Geology and Ground-Water Resources of the Upper Lodgepole Creek Drainage Basin, Wyoming

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1483

Prepared as part of the program of the Department of the Interior for the development of the Missouri River basin

Geology and Ground-Water Resources of the Upper Lodgepole Creek Drainage Basin, Wyoming

By L. J. BJORKLUND

With a section on
CHEMICAL QUALITY OF THE WATER

By R. A. KRIEGER *and* E. R. JOCHENS

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1483

Prepared as part of the program of the Department of the Interior for the development of the Missouri River basin

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

Bjorklund, Louis Jay, 1905–

Geology and ground-water resources of the upper Lodgepole Creek drainage basin, Wyoming. With a section on Chemical quality of the water, by R. A. Krieger and E. R. Jochens. Washington, U. S. Govt. Print. Off., 1959.

iv, 40 p. maps (2 fold. in pocket) diagr., tables. 25 cm. (U. S. Geological Survey. Water-supply paper 1483)

Prepared as part of the program of the Dept. of the Interior for the development of the Missouri River Basin.

Bibliography : p. 33–34.

1. Geology—Wyoming—Lodgepole Creek Valley. 2. Water, Underground — Wyoming — Lodgepole Creek Valley. 3. Water-supply — Wyoming—Lodgepole Creek Valley. 4. Water—Composition. I. Title : Lodgepole Creek drainage basin, Wyoming. (Series)

[TC801.U2 no. 1483] G S 59–241

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND GROUND-WATER RESOURCES OF THE UPPER LODGEPOLE CREEK DRAINAGE BASIN, WYOMING

By L. J. Bjorklund

ABSTRACT

The principal sources of ground-water supply in the upper Lodgepole Creek drainage basin—the part of the basin west of the Wyoming-Nebraska State line—are the Brule formation of Oligocene age, the Arikaree formation of Miocene age, the Ogallala formation of Pliocene age, and the unconsolidated deposits of Quaternary age.

The Brule formation is a moderately hard siltstone that generally is not a good aquifer. However, where it is fractured or where the upper part consists of pebbles of reworked siltstone, it will yield large quantities of water to wells. Many wells in the Pine Bluffs lowland, at the east end of the area, derive water from the Brule. The Arikaree formation, which consists of loosely to moderately cemented fine sand, will yield small quantities of water to wells but is not thick enough or permeable enough to supply sufficient water for irrigation. Only a few wells derive water from it. The Ogallala formation consists of lenticular beds of clay, silt, sand, and gravel which, in part, are cemented with calcium carbonate. Only the lower part of the formation is saturated. Nearly all the wells in the upland part of the area tap the Ogallala, but they supply water in amounts sufficient for domestic and stock use only. Two of the wells have a moderately large discharge, and other wells of comparable discharge probably could be drilled in those parts of the upland where the saturated part of the Ogallala is fairly thick. Most of the unconsolidated deposits of Quaternary age are very permeable and, where a sufficient thickness is saturated, will yield large quantities of water to wells. These deposits are a significant source of water supply in the southeastern part of the area.

The Chadron formation of Oligocene age, which underlies the Brule formation, is a medium- to coarse-grained sandstone where it crops out in the Islay lowland. No wells tap the Chadron, but it probably would yield small quantities of water to wells. It lies at a relatively shallow depth beneath most of the Islay lowland, near the west end of the area, and at a depth of about 300 feet beneath the Pine Bluffs lowland. In the latter area it probably is finer grained and may not be permeable enough to yield water to wells.

All the ground water in the area is derived from precipitation. It is estimated that about 5 percent of the precipitation infiltrates directly to the zone of saturation. The remainder either is evaporated immediately; is retained by the soil, later to be evaporated or transpired; or is discharged by overland flow to the surface drainage courses. Most of the water that reaches the surface drainage courses eventually sinks to the zone of saturation or is evaporated. The slope of the water table and the movement of ground water

are generally eastward. The depth to water ranges from less than 10 feet in parts of the valley to about 300 feet in the upland areas. In much of the Pine Bluffs lowland, the depth to water is less than 50 feet. Ground water not pumped from wells within the area is discharged by evapotranspiration where the water table is close to the land surface, by outflow into streams, or by underflow eastward beneath the State line.

The chemical quality of ground water from the principal sources is remarkably uniform, and the range in concentration of dissolved constituents is narrow. In general, the water is of the calcium bicarbonate type, is hard (hardness as $CaCO_3$ is as high as 246 ppm), and contains less than about 400 parts per million of dissolved solids, which is a moderate mineralization. Silica constitutes a large proportion of the dissolved solids.

The water is suitable for irrigation and, except for iron in water from some wells that tap the Ogallala formation, meets the drinking water standards of the U.S. Public Health Service for chemical constituents. Because the water is siliceous, alkaline, and hard, it is unsuitable for many industrial uses unless treated.

INTRODUCTION

PURPOSE OF INVESTIGATION

This investigation was made by the U.S. Geological Survey as a part of the program of the Department of the Interior for conservation, development, and use of the water resources of the Missouri River basin. The purposes of this study were to compile existing information on ground-water supplies in the Wyoming half of the Lodgepole Creek drainage basin; to collect and analyze data on public, industrial, and irrigation wells in the area; to determine the chemical quality of the water and evaluate the suitability of the water for general use; to determine where additional large-scale pumping would be feasible; to estimate how much additional ground water can be pumped without exceeding the perennial yield; and to indicate where detailed ground-water studies are needed.

The investigation was under the general supervision of G. H. Taylor, regional engineer of the Ground Water Branch of the Geological Survey, who is in charge of ground-water investigations in the Missouri River basin. H. M. Babcock, district engineer of the Ground Water Branch for Wyoming, directly supervised the fieldwork. The quality-of-water study was under the general supervision of P. C. Benedict, regional engineer of the Quality of Water Branch for the Missouri River basin.

LOCATION AND EXTENT OF AREA

The area described in this report is that part of the Lodgepole Creek drainage basin west of the Wyoming-Nebraska State line. It is roughly triangular in outline; its western apex is in eastern Albany County and it broadens eastward across Laramie County to a width

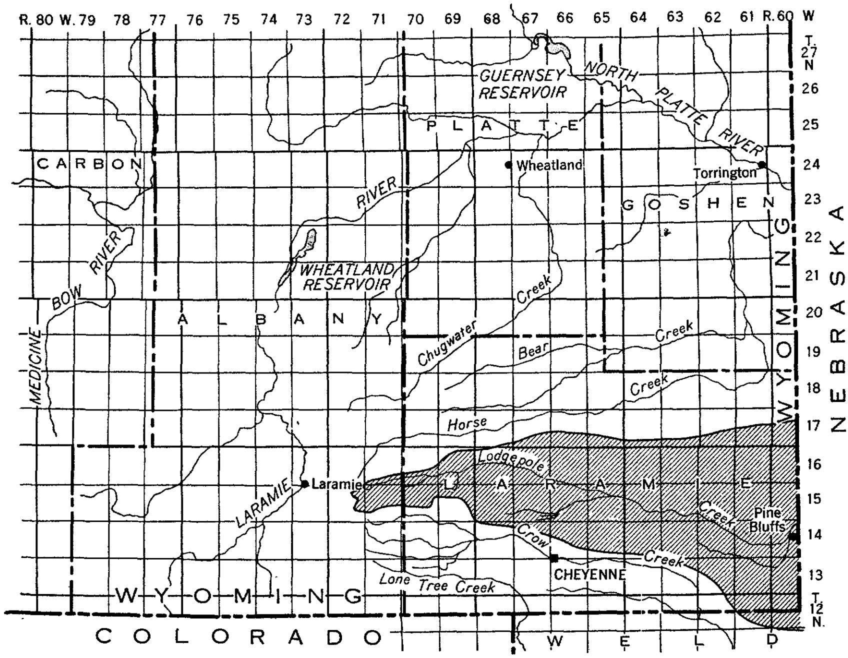

Figure 1.—Map showing location of area described in this report.

of about 33 miles at the State line. The area is about 65 miles long and comprises about 1,130 square miles, of which 10 is in Colorado. (See fig. 1.)

SCOPE OF INVESTIGATION

All known reports on the geology and water resources of the area or its immediate vicinity were examined, and data having a direct bearing on this investigation were abstracted from them. The collection of new data for this investigation was limited to that part of the area for which little or no recent information could be obtained from existing reports. A geologic map (pl. 1) and a map showing the depth to water and contour of the water table (pl. 2) were prepared from data given in other reports and from data collected by the author of this report.

Sixty-two wells, including 10 of large discharge, were visited. The locations of these wells are shown on plate 2, and pertinent data regarding the wells are given in table 5. Information about the date and method of drilling, depth and diameter, aquifer tapped, type of pump and power, use made of the water, depth to water, water-level drawdown when pumped, and yield was obtained by interviewing the owners or by direct observation and measurement. The altitude of the land surface at 33 of the wells was determined by hand leveling from points of known altitude, such as bench marks of the U.S. Coast and Geodetic Survey, highway-elevation data furnished by the Wyoming State Highway Department, and altitudes of seismograph-shothole sites furnished by the Phillips Petroleum Co. and the Shell Oil Co.

Because data on the chemical quality of the water in the report area were available in the files of the Geological Survey, only 4 samples of ground water from the Ogallala formation and 2 samples of water from Lodgepole Creek were collected and analyzed in 1953 for this investigation.

PREVIOUS INVESTIGATIONS

Darton, Blackwelder, and Siebenthal (1910) mapped in detail the geology of the Lodgepole Creek drainage basin west of the center of R. 68 W. Although they briefly discussed the occurrence of ground water in the Laramie Basin, Albany County, they made no specific mention of ground-water conditions in the Lodgepole Creek drainage basin.

As a result of interest in the extension of "irrigation by pumping shallow ground water or by discovering artesian water," Meinzer (1917) made a brief field investigation of the Lodgepole Creek valley in the fall of 1915. He concluded that shallow wells yielding enough water for practical irrigation could be drilled in most parts of the valley, that pumping on a moderate scale would not appreciably reduce the supply of stream water, and that the quality of the ground water was suitable for irrigation purposes. He concluded also that flowing wells could be obtained by deep drilling in some parts of the valley but that the quantity of water generally would be too small for irrigation. Although Meinzer did not discuss the quality of the water from deep flowing wells, data now available for areas to the west and south indicate that the water has a high percent sodium and is rather highly mineralized; thus its usefulness for irrigation would be limited.

The U.S. Department of Agriculture (1940) surveyed the use then being made of land and water resources in the Lodgepole Creek drainage basin and made recommendations for their further development. The report points out opportunities to practice water spreading in draws tributary to Lodgepole Creek in Wyoming and states that water spreading would result in greater recharge to the ground-water supply and a probable increase in streamflow. Pump irrigation of farmstead gardens on the upland was said to be feasible, as well as additional pump irrigation on a large scale in the lowland parts of the area.

The geology and ground-water resources of the Egbert-Pine Bluffs part of the area have been the subject of unpublished reports by

Knight and Morgan (1936) and Burleigh, Gwillim, Dunnewald, and Pearson (1938). A published report by Rapp, Warner, and Morgan (1953) on the geology and ground-water resources of the Egbert-Pine Bluffs-Carpenter area is based in large part on these earlier unpublished reports. Two investigations of the geology and ground-water resources of the Cheyenne vicinity (Foley, 1942, and Morgan, 1946) included part of the western half of the area described in this report. A study of the Horse Creek–Bear Creek area (Babcock and Rapp, 1952) included that part of the Lodgepole Creek drainage basin in T. 17 N., Rs. 60–68 W.

The geology and ground-water resources of the Crow Creek drainage basin, which adjoins the Wyoming half of the Lodgepole Creek drainage basin on the south, and of the Horse Creek drainage basin, which adjoins it on the north, are described in reports by Babcock and Bjorklund (1956) and Babcock (1952), respectively.

A report by Bjorklund (1957) describes the geology and ground-water resources of the Nebraska half of the Lodgepole Creek drainage basin.

WELL-NUMBERING SYSTEM

Wells referred to in this report are numbered according to their location within the U.S. Bureau of Land Management's survey of the area and are in the sixth principal meridian and base-line system. The first numeral of the well number denotes the township, the second the range, and the third the section in which the well is situated. The lowercase letters following the section number indicate the position of the well within the section. The first letter denotes the quarter section; the second, the quarter-quarter section; and the third, the quarter-quarter-quarter section, or 10-acre tract. These subdivisions are designated a, b, c, and d in a counterclockwise direction beginning in the northeast quarter. (See fig. 2.)

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

All but the extreme western end of the Lodgepole Creek drainage basin lies within the High Plains section of the Great Plains physiographic province. The altitude of the area ranges from about 5,000 feet where Lodgepole Creek leaves Wyoming to about 8,800 feet at the upper end of the Lodgepole Creek drainage basin in the Laramie Mountains.

In R. 70 W., near the upper end of the Lodgepole Creek drainage basin, Lodgepole Creek leaves the mountainous area and, joined by the North Fork, enters a broad lowland that is bounded on the west

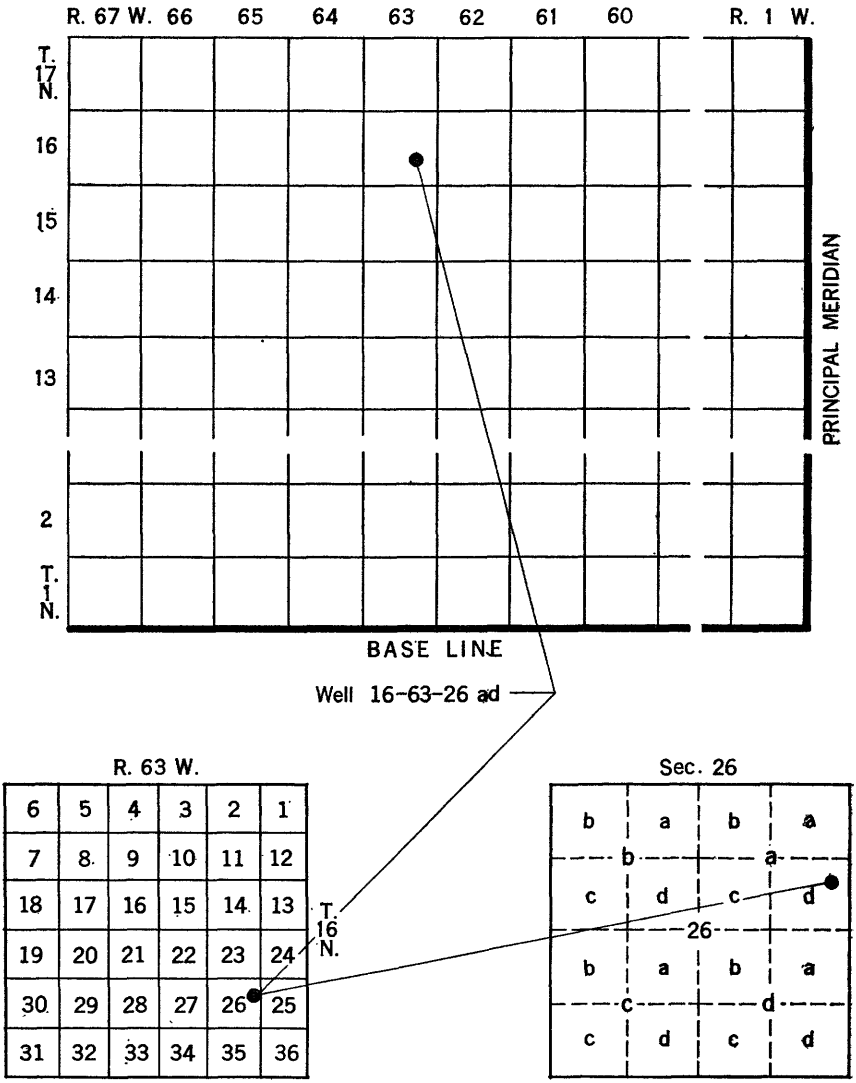

FIGURE 2.—Well-numbering system.

by the northwest-trending mountain front and on the east by the Islay escarpment. (See pl. 1.) The west-facing Islay escarpment is about 250 feet high; from its crest the surface of the High Plains slopes gently eastward about 50 feet per mile in R. 67 W., 35 feet per mile in R. 66 W., and 25 feet per mile in R. 65 W. After crossing the lowland, Lodgepole Creek is joined by the South Fork and enters a steep-sided, flat-bottomed valley that narrows to a width ranging from a third of a mile to a mile. In R. 61 W. Lodgepole Creek emerges from the east end of its 44-mile-long valley and crosses another lowland plain, the Pine Bluffs lowland, that is bounded on the east by the west-facing Pine Bluffs escarpment, also about 250 feet high. Near the east side of the lowland plain, Lodgepole Creek is joined first by Muddy Creek and then by Spring Creek and enters another steep-sided valley where it crosses the State line into Nebraska. Chevington Draw, which drains much of the northern part of the area, terminates in the lowland just west of the Pine Bluffs escarpment and north of Lodgepole Creek.

The average gradient of Lodgepole Creek is about 29 feet per mile between the Islay escarpment and the State line.

Meinzer (1917) described the flow of Lodgepole Creek in Wyoming as follows:

> * * * Lodgepole Creek is noted for its early spring floods, due to melting snows and heavy spring rains. * * * In the upper part of its course, where it receives its water from the mountains, the Creek fluctuates greatly in volume * * *. Near Egbert the flood waters sink rapidly into the gravels * * *.

When measured in September 1915 (Meinzer, 1917), the flow of Lodgepole Creek in sec. 23, T. 16 N., R. 69 W., where the creek enters its gorgelike valley, was 7.5 (cubic feet per second). From this point to the diversion dam in sec. 36, T. 16 N., R. 67 W., the flow appeared to decrease slightly. At the dam the flow was diverted into Pole Creek Reservoir (One-Mile Reservoir) which has a capacity 2,120 acre-feet but is rarely full. For a short distance below the dam, the channel was dry, but within 2 miles the flow was 1 cfs. In sec. 8, T. 15 N., R. 65 W., the stream disappeared and the channel was dry for a distance of nearly 10 miles. From an area of springs near the west margin of sec. 26, T. 15 N., R. 64 W., to a point north of Egbert, in sec. 13, T. 14 N., R. 62 W., flow was continuous, but nowhere more than 2 cfs. From that point to its junction with Muddy Creek, just southwest of Pine Bluffs, Lodgepole Creek was entirely dry. Inflow from Muddy and Spring Creeks plus inflow of ground water gave Lodgepole Creek a flow of 6 cfs at a point half a mile east of the State line. Although the flow of Lodgepole Creek was not measured during the present investigation, it was noted that the characteristics of flow were essentially the same as those described by Meinzer.

The water-facilities plan prepared by the U.S. Department of Agriculture (1940) for the Lodgepole Creek drainage basin states that adjudicated water rights in the area date from May 1, 1874, and that they total 203 cfs for irrigation of 14,200 acres. These figures include appropriations from Muddy Creek for adjudicated water rights of 16 cfs to irrigate 1,100 acres and permits for diversion of 2.28 cfs to irrigate 160 acres. In addition to the adjudicated water rights, there are permits for storage of 71 acre-feet.

Water draining from a large part of the upland north of Lodgepole Creek follows Chevington Draw, which heads a short distance east of the Islay escarpment (T. 16 N., R. 68 W.) and extends east-southeastward to sec. 30, T. 15 N., R. 60 W. The draw is relatively deep and well defined west of the point where it opens onto the Pine Bluffs lowland. Local residents state that the draw occasionally floods and that the floodwater ponds for a short time on the lowland at the end of the draw. Although some of the water evaporates, the ponded water is believed to be dissipated largely by seepage to the zone of saturation (U.S. Dept. Agriculture, 1940).

Spring Creek is a small perennial stream that heads in the northeastern part of T. 14 N., R. 61 W., and flows eastward to its junction with Lodgepole Creek. Although no distinguishable channels connect the head of Spring Creek with the arroyos that open onto the Pine Bluffs lowland between Chevington Draw and Lodgepole Creek, it is believed that floodwaters from the arroyos sometimes reach Spring Creek.

A steep-sided valley in which no stream channel is distinguishable extends west from Egbert to a few miles west of Hillsdale. Possibly the stream that cut this valley was captured by headward erosion of the tributary that now enters Lodgepole Creek in sec. 33, T. 15 N., R. 63 W.

Muddy Creek, which drains much of the upland south of Lodgepole Creek, flows east-southeastward to sec. 18, T. 13 N., R. 60 W., where it turns abruptly northward to join Lodgepole Creek. According to Rapp, Warner, and Morgan (1953), Muddy Creek normally has a low flow through Rs. 62 and 61 W., is dry from the west line of R. 60 W., to sec. 15, T. 14 N., R. 60 W., and from there has a perennial flow to its junction with Lodgepole Creek. The unnamed tributary that heads in the southwestern part of T. 12 N., R. 60 W., normally is dry but it is joined by small arroyos from the west, of which several have short stretches of perennial flow.

CLIMATE

The climate of the Lodgepole Creek drainage basin in Wyoming is similar to that of other parts of the High Plains and is characterized by a wide range in temperature, relatively light precipitation, and a high rate of evaporation. Recorded temperatures have ranged from −30° F to slightly higher than 100° F. The summer days are moderately hot and the nights generally are cool. In winter, cold waves sometimes are accompanied by blizzards that last as long as a week. The prevailing wind is from the south and southeast during the summer and from the north and northwest during the winter. Wind velocities generally are highest during the spring and lowest in late summer, although high winds may occur during any month of the year. About 70 percent of the precipitation falls during the growing season, April through September. Summer rains usually occur as thunderstorms and generally are sporadic and unevenly distributed.

The normal monthly, seasonal, and yearly temperature and precipitation at Cheyenne, which is on the upland and just south of the Lodgepole Creek drainage basin, are as follows:

Average temperature and normal precipitation at Cheyenne

Period	Average temperature (° F)	Normal precipitation (inches)
December	28.5	0.55
January	25.5	.42
February	27.5	.67
Winter	27.1	1.64
March	33.1	1.02
April	40.9	1.99
May	50.3	2.43
Spring	41.1	5.44
June	60.4	1.61

Period	Average temperature (° F)	Normal precipitation (inches)
July	66.7	2.10
August	65.6	1.55
Summer	64.2	5.26
September	57.0	1.20
October	44.8	.96
November	34.8	.52
Fall	45.5	2.68
Year	44.6	15.02

POPULATION AND AGRICULTURE

About 2,200 persons reside in the report area. According to the 1950 census, the population of the principal towns was as follows: Pine Bluffs, 846; Burns, 216; and Hillsdale, 164.

Stock ranching and cash-grain farming are the principal types of land use in the area. Approximately one-third of the farmland is cultivated; most of this land is in the eastern part of the area. An estimated 12,000 acres is irrigated either by diversion from streams or by water pumped from wells.

GEOLOGY

PRE-TERTIARY ROCKS

All the Lodgepole Creek drainage basin in Albany County and about the western 3 miles of the basin in Laramie County are underlain by coarse-grained, massive Precambrian granite. Upturned against the east side of this mass (in the east half of R. 70 W.) is a series of sedimentary rocks ranging in age from Pennsylvanian to Late Cretaceous and aggregating 7,000 to 8,000 feet in thickness. These strata are nearly vertical where they are in contact with the granite, but about 3½ miles to the east the uppermost strata dip less than 5° to the east and pass below the nearly flat-lying younger rocks of Tertiary age. Farther east the dip probably is less than 1°. Sedimentary rocks of pre-Tertiary age underlie all the Lodgepole Creek drainage basin east of their area of outcrop, but east of the Islay escarpment they can be reached only by deep drilling. Because generally they are of low permeability and in most of the area are far beneath the land surface, the sedimentary rocks of pre-Tertiary age are not considered a feasible source of water supply. The Precambrian rocks also are not regarded as water bearing.

TERTIARY SYSTEM

West of the Islay escarpment the rocks of Tertiary age overlap the upturned older rocks, but east of the escarpment they overlie the older rocks with little or no difference in dip, which in all the rocks is 15 to 30 feet per mile. The Tertiary formations recognized in the Lodgepole Creek drainage basin are the Chadron and Brule formations of the White River group of Oligocene age, the Arikaree formation of Miocene age, and the Ogallala formation of Pliocene age.

CHADRON FORMATION

The Chadron formation crops out along Lodgepole Creek in secs. 25 and 26, T. 16 N., R. 70 W., and in sec. 30, T. 16 N., R. 69 W. It is absent to the west but is present beneath the Brule formation both to the north and to the south of the outcrop and for an undetermined distance to the east. It probably underlies all the report area east of the Islay escarpment. Where exposed, the Chadron formation ranges in thickness from a fraction of a foot to 40 feet. Its thickness where buried is not known.

The Chadron formation is exposed much more extensively both in the upper part of the Horse Creek drainage basin to the north and in the upper part of the Crow Creek drainage basin to the south. In both places, as well as along Lodgepole Creek, it consists mainly of medium- to coarse-grained brown sandstone. It is conglomeratic in many places and is coarsest grained near its contact with Precambrian rocks. Locally the formation contains deposits of volcanic ash and lenses of siliceous limestone.

Although the Chadron formation probably would yield at least small quantities of water, it is not tapped, so far as is known, by any wells in the Lodgepole Creek drainage basin. It can be reached at a relatively shallow depth in parts of both the Islay and the Pine Bluffs lowlands, but in the latter it may be too fine grained to yield much water to wells.

BRULE FORMATION

The Brule formation of Oligocene age is a compact, moderately hard, brittle siltstone that locally contains lenticular beds of volcanic ash, sandstone, and fragments of siltstone. Although it generally appears to be massive, the Brule formation has regular but indistinct bedding planes. It typically weathers into cubical blocks and slabs, but in places extensive erosion produces miniature badlands. In fresh exposures the material is generally buff or flesh colored, but weathered surfaces are light pink or almost white.

Because the Brule formation was eroded before the overlying Arikaree formation was deposited and again when later erosion removed the Arikaree, its thickness is not at all uniform. The Brule thins and disappears west of the Islay escarpment; near Pine Bluffs, where penetrated by drilling, it is at least 334 feet thick (Rapp, Warner, and Morgan, 1953, p. 41). The formation is exposed in the lowland west of the Islay escarpment, in the lowland west of the Pine Bluffs escarpment, and in the lower part of both escarpments. It is believed to underlie all the upland area east of the Islay escarpment. Its presence at the surface in the lowland area west of the Pine Bluffs escarpment is believed to be due to the preservation of a greater thickness of the formation in this part of the area rather than to upwarping.

Surficially, the Brule formation is cut vertically and along bedding planes by open joints, some of which are as much as an inch wide. Even larger fissures are present and penetrate the formation to unknown depths; some possibly extend all the way through the formation. Many of these fissures are several inches wide and are capable of transmitting large quantities of water.

In many places where it is overlain by a protective cover of younger deposits, the top part of the Brule consists of rounded pebbles of reworked siltstone. This zone generally is very permeable and where saturated will readily transmit water to wells.

The Brule formation is the principal aquifer in the lowland west of the Pine Bluffs escarpment. Rapp, Warner, and Morgan (1953) inventoried 79 wells tapping the Brule formation in this part of the Lodgepole Creek drainage basin. Of these, 59 were irrigation wells, 1 was a public-supply well, and 1 was a railroad well. The yields (mostly reported) for 47 wells ranged from 360 to 2,000 gpm (gallons per minute) and averaged about 800 gpm. Only a few wells in other parts of the report area tap the Brule formation. Three are on the upland in T. 15 N., R. 68 W., and tap the Ogallala formation in addition to the Brule; the others are in the lowland west of the Islay escarpment. Wells 15–69–8ccb and 15–69–9ca, both owned by the city of Cheyenne but not in use, yielded 240 and 350 gpm, respectively, from the Brule.

Unless a well drilled into the Brule formation intersects some fissures or penetrates a layer of permeable reworked material, the yield of the well is very meager. It is quite possible, therefore, that of two nearby wells tapping the Brule one may have a high rate of yield and the other may yield only an insignificant amount. Generally the wells having a large sustained yield are those drilled into fissured strata of the Brule where it is overlain by a layer of saturated gravel. The water percolates downward from the saturated gravel into interconnecting joints which in turn transmit the water to the larger fissures. It is evident from the sustained yield of wells that the network of interconnecting joints and fissures is of considerable extent.

ARIKAREE FORMATION

The Arikaree formation of Miocene age consists of massive to poorly bedded, fine-grained sand and brownish to dark-gray sandstone. The sandstone is concretionary and generally consists of irregular cylindrical masses, as much as 2 or 3 feet thick and 10 feet long, which are alined in a general northwest direction.

It is not known how much of the area is underlain by the Arikaree formation. It crops out in the Pine Bluffs escarpment north of the town of Pine Bluffs and in several places along the west side of the Pine Bluffs lowland, but is absent in the Pine Bluffs escarpment south of the town of Pine Bluffs and was not seen on the north side of Chevington Draw from sec. 32, T. 16 N., R. 61 W., to sec. 20, T. 15 N., R. 60 W. Because the Arikaree crops out in the Horse Creek drainage basin from R. 69 W. to R. 60 W., it is assumed that the Arikaree underlies much of the upland in the report area east of the Islay escarpment, although no outcrops of the Arikaree were identified in that escarpment.

In the outcrop area, the thickness of the Arikaree ranges from less than a foot to 70 feet. Because the formation was laid down on the irregular surface of the Brule formation, it is quite possible that in the report area deposition was limited to the topographically low places. Furthermore, in some places the Arikaree may have been entirely removed by erosion prior to deposition of the overlying Ogallala formation. Therefore, absence of the Arikaree in any given place may be due either to nondeposition or to removal by pre-Ogallala erosion.

Rapp, Warner, and Morgan (1953) reported that three of the wells they inventoried tapped the Arikaree formation. One was the public-supply well at Burns, one a domestic and stock well, and one an unused well. At Hillsdale the railroad well (14–63–6bb) taps the Arikaree, and it is possible that the deep wells in and near Albin obtain part of their water from this formation. Because the Arikaree is not very permeable, it probably would not yield sufficient water for irrigation.

OGALLALA FORMATION

Overlying the Arikaree formation, or the Brule formation where the Arikaree is absent, is the Ogallala formation of Pliocene age. The Ogallala consists of lenticular beds of clay, silt, sand, and gravel and in part is cemented by calcium carbonate. The cemented layers, called mortar beds, are more resistant to weathering than the others and form prominent ledges where erosion has cut into the formation. The gravel in the Ogallala was derived from a great variety of igneous, sedimentary, and metamorphic rocks exposed in the mountains to the west and consists mainly of pebbles of quartz, quartzite, feldspar, gneiss, schist, sandstone, and granite. Many of the granite pebbles are partly decomposed and are easily broken. According to Wenzel and Waite (1941), the formation was laid down by desert-type streams that aggraded their channels, spilled over into new channels, and left a series of braided deposits of sand and gravel; also there were many temporary lakes into which silt and clay were carried.

All the upland east of the Islay escarpment as well as the Lodgepole Creek valley from R. 68 W. to R. 63 W., is underlain by the Ogallala formation. At one time the materials exposed in the upland west of the Pine Bluffs lowland were referred to as the Arikaree sandstone (Darton, Blackwelder, and Siebenthal, 1910; Meinzer, 1917; Campbell and others, 1925; and U.S. Dept. Agriculture, 1940), but Foley (1942) and Morgan (1946), working in the vicinity of Cheyenne, determined them to be the Ogallala formation. The new geologic map of Wyoming (Love, Weitz, and Hose, 1955) shows the Ogallala extending a few miles north into the Horse Creek drainage basin.

Because the Ogallala was deposited on an uneven surface and because, since deposition, it has been eroded deeply, the thickness of the Ogallala is not uniform. It thins to a featheredge along the west side of the Pine Bluffs lowland and probably is as much as 350 feet thick in places beneath the upland. The Ogallala is well exposed in the Pine Bluffs and Islay escarpments and in the steep slopes along Lodgepole Creek and some of its tributaries; away from the valleys, the surface of the Ogallala is a broad, rolling plain.

Several wells drilled in the Lodgepole Creek valley between R. 68 W. and R. 62 W. draw water from both unconsolidated deposits of Quaternary age and underlying bedrock—probably the Ogallala

503189—59——2

formation—and almost all the wells on the upland derive water from the lower, saturated part of the Ogallala formation. Nearly all these wells have relatively small yields and supply water for domestic and stock use only. However, wells 16–64–3cc and 17–60–20ad discharge 250 and 120 gpm, respectively, and the water is used for irrigation. Without doubt, comparable discharges could be obtained from wells drilled into the Ogallala in other parts of the upland area. Babcock and Bjorklund (1956) reported that the Cheyenne municipal-supply wells in Tps. 13 and 14 N., R. 68 W. (just south of the divide between Lodgepole and Crow Creeks) tap the Ogallala. Of these, the 22 wells for which they give data have discharges ranging from 200 to 530 gpm and averaging 350 gpm.

UNCONSOLIDATED DEPOSITS OF QUATERNARY AGE

Extensive tracks in the southeastern part of the Lodgepole Creek drainage basin in Wyoming, as well as in the narrow valley of Lodgepole Creek west of R. 61 W., are underlain by unconsolidated deposits of Quaternary age. The deposits in the southeastern part of the area were differentiated by Rapp, Warner, and Morgan (1953) into older and younger terrace deposits and alluvium; but because of their similarity in composition and water-bearing properties, they are not differentiated in this report. At least somewhere within the basin each of the formations of Tertiary age is directly overlain by unconsolidated deposits of Quaternary age.

The unconsolidated deposits of Quaternary age consist mainly of gravel and sand but also contain scattered lenses of silt and clay. The gravel is composed mostly of fragments of weathered granite derived from the Ogallala formation or carried into the area from the Laramie Mountains on the west. In places, however, some of the fragments are composed of siltstone derived from the Brule formation. Because the unconsolidated deposits of Quaternary age fill or partly fill old valleys cut into the underlying rock, they are thickest where they fill the deepest valleys and thinnest at the edges of the valleys. The thickest of these deposits do not necessarily underlie present drainage courses and, thus, can be located only by drilling. To date, sufficient test drilling has not been done in the area to determine the course of any of the buried valleys. Rapp, Warner, and Morgan (1953) reported the thickness of the Quaternary deposits to be 107 feet in a test hole drilled in the SE¼ sec. 18, T. 14 N., R. 60 W., and 120 feet in a test hole drilled in the SW¼ sec. 32, T. 13 N., R. 61 W. All other known thicknesses are 100 feet or less.

Most of the unconsolidated deposits of Quaternary age are very permeable and, where a sufficient thickness is saturated, yield large quantities of water to wells. The discharge of 9 wells for which Rapp, Warner, and Morgan (1953) presented data ranged from about 425 to 1,500 gpm. Two irrigation wells in the southwestern part of T. 15 N., R. 62 W., tap the unconsolidated Quaternary deposits underlying the Lodgepole Creek valley and each discharges about 1,000 gpm. In many places, additional wells of large discharge could be drilled into the unconsolidated deposits of Quaternary age. Prospective sites for such wells should be test drilled first to determine whether installation of a permanent well is feasible insofar as the thickness and permeability of the water-bearing materials are concerned and, if feasible, to determine what type of installation would give the best results.

Where jointed and fissured strata of the Brule formation are directly overlain by permeable saturated unconsolidated deposits of Quaternary age, wells drilled through these deposits and into the Brule are likely to have a large sustained discharge.

GROUND WATER

Below the water table, all the pore spaces in the rocks that underlie the Lodgepole Creek drainage basin are filled with water, forming what is known as the zone of saturation. This is the water that is pumped from wells, that issues from springs, that subirrigates the lowland areas where plants stay green without rain or surface irrigation, and that sustains perennial flow in some stretches of Lodgepole Creek and its tributaries. Natural discharge of ground water occurs only when the ground-water reservoir is filled beyond its capacity. Some of the water within the zone of saturation is confined beneath a relatively impermeable layer and therefore is said to be confined, or artesian. The water level in a well drilled into confined water may stand below, at, or above the water table; or water may flow from the well at the land surface.

The rocks older than the Brule formation probably are fully saturated throughout the area east of their outcrop. In the Islay and Pine Bluffs lowlands, where the Brule is exposed, only its lower part is saturated; but beneath the uplands, where it is overlain by water-bearing rocks, it probably is fully saturated. Except near its outcrop along the margins of the Pine Bluffs lowland, the Arikaree probably is everywhere fully saturated. In the uplands, only the lower part of the Ogallala is water bearing. In places where only the lower part of the Ogallala remains and is buried beneath water-bearing unconsolidated deposits of Quaternary age, it is fully saturated. Although the unconsolidated deposits of Quaternary age are almost wholly saturated in a few places, they generally contain water only in the lower part or are completely dry.

Because some wells in the Islay lowland are flowing wells, it is known that artesian conditions exist at least locally in that part of the report area. Elsewhere in the report area, however, no wells flow at the land surface or have a water level significantly higher than the water table. Possibly some wells drilled to greater depths than those now reached would tap water under artesian pressure, though probably not great enough to raise the water to the land surface.

SHAPE AND SLOPE OF THE WATER TABLE

Because the water table generally slopes in the same direction as the land surface, it is highest beneath the uplands and lowest beneath the valleys. Irregularities in the steepness and direction of slope are caused by differences in the thickness and permeability of the water-bearing material and by additions to and discharge from the zone of saturation. Ground water moves in the direction of the greatest slope of the water table, and the rate of movement is proportional to the slope and to the permeability of the water-bearing material.

The approximate shape and slope of the water table in the Lodgepole Creek drainage basin in Wyoming are shown on plate 2 by contour lines. Throughout the area between the Islay escarpment and the Pine Bluffs lowland, the water table slopes in a generally eastward or northeastward direction. Along Spring Creek and along the lower stretches of Lodgepole and Muddy Creeks, the contour lines bend upstream, indicating that the ground water moves toward these streams from both sides.

RECHARGE

Recharge is the addition of water to the ground-water reservoir. As shown by the shape of the contour lines on plate 2, little or no ground water enters the Lodgepole Creek drainage basin by underflow; hence, precipitation is the source of all recharge to the ground-water reservoir in the basin. It is estimated that about 5 percent of the precipitation infiltrates directly to the zone of saturation; the remainder either is evaporated immediately; is retained by the soil, later to be evaporated or transpired; or is discharged by overland flow to the surface drainage courses. Most of the water retained by the soil eventually is depleted by growing plants or by evaporation, and nearly all the water reaching the surface drainage courses eventually sinks into underlying unconsolidated deposits. Very little, if any, of the precipitation that falls on the Lodgepole Creek drainage basin west of the Wyoming-Nebraska State line crosses the State line as direct overland runoff.

In addition to recharge from direct infiltration of precipitation and seepage from streams, a minor amount of recharge results from infiltration of irrigation water.

The rocks older than the Brule are recharged principally, if not wholly, where they crop out west of the Islay escarpment. The Brule formation is recharged in the Islay and Pine Bluffs lowlands, both where it is exposed and where it is mantled by unconsolidated deposits of Quaternary age. If not fully saturated where present beneath the upland, water probably enters it from overlying Tertiary formations. Where the Arikaree is overlain by the Ogallala or by unconsolidated deposits of Quaternary age, water enters it by passing first through the overlying beds; water enters the Arikaree directly where it crops out between Hillsdale and Egbert and north of Egbert; but little or no water enters it where it is exposed in the Pine Bluffs escarpment. The Ogallala formation and the unconsolidated Quaternary deposits are recharged by direct infiltration throughout the areas where they are at the surface. The Quaternary deposits are recharged also by underflow from the Arikaree and Ogallala formations.

DISCHARGE

Water in the rocks older than the Brule formation moves generally eastward and leaves the area by underflow. Because these rocks dip away from the outcrop area, the water in them is confined under artesian pressure. Possibly a small amount of water escapes upward through fissures in the Brule formation. So far as is known, no wells in the area tap rocks older than the Brule.

West of the center of R. 64 W., ground water is discharged by natural processes in only two small areas. One of these is in the Islay lowland in the vicinity of the junction of the South Fork with Lodgepole Creek and the other is in the valley of Lodgepole Creek in R. 66 W., and the eastern half of R. 67 W. In both areas the water table is close to the land surface and evapotranspiration losses are high, especially during the growing season. In the latter area, some ground water is discharged as surface flow, but the water sinks back into the ground before it reaches sec. 8, T. 15 N., R. 65 W.

Because the Brule formation, which is exposed throughout much of the Pine Bluffs lowland, cannot transmit all the ground water moving toward the lowland from the west, much of the ground water discharges into Lodgepole and Muddy Creeks or enters the unconsolidated deposits of Quaternary age overlying the Brule. Lodgepole Creek becomes effluent (receives ground-water discharge) in sec. 26, R. 15 N., T. 64 W., and Muddy Creek is effluent throughout much of Rs. 62 and 61 W. The unconsolidated deposits of Quaternary age south of Muddy Creek discharge ground water to the unnamed eastward-flowing creeks in R. 61 W. The ground water discharged into these creeks becomes surface water for only a short time, however, because all the flow sinks into the unconsolidated deposits. Near its junction with Lodgepole Creek, Muddy Creek again becomes effluent and Spring Creek, a short tributary joining Lodgepole Creek about 2 miles farther downstream, also is effluent. During the period 1931–50, the average discharge of Lodgepole Creek at Bushnell, Nebr., about 8 miles east of the State line, was about 13 cfs. This, therefore, is approximately equal to the amount of ground water discharged from the Lodgepole Creek drainage basin in Wyoming as surface flow.

Along each of the stretches where streams are effluent, the water table is close to the land surface. In such areas much ground water is transpired by vegetation or is evaporated.

Although many wells of small discharge are scattered throughout the area, nearly all the wells of large discharge are in that part of the area described by Rapp, Warner, and Morgan (1953). Of the 62 wells for which they reported the discharge, 10 yielded less than 500 gpm, 34 yielded between 500 and 1,000 gpm, and 18 yielded between 1,000 and 2,000 gpm. Nearly all were irrigation wells, and their combined pumpage in 1949 was estimated to be about 15,000 acre-feet. The large-discharge wells outside the area studied by Rapp, Warner, and Morgan (1953) include 2 wells owned but not used by the city of Cheyenne, 5 irrigation wells, and 3 industrial wells. Two of the irrigation wells discharge 1,000 gpm each, but all the others discharge less than 500 gpm. (See table 5.)

Along the western side of the Pine Bluffs lowland, several springs issue at the contact of the Brule formation with the overlying more permeable formations.

All the ground water that is not discharged from the area by pumping from wells, evapotranspiration, or surface flow leaves the area by underflow either beneath the Wyoming-Nebraska State line or beneath the divide that forms the north boundary of the Lodgepole Creek drainage basin. (See pl. 2.)

The underflow across the State line is computed to be about 12.5 cfs. According to Rapp, Warner, and Morgan (1953), the underflow through the unconsolidated deposits of Quaternary age at the State line is about 7.5 cfs. By using a coefficient of permeability of 650 gallons per day per square foot, a hydraulic gradient of 21 feet per mile, and a cross-sectional area of saturated material 16 miles long and 15 feet thick, the underflow through the Ogallala is computed to be about 5 cfs. The coefficient of permeability was based on recent tests made of the Ogallala formation in the Frenchman Creek drainage basin in northeastern Colorado and southwestern Nebraska. The underflow across that part of the State line south of Lodgepole Creek is thought to be negligible.

Although the contour lines on the water table (pl. 2) are based on few control points, it is obvious that some, if not a considerable part, of the ground water originating within the Lodgepole Creek drainage basin is moving northeastward into the adjacent drainage basin of the North Platte River. The water-table divide between the two drainage basins is not at all distinct and may actually pass under Lodgepole Creek in about R. 65 W. No estimate is made of the total amount of water that moves northeastward beneath the surface divide, but according to Bjorklund (1957) about 3.1 cfs (2,250 acre-feet per year) of the underflow beneath the State line is moving toward the North Platte River.

DEPTH TO WATER

Because the water table is much smoother than the land surface, the depth to water generally is greatest in the upland parts of the area and least in the lowland parts. (See pl. 2.) In several places both north and south of Lodgepole Creek, the depth to water is between 200 and 300 feet. The depth to water is more than 100 feet, but less than 200 feet, in nearly all the remaining upland north of Lodgepole Creek and in about half of the upland south of the creek. In much of the Pine Bluffs lowland and along the valley of Lodgepole Creek to the west, the depth to water is less than 50 feet; and, along those stretches where streams are perennial, the depth to water is less than 10 feet. Bordering the Lodgepole Creek valley and the two lowland areas is an intermediate zone where the depth to water is between 50 and 100 feet. This zone is fairly wide in some places, especially west of the Pine Bluffs lowland and south of Lodgepole Creek.

CHEMICAL QUALITY OF THE WATER

By R. A. KRIEGER and E. R. JOCHENS

As part of the investigation of the Lodgepole Creek drainage basin in Wyoming, a study was made to determine the chemical quality of the water and to evaluate the suitability of the water for irrigation, domestic, and industrial uses. Results of chemical analyses of 56 samples of ground water and 5 samples of surface water collected during the period 1943–53 are given in tables 1 and 2. The locations of the wells, springs, and streams that were sampled are shown on plate 2. The samples were collected in soft-glass or in chemically resistant bottles and were analyzed by methods generally used by the Geological Survey (Am. Public Health Assoc., 1946).

Most of the analyses in table 1 are of water from irrigation wells in the southeastern part of the report area (Rapp, Warner, and Morgan, 1953); these wells are less than 125 feet deep and tap the

TABLE 1.—*Chemical analyses of ground water, upper Lodgepole Creek drainage basin, Wyoming*

[Geologic source: su, undifferentiated sedimentary rocks of Pennsylvanian to Late Cretaceous age; Tb, Brule formation; Ta, Arikaree formation; To, Ogallala formation; Qud, unconsolidated deposits of Quaternary age. Results in parts per million except as indicated]

Well	Geologic source	Depth of well (feet)	Date	Temperature (° F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25° C)	pH
12-60- 5ccd	Tb,Qud(?)	118	9-23-47	50	55	0.05	28	11	50		182	40	17	0.8	7.5	0.10	293	115	0	48	463	7.7
13-60- 5ac	Tb,Qud(?)	88.2	9-23-47	51	62	------	69	18	39		324	47	9.0	.8	1.8	------	388	246	0	26	551	7.2
- 8cbb	Tb	77.5	4- 3-43	------	------	------	68	15	34		318	22	10	------	4.0	.04	------	231	0	24	532	------
			9-26-47	52	57	------	66	15	34		302	34	11	.2	.6	------	378	226	0	24	554	7.7
-17bdd	Tb	80	10- 7-47	52	66	------	32	11	34		172	32	9.0	.5	11	------	274	125	0	37	365	7.2
-31aaa	Tb	100	4- 3-43	------	------	------	28	9.2	51		196	28	13	1.0	8.6	.04	------	108	0	51	386	------
-61-11bdd	Tb	60	9-23-47	50	60	------	60	15	15		248	28	7.0	.8	.0	------	305	211	8	13	433	7.7
-15cdd	Tb, Qud	125	9-26-47	52	64	------	36	13	54		222	63	8.0	.6	.0	------	333	143	0	45	462	7.9
-29abb	Tb, Qud	85	10- 7-47	52	53	------	39	12	18		176	30	4.0	.8	2.1	------	238	147	3	21	335	7.7
-30cbb	Qud	83	9-26-47	53	47	------	45	11	10		163	29	9.0	.8	2.2	------	234	158	24	13	335	8.0
-62-28add	Qud	60.0	10- 7-47	52	51	------	68	13	16		202	42	16	.6	30	------	358	223	57	13	486	7.8
14-60- 6dbb	Tb	73.3	9-23-47	52	65	------	38	11	14		171	22	4.0	.6	.0	------	238	140	0	18	314	7.9
- 8bba	Tb	80	9-23-47	52	66	------	35	14	23		176	33	8.0	.6	3.0	------	251	145	1	25	338	8.1
- 8bcc	Tb	80	9-23-47	53	61	------	42	7.0	26		188	26	2.0	.6	5.5	------	250	134	0	30	333	7.7
-11ac	Qud(?)	--------	10- 7-47	56	55	.15	67	12	17		247	30	9.5	.8	6.0	.10	318	216	13	15	512	8.0
-11bcc	Qud	60	10- 7-47	51	55	------	53	10	33		222	44	8.0	.6	5.5	------	302	173	0	29	423	7.2
-15dbb	Tb	125	9-25-47	54	53	1.05	68	14	23	8.4	270	41	14	.8	5.0	.13	354	227	6	17	569	8.0
-16cdd	Qud,Tb(?)	91.1	9-23-47	53	65	------	34	7.5	26		154	28	5.0	.4	11	------	230	116	0	33	306	8.1
-17abb	Tb	80	9-23-47	52	65	------	39	12	26		189	30	7.0	.8	2.9	------	266	147	0	28	349	7.2
-19abb	Tb, Qud	110	9-23-47	52	55	------	42	4.4	24		189	8.6	5.0	.6	2.1	------	242	123	0	29	337	8.0
-19da	Tb, Qud	110	9-23-47	52	44	------	50	2.2	26		190	22	5.0	.6	3.2	------	245	134	0	30	395	7.9
-20ac	Tb, Qud	90	10- 6-47	52	50	------	46	8.5	26		190	32	4.6	.8	10	------	264	150	0	27	363	7.3
-28bbb	Tb, Qud	96	10- 7-47	52	56	------	58	12	29		218	51	12	.2	10	------	327	194	15	25	445	7.7
-29bbc	Tb, Qud	78	9-25-47	52	52	------	48	4.6	25		194	21	6.0	.6	3.0	------	261	139	0	28	369	8.1
-29cbd	Tb, Qud	100	10- 7-47	53	62	------	40	10	32		188	37	6.0	.6	9.5	------	270	141	0	33	370	7.3

-30cbc	Tb, Qud	93	4-3-43	------	------	------	49	12	24		226	22	8	1.2	2.0	.02	------	172	0	23	373	------
-32ab	Tb. Qud	90	9-26-47	52	64	------	59	20	25		269	40	13	.2	4.0	------	369	229	8	19	487	7.7
-32dbb	Tb, Qud	41.3	10-7-47	50	57	------	68	17	42		320	44	10	.8	10	------	374	244	0	27	552	7.2
-61-18bcb	Ta, Qud	45	9-25-47	53	36	------	26	7.4	67		208	26	12	.8	30	------	301	95	0	60	474	7.6
-18cbb	Tb, Ta, Qud.	100	4-3-43	------	------	------	62	8.7	18		246	14	6	1.3	2.0	.02	------	190	0	17	409	------
-21bbb	Tb, Qud	95	9-25-47	53	46	------	52	10	18		[2]198	37	4.0	.9	1.8	------	266	171	9	19	365	8.3
-27ccb	Tb	80	9-24-47	52	60	------	23	8.7	53		154	42	18	.8	15	------	288	93	0	56	444	7.2
-62-7dbb	Tb, Ta	254	9-26-47	54	55	[1].05	59	12	8.2	6.0	184	22	16	.6	40	.10	294	196	45	8	452	8.0
-11dbb	Qud, Tb(?), Ta.	90	9-25-47	------	48	------	66	12	12		255	21	4.0	.8	2.5	.17	283	214	5	11	466	7.6
-22bbb	Ta, Qud	120	4-3-43	------	------	------	46	13	29		238	20	9	1.2	.2	.04	------	168	0	27	402	------
-24bbb	Tb, Ta	95	9-25-47	53	63	------	35	10	33		188	27	4.4	.8	13	------	274	128	0	36	363	7.3
-63-20bbb	To	112	9-23-47	52	55	.35	53	13	9.2		185	21	16	.6	10	.11	270	186	34	10	421	7.7
15-60-4aaa	To	108	9-25-47	52	59	------	52	16	22		168	47	34	.4	10	------	336	196	58	20	456	8.0
-20cdb	Tb	108	7-24-47	------	57	.05	44	7.9	1.1		144	15	4.5	.4	4.5	.10	214	142	24	2	313	7.3
-21ca	To	125	9-26-47	53	60	------	28	11	9.7		146	13	1.0	.6	.0	------	191	115	0	19	249	8.0
-28cbb	Tb	100	9-24-47	53	28	------	37	5.9	21		160	11	6.0	.2	12	------	258	117	0	28	310	7.3
-29bdc	Tb	108	9-24-47	52	26	------	36	8.3	14		152	12	6.0	.2	11	------	256	124	0	20	313	7.1
-32aa	Tb	108	9-24-47	52	28	------	38	5.5	19		152	11	6.0	.2	16	------	255	116	0	26	311	7.0
-34bca	Tb	95	10-6-47	50	62	------	35	8.5	19		142	27	7.0	.4	11	------	230	122	6	25	305	7.4
-61-28add	Tb	100	9-25-47	56	64	------	37	10	15		169	20	2.0	.6	3.4	------	232	133	0	20	314	8.0
-66-16ac	To(?)	91.0	4-16-53	49	28	.89	70	11	11	3.5	191	23	38	.4	9.7	.04	336	220	63	10	491	7.5
-67-31ddc	To	174.0	4-3-43	------	------	------	52	7.4	10		194	6	6	.4	10	.04	------	160	1	12	327	------
-68-32aaa	To, Tb	425	4-3-43	------	------	------	42	6.3	20		172	20	4	.6	5.6	.04	------	131	0	25	294	------
-69-5c	Tb	------	4-3-43	------	------	------	38	6.6	15		169	8	3	.6	2.0	.02	------	122	0	21	276	------
-6ac	Tb	182	4-3-43	------	------	------	37	15	17		204	14	5	.6	.2	.04	------	154	0	19	323	------
-8ccb	Tb	375	4-3-43	------	------	------	------	------	12		135	10	4	.4	.5	.02	------	102	0	20	225	------
-70-12bc	su	Spring	4-2-43	------	10	------	55	14	6.4	1.2	233	7.0	2.9	.5	10	.02	219	195	4	7	366	7.8
16-63-29cb	To	140	4-28-53	53	2.5	5.4	17	1.1	4.5	3.4	59	1.0	5.5	.8	.6	.02	70	47	0	16	128	7.3
-69-33bbb	Tb	100	4-3-43	------	------	------	44	7.4	32		232	10	6	.6	.2	.02	------	140	0	33	360	------
17-62-26aa	To	220.0	4-27-53	54	47	------	57	9.0	6.1	3.7	183	15	9.5	.2	14	.04	264	179	29	7	379	7.7
-63-31aa	To	335	4-20-53	54	54	1.1	52	8.4	8.1	4.1	198	3.0	5.5	.4	7.3	.04	252	164	2	9	357	7.9

[1] Manganese (Mn), 0.00 ppm.
[2] Includes equivalent of 10 ppm of carbonate (CO_3).

TABLE 2.—*Chemical analyses of surface water, upper Lodgepole Creek drainage basin, Wyoming*

[Results in parts per million except as indicated. Sampling sites identified according to well-numbering system]

Sampling site	Discharge (cfs)	Date	Temperature (° F)	Silica (SiO_2)	Dissolved iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K as Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$		Percent sodium	Specific conductance (micromhos at 25°C)	pH
																Calcium, magnesium	Noncarbonate			
South Fork of Lodgepole Creek:																				
15-70-11	------	4- 2-43	------	------	------	------	------	4	69	8	2	1.6	0.2	0.02	------	64	7	11	137	------
15-69-3c	[1] 10	4- 2-43	------	------	------	39	7.2	6.1	151	8	3	1.3	.5	.02	------	127	3	9	244	------
Lodgepole Creek:																				
15-66-12b	[2] 13	4-16-53	57	20	0.01	66	7.7	10	234	15	6.5	.9	.0	.04	262	196	4	10	407	8.1
15-64-25a	[2] 11	4-22-53	63	34	.00	57	9.5	12	232	6.0	5.5	.8	.3	.05	256	181	0	12	402	8.2
14-60-10c	[1] 5	4- 3-43	------	------	------	42	13	22	[3] 216	12	8	.8	2.8	.02	------	158	0	23	357	------

[1] Estimated. [2] At Bushnell, Nebr. [3] Includes 16 ppm of carbonate (CO_3).

Brule formation or unconsolidated Quaternary deposits, or both. The analyses of water from wells 14–60–15dbb and 14–62–7dbb represent the quality of water used for municipal supply in Pine Bluffs and Burns, respectively. The analyses in table 2 represent the quality of the water in Lodgepole Creek and in the South Fork of Lodgepole Creek during periods of low flow in early spring.

Some of the terms used in this section of the report are defined as follows:

A part per million (ppm) is a unit for expressing the concentration by weight of a chemical constituent, usually as milligrams of constituent per kilogram of solution or as grams of constituent per million grams of solution.

An equivalent per million (epm) is a unit for expressing the concentration of chemical constituents or ions in terms of their equivalent weights. One epm of a positively charged ion (cation) will react with one epm of a negatively charged ion (anion). Parts per million are converted to equivalents per million by multiplying by a factor which is the reciprocal of the equivalent weight (combining weight) of the ion.

Cation	Factor	Anion	Factor
Calcium (Ca^{++})	0. 0499	Bicarbonate (HCO_3^-)	0. 0164
Magnesium (Mg^{++})	. 0822	Carbonate ($CO_3^{=}$)	. 0333
Sodium (Na^+)	. 0435	Sulfate ($SO_4^{=}$)	. 0208
Potassium (K^+)	. 0256	Chloride (Cl^-)	. 0282
		Fluoride (F^-)	. 0526
		Nitrate (NO_3^-)	. 0161

Specific conductance is a measure of the ability of a water to conduct an electrical current and is expressed in micromhos per centimeter at 25°C. Specific conductance can be used to estimate the mineralization of a water. The following equations are generally applicable to the moderately mineralized calcium bicarbonate water in the upper Lodgepole Creek drainage basin:

$$\text{Specific conductance} \times (0.7 \pm 0.15) = \text{ppm dissolved solids}$$

$$\frac{\text{Special conductance}}{100} \times (1.05 \pm 0.15) = \text{epm total anions or cations}$$

Percent sodium is the ratio, expressed as a percentage, of sodium to the sum of the principal cations (calcium, magnesium, sodium, and potassium)—all ions in equivalents per million.

Sodium-adsorption ratio, or *SAR*, (U.S. Salinity Lab. Staff, 1954), is related to the adsorption of sodium by the soil and is an index of the sodium, or alkali, hazard of irrigation water. It is calculated from concentrations in equivalents per million of sodium, calcium, and magnesium as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

"Residual sodium carbonate" (Eaton, 1950) is the amount, expressed in equivalents per million, of carbonate plus bicarbonate that would remain in solution if all the calcium and magnesium were precipitated as calcium and magnesium carbonates.

$$\text{Residual sodium carbonate} = (CO_3 + HCO_3) - (Ca + Mg)$$

GROUND WATER

Ground water in the upper Lodgepole Creek drainage basin generally is of the calcium bicarbonate type, is hard, and is moderately mineralized. Silica constitutes a large proportion of the dissolved solids. The average concentration of dissolved solids in the samples was 277 ppm (residue on evaporation), the average hardness was 159 ppm, and the average specific conductance was 386 micromhos. (See table 1.) The average temperature of the ground-water samples was 52° F, and the temperature ranged from 49° to 56° F.

Average concentration and percentage composition of dissolved constituents in ground water from the Lodgepole Creek drainage basin, Wyoming

Constituent	Average concentration (ppm)	Percentage composition, by weight
Silica (SiO_2)	52	19.0
Calcium (Ca)	47	17.2
Magnesium (Mg)	10	3.7
Sodium and potassium as sodium (Na)	24	8.8
Bicarbonate as carbonate (CO_3)	[1]98	35.8
Sulfate (SO_4)	26	9.5
Chloride (Cl)	8.7	3.2
Fluoride (F)	.6	.2
Nitrate (NO_3)	7.2	2.6
Dissolved solids (sum)	273.5	100.0

[1] Average bicarbonate (HCO_3) concentration was 199 ppm.

Although the data in table 1 represent water from several different water-bearing formations, the quality of the water was remarkably uniform. The range in concentration of dissolved constituents in the ground water was narrow if water from well 16–63–29cb, which had the lowest mineralization of all, is excluded. (See table 3.) The quality of water from wells tapping the Brule formation, the Arikaree formation, and unconsolidated Quaternary deposits is likely to be affected by the mineral composition of the Ogallala formation because some of the recharge to these rocks passes through the Ogallala. For example, some of the calcium bicarbonate in water from the other water-bearing formations probably results from the solution of calcium carbonate from the mortar beds in the Ogallala.

Water from well 13–60–8cbb was analyzed in both 1943 and 1947; the change in the chemical quality during the 4-year period was insignificant. (See table 1.)

TABLE 3.—*Ranges in concentration of some dissolved constituents and in hardness and specific conductance of ground water*

Geologic source	Number of samples	Range in concentration (ppm)						Range in specific conductance (micromhos at 25°C)
		Calcium (Ca)	Magnesium (Mg)	Sodium (Na)+potassium (K) as sodium	Bicarbonate (HCO_3)	Sulfate (SO_4)	Hardness as $CaCO_3$	
Brule formation	20	23–68	5.5–15	1.1–53	135–318	8–42	93–231	225–569
Brule formation and unconsolidated Quaternary deposits, undifferentiated	15	28–69	2.2–20	18–54	154–324	8.6–63	115–246	306–552
Ogallala formation [1]	7	28–70	7.4–16	8.2–22	146–198	3.0–47	115–220	249–491
Unconsolidated Quaternary deposits	4	45–68	10–13	10–33	163–247	29–44	158–223	335–512
Sedimentary rocks of Pennsylvanian to Late Cretaceous age and combinations of Arikaree formation, Brule formation, Ogallala formation, and unconsolidated Quaternary deposits, undifferentiated	8	26–66	6.3–14	7.1–67	172–255	7.0–27	95–214	294–474

[1] Data for water from well 16–63–29cb not included.

SURFACE WATER

The chemical quality of the surface water in the report area is similar to that of the ground water. Because streams in the drainage basin are effluent only in certain reaches and because they are at base flow most of the time, the water in them should be representative of ground water at shallow depth in the area.

The analysis in table 2 for the South Fork of Lodgepole Creek at 15–70–11 represents mostly snowmelt runoff from granitic rocks, whereas that for the creek at 15–69–3c, about 5 miles downstream, represents not only direct runoff but also water discharged from the Casper formation of Late Pennsylvanian and Permian age and the Brule formation. The spring at 15–70–12bc (table 1) was discharging an estimated 300 gpm from the Casper formation into the South Fork in April 1943. Water from the Ogallala formation, the Ogallala and Brule formations, and the Brule formation is represented by analyses for Lodgepole Creek at 15–66–12b, 15–64–25a, and 14–60–10c, respectively.

The data in table 2 indicate that the mineralization of the water is higher in the downstream than in the upstream reaches of Lodgepole Creek. For example, in April 1943 the specific conductance of the water was 137 micromhos in the upper reaches of the South Fork of Lodgepole Creek, whereas it was 357 micromhos in Lodgepole Creek near the eastern edge of the area. Corresponding increases in hardness and in bicarbonate concentration are apparent.

SUITABILITY OF THE WATER

DOMESTIC USE

The U.S. Public Health Service (1946) established standards for bacterial, chemical, and physical characteristics of drinking water used on public carriers and others subject to Federal quarantine regulations. These standards have been accepted by the American Water Works Association as standards for all public water supplies. Listed below are the standards that pertain to some of the chemical constituents.

Constituent	*Recommended maximum concentration (ppm)*
Iron and manganese (Fe+Mn)	0.3
Magnesium (Mg)	125
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	[1] 1.5
Dissolved solids	[2] 500

[1] Maximum allowable.
[2] 1,000 ppm permitted when water of better quality is not available.

Iron in water will stain fabrics and porcelain and can be tasted when present in concentrations of more than about 1 ppm. Manganese has similar effects. Iron and manganese concentrations were determined for only a few of the ground-water samples; however, the 9 iron determinations indicate that water from some wells that tap the Ogallala formation contained iron in excess of 0.3 ppm and that water from some wells that tap the Brule formation contained less than 0.3 ppm of iron. (See table 1.) However, the 4 wells that produced water containing 0.35 to 5.4 ppm of iron had small diameters (6 inches or less) were pumped at only low rates and may have had rusty casings. Therefore, the 4 iron concentrations may not be representative of water from the Ogallala. The concentration of manganese in water used for municipal supply in both Pine Bluffs and Burns (wells 14–60–15dbb and 14–62–7dbb) was 0.00 ppm.

Concentrations of magnesium, sulfate, chloride, fluoride, and dissolved solids in the ground water were all lower than the recommended maximum concentrations.

Because nitrate is the end product of aerobic stabilization of nitrogenous organic matter, its presence in significant amounts in ground water is often an indication of pollution of the water by sewage or other organic matter. Nitrate, when present in drinking water in excess of about 44 ppm (equivalent to 10 ppm of nitrogen as N), can cause the disease methemoglobinemia when the water is ingested by infants (Maxcy, 1950). The maximum concentration of nitrate found in the ground water in the report area was 40 ppm. All concentrations higher than 20 ppm were found in water from domestic or stock wells, probably because this type of well usually is close to sources of pollution (such as barnyards and cesspools).

Magnesium and calcium cause water to be hard. Hard water forms deposits of insoluble salts in utensils and boilers when heated and forms insoluble curds when soap is used. Other substances, such as iron, manganese, and acids, also cause hardness in water. Although specific limits of hardness cannot be set, the following are general criteria:

Hardness as $CaCO_3$ (ppm)	Rating	Suitability
<60	Soft	Suitable for many uses without further softening.
60–120	Moderately hard	Usable except in some industrial applications.
120–200	Hard	Softening required by laundries and some other industries.
>200	Very hard	Softening desirable for most purposes.

Ground water in the report area ranged from soft to very hard; the average hardness was 159 ppm.

IRRIGATION USE

Factors important in the evaluation of water for irrigation include the total mineralization, the relative concentration of sodium and of carbonate and bicarbonate, and the concentration of boron.

Specific conductance indicates the degree of mineralization of water. The osmotic-pressure balance between the plant and the soil solution enables the plant to take in water and nutrients through its roots. High mineralization of irrigation water upsets this balance.

Sodium is not a desirable constituent in water used for irrigation, especially when its concentration is high relative to the concentrations of the other cations. High relative concentration of sodium in irrigation water can cause the soil particles to deflocculate if sodium replaces the calcium by base exchange in the soil. Deflocculation of the soil particles can cause the soil to become relatively impermeable to water and unsuitable for cultivation. Percent sodium and sodium-adsorption-ratio are measures of the relative concentration of sodium and are useful as indexes of the sodium (alkali) hazard of irrigation water.

Several methods, based on dissolved-salt content and relative sodium concentration, have been proposed for rating the suitability of irrigation water (Wilcox, 1948; Thorne and Thorne, 1951; U.S. Salinity Lab. Staff, 1954). In all three methods such factors as climate, drainage, irrigation practices, and soil characteristics are assumed to be average. According to these methods, the most suitable irrigation water has a specific conductance of less than about 750 micromhos, a percent sodium of less than about 65, and a sodium-adsorption-ratio of less than about 6. In water from the Lodgepole Creek drainage basin in Wyoming, the maximum specific conductance was 569 micromhos, the maximum percent sodium was 60, and the maximum sodium-adsorption-ratio was 3.0.

After irrigation water has been applied to the soil, evapotranspiration causes salts in the soil water to become more concentrated. If the relative concentration of carbonate and bicarbonate is high, calcium and magnesium carbonate may precipitate, and the resultant solution will contain residual sodium carbonate (Eaton, 1950). Water containing residual sodium carbonate is strongly alkaline and thus has the ability to dissolve organic matter in the soil, which may take on a gray or black coloration; such a soil is referred to as "black alkali." Wilcox, Blair, and Bower (1954) reported the following tentative conclusions: Water containing more than 2.5 epm of residual sodium carbonate is not suitable for irrigation over a long period without use of soil amendments, water containing between 1.25 and 2.5 epm is marginal, and water containing less than 1.25 epm probably is safe. Ground and surface waters in the Lodgepole Creek drainage basin in Wyoming contained less than 1.25 epm of residual sodium carbonate except for water from well 14–61–18bcb, which contained 1.5 epm. Therefore, the water probably is safe for use on most soils.

Boron is an essential plant nutrient, but small amounts (as little as 1 ppm) of it can easily injure some plants. Although the concentration of boron in all samples was not determined, the maximum concentration determined for ground water from representative wells tapping the various water-bearing rocks in the area was 0.17 ppm. The maximum concentration determined for surface water was 0.05 ppm. These concentrations are well below the limit of 0.33 ppm for water used for irrigating even the most boron-sensitive crops (Wilcox, 1948).

Thus, ground and surface waters of the upper Lodgepole Creek drainage basin are rated suitable for irrigation.

INDUSTRIAL USE

Industrial water-quality requirements vary widely. Table 4 is a compilation of water-quality tolerances for several different industrial applications. The suitability of an individual water supply for industrial use can be evaluated by comparing chemical-quality data in table 1 with the tolerances shown in table 4.

Because most of the ground water in the area is siliceous, alkaline, and hard and locally may contain iron in excess of generally accepted limits, it would be unsuitable for many industrial applications unless treated. However, the ground water is generally clear, colorless, and odorless, has a temperature of about 52°F, and reportedly is noncorrosive to galvanized iron.

503189—59——3

TABLE 4.—*Water-quality tolerances for industrial applications* [1]

[Range of recommended threshold or limiting values in parts per million]

Industry	Turbidity (as SiO_2)	Color (units)	Taste	Odor	Oxygen consumed	Dissolved oxygen	Total solids	Hardness (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	Iron (Fe)	Manganese (Mn)	Fe+Mn
Baking	10	10	None	Low				(2)		0.2	0.2	0.2
Boiler feed water:												
Pressure=0–150 psi	20	80			15	1.4	3,000–500	80				
Pressure=150–250 psi	10	40			10	.14	2,500–500	40				
Pressure=250–400 psi	5	5			4	.00	1,500–100	10				
Pressure=over 400 psi	1	2			3	.00	50	2				
Brewing:												
Light beer	0–10	0–10	None	Low			500		75–80	0.1–1.0	.1	.1
Dark beer	0–10	0–10	None	Low			1,000		80–150	.1–1.0	.1	.1
Carbonated beverages	1–2	5–10	None	Low	1.5		850–855	200–250	50–128	.1–.2	.2	.1–1.5
Confectionery			Low	Low			50–100			.2	.2	.2
Cooling water	50							50		.5	.5	.5
Food canning and freezing	1–10		None	Low				50–85		.2	.2	.2
Food equipment washing	1	5–20	None	None			850	10				.2
Food processing—general	1–10	5–10	Low	Low			850	10–250	30–250	.2	.2	.2–.3
Ice manufacturing	1–5	5	None	Low	3		170–1,300	70–72	30–50	.03–.2	.2	.2
Laundering								0–50	60	.2–1.0	.2	.2
Plastics	2	2					200			.02	.02	.02
Pulp and paper:												
Ground wood pulp	50	30					500	200	150	.3	.1	
Soda and sulfate pulps	25	5					250	100	75	.1	.05	
Kraft paper (bleached)	40	25					300	100	75	.2	.1	
Kraft paper (unbleached)	100	100					500	200	150	1.0	.5	
Fine paper	10	5					200	100	75	.1	.05	
Rayon (viscose):												
Pulp	5	5					100	8	50	.05	.03	.05
Manufacture	.3							55		.0	.0	.0
Steel manufacture								50				
Sugar manufacture										.1		
Tanning operations	20	10–100						50–513	128–135	.1–2.0	.1–.2	.2
Textile manufacture	.3–25	5–70						0–50		.1–1.0	.05–1.0	.2–1.0

Industry	Aluminum (as Al_2O_3)	Silica (SiO_2)	Calcium (Ca)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Hydroxide (OH)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	pH	Other
Baking											H_2S, 0.2
Boiler feed water:											
Pressure=0–150 psi	5	40		50	200	50				>8.0	H_2S, 5
Pressure=150–250 psi	.5	20		30	100	40				>8.4	H_2S, 3
Pressure=250–400 psi	.05	5		5	40	30				>9.0	H_2S, 0
Pressure=over 400 psi	.01	1		0	20	15				>9.6	H_2S, 0
Brewing:											
Light beer		50	100–200		50–68		[2]		1	6.5–7.0	NO_3, 30; H_2S, 0.2
Dark beer		50	200–500		50–68		[3]		1		NO_3, 30; H_2S, 0.2
Carbonated beverages							250	250	.2–1.0		H_2S, 0–0.2
Confectionery										>7.0	H_2S, 0.2
Cooling water											
Food canning and freezing								[4]	1	>7.5	H_2S, 1
Food equipment washing								250	1		
Food processing—general									1		
Ice manufacturing		10							1		
Laundering										6.0–6.8	
Plastics											
Pulp and paper:											
Ground wood pulp		50						75			CO_2, 10
Soda and sulfate pulps		20						75			CO_2, 10
Kraft paper (bleached)		50						200			CO_2, 10
Kraft paper (unbleached)		100						200			CO_2, 10
Fine paper		20									CO_2, 10
Rayon (viscose):											
Pulp	<8	<25									Cu, <5
Manufacture										7.8–8.3	
Steel manufacture								175		6.8–7.0	
Sugar manufacture			20	100			20	20			Mg, 10
Tanning operations										6.0–8.0	
Textile manufacture			10	200			100	100			Mg, 5

[1] California Institute of Technology, 1952. [2] Some hardness desirable. [3] Presence of $CaSO_4$ advantageous. [4] Sodium chloride, NaCl, 1,000–1,500 ppm.

PRESENT AND POTENTIAL DEVELOPMENT OF WATER RESOURCES

Large-scale use of ground water at present is limited to the southeastern part of the area. According to Rapp, Warner, and Morgan (1953), the first attempts to develop ground water for irrigation in that part of the area were made in the late 1920's, but it was not until the drought years of the 1930's that irrigation wells became common. Where the unconsolidated deposits of Quaternary age are the source of irrigation water, the irrigation installations generally consist of a single well 18 to 36 inches in diameter; however, where the Brule formation is the source of supply, many of the installations consist of two or more wells which are connected below the surface but only one is equipped with a pump. Not all the wells drilled to supply water for irrigation yielded a sufficient quantity. Wells drilled into the unconsolidated Quaternary deposits are a success only if they penetrate a sufficient thickness of highly permeable saturated material, and wells drilled into the Brule formation are a success only if they penetrate fissures or a zone of permeable gravel. The discharge of some wells tapping the Brule diminishes rapidly with continual pumping during the irrigation season. This is especially true of wells situated where the Brule is not overlain by permeable water-bearing material.

A few wells of moderately large discharge are in other parts of the area. Two of these (16–64–3cc and 17–60–20ad) are on the upland north of Lodgepole Creek and tap the Ogallala formation. Two others (15–69–8ccb, –9ca) are wells owned by the city of Cheyenne but were not in use at the time of this investigation. These wells are believed to tap the Brule formation, but possibly they penetrate the underlying Chadron formation also.

Without test drilling, it is impossible to determine which parts of the upland are underlain by permeable water-bearing material sufficiently thick to yield enough water for irrigation. Because some successful wells already have been drilled, it is apparent that others also could be drilled. However, the great depth to water and consequent high initial cost and operating expense of wells are deterrents to extensive development, at least in the near future.

Theoretically, maximum development of the ground-water resources of the area would consist of intercepting all the ground water that otherwise would be discharged by natural means. Development to such a point would not be practical, however. For one thing, discharge of some ground water by natural means is essential to dispose of salts. Also, pumping of ground water, insofar as it does not reduce natural discharge by evapotranspiration, reduces the flow of the streams. Plans for development of the ground-water resources of the area, therefore, must take into account the extent to which nonbeneficial water losses can be lessened by reducing natural ground-water discharge. Because excessive pumping of ground water ultimately would result in a decrease of flow in Lodgepole Creek, existing surface water rights would be affected, and any unnatural diminution of flow is likely to be charged to pumping of ground water.

The most likely places for successful development of additional wells of large discharge are the valley lands along Lodgepole Creek and its principal tributaries, and the area of thick unconsolidated deposits of Quaternary age south of Muddy Creek. Most of the existing wells are in these parts of the area. It is believed that maximum development has been reached in the vicinity of Pine Bluffs, but elsewhere in the area no evidence, such as a progressively lowering water table or marked diminution of ground-water discharge into streams, indicates that development is approaching a maximum. Because quantitative data are lacking, it is not possible to predict how far development can proceed before the ground-water supply is overdrawn. However, a close watch on water levels in the vicinity of large ground-water withdrawals would reveal impending overdevelopment.

REFERENCES CITED

American Public Health Association, 1946, Standard methods for the examination of water and sewage, 9th ed.: New York, Am. Public Health Assoc. and Am. Water Works Assoc.

Babcock, H. M., 1952, Memorandum on the ground-water resources of the Horse Creek and Cherry Creek drainage basins, Wyoming: U.S. Geol. Survey open-file rept. (processed).

Babcock, H. M., and Bjorklund, L. J., 1956, Ground-water geology of parts of Laramie and Albany Counties, Wyo., and Weld County, Colo., with a section on the chemical quality of the ground water, by L. H. Kister: U.S. Geol. Survey Water-Supply Paper 1367.

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, Wyo., with a section on the chemical quality of the water, by W. H. Durham: U.S. Geol. Survey Circ. 162.

Bjorklund, L. J., 1957, Geology and ground-water resources of the lower Lodgepole Creek drainage basin, Nebraska, with a section on the chemical quality of the water, by E. R. Jochens: U.S. Geol. Survey Water-Supply Paper 1410.

Burleigh, H. P., Gwillim, H. C., Dunnewald, T. J., and Pearson, H. W., 1938, Report on irrigation by recovery of ground water in the Egbert-Pine Bluffs area: Wyoming Dept. Agriculture, Bur. Agr. Econ., Div. Land Econ. (MS. rept.)

California Institute of Technology, 1952, Water quality criteria: State Water Pollution Control Board Pub. 3.

Campbell, M. R., and others, 1925, Geologic map of Wyoming: U.S. Geol. Survey Geol. Atlas, State of Wyoming. Scale 1:500,000.

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

Eaton, F. M., 1950, Significance of carbonates in irrigation waters: Soil Sci., v. 69, no. 2, p. 123–133.

Foley, F. C., 1942, Progress report on the geology and ground-water resources of the Cheyenne area, Wyoming: U.S. Geol. Survey open-file rept., Washington, D.C., and Cheyenne, Wyo.

Knight, S. H., and Morgan, A. M., 1936, Report on the underground-water resources of the Egbert-Pine Bluffs region: Wyoming Geol. Survey (Ms. rept.)

Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming: U.S. Geol. Survey. Scale 1:500,000.

Maxcy, K. F., 1950, Report on the relation of nitrate concentrations in well waters to the occurrence of methemoglobinemia: Natl. Research Council Bull., Sanitary Engineer, p. 265, app. D.

Meinzer, O. E., 1917, Ground water for irrigation in Lodgepole Valley, Wyoming and Nebraska, with a section on the cost of pumping for irrigation in western Nebraska, by H. C. Diesem: U.S. Geol. Survey Water-Supply Paper 425–B.

Morgan, A. M., 1946, Progress report on geology and ground-water resources of the Cheyenne area, Wyoming: U.S. Geol. Survey open-file rept., Washington, D.C., and Cheyenne, Wyo.

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, Wyo.: U.S. Geol. Survey Water-Supply Paper 1140.

Thorne, J. P., and Thorne, D. W., 1951, Irrigation waters of Utah, their quality and use: Utah Agr. Expt. Sta. Bull. 346.

U.S. Department of Agriculture, 1940, Water facilities area plan for Lodgepole Creek watershed in Wyoming and Nebraska: U.S. Dept. Agriculture, Bur. Agr. Econ. (mimeo. rept.)

U.S. Public Health Service, 1946, Drinking-water standards: Public Health Repts., v. 61, no. 11, p. 371–384.

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

Wenzel, L. K., and Waite, H. A., 1941, Ground water in Keith County, Nebr.: U.S. Geol. Survey Water-Supply Paper 848.

Wilcox, L. V., 1948, The quality of water for irrigation use: U.S. Dept. Agriculture Tech. Bull. 962.

Wilcox, L. V., Blair, G. Y., and Bower, C. A., 1954, Effect of bicarbonate on suitability of water for irrigation: Soil Sci., v. 77, no. 4, p. 259–266.

TABLE 5.—*Records of wells*

Well number: See text for description of well-numbering system.
Type of well: Dr, drilled; Du, dug; Sp, spring.
Depth of well: Measured depths are given in feet and tenths; reported depths are given in feet only.
Type of casing: C, concrete or masonry; N, none; P, metal pipe.
Character of material: G, gravel; S, sand; Sls, siltstone.
Geologic source: su, undifferentiated sedimentary rocks of Pennsylvanian to Late Cretaceous age; Tb, Brule formation; Ta, Arikaree formation; To, Ogallala formation; Qud, unconsolidated deposits of Quaternary age.
Type of pump: Cy, cylinder; N, none; T, turbine.
Type of power: D, diesel engine; E, electric motor; F, natural flow; G, gasoline engine; H, hand operated; N, none; T, tractor; W, windmill.
Use of water: D, domestic; I, irrigation; In, industrial; N, none; P, public supply; S, stock.
Measuring point: Bpb, bottom of pump base; Hpb, hole in pump base; Ls, land surface; Tc, top of casing; Tpp, top of pump platform.
Depth to water: Measured depths are given in feet, tenths, and hundredths; reported depths are given in feet only.
Remarks: A, acres irrigated; Ca, sample collected for chemical analysis; D, reported discharge in gallons per minute; DD, reported drawdown, in feet; Piw, plans irrigation well at site; S, sprinkling system; T, temperature of water in degrees Fahrenheit.

Well	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Type of pump	Type of power	Use of water	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
13-60-31aaa	W. T. Young	------	Dr	100	20	P	Sls G	Tb Qud?	T	T	I	Tc	1.0	5,186	39.55	11-13-40	Ca
14-60-11ac	------	------	------	------	------		------	------	------	------	I	------	------	------	------	------	Ca, T56
-19da	O. M. Young	1940	Dr	110	20	P	Sls, S, G	Tb, Qud	T	E	I	------	------	------	------	------	Ca, D450, DD6.4
-61-18cbb	Dale Bomhoff	------	Du, Dr	100	72-18	N	------	Tb, Ta, Qud	------	------	I	Ls	------	------	27.62	4- 3-43	Ca
-63- 6bb	Union Pacific R.R. Co.	1905	Du	65.5	180	C	S, G	Ta	T	E	In	Hpb	1.0	5,638	43.34	4-22-53	D400
-64- 6cc	do	------	Dr	156.5	8	P	S, G	To	Cy	W	D, P	Tpp	0	5,834	113.50	4-21-53	
-65-18ad	Howard Christensen	1925	Dr	257.5	6	P	S, G	To	Cy	W	S	Tc	0	------	227.93	4-21-53	
15-60-21ca	Geo. Phillips	------	Dr	125	------	------	------	To	------	------	D, S	------	------	------	------	------	Ca, T53
-32aa	W. T. Young	1940	Dr	108	20	P	Sls	Tb	T	E	I	Tc	2.0	------	52.76	12- 5-45	Ca
-61- 1ab	Berggren brothers	------	Dr	126.5	6	P	S, G	Tb	Cy	W	S	Tc	1.5	5,288	105.05	3-12-53	
-62-31ab	A. E. Schliske, Jr.	1952	Dr	100	18	P	S, G	Ta?, Qud	T	E	I	Hpb	3.0	5,460	26.82	4-28-53	A70, D1,000, DD15
-32bc	A. W. Steege	1953	Dr	100	18	P	S, G	Ta?, Qud	T	E	I	Hpb	2.5	5,450	22.52	4-28-53	A70, D1,000, DD33
-64-26cc	Harold McWilliams	------	Dr	100	30	P	S, G	To, Qud	T	T	I, S	Tc	.4	------	21.38	4-22-53	A15
-33dc	William Dolan	------	Dr	68.5	6	P	S, G	To	Cy	W	S	Tc	1.0	5,733	61.08	4-22-53	
-66-12bb	Warren Livestock Co.	1900	Dr	60	4	P	S, G	To, Qud	Cy	W	D	Ls	------	5,971	17	4-16-53	

TABLE 5.—*Records of wells*—Continued

Well	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Type of pump	Type of power	Use of water	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
15-66-16ac	Harold F. Johnson	1949	Dr	91.0	5	P	S, G	To?	Cy	W	S	Tc	2.0	6,070	31.23	4-16-53	Ca, T49
-30bc	Chris Younglove	1935	Dr	88.0	5	P	S, G	To	N	N	N	Tc	.3	6,225	82.07	3-20-53	
-67- 4bc			Dr		6	P	S, G	To	N	N	N	Tc	0		174.32	6-25-43	
-12aa	Eugene Warner		Dr	101.0	6	P	S, G	To	Cy	W	D, S	Tc	1.5	6,213	93.33	3-25-53	
-14cc			Dr		3	P	S, G	To	Cy	N	N	Tc	1.6		113.96	6-26-43	
-14dd			Dr			P	S, G	To	N	N	N	Tpp	.7		70.64	6-26-43	
-16cc	Warren Livestock Co.		Dr			P	S, G	To	Cy	W	S	Tc	1.9		145.00	6-25-43	
-24ad	Harry Raymore		Dr	93.5	4	P	S, G	To	Cy	W	D, S	Tpp	.2	6,208	79.45	3-25-53	
-31ddc	John Dobesch		Dr	174.0	5	P	S, G	To	Cy	W	D, S	Tc	1.0	6,476	156.00	3-18-53	Ca
-32db	Warren Livestock Co.		Dr	156.0	7	P	S, G	To	Cy	W	S	Tc	2.8	6,417	138.71	3-17-53	
-68-14cc	do		Dr			P	S, G	To	Cy	W	D, S	Tc	.8		215.74	6-23-43	
-30cd	do		Dr	498	8	P	S, G, Sls	Tb, To	Cy	W	S	Tc	2.8	6,716	199.20	6-20-42	
-32aaa	C. T. Adolphson	1916	Dr	425	6	P	S, G, Sls	Tb, To	Cy	W	D, S	Tc	.5		179.10	3-18-53	Ca
-33ab	Warren Livestock Co.		Dr	317	6	P	S, G, Sls	Tb, To	Cy	W	S	Tc	5.7	6,610	173.25	3-18-53	
-34aa	do		Dr		6	P	S, G	To	Cy	W	S	Tc	.9	6.574	203.55	5-15-45	
-69- 5c	City of Cheyenne	1942	Dr				Sls	Tb	N	N	N	Ls			86.63	4- 3-43	Ca
- 6ab	King Merritt		Dr		6	P	Sls	Tb	N	F	S						D2
- 6ac	City of Cheyenne	1942	Dr	182	10	P	Sls	Tb	T	E	P						Ca
- 6dd	King Merritt		Dr	265.0	5	P	Sls	Tb	N	N	N	Tc	.8		152.39	1- 2-43	
- 8ccb	City of Cheyenne	1942	Dr	375	12	P	Sls	Tb	N	N	N	Tc	1.6	6,833	112.50	3-20-53	Ca, D240, DD30
- 9aa	King Merritt		Dr	50	5	P	S, G	Tb	Cy	W	D, S	Tc	.7	6,759	1.43	6-25-42	
- 9ca	City of Cheyenne	1942	Dr	308	10	P	Sls	Tb	T	N	N	Bpb	1.0	6,857	74.80	6-23-42	D350, DD-50, T52
-13bb	Warren Livestock Co.		Dr	157.0	8	P	S, G	To	Cy	W	S	Tc	2.5		149.65	3-20-53	
-15bb	John M. Vance		Dr	150	5	P	Sls	Tb	Cy	H	D	Tc	.5	6,772	97.83	8- 6-42	
-24bb	I. L. Goodman		Dr	141.0	6	P	S, G	To	Cy	W	S	Tc	.5		129.55	1-29-53	
-70-12bc	Lorenz Ranch		Sp				Sls	su	N	F							Ca, D300

16-60- 6ba	Leonard Lundberg	1950	Dr	227.0	6	P	S, G	To	Cy	W	S	Tc	1.2	5,372	210.89	3-10-53	
-22cc	Mrs. May Timesch	1910	Dr	212.0	6	P	S, G	To	Cy	H	D	Tc	1.0	5,270	190.91	3-12-53	
-28dd	John Jessen		Dr	177.0	4	P	S, G	To	N	N	N	Tc	1.0	5,257	159.70	3-12-53	
-30bc	Berggren brothers	1901	Dr	190	6	P	S, G	To	Cy	W	D, S	Tc	1.3	5,326	141.50	3-11-53	
-32ba	Farmers Union Coop		Dr	250	10	P	S, G	To	Cy	G	In	Tc	1.0		106.49	3-16-53	
-61-12cd	Warren Anderson	1910	Dr	200	6	P	S, G	To	Cy	W	D, S	Tc	1.5	5,355	180.75	3-10-53	
-21ca	B. Scheel	1951	Dr	257.0	8	P	S, G	To	N	N	N	Tc	.3	5,412	152.55	3-16-53	
-24ad	Don Kunau			179.5	6	P	S, G	To	Cy	W	D, S	Tc	.5	5,369	165.59	3-11-53	
-63- 3da	George M. Armstrong	1953	Dr	252	4	P	S, G	To	Cy	G	S	Tc	1.5	5,676	233.45	4-27-53	
-26ad	Carl Weber	1910	Dr	181.5	4	P	S, G	To	Cy	W	D, S	Tc	1.0	5,627	153.50	4-27-53	
-29cb	Clifford Statz	1940	Dr	140	4	P	S, G	To	Cy	W	S	Tc	2.0	5,677	125.84	4-22-53	Ca, T53
-64- 3cc	David Johnson		Dr	185.0	9	P	S, G	To	T	G	I	Tc	1.0	5,778	157.25	1-30-53	D250
-36da	W. C. Bowser		Dr	132.5	3	P	S, G	To	Cy	W	S	Tc	1.0		116.33	4-22-53	
-65-21da	Earl Anderson	1944	Dr	208.0	6	P	S, G	To	Cy	W	S	Tc	.5	5,966	182.35	4-16-53	
-66-6cb	F. R. Holmes	1922	Dr	208	6	P	S, G	To	Cy	W	D, S	Ls			178		
-31dc	Fred Boice	1953	Dr	70		N	S, G	To, Qud	N	N	N	Ls			9.30	4-20-53	Plw
-67-24da	Vyrle Bixby	1930	Dr	44.0	6	P	S, G	To	Cy	W	D, S	Tc	1.2	6,215	[1]37.84	4-21-53	
-36ad	Wyoming State Highway Dept.		Du			N	S, G	Qud	N	N	N	Ls		6,118	2.00	3-25-53	
-69-27bc	C. C. Davis	1904	Dr	98.5	6	P	Sls	Tb	N	F	S						D35, T50
-32aa	do		Dr	100	6	P	Sls	Tb	N	F	S						D15, T48
-33bbb	do	1904	Dr	100	6	P	Sls	Tb	N	F	S						Ca, D20, T48
17-60-20ad	John W. Freeburg	1945	Dr	304	18	P	S, G	To	T	E	I	Hpb	1.3	5,307	209.64	3-10-53	A5, D120, S
-20dc	Town of Albin	1928	Dr	258	5	P	S, G	To	T	E	P	Ls			240		
-29ab	Union Pacific R.R. Co.	1928	Dr	400	12	P	S, G	Ta?, To	Cy	D	In	Tc	1.0		195.00	6-13-52	D66
-29ba	Town of Albin	1931	Dr	300	8	P	S, G	Ta?, To	T	E	P	Ls			240		
-62-26aa	Stock Growers Bank	1918	Dr	220.0	6	P	S, G	To	Cy	W	D, S	Tc	.5	5,492	189.94	4-20-53	Ca, T53½
-28bc	George Ramsa	1928	Dr	232.0	4	P	S, G	To	Cy	W	S	Tc	.5	5,567	230.00	4-20-53	
-63-28aa	R. B. Anderson	1920	Dr	273	4	P	S, G	To	Cy	E	S	Ls		5,667	243		
-31aa	E. L. Talbert	1937	Dr	335	6	P	S, G	To	Cy	E	D, S	Tc	1.0	5,757	292.60	4- 8-53	Ca, T53½
-66-30cc	F. R. Holmes	1915	Dr	160	4	P	S, G	Ta?, To	N	N	N	Tc	1.0		133.84	4-21-53	

[1] Perched water table.

INDEX

O