements for November and December, are shown for comparison in figure 13. The magnitude of water-level fluctuations measured in several wells during the investigation suggests that barometric pressure was the cause of fluctuation.

Although 1964 was one of the driest years of record in Laramie County, lack of recharge did not cause a decline in water levels in the Tertiary formations, except perhaps for the White River Formation in the Pine Bluffs lowland. Water levels in most of the Tertiary formations are probably sensitive only to long-term trends in precipitation.

Graphs of water levels in well 14–67–18ddc, in the Cheyenne well field, and well 14–60–5bcb, in the Pine Bluffs lowland (fig. 14), show the effect of seasonal pumping. The slow recovery of the water level in well 14–60–5bcb in the latter part of 1964 might seem to indicate lack of recharge among other things; however, most of the recharge occurs in the spring, and the slow recovery is mostly the result of pumping late in the year.

Long-term water levels in the Cheyenne well field and the Pine Bluffs lowland are shown graphically in figure 15. No significant change in water levels for the period of record has occurred in the Pine Bluffs area. In the Cheyenne well field, there was an initial decline with a subsequent leveling off at a point where recharge and natural and artificial discharge reached a new equilibrium. The zero

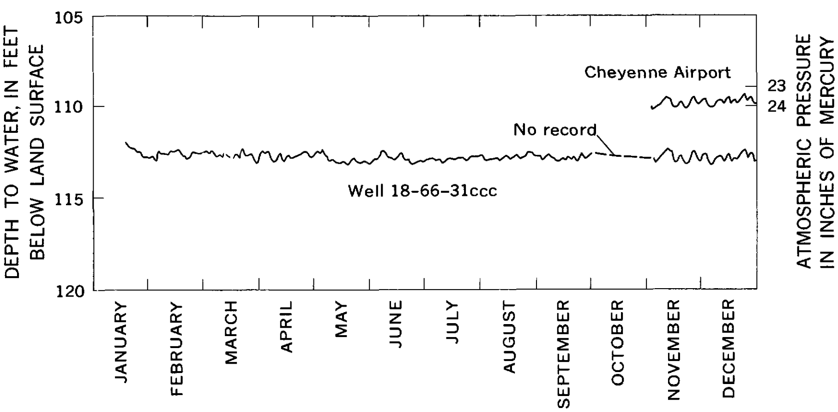

FIGURE 13.—Water-level fluctuations in well tapping the Arikaree Formation. Recorded automatically.

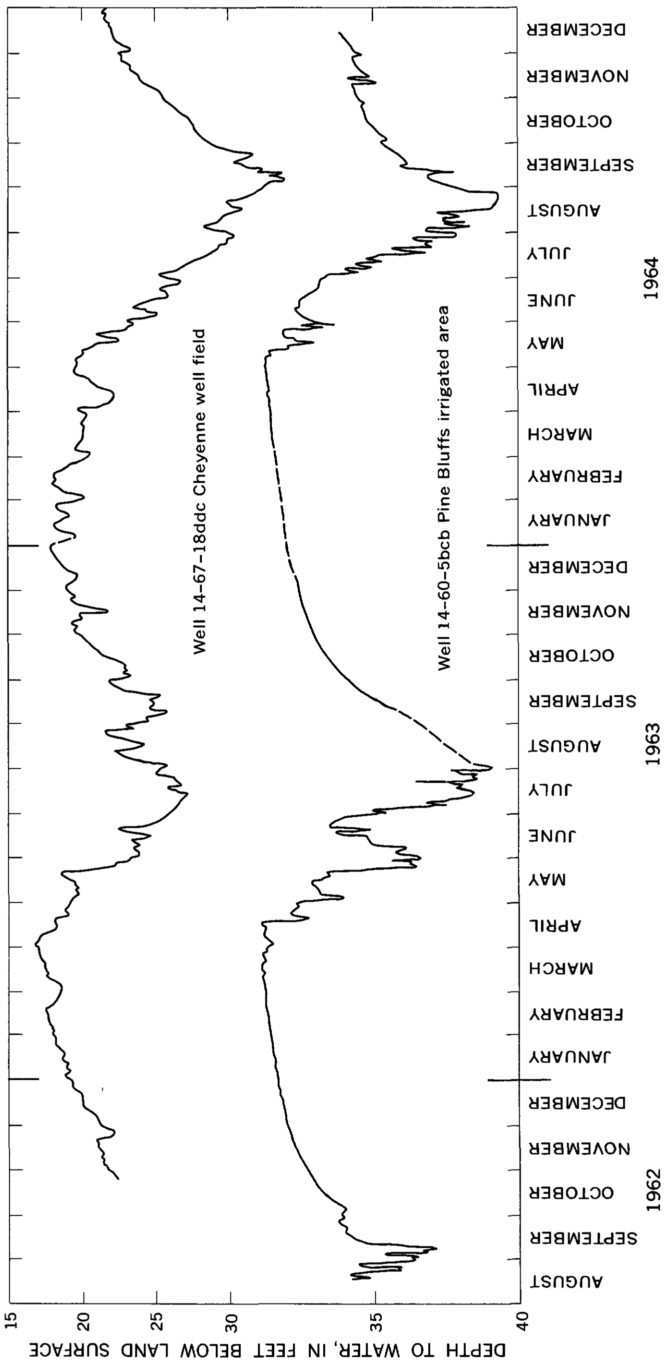

FIGURE 14.—Seasonal fluctuations of water levels in areas of heavy pumping.

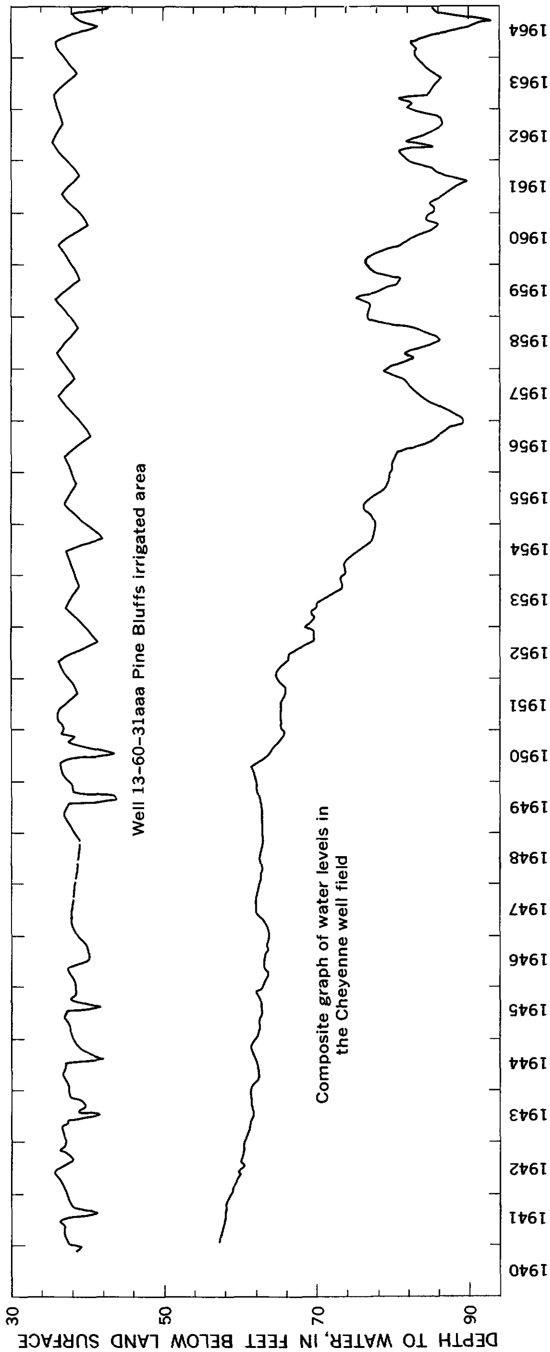

FIGURE 15.—Long-term trend of water levels in areas of heavy pumping.

contour in figure 9 shows the extent of the area in which the Cheyenne well field influenced the water level in 1964. Water levels in the Federal well field, which are not included in the averages shown in figure 15, declined greatly the first year of pumping. However, in subsequent years, levels fluctuated less, and the water now recovers to nearly the same level each winter.

RECHARGE

Precipitation.—Morgan (1946, p. 19) estimated the recharge from precipitation to be about 0.83 inch per year in the vicinity of Cheyenne, Wyo., or about 5.5 percent of the average annual precipitation. Rapp, Warner, and Morgan (1953, p. 22) used the same estimate for the Egbert-Pine Bluffs-Carpenter area. Assuming that recharge from precipitation in Laramie County is about 5 percent of the average annual precipitation and that the average annual precipitation is about 15 inches, the annual recharge from this source in Laramie County (2,709 sq. mi.) would be about 108,400 acre-feet.

Streams.—Recharge to the ground-water reservoir is also contributed by streams that head in the mountains west of the county line. Stream discharge is usually maximum during April, May, and June because of spring runoff. Seepage runs (measurement of gain or loss of streamflow) were made during May and June 1964 on six streams that flow over sedimentary rocks of pre-Tertiary age in the western part of the county. Data in the following table show that these rocks are capable of accepting recharge from the six streams at the rate of at least 5.46 cfs (cubic feet per second). The rate of seepage is probably greater when surface runoff occurs. Evapotranspiration losses—combined losses due to evaporation from land and water surfaces and transpiration by plants—are included in the seepage figure. However, these losses are probably small because the distance between the points of measurement of streamflow is short (about half a mile) and the vegetation is sparse.

Date of measurement	Stream	Discharge upstream from outcrop of pre-Tertiary sedimentary rocks (cfs)	Discharge downstream from outcrop of pre-Tertiary sedimentary rocks (cfs)	Recharge to pre-Tertiary sedimentary rocks (cfs)
1964				
May 27	South Fork Lodgepole Creek [1]	15.50	12.59	2.91
June 9	Duck Creek	.22	0	.22
Do	Goose Creek	.06	0	.06
Do	Lone Tree Creek	2.02	.32	1.70
June 16	South Fork Horse Creek	1.33	.95	.38
June 18	North Fork Horse Creek	1.98	1.79	.19
Total				5.46

[1] Records of Laramie County Water Commissioner.

Foley (1943, p. 51) estimated recharge to the Ogallala Formation of Tertiary age from Duck, Goose, and Lone Tree Creeks to be about 2.5 million gallons per day (3.87 cfs). Rapp, Warner, and Morgan (1953, p. 20) estimated that streamflow annually contributes 8,000 acre-feet (11.05 cfs) of recharge to aquifers in the Egbert–Pine Bluffs lowland and the Carpenter area.

DISCHARGE

Ground water in Laramie County is discharged by flow into streams, seeps, and springs; by evapotranspiration; and by pumping wells. Some also leaves the county as underflow.

Seeps and springs.—Many seeps and springs in the Ogallala Formation in the western part of the county supplement surface flow in the tributaries to Crow and Lone Tree Creeks. Lines drawn through the eastern boundary of these seeps and springs, as they existed in 1942 and as they currently exist, are shown on plate 2. Morgan (1946, p. 14) related the spring line to the approximate eastern boundary of an area underlain by an appreciable thickness of permeable water-bearing beds. Eastward movement of water in the more permeable beds is impeded where these beds lens out and, eventually, some of this water discharges at the surface as seeps and springs. The eastward migration of the spring line between 1942 and 1964 is attributed to a decrease in the amount of water moving through the beds because of pumping in the Cheyenne well field. Even though the more permeable beds lens out, the permeability of adjacent rocks is great enough to transmit this lesser amount of water farther east before the permeability is reduced to such an extent that the formation cannot transmit all the water.

Foley (1943, p. 51) also noted that seeps and springs occur along the escarpment south of the Colorado-Wyoming State line and in some of the valleys that cut back into the escarpment. These are contact seeps and springs occurring near the base of the Ogallala Formation. Several contact springs occur near the Ogallala-Arikaree contact on the south side of Horse Creek. Springs that occur near the contact of these two formations in the south half of T. 14 N., R. 62 W., are the beginning of perennial flow in Muddy Creek. A few springs occur in the Pine Bluffs lowland at the contact between the White River Formation and the overlying terrace deposits.

A large spring in sec. 8, T. 13 N., R. 69 W., yielding nearly 2 cfs from the Casper Formation was developed by the Union Pacific Railroad to supply water for steam engines. Since the use of steam engines has been discontinued by the railroad, only enough water is pumped from the spring for domestic supplies at Granite and Harriman, Wyo. Most of the discharge flows into the South Fork of South Crow Creek and is diverted for irrigation. The aquifer from which the spring issues is probably recharged by seepage from streams, principally Lone Tree Creek which flow across the Casper outcrop.

Streams.—The average annual discharge of Lodgepole Creek is 13 cfs, or about 9,410 acre-feet per year, for the 32 years of record at a gaging station near Bushnell, Nebr., about 10 miles east of Pine Bluffs. Rapp, Warner, and Morgan (1953, p. 26) estimated the underflow at the gaging station to be 1.5 cfs. Total discharge from the area above the gaging station, therefore, averages 14.5 cfs, or nearly 10,500 acre-feet per year.

The contour lines on plate 2 show that the other streams, particularly Horse and Chugwater Creeks, obtain part of their flow from ground-water discharge.

Underflow.—Underflow from the county through the Tertiary and younger rocks is predominantly through flood-plain deposits underlying the principal streams and through terrace deposits in the Pine Bluffs–Carpenter area. The only other area where much water probably leaves as underflow is in the north-central part of the county, where there is as much as 200 feet of saturated Arikaree Formation (pl. 2). No data are available on movement of water through pre-Tertiary formations.

Wells.—Most large-yield wells are in the Cheyenne and Federal well fields, and in the irrigation area near Pine Bluffs and Carpenter. There are probably not more than 20 large-yield wells elsewhere. However, small-yield wells can generally be developed throughout the county.

Records show that about 4,576 acre-feet of water was pumped from all the Cheyenne municipal wells in 1964. The amount of water pumped in 1964 by other municipalities and communities was estimated to be as follows:

Community	*Estimated ground water pumped, 1964 (acre-feet)*
Fox Farm [1]	466
Orchard Valley [1]	492
Burns	98
Albin	58
Pine Bluffs	381
Total	1, 495

[1] Adjacent to Cheyenne.

An estimated 17,000 acre-feet of water was pumped for irrigation in the Pine Bluffs–Carpenter area in 1964. All other uses of ground water in the county (including irrigation outside the Pine Bluffs–

Carpenter area) probably do not exceed 5,000 acre-feet per year. Total ground-water discharge from wells in Laramie County was estimated to be about 28,000 acre-feet in 1964.

Evapotranspiration.—Estimates of soil-moisture losses by evapotranspiration in Wyoming have been computed by the U.S. Department of Commerce and the U.S. Department of Agriculture. At Cheyenne and Pine Bluffs, estimated evapotranspiration losses range from 9.0 to 10.3 inches per year, assuming a 2-inch available-water capacity for annual 32°F and 28°F frost-free seasons, respectively; and from 9.5 to 12.1 inches per year, assuming a 6-inch available-water capacity for annual 32° F and 28° F frost-free seasons, respectively. The frost-free season is the average number of days between the last occurrence of this temperature in the spring and the first occurrence in the fall. Available water capacity, stated as inches of water, is the difference between the amount of water remaining in the soil after the soil has been saturated and allowed to drain freely, and the amount of water left in the soil when plants growing in that soil first show permanent wilting.

The estimates given above are soil moisture losses due to evapotranspiration and do not necessarily reflect direct loss of ground water. However, water lost to the atmosphere cannot contribute to ground-water recharge. In areas where the water table is near the land surface, much ground water is lost by evapotranspiration. Evapotranspiration losses in such areas were estimated to range from 17.1 to 18.8 inches per year at Cheyenne and from 18.0 to 20.2 inches per year at Pine Bluffs, for annual 32°F and 28°F frost-free seasons, respectfully.

Summary.—Recharge to the ground-water reservoir in Laramie County is derived principally from precipitation and is estimated to be about 108,400 acre-feet per year. Streams contribute only a small additional amount of recharge, perhaps about 5,000 acre-feet per year. Yearly discharge of ground water by pumpage in Laramie County is estimated to be about 28,000 acre-feet. The balance of the recharge leaves the county by other means—an estimated 20 percent by streamflow, 20 percent by underflow, and 60 percent by evapotranspiration.

FUTURE DEVELOPMENT

Ground water is extensively developed in Laramie County, but concentrated development is limited to three areas—Cheyenne well field, Federal well field, and the Pine Bluffs lowland. Additional supplies of water can be developed in most areas, but the potential for large yields is limited and exploratory drilling may be required.

Precambrian rocks of the Laramie Range will yield adequate supplies for domestic and stock use in many places if well sites are selected carefully. Small yields may also be obtained from the Mesozoic formations, which are at or near the surface along the mountain front and in the northwestern part of the area. Large yields might be obtained from the Casper Formation at economical drilling depths in some areas near the mountains.

The White River Formation will probably yield small quantities of water to wells nearly everywhere in Laramie County and large yields are possible in some areas, particularly where pipes have formed (see p. 27) and where the formation contains gravel deposits in which wells can be completed.

The Arikaree Formation, which has not been developed extensively in Laramie County, will yield large supplies of water to wells in places. The formation is comparatively homogeneous and is the most predictable aquifer in the area. Although data are meager, yields from the formation can probably be predicted fairly accurately by the combined use of the saturated thickness map (pl. 2) and the probability curve (fig. 8). Unless wells in the Arikaree are properly constructed, loose fine sand may enter them.

Small to large supplies of water can be developed from the Ogallala Formation. The formation's average transmissibility is low, but its sand and gravel lenses will yield large quantities of water. One of the best areas for developing large supplies of water is where a maximum saturated thickness of both Ogallala and Arikaree Formations is present. To obtain maximum yields, with minimum pumping lift, wells should be drilled completely through both formations.

The alluvium will yield small supplies of water in much of the area, and it may be the best source of water in, and near, the mountains. Large supplies can probably be developed from alluvium underlying the flood plains of some streams and from the terrace along the lower part of Horse Creek. Intensive development of ground water in the Pine Bluffs area causes considerable interference between wells during the irrigation season. However, water levels are not permanently lowered and generally recover to about the same level each spring. Many of the wells are marginal producers because of the small amount of saturated gravel. During summer, water levels decline so much that some wells can be pumped only intermittently or at a reduced discharge. Further development would aggravate this situation. Similar interference and reduced yields will occur wherever there is large ground-water development in areas of small saturated thickness.

CHEMICAL QUALITY OF GROUND WATER AND OF SURFACE WATER

By John R. Tilstra

CHEMICAL CHARACTERISTICS OF WATER

The amount and type of chemical constituents in water are generally determined by the solubility and physical properties of the materials in contact with the water, the duration of contact, the temperature of the water, and the pressure under which it is confined. The most abundant chemical constituents in ground water and surface water are generally sodium, calcium, magnesium, bicarbonate, sulfate, chloride, and silica. However, iron, manganese, postassium, fluoride, and nitrate are commonly present in trace amounts.

Chemical-quality data collected during 1960–64 are given in tables 3 and 4. Most of the recent samples are from the Cheyenne municipal well field and from wells in the Carpenter–Pine Bluffs area. (See pl. 2.) In addition, about 100 older analyses, some of which have been published by the U.S. Geological Survey, supplement the new data.

Concentrations of chemical constituents are expressed as parts per million. One part per million is the unit weight of a constituent in a million unit weights of water. Specific conductance and sodium-absorption-ratio (SAR) are used in evaluating water for irrigation use. The specific conductance of water is a measure of its ability to conduct an electric current and is directly proportional to dissolved-solids content (salinity). Sodium-absorption-ratio expresses the amount of exchangeable sodium in water.

CLASSIFICATION OF WATER USE

DOMESTIC USE

Water for domestic use should not have objectionable taste, odor, or color, and should not contain excessive amounts of biological and chemical constituents that may be physiologically harmful. The U.S. Geological Survey generally uses the U.S. Public Health Service standards for interstate common carriers (U.S. Public Health Service, 1962) as a guide for evaluating the suitability of domestic supplies. The following table lists the chemical constituents that commonly occur in water and gives the recommended limit for a public supply.

Constituent	*Maximum permissible concentration (ppm)*
Iron (Fe)	0.3
Fluoride (F)	[1] 1.5
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Chloride (Cl)	250
Dissolved solids	500

[1] Estimated maximum for Laramie County (U.S. Pub. Health Ser., 1962).

Hardness is a property of water that causes soap to form an insoluble curd. Several chemical constituents cause hardness, but the degree of hardness for most water can be estimated from the concentration of alkaline earths, such as calcium and magnesium. The U.S. Geological Survey uses adjective ratings to describe hardness attributed to $CaCO_3$. Thus, soft water contains 0–60 ppm; moderately hard, 61–120 ppm; hard, 121–180 ppm; and very hard, more than 180 ppm.

Concentration ranges for some of the principal aquifers are compared with the U.S. Public Health Service standards in the following table.

Concentrations, in parts per million

Constituent	White River Formation	Arikaree Formation	Ogallala Formation	Alluvium	U.S. Public Health Service standards
Iron	0.00– 1.1	0.03– 0.14	0.02– 5.8	0.00– 0.19	0.3
Fluoride	.4 – .9	.6 – .7	.3 – .9	.6 – 1.0	1.5
Nitrate	1.0 – 13	8.7 – 26	1.6 – 16	5.8 – 17	45
Sulfate	3.8 – 74	12 – 27	.3 – 30	16 – 65	250
Chloride	2.5 – 13	3.9 – 16	1.0 – 17	5.4 – 27	250
Dissolved soilds	208 –424	286 –330	167 –308	260 –486	500
Hardness	98 –264	170 –216	125 –219	152 –317	----------
Number of samples	12	3	13	5	----------

INDUSTRIAL USE

Water-quality requirements for industrial use depend on the type of industry and the specific use of the water. For example, quality requirements of water used for coolant purposes will differ significantly from requirements for food and beverage manufacture. Generally, if the water is soft and satisfies the U.S. Public Health Service, standards, it will also be satisfactory for most industrial uses.

IRRIGATION

The amount and type of chemical constituents should be considered in appraising water for irrigation use. However, water quality is not the only criterion in determing whether land should be irrigated—climate, soil drainage, soil and crop types, and water management may affect agricultural productivity to a greater extent.

According to the U.S. Salinity Laboratory Staff (1954), the chemical characteristics most important in the appraisal of irrigation supplies are: (1) Total concentration of dissolved minerals or salts; (2) sodium concentration and relative proportion of sodium to other cations; (3) concentrations of boron and other elements that may be toxic; and (4) under some conditions, the bicarbonate and carbonate concentrations as related to the calcium and magnesium concentrations (residual-sodium-carbonate).

TABLE 3.—*Chemical analyses of ground water in Laramie County, Wyo.*

[Results in parts per million except as indicated. Analyses by U.S. Geol. Survey]

Location	Depth (feet)	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Sodium-adsorption-ratio (SAR)	Residual-sodium-carbonate (RSC)
Lance Formation																							
18-62-3bda [1]	704	5- 1-62	52	13	0.10	3.2	1.0	270		592	18	32	31	2.8	0.0	------	688	12	0	1,100	8.5	34	10.06
3bdb [1]	713	5- 1-62	58	12	.11	3.2	.5	247		560	27	28	6.9	2.0	.0	------	625	10	0	1,010	8.6	34	8.98
White River Formation																							
13-60-18dda [2]	100	6-26-64	51	------	0.03	------	------	48	------	218	0	74	------	------	------	------	396	194	15	600	8.0	1.5	0.00
13-63-33cbb	------	6-26-64	------	------	.00	------	------	11	------	172	0	12	------	------	------	------	260	156	15	367	7.8	.4	.00
13-69-16cbd [3]	315	4-21-61	40	58	.29	35	8.9	18		152	0	20	6.5	0.4	8.8	------	240	124	0	326	7.3	.7	.01
17daa [3]	555	6- 9-61	45	55	.02	47	6.2	------	5.3	172	0	3.8	2.5	.4	6.0	------	208	143	2	307	7.4	.2	.00
14-60-28bbb [2]	------	8- 7-64	53	52	.00	81	15	24	4.5	290	0	44	13	.6	13	0.24	390	264	26	594	7.7	.6	.00
15-60-34bcb	93	7- 7-64	53	59	.00	40	8.8	12	3.4	154	0	16	9.3	.5	12	.16	234	136	10	333	7.5	.4	.00
34dac	315	5- 2-62	52	58	1.1	24	9.2	29		160	0	14	5.7	.7	6.6	------	234	98	0	313	7.7	1.3	.66
34bdb	318	5- 2-62	52	61	.26	32	12	12		151	0	12	6.7	.6	8.5	------	232	128	4	320	7.6	.5	.91
15-69-6ada	182	8-11-64	49	23	.01	49	16	16	3.2	249	0	13	3.6	.6	3.2	.05	257	187	0	419	7.9	.5	.34
21dcc	223	8-11-64	49	27	.05	30	6.8	47	3.1	219	0	16	7.4	.6	1.0	.04	252	103	0	399	7.7	2.0	1.53
34aaa	312	8-11-64	46	58	.06	50	7.8	18	5.5	206	0	17	5.6	.9	2.5	.04	274	157	0	385	7.6	.6	.24
18-62-9bdc	------	6-27-64	58	------	------	------	------	41	------	288	0	62	------	------	------	------	424	232	0	608	7.5	1.2	.08
Arikaree Formation																							
14-62-7dbb	------	6-26-64	------	49	0.14	21	40	12	4.4	208	0	27	16	0.7	26	0.58	330	216	45	476	7.8	0.4	0.00
14-64-28baa	------	6-26-64	------	46	.03	51	14	7.9	3.0	218	0	12	3.9	.6	8.7	.03	286	185	6	389	7.8	.2	.00
17-60-20abb	------	6-27-64	------	------	------	------	------	16	------	184	0	19	------	------	------	------	294	170	19	408	7.4	.5	.00

Ogallala Formation																							
13-64-23aaa	300	5-2-62	54	57	0.03	54	13	9.7		218	0	11	6.4	0.4	8.4	------	286	186	7	407	7.4	0.3	0.00
23daa	338	5-2-62	56	65	5.8	44	11	14		182	0	15	6.2	.6	16	------	281	156	7	379	7.5	.5	.00
13-67-16bcc	185	8-10-64	51	27	.07	34	22	9.0	3.1	172	0	18	17	.5	8.3	0.07	241	175	34	386	7.7	.3	.00
13-68-4adc	255	8-11-64	51	24	.05	47	6.7	5.0	1.7	167	0	8.0	2.6	.4	6.9	.02	201	145	8	302	7.7	.2	.00
14-67-18cbd	225	8-11-64	51	27	.04	53	6.8	9.1	3.9	184	0	19	3.8	.7	5.7	.06	214	160	9	354	7.6	.3	.00
14-68-14cad	163	8-11-64	50	40	.02	67	13	9.4	3.7	240	0	30	6.0	.9	1.6	.05	308	219	22	452	7.9	.3	.00
23ddc	250	8-11-64	50	28	.06	45	5.5	4.4	2.0	157	0	6.5	2.8	.4	7.0	.02	191	135	6	281	7.4	.2	.00
27dcc	250	8-11-64	52	30	.07	47	5.0	5.9	2.1	169	0	6.0	2.5	.4	6.8	.03	189	138	0	294	7.6	.2	.01
36bca	194	8-11-64	54	20	.15	41	5.5	5.0	1.7	149	0	6.0	1.6	.6	3.9	.02	167	125	3	262	7.8	.2	.00
16-65-3bbb [4]	513	6-8-61	40	51	1.3	51	6.6	2.8		182	0	.3	2.1	.5	7.5	------	218	154	5	314	7.5	.1	.00
3cca [4]	638	10-28-60	------	52	1.4	46	7.8	6.0		176	0	4.8	2.7	.3	7.6	------	223	147	3	311	7.5	.2	.00
16-68-2daa	459	4-14-61	40	23	.34	43	5.5	7.8		162	0	8.0	1.5	.8	1.8	------	175	130	0	278	7.9	.3	.06
11aad	473	9-8-60	40	24	.09	44	6.1	8.5		164	0	8.5	1.0	.8	8.3	------	181	135	1	292	7.4	.3	.00
Alluvium																							
12-62-2bcb	104	6-26-64	------	46	0.04	46	9.0	14	5.2	183	0	16	5.4	0.8	12	0.08	260	152	2	364	7.8	0.5	0.00
13-62-29ccc2	80	6-26-64	------	53	.19	48	12	13	4.8	190	0	16	6.9	1.0	17	.05	276	170	14	389	7.8	.4	.00
14-60-10acc	--------	6-26-64	------	------	.07	------	------	30	------	320	0	65	16	------	------	------	322	297	35	674	7.9	.8	.00
11bcc	--------	8-7-64	52	50	.00	109	11	45	8.9	403	0	43	27	1.0	5.8	.41	486	317	0	774	7.5	1.1	.27
18-61-5dac	--------	6-22-64	53	56	.02	53	18	77	10	348	0	65	11	.6	8.0	.24	474	208	0	697	7.8	2.3	1.54

[1] Water is principally from Lance Formation, although some is from White River Formation.
[2] Probably represents water from the overlying alluvium.
[3] Water is principally from White River Formation, although some is from Lance Formation.
[4] Mixture of water from Ogallala and Arikaree Formations.

TABLE 4.—*Chemical analyses of surface water in Laramie County, Wyo.*

[Results in parts per million except as indicated. Analyses by U.S. Geol. Survey]

Location of sampling site	Estimated discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue at 180°C (ppm)	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Residual-sodium-carbonate (RSC)
Crow Creek near Silver Crown (14-68-19a)	<1	------	------	------	------	15	------	258	0	17	------	------	------	------	288	0.39	205	0	14	0.5	443	8.0	0.13
Below Hereford Ranch Reservoir 1 (13-66-1c)	2	------	------	------	------	100	------	79	39	96	------	------	------	------	522	.71	164	34	57	3.4	803	9.5	.00
South Fork Lodgepole Creek near Federal (15-69-3c)	<1	------	------	------	------	11	------	264	0	15	------	------	------	------	272	.37	212	0	10	.3	435	8.0	.09
Horse Creek: Near Horse Creek, Wyo. (17-69-30c)	2	19	0.33	118	32	32	3.6	329	0	207	3.5	1.4	0.3	0.09	584	.79	427	157	14	.7	860	8.1	.00
Near Horse Creek oil field (17-68-21a)	3	------	.08	------	------	29	------	260	0	105	------	------	------	------	398	.54	266	53	19	.8	601	8.0	.00
Near U.S. Highway 87 (17-67-1c)	1	------	.04	------	------	29	------	303	0	91	------	------	------	------	402	.55	285	37	18	.7	634	8.1	.00
Near Meriden (18-63-8)	3	------	------	------	------	14	------	192	0	19	------	------	------	------	232	.32	150	0	17	.5	348	7.4	.15
At Goshen County line (18-61-1b)	5	45	.04	44	9.7	40	7.0	258	0	23	5.5	.8	1.4	.19	290	.39	150	0	35	1.4	453	8.2	1.23
Chugwater Creek near Farthing (19-70-35a)	5	17	.14	140	33	35	2.7	302	0	295	5.1	.4	.2	.18	694	.94	486	238	13	.7	975	8.0	.00
Bear Creek near La Grange, Goshen County (19-61-6c)	3.5	------	------	------	------	62	------	271	0	17	------	------	------	------	300	.41	114	0	54	2.5	449	8.2	2.16

The U.S. Salinity Laboratory classifies irrigation water according to its salinity and sodium hazard (fig. 16). Nearly all the water samples collected during this study are of medium-salinity and low-sodium hazard classification (C2–S1). Medium-salinity water (C2) can be used if a moderate amount of leachinng occurs. Plants that have moderate salt tolerance can generally be grown without special practices for salinity control. Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of development of harmful levels of exchangeable sodium.

Residual-sodium-carbonate (RSC) and boron concentrations are not sufficiently high to cause adverse soil conditions or affect crop yield. This does not imply that levels of RSC or boron are particularly low, but rather that drainage in the developed and potential agricultural areas is generally adequate to accommodate present levels.

QUALITY OF GROUND WATER

Chemical composition must be considered when ground-water supplies for various uses are evaluated. Most analyses in table 3 are of water from formations and localities where large supplies occur. The chemical quality of this water is suitable for domestic, stock, and irrigation use; however, softening is desirable if the water is used for laundering.

Few data on the chemical composition of water from pre-Tertiary rocks are available. The Casper Formation, near the outcrop in the western part of the county, is known to produce water of suitable quality for domestic and irrigation use. Previous U.S. Geological Survey investigations in areas adjacent to Laramie County indicate that water from the Lance and Fox Hills Formations is inferior for most uses.

The chemical composition of water from Tertiary and Quaternary rocks does not differ appreciably from one formation or locality to another. Most analyses (table 3) represent water from a single formation, whereas a few represent water from two or more formations. For example, several of the wells tapping the White River Formation in the Carpenter–Pine Bluffs area probably also derive some water from the alluvium. However, the extent to which this mixing occurs cannot be determined owing to the similarity in chemical composition of water from these formations.

Irrigation tends to deteriorate the quality of water in two ways: (1) Much of the water applied in irrigation is lost by evaporation from the land surface and by plant transpiration, causing some solutes (salts) to remain on the land surface and in the plant-root zone. Subsequent applications of water leach these solutes out of the soil by

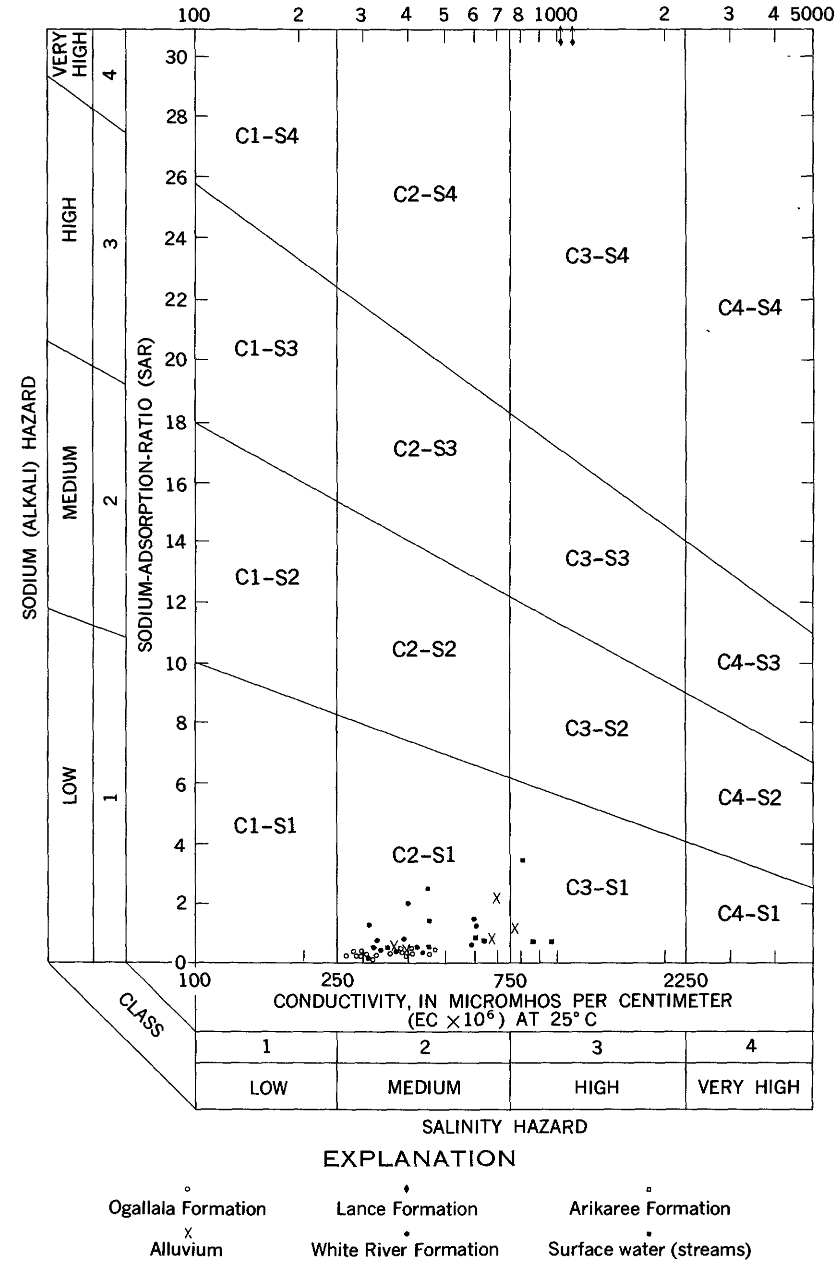

FIGURE 16.—Classification of irrigation water.

seepage and increase mineralization of the ground water. (2) Some animal and chemical fertilizers applied to the land surface are leached into the aquifer, also increasing the mineralization and possibly contaminating the water in the aquifer to the extent that it may no longer be suitable for domestic supplies.

Water from two wells in the Cheyenne municipal well field and two wells in the Carpenter–Pine Bluffs area, analyzed in 1947, was reanalyzed in 1964 to determine if quality had deteriorated. The data indicate very little change in chemical composition of water from the Cheyenne well field and the Carpenter area; however, water from an irrigation well (14–60–11bcc), about half a mile northeast of Pine Bluffs, showed an increase in dissolved solids from 302 ppm (1947) to 486 ppm (1964).

Water from some of the irrigation wells in the Carpenter–Pine Bluffs area has relatively high (about 10 ppm) concentrations of nitrate, which are probably due to pollution from chemical and organic fertilizers.

QUALITY OF SURFACE WATER

Chemical composition of surface water in Laramie County is largely influenced by ground-water inflow and seepage, and by irrigation use. Although the quality of the water is generally suitable for irrigation use, streamflow during the irrigation season is sufficient only for limited irrigation on the stream flood plains.

Analyses of water from the principal streams (table 4) indicate a relatively wide range in chemical composition, not only from one stream to another but also along the reach of a particular stream. Horse Creek was sampled at five sites during June 23–27, 1964, and, although concentrations of principal constituents differed from place to place, all the water sampled was of a calcium bicarbonate type.

The chemical composition of streams is affected by runoff from snowmelt and rainfall, but these effects are generally of short duration. During high runoff, the streams are generally less mineralized than during base-flow conditions. Chemical composition is also influenced by return flow from irrigated areas.

RECORDS OF SELECTED WELLS AND SPRINGS

Location: See description of well-numbering system (p. 3).

Depth of well: Depths are given in feet below land-surface datum.

Geologic source: p€r, Precambrian rocks; PPc, Casper Formation; Kl, Lance Formation; Twr, White River Formation; Ta, Arikaree Formation; To, Ogallala Formation; Qt, terrace deposits; Qfp, flood-plain deposits.

Use of water: D, domestic; I, irrigation; In, industrial; N, none; P, public; S, stock.

Depth to water: Measured depths to water level are given in feet and hundredths; reported depths are given in feet.

Remarks: Ca, sample collected for chemical analysis; D, discharge in gallons per minute (M, measured; R, reported); DD, drawdown in feet while discharging at preceding rate (measured drawdowns are given in feet and tenths; reported and estimated drawdowns are given in feet); B3d, battery of three wells (or number given); T, temperature in degrees Fahrenheit; K, specific conductance (micromhos at 25°C).

Location	Owner or tenant	Year drilled	Depth of well (feet)	Diameter of well (inches)	Geologic source	Use of water	Altitude of land surface above mean sea level (feet)	Distance to water below land surface (feet)	Altitude of water level above mean sea level (feet)	Date of measurement	Remarks
12-62-2acc	Earl I. Mead	1963	102	16	Qt	I	5,345	59	5,286	Jan. 1963	D300R
2bcb	Gary Ford	1945	104	36	Qt	I	5,358	70.35	5,288	May 1964	D677M, Ca
2dbc	Ted Mead		100		Qt	I	5,343	55.44	5,288	do	D456M
3ada	Gary Ford	1962	104	18	Qt	I	5,361	70.35	5,291	Apr. 1964	D950R
10abal	Ray True	1950	105	18	Qt	I	5,358	72.34	5,286	Oct. 1964	D350R
11acc	Ross Youngland	1947	105	18	Qt	I	5,335	53.61	5,281	do	D900R
19aaa	Ben Blake	1959	85	18	Qt	I	5,340	18	5,322	Aug. 1959	
22abb	Frank Dwinell	1952	125	18	Qt	I	5,325	40.07	5,285	May 1964	D696M
12-63-5dbc	do	1962	220	6	Twr	S	5,510	56.18	5,454	Dec. 1964	
12-64-2add	Wyo. Hereford Ranch		185	6	Twr		5,640	114.48	5,526	Apr. 1964	T51, K340
2bcb	do		74	6	To(?)		5,618	39.41	5,579	do	
4cbc	do		70		To	S	5,692	33.27	5,659	do	
11daa	do		197	6	Twr	S	5,670	150	5,520	Apr. 1961	
12-66-6aaa	Warren Livestock Co.			5	To	S	6,179	57.72	6,121	Apr. 1964	
9dca	do		265	8	To	S	6,250	208.31	6,042	do	T48, K320
17caa	do		208	6	To	S	6,294	188.73	6,105	do	T51, K345
12-68-11aab	do		Spring		To	S	6,335		6,335	Sept. 1963	T65, K185
12-69-7bbb	do		85	8	To	S	7,259	59.77	7,199	do	T49.5, K340
13-60-5ccb	Herbert Campbell	1945	100 and 90	18	Twr	I	5,125	40	5,085	June 1945	D250R, B3W (one 100 ft, two 90 ft)
17bcd	Moritz Bros.	1941	80		Twr	I	5,135	38.41	5,097	Oct. 1964	
18dda	Albert Andels	1945	100	18	Twr	I	5,141	29	5,112	Oct. 1957	D750R, DD20, Ca
30bcc	Myles Gardner	1961	85		Twr	I	5,178	32	5,146	July 1961	
31aaa	W. T. Young		100	20	Twr	I	5,186	35.92	5,150	Apr. 1964	B5w
13-61-5baa	Chamberlain Ranches		93	18	Twr	I	5,260	19.49	5,240	Jan. 1965	D1,000R
11aca	Dolan Cattle Co.	1962	80	18	Twr	I	5,184	30	5,154	Mar. 1962	
31cbb	Max Thelen		104	32	Qt	N	5,325	57.08	5,268	Oct. 1964	
13-62-25cab	Stanley N. Lang	1962	103	18	Qt	I	5,347	64	5,283	May 1962	D700R, DD21
29ccc2	A. R. McComas		80		Qt	D	5,435	56	5,379	June 1964	Ca
13-63-10ccb	J. A. Walden	1909	100	6	To	D, S	5,581	76.99	5,504	Oct. 1964	
26caa	Francis Oline	1959	175	20	Twr	I	5,480	58	5,422	Nov. 1959	D400R, DD11
32dcc					Twr	S	5,478			June 1964	Ca
13-64-10dca	Wyo. Hereford Ranch		115	5	To	S	5,740	87.62	5,652	Apr. 1964	
15baa	do		120	4	To	S	5,762	105.29	5,657	do	
19cac	do		150		To	S	5,828	107.94	5,720	do	
23aaa		1958	300	10	To(?)	D, In	5,672	70	5,602	July 1958	D350R, DD7, Ca
23daa		1958	338	10	To(?)	D, In	5,696	98	5,598	do	D220R, DD7, Ca
30daa	Wyo. Hereford Ranch		160	8	To	S	5,838	146.24	5,692	Apr. 1964	

Location	Owner or tenant	Year drilled	Depth of well (feet)	Diameter of well (inches)	Geologic source	Use of water	Altitude of land surface above mean sea level (feet)	Distance to water below land surface (feet)	Altitude of water level above mean sea level (feet)	Date of measurement	Remarks
13-65-6cca	Wyo. Hereford Ranch		75	5	To	S	5,925	41.20	5,884	Apr. 1964	
9ddd	do		220	8	To	S	5,900	106.48	5,794	do	T48, K305
10baa	do		90	6	To	S	5,870	73.65	5,796	do	
13bca	do		150	5	To	S	5,850	115.30	5,735	do	T51, K485
25acd	do		222	6	To	S	5,920	192.33	5,728	do	
33cba	do		185		To	S	5,922	119.11	5,803	do	
34cdc	do		155	5	To	S	5,910	132.84	5,777	do	
13-66-5aa	Frontier Refining Co	1963	85	8	To	In	6,035	50	5,985	Mar. 1963	D63R
13bcd	Wyo. Hereford Ranch		300+	5	To	S	6,118	243.10	5,875	Apr. 1964	
18aca	Orchard Valley	1955	493	10	To	P	6,035	114.60	5,920	Mar. 1957	D308M, DD79.7
22acb	Lummis Livestock Co	1948	300	5	To	S	6,182	183.42	5,999	Apr. 1964	T62, K250
28dba	do	1940	170	6	To	S	6,165	139.29	6,026	do	T56, K480
31aa	Beverly Hills Public Utility.	1961	485		To	N	6,215	130	6,085	June 1961	
13-67-cad	Holdings Little America	1964	170	6	To	D, I	6,110	Flowing		July 1964	D140R, DD42
7dad1	Dan Rees		26	8	To	N	6,340	7.70	6,332	Sept. 1963	
8cbb	do	1936	168	10	To	S	6,320	Flowing		Apr. 1964	D34.2M, T51, K263
15bba	Warren Livestock Co	1935		10	To	N	6,200	18.00	6,182	do	
16bca	Colorado Interstate Gas Co.	1964	173	8	To	In	6,271	21.10	6,250	Dec. 1964	D32M, DD110
16bcc	do	1964	185	8	To	In	6,282	28.95	6,253	do	D50M, DD130, Ca
16cbb	do	1964	182	8	To	In	6,278	30.79	6,247	do	D50M, DD74
17add	do	1964	172	8	To	In	6,294	29.32	6,265	do	D49M, DD108
17bbc	Dan Rees	1935	300	8	To	I, S	6,335	Flowing		May 1964	D15.7M
17daa	Colorado Interstate Gas Co.	1964	171	8	To	In	6,283	28.48	6,255	Dec. 1964	D28M, DD84
17dab	do	1964	185	8	To	In	6,297	31.60	6,265	do	D20M, DD52
17dba	do	1964	190	12	To	In	6,307	34.89	6,272	Sept. 1964	D45M, DD128
18aca1	Dan Rees			3	To	I, S	6,361	Flowing		Apr. 1964	D4.3M, T52, K280
18aca2	do	1954	190	5	To	I, S	6,364	Flowing		do	D16M, T52, K280
18dba	do	1952	175	5	To	I, S	6,351	Flowing		do	D3.3M, T52, K285
18dbd	do				To	I, S	6,353	Flowing		do	D1.6M
19aba	do	1952	205	3	To	I, S	6,380	Flowing		do	D34.2M
19caa	Warren Livestock Co	1939		8	To	S	6,418	29.29	6,389	do	
21bdb	do			5	To	S	6,278	3.70	6,274	Dec. 1963	
27bba	do			10	To	S	6,259	37.40	6,222	do	
28bcd	do		158	10	To	S	6,406	100.50	6,305	do	T54.5, K320
34bcb	Wyo. Highway Dept	1962(?)	500	9	To	N	6,350	129.25	6,221	do	D60R
13-68-1bcd	Art and Jerry King	1956	91	3	To	N	6,410	27.03	6,383	Sept. 1963	
3bba	City of Cheyenne		187	10	To	P	6,553	115.08	6,438	Apr. 1964	

4aad	do	1944	202	10	To	S	6,569	115.39	6,454	do	
4acd	do	1944	255	10	To	P	6,596	132.85	6,463	do	Ca
4dcc	do		200	10	To	P	6,625	147.68	6,477	do	
10add	Art and Jerry King	1947	120	6	To	S	6,540	63.73	6,476	Sept. 1963	T65, K263
12dca	do	1920	81	8	To	S	6,450	69.21	6,381	Apr. 1964	T53, K297
14bbb	City of Cheyenne		222		To	P	6,603				
14cbd	do		210	10	To	P	6,567	65.20	6,502	Apr. 1964	
22cad	Warren Livestock Co		637	18	To, Twr(?)	I, S	6,511	Flowing		Oct. 1964	D40.4M
25bbc	do	1932	143	8	To	S	6,394	Flowing		do	D13.5M
31cdc	do			8	To, Twr(?)	S	6,763	181.20	6,582	Aug. 1964	
35dad	do		175	10	To	S	6,392	Flowing		Dec. 1963	D12M
35ddb	do			10	To	S	6,395	Flowing		June 1964	D38M
13-69-8dbb	Union Pacific Railroad Co.		Spring		PPc	D, I	6,970	Flowing		do	D875M
16cbb		1959	315	8	Twr	D, In	7,053	Flowing		June 1959	D130R, DD39, Ca
16cbd		1959	428	8	Twr, Kl(?)	D, In	7,037	5	7,032	do	D18R, Ca
17daa		1959	555	8	Twr, Kl(?)	D, In	7,062	6	7,056	do	D20R
21ddc	Warren Livestock Co		220	8	To, Twr(?)	S	7,145	196.57	6,948	Sept. 1963	
33add	do		130	8	To	S	7,090	104.65	6,985	June 1964	
13-70-13dbd	A. H. Willadsen	1950	100	6	p€r	S	7,320	22.74	7,297	Sept. 1963	T52, K260
15cba	Walter Ferguson	1953	50		Qfp	I	7,520	9.80	7,510	do	
24aca	A. H. Willadsen	1900	12	30	p€r	N	7,310	9.75	7,300	do	
32ba	D. J. Terman	1962	46	6	p€r	D	7,570	12	7,558	July 1962	
14-60-5bcb	C. C. Gross		100	18	Twr	N	5,082	31.27	5,051	May 1964	B9w
10acc	M. L. Larsen	1939	72	36	Qt	I	5,029	19.02	5,010	June 1964	Ca
11bcc	Earl Vowers		60	24	Qt	I	5,023	17.00	5,006	May 1964	Ca
18ddc	Kenneth L. Fornstrom	1961	100	18	Qt	I	5,132	65	5,067	Dec. 1961	
19dab	Rodney and Reuben Anderson.	1962	160	24	Twr(?)	I	5,120	45	5,075	July 1962	D1,000R, DD15
28bbb	Elmer Glantz	1934	100	20	Twr	I	5,093	25.14	5,068	Apr. 1964	Ca
29ddc	Katherine Campbell	1962	108	18	Qt, Twr	I	5,095	34.34	5,061	Oct. 1964	D1,600R
30aaa	E. G. Sanders	1960	104	18	Qt, Twr	I	5,120	46	5,074	Mar. 1960	D500R
14-61-31cdb	Chamberlain Ranches		90	18	Twr	I	5,290	25.44	5,265	Jan. 1965	D1,500R
14-62-7dbb	Town of Burns	1917	131	6	Ta	P	5,512	100	5,412	Nov. 1948	Ca
20ccb	J. J. Bastian	1955(?)	200	18	Ta(?)	I	5,482	85.30	5,397	Feb. 1964	D600R
14-63-2bab	Albert Schrul	1959	120	5	To(?)	D, S	5,585	80	5,505	1959	
31ccd	Wyo. Hereford Ranch		100	3	To(?)	S	5,661	74.23	5,587	Apr. 1964	T52, K770
14-64-2acd	Wayne Nicodemus	1938(?)	130	4	To	S	5,695	64.22	5,631	Aug. 1963	
5aca	Mueller Bresnahan	1910(?)	121	5	Ta	S	5,805	102.64	5,702	do	
6bcd	Mr. Boice	1910(?)	98	60	To	S	5,810	94.20	5,716	July 1963	T54, K380
7bbb	Tri-County Grain Co	1945	195	3	To, Ta(?)	D, S	5,895	160.27	5,735	do	T59, K375
10ddc	Dana McWilliams	1950	133	4	To	S	5,760	110.09	5,650	Aug. 1963	
11dda	Fred Wilson	1938(?)	80	5	To	N	5,710	72.26	5,638	do	
12bcc	Claude Stoner	1912(?)	110	4	To	N	5,710	96.86	5,613	do	
12daa	do	1910(?)	130	4	To	D, S	5,700	100	5,600	1957	T70, K510
14bab	Dana McWilliams	1910	120	4	To	D, S	5,752	105	5,647	Aug. 1963	
14dad	John Kauffman	1912(?)	118	6	To	N	5,725	98.29	5,627	do	
16dbb	Dana McWilliams	1900(?)	91	6	To	S	5,762	84.87	5,677	do	T55, K345
20bcc	Mr. Lowe		185	6	To, Ta	S	5,857	150.20	5,707	do	
21ccc	Dana McWilliams	1910(?)	149	6	To	S	5,810	129.98	5,680	do	T55, K435

Location	Owner or tenant	Year drilled	Depth of well (feet)	Diameter of well (inches)	Geologic source	Use of water	Altitude of land surface above mean sea level (feet)	Distance to water below land surface (feet)	Altitude of water level above mean sea level (feet)	Date of measurement	Remarks
14-64-23aad	John Kauffman		122		To	S	6,720	103.57	5,616	Aug. 1963	T71, K375
24aad	do	1912(?)		6	To	N	5,680	89.18	5,591	do	
28baa1	Edgar E. Baker	1960	184	6	To, Ta	D, I	5,780	110	5,670	Apr. 1964	D150R, Ca
28baa2	do	1964	240	16	To, Ta	I	5,780	109.74	5,670	do	D600R
32ccb	Wyo. Hereford Ranch		125	6	To	S	5,818	109.09	5,709	do	T50, K375
14-65-1ddb	G. L. Nickerson	1916(?)	131	6	To	S	5,840	112.36	5,728	July 1963	T55, K400
2abb	C. H. Beckle	1945	122	8	To, Ta(?)	S	5,860	104.33	5,756	Aug. 1963	T65, K360
3bcb	Delbert Child	1956	152	5	To, Ta(?)	S	5,889	101.94	5,787	July 1963	T52.5, K360
5cdb	Wayne Child		139	5	To	S	5,930	116.50	5,813	do	T54, K375
5dda	do		170		To	S	5,925	120.15	5,805	do	T55, K365
7bad	Howard Christensen	1960	170	5	To	S	5,962	90	5,872	Nov. 1960	
8dda	I. H. Hurt	1917	232	6	To, Ta	D, S	6,010	216	5,794	July 1963	T64, K395
10dda	C. H. Beckle	1915	194	4	To	D, S	5,950	192	5,758	Aug. 1963	
16bdd	do	1945	240	5	To	S	5,970	202.52	5,767	do	
19cbc	Memorial Gardens	1960	580	6	To	I	6,098	274.63	5,823	Jan. 1964	
20daa	M. H. Krug	1962	320	5	To	D, S	6,025	230	5,795	do	T69, K390
29bbb	E. J. Christensen	1900	296	4	To	D, S	6,062	256	5,806	do	T57, K360
34dcb	Wyo. Hereford Ranch		74		To	S	5,852	50.79	5,801	do	
14-66-3cac	C. W. Wood		400	6	To	D, S	6,192	224.00	5,968	July 1963	
4dbc	Alan Bell		250		To	D, S	6,210	186.70	6,023	do	
5dba	Thomas Fennell	1930(?)	275		To	D, S	6,215	185.79	6,029	do	T58, K335
9cca	George Carpenter	1955	115	6	To	D, S	6,130	107.65	6,022	do	T60, K378
11dbb	Wayne Child	1963	99	5	To	S	6,010	80	5,930	Feb. 1963	
19bbd	Frank Baird	1933	98	3	To	D	6,146	75	6,071	Apr. 1955	
34aca	Edsel K. Dimon	1954	232	5	To	D	6,017	142	5,875	Mar. 1954	
14-67-4bba	Harold Wright		180(?)	8	To	D,S	6,385	120.70	6,264	Apr. 1964	
6dad	John Bell			6	To	S	6,438	132.68	6,305	do	
7ccb	City of Cheyenne	1956	311(?)		To	P	6,328	53.86	6,274	Mar. 1964	
7dcb	do	1956	310(?)		To	P	6,333	62.00	6,271	do	
18cbd	do	1955	225	12	To	P	6,270	Flowing		do	Ca
18ddc	do	1955	229	6	To	N	6,249	20.05	6,229	do	
19bbd	do	1955	274	6	To	N	6,302	38.27	6,264	do	
20aa	do	1934	12	Gallery	Qfp	P					Collecting gallery
24acb	do	1955	341	12	To	P	6,168				
27ac	do			Gallery	Qfp	P					Collecting gallery
30abb	Shellback Ranch		332	12	To	S, I	6,315	24.22	6,291	Feb. 1964	D225R
31ddc				6	To	S	6,315	13.46	6,302	Apr. 1964	D5M
14-68-10dcd			175	5	To	S	6,440	128.39	6,312	do	
13acb	City of Cheyenne	1955	212	12	To	P	6,274	3.72	6,270	Mar. 1964	
13ccd	do	1956	266	12	To	P	6,330	57.19	6,273	do	

13dad	do	1955	190	12	To	P	6,258	Flowing		do	
14ada	do	1955	151	12	To	N	6,277	9.82	6,267	do	
14cad	do	1955	163	12	To	P	6,316	39.38	6,277	do	Ca
14dcd	do	1955	208	12	To	P	6,344	69.09	6,275	do	
23ddc	do	1940	250	10	To	P	6,393	79.17	6,314	do	Ca
24bdd	do	1955	250	12	To	P	6,328	59.99	6,268	do	
24ddd	do	1934	286	10	To	P	6,318	33.78	6,284	Apr. 1964	
25bcb	do		334	10	To	P	6,375				
25dda	do		368	12	To	P	6,383	52.00	6,331	Apr. 1964	
26bdd	do		215	15	To	P	6,398	24.22	6,374	Mar. 1964	
26cbc	do	1940	220	10	To	P	6,445	57.52	6,387	do	
27dcc	do	1940	250	10	To	P	6,483	81.71	6,401	do	Ca
28bcb2	Art Francis			6	To	N	6,545	124.91	6,420	do	
28bda	Francis Livestock Co.	1956	110	5	To	S	6,490	91.10	6,399	Apr. 1964	
33dcc	City of Cheyenne	1945	307	10	To	P	6,634	178.31	6,456	do	
34aab	do	1940	235	10	To	P	6,469	68.76	6,400	Mar. 1964	
34dbd	do	1943	190	10	To	P	6,524	106.81	6,417	Dec. 1964	
34ddd	do		230	10	To	P	6,550	122.28	6,428	Apr. 1964	
35cac	do	1945	235	10	To	P	6,517	108.81	6,408	do	
35cdd	do		230	10	To	N	6,512				
36acc	do		184	10	To	P	6,409	50.07	6,359	Apr. 1964	
36adb	do		152	12	To	P	6,365	36.99	6,328	do	
36bca	do	1941	194	12	To	P	6,428	46.68	6,381	do	Ca
14-69-3cbb	Francis Livestock Co.	1963	10	12	Qfp	S	6,600	3	6,597	Nov. 1963	D40R, DD5
10baa	do	1917		80	Twr	S	6,580	26.07	6,554	Aug. 1963	
22dba	Ed Francis	1963	16		Qfp	S	6,538	1.78	6,536	do	
23acc	Francis Livestock Co.	1960	10	24(?)	Qfp	S	6,490	6	6,484	Jan. 1960	
23bac	do	1946	156		Twr	D, S	6,529	30	6,499	Sept. 1946	
30bcb	Ed Ferguson		12	30	Qfp	S	6,730	7.65	6,722	Sept. 1963	
15-60-19dab	Reuben V. Anderson	1954	125	16	Twr	I	5,155	55	5,100	Nov. 1954	D750R
34bcb	Glen Macy		95	36	Twr	S	5,112	74	5,038	Nov. 1947	Ca
34dac		1959	315	7	Twr	D, In	5,096	58	5,038	Apr. 1960	Ca
34dbd		1959	318	7	Twr	D, In	5,082	47	5,035	Aug. 1959	Ca
15-61-4dcd	Chester Bruns	1961	240	16	Ta	I	5,285	73	5,212	May 1961	D900R, DD27
9bbb	Ben Hatcher	1960	175		Ta	I	5,308	90	5,218	May 1960	D200R, DD50
15-62-7cbb		1913(?)	137	4	To	N	5,603	128.40	5,475	Dec. 1963	
9bbc	Herbert Woolington	1900(?)	57	5	To	S	5,470	49.57	5,420	May 1964	T56.5, K380
12bdb	Earl Woolington		75	6	To	S	5,382	50.04	5,332	do	
12ddd	do		145		To	N	5,430	123.86	5,306	do	
16bdd	Herbert Woolington		113	4	To	S	5,512	98.99	5,413	do	
15-63-2ada	Laurence Anderson	1900	115	4	To	D, S	5,585	100	5,485	Dec. 1963	
10ddd	Benjamin Trimble	1912(?)	109	4	To	D, S	5,623	100	5,523	do	
24dad	A. D. Martin	1910(?)	98	6	To	D, S	5,550	86	5,464	do	
25dbd	Kenneth Youtz	1962	160	14	Ta	I	5,480	25.56	5,454	May 1962	
32bbc	Paul and Vernon McDowell.	1964			To	I	5,680	96.32	5,584	Nov. 1964	
15-64-3aad	Leroy Goertz	1955	270	18	Ta	I	5,795	173.51	5,621	Oct. 1964	D1, 600R
21dac	Harold McWilliams	1941	48	5	To	S	5,710	28	5,682	Aug. 1963	
24cad	do	1941	65	5	To	S	5,679	45	5,634	do	
26cbc	do	1941	100	5	To	D, S	5,655	14	5,641	do	T65, K460

Location	Owner or tenant	Year drilled	Depth of well (feet)	Diameter of well (inches)	Geologic source	Use of water	Altitude of land surface above mean sea level (feet)	Distance to water below land surface (feet)	Altitude of water level above mean sea level (feet)	Date of measurement	Remarks
15-64-27bbb	W. H. Dolan	1930(?)	28	16	Qfp	S	5,679	16.70	5,662	Aug. 1963	
28ddb	Mr. Whitehead		42	4	To	S	5,710	22.28	5,688	do	
31ccc	Mr. Boice		135	3	To	S	5,835	112.07	5,723	July 1963	
32bdb	Mueller Bresnahan	1955	110	5	To	S	5,775	70.59	5,704	Aug. 1963	
35acb	Harold McWilliams	1958	100	5	To	S	5,705	85	5,620	do	
15-65-8aac	Warren Livestock Co				To	S	5,907	43.87	5,863	Aug. 1964	
14bda	Francis Warren	1963		6	To	S	5,858	87.61	5,770	do	
25cdd	Mr. Boice		84	5	To	S	5,820	82	5,738	July 1963	T66, K405
30aad	Wayne Child		163	6	To	S	5,990	152.70	5,837	do	T57.5, K420
30dad	do		139		To	S	5,962	135.61	5,826	do	T54, K410
32ccd	do	1910(?)	260	4	To	D, S	6,032	199.03	5,833	do	T54, K355
32ddd	Delbert Child	1910	216	6	To	D, S	5,983	176	5,807	do	T56, K395
34adc	do		114	5	To	S	5,848	74.16	5,774	do	T57, K360
35bcb	do	1953	117	5	To	S	5,835	73.29	5,762	do	T55, K380
15-66-27dbb	Jordan Ranch Co	1910(?)	189	6	To	S	6,125	166.05	5,959	do	T57, K345
33bbb	do	1910(?)	203		To	S	6,151	132.86	6,018	Jan. 1965	T63, K320
36bbc	do		182		To	S	6,065	161.99	5,903	July 1963	T69, K345
15-67-2dba	Ervin A. Mueller	1956	181	16	To	I	6,240	72.47	6,168	Apr. 1964	
28cdc	Theodore Fedder		191	6	To	S	6,410	139.87	6,270	do	
30bdd			190		To	S	6,480	169.33	6,311	Aug. 1963	T56.5, K265
34ccc	Clyde Magill	1961	300		To	D	6,325	93.20	6,232	Mar. 1961	D15R, DD15
15-68-6cdd	C. C. Davis		260	6	To	S	6,766	220.00	6,546	Aug. 1963	T54, K340
35cca	Marie Merritt	1960	430	6	To	S	6,612	160	6,452	Oct. 1960	D10R
15-69-4abc	C. C. Davis		90	6	Twr	S	6,745	33.82	6,711	Aug. 1963	
6aca	City of Cheyenne	1942	182	10	Twr	P	6,841	56.45	6,785	Mar. 1964	Ca
16acb	do	1954	351	12	Twr	P	6,785	55.60	6,729	do	
21dcc	do	1954	223	12	Twr	P	6,668	33.96	6,634	do	Ca
27ccd	do	1954	236	24	Twr	P	6,616	13.83	6,602	do	D450M, DD123
28dba	do	1954	294	12	Twr	P	6,642	36.67	6,605	do	
32bba			130	6	Twr	S	6,794	42.22	6,752	Dec. 1963	
33abb	City of Cheyenne	1954	238	12	Twr	P	6,680	65.96	6,614	Mar. 1964	
34aaa	do	1954	312	12	Twr	P	6,595	18.84	6,576	do	Ca
16-61-2daa	G. R. Lerwick	1911	180	5	Ta(?)	S	5,350	165.91	5,184	Sept. 1964	
4cbb	Leonard Anderson	1912(?)	206	4	Ta(?)	N	5,452	200.00	5,252	do	
14bbc	Warren G. Anderson	1911(?)	220	5	Ta	N	5,410	194.87	5,215	do	
19bdd	Delbert Rohweder	1960	160	5	To	S	5,405	125	5,280	Dec. 1960	
30bbb	Faye Marquiss	1910(?)	169	5	To	N	5,450	154.54	5,295	Mar. 1964	
16-62-3aab	John Ecklund	1890	235	6	To, Ta	S	5,500	166.17	5,334	Sept. 1964	
7cac	Kenneth Deselm	1962	245	6	Ta(?)	S	5,600	200	5,400	Apr. 1962	D15R
12ada	Curtis Miller	1911(?)	235(?)	5	To, Ta	S	5,512	222.24	5,290	Sept. 1964	

14aaa	Warren G. Anderson	1912(?)	238		To, Ta	N	5,530	228.96	5,301	do	
20ccb	T. W. Bastian	1914(?)	192		Ta	S	5,574	160.22	5,414	May 1964	
21ddd	do		99	6(?)	To	S	5,450	81.56	5,368	Sept. 1964	
23acd	Max E. Hutchinson	1962	245	16	Ta(?)	I	5,482	165	5,317	Aug. 1962	
32ccb	Mary Thompson	1910(?)	86	6	To	S	5,518	75.25	5,443	Sept. 1964	T50, K260
34ccc	Willis King	1913(?)	113	4	To	N	5,495	96.50	5,398	do	
35add	do		165	6	Ta(?)	S	5,433	102.34	5,331	do	T50, K260
16-63-8aaa	Albert Sandberg	1913(?)	220	4	Ta	D, S	5,675	200	5,475	Dec. 1963	
13bab	N. M. Butler		135(?)	6	Ta	N	5,555	119.67	5,435	Sept. 1964	
22cbb	Wayne Bishop		185	3	Ta	N	5,660	164.05	5,496	Dec. 1963	
30ddd	Clifford Spatz	1912	175	4	To	S	5,705	150.46	5,555	May 1963	
33cca	do	1912(?)	120		To, Ta(?)	S	5,628	91.50	5,536	Dec. 1963	
36cca	Laurence Anderson		90	4	To	S	5,560	67.85	5,492	do	
16-64-11dcc	Charles Bollin		235	4	To	S	5,768	208.86	5,559	do	
14cbb	Tom Johnson	1915(?)			To	S	5,818	241.03	5,577	do	
19bdd	Ora G. Epler	1960	210	6	To	S	5,872	175	5,697	May 1960	
20baa	Charles Keslar	1910	206	3	To	N	5,830	179.95	5,650	Dec. 1963	
27abb	do	1940	200		To	S	5,800	184.88	5,615	do	
28aad	M. E. Keslar	1948		4	To	S	5,800	168.36	5,632	do	
28dcc	Theodore Fedder			3	To	S	5,840	185.05	5,655	do	
16-65-3bbb		1958	513	10	To, Ta	D, In	5,887	153	5,734	Feb. 1958	D300R, Ca
3cca		1958	638	10	To, Ta	D, In	5,895	162	5,733	do	D300R, Ca
8dcc	Warren Livestock Co		198	5	To	S	6,003	183.24	5,820	Sept. 1963	
9bba	do		215	6	To	S	5,940	158.30	5,782	do	
30bad	do		165		To	S	6,033	144.56	5,888	Dec. 1963	
35acc	Prosper Combs	1959	202	6	To	S	5,931	190	5,741	Aug. 1959	
16-66-7ddd	Boice Bros., Inc		162	5	To	S	6,212	131.37	6,081	Sept. 1963	T57, K250
13bdd	Jay Berry	1947	265		To, Ta	S	6,092	194.32	5,898	do	T52, K340
14bbc		1911(?)		4	To(?)	N	6,142	190.48	5,952	do	
14cbc	Keith Holmes			4	To	S	6,138	187.45	5,951	do	T49.5, K290
15add	Boice Bros., Inc	1961	240	5	To	S	6,138	180	5,958	Aug. 1961	D12R
18cba	Dan Pry		192	5	To	S	6,263	146.21	6,117	Sept. 1963	T54, K285
22ddd	O. K. Allen		230	4	To, Ta(?)	S	6,153	205.15	5,948	do	T54, K325
23bbb	do		219	4	To, Ta(?)	N	6,138	194.54	5,943	do	
24bba	Jay Berry		229	5	To, Ta(?)	S	6,109	200.00	5,909	do	T54, K345
26bbc	Edna and Merle McGowen.	1950	197	4	To	D, S	6,128	175	5,953	do	T60, K400
26cbb	do	1911	210	3	To	S	6,120	180	5,940	do	T52, K305
16-67-3cba	Warren Livestock Co		220	6	To	S	6,393	156.06	6,237	Aug. 1963	T55.5, K300
3dcd	do		242	5	To	S	6,353	140.14	6,213	do	T54.5, K295
8bcb	Gene Tuck		233	3	To	S	6,493	211.92	6,281	do	
10cbc	Floyd Holmes, Jr		217	5	To	S	6,410	177.82	6,232	do	T53, K345
13aaa	do			6	To	S	6,274	121.70	6,152	Sept. 1963	T51, K255
17bdb	Gene Tuck		156	5	To	S	6,431	136.06	6,295	Aug. 1963	
16-68-2daa		1958	459	10	To	D, In	6,547	137	6,410	Feb. 1958	D284R, DD59, Ca
11aad		1958	473	10	To	D, In	6,538	124	6,414	do	D309R, DD75, Ca
12dbd	E. W. Caldwell		270	6	To	S	6,520	207.11	6,313	Aug. 1963	
19bbb	Gene Tuck			3	To	S	6,535	Flowing		do	T50, K465
29daa	do		260	5	To	S	6,691	258.00	6,433	do	T53, K325
31adc	do		320	4	To	S	6,753	202.52	6,550	do	T55.5, K340
16-69-5daa	C. C. Davis			6	To	S	7,049	220.92	6,828	do	

Location	Owner or tenant	Year drilled	Depth of well (feet)	Diameter of well (inches)	Geologic source	Use of water	Altitude of land surface above mean sea level (feet)	Distance to water below land surface (feet)	Altitude of water level above mean sea level (feet)	Date of measurement	Remarks
16-69-6bab	Bill and Harold Dereemer.	1937	28	6	Qfp	S	6,552	7	6,545	Aug. 1963	T68, K710
11abb	C. C. Davis		263	6	To	S	6,874	183.12	6,691	do	
28bbc	do		85	4	Qfp	S	6,681	24.00	6,657	do	T71, K525
29bac	Hugh McPhee	1922	100	5	(?)	D, S	6,715	22	6,693	do	T60, K770
17-60-4cbb	Ed Branigan	1911	285(?)	6	Ta	D, S	5,362	282.48	5,080	Sept. 1964	T55, K510
8cba	Ray Haldeman	1911(?)	300+		Ta	N	5,392	287.40	5,105	do	
29abb	Town of Albin	1931	300	8	Ta	P	5,355	240	5,115	Mar. 1953	Ca
30ddd	R. M. Holgerson	1912	200	5(?)	Ta	S	5,315	185.92	5,129	Sept. 1964	
34cbb	Ed P. Anderson	1912(?)	192	8	Ta	N	5,285	182.46	5,103	do	
17-61-3dac	Ray Strube		260	6	Ta	S	5,290	187.90	5,102	do	
14bba	W. T. Young		280		Ta	N	5,395	242.25	5,153	do	
14cdc	do	1910(?)	280		Ta	N	5,435	266.02	5,169	do	
17cda	Fred Lush	1963	255	5	Ta	S	5,445	206.44	5,239	June 1964	
18dcc	Walter Brently	1913(?)	213		Ta	S	5,451	187.01	5,264	do	
23dab	Orville Lerwick		280	5	Ta	S	5,415	244.59	5,170	Sept. 1964	
32aaa	John Ecklund	1900	200	5	Ta	D, S	5,443	195	5,248	do	
17-62-8aab	Hunter Ranch Co		275		Ta	S	5,338	90.00	5,248	June 1964	
14dcd	George Davis		240		Ta	S	5,496	196.84	5,299	do	
16ccc	George Romsa		256	4	Ta	S	5,555	227.50	5,327	do	
32aaa	Floyd Lemaster	1910(?)	236		Ta	D, S	5,550	230	5,320	Sept. 1964	
35ada	George Davis	1951	220	4	Ta	S	5,510	208.37	5,302	do	
17-63-6acb		1962	150		Ta	D, In	5,398	78	5,320	June 1962	
9ddc	Rutledge & Donahue, Inc.				Ta	S	5,485	129.96	5,355	June 1964	
12cac	C. C. Gross		Spring		Ta	S	5,300		5,300	July 1964	D30R
18abc	Kenneth Kirkbride		170	5	Ta	S	5,540	151.03	5,389	May 1964	
24aad	Marvin Sandberg	1912(?)	262	4	Ta	N	5,608	254.18	5,354	Sept. 1964	
34ada	do	1912(?)	275	5	Ta	N	5,682	260.74	5,421	do	
17-64-2bbd	Kenneth Kirkbride		94	5	Ta	S	5,425	42.14	5,383	Apr. 1964	T56, K320
12acc	do		82		Ta	S	5,463	73.97	5,389	May 1964	
14ad	do		162		Ta	S	5,570	143.73	5,426	do	T49, K265
34cbb			300+	6	Ta	N	5,820	281.24	5,539	Apr. 1964	
17-65-11ccb	Warren Livestock Co		165	6	Ta	S	5,660	100.72	5,559	Sept. 1963	
16bda	do		125	6	Ta	S	5,681	82.22	5,599	do	
23cad	do		195	7	Ta	S	5,763	136.42	5,627	do	T57, K405
25dca	do		270	5	Ta	S	5,870	249.80	5,620	do	
27adc	do			6	Ta	S	5,862	187.33	5,675	do	
29dcd	do			6	Ta	S	5,938	160.05	5,778	do	

17-66-3ca	Lewis Ranch	1956	305	12	Ta	N	5,725	20.84	5,704	Oct. 1964	
13dad	Warren Livestock Co.		Spring		Ta	S	5,725		5,725	Sept. 1963	T71, K210
14bcc	Jay Berry		58		Ta	S	5,806	35.80	5,770	do	
19bdc	Lewis Ranch		Seep		Ta	S	6,000		6,000	do	
19daa	do		Seep		Ta	S	6,000		6,000	do	
20cdd	do		Spring		Ta	S	6,000		6,000	do	D2E, T52, K335
20ddc	do		Seep		Ta	S	6,010		6,010	do	
22baa	Jay Berry	1914	94	3	Ta	S	5,878	85.67	5,792	do	T63, K345
23bca	do	1959	120	5	Ta	S	5,890	89.20	5,801	do	T51.5, K295
28abb	Lewis Ranch		Seep		Ta	S	6,000		6,000	do	
32ddb	E. L. Zimmerman	1945	192	4	To	S	6,202	164.20	6,038	do	
33cdd	Warren Livestock Co.		285	6	To, Ta	S	6,175	204.29	5,971	do	
34dcc	E. L. Zimmerman		213	4	Ta	S	6,140	197.23	5,943	do	
36cdb	Warren Livestock Co.		179	5	Ta	S	6,045	148.03	5,897	do	
17-67-24aad	Lewis Ranch		Spring		Ta	S	6,000		6,000	do	D1E, T51, K335
24bbb	do		Spring		Ta	S	6,020		6,020	do	D3E
24bcb	do		Spring		Ta	S	6,020		6,020	do	D10E, T70, K335
24bdb	do		Spring		Ta	S	6,020		6,020	do	D1E
27acd	Bruce Nimmo		220	5	To	S	6,280	182.51	6,097	do	T53.5, K325
29aaa	Tice Moyers		20	4	To	S	6,200	3.90	6,196	Aug. 1963	T52.5, K400
36cca	Warren Livestock Co.		145	6	To	S	6,278	106.00	6,172	Sept. 1963	T52, K365
17-68-31dc	Mobil Oil Co.	1963	746	10	To	In	6,805				D60R
31ddc1	do	1942	616	8	To	In	6,803				D30R
31ddc2	do	1948	765	6	To	In	6,802	370	6,432	Oct. 1964	
17-69-3cda	Nimmo Livestock Co.		143	5	To	S	6,800	15.64	6,784	Aug. 1963	
6add	Whitaker Ranch Co.			6	Twr	S	6,848	52.63	6,795	do	
7dab	do		175	6	To	S	7,036	157.20	6,879	do	
9bba	Nimmo Livestock Co.		100	6	To	S	6,892	71.21	6,821	do	
10aca	do		250	6	To	S	6,866	133.58	6,732	do	
15abc	Joseph E. Dereemer				To	S	6,787	71.22	6,716	do	
15acd	do	1930	98		To	D, S	6,780	79.00	6,701	do	
15bcc	do	1940	138	6	To	S	6,858	106.92	6,751	do	T52, K300
16bab	do		153	5	To	S	6,920	140.38	6,780	do	T55, K240
19cad	Jim Tugman		100	6	Twr	S	6,560	55.18	6,505	do	T53.5, K330
21dcc	Bill and Harold Dereemer.		78	6	Twr	S	6,455	35	6,420	do	
28add	do	1954		6	Twr	S	6,404	13	6,391	do	
32aad	do	1954	150	6	Twr	S	6,561	79	6,482	do	
33abc	do	1954	90	6	Twr	S	6,528	50	6,478	do	
17-70-4dcc	Whitaker Ranch Co.		83	5	(?)	N	6,800	29.22	6,771	June 1964	
18-61-5dac	Fred Petsch				Qfp	D, S					Ca
18-62-3bda		1959	704	7	Twr, Kl	D, In	5,069	312	4,757	Apr. 1960	Ca
3bdb		1959	713	7	Twr, Kl	D, In	5,067	311	4,756	Aug. 1956	Ca
9bdc	Meriden Store		80	6	Twr	D	4,950	43.30	4,907	Sept. 1964	Ca
12acd	Fred Petsch	1962	80	6	Qt	I	4,905	14.27	4,891	June 1964	
15ddb	do	1961	90	12(?)	Twr	I	4,905	33.37	4,872	do	
20bba	J. W. Kirkbride	1910(?)		5	Twr	N	4,963	10.52	4,952	Sept. 1964	
30bcd	Donahue & Rutledge, Inc.		Spring		Ta	S	5,055		5,055	May 1964	D15E

Location	Owner or tenant	Year drilled	Depth of well (feet)	Diameter of well (inches)	Geologic source	Use of water	Altitude of land surface above mean sea level (feet)	Distance to water below land surface (feet)	Altitude of water level above mean sea level (feet)	Date of measurement	Remarks
18-63-10caa	Donahue & Rutledge, Inc.		100	4	Twr	S	5,190	67.72	5,122	May 1964	
14aad	do		100	4	Twr	S	5,075	76.30	4,999	do	
17dcd	Kenneth Kirkbride		200	5	Ta	S	5,320	139.02	5,181	do	
20cbc	J. W. Kirkbride	1958	160	6	Ta	S	5,307	50	5,257	Sept. 1958	
23daa	Donahue & Rutledge, Inc.		100		Twr	S	5,037	44.98	4,992	May 1964	T60, K325
18-64-1caa	Kenneth Kirkbride		165		Ta	S	5,307	114.34	5,193	Apr. 1964	
28bdc	do		55	5	Ta	S	5,332	37.65	5,294	do	T54.5, K265
18-65-7ddd			116	5	Ta	N	5,640	83.86	5,556	June 1964	
18-66-7bbd	Nimmo Livestock Co.		84	6	Twr	S	5,747	54.84	5,692	Aug. 1963	
11aab			Spring		Ta	S	5,525		5,525	June 1964	
27ccd			192	6	Ta	S	5,830	131.89	5,698	Sept. 1963	T53, K365
31ccc	Nimmo Livestock Co.	1946	150	6	Ta	N	5,930	112.55	5,817	do	
18-67-4acb	Presly Duvall	1940	219	4	Twr	S	5,924	97.55	5,826	Aug. 1963	
8dab	Hoyt Duvall	1938			Twr	S	5,925	50	5,875	do	T55, K445
16bbd	Richard Duvall		145	8	Twr	S	5,978	102.85	5,875	do	
18-68-12acc	F. L. Duvall	1960	153	5	Twr	S	6,061	65	5,996	Sept. 1960	D7.5R
24dbb	Nimmo Livestock Co.	1960	130	6	Ta(?)	S	6,125	31.83	6,093	Aug. 1963	
18-69-6dbd	Jordan Ranch Co.		295	4	Twr	S	6,813	215.17	6,598	do	
13aaa	Charles Hirsig			5	To	S	6,455	17.51	6,437	do	
16bb	do		60	5	To	N	6,655	30.30	6,625	do	
26bdd	Nimmo Livestock Co.	1963	115	6	To	S	6,650	26.76	6,623	do	T55, K320
18-70-1cdd	Jordan Ranch Co.	1939	81	6	Twr	S	6,445	60.34	6,385	do	
13aba	do		132	6	Twr	S	6,580	91	6,489	do	
19-65-8aad	Ira P. Trotter	1959	137	5	Twr	S	5,430	102	5,328	May 1959	D5R
19-66-17cda	Earl Vowers	1950	48	8	Qfp, Twr	I	5,620	27	5,593	May 1950	D725R
19-67-5bcc	Donald Gillespie	1920(?)	145	5	Twr	S	5,974	135	5,839	Aug. 1963	T57, K360
10aaa	H. Gard		145	5	Twr	N	5,819	110.74	5,708	do	
28cda	Presley Duvall	1915		5	Twr	S	5,845	57.66	5,787	do	
33daa	Mr. Bell				Twr	S	5,813	30.51	5,782	do	
19-68-13dda	Clyde Caster			5	Twr	N	6,052	130.69	5,921	do	
28bdd	Ross Welty	1915(?)	175	5	Twr	S	6,226	122.18	6,104	do	
19-69-2dba	Jordan Ranch Co.	1949	26	8	Qfp	D, S	5,872	11.50	5,860	do	
11bac	do	1949	22	10	Qfp	S	5,888	7.51	5,880	do	T53.5, K860
32ddd	do	1939	190	6	To	S	6,728	163.75	6,564	do	
33acd	do	1939	144	6	To	S	6,630	67.42	6,563	do	
19-70-25add	do		72	4	Qfp	N	6,110	18.09	6,092	do	
32cdd	John Bell		22	8	Qfp	S	6,365	10.48	6,355	do	

REFERENCES CITED

Adams, G. I., 1902, Geology and water resources of the Patrick and Goshen Hole quadrangles, in eastern Wyoming and western Nebraska: U.S. Geol. Survey Water-Supply Paper 70, 50 p.

Babcock, H. M., and Bjorklund, L. J., 1956, Ground-water geology of parts of Laramie and Albany Counties, Wyoming, and Weld County, Colorado: U.S. Geol. Survey Water-Supply Paper 1367, 61 p.

Babcock, H. M., and Rapp, J. R., 1952, Reconnaissance of the geology and ground-water resources of the Horse Creek-Bear Creek area, Laramie and Goshen Counties, Wyoming: U.S. Geol. Survey Circ. 162, 28 p.

Bergstrom, J. R., 1953, The Mesaverde Formation of the Laramie Basin, *in* Wyoming Geol. Assoc. Guidebook 8th Ann. Field Conf., Laramie Basin, Wyoming and North Park, Colorado, 1953: p. 56–60.

Bjorklund, L. J., 1959, Geology and ground-water resources of the upper Lodgepole Creek drainage basin, Wyoming: U.S. Geol. Survey Water-Supply Paper 1483, 40 p.

Brady, R. T., 1949, Geology of the East Flank of the Laramie Range in the vicinity of Federal and Hecla, Laramie County, Wyoming: Univ. of Wyoming, Master's thesis, 41 p.

Burleigh, H. P., Gwillim, E. C., Dunewald, T. J., and Pearson, H. W., 1938, Report on irrigation by recovery of ground waters in the Egbert-Pine Bluffs area, Wyoming: U.S. Dept. Agriculture, Bur. Agr. Economics open-file report, 54 p.

Cady, R. C., 1935, Report on the test well at the Veterans Administration Facility, Cheyenne, Wyoming: U.S. Geol. Survey open-file report, 37 p.

Darton, N. H., Blackwelder, Eliot, Siebenthal, C. E., 1910, Description of the Laramie and Sherman quadrangles [Wyoming]: U.S. Geol. Survey Geol. Atlas Folio 173, 13 p.

Denson, N. M., and Bergendahl, M. H., 1961, Middle and upper Tertiary rocks of southeastern Wyoming and adjoining areas, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C168–C172.

Dockery, W. L., 1940, Underground water resources of Horse Creek and Bear Creek valleys, southeastern Wyoming: Wyoming Geol. Survey Bull. 30, 32 p.

Foley, F. C., 1943, Progress report on the geology and ground-water resources of the Cheyenne area, Wyoming: U.S. Geol. Survey open-file report, 96 p.

Gray, L. O., Jr., 1946, Geology of the East Flank of the Laramie Range in the vicinity of Horse Creek, Laramie County, Wyoming: Univ. of Wyoming, Master's thesis, 25 p.

Hammond, C. R., 1949, The geology of the East Flank of the Laramie Range in the vicinity of Iron Mountain, Wyoming: Univ. of Wyoming, Master's thesis, 63 p.

Haun, J. D., 1948, Geology of a portion of the East Flank of the Laramie Range: Univ. of Wyoming, Master's thesis, 40 p.

Jacob, C. E., 1943, Correlation of gound-water levels and precipitation on Long Island, New York: Am. Geophys. Union, 24th Ann. Mtg., 1943, Trans., pt. 2, p. 564–573 [1944]. Reprinted as New York State Water Power and Control Comm. Bull. GW–14, 1945.

——— 1950, Flow of ground water, chap. 5 *of* Rouse, Hunter, Engineering hydraulics: New York, John Wiley & Sons, p. 321–386.

Lee, W. T., 1927, Correlation of geologic formations between east-central Colorado, central Wyoming and southern Montana: U.S. Geol. Survey Prof. Paper 149, 80 p.

Littleton, R. T., 1950, Reconnaissance of the geology and ground-water hydrology of the Laramie Basin, Wyoming: U.S. Geol. Survey Circ. 80, 37 p.

Love, J. D., and others, 1955, Geologic map of Wyoming: U.S. Geol. Survey Map.

McGookey, D. P., 1952, Pennsylvanian and Early Permian stratigraphy of the southeast portion of the East Flank of the Laramie Range, Wyoming and Colorado: Univ. of Wyoming Master's thesis, 45 p.

McLaughlin, T. G., 1948, Ground water in the Julesburg area, Colorado: Colorado Water Conserv. Board Circ. 1, 20 p.

Maughan, E. K., 1963, Mississippian rocks in the Laramie Range, Wyoming, and adjacent areas, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–C, p. C23–C27.

——— 1964, The Goose Egg Formation in the Laramie Range and adjacent parts of southeastern Wyoming, *in* Geological Survey research, 1964: U.S. Geol. Survey Prof. Paper 501–B, p. B53–B60.

Meinzer, O. E., 1917, Ground water for irrigation in Lodgepole Valley, Wyoming and Nebraska: U.S. Geol. Survey Water-Supply Paper 425–B, p. 37–69.

——— 1923a, The occurrence of ground water in the United States with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489, 321 p.

——— 1923b, Outline of ground-water hydrology, with definitions: U.S. Geol. Survey Water-Supply Paper 494, 71 p.

Morgan, A. M., 1946, Progress report on geology and ground-water resources of the Cheyenne area, Wyoming: U.S. Geol. Survey open-file report, 55 p.

Newhouse, W. H., and Hagner, A. F., 1957, Geologic map of anorthosite areas, southern part of Laramie Range, Wyoming: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–119.

Parker, G. G., 1963, Piping, a geomorphic agent in landform development of drylands: Berkeley, Internat. Assoc. Sci. Hydrology, Pub. 65, p. 103–113.

Rapp, J. R., Visher, F. N., and Littleton, R. T., 1957, Geology and ground-water resources of Goshen County, Wyoming: U.S. Geol. Survey Water-Supply Paper 1377, 145 p.

Rapp, J. R., Warner, D. A., and Morgan, A. M., 1953, Geology and ground-water resources of the Egbert-Pine Bluffs-Carpenter area, Laramie County, Wyoming: U.S. Geol. Survey Water-Supply Paper 1140, 67 p.

Theis, C. V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519–524. Also as U.S. Geol. Survey Ground Water Note 5, 1952.

——— 1941, Preliminary memorandum on ground-water supply of Cheyenne, Wyoming: U.S. Geol. Survey open-file report, 17 p.

Theissen, A. H., 1911, Precipitation averages for large areas: Monthly Weather Rev., July, p. 1082.

U.S. Geological Survey, 1963, Ground-water levels in the United States, 1956–60: U.S. Geol. Survey Water-Supply Paper 1760, 222 p.

U.S. Public Health Service, 1962, Drinking water standards: Public Health Service Pub. 956, 61 p.

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

Weist, W. G., Jr., 1965, Reconnaissance of the ground-water resources in parts of Laramer, Logan, Morgan, Sedgwick, and Weld Counties, Colorado: U.S. Geol. Survey Water-Supply Paper 1809–L, p. L1–L24.

Welder, G. E., and Weeks, E. P., 1965, Hydrologic conditions near Glendo, Platte County, Wyoming: U.S. Geol. Survey Water-Supply Paper 1791, 82 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

Wenzel, L. K., Cady, R. C., and Waite, H. A., 1946, Geology and ground-water resources of Scotts Bluff County, Nebraska: U.S. Geol. Survey Water-Supply Paper 943, 150 p.

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