GEOLOGICAL SURVEY CIRCULAR 162

RECONNAISSANCE OF THE GEOLOGY AND GROUND-WATER RESOURCES OF THE HORSE CREEK-BEAR CREEK AREA LARAMIE AND GOSHEN COUNTIES WYOMING

By H. M. Babcock and J. R. Rapp

WITH A SECTION ON THE CHEMICAL QUALITY OF THE WATER

By W. H. Durum

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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RECONNAISSANCE OF THE GEOLOGY AND GROUND-WATER RESOURCES OF THE HORSE CREEK-BEAR CREEK AREA LARAMIE AND GOSHEN COUNTIES, WYOMING

WITH A SECTION ON THE CHEMICAL QUALITY OF THE WATER

ABSTRACT

The area described in this report is in northern Laramie and southern Goshen Counties, Wyo., in the extreme western part of the High Plains section of the Great Plains physiographic province. A reconnaissance of the geology and ground-water resources was made along Horse and Bear Creeks, tributaries of the North Platte River, to determine the possibilities of developing ground-water supplies for irrigation.

The outcrop areas of the formations exposed in the Horse Creek-Bear Creek area are shown on a geologic map included in the report. These formations range in age from Early Cretaceous to Recent. The Lower and Upper Cretaceous formations are not considered important aquifers in the area. The Tertiary formations include the Chadron, Brule, and Arikaree. The Chadron formation is not an important aquifer in the area; the Brule formation, a siltstone, yields small to moderate amounts of water to wells and springs through fissures; and the Arikaree sandstone, consisting mainly of sandstone, yields small quantities of water to wells and springs. Many small springs and seeps occur along the Brule and Arikaree contact. The Quaternary alluvium, which is the principal water-bearing formation in the area, consists of stream-laid deposits of coarse sand and gravel, which contain beds and lenses of silt and clay. The alluvium readily yields water to wells.

Unconfined ground water is contained in the alluvium of the stream valleys, and in places it occurs in quantities sufficient for irrigation. Near the town of Lagrange, in the eastern part of the area, irrigation wells yielding 450 to 900 gpm obtain water from the alluvium. Additional irrigation wells having comparable yields could be developed from the alluvium in this area and also in other places along Horse and Bear Creeks.

The water table in the valleys is as much as 40 ft below land surface, but in most places it is less than 20 ft. In general the water table is encountered at a greater depth in the interstream areas than in the alluvium of the valleys of Horse and Bear Creeks, and in some places it is more than 100 ft below the land surface.

Ground water from different sources in the area is similar in mineral content but differs considerably in chemical character. Water in the alluvium and Arikaree sandstone is principally of the calcium bicarbonate type, whereas water in the Brule formation is essentially of the sodium bicarbonate type. The range in dissolved solids of the samples analyzed is from 206 to 584 ppm, in hardness from 82 to 257 ppm, and in percent sodium from 8 to 77. Although the water in both unconsolidated and bedrock aquifers is hard, it is generally satisfactory for domestic use. Residual sodium carbonate in samples of water from the Brule formation may limit use of this water for irrigation.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this investigation was to determine the possibility of developing ground-water supplies for irrigation in the valleys of Horse and Bear Creeks. This investigation is one of a series being made by the Department of the Interior for the control, conservation, development, and use of the water resources of the Missouri River basin. The studies are designed to give a quantitative and qualitative evaluation of the ground-water resources of the areas to be irrigated under the development program.

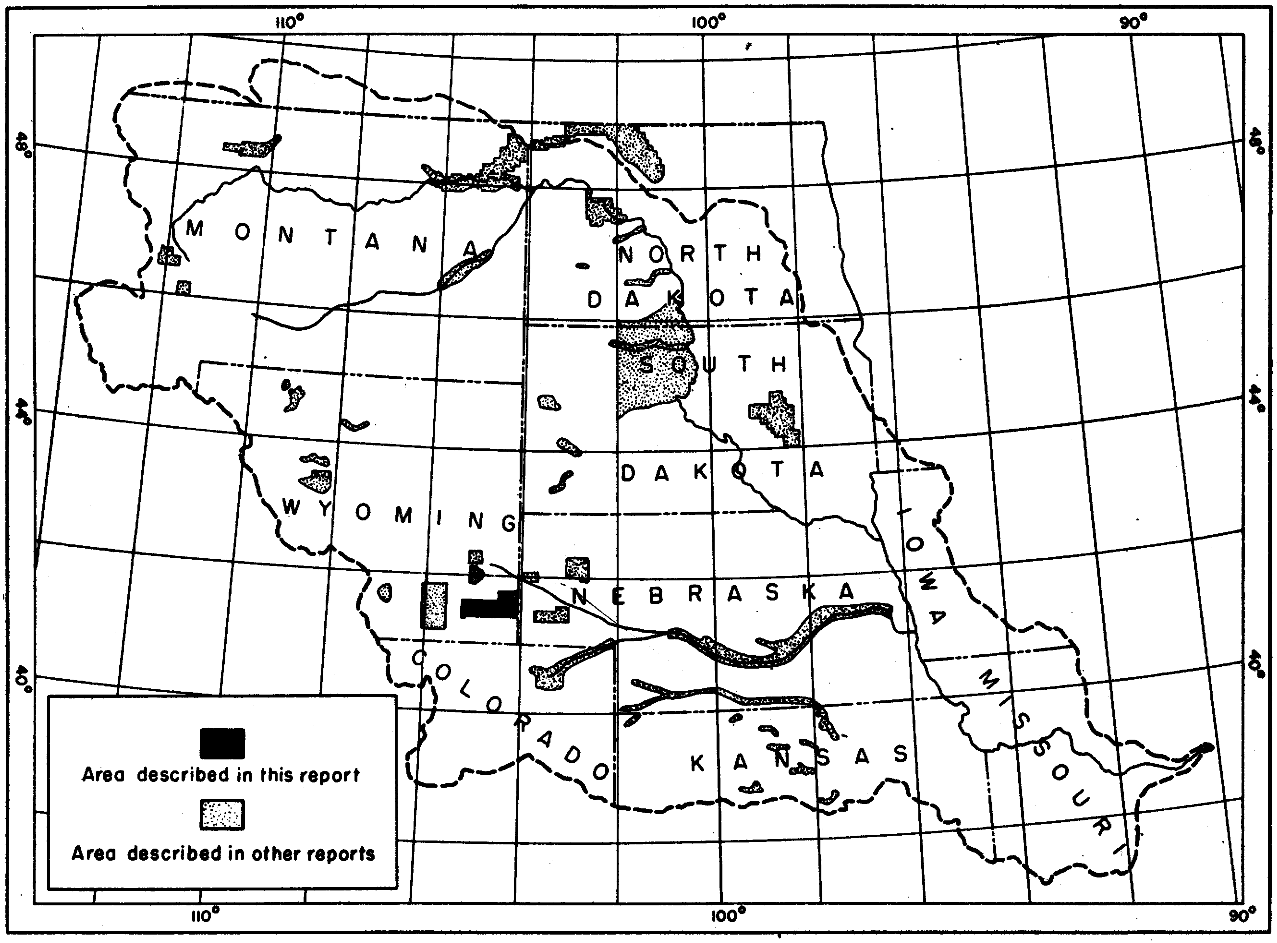

Figure 1.--Map of the Missouri River drainage basin showing areas in which ground-water studies have been made under Missouri Basin development program.

The field work upon which this report is based was performed during the period July to October 1949. The work was under the general supervision of A. N. Sayre, chief, Ground Water Branch, United States Geological Survey, and G. H. Taylor, regional engineer in charge of ground-water investigations in the Missouri River drainage basin, and under the immediate supervision of S. W. Lohman, district geologist for Colorado and Wyoming. The quality-of-water studies were under the general supervision of S. K. Love, chief, Quality of Water Branch, U. S. Geological Survey, and under the immediate supervision of P. C. Benedict, regional engineer in charge of quality-of-water studies in the Missouri River drainage basin. The water analyses were made by R. P. Orth, chemist, in the Quality of Water laboratory, Geological Survey, Lincoln, Nebr.

LOCATION AND EXTENT OF THE AREA

The area covered by this investigation is in northern Laramie and southern Goshen Counties, in southeastern Wyoming. (See pl. 1 and figs. 1 and 2.) It lies within Tps. 17-

20 N., Rs. 61-70 W., sixth principal meridian and base-line system, and covers about 1,000 sq mi.

The area is transected by branch lines of the Union Pacific Railroad on the east side and the Colorado and Southern Railway on the west. U. S. No. 85 crosses the eastern part of the area, and U. S. No. 87 crosses the western part. Several county roads, which are graveled and maintained throughout the year, serve the remainder of the area.

western part of the area was studied and mapped by Darton, Blackwelder, and Siebenthal (1910). Schlaikjer (1935a, b) mapped the geology of the Goshen Hole, which includes the northeastern part of the area. The ground-water resources of the Horse and Bear Creek valleys were described briefly by Dockery in 1940.

Meinzer (1917) described the geology and ground-water resources of the Lodgepole Creek valley, which is south of the Horse Creek-

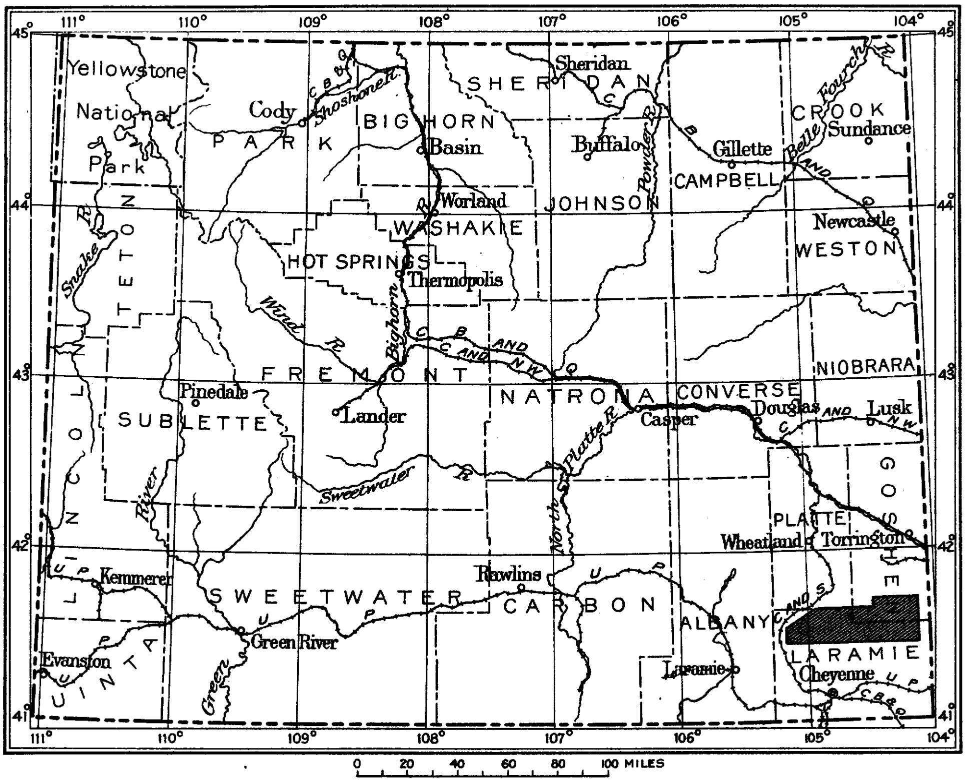

Figure 2.—Index map of Wyoming, showing the location of the Horse Creek-Bear Creek area.

PREVIOUS INVESTIGATIONS

The geology and water resources of the Horse Creek-Bear Creek area and of adjacent areas have been discussed in several papers. These publications have been very useful in the preparation of this report.

The geology and water resources of the eastern part of the Horse Creek-Bear Creek area were described by Adams (1902) in a report on the Patrick and Goshen Hole quadrangles. The geology of the extreme south-

Bear Creek area. The geology and ground-water resources of the Egbert-Pine Bluffs-Carpenter area, which is southeast of the Horse Creek-Bear Creek area are described in a report by Rapp, Warner, and Morgan (in preparation).

Records of wells in the northeastern part of the area were obtained by personnel of the Ground Water Branch of the Geological Survey in 1943; these records were used in the preparation of this report.

METHODS OF INVESTIGATION

Records were obtained of 92 wells and springs in the area. Well drillers or well owners contributed the little information available regarding the character of the water-bearing materials penetrated and the yield and drawdown of the wells. Records of "shot holes" drilled during seismic surveys by oil companies were studied, but they are not listed in this report. Eleven samples of water for chemical analysis were collected from representative wells, springs, and creeks. Thirty-eight of the wells were measured with a steel tape to determine their depth and the depth to water below some fixed measuring point, generally the top of the pipe clamp or the bottom of the pump base. Reported data are listed for those wells that could not be measured. Six representative wells were selected for periodic observations of the water level in order to obtain information concerning the seasonal fluctuations of the water table.

The geologic and hydrologic field data were recorded on aerial photographs; the map of the area (see pl. 1) was compiled from these photographs. The geologic mapping and hydrologic studies were concentrated along the valleys of Horse and Bear Creeks where irrigation from wells is deemed most practicable. The upland areas adjacent to the creeks also were mapped, however, in order to understand better the regional geology.

Wells and springs shown on the map were located within the sections by use of an odometer and by inspection of the aerial photographs; their locations are believed to be accurate to 0.1 mile.

WELL-NUMBERING SYSTEM

In this report, wells and springs shown on the map are numbered according to their location within the General Land Office system of land subdivision. The well number shows the location of the well by township, range, section, and position within the section. The first numeral of a well number indicates the township, the second the range, and the third the section in which the well is located. The lower-case letters following the section number locate 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 (10-acre tract). The section divisions are lettered a, b, c, and d, in a counterclockwise direction, beginning in the northeast quarter. When more than one well is situated in a 10-acre tract consecutive numbers beginning with 1 are added. A graphical illustration of this method of well numbering is shown in figure 3.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Horse Creek-Bear Creek area lies in the extreme western part of the High Plains section of the Great Plains physiographic province. The highest point, which lies in the western part of the area, is about 7,100 ft above sea level; the lowest point, where Horse Creek leaves the area, is about 4,400 ft above sea level. The relief of the area, therefore, is about 2,700 ft.

In the extreme western part of the area is a well-defined lowland, 2 to 5 miles wide. This lowland lies between the foothills of the Laramie Range and the western margin of the High Plains. The valley floor is a gently rolling surface cut into upper Mesozoic and Tertiary rocks. A westward-facing escarpment, which rises about 500 ft above the valley floor, bounds the valley on the east. From the crest of this escarpment, the gently rolling High Plains slope eastward from an altitude of about 7,100 ft to about 5,300 ft at the eastern margin of the mapped area. These highlands are incised by the valleys of Horse and Bear Creeks and their tributaries. In the northeastern part of the area the continuity of the highlands is ended abruptly by Goshen Hole, a somewhat semicircular erosional basin. Goshen Hole is bounded by a nearly continuous escarpment, which is from 400 to 1,000 ft high. The floor of Goshen Hole is a gently rolling surface of low relief that has been cut in Oligocene and Cretaceous rocks.

Horse and Bear Creeks drain a long, narrow segment of the upland area that lies east of the Laramie Range; this segment is bounded on the south by the drainage basin of Lodgepole Creek and on the north by the drainage basin of Chugwater Creek. The valleys of Horse and Bear Creeks are narrow with only local

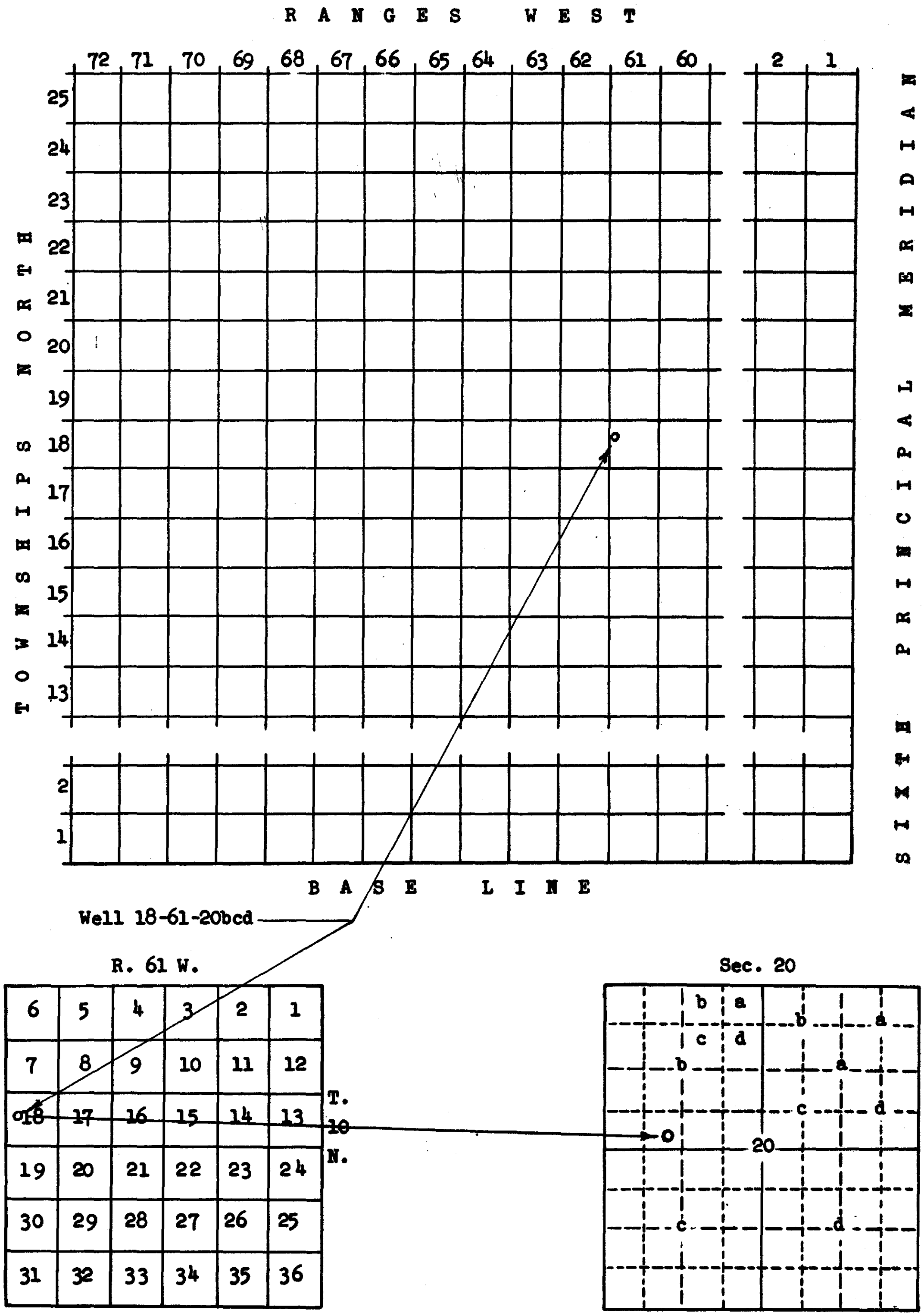

Figure 3.--Sketch showing well-numbering system.

widening throughout their courses in the upland area. In the area studied Horse Creek is perennial throughout its course, and Bear Creek is perennial in the lower two-thirds of its course. Locally, however, the channels may be temporarily dry owing to diversion of water for irrigation.

Horse Creek rises in the Laramie Range and flows eastward across most of the area. About 4½ miles west of the Wyoming-Nebraska State line it turns northward, flows across Goshen Hole, and then eastward to its confluence with the North Platte River. The length of the valley of Horse Creek in the area is about 70 miles. Horse Creek enters the area at an altitude of about 6,500 ft and leaves the area at an altitude of about 4,400 ft. It has an average gradient of about 30 ft to the mile.

Bear Creek rises on the Great Plains about 4 miles east of the front of the Laramie Range. It flows eastward approximately parallel to Horse Creek for about 50 miles; it then turns northward and joins Horse Creek near the southern boundary of Goshen Hole.

CLIMATE

The climate of the area is similar to that of other parts of the High Plains section and is characterized by low precipitation, high evaporation, and a wide range in temperature. The weather is variable from year to year; but usually the summers are dry and mild, and the winters are very cold.

Weather information has been recorded intermittently since 1902 by the U. S. Weather Bureau at Lagrange, which is at the eastern edge of the area. Precipitation for the years of complete record is shown in figure 4. The normal annual precipitation is 16.63 in. During the period of record the annual precipitation ranged from a minimum of 10.19 in. to a maximum of 25.05 in. About 43 percent of the annual precipitation occurs during April, May, and June. The wettest month is May, during which the normal precipitation is 2.43 in., or about 15 percent of the annual precipitation; the driest month is January, during which the normal precipitation is 0.51 in., or about 3 percent of the annual precipitation.

The mean annual temperature at Lagrange is 48.3 F. The frost-free growing season usually begins in the latter part of May and ends during the latter part of September. The average length of the growing season at Lagrange is 126 days.

AGRICULTURE

Most of the area is sparsely populated and is utilized for range feed in the raising of livestock or for dry farming. Some plots in

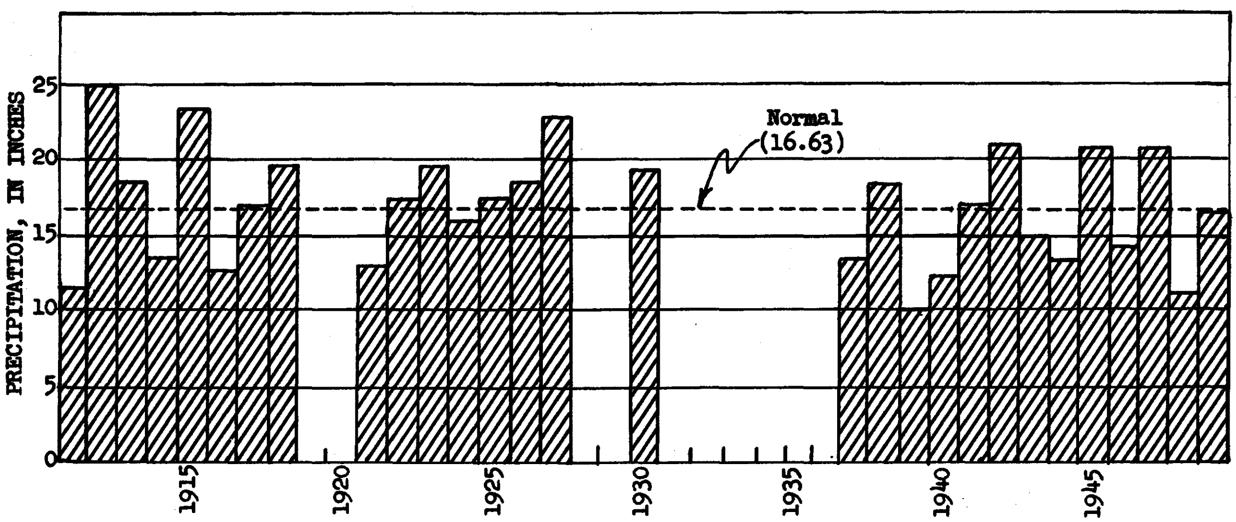

Figure 4.--Graph showing annual precipitation at Lagrange, Wyo. (From records of the U. S. Weather Bureau)

the stream valleys are irrigated; most of these plots are used to raise hay for winter feed for livestock. In the extreme northeastern part of the area the surface flow of Horse and Bear Creeks is collected in the Hawk Springs reservoir and is used for irrigation farther downstream.

GEOLOGY AND GROUND WATER

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Pre-Tertiary Rocks

The Horse Creek-Bear Creek area is underlain by thick pre-Tertiary sedimentary rocks that range in age from late Paleozoic through late Mesozoic and that lie on granites and other crystalline rocks of pre-Cambrian age. The oldest sediments exposed in the area are those of the Colorado group of Early and Late Cretaceous age. These sediments are exposed in a narrow belt along the extreme western part of the area. (See pl. 1.) Here they are sharply upturned and in some places are overturned, faulted, or complexly warped. Eastward from the outcrop area they dip steeply beneath a cover of younger sediments. The eastward dip of the beds decreases progressively with increased distance from the Laramie Range. Logs of oil wells reveal that these older sediments lie at considerable depths within relatively short distances from their outcrop areas. For example, the log of well 17-67-4dca indicates that the Fox Hills sandstone dips eastward to a depth of 4,020 ft within a distance of about 13 miles from the outcrop area. The excessive depths at which this and older formations lie beneath most of the area eliminate them from further consideration on the basis of cost of development as sources of ground water.

Colorado Group

The Colorado group, which in this area is of Early and Late Cretaceous age, includes the Benton shale and the Niobrara formation. These strata crop out in a narrow strip along the western margin of the area, where they are upturned sharply. The Colorado group ranges in thickness from 1,075 to 1,400 ft. Because of its relative unimportance as an aquifer, the two formations that it comprises are mapped as one unit on plate 1.

The Benton shale consists mainly of gray to black shale containing thin beds of limestone and sandstone. It ranges in thickness from 700 to 1,000 ft. The Mowry shale member near the base of the Benton shale consists of hard shale and thin-bedded fine-grained resistant sandstone, which contains many fossilized fish scales. The sandstone forms rounded ridges and weathers to a light silvery gray.

The Niobrara formation consists mainly of limestone and calcareous shale. At the base of the formation is a massive bed of limestone that contains Inoceramus deformis. Another bed of limestone occurs near the middle of the formation, and at the top are layers of impure shaly limestone that weather to a bright yellow. Slabby aggregates of Ostrea congesta occur in many of the beds. The Niobrara formation ranges in thickness from 375 to 400 ft.

Pierre Shale

The Pierre shale of Late Cretaceous age consists mainly of dark-gray to brown fine-grained shale, sandy shale, and slabby sandstone. The top 1,000 ft of the formation consists largely of gray shale and sandy shale. The Pierre shale is exposed in the western part of the area, where the beds are vertical or very nearly so. The formation is about 3,000 to 5,000 ft thick. Generally in the area, it is considered a poor source of ground water; however, one well drilled into the outcrop area yields a small amount of water from a bed of sandstone.

Fox Hills Sandstone

The Fox Hills sandstone of Late Cretaceous age consists mainly of brown medium-grained sandstone. The sandstone is moderately hard and contains beds of tan-gray shale and sandy shale. Generally it is eroded rather uniformly; however, a notable exception is Chimney Rock. (See fig. 5.) It is interesting to compare this photograph with that shown as figure 10 of the report by Darton, Blackwelder, and Siebenthal (1910) to see the effects of erosion on the outcrop during a period of about 40 yr. Like the older formations, the Fox Hills sandstone crops out only in the western part of the Horse Creek-Bear Creek area, where it ranges from 400 to 700 ft in thickness. The small amount of water yielded by well 17-70-25aab is thought to come from the Fox Hills sandstone. Small amounts of water probably can be obtained from this formation in or very near the outcrop area.

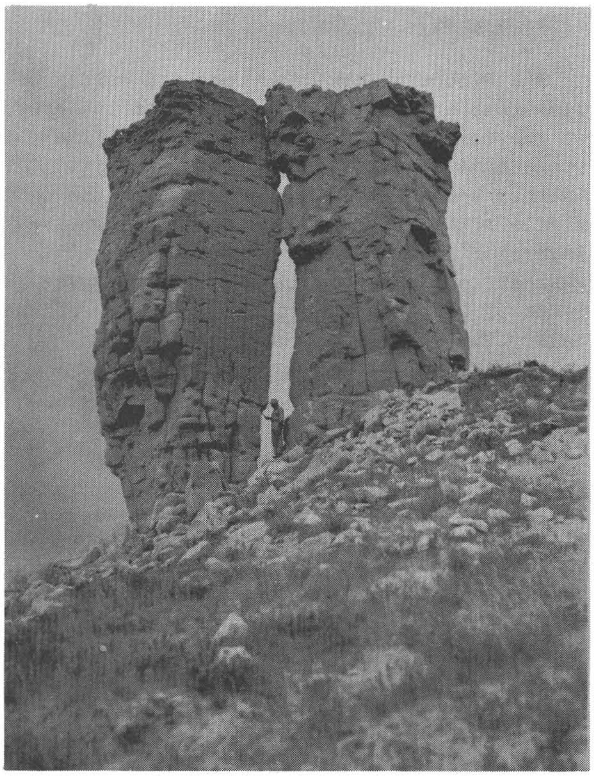

Figure 5.--Chimney Rock, an unusual erosional remnant of the Fox Hills sandstone in sec. 30, T. 17 N., R. 69 W.

Lance Formation

The Lance formation of Late Cretaceous age consists mainly of variegated sandstone and shale but includes beds of yellow to brown cross-bedded channel sandstone, a few large rounded sandstone concretions, and a few beds of lignite, black shale, and limestone. Schlaikjer (1935a, p. 65) separated the Lance formation into three divisions: a lower succession of continental deposits 100 to 200 ft thick, which contains ceratopsian and other reptilian remains; a middle sequence of brackish-water deposits, 80 to 125 ft thick; and an upper sequence of continental deposits, 60 to 100 ft thick, which contains *Triceratops eurycephalus* Schlaikjer, an advanced species. The only exposures of the Lance formation are in Goshen Hole, in the northeastern part of the area. The westward extension of this formation is not known because of the thick cover of younger deposits. The formation is about 240 to 425 ft thick. No wells in the area are known to obtain water from the Lance formation; however, spring 20-61-17dda flows an estimated 10 gpm from this formation. The pervious channel sandstones of the Lance formation should yield moderate amounts of water to wells, but most of the formation consists of less permeable fine-grained materials and is not considered a good aquifer.

Tertiary Rocks

Tertiary formations in the Horse Creek-Bear Creek area include the Chadron and Brule formations of the White River group, and the Arikaree sandstone. Classification of the Chadron and Brule formations of Oligocene age, and the Arikaree sandstone of Miocene age was made on the basis of vertebrate remains collected from these sediments by Schlaikjer (1935b, pp. 97-189). The Brule formation and the Arikaree sandstone cover a large part of the area studied.

Chadron Formation

General features.--The Chadron formation crops out in two widely separated places in the Horse Creek-Bear Creek area: on the floor and east side of the lowland along the western margin of the area, and in the extreme northeastern part of the area in Goshen Hole. It is thought to underlie most of the area but in most places is covered with younger sediments. In the western part of the area the Chadron formation ranges in thickness from a feather edge to 40 ft; in the eastern part, from a feather edge to 80 ft.

In the extreme western part of the area the Chadron formation consists mainly of medium- to coarse-grained brown sandstone. In many places it is conglomeratic and, in general, contains much coarser materials where it is near or in contact with pre-Cambrian rocks. Locally it contains deposits of volcanic ash. A lenticular bed of siliceous limestone at the base of the formation ranges in thickness from a feather edge to about 2 ft. In the western part of the area identification has been made entirely on the basis of stratigraphic position because no Titanotherium or other characteristic vertebrate remains have been found.

In the extreme northeastern part of the area, in Goshen Hole, the Chadron formation consists mainly of gray, red, brown, or green soft silt and clay that locally may be quite sandy. Green fine- to coarse-grained channel sandstones generally occur near the top of the Chadron formation. Most of these sandstones are well-cemented and form small mesa-like prominences that are especially noticeable north of the area studied. In the northeastern part of the area the Chadron formation is easily recognized by the variegated clay and silt, by the greenish sandstone, and by the abundant titanothere remains.

Water supply.--Only one well (17-69-28cbb) in the Horse Creek-Bear Creek area is known to yield water from the Chadron formation. It is in the western part of the area where the formation consists of medium- to coarse-grained material. In and near this outcrop area the Chadron formation probably would yield small quantities of water to other wells. In the eastern part of the area the part of the formation that consists of silt and clay is a poor source of water; however, the channel sandstones probably would yield small to moderate quantities of water to wells.

Brule Formation

Character.--In the Horse Creek-Bear Creek area the Brule formation is a moderately hard bentonitic siltstone that is compact and brittle and locally may be sandy or argillaceous. No mechanical analyses were made of the material in this area, but megascopically it compares favorably with that described by Wenzel, Cady, and Waite (1946, pp. 66-70) in the Scotts Bluff area, Nebraska. Fresh exposures are buff or flesh-colored; however, weathered surfaces are light pink to almost white. The Brule formation typically weathers into cubical blocks and slabs as large as 6 in. by 3 ft by 2 to 5 ft. In places, extensive erosion of outcrops has produced miniature badlands.

The Brule formation generally is massive and featureless. It has regular bedding planes, but they are indistinct and very difficult to trace. Light-colored resistant zones cemented by calcium carbonate have produced a layered effect in some places; these zones are not persistent but grade laterally into massive beds. Lenticular beds of volcanic ash and sandstone occur locally in the formation. In the western part of the area a thin lenticular bed of siliceous limestone occurs near the base of the formation. Well drillers reportedly have encountered gravel in the Brule formation. Long, thin columnar aggregates of barite crystals and long, thin veins of calcite occur in places in the Brule.

Superficially, the Brule formation is cut vertically and along bedding planes by joints. The joints generally are small, the maximum width being about an inch. In addition, fissures penetrate the formation to unknown depths; some possibly extend completely through the formation. On badland surfaces fissures as wide as 10 in. were found; however, they probably attain even greater widths, as shown by the comparative ease with which traces of these fissures are seen on aerial photographs. (See fig. 6.) Some of the fissures and joints are filled with materials derived from overlying sediments, from the wall rock, or from both.

Inasmuch as the Brule formation is composed mainly of relatively impervious siltstone, it has a relatively low permeability. Locally, however, its permeability is greatly increased by the presence of joints and fissures and also by a few lenticular beds of sandstone.

Distribution and thickness.--The Brule formation crops out in a north-south trending strip in the western part of the Horse Creek-Bear Creek area, in narrow strips along parts of the valleys of Horse and Bear Creeks and their main tributaries, and more extensively in Goshen Hole. Generally the Brule formation makes up the bases and lower slopes of escarpments. Where exposed it is as much as 300 ft thick in the western part of the area and about 450 ft in the eastern part.

Water supply.--The Brule formation supplies water to many wells in the area, in small quantities that are adequate for domestic and stock purposes. Locally, however, ample water for irrigation may be obtained from fissures. Water percolates downward through overlying permeable materials into interconnecting joints, which in turn transmit the water to larger fissures. The underground drainage system, consisting of the overburden and the network of joints and fissures, seems to be quite extensive. Logs of successful irrigation wells show a moderate thickness of saturated gravel above the Brule formation. The Brule formation also yields water to springs and seeps in the area, especially along the lower stretches of Horse Creek and Bear Creek; many large springs occur in places where several fissures join. (See fig. 6.)

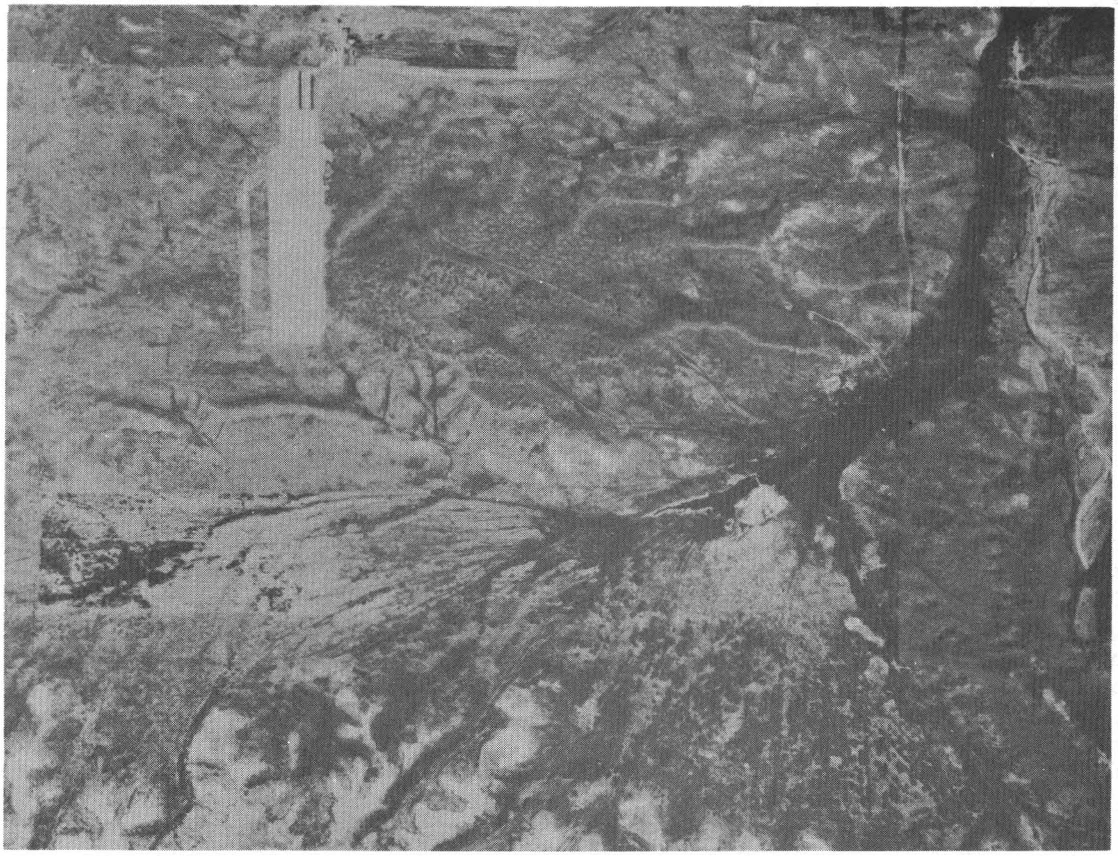

Figure 6.--Aerial photograph showing fissures in the Brule formation in sec. 9, T. 17 N., R. 64 W. Ground water issues as springs and seeps where these fissures converge in the central part of the area shown. Here the total flow is estimated to be 100 gpm. Outcrops of the younger Arikaree sandstone appear as white areas in the lower part of the picture.

Arikaree Sandstone

General features.--In the Horse Creek-Bear Creek area the character of the material that is referred to the Arikaree sandstone varies greatly. In its extreme western exposures the Arikaree is coarse to very coarse-grained; in the central and eastern exposures it is predominantly fine-grained. The formation is about 200 to about 700 ft thick.

In the western part of the area the Arikaree sandstone unconformably overlies the Brule formation. There the Arikaree consists of coarse sand and gravel that in places is loosely to tightly cemented into sandstone and conglomerate. Most of the coarse, angular to subangular materials are derived directly from the granitic rocks (Sherman granite) that make up the core of the nearby Laramie Range. All or parts of these deposits may not belong to the

Arikaree formation and there is some disagreement among geologists as to whether these coarse-grained materials are in the Arikaree sandstone (of Miocene age) or in the Ogallala formation (of Pliocene age). As no fossil remains have been found in these materials, the differing classifications have been based entirely on stratigraphic position. Darton, Blackwelder, and Siebenthal (1910, p. 11) classified them as Arikaree, and their classification is used in this report. Eastward these materials grade into and interfinger with beds of fine-grained materials that have the appearance of the typical Arikaree with its pipy concretions as described by Darton (1903, pp. 23-29).

In the eastern part of the area the Arikaree sandstone mainly consists of loose to moderately cemented, fine-grained sand interbedded with layers of hard, tough fine-grained sandstone and lenses of loose to tightly cemented gravel. Also included in the Arikaree sandstone, especially in the upper part, are beds of volcanic ash. The Arikaree sandstone generally is light gray but in some places is light brown in fresh exposures and weathers to dark gray.

In Goshen Hole the lower part of the Arikaree sandstone consists of about 400 ft of massive light- to dark-gray soft sandstone that contains channel sand and concretionary sandstone. A cross-bedded sand at the base of the Arikaree sandstone in many places (see fig. 7) is more prevalent to the north and west of Sixty-six Mountain and Bear Creek Mountain. The massive sand, which is only slightly indurated in most places, forms the vertical face of most of the Goshen Hole escarpment. Westward it is overlain by a succession of beds of sand and sandstone. Among these deposits of sand and sandstone are several beds of clean white volcanic ash that range in thickness from a feather edge to several feet. Vertebrate remains found by Schlaikjer (1935b, pp. 117-120) indicate that the massive sandstone correlates with the lower part of the Harrison beds of Hatcher (1902, p. 117); the overlying beds to the west correlate with the upper part of the Harrison beds of Hatcher. These divisions have not been mapped separately and in this report are included in the Arikaree sandstone.

Water supply.--The Arikaree sandstone yields water to many domestic and stock wells in the area, but normally the yield is small. The only known flowing well in the area (17-68-21dcc) is thought to produce water from the Arikaree sandstone. Inasmuch as this formation generally is high topographically and hence is well-drained, the depth to water is considerable, generally being 100 ft or more. Locally, however, perched water-table conditions may be encountered. The Arikaree sandstone also yields water to springs and seeps in the area. Some of these issue from thin beds of sandstone, but most of them occur along the contact between the Brule and Arikaree formations. The water percolates downward through the permeable materials of the Arikaree to the top of the Brule formation and thence moves laterally down the

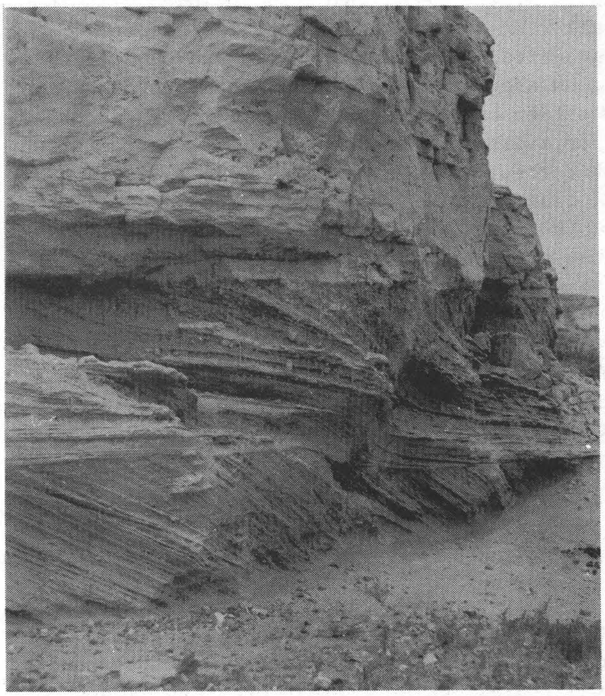

Figure 7.--Outcrop of the Arikaree sandstone along Bear Creek in sec. 4, T. 19 N., R. 63 W., showing the basal cross-bedded sand overlain by a somewhat indurated sand.

hydraulic gradient. It reaches the surface as springs or seeps in the low places or along escarpments where the Brule and Arikaree contact is exposed. These springs generally are small, and the water that issues from them disappears into the slope wash within a short distance. The spring line generally is marked by a concentration of vegetation.

Quaternary Rocks

General

Quaternary deposits in the Horse Creek-Bear Creek area include: stream-laid terrace deposits; aeolian deposits, laid down in protected places by the active winds of the area; slope wash, laid down on the slopes bordering the stream valleys; and alluvium, which underlies the flood plains of the present streams. The alluvium is the only Quaternary deposit sufficiently thick and extensive to be considered a good source of ground water; it is, therefore, the only Quaternary deposit shown on the map. A small strip of terrace deposits in the southeastern part of the area, which is included with the alluvium, represents the filled channel of ancestral Horse Creek. This old channel begins about 2 miles east of the town of Meriden and continues in an easterly direction for a distance of about 9 miles, where it is intercepted by Horse Creek (see pl. 1). Another terrace, believed to be of considerable extent, lies east of the mapped area in the vicinity of the town of Lagrange. This terrace was laid down by the eastward-flowing Horse and Bear Creeks before their courses were altered by their capture from the north. Adams (1902, p. 21 and pl. 2) points out and illustrates that these creeks at one time continued eastward into Nebraska and followed the present course of Pumpkin Creek.

Alluvium

Character and origin.--Alluvium in the Horse Creek-Bear Creek area consists of stream-laid deposits of fine to coarse sand and gravel, which contain beds and lenses of silt and clay. The alluvium in the western part of Horse Creek valley consists mainly of coarse sand, gravel, cobbles, and boulders that were derived directly from the rocks of the Laramie Range. Eastward along the valleys of Horse and Bear Creeks the alluvial materials become more fine-grained for they were derived mainly from local outcrops of the Brule and Arikaree formations. This is especially apparent in areas where the older alluvium was removed by the streams as their gradients were increased by stream piracy from the north. The alluvium again becomes coarse in the widespread deposit in the vicinity of Lagrange. The origin of this deposit is intimately related to the development of Goshen Hole.

The retreat of the Goshen Hole escarpment is due largely to erosion by ground-water discharge. Ground water that issues as springs and seeps along the contact of the Brule and Arikaree formations on the face of the escarpment erodes the less resistant Brule from under the Arikaree, thus undermining the latter until it sloughs off. The escarpment retreated in this manner until it intercepted Horse and Bear Creeks. As a result of this interception the stream courses were altered and shortened, and their gradients were increased greatly. This local rejuvenation increased the transporting power of the streams, and, as a result, alluvium was removed along the stream channels and was carried to a point where the decreased stream gradient allowed the material to be redeposited. This accounts for the extensive deposit of coarse alluvial materials near the town of Lagrange.

Extent and thickness.--Alluvial deposits occur along the valleys of Horse and Bear Creeks and their main tributaries. Throughout most of the central part of the area these deposits are very narrow, generally less than one fourth of a mile wide; but in the western and northeastern parts, especially in Goshen Hole, the alluvium is as much as 5 miles wide.

The thickness of the alluvium in the central and western parts of the area is not known; near the town of Lagrange it is 19 to 45 ft thick.

Water supply.--Many wells in the Horse Creek-Bear Creek area obtain water from the alluvium in quantities sufficient for stock and domestic purposes. Near the town of Lagrange irrigation wells in the alluvium yield 400 to 900 gpm.

OCCURRENCE, SOURCE, AND MOVEMENT OF GROUND WATER

The fundamental principles of the occurrence and movement of ground water are set forth in an authoritative and detailed report by Meinzer (1923). Only a brief discussion of the subject will be made here, and the reader is referred to Meinzer's report for a more detailed account.

Ground water in the Horse Creek-Bear Creek area occurs in the pore spaces of the materials underlying the area. The depth below which these materials are saturated in the valleys--that is, the depth to the water table--ranges from a few feet to about 40 ft below the land surface, but in most places it is less than 20 ft. In the interstream areas the water table generally is at greater depths than in the valleys and in some places is more than 100 ft below the land surface. The depth to the water level in wells in the Horse Creek-Bear Creek area is given in column 13 of table 5.

The ultimate source of all ground water in the area is precipitation on this and nearby areas. A part of the rain and snow melt in the area is carried off by streams, a part evaporates, and the remainder percolates directly into the ground. Part of the water that enters the ground is used by plants, but some of it eventually reaches the zone of saturation. Water that percolates downward to the zone of saturation in the upland areas moves laterally toward the stream valleys, where it either emerges as surface flow or enters the ground-water body in the alluvium.

Ground water moves from areas of high altitude or head to those of low altitude or head in the direction of the hydraulic gradient. The rate at which water moves through the materials depends largely on the size and shape of the pore spaces and on the slope of the water table. The sand and gravel deposits of the alluvium generally contain relatively large interconnecting pore spaces through which water moves freely under low water-table gradients. The high permeability of the sand and gravel that compose the alluvium is indicated by the large yields of some of the wells in this material. The materials composing most of the other formations in the area generally are fine-grained, have a low permeability, and do not transmit water freely. Consequently, these formations generally do not yield water readily to wells.

Horse and Bear Creeks are effluent streams throughout most of their courses--that is, they receive water from the zone of saturation. In a few places where the alluvium widens, however, the streams are influent for short distances. This condition is especially noticeable in the vicinity of Lagrange where the valleys of Horse and Bear Creeks merge and where the width of the alluvium increases from a few hundred feet to several miles.

GROUND-WATER DISCHARGE

Water is discharged from the underground reservoirs of the Horse Creek-Bear Creek area through evapotranspiration, seepage into streams, wells, springs, and underflow that leaves the area. No attempt was made to determine the amounts of water discharged by these processes.

The amount of ground water discharged by evapotranspiration probably is large, as the water table is near the land surface in the stream valleys and as a large part of the valley area is covered by vegetation, which withdraws water from the ground-water reservoir. The amount of ground water discharged by this process varies with the season, the rates of transpiration and evaporation being greatest during the growing season when the temperatures are highest.

Water is pumped from wells for irrigation, stock, and domestic use. The total amount of water pumped annually for irrigation probably does not exceed a few hundred acre-feet. Most of the stock and domestic wells in the area yield only small amounts of water.

FLUCTUATIONS OF WATER LEVELS

The water table in the area does not remain stationary but fluctuates with changes in the rates of recharge and discharge. If the discharge from a ground-water reservoir exceeds the recharge, the water table declines, and vice versa. The fluctuations of the water table therefore depend upon the net rate at which the reservoir is depleted or replenished.

Six wells in the area were selected for periodic observation of the water-level fluctuations (see table 1). Water-level measurements were made in four of these wells in 1943 but were not resumed until 1948 or

Table 1.--Water levels in observation wells, in feet below land-surface datum

18-67-28cac

Date	Water level	Date	Water level	Date	Water level	Date	Water level
Sept. 1, 1949	8.90	Dec. 9, 1949	11.21	May 23, 1950	7.07	Nov. 14, 1950	10.27
Oct. 27	7.22	Jan. 24, 1950	11.36	July 21	7.82	Feb. 28, 1951	8.74
Nov. 16	11.07	Mar. 27	11.41	Sept.19	8.95	Mar. 27	7.20

19-61-2ccd

May 10, 1943	15.99	July 27, 1949	14.97	Feb. 1, 1950	17.20	Sept.26, 1950	15.97
July 27	14.44	Aug. 30	16.02	27	17.20	Oct. 31	13.84
Mar. 1, 1949	13.77	Sept.29	14.95	May 30	15.22	Nov. 29	14.90
May 3	14.63	Oct. 31	14.42	June 21	15.33	Feb. 20, 1951	18.34
June 4	14.41	Nov. 29	16.01	July 21	15.18	Mar. 23	19.90
July 6	14.57	Dec. 29	17.19	Aug. 29	16.01		

19-61-4cdd1

Apr. 16, 1943	6.37	July 27, 1949	8.47	Feb. 27, 1950	8.94	Sept.26, 1950	7.64
Nov. 5, 1948	7.39	Sept.29	6.41	Mar. 29	8.90	Oct. 31	6.60
29	7.47	Oct. 31	5.55	May 2	7.53	Nov. 29	6.20
Apr. 1, 1949	7.40	Nov. 29	6.17	30	5.87	Jan. 17, 1951	7.26
May 3	5.99	Dec. 29	7.00	July 21	7.43	Feb. 20	8.17
June 4	4.07	Feb. 1, 1950	7.99	Aug. 29	7.71	Mar. 23	9.03

19-62-2add

May 3, 1943	58.58	Aug. 30, 1949	57.77	Feb. 27, 1950	57.62	Sept.26, 1950	57.53
Apr. 1, 1949	57.42	Sept.29	57.76	Mar. 29	57.68	Oct. 31	57.63
May 3	57.53	Oct. 31	57.66	May 30	57.47	Nov. 29	57.62
June 4	57.46	Nov. 29	57.71	June 21	57.58	Jan. 17, 1951	58.22
July 6	57.53	Dec. 29	57.68	July 21	57.64	Feb. 20	57.59
27	57.67	Feb. 1, 1950	57.65	Aug. 29	57.68	Mar. 23	57.60

19-62-26dba

Nov. 21, 1948	27.34	Sept.29, 1949	24.95	May 30, 1950	26.28	Nov. 29, 1950	27.66
Apr. 1, 1949	22.54	Oct. 29	25.72	June 21	26.50	Jan. 3, 1951	27.52
May 3	23.14	Feb. 1, 1950	26.26	July 21	26.90	Feb. 20	27.68
June 4	23.46	27	26.38	Aug. 29	27.05	Mar. 23	27.73
July 26	23.86	Mar. 29	26.67	Sept.26	27.72		
Aug. 30	24.65	May 2	26.63	Nov. 3	27.59		

20-61-27ddc

June 6, 1943	28.72	Aug. 30, 1949	29.15	Mar. 29, 1950	29.68	Sept.26, 1950	30.18
July 27	28.57	Sept.29	29.23	May 2	29.55	Oct. 31	30.30
Apr. 1, 1949	31.36	Oct. 31	30.00	30	28.58	Nov. 29	30.15
May 3	31.00	Nov. 29	29.18	June 21	29.55	Jan. 17, 1951	30.11
June 4	30.53	Dec. 29	28.82	July 21	29.65	Feb. 20	30.45
July 6	29.86	Feb. 1, 1950	29.53	Aug. 29	30.00	Mar. 23	30.34
27	29.55	27	29.28				

1949. From the available data it seems that there has been no significant change in the water levels in the area since 1943; the measurements, however, indicate a seasonal rise and decline.

When the recharge is equal to the discharge, the water table is more or less stable within seasonal limits. If extensive development of ground water for irrigation is undertaken in the future, considerable change in the water levels can be anticipated. Water levels will decline in the vicinity of the pumped wells during the irrigation season, but they can be expected to recover during the nonirrigation season when replenishment of the ground-water reservoir exceeds the natural discharge. The withdrawal of water from the alluvium will cause a decrease in the flow of the streams, and during periods of heavy withdrawal the streams may cease flowing in places.

GROUND WATER FOR IRRIGATION

Present Development

Information was obtained on eight irrigation wells in the area. Six of these wells obtain water from the alluvium, and two obtain water from both the alluvium and the Brule formation.

The yields of irrigation wells in the area range from 450 to 900 gpm. Wells 19-61-4cdd1 and 19-61-4cdd2 are connected by a syphon and have a combined yield of 1,200 gpm.

Potential Development

The amount of water that can be withdrawn from a ground-water reservoir without causing excessive permanent lowering of the water table depends upon the capacity of, and the recharge to, the reservoir. When water is pumped continuously from a ground-water reservoir faster than it is being replenished, the water levels in wells decline and the supply eventually may be depleted. Water can be pumped from a ground-water reservoir in excess of the rate of recharge for short periods of time without depleting the reservoir if there is sufficient recharge during the nonpumping period to replace the water removed.

In parts of the Horse Creek-Bear Creek area ground water in sufficient quantities for irrigation could be obtained from properly constructed wells in the alluvium. The best possibilities for developing successful irrigation wells are in the alluvium near the town of Lagrange. Wells that would yield 500 to 1,000 gpm probably could be developed in some places if selection of the sites were preceded by adequate test drilling to determine the maximum thickness of the saturated alluvium. In some places where sufficient water cannot be obtained from the alluvium alone, additional water may be obtained by drilling into the underlying Brule formation. Irrigation wells also could be developed in the alluvium in places along the valleys of Horse and Bear Creeks to supply water for some of the small plots of irrigable land along these valleys. Pumping tests should be made to determine the yield and the proper spacing of wells and to assist in determining the safe yield of the aquifer. If additional ground water is developed for irrigation, records should be kept of the amount of water pumped, and water-level measurements should be continued to warn against the possibility of overdevelopment.

CHEMICAL QUALITY OF THE GROUND WATER

By Walton H. Durum

INTRODUCTION

In this section, a description is given of the present quality of water from wells and springs in the Horse Creek-Bear Creek area, particularly as related to the suitability for domestic and irrigation use. This information is based on the results of analyses of 11 water samples (see fig. 8) that were collected in September and October 1949 by J. R. Rapp. In addition to being essential to the evaluation of the water for various uses, the analytical data are helpful in the determination of the geologic source of the water supply and otherwise contribute to the overall hydrologic inventory of the ground-water resources in the area. Geochemical as well as base-flow relationships are discussed briefly.

CHEMICAL CHARACTER OF THE GROUND WATER

General Conditions

The results of analyses, in parts per million, of waters sampled in the Horse Creek-Bear Creek area are given in table 2, in which the data for ground water are arranged in order by well number and under geologic source. Analytical results of four surface-water samples from Horse Creek and Bear Creek are shown also. None of the waters is highly mineralized, but all contain moderate amounts of dissolved solids. The range in dissolved solids is from 206 to 584 ppm. The principal constituents are calcium, sodium, and bicarbonate. Silica is generally present in quantities about equal to the concentration of the major basic constituent. The range in mineral substances in the samples of both ground and surface water is as follows: calcium, from 22 to 80 ppm; sodium, from 7.5 to 149 ppm; bicarbonate, from 177 to 556 ppm; and sulfate, from 0.1 to 75 ppm. The silica content ranges from 28 to 64 ppm. The quantities of chloride, fluoride, nitrate, boron, and iron are low. The hardness of the water ranges from 82 to 257 ppm.

Although the water samples are similar in the content of dissolved solids, the composition of the mineral substances differs markedly. The chemical character of the several waters is shown in figure 9, where equivalents per million (from table 3) are plotted graphically. Calcium, magnesium, and sodium plus potassium (the basic radicals) are plotted in ascending order in the left column, and bicarbonate, sulfate, and chloride-fluoride-nitrate (the acid radicals) are plotted in like order in the right column; the height of the column represents the total equivalents per million of the group. Also in figure 9 is a trilinear graph in which the vertices equal 100 percent of the major basic radical--either calcium magnesium or sodium plus potassium. The percentages of the individual constituents, calculated from table 3, are plotted for each of the waters and designated as to geologic source. The distinct gradation from the calcium-type water in the alluvium and Arikaree sandstone to the sodium-predominant water in the Brule formation is depicted in the trilinear graph in figure 9.

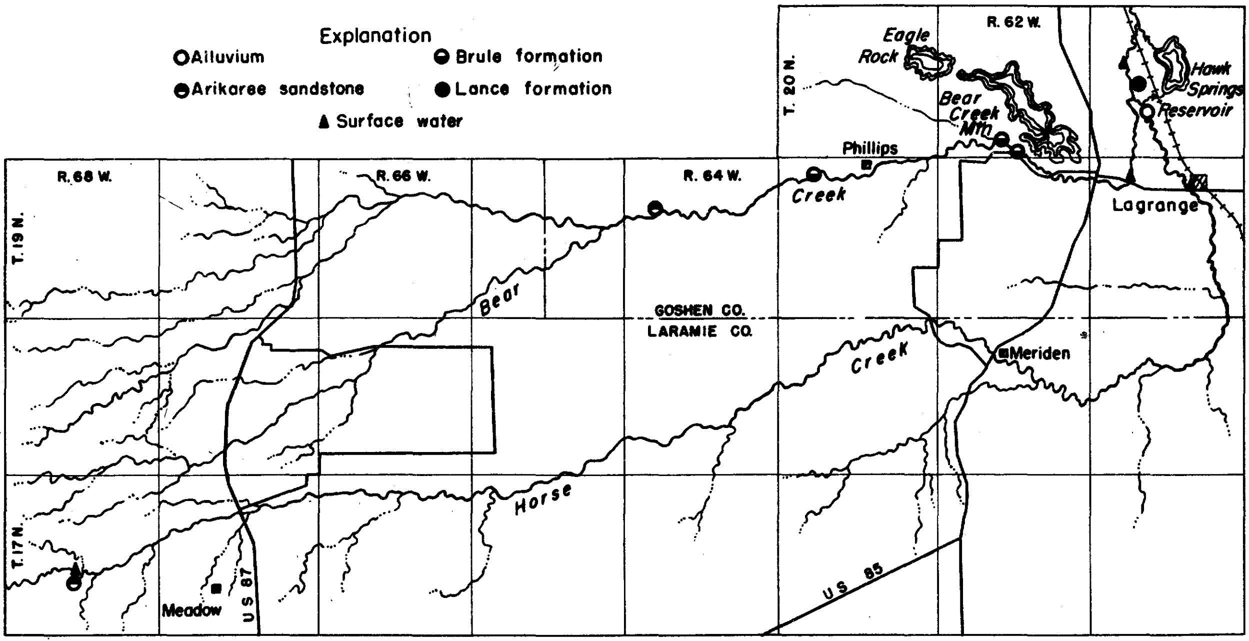

Figure 8.--Map showing sampling points in the Horse Creek-Bear Creek area, Wyoming.

Lance Formation

The character of the sample from a spring that is believed to originate in the Lance formation is not unlike that of the samples of water from the overlying Brule formation. As is true of the other samples that were

Table 2.--Chemical analyses, in parts per million, and related physical measurements of water in the Horse Creek-Bear Creek area, Wyoming

Well, spring, or surface location	Date of collection	Depth of well (feet)	Temperature (°F)	pH	Specific conductance (micromhos at 25 C)	Silica (SiO_2)	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	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Percent sodium
Lance formation																					
20-61-17dda....................	10-24-49	Spring	56	7.7	608	53	0.02	50	11	60	18	332	39	10	0.4	2.3	0.20	416	171	0	40
Brule formation																					
19-63-5cdd.....................	9-30-49	Spring	59	7.2	333	58	0.02	42	7.5	17	9.6	195	12	4.0	...	6.8	0.30	250	136	0	20
20-62-33acb....................	10-18-49	33	52	7.8	813	64	.02	51	18	122	9.6	556	20	4.2	0.6	5.6	.20	584	202	0	55
20-62-34cbc....................	9-30-49	Spring	50	8.1	760	62	.02	22	6.5	149	10	475	23	9.4	...	5.2	.30	560	82	0	77
Arikaree sandstone																					
17-68-21dcc....................	9-25-49	155	52	7.4	300	30	0.02	45	5.3	9.4	5.6	177	6.0	2.0	0.6	6.2	0.20	206	135	0	13
19-64-8cdd.....................	10-25-49	Spring	52	7.6	362	54	.02	57	8.7	7.5	5.6	223	.1	2.0	.6	1.7	.20	286	178	0	8
Alluvium																					
20-61-28bba....................	9-28-49	35	55	7.7	533	51	0.02	75	12	23	6.4	320	29	9.2	0.2	2.8	0.10	390	237	0	17
Surface water																					
Horse Creek west of Meadow.....	9-25-49	......	..	7.8	559	28	0.02	80	14	23	8.0	283	75	4.8	0.4	1.5	0.10	392	257	25	16
Horse Creek at Lagrange........	9-28-49	......	..	7.3	438	40	.02	22	18	38	21	236	33	7.0	...	1.5	.20	298	129	0	35
Horse Creek north of Lagrange..	9-28-49	......	52	7.8	619	46	.02	60	14	57	7.2	365	30	10	.6	2.2	.20	436	207	0	36
Bear Creek 2.5 miles west of Lagrange......................	9-28-49	......	..	7.8	481	45	.02	46	11	43	5.6	302	9.0	7.4	.4	1.2	.30	344	161	0	36

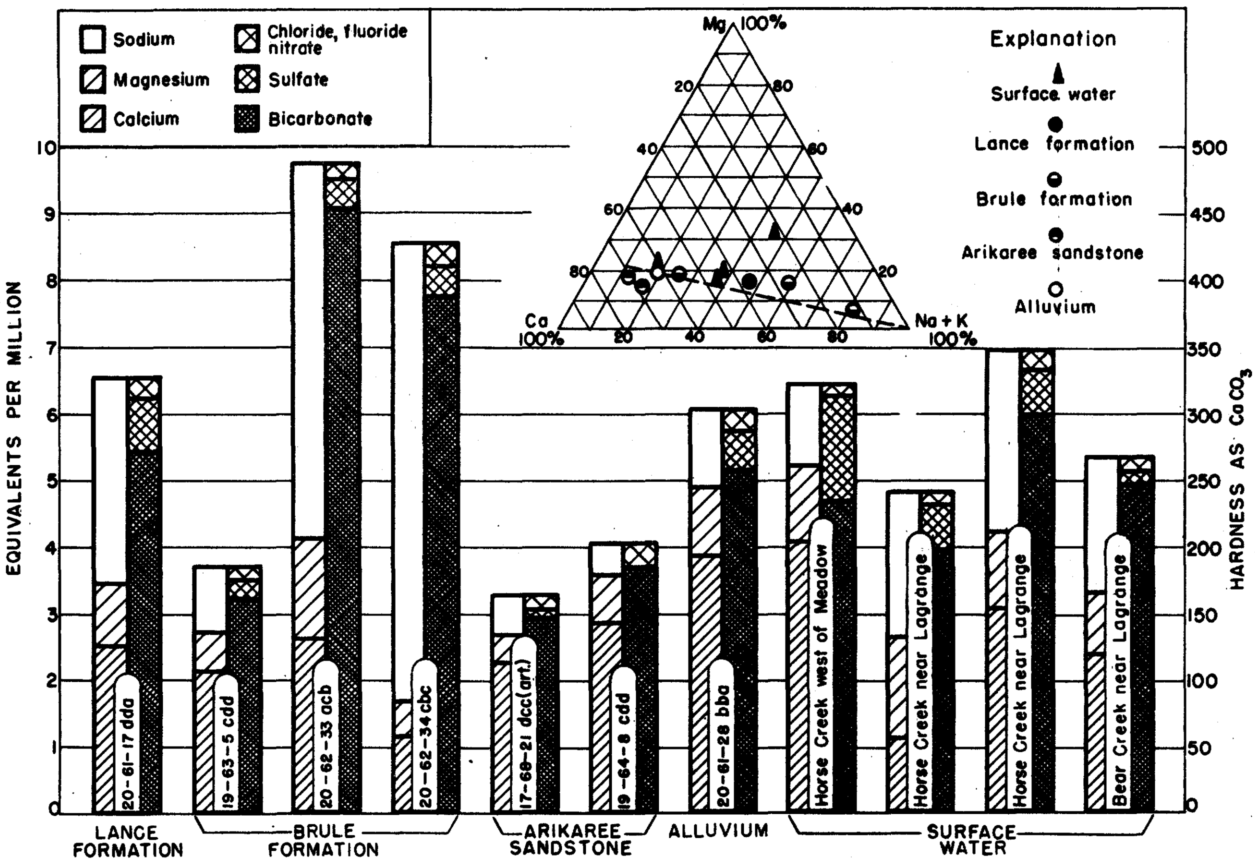

Figure 9.--Mineral constituents and reacting values of basic radicals in waters, Horse Creek-Bear Creek area, Wyoming.

Table 3.--Chemical analyses, in equivalents per million, of water in the Horse Creek-Bear Creek area, Wyoming

Well, spring, or surface location	Na + K	Ca	Mg	SO_4	Cl,F,NO_3	HCO_3
Lance formation						
20-61-17dda	3.09	2.52	0.92	0.80	0.34	5.39
Brule formation						
19-63-5cdd	0.99	2.08	0.62	0.25	0.22	3.22
20-62-33acb	5.61	2.57	1.50	.41	.24	9.03
20-62-34cbc	6.84	1.12	.54	.46	.35	7.69
Arikaree sandstone						
17-68-21dcc	0.55	2.24	0.44	0.13	0.19	2.91
19-64-8cdd	.47	2.83	.72	.00	.36	3.66
Alluvium						
20-61-28bba	1.18	3.83	1.01	0.59	0.32	5.11
Surface water						
Horse Creek west of Meadow	1.21	4.01	1.15	1.56	0.18	4.63
Horse Creek at Lagrange	2.20	1.10	1.48	.69	.22	3.87
Horse Creek north of Lagrange	2.70	3.03	1.15	.62	.35	5.91
Bear Creek 2.5 miles west of Lagrange	2.04	2.34	.92	.19	.25	4.86

collected in the area, this water is of the bicarbonate type and has about equal quantities of the earths (calcium plus magnesium) and the alkalies (sodium plus potassium). The dissolved solids and hardness are 416 and 171 ppm, respectively. The percentage of sodium is 40, which is somewhat lower than that of the typical high-sodium water in the Brule formation.

Brule Formation

Water from the Brule formation, as represented by the analyses of water from well 20-62-33acb and from spring 20-62-34cbc, is of the sodium bicarbonate type and has a higher content of dissolved solids (584 and 560 ppm, respectively) than other samples of water collected in the area. The ratio of sodium to calcium and magnesium in the two samples is high; the percentage of sodium is 55 and 77 percent, respectively. The spring water has a moderate hardness of 82 ppm as compared with a hardness of 202 ppm in the water from well 20-62-33acb. A third sample of water from the Brule formation, from spring 19-63-5cdd, is of the calcium bicarbonate type and has less than half the mineral content of the other two waters. The dissolved solids content is 250 ppm, the percentage of sodium is 20, and the water is moderately hard (136 ppm). Although this water issues from the Brule formation, it is similar chemically to water from the Arikaree sandstone. This similarity indicates that the water percolates from the Arikaree into the Brule within a relatively short distance from the point of issue. The silica content in the samples from the Brule formation is uniformly high, the sulfate and chloride are low, and the quantities of the minor constituents--fluoride, nitrate, and boron--also are low.

Other investigators (Wenzel, Cady, and Waite, 1946, p. 127) found both calcium bicarbonate and sodium bicarbonate waters in the Brule formation in Scotts Bluff County, Nebr. Thus the type of water obtained from the Brule formation appears to be related to several factors, most important of which is the type of minerals encountered by the water as it percolates from the recharge area. Deep water-bearing zones in the Brule formation are more likely to yield soft sodium bicarbonate waters that have been altered by contact with minerals that are capable of entering into base exchange reaction. Such base exchange reaction is that in which the calcium in the water is replaced by sodium, wholly or in part. Included in this group are such minerals as silicates, kaolinites, and micas. Water that issues from the upper part of the Brule formation, such as that from spring 19-63-5cdd, is likely to be the calcium bicarbonate type, characteristic of the water found in the zones that lie above the Brule formation.

Arikaree Sandstone

Samples of the water in the Arikaree sandstone, from flowing well 17-68-21dcc and from spring 19-64-8cdd, are similar both in mineral content and in chemical character. These samples contain 206 and 286 ppm of dissolved solids, respectively, and are of the calcium bicarbonate type. The hardness of these samples is 135 and 178 ppm, whereas the same samples have a very low percentage of sodium. The amounts of sulfate and chloride are lower, and the quantities of fluoride, nitrate, and boron are about the same as in the samples from the underlying formations.

Alluvium

The chemical character of the single sample from the alluvium (well 20-61-28bba) does not differ appreciably from that of the samples that were obtained from the Arikaree sandstone. The water is hard, moderately low in dissolved solids (390 ppm), and is calcium bicarbonate in type. As this sample showed a somewhat higher sulfate content than that shown by the water in the Arikaree, it is thought that the sulfate content of shallow ground water is derived from local deposits of detritus of the Brule formation or from influent water from Horse Creek, which normally carries appreciable quantities of sulfate. As is true of water samples from other stratigraphic units, the quantities of chloride, fluoride, nitrate, and boron are low.

RELATION TO SURFACE WATER

Samples were obtained of base flow at three points along Horse Creek between Horse Creek and Lagrange, Wyo. (See fig. 8.) The mineral content of the water in successive reaches of the stream changes only slightly. The dissolved solids increase from 392 ppm near the town of Meadow to 436 ppm north of Lagrange. The amount of calcium at the three sampling points was 80, 22, and 60 ppm, respectively, and the sodium was 23, 38, and 57 ppm, respectively.

The source of sulfate in Horse Creek (75, 33, and 30 ppm) is presumed to be the Pierre shale, which crops out at the headwaters of the stream (T. 17 N., R. 70 W.). Increases in the percentage of sodium, as shown in the results of analyses at the two downstream sampling points, would be expected as a result of inflow of water from the Brule formation as well as from return flow waters from irrigated tracts.

The lower concentration of sulfate in the water below the confluence of Horse and Bear Creeks probably is related to the effluent waters of Bear Creek, which have a lower sulfate content than the Horse Creek waters but are otherwise similar in composition and dissolved solids content.

Future increase in irrigation activity upstream will result in return flow to Horse and Bear Creeks downstream that will tend to modify the chemical character of the water as well as to increase the content of dissolved solids. North of Lagrange, Horse Creek is an influent stream, and, for this reason, the chemical quality of the water in the alluvium probably is altered accordingly.

RELATION TO USE

Generally, water is satisfactory for most domestic purposes if the dissolved solids do not exceed 500 ppm and the iron content is less than a few tenths of a part per million. Standards that are recommended by the U. S. Public Health Service for public supplies include the following suggested limits of chemical substances in natural or treated waters:

Constituent	Maximum parts per million
Iron and manganese together........	0.3
Magnesium.........	125
Sulfate...........	250
Fluoride..........	1.5
Chloride..........	250
Dissolved solids..	500 (1,000 permitted)

None of the waters that were analyzed in connection with this study has mineral constituents in excess of the recommended limits given above. The hardness in some of these waters, however, is somewhat higher than is desirable.

Four of the seven ground-water samples were collected from sources that are used for domestic purposes. The remaining three are springs that are used for stock watering only.

Future development of ground-water supplies in the Horse Creek-Bear Creek area for irrigation use is partly contingent upon the chemical quality of the water. Among the various methods of rating water for irrigation use is the classification suggested by Wilcox (1948, p. 27), in which the water is evaluated with respect to the percentage of sodium and to electrical conductivity (a measurement of the total ions in solution).

The quality classification of the individual waters is shown in figure 10 where percent sodium is plotted against specific conductance. All the waters that were analyzed rate "excellent to good," with the exception of two of the samples from the Brule formation. These waters are excessively high in the percentage of sodium and carry lower-quality ratings for irrigation use. These observations are an indication that sodium bicarbonate waters from the Brule formation, if used at all, should be applied only to those lands having excellent drainage conditions. As with any method for interpretation of analyses of waters for irrigation, the Wilcox diagrammatic classification largely is empirical and is derived principally from actual field tests. It applies only where normal or average conditions exist relative to soil, crops, permeability, drainage, quantity of water used,

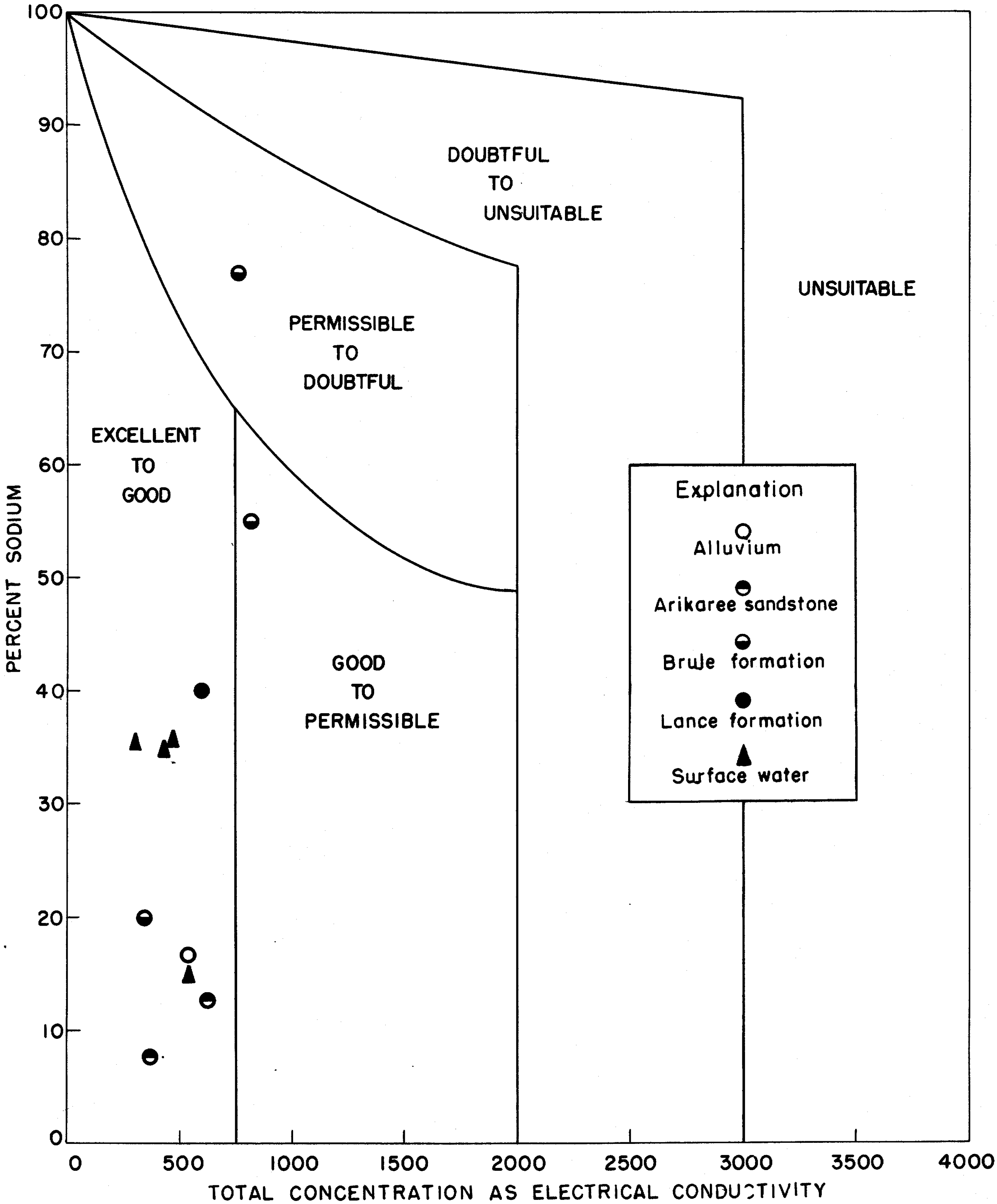

Figure 10.--Classification of waters in the Horse Creek-Bear Creek area for irrigation use (after Wilcox).

and climate. For example, water from the Colorado River at Yuma, Ariz., was classified as good to permissible from the results of a analyses of 12 daily samples and one 10-day composite sample that were collected in 1932. This water is used satisfactorily on thousands of acres of diversified crops, but where drainage is impaired, salinity conditions developed quickly. (Wilcox 1948, pp. 23-28.)

CONCLUSIONS

Unconfined ground water is contained in the alluvium of the stream valleys in sufficient quantities for irrigation. Wells that yield 500 to 1,000 gpm probably could be developed. The best locality for developing irrigation wells in the alluvium is in the northeastern part of the area near the town of Lagrange, where the extent and thickness of the alluvium is greatest.

The results of analyses of 11 ground- and surface-water samples in the Horse Creek and Bear Creek area disclose waters of moderately low mineral content, with the dissolved solids ranging from 206 to 584 ppm and hardness ranging from 82 to 257 ppm. On the basis of the existing data, it can be said that waters from the alluvium and the Arikaree sandstone are similar to each other in chemical character and are slightly lower in mineral content than water from the older water-bearing formations. The water from the alluvium and the Arikaree sandstone is also lower in percentage of sodium, and the dissolved solids consist principally of calcium bicarbonate. Water from the Brule formation is essentially sodium bicarbonate in type, having higher concentrations of dissolved solids and percentages of sodium than are generally found in water from overlying stratigraphic units.

The sampled ground water contains only small quantities of the minor constituents--iron, fluoride, nitrate, and boron--and is satisfactory for all domestic uses. Water from the Arikaree sandstone and the alluvium, by reason of low percentage of sodium and moderately low mineral content, rates "excellent to good" as a source of irrigation supplies. Two of the samples from the Brule formation have a higher percentage of sodium and are given lower water classifications. The suitability of the water in the Brule formation and in water-bearing zones in the Lance formation can be determined only by further study.

This reconnaissance investigation was not designed to give the detailed data required for the determination of the proper location and construction of wells; hence, a more detailed investigation of the water-bearing properties of the alluvium should be made prior to the construction of irrigation wells. The selection of sites for irrigation wells should be preceded by adequate test drilling to determine the maximum thickness of the saturated alluvium. Pumping tests should also be made to determine the yield and the proper spacing of the wells as well as to assist in determining the safe yield of the aquifer. The pumping-test data should be supplemented by laboratory tests of the hydrologic properties of the alluvium. If additional development of ground water for irrigation is undertaken, a considerable change in water levels can be expected. Periodic measurement of water levels in observation wells should therefore be continued so that the changes in ground-water levels can be observed, and the possibility of overdevelopment can be foreseen. Records of ground-water pumpage should also be maintained.

Samples of water for chemical analysis should be collected periodically in order to determine whether the re-use of the ground water is effecting undesirable changes in the mineral content of the soil and ground water.

LOGS OF WELLS

Logs of wells obtained from well drillers and well owners are presented in table 4. It was not possible to verify the logs by examination of the drill cuttings; consequently, the logs are presented with the drillers' terminology largely unchanged. It is believed that the logs are reasonably accurate and that they give a fairly good description of the materials that were penetrated.

Table 4.—Drillers' logs of wells in the Horse Creek-Bear Creek area

17-67-4dca

	Thickness (feet)	Depth (feet)
Unlogged strata..........	4,020	4,020
Fox Hills sandstone......	1,360	5,380
Mesaverde formation......	465	5,845
Steele shale.............	2,855	8,700
Niobrara limestone.......	1,002	9,702
Muddy sand...............	138	9,840
Dakota sandstone.........	100	9,940
Lakota sandstone.........	40	9,980

17-68-21dcc

Gravel and boulders......	15	15
Rock.....................	30	45
Rock and clay............	60	105
Clay.....................	35	140
Gravel...................	15	155

17-70-25baa

Soil.....................	8	8
Gravel...................	2	10
Sand, black..............	1	11

18-62-17ccd

Soil.....................	3	3
Hardpan (Brule formation)	54	57

19-61-2ccb

Gravel...................	19	19
Clay (Brule formation)...	31	50

19-61-4cdd2

Sand and gravel..........	33	33
Hardpan (Brule formation)	32	65

19-61-4cdd4

	Thickness (feet)	Depth (feet)
Gravel...................	33	33
Clay (Brule formation)...	6	39

19-61-11abc

Soil and gravel..........	21	21
Clay (Brule formation)...	130	151

20-61-22dcb

Sand and gravel..........	45	45
Clay (Brule formation)...	9	54

20-61-26cbb

Soil.....................	10	10
Sand and gravel..........	32	42
Clay (Brule formation)...	168	210

RECORDS OF WELLS AND SPRINGS

Records of 92 wells and springs in the Horse Creek-Bear Creek area, which were obtained during the investigation, are given in table 5. The location of these wells is shown on plate 1. All information classed as reported was obtained from the owner or driller.

Table 5.--Records of wells and springs in the Horse Creek-Bear Creek area, Wyoming

Well no.: See text for description of well-numbering system.
Type of supply: Dr, drilled well; Du, dug well; Sp, spring.
Depth of well: Measured depths are given in feet and tenths below land-surface datum; reported depths are given in feet.
Type of casing: C, concrete, brick, or tile pipe; P, iron or steel pipe; S, stone.
Principal water-bearing material
Character of material: G, gravel; S, sand; Sl, siltstone; Ss, sandstone.
Geologic source: Kfh, Fox Hills sandstone; Kl, Lance formation; Kp, Pierre shale; Qa, Quaternary alluvium; Ta, Arikaree sandstone; Tb, Brule formation; Tc, Chadron formation.
Method of lift: C, cylinder; Cf, centrifugal; F, natural flow; J, jet; N, none; T, turbine.
Type of power: E, electric motor; G, gasoline engine; H, hand-operated; N, none; W, windmill.
Use of water: D, domestic; I, irrigation; In, industrial; N, none; O, observation; S, stock.
Measuring point: Bpb, bottom of pump base; Hph, hole in pump housing; Ls, land surface; Tbc, top of board cover; Tc, top of casing; Tcu, top of curb; Tpb, top of pump base; Tpc, top of pipe clamp.
Depth to water: Measured depths are given in feet, tenths, and hundredths; reported depths are given in feet.
Remarks: Ca, sample collected for chemical analysis; D, discharge in gallons a minute; E, estimated; M, measured; R, reported; DD, drawdown in feet while discharging at the preceding rate; L, log of well given in table 4; T, temperature in degrees Fahrenheit.

Well no.	Property owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power	Use of water	Measuring point: Description	Measuring point: Distance above (+) or below (-) land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
17-64-9daa	Unknown..............	Sp	....	..	..	Sl	Tb	F	S	...	...	......	....	T54, D100E
17-67-1abb	Mr. Lewis............	Dr	120	6	P	Ss	Ta	C,W	D	...	...	......	....	
-4dca	Birdwell-Seaboard Co.	Dr	9,980	13	P	....	.....	N	N	...	...	......	....	L
-10abb	H. P. Lewis..........	Du	12.5	60	S	S,G	Qa	C,H	D	Tbc	+0.5	10.30	8- 8-49	
17-68-12dcd	Nimmo Livestock Co...	Dr	117	6	P	Ss	Ta	C,W	D	Ls	...	60	1949	
-21acb	D. Whitaker..........	Dr	30	6	P	S,G	Qa	C,W	D	Ls	...	10	8- 4-49	
-21dcc	.....do..............	Dr	155	4	P	G	Ta	F	D	...	...	......	8- 4-49	T52, D10E, Ca, L
-31ddb	General Petroleum Co.	Dr	616	..	P	Ss	Ta	C,G	D	...	...	......	....	
17-69-27aaa	Mrs. Caldwell.........	Du	30	48	..	S,G	Qa	C,E	D	Ls	...	10	8- 3-49	
-28cbb	W. S. Dereemer.......	Dr	116	6	P	Ss	Tc	C,W	S	Ls	...	76	8- 3-49	
-29bcb	C. F. Smith..........	Du	20	..	C	S,G	Qa	C,W	S	Tpb	+.2	14.15	8- 3-49	
17-70-25aab	Mr. Tugman...........	Dr	60	5	P	Ss	Kfh?	C,W	S	Ls	...	52	8- 9-49	
-25baa	.....do..............	Du	11	48	C	G	Qa	C,E	D	Ls	...	5	8-19-49	L

-25caa	Anthony Schepp.......	Dr	62	6	P	Ss	Kp	C,H	D	Tbc	+.4	17.98	8- 3-49	
-35bad	C. C. Davis..........	Du	17	..	S	S,G	Qa	C,W	D	Ls	...	9	8- 3-49	
18-61-1baa	J. Johnson...........	Sp	....	..	..	Sl	Tb	F	D	...	...	......	....	T53, D20E
-9cac	N. Brown.............	Dr	120	6	P	Sl	Tb	C,W	D	...	...	......	....	
-15dba	.....do..............	Dr	60	6	P	Sl	Tb	C,W	S	Bpb	+1.7	13.80	8- 2-49	T54
-16bab	.....do..............	Sp	....	..	..	Sl	Tb	F	S	...	...	......	....	T53, D10E
-19ddc	Unknown..............	Dr	....	6	..	Sl	Tb	C,W,H	S	Tc	+.5	9.28	8- 2-49	
-20bcd	.....do..............	Dr	....	6	..	Sl	Tb	N	N	Tc	+1.7	10.10	8- 2-49	
18-62-6dca	J. W. Brown..........	Du	25	60	..	Sl	Tb	C,W	D	Ls	...	22	7-28-49	
-9bdc	Meriden store........	Dr	80	6	P	Sl	Tb	C,E	D	...	...	40	7-28-49	
-9dac	D. Donahue...........	Dr	80	6	P	Sl	Tb	C,W	D,S	...	...	......	....	T53
-10bdc1	F. Petch.............	Dr	80	6	P	Sl	Tb	C,E	D	...	...	......	....	T57
-10bdc2	.....do..............	Dr	100	6	P	Sl	Tb	N	N	Tc	+1.3	22.54	7-28-49	
-10dcc	.....do..............	Dr	75	6	P	Sl	Tb	C,W	D	...	...	......	....	
-11aac	.....do..............	Dr	75	6	P	Sl	Tb	C,H	D,S	Ls	...	21	8- 4-49	T54
-15bdd	.....do..............	Dr	100	6	P	Sl	Tb	C,W	D	...	...	......	....	
-17ccd	A. Ziegler...........	Dr	57	4	P	Sl	Tb	C,W	D	Ls	...	41	7-28-49	L
-24ada	Bill Scoon...........	Dr	....	..	..	Sl	Tb	C,W	D	Tc	.0	21.50	8- 2-49	
-24bdd	T. Hunters...........	Dr	22	6	P	Sl	Tb	C,W	D,S	Ls	...	16	7-28-49	
18-63-1abd	J. Brown.............	Dr	....	6	..	Sl	Tb	C,W	D	Tpc	-3.0	76.50	7-28-49	
-25cac	C. C. Donahue........	Sp	....	..	..	Sl	Tb	F	D,S	...	...	......	....	T53, D100E
18-65-35bda	A. Kirkbride.........	Dr	50	6	P	Sl	Tb	C,W	S	Ls	...	25	1-16-50	
18-66-4daa	I. B. Trotter........	Du	40	48	S	G	Qa	C,H	D	Ls	...	20	8-12-49	
-11baa	Mrs. Nellie Pence....	Dr	40	..	..	Sl	Tb	C,W	D,S	Ls	...	20	8-12-49	T52.5
-30cdd	Mary A. Kirkbride....	Dr	130	..	..	Ss	Ta	C,W,G	D,S	Ls	...	100	8- 8-49	
18-67-5caa	Richard DuVall.......	Dr	80	6	P	Ss	Ta	C,W	D,S	Tcu	+.6	60.18	8-29-49	
-28cac	E. Nimmo.............	Du	49.8	72	S	G	Qa	C,H	D,O	Tbc	+.6	9.50	9- 1-49	
18-68-1dba	Richard DuVall.......	Dr	102	6	P	Ss	Ta	C,W	S	Ls	...	77	8-29-49	
19-61-2cbd	U. P. R. R. Co.......	Dr	115	18	C	Sl	Tb?	T,E	In	Ls	...	30	1948	D125R
-2ccb	D. Rodeman...........	Dr	50	6	P	G,Sl	Qa,Tb	C,W	S	Ls	...	13	1949	L
-2ccd	City of Lagrange.....	Dr	30.8	5	P	S,G	Qa	N	O	Tc	+.9	16.92	8-30-49	
-3bba	Frank L. Graves......	Dr	64	6	P	S,G	Qa	C,H,E	D,S	Hph	+2.4	40.01	10-25-49	
-4cdd1	Hugh Stemler.........	Du,Dr	33	48	P	S,G	Qa	C,H	D,I,O	Tcu	+.7	7.11	9-29-49	D1,200M, L
-4cdd2	.....do..............	Du,Dr	65	48	C	S,G	Qa	T,G	I	Tcu	.0	7	9-29-49	
-4cdd3	.....do..............	Dr	55	18	P	S,G	Qa	T,E	I	Tpb	+.6	5.78	5- 3-49	D900R
-4cdd4	.....do..............	Dr	39	18	P	S,G	Qa	T,E	I	Ls	...	6	1949	D600R, L
-6bcd	Virgil M. Jones......	Dr	160	..	P	Sl	Tb	C,G	D	Ls	...	30	10-18-49	D10R
-9dba	E. Johnson...........	Dr	57.5	..	..	Sl	Tb	C,W	S	Tpc	+.3	20.44	6-16-43	
-10acd	.....do..............	Dr	70.5	5	P	Sl,G	Tb,Qa	C,W	S	Tc	+.7	11.97	6-16-43	
-11abc	G. Wendt.............	Dr	151	20	P	Sl,G	Tb,Qa	T,G	I	Bpb	+.3	19.26	6-21-43	D850E, DD34, L

Table 5.--Records of wells and springs in the Horse Creek-Bear Creek area, Wyoming--Continued

Well no.	Property owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power	Use of water	Measuring point: Description	Measuring point: Distance above (+) or below (-) land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
19-62-2add	E. Krohn............	Dr	92	..	..	Sl	Tb	C,N	O	Bpb	+1.4	59.17	8-30-49	
-2bcc	Eldon L. Preston.....	Dr	60	6	P	Sl	Tb	J,E	D	Ls	...	......	....	T55
-19aaa	Andrew Oleson........	Dr	159	4	P	Ss	Ta	C,N	D,S	Tc	+.3	60.69	5- 4-43	
-26dba	J. E. Jones..........	Dr	42	5	P	Sl	Tb	C,W	S,O	Tc	+.2	27.54	11-21-48	
19-63-3abc	R. W. Yates..........	Dr	160	6	P	Sl	Tb	C,W,H	D	Ls	...	80	10-18-49	
-3acb	.....do...............	Du	....	48	S	S,G	Qa	C,H	N	Tcu	+.3	11.30	10-18-49	T52
-5cdd	C. F. Swarm..........	Sp	....	..	..	Sl	Tb	F	S	...	...	......	....	T59, D10E, Ca
-6add	E. K. Parsons........	Dr	176	5	P	Sl	Tb?	N	N	Tc	+.9	147.54	5- 7-48	
-8baa	C. F. Swarm..........	Dr	100	5	P	Sl	Tb?	C,W	D,S	Ls	...	60	9-30-49	T59
-33bda	D. Kirkbride.........	Dr	127	4	P	Sl	Tb?	N	N	Tc	+.3	93.67	5- 4-43	
19-64-1bda	Wm. and J. W. Brown..	Dr	98.5	5	P	Sl	Tb?	C,N	N	Tc	+.3	68.44	5- 7-43	
-8cdd	Daniel Jensen........	Sp	....	..	..	Ss	Ta	F	D,S	...	...	......	....	T52, D15E, Ca
-12adc	State of Wyoming.....	Dr	17	5	P	S,G	Qa	C,N	N	Tc	+.7	8.44	5- 4-43	
-18bab	C. D. Griffin........	Dr	....	6	P	Ss	Ta	C,H	D	Hph	+1.7	8.33	10-25-49	
19-65-17acd	I. P. Trotter........	Sp	....	..	..	Ss	Ta	F	D.S	...	...	......	....	D20E
19-67-11aad	H. F. Gard...........	Dr	162	4	P	Sl	Tb	C,W	D,S	Ls	...	115	8-10-49	
-12bbc	H. W. Gard...........	Dr	154	6	P	Sl	Tb	C,W	S	Ls	...	110	8-10-49	T53
-16add	Frank Bliss..........	Dr	140	8	P	Sl	Tb	C,W	S	Ls	...	90	8-10-49	
-21bdd	.....do...............	Dr	190	6	P	Sl	Tb	C,W	S	Ls	...	130	8-10-49	
-22abb	.....do...............	Dr	190	5	P	Sl	Tb	C,W	D,S	Ls	...	120	8-10-49	
-25bcd	R. E. Swinbank.......	Du	16	36	C	S,G	Qa	C,E	D,S	Ls	...	8	9- 1-49	
19-68-21ddd	Roscoe Welly.........	Dr	98	5	P	Ss	Ta	C,W	D,S	Ls	...	85	1914	
-22add	Clyde E. Caster......	Dr	130	6	P	Ss	Ta	C,W	D,S	Ls	...	100	8-10-49	T50.5
-28aad	Ray Derby............	Dr	72	6	P	Ss	Ta	C,W	D,S	Ls	...	45	8-10-49	T50
20-61-1bbb	R. B. Boynton........	Dr	132.5	..	..	....	.....	C,N	N	Bpb	+.4	45.62	4- 6-43	
-14ccb	Daniel Phinney.......	Dr	....	5	P	S,G	Qa	C,W	S	Tc	.0	8.11	11-29-48	
-17dda	A. F. Chaha..........	Sp	....	..	..	Ss	Kl	F	S	...	...	......	....	T56, D10E, Ca
-22dcb	Curtis Templin.......	Dr	54	18	P	S,G	Qa	T,G	I	Tc	+.2	15.62	6-21-43	D450R, L
-23dcb	F. Sanders...........	Dr	50	6	P	S,G	Qa	C,W	S	Ls	...	50	1949	
-26cbb	Eugene Hanson........	Dr	210	20	P	G,Sl	Qa,Tb	T,G	I	Bpb	+.4	24.77	9-25-49	D870R, L

-27ddc	Curtis Templin.......	Dr	86	6	P	G,Sl	Qa,Tb	C,N	O	Tc	+.9	30.05	8-30-49	
-28bba	John Meyers..........	Dr	35	10	P	G	Qa	Cf,E	D	Tc	.0	9.07	9-28-49	T55, D400R, Ca
-34cbc	N. Sherard...........	Dr	24.4	24	P	G	Qa	T,G	I	Tc	+1.2	4.01	6- 4-43	
20-62-24dba	Earl P. Arnold.......	Du,Dr	57.3	36	C	Sl	Tb	C,W	D,S	Tc	+1.0	53.44	4- 6-43	
-33acb	C. B. Kessler........	Dr	33	6	P	G	Tb	C,E	D	Ls	...	20	10-18-49	T52, D15E, Ca
-34cbc	Fred N. Stull........	Sp	....	..	..	Sl	Tb	F	S	...	...	......	....	T49.5, D10E, Ca
20-63-34daa	Julia W. Yates.......	Dr	102	5	P	Sl	Tb	N	N	Tcu	+.8	65.61	5- 3-43	
-35bbb	Joe Matje............	Dr	....	..	..	Sl	Tb	C,H,W	D,S	Hph	-2.2	60.47	10-26-49	
-35dcc	A. R. Kessler........	Dr	70	5	P	Sl	Tb	J,E	D,S	Ls	...	50	9-30-49	T60

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