Ground-Water Resources and Geology of Northern and Western Crook County, Wyoming

By HAROLD A. WHITCOMB *and* DONALD A. MORRIS

With a section on

THE CHEMICAL QUALITY OF THE GROUND WATER

By RUSSELL H. LANGFORD

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1698

Prepared in cooperation with the State Engineer of Wyoming

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library catalog card for this publication appears after page 92.

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

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

GROUND-WATER RESOURCES AND GEOLOGY OF NORTHERN AND WESTERN CROOK COUNTY, WYOMING

By Harold A. Whitcomb and Donald A. Morris

ABSTRACT

The area described in this report, about 2,200 square miles, lies in the northern and western parts of Crook County, Wyo. Because perennial supplies of surface water are few in Crook County, the major source of water for farm and ranch use is ground water from drilled and dug wells. The ground-water reservoir is recharged principally by precipitation on the Black Hills, the major physiographic feature of the region.

Most of the exposed rocks are sedimentary and range in age from Triassic to Recent; older rocks, ranging in age from Cambrian to Permian, crop out a few miles east of the report area. With few exceptions, rocks underlying the region yield only meager quantities of water to wells.

The Minnelusa Formation yields moderately large quantities of water to flowing wells from a depth of about 700 feet in the vicinity of Hulett. Elsewhere, the formation lies too deep to be developed economically for most uses. The siltstone and silty sandstone of the Spearfish, Sundance, and Morrison Formations supply water to many stock and domestic wells where these rocks are exposed or lie only a short distance below the surface. The small yields generally expected do not warrant the expense of drilling deep wells into these formations. The massive Hulett Sandstone Member of the Sundance Formation may be an exception, because it is coarser grained and relatively thick.

The Lakota and Fall River Formations are the principal aquifers in the northern part of Crook County, they crop out or lie at a relatively shallow depth in a large part of the Black Hills. Water in these formations commonly is under sufficient artesian pressure to flow or to rise within a short distance of the land surface. Yields of the flowing wells generally are small but are adequate for stock and domestic purposes. The Newcastle Sandstone supplies water to a few stock and domestic wells in or near the area of outcrop along the western flank of the Black Hills. The regional dip of beds along the uplift causes the formation to be deeply buried elsewhere in Crook County.

A thick sequence of shale, which overlies the Newcastle sandstone, is not considered to be water bearing, except possibly for small quantities of ground water in the Groat Sandstone Bed of the Gammon Ferruginous Member of the Pierre Shale. The shaly and silty Fox Hills Sandstone contributes small amounts of water to a few stock and domestic wells in a small area in the western part of the county. Many stock and domestic wells yield small quantities of water from relatively massive sandstone beds in the Lance and Fort Union Formations. Moderate supplies may be obtained from these formations locally.

The alluvium in the valleys of the Belle Fourche and Little Missouri Rivers yields water to a few stock and domestic wells and to at least one irrigation well.

Pumping tests of three wells in the Belle Fourche River valley indicate that quantities of water adequate for small-scale irrigation may be obtained locally.

The specific capacity of 18 wells drilled in consolidated sedimentary rocks ranges from 0.06 to 1.7 gpm (gallons per minute) per foot of drawdown. Coefficients of permeability range from 0.5 to 35 gpd (gallons per day) per square foot. Seven wells drilled in the unconsolidated deposits of the Belle Fourche valley between Moorcroft and Devils Tower have specific capacities ranging from about 0.5 to 18 gpm per foot of drawdown. Coefficients of permeability range from 52 to 610 gpd per square foot.

Most of the ground water utilized in Crook County is recovered from drilled wells 30 to nearly 1,000 feet deep, which either flow or are equipped with cylinder or jet pumps. Large supplies of water may be developed from the deep-lying Minnelusa Formation and Pahasapa Limestone. Moderate supplies may be obtained in some areas from sandstone of the Fall River and Lakota Formations and from alluvial deposits in some parts of the Belle Fourche River valley. Generally, only small amounts of water may be expected from wells penetrating the other aquifers. Yields from most wells in Crook County may be increased appreciably by installing pumps of greater capacity, but yields in excess of 100 gpm would be exceptional in most places.

Studies of the chemical quality of water from most of the major water-bearing formations indicate that the ground water is generally of the calcium sulfate or sodium sulfate type, is hard, and is moderately to highly mineralized. Water from the Pahasapa Limestone and the lower part of the Minnelusa Formation normally contains less than 1,000 ppm (parts per million) of dissolved solids, whereas water from gypsiferous rocks, such as the Spearfish and Gypsum Spring Formations, contains from 2,000 to 3,000 ppm. Most of the ground water contains iron, sulfate, and dissolved solids in excess of the recommended concentration limits for domestic use. The water is harder, more alkaline, and more highly mineralized, and it contains more iron than is recommended for many industrial applications. Most ground water in the area is suitable for stock watering; however, its use for irrigation is limited because of its high to very high salinity hazard and low to medium sodium hazard.

INTRODUCTION

SCOPE AND PURPOSE OF THE INVESTIGATION

The investigation of the ground-water resources of northern and western Crook County is a part of the program of ground-water investigations being made in Wyoming by the U.S. Geological Survey in cooperation with the Wyoming State Engineer. It was begun as a study of the availability of ground water for irrigation in the valley of the Belle Fourche River in Crook County and was later expanded to encompass that part of the county for which preliminary geologic maps recently had become available.

The purpose of the investigation was to evaluate the ground-water resources and to determine the possibility of developing additional supplies of ground water where present supplies are unsuitable or inadequate. The work involved a study of the character, thickness, and extent of the principal water-bearing formations and the occurrence, movement, quantity, and quality of the ground water. It consisted of a reconnaissance of the stratigraphy and structure of the area and the collection of hydrologic data on 143 representative water wells. Pumping tests were made at 21 wells, and samples of water were collected for chemical analysis from 20 wells. During the investigation, 26 test holes were augered at 5 selected sites in the alluvium of the Belle Fourche River valley to determine its physical character and thickness. Data obtained from one line of test holes were used in estimating the underflow in the alluvium across the Wyoming-South Dakota State line.

The work was begun in April 1956 by D. A. Morris, who collected most of the hydrologic data. Mr. Morris was transferred to another office in October 1956, and responsibility for the investigation was assumed by H. A. Whitcomb. The study was made under the supervision of H. M. Babcock and E. D. Gordon, successive district supervisors in charge of ground-water investigations in Wyoming. The quantitative analyses of water-bearing materials were made under the supervision of A. I. Johnson in the Hydrologic Laboratory of the Geological Survey at Denver, Colo. The quality-of-water studies were made under the supervision of D. M. Culbertson, district engineer of the Quality of Water Branch of the Geological Survey, Lincoln, Nebr.

LOCATION AND EXTENT OF AREA

Crook County occupies the extreme northeast corner of Wyoming, and borders on Montana to the north and South Dakota to the east. The area described in this report comprises the northern and western parts of the county and includes an area of approximately 2,200 square miles lying principally within the drainage basins of the Belle Fourche and Little Missouri Rivers. (See fig. 1.)

PREVIOUS INVESTIGATIONS

Several previous investigations of the geology and hydrology of the general area have been utilized in the preparation of this report. Among the earliest published studies of Crook County and adjacent areas are those made of the northern part of the Black Hills by Darton (1905 and 1909) and Darton and O'Harra (1905 and 1907). Dobbin and Reeside (1929) described the contact between the Fox Hills and Lance Formations along the western flank of the Black Hills. Rubey (1930) studied the Upper Cretaceous sedimentary rocks of the Black Hills region. Oil and Gas Investigations Map OM 122 (Love and Weitz, 1951) showed the geology and structure of the Powder River Basin, which includes the western flank of the Black Hills. Grace (1952) made a study of the Newcastle Formation in the Black Hills region for the Wyoming State Geological Survey. Knetchel and Patterson (1955) prepared a geologic map of the Northern Black Hills

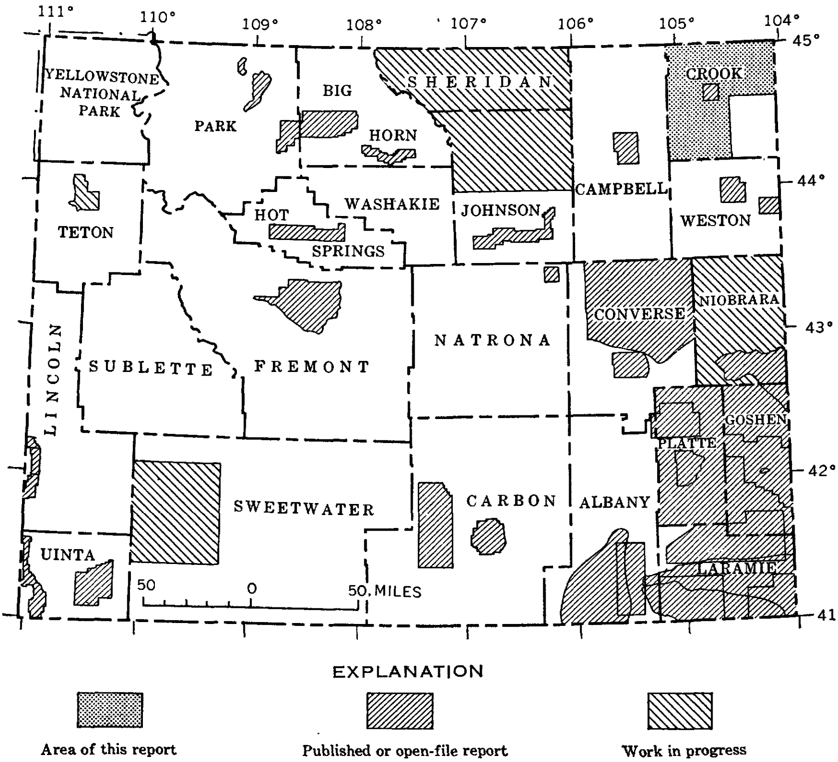

FIGURE 1.—Index map of Wyoming showing area described in this report and other areas in which ground-water investigations have been made or are being made.

district showing the stratigraphy and structure. At the time field data for this report were being compiled, a detailed study of the stratigraphy and structure of the northern and western parts of the Black Hills region was being made by a Geological Survey field party. The preliminary results of this study were published as a geologic map (Mapel and others, 1959).

WELL-NUMBERING SYSTEM

Wells, springs, and oil-test holes shown on the geologic map are numbered according to the Federal system of land subdivision. Numbers and letters show the location of the well, spring, or test hole by township, range, section, and position within the section, as shown in figure 2.

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 letters following the section number indicate the position of the well within the section. The first letter denotes the quarter section and the second letter the quarter-quarter section (40-acre tract). The

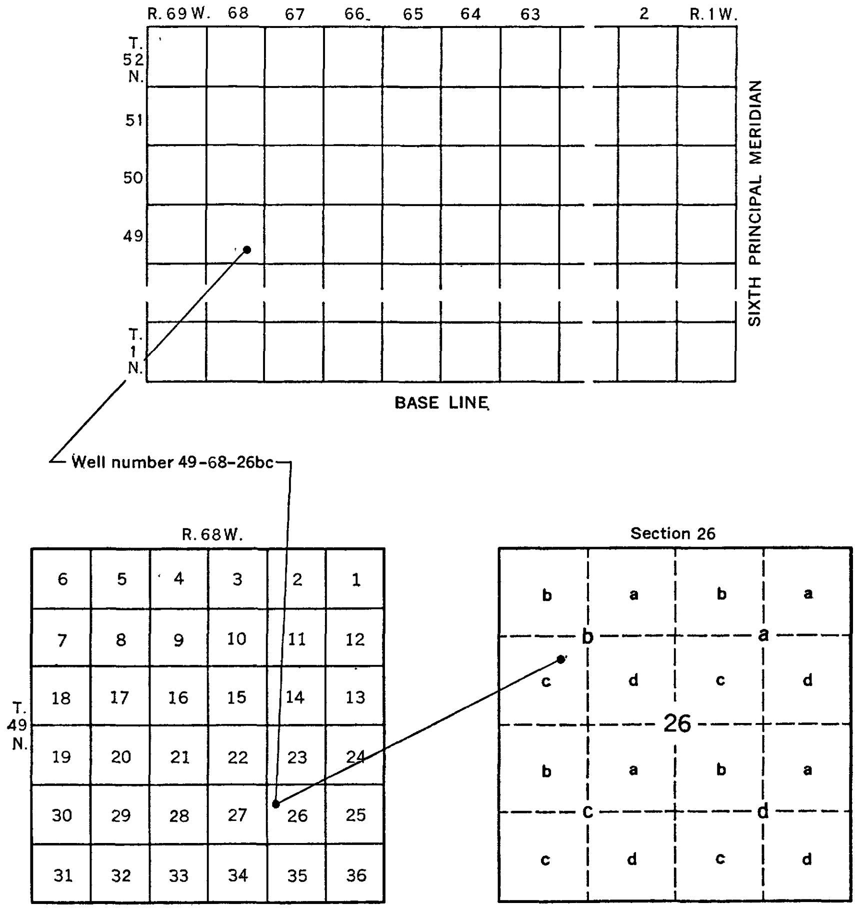

FIGURE 2.—Well-numbering system.

subdivision of the sections and quarter sections are lettered a, b, c, and d in a counterclockwise direction, beginning in the northeast quarter. Where more than one well are in a 40-acre tract, consecutive numbers beginning with 1 are added to the well number.

ACKNOWLEDGMENTS

The writers appreciate the cooperation of the several well drillers operating in the Black Hills area, who furnished much well data that could not have been obtained otherwise. Mr. Henry Moore of Moorcroft, Wyo., was especially helpful in this respect. Ranch owners or tenants permitted and often assisted the authors in collecting hydrologic data and water samples. The office of Production and Marketing Administration of the U.S. Department of Agriculture at Sundance, Wyo., contributed records of wells drilled under the

Agricultural Conservation Program and permitted the use of aerial photographs of Crook County. The authors are indebted to Mr. K. L. Arthur of the Eastern Clay Products Division of International Mining and Chemicals Co. at Belle Fourche, S. Dak., who provided men and equipment to auger several test holes in the alluvium of the Belle Fourche River valley.

Many geologic data were made available prior to publication to the authors of this report by C. S. Robinson and others (unpub. data) of the U.S. Geological Survey. The accompanying geologic map is based on a preliminary geologic map compiled by W. J. Mapel, C. S. Robinson, and P. K. Theobald (1959), and stratigraphic descriptions are, in large part, abstracted from their studies.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Black Hills, which are a major physiographic feature of northeastern Wyoming and southwestern South Dakota, have exercised a strong influence upon the topography of Crook County. They are the result of the upwarping of the earth's crust in the form of an elongated northwest-trending dome about 120 miles long and 60 miles wide. Subsequent stream erosion has removed much of the sediments on the higher part of the uplift, exposing in places the crystalline rocks of the core. During the folding, several large igneous bodies intruded the rocks of the core and the overlying sedimentary rock.

The present topography of the Black Hills is characterized by a high, deeply dissected central region, encircled by almost continuous hogback ridges, which are separated by asymmetrical strike valleys. The broad rolling surfaces of the surrounding plain extend outward from the foothills. The major topographic features in Crook County are shown in relief on plate 1. Erosion has been less effective at lower elevations, and the northwestern part of the Black Hills is not so deeply dissected as the central part. The Bear Lodge Mountains, which form the crest of the Black Hills in Crook County, consist of broad dissected plateaus underlain by flat-lying or only slightly dipping resistant sandstone. Streams flowing eastward, northward, and westward from the summit of the Bear Lodge Mountains have carved a terrain of shallow canyons, narrow valleys, and flat-topped buttes and mesas on the gently dipping flanks of the uplift. Along the western margin of the Black Hills, where the dip of the beds steepens abruptly to form the Black Hills monocline, the upturned edges of resistant strata form a line of hogback ridges, which gradually decrease in prominence and finally disappear northwest of the little Missouri River. The gentle dips on the northern and eastern flanks of the northern Black Hills result in a relatively smooth slope between the plains and the mountains.

The plains bordering the Black Hills on the north and west extend virtually without interruption for many miles beyond the limits of the mapped area. Their surface, which generally is underlain by soft shale, is characterized by low rolling hills and meandering stream valleys. Only a few isolated ridges of more resistant rocks rise above this surface.

Elevations in the Wyoming or northern part of the Black Hills are considerably lower than those in the central part, which lies in west-central South Dakota. The crest of the Bear Lodge Mountains, which form the summit of the northern Black Hills, is at an altitude of about 4,750 feet, as compared with the top of Harney Peak, the the highest point in South Dakota, which rises to a height of 7,242 feet. Altitudes along the course of the Belle Fourche River range from about 4,200 feet in the southwestern part of the mapped area to about 3,100 feet where the river crosses the South Dakota State line. Thus, the maximum relief in the area is only about 1,650 feet.

The Belle Fourche and Little Missouri Rivers compose the major drainage systems of the northern Black Hills. The Belle Fourche River flows into the Cheyenne River in west-central South Dakota, and the Little Missouri, which parallels the course of the upper Belle Fourche River, flows along the northwestern flank of the Black Hills to empty into the Missouri River in western North Dakota. Streamflow in both the Belle Fourche and Little Missouri Rivers is extremely variable, ranging from no flow at times during the winter to sporadic floods of several hundred cubic feet per second during the summer. (See fig. 3.) Peak flows may reach several thousand cubic feet per second after extremely heavy rainfall in the Black Hills. Keyhole Dam, constructed by the U.S. Bureau of Reclamation about 12 miles northeast of Moorcroft, impounds the runoff in the upper Belle Fourche River for controlled release to farms and ranches downstream.

CLIMATE

The Black Hills were given their name by the early visitors to the region because of the dark-green color of the conifers covering the flanks and crests of the mountains. The high precipitation and low temperatures of the mountains permit pine, cedar, and aspen to thrive. The normal annual precipitation during the period of record, and the monthly precipitation for the stations at Moorcroft and Devils Tower, are shown graphically in figure 4. More than 50 percent of the annual precipitation at these stations occurs during April–July. Rainfall during the spring and summer generally occurs as brief but

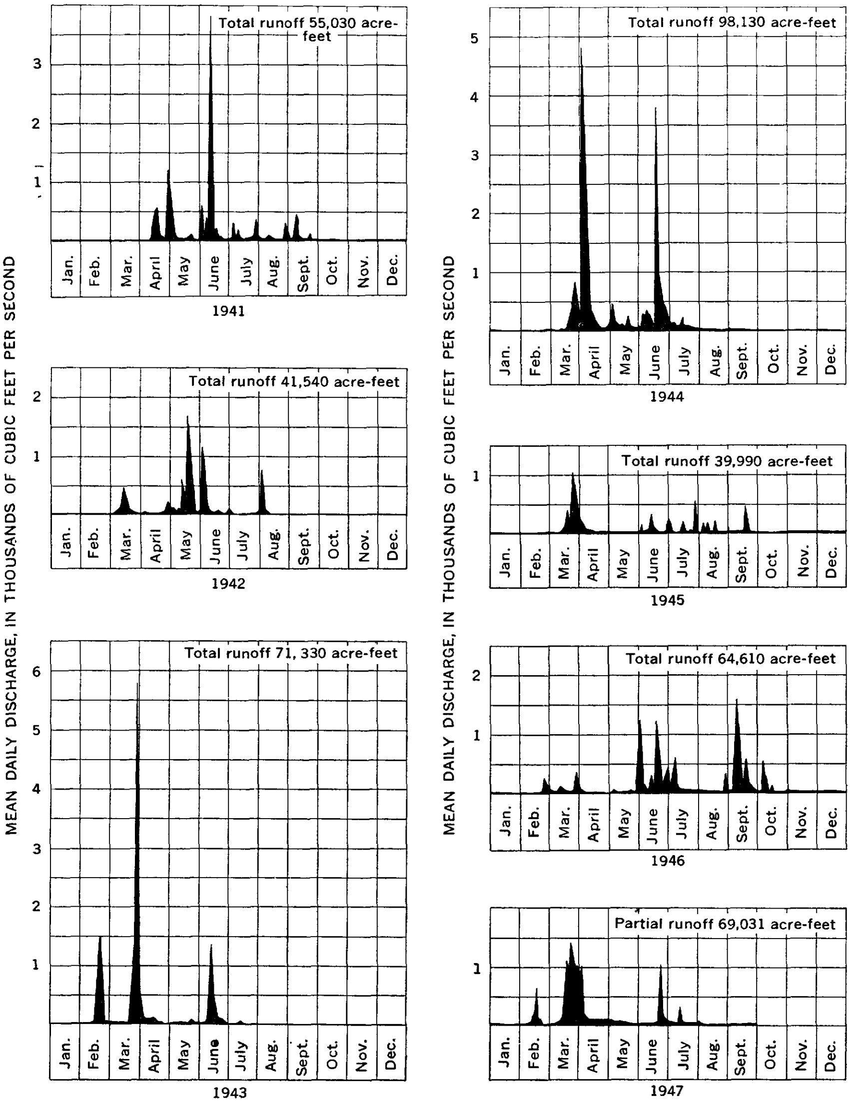

FIGURE 3.—Hydrographs showing mean daily discharge of Belle Fourche River at Hulett, Wyo., 1941-47. (Records of U.S. Bureau of Reclamation.)

rather heavy showers. Light snowfalls are common throughout the winter, and occasional heavy snows, accompanied by strong winds, isolate ranches and communities off the main routes of travel.

The average annual temperature at Moorcroft is 44.5° F and that at Devils Tower is 46.2° F. The average temperature for July is about 55 degrees higher than that for January.

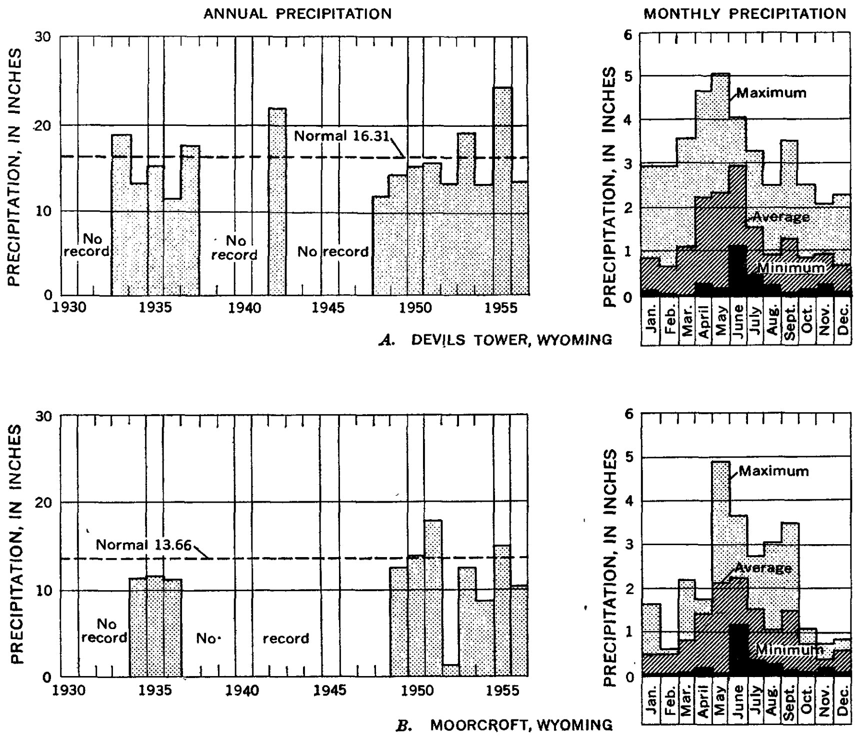

FIGURE 4.—Precipitation records at (*A*) Devils Tower and (*B*) Moorcroft, Wyo. (Records from U.S. Weather Bureau.)

POPULATION AND DEVELOPMENT

The early white settlers in Crook County came in search of the mineral wealth reported by visiting hunting and trapping parties to abound in the Black Hills. The mining camps of the 1870's gradually gave way to stable mining towns, such as Lead and Deadwood, S. Dak. Farmers and cattlemen moved into the area to supply produce to the ready markets provided by the thriving communities. With the ever-widening market made available to the farmer and rancher by improved and expanded methods of transportation, the Black Hills region of both Wyoming and South Dakota has become an important cattle- and sheep-producing area. In addition, the scenic beauty of the Black Hills attracts many tourists, and the tourist business is important in the economy of many communities.

Crook County is primarily rural; the largest community, Moorcroft, had a population of only 819 in 1960. The population of the county in 1960 was 4,629, a density of only about 1.6 persons per square mile.

GEOLOGY

SUMMARY OF STRATIGRAPHY

The rocks of northern and western Crook County are predominantly clastic and range from claystone to fine-grained sandstone. Some coarse and conglomeratic sandstone and massive limestone occur near the base of the stratigraphic sequence at great depth below the land surface. This sedimentary series is underlain by igneous and metamorphic rocks of Precambrian age. The physical character and thickness of these formations are shown graphically on plate 2; also shown are their structural relations and areas of outcrop. Relatively few strata are sufficiently permeable to be considered aquifers, and only the known or the potential sources of ground water are discussed in detail in this report.

STRUCTURAL DEVELOPMENT OF THE BLACK HILLS

The upwarping of the earth's crust that produced the Black Hills dome probably occurred at about the time similar forces were forming the Rocky Mountains to the west. The intrusion of several large igneous masses into the rocks underlying the area accompanied the uplifting. The total amount of displacement measures several thousand feet; however, the crest of the Black Hills dome probably never attained an elevation comparable to the degree of uplifting, because erosion was accelerated as the land surface rose. The age of the uplift that formed the present Black Hills has been established as late Oligocene, or possibly as late as early Miocene (Robinson and others, unpub. data). Several erosional cycles in the valleys of the streams that have incised the dome suggest that uplifting continued intermittently throughout much of the Tertiary Period.

Erosion increased during the early part of the Quaternary Period, perhaps owing to continued uplift, increase in rainfall, or both. Later, erosion apparently decreased, and streams laid down sand and gravel, the remnants of which form the high terraces along the Belle Fourche River and less conspicuous terraces along the Little Missouri. Darton (1909, p. 77) postulates a tilting of the Black Hills dome to the northeast during early Quaternary time, as indicated by the deflection of many streams from their old valleys into more recently eroded canyons. During this period, a tributary of the Cheyenne River captured the Belle Fourche River, which originally flowed north to join the Little Missouri. Darton (1909, p. 77) reports other examples of stream piracy in the Black Hills region.

Uplift may prevail at the present time, as streams in the Black Hills region apparently are downcutting. Both the Belle Fourche and the Little Missouri Rivers occupy narrow flood plains several feet below the valley floor. Tributary streams are cutting trenches and gullies in the valley floors, creating miniature "bad lands" in some areas.

GROUND WATER AND ITS RELATION TO GEOLOGIC CONDITIONS

OCCURRENCE AND MOVEMENT

The principles governing the occurrence and movement of ground water have been discussed in detail by Meinzer (1923) and many others; therefore, the subject is treated only briefly in this report.

The water occupying the zone of saturation in the rocks below the surface of the earth is called ground water. Because not all saturated rocks are sufficiently permeable to yield measurable quantities of water to wells or springs and seeps, ground water may be defined practically as that water below the land surface that is recoverable in usuable quantities. The water-bearing material, or aquifer, from which man can extract water, is called a ground-water reservoir. Thomas (1951, p. 29) stated:

> Because there is usually movement of water through a ground-water reservoir, the connotation is not quite the same as for surface reservoirs, which are constructed to halt and accumulate the flow of streams. But movement underground is generally so slow, compared with that in streams or in the atmosphere, that it represents a definite retardation in the hydrologic cycle. Ground-water reservoirs thus provide slow-moving storage from which man may obtain water as he requires. If an analogy is permitted with the distribution system for manufactured goods, the ground-water reservoirs might correspond to giant warehouses in which the movement of goods in ton-miles is far slower than the rail, plane, or trucking phases of the system.
>
> Nevertheless, an essential characteristic of ground-water reservoirs is movement of water through them. Most of the saturated materials underground are dense rocks, shales, clays, or glacial tills. They are not suitable reservoirs at all, as far as man is concerned, for they hold water in pores so small that it cannot be transmitted in usable quantities to wells or springs.
>
> Wells will yield a perennial supply only to the extent that water can be transmitted to them through the entire course of the aquifer from the place where the water enters the ground. Even without wells, the ground-water phase of the hydrologic cycle is one of movement from the places where water enters the aquifer—the "recharge" areas—to the place where the water is discharged from the ground, either by evapotranspiration [evaporation from land and water surfaces and transpiration by plants], by springs, or by seepage to streams or lakes or directly into oceans. Thus, as a rule, usable ground water does not remain at rest under a piece of land until the owner is ready to use it but is moving continually to some point of discharge at the surface.

Ground water in the report area is derived chiefly from the infiltration of rain or snow. In addition to the direct infiltration of precipitation, the rocks are recharged by infiltration of water from streams crossing outcrop areas. A small amount of artificial recharge is derived from surface-water irrigation on the bottomlands along the middle and lower course of the Belle Fourche River, where a few farms utilize water released from Keyhole Reservoir. Because most of the

724-488—64——2

rocks exposed in the report area are composed of fine-grained material of low permeability, the amount of recharge is small in proportion to the amount of water that runs off.

Most of the ground water moving out of Crook County is in the form of underflow through artesian aquifers. Some is transmitted eastward into South Dakota, some northward into Montana, and some westward into the Powder River Basin. Springs and seeps along the Belle Fourche River and its tributaries support perennial flows in some sections of the streams. Relatively little ground water is discharged by wells and evapotranspiration.

Ground water in Crook County occurs under both water-table and artesian conditions. (See fig. 5.) Water-table conditions exist where the water in the zone of saturation of an aquifer is not confined between less permeable beds, and the water is under atmospheric pressure. The water table is the upper surface of the unconfined zone of saturation. Water-table conditions are confined principally to unconsolidated alluvial deposits of the Belle Fourche and Little Missouri Rivers and their major tributaries. Water levels in alluvial deposits generally fluctuate in response to seasonal variations in stream flow; they rise when recharge exceeds discharge and decline when discharge exceeds recharge. Except for seasonal fluctuations, water levels in the alluvium of the Belle Fourche River valley have remained fairly constant since 1949, the beginning of the period of record. To determine the magnitude and trend of water-level fluctuation, records of water-level measurements must be made at regular intervals for several years.

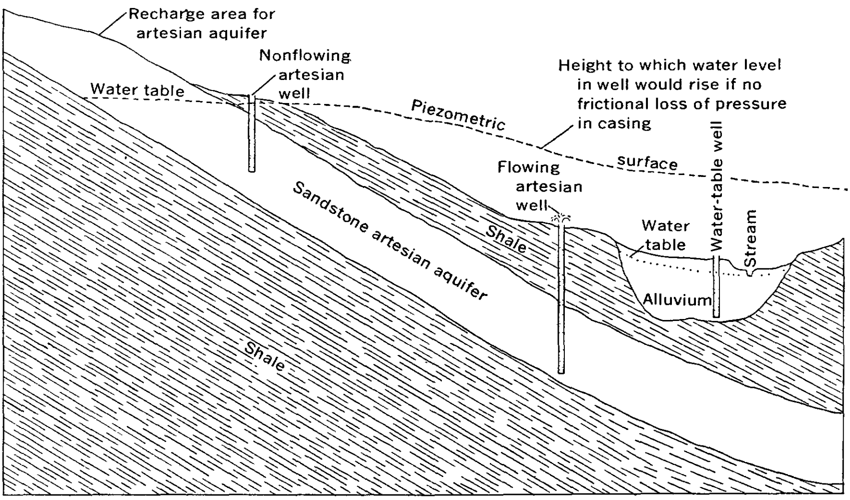

FIGURE 5.—Diagram showing water-table and piezometric surfaces in unconfined and confined aquifers.

Ground water in the consolidated sedimentary rocks of Crook County generally is under artesian pressure. Artesian water occurs where the zone of saturation of an aquifer is confined between relatively impermeable beds, and the water is under hydraulic pressure.

The structure of the Black Hills promotes artesian conditions throughout Crook County and adjacent areas. Most of the aquifers dip more or less steeply away from the crest of the Black Hills and are composed of strata of relatively permeable sandstone interbedded with nearly impermeable shale and siltstone. Water entering the permeable beds in the area of outcrop moves by gravity down the dip of the beds between the confining layers. The water thus confined is under artesian pressure and will rise in wells that penetrate the permeable beds. Artesian pressures generally increase with depth and distance from the outcrop area. The imaginary surface defined by the level of water in wells is called the piezometric surface. An artesian piezometric surface fluctuates in response to changes in the relation of recharge to discharge; however, the response is more pronounced and occurs much more rapidly and over a wider area than that of a water table. Records of the magnitude and trend of fluctuations of piezometric surfaces in the report area are not available, but they probably have declined slightly because of a recent prolonged period of below-average precipitation.

PHYSICAL AND HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS

The ability of a formation to transmit water, and thus the quantity of water it will yield to wells, depends upon its physical and hydrologic properties. Detailed geologic studies of exposed rocks and careful examination of rock material penetrated in drilling are useful in determining the hydrologic properties of an aquifer, but more accurate quantitative estimates require more comprehensive analyses of the material by means of laboratory and field tests.

The more important hydrologic properties of an aquifer are defined in the following paragraphs and will be used in the discussion of the water-bearing properties of geologic formations in a later section.

FIELD DETERMINATIONS

Pumping tests were made on 19 wells and shut-in-pressure tests were made on 2 flowing wells to determine the water-bearing characteristics of aquifers that presently yield water to wells in northern and western Crook County. The results of these tests are shown in table 1. Reported drawdown and discharge data for six additional wells also are included.

Coefficient of permeability.—The permeability of a formation generally is expressed as the field coefficient of permeability, which is the number of gallons of water a day that moves laterally through each mile of water-bearing bed (measured at right angles to the direction of flow), for each foot of saturated thickness, and for each foot per mile of hydraulic gradient.

Coefficient of transmissibility.—Transmissibility may be expressed as the number of gallons of water per day, at the prevailing temperature, transmitted through each mile strip and extending the height of an aquifer, under a hydraulic gradient of 1 foot per mile; hence, it is the product of the average field coefficient of permeability and the thickness of the aquifer, in feet.

Coefficient of storage.—Coefficient of storage is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Specific capacity.—Specific capacity is expressed as the number of gallons of water per minute that a well will yield for each foot the water level in the well is drawn down. This relation is approximately constant only for the first few feet of drawdown; it varies with time and differs from well to well because of differences in well construction and development. The specific capacity of an efficiently constructed well has a direct relation to the permeability of the water-bearing formation. It is of value in estimating the permeability of an aquifer by comparison with the specific capacities of wells in aquifers where the relationship between specific capacity and permeability has been determined. Such a comparison should involve only wells of like diameter and similar construction penetrating a comparable thickness of the same aquifer.

Most of the wells tested were equipped with small-capacity cylinder or jet pumps. Owing to the very low rate of pump discharge and the erratic discharge from pumps powered by windmills, the generally short duration of the pumping tests, and the absence of nearby observation wells, the coefficients of transmissibility obtained are of value only for comparing magnitudes of transmissibility and generally have little quantitative significance. The one exception, perhaps, was the test on well 54–65–13ba, which was pumped at 266 gpm (gallons per minute) for 11 hours. The transmissibility of the aquifers at the sites of two flowing wells was determined by "shutting in" the flow and periodically measuring by means of a pressure gage the increase in artesian head at the well.

LABORATORY DETERMINATIONS

Twelve samples of the alluvium underlying the valley of the Belle Fourche River were analyzed in the Hydrologic Laboratory of the Ground Water Branch to determine the physical and hydrologic

TABLE 1.—*Aquifer-test data and specific capacities of some wells in Crook County, Wyo.*

[Letter symbols: f, flowing well; r, reported value]

Formation	Well	Date	Duration of test (hours of pumping and recovery)	Well discharge (gpm)	Drawdown in discharging well (feet, rounded to nearest tenth)	Specific capacity of discharging well (gpm per foot of drawdown)	Saturated thickness of aquifer (feet)	Coefficient of transmissibility (gpd per ft)	Average field coefficient of permeability (gpd per sq ft)
Minnelusa	53-65-18ba	1955	------	1.5(r)	1.17(r)	1.4	58	--------	------
Do	54-64- 7bc1	1935	------	375 (r)	80 (r)	4.7	40	--------	------
Spearfish	7cb	July 12, 1956	2	6.4	11.8	.54	24	150	6
Do	55-64-21cd	Aug. 11, 1956	2	3.7	6.1	.61	46	370	8
Sundance	51-66-27bd	April 1948	------	19.6(r)	311.8 (r)	.06	------	--------	------
Morrison	56-63- 7bd	Aug. 2, 1956	2½	3.5	17.3	.2	40	160	4
Do	26da	Aug. 2, 1956	2	6.2	23.7	.26	32	160	5
Lakota	56-62-29dd	July 21, 1956	2	2.9	12.3	.24	------	--------	------
Do	56-65- 8cc(f)	Nov. 2, 1956	------	25 (r)	20 (r)	1.2	------	--------	------
Lakota and Fall River	55-61- 8dc(f)	Aug. 3, 1956	2	3.2	33.5	.1	115	220	2
Do	56-62-28bb(f)	July 21, 1956	4	9.9	21.2	.47	60	810	14
Fox Hills	53-67- 8bb	Nov. 6, 1956	4	5.5	26.4	.21	------	--------	------
Lance	49-68-36db	June 19, 1956	2	1.4	3.4	.41	29	170	6
Do	50-68-14cd	June 21, 1956	2½	4.4	2.6	1.7	40	1,060	26
Do	24cd2	June 21, 1956	2	5.8	3.8	1.5	60	2,100	35
Do	53-68-15cd	Nov. 2, 1956	------	10 (r)	50 (r)	.2	------	--------	------
Fort Union	49-68-16ca	June 22, 1956	7	2.3	4.1	.56	87	430	5
Do	27bc	June 22, 1956	2	3.2	17.3	.18	107	60	.5
Do	28ab	June 21, 1956	2½	5.0	12.2	.41	30	160	6
Do	29bc	June 27, 1956	3	1.3	14.0	.09	70	30	.5
Alluvium	50-67- 4cc	June 19, 1956	2	5.5	.3	18.3	19	11,000	580
Do	5dc	May 10, 1958	2	8.0	9.2	.87	22	340	14
Do	51-67-31dd	June 18, 1956	2	4.1	8.3	.49	------	--------	------
Do	53-67- 9cc	Nov. 1, 1956	------	18 (r)	40 (r)	.45	------	--------	------
Do	54-65-12da	July 13, 1956	2	6.8	.6	11.3	13	------	------
Do	13ba	Oct. 3, 1956	20	266	18.3	14.5	34	20,600	610
Do	55-64-32cb	Oct. 4, 1956	2	2.7	3.7	.73	4	210	52

properties of the alluvial material. These studies included particle-size analyses and determinations of porosity, specific retention, specific yield, and coefficient of permeability. The results of the laboratory analyses are summarized in tables 2 and 3.

Grain size.—A particle-size analysis, or mechanical analysis, of granular material consists of separating into groups the grains of different sizes and determining the percentage, by weight, of the total sample each size group constitutes.

Porosity.—The porosity of a rock is expressed as the percentage of its total volume that is occupied by interstices. In a saturated rock, the porosity is the percentage of the total volume of rock that is occupied by water. The porosity indicates only the amount of water the rock can hold, not the amount it can yield to wells. Some rocks, such as claystone and siltstone, may have a high porosity but will yield very little water to wells.

Specific retention, and specific yield.—The specific retention of a water-bearing material is the quantity of water that it will retain against the pull of gravity if it is drained after having been saturated.

TABLE 2.—*Results of laboratory tests to determine the physical properties of alluvial material in the valley of the Belle Fourche River*

Test hole	Interval sampled (ft)		Particle size (millimeters)											
					Percent sand					Percent gravel				
	From	To	Percent clay less than 0.004	Percent silt 0.004–0.0625	Very fine 0.0625–0.125	Fine 0.125–0.25	Medium 0.25–0.5	Coarse 0.5–1.0	Very coarse 1.0–2.0	Very fine 2.0–4.0	Fine 4.0–8.0	Medium 8.0–16.0	Coarse 16.0–32.0	Very coarse 32.0–64.0
Samples from test holes augered 1.5 miles northeast of Moorcroft [See pl. 2, section *A–A′*.]														
50–68–25ca	10	12	7.5	2.6	6.8	39.4	30.3	11.1	1.8	0.4	0.1	---	---	---
	12	15	7.0	1.3	9.0	31.8	35.3	11.7	2.4	1.4	.1	---	---	---
	15	18	6.4	3.2	8.0	34.8	21.3	9.7	3.7	4.2	8.6	0.1	---	---
50–68–25bb	6	20	6.8	4.5	4.4	11.1	8.9	9.0	5.8	11.8	22.6	14.0	1.1	---
Sample from test hole augered about 1 mile northeast of Devils Tower [See pl. 2, section *E–E′*.]														
53–65– 8bb	10	24	6.2	4.9	4.3	11.9	13.2	14.9	10.6	14.2	14.6	5.2	---	---
Samples from test holes augered 0.25 mile east of Wyoming-South Dakota State line														
1– 9–18cc1	9	17	9.5	8.5	3.9	9.2	13.3	9.5	7.6	9.0	11.7	9.9	1.9	6.0
18cc2	13	28	10.5	11.0	4.4	8.2	10.9	11.6	10.2	8.0	15.4	9.8	---	---
18cc3	12	15	10.8	12.3	4.3	4.5	4.9	9.3	7.3	12.8	12.6	10.7	10.5	---
	15	23	10.3	10.3	5.1	11.1	6.7	4.8	7.0	11.5	14.5	11.4	7.3	---
18cc4	12	18	9.7	11.3	3.8	5.6	12.6	13.7	8.2	10.1	11.4	6.3	7.3	---
	18	24	14.8	8.9	8.4	21.8	14.0	10.6	7.9	5.9	3.7	2.9	1.4	---
18cc5	12	16	11.9	14.2	4.4	6.4	7.9	11.0	11.1	12.3	8.7	7.7	4.4	---

Specific retention is expressed as the ratio of the retained water to the total volume of material.

The specific yield of a water-bearing material is defined as the ratio of the volume of water it will yield by gravity to its own volume and is numerically equal to the porosity minus the specific retention.

Coefficient of permeability.—The coefficient of permeability, as determined in the laboratory, is expressed as the number of gallons per day transmitted through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60° F. Permeability depends principally upon the degree of assortment and the arrangement and size of the rock particles. It is generally very low for clay and high for well-sorted sand and gravel.

TABLE 3.—*Results of laboratory tests to determine the hydrologic properties of alluvial material in the valley of the Belle Fourche River*

Test hole	Interval sampled (ft)		Specific retention [1]	Porosity [1]	Specific yield [1]	Coefficient of permeability (gpd per sq ft) [2]
	From	To				
Samples from test holes augered 1.5 miles northeast of Moorcroft [See pl. 2, section A–A′]						
50–68–25ca	10	12	10.2	45.0	34.8	60
	12	15	7.1	45.9	38.8	180
	15	18	4.1	40.2	36.1	80
50–68–25db	6	20	8.3	32.1	23.8	30
Sample from test hole augered about 1 mile northeast of Devils Tower [See pl. 2, section *E′–E″*]						
53–65– 8bb	10	24	16.2	32.9	16.7	40
Samples from test holes augered 0.25 mile east of Wyoming-South Dakota State line						
1– 9–18cc1	9	17	20.8	30.2	9.4	1
–18cc2	13	28	22.9	29.3	6.4	.8
–18cc3	12	15	28.2	30.3	2.1	.3
	15	23	26.3	31.9	5.6	.4
–18cc4	12	18	22.8	28.9	6.1	.4
	18	24	20.4	37.5	17.1	2
–18cc5	12	16	28.4	31.7	3.3	.1

[1] Percent of volume of material.
[2] At 60°F.

RECOVERY AND UTILIZATION OF GROUND WATER

SPRINGS AND SEEPS

Springs and seeps contribute to the flow of many small streams in the northern part of the Black Hills. Perennial flows in some reaches of the Belle Fourche and Little Missouri Rivers are derived from seepage in areas where the stream has cut below the water table in the adjacent bedrock. Discharges generally are subject to seasonal fluctuations and normally are lowest during the summer. The water is used mainly for stock supplies, although in parts of the Belle Fourche River valley small quantities are used for irrigation. Springs supply small quantities of water for domestic use in some areas.

WELLS

No attempt was made to inventory all the domestic and stock wells in the area, but representative wells were selected where information was needed. Pertinent data on inventoried wells are given in table 11, and their locations are shown on plate 2. Drillers' logs of water wells and oil-test holes obtained during the investigation are given in table 12.

The quantity of water pumped by stock and domestic wells is not known, and little statistical data are available on the utilization of ground water by public systems. A compilation of the readings of 76 percent of the water meters in the community of Moorcroft indicates that approximately 8 million gallons of water was pumped from the two community wells during the water year from September 1954 through August 1955. On the basis of a population of about 500 persons (517 in 1950), the per capita consumption was estimated to be 16,000 gallons a year.

Most of the ground water in the report area is obtained from drilled wells ranging from about 30 feet to nearly 1,000 feet in depth and from 4 to 6 inches in diameter. In general, the wells are cased to prevent caving and, in some areas, to shut out water of unsuitable chemical quality. The casing may be set on the bottom of the hole and perforated or screened opposite the aquifer, or it may be terminated at the top of the aquifer, leaving the hole uncased below. Only two wells in the area are known to be gravel packed. A few shallow dug wells yield water from alluvial deposits for domestic and stock use.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

Oil and Gas Investigations Map OM–191 (Mapel and others, 1959) was used in this report. Only the locations of wells and springs and contours showing approximate drilling depths to the Fall River Formation were added. Map symbols used in reference to other mineral resources in the report area are not directly relevant to the ground-water study but are retained because of their significance to the future economic development of the region. Much of the geologic discussion was extracted from data provided by C. S. Robinson (Robinson and others, unpub. data) prior to the publication of Professional Paper 404. The reader is referred to this publication for a more detailed discussion of the geology and mineral resources of the Black Hills area.

ROCKS OF PRE-MISSISSIPPIAN AGE

Formations lying below rocks of Mississippian age in northern and western Crook County generally are buried too deeply to be utilized economically as a source of ground water. No attempts have been made to develop water from these formations because at most places there are several shallower productive aquifers.

MISSISSIPPIAN SYSTEM

The Mississippian System in Crook County is represented by rocks considered to be of Early Mississippian age. No Upper Mississippian strata have been recognized in the Black Hills, and limestone of the Lower Mississippian is overlain unconformably by sandstone and shale of Pennsylvanian age.

ENGLEWOOD LIMESTONE

The Englewood Limestone does not crop out in the report area but is present at depths of about 1,800 to more than 3,600 feet. The formation may crop out in the southern flank of the Bear Lodge Mountains near Warren Peaks about 4 miles east of the mapped area, where the upwarping of beds by igneous intrusion has brought strata of Mississippian age to the surface. (See pl. 1.) The formation, as exposed in the lower walls of Spearfish Canyon near Spearfish, S. Dak., on the eastern flank of the Black Hills, was described by Darton (1909, p. 20) as "dove-colored slabby limestones with purplish concretions, merging upward into purplish-gray shales." Its thickness ranges from 30 to 60 feet; however, a gradational contact with the overlying Pahasapa Limestone in places makes accurate measurement difficult. No wells in the report area tap the Englewood Limestone; but, because it is thin bedded, shaly, and relatively thin, it is probably not a major aquifer in Crook County.

PAHASAPA LIMESTONE

Outcrop and extent.—The Pahasapa Limestone is exposed about 5 miles east of the report area in the southeastern part of T. 53 N., R. 64 W. It crops out as a narrow band of steeply dipping beds that nearly encircle the intrusive mass of Warren Peaks, a southern extension of the Bear Lodge Mountains. Except in areas of local uplift or near the core of the Black Hills dome, the formation generally is deeply buried throughout Crook County. Near the South Dakota State line, about 2 miles south of the mapped area in sec. 21, T. 54 N., R. 60 W., an oil-test hole penetrated the Pahasapa Limestone at 1,957 feet. In the southwestern part of the area, the log of a deep test hole records Pahasapa Limestone at a depth of 2,790 feet. (See log 51–67–25ca, table 12.) The minimum depth to the formation in the report area is estimated to be approximately 1,200 feet near Hulett.

Lithology and thickness.—The Pahasapa is a white to light-gray, fine-grained, and very thick-bedded limestone that contains nodules and layers of chert in some outcrops. Where exposed in the walls of deep canyons on the eastern flank of the Black Hills uplift, the limestone is cavernous in places; well drillers have noted fissures and caverns in the formation elsewhere. The formation ranges in thickness from about 550 feet in the Bear Lodge Mountains (Darton, 1909, p. 21) to 896 feet in an oil-test hole drilled about 3 miles northwest of New Haven, Wyo. (See log 55–67–9cc, table 12.) Because of the generally steep dip of the beds in the New Haven area, the true thickness of the limestone probably is somewhat less than that logged in the oil-test hole. Two oil-test holes drilled in the vicinity of Hulett logged 604 and 631 feet of Pahasapa Limestone.

Water supply.—No water wells in the report area penetrate the Pahasapa Limestone, but wells drilled in adjacent areas have met with variable success. A 767-foot test hole drilled by the town of Sundance in 1950 was abandoned after penetrating 175 feet of Pahasapa. The water level in the hole was about 490 feet below the surface, and a pumping test indicated that the formation would yield only about 12 gpm. Williams (1948, p. 14) describes a large flowing well constructed in the Pahasapa at Osage, in Weston County, Wyo., about 30 miles southeast of Moorcroft. Two municipal wells drilled in 1948 and 1951 at Newcastle, Weston County, about 45 miles southeast of Moorcroft, had measured flows of 1,450 and 650 gpm in July 1960. Comparable yields probably can be expected from wells penetrating fissured and cavernous zones in the formation elsewhere along the flanks of the Black Hills, but these zones are generally at too great a depth for the drilling of wells to be economically feasible for most uses.

Water in the Pahasapa in the Hulett area is probably more highly mineralized than that in the Newcastle and Osage areas because of the greater distance from the area of recharge, but, except for excessive hardness, it should be suitable for most uses.

Wells drilled in that part of the Belle Fourche River valley underlain by the Spearfish Formation may be expected to reach the top of the Pahasapa Limestone at depths ranging from about 1,200 to 1,300 feet. Drilling depths may be somewhat greater before a fissured or cavernous zone is penetrated. The Pahasapa Limestone is undoubtedly saturated, and the water may be under sufficient artesian pressure to flow, but it normally is massive, fine grained, and relatively impermeable. The construction of wells in the formation should be preceded by exploratory test drilling to locate any fissured and cavernous zones that may exist.

PENNSYLVANIAN AND PERMIAN SYSTEMS

MINNELUSA FORMATION

Outcrop and extent.—The Minnelusa Formation is not exposed in the report area; the nearest outcrops are on the south flank of the Bear Lodge Mountains about 4 miles to the east. The Minnelusa is reported at a depth of 628 feet in 2 wells drilled for the community of Hulett and at about 550 feet in 2 wells drilled in the Belle Fourche River valley near Devils Tower. The formation also has been logged at depths ranging from about 1,500 to more than 3,500 feet in oil-test holes drilled in the eastern, northern, and western parts of Crook County.

Lithology and thickness.—The Minnelusa Formation, where exposed, consists of a massive white to yellowish- and reddish-gray sandstone, variable amounts of pink and purplish-gray limestone and dolomite, and red, purple, and black shale. The sandstone is fine to coarse grained, fairly well sorted, firmly to moderately cemented, thick bedded, and crosslaminated. In Cold Springs Canyon, in southeastern Crook County about 10 miles east of Sundance, the formation consists principally of a basal yellowish-gray sandstone containing thin beds of sandy limestone, a middle unit of soft reddish-brown sandstone, and an upper resistant white sandstone unit (Darton, 1909, p. 24). The sandy facies of the Minnelusa is much less dominant in some areas, however. A short distance west of the stratigraphic section described by Darton, near Sundance, the upper part of the formation consists mostly of thin-bedded limestone and shale and massive beds of gypsum and anhydrite (Brady, 1958, p. 45).

Logs of oil-test holes indicate that the Minnelusa Formation is about 600 feet thick in the vicinity of Hulett and in the northeastern part of Crook County near the South Dakota State line and is about 700 feet thick in the northwestern part. More than 900 feet of Minnelusa was logged in an oil-test hole drilled on the Black Hills monocline in the southwestern part of the report area. This thickness is exaggerated, however, because of the relatively steep dip of strata penetrated in drilling along the western flank of the Black Hills dome. The average thickness probably is closer to 700 feet.

Water supply.—Data obtained from pumping tests and from reported yields of wells are too meager to permit reliable estimates of the permeability of the Minnelusa Formation in the report area. Available data are given in tables 1 and 11. The formation yields moderately large quantities of water to the two flowing wells (54–64–7bc1 and 7bc2) supplying the community of Hulett and to well 54–

65–13bd, 1½ miles southwest of Hulett. Well 54–65–29dd, about 5 miles southwest of Hulett, had a reported flow of 225 gpm in 1944, but in July 1956 the water level was 7 feet below the land surface.

A 608-foot well (53–65–18ba) drilled at Devils Tower National Monument in 1936 does not flow and yields only a small quantity of water from pumping. The quality of the water causes it to be unsuitable for most domestic uses.

The Minnelusa Formation is reported to yield large quantities of water to flowing wells on the eastern flank of the Black Hills uplift in western South Dakota. Smaller flows (20 and 50 gpm) are obtained from two wells penetrating the formation in the vicinity of Newcastle (Williams, 1948, p. 9–12). The Minnelusa probably is the most dependable source of large supplies of ground water in the report area. Water levels in wells penetrating the formation generally will be near the land surface, and at lower elevations wells may flow. However, the Minnelusa Formation lies at too great a depth throughout most of Crook County to be considered an economical source of water.

In drilling for water in the Minnelusa, the hole should be carefully logged as an aid in choosing the best potential water-bearing zone. Before a choice is made, however, a water sample should be taken for chemical analysis. To insure a minimum of contamination by highly mineralized water from overlying formations, the well should be tightly cased throughout, and the casing should be cemented several feet into the Minnelusa Formation. It may be necessary to extend the casing deeper into the formation if the upper part contains an appreciable number of evaporite deposits.

If an adequate supply of chemically suitable water is not found in the Minnelusa Formation, the well might be deepened to the Pahasapa Limestone, which lies about 600 feet below the top of the Minnelusa and 1,200 feet below the land surface in the Hulett area. However, because yields from the Pahasapa apparently depend principally upon the number of fissured or cavernous zones penetrated, not all wells drilled into the formation will yield large quantities of water.

PERMIAN SYSTEM

OPECHE FORMATION

The Opeche Formation, which overlies the Minnelusa Formation, consists of approximately 75 feet of alternating beds of reddish-brown and maroon fine-grained to silty and shaly sandstone, siltstone, and claystone, and thin beds of gypsum and anhydrite. The formation is not considered to be an aquifer in the area because of its generally low permeability. Water in the Opeche Formation probably is highly mineralized because of the presence of evaporite deposits, and it should be cased out of wells penetrating the formation.

MINNEKAHTA LIMESTONE

The Minnekahta consists of about 40 feet of light- to pinkish-gray fine-grained thin-bedded limestone. The formation persists over a wide area in Crook County, but is not considered to be a source of ground water because it is relatively impermeable and the water contained in it is reported to be of poor quality.

PERMIAN AND TRIASSIC SYSTEMS

SPEARFISH FORMATION

Outcrop and extent.—"Red beds" of the Spearfish Formation are the oldest rocks exposed in the report area. Outcrops are confined mostly to the lower slopes of the valley of the Belle Fourche River from about 2 miles south of Devils Tower to nearly 5 miles northeast of Hulett. South and east of the mapped area broad expanses of Spearfish Formation are exposed, and the term "Red Valley" is applied to the conspicuous oval depression eroded into the soft siltstone and shale that encircle the Black Hills.

Lithology and thickness.—The Spearfish Formation in the Devils Tower–Hulett area consists of about 700 feet of red shale, siltstone, and fine-grained silty sandstone containing stringers and lenses of gypsum; thick beds of massive white gypsum occur in the lower part. The rocks are soft and friable and weather to form smooth gentle slopes and broad flat valleys.

Water supply.—The siltstone and shaly sandstone of the Spearfish yield small quantities of water to shallow wells and a few springs and seeps in areas of outcrop along the Belle Fourche River. Larger supplies probably could be obtained from the formation by deeper drilling. The results of the pumping tests made on two wells that penetrate the Spearfish are given in table 1.

Water from the Spearfish Formation normally is too highly mineralized to be acceptable for most domestic and irrigation uses, and in some places it is only fair for stock watering (table 5). In areas underlain by the "red beds," attempts should be made to develop water from the alluvial deposits of the valley of the Belle Fourche River in preference to drilling into the Spearfish Formation. The water from the alluvium is chemically similar to that from the Spearfish, but concentrations of dissolved solids are likely to be less because of periodic dilution by flow in the Belle Fourche River. If water is not available in the alluvium, an uncased hole drilled through the Spearfish Formation to tap the moderately mineralized water of the underlying Minnelusa Formation might yield a mixed water of lower mineralization than that obtained solely from the Spearfish. Locally, the upper part of the Minnelusa consists principally of beds of gypsum and anhydrite containing water comparable to that in the Spearfish.

Drilling should not be terminated until a considerable thickness of white to pinkish-gray sandstone of the Minnelusa Formation has been penetrated.

JURASSIC SYSTEM

The Jurassic System in the area studied includes rocks of Middle and Late Jurassic age; no lower Jurassic strata have been identified in Crook County. The Gypsum Spring Formation of Middle Jurassic age lies unconformably on the Spearfish Formation and is overlain, in ascending order, by the Sundance and Morrison Formations of Late Jurassic age.

GYPSUM SPRING FORMATION

The series of interbedded massive white gypsum, thin gray cherty limestone, and red claystone of the Gypsum Spring Formation is about 125 feet thick in the walls of the valley of the Belle Fourche River about 10 miles northeast of Hulett (Mapel and Bergendahl, 1956; Imlay, 1947), but at some places in the northern part of the Black Hills the formation apparently is absent. Because of its lack of persistence, it is mapped with the overlying Sundance Formation. The Gypsum Spring Formation is not considered to be a potential source of ground water in the northern Black Hills because of its low permeability and the poor quality of the water contained in it.

SUNDANCE FORMATION

The Sundance Formation comprises, in ascending order, the Canyon Springs Sandstone, the Stockade Beaver Shale, the Hulett Sandstone, the Lak, and the Redwater Shale Members. The Hulett is the only member of the formation having favorable water-bearing characteristics; therefore, it is the only member of the Sundance Formation that is mapped separately and discussed in detail in this report. The remainder of the formation is composed principally of yellowish- to greenish-gray siltstone and shale containing thin beds of shaly sandstone and limestone.

HULETT SANDSTONE MEMBER

Outcrop and extent.—The Hulett Member, a prominent massive sandstone ledge between softer shale members of the Sundance Formation, crops out in the walls of the valley of the Belle Fourche River and its tributaries from about 7 miles southwest of Devils Tower to nearly 15 miles northeast of Hulett. Where overlying beds have been removed by erosion, the Hulett forms a resistant capping bed on ridges and low buttes. At both the northern and southern ends of the outcrop, the Hulett dips beneath younger beds. The areal extent of the sandstone is not known because only a few water wells penetrate it, and these are near the outcrop area. Logs of oil-test holes drilled through the Sundance Formation elsewhere in the area indicate that the sandstone either is absent or was not noted.

Lithology and thickness.—The Hulett in the type locality near Hulett is yellowish gray to pale pink, generally fine grained, fairly well sorted, firmly cemented, and thin to thick bedded. Weathered outcrops are slabby to massive and commonly are crossbedded and ripple marked. Thin beds of greenish-gray claystone occur locally in the lower part.

The Hulett Sandstone Member, where exposed, ranges in thickness from 55 to about 90 feet; the maximum thickness was measured near Hulett. The contact with the overlying Lak Member generally is sharp and well defined because of the abrupt change from the resistant cliff-forming sandstone to the soft slope-forming sandstone and shale above. In its lower part, however, the sandstone becomes somewhat shaly, and the contact between it and the underlying Stockade Beaver Shale Member in places is less definite. Following is a description of a section of the Sundance Formation containing a conspicuous outcrop of the Hulett:

Stratigraphic section of the Sundance Formation about 1 mile northwest of Hulett in the SE¼ sec. 2 and NW¼ sec. 12, T. 54 N., R. 65 W., Crook County, Wyo.

[Generalized from Robinson and others, unpub. data]

	Feet
Morrison Formation.	
Sundance Formation:	
Redwater Shale Member:	
Sandstone, grayish-yellow, fine-grained, well-sorted, calcareous	2–4
Shale, grayish-green; some interbedded light-gray fine-grained friable sandstone; a few thin beds of gray limestone in upper part	180
Thickness, rounded	180
Lak Member:	
Sandstone, yellowish-gray, fine-grained, well-sorted, calcareous, poorly cemented, massive	9
Sandstone, reddish-orange and yellowish-gray, fine-grained to silty, poorly cemented	16
Sandstone, yellowish-gray, fine-grained, poorly cemented, thin-bedded to massive	33
Thickness	58
Hulett Sandstone Member:	
Sandstone, yellowish-gray, fine-grained, calcareous, firmly cemented; thin bedded in lower 20 ft and upper 15 ft; remainder is medium to thick bedded; a few partings of greenish-gray shale in lower 6 ft; forms a cliff	90

Stratigraphic section of the Sundance Formation about 1 mile northwest of Hulett in the SE¼ sec. 2 and NW¼ sec. 12, T. 54 N., R. 65 W., Crook County, Wyo.—Continued

	Feet
Sundance Formation—Continued	
Stockade Beaver Shale Member:	
Shale, greenish-gray; interbedded light-gray, fine-grained, calcareous sandstone near base and top	48
Sandstone, light yellowish-gray, fine-grained, calcareous, friable, soft	11
Shale, greenish-gray, sandy; poorly exposed	9
Sandstone, light-brown and greenish-gray, fine-grained, calcareous, thin-bedded; grades to silty and shaly sandstone in lower part	6
Sandstone, light-gray, fine- to medium-grained	6
Thickness, Stockade Beaver Shale Member	80
Thickness, Sundance Formation (rounded)	410
Gypsum Spring Formation.	

Water supply.—Records were collected of 22 stock and domestic wells that probably obtain all or most of their water from the Sundance Formation. Well 51–66–27bd at Keyhole Reservoir is reported to be 690 feet deep and undoubtedly penetrates the Sundance Formation. The chemical quality of the water suggests that it is from the shales of the upper part of the formation. The results of a pumping test made when the well was completed are given in table 1. Wells 54–60–4bb and 56–63–10ca (logs, table 12) are 780 and 400 feet deep and probably penetrate the Hulett Sandstone Member. The flow from these wells is 0.5 and 5 gpm, respectively.

The Hulett Sandstone Member may not yield large quantities of ground water anywhere in the report area, but wells penetrating it probably are generally capable of producting larger supplies than are normally required for stock and domestic use. The importance of the sandstone as a potential source of ground water is limited by its great depth throughout much of the area.

Wells drilled in areas of outcrop of the Sundance Formation should be located to penetrate the Hulett Sandstone Member. However, test holes drilled in or near outcrops of the Hulett are likely to be dry because the regional dip of the beds causes the sandstone to be drained of much of its water. The chances of tapping water in the member improve as the distance from the outcrop increases. To obtain the maximum quantity of water available, drilling should be continued until the gray shale of the Stockade Beaver Shale Member is penetrated. Additional water might be obtained from the Stockade Beaver and underlying Canyon Springs Member, but its chemical quality may make it objectionable for some uses.

MORRISON FORMATION

Outcrop and extent.—Outcrops of the Morrison Formation are widely dispersed, though generally not broadly exposed, over much of the central part of the report area. They characteristically form steep slopes below the more resistant sandstone benches and cliffs of the overlying Lakota and Fall River Formations. The formation has been penetrated by many deep oil-test holes drilled on the plains adjacent to the Black Hills. On the geologic map, the Morrison Formation was combined with the overlying Lakota Formation of Cretaceous age.

Lithology and thickness.—The Morrison Formation consists of a sequence of continental deposits of colorful greenish-gray to green and pink to red claystone and siltstone containing some lenticular thin gray sandstone and shaly limestone beds. The sandstone, which occurs mostly in the lower part of the formation, is characteristically light gray, very fine grained, fairly well sorted, and weakly cemented. The sandstone beds are lenticular, rarely exceed 6 feet in thickness, and are crossbedded and ripple marked in places. Outcrops of the Morrison Formation in the northern Black Hills are 150 feet thick in some areas, but elsewhere the formation apparently is absent.

Water supply.—The Morrison Formation yields small quantities of water to a few domestic and stock wells where no other source of water is economically available, but in most of the area it is overlain by the generally more productive sandstones of the Lakota and Fall River Formations. The water generally is under sufficient artesian pressure to be raised within a few feet of the land surface. The results of pumping tests made on two wells penetrating the Morrison are given in table 1.

Because of the characteristically low permeability of the Morrison Formation, the availability of ground water in alluvial deposits of stream valleys should be investigated first in areas of Morrison outcrops. If the valley fill contains an insufficient quantity of water, wells should be drilled as deeply as is economically feasible into the Morrison and, possibly, into the underlying Sundance Formation in an attempt to penetrate the Hulett Sandstone Member. Wells drilled in areas of Morrison outcrops should penetrate the Hulett at a maximum depth of about 400 feet. Drilling should be terminated at the base of the Hulett Member because of the relative impermeability of strata below it and the generally poor quality of water contained in them.

CRETACEOUS SYSTEM

Rocks of Cretaceous age are exposed in approximately 75 percent of the mapped area and constitute more than 50 percent of the average maximum thickness of sedimentary strata in Crook County. How-

724-488—64——3

ever, they contain the bulk of the relatively impermeable sedimentary rocks in the stratigraphic sequence and for the most part are not considered to be potential aquifers.

INYAN KARA GROUP

Because of the difficulty of differentiating between the Lakota Formation, Fuson Shale, and Fall River Formation in the northern part of the Black Hills, Rubey (1930, p. 5) applied the name Inyan Kara Group to these formations. Recent studies by Waagé (1959) have led to the conclusion that the Fuson Formation, named by Darton for the type locality in the southeastern part of the Black Hills, is not present or is indistinguishable from the Lakota and Fall River in the northern Black Hills. Owing to its small areal extent, the Fuson, where present, is considered to be a member of the Lakota Formation. In the report area the Inyan Kara Group comprises the Lakota and the Fall River Formations. It is composed of a lower and an upper sandy unit generally separated by a sequence of alternating shaly claystone, siltstone, and thin sandstone.

The contact between the Lakota and Fall River Formations lies within the shaly sequence and commonly is marked by a rather abrupt change from the variegated claystone of the Lakota below to the dark carbonaceous shale of the Fall River Formation above. The tabular character and the greater lateral extent of the sandstone beds in the Fall River Formation are features that aid in distinguishing it from the underlying Lakota Formation, in which the sandstone is more lenticular. The following description of a partial section of the Inyan Kara Group illustrates the lithology of the Lakota and Fall River Formations.

Stratigraphic section of parts of the Fall River and Lakota Formations in sec. 12, T. 55 N., R. 65 W., Crook County, Wyo.

[Generalized from Robinson and others, unpub. data]

	Feet
Top of hill.	
Fall River Formation (in part):	
Sandstone, yellowish-brown to yellowish-white, fine-grained, micaceous, ripple-marked	10
Shale and interbedded sandstone; shale is medium to dark gray; sandstone is shaly, yellowish gray, fine to very fine grained and micaceous	31
Sandstone and some interbedded shale, yellowish- to light-brownish-gray, fine-grained, micaceous; weathers light brown	4
Shale interbedded with siltstone and sandstone, gray, yellowish-gray, and yellowish-brown	7
Shale, very dark gray to black	14
Sandstone, yellowish-brown to light-gray, fine- to very fine grained	4
Shale, silty, purplish-gray; weathers pink	5
Sandstone, light-gray to grayish-yellow, very fine grained	14
Siltstone, medium-gray, soft	1. 5

Stratigraphic section of parts of the Fall River and Lakota Formations in sec. 12, T. 55 N., R. 65 W., Crook County, Wyo.—Continued

	Feet
Fall River Formation—Continued	
Sandstone, light-gray to grayish-yellow, very fine grained	7.5
Siltstone, gray; interbedded and interlaminated with light-gray very fine grained sandstone; very thin bedded	11
Sandstone, light-gray, very fine grained, thin-bedded	4
Siltstone, light- to medium-gray, shaly, carbonaceous	5
Measured thickness of the Fall River Formation	118
Lakota Formation (part):	
Siltstone, medium-gray, weathers yellow locally; clayey	10
Sandstone, light-gray, very fine grained, carbonaceous	4
Claystone, medium-gray to black	80.5
Claystone, light-gray, olive gray, and greenish-gray	62
Poorly exposed; appears to be mostly medium-gray slightly silty claystone, mottled yellow, purplish gray, and red; soft	9
Siltstone, light-gray, fissile, soft	2
Sandstone, light-gray to grayish-yellow, fine- to very fine grained, friable	2.5
Claystone, grayish-red and yellow at base becoming medium-gray at top	6.5
Covered	25±
Sandstone, very light gray, fine- to very fine grained, friable	10
Measured thickness, Lakota Formation	212±

LAKOTA FORMATION

Outcrop and extent.—The Lakota Formation is exposed over large areas in northern and western Crook County. It underlies flat or slightly outward-dipping plateau surfaces in the Bear Lodge Mountains and dip slopes on the eastern flanks of the Black Hills uplift. The beds of sandstone and associated conglomerate of the Lakota Formation have been identified in many deep wells drilled in the extreme northern and western parts of Crook County.

Lithology and thickness.—The Lakota Formation varies widely in composition and appearance throughout the report area. At most places it is composed of a variable sequence of lenticular sandstone and variegated siltstone and claystone. Locally the rocks consist predominantly of green, red, yellow, and gray claystone and siltstone interspersed with thin lenticular sandstone beds. The sandstone is light to yellowish gray, fine to coarse grained, well sorted, and friable, although coarse-grained and conglomeratic sandstone is not uncommon. Beds are generally lenticular and thin bedded to massive, though crossbedding and ripple marks are common in some outcrops. The thickness of the formation in the northern part of the Black Hills ranges from about 50 to as much as 300 feet; it may vary greatly within short distances.

Water supply.—The Lakota and the Fall River Formations are the principal aquifers in the report area. Few wells in Crook County obtain water solely from the Lakota, however, because in most areas it is overlain by the Fall River, and wells generally are constructed to derive water from both formations. Wells drilled into sandstone of the Lakota Formation low on the flanks of the uplift commonly flow; but in or near areas of outcrop, artesian pressures generally are not great enough to raise the water to the surface. The horizontal and vertical lithologic variations of the formation suggest a wide range in its capacity to transmit water, but in most places it will yield at least small supplies of water to wells, and moderate quantities may be expected in some areas. Yields generally are in proportion to the number, thickness, and extent of sandstone beds tapped.

Most of the wells flow, but the yield is generally small, ranging from reported flows of less than 1 to about 10 gpm. However, the flow of well 56–62–1ca from the Lakota Formation was measured at 70 gpm, and the flow of well 54–67–22da penetrating both the Fall River and Lakota Formations is reported to be more than 150 gpm. The results of a shut-in-pressure test made on well 56–62–28bb (log, table 12), which taps both the Lakota and Fall River Formations, are given in table 1.

In the areas of outcrop of the Lakota Formation, the sandstone in the upper part of the formation is generally dry. Springs and seeps, which are common along the contact with the underlying Morrison Formation, are fed by water moving downward through sandstone of the Lakota. Consequently, wells drilled near the contact of the Lakota and Morrison Formations generally are unsuccessful because much of the water has been drained from the Lakota. Except for these areas of local drainage, however, most of the water in the Lakota Formation moves downdip, away from the areas of outcrop, and the saturated thickness of the formation generally increases rapidly with distance from the contact with the underlying Morrison Formation. Wells drilled in areas underlain by the Lakota Formation should penetrate the entire thickness of the formation to obtain the maximum amount of water available. If an adequate supply of water is not found, generally it is advisable to drill into the Lakota at another site, if possible, rather than to continue into the Morrison Formation.

FALL RIVER FORMATION

Outcrop and extent.—The Fall River Formation crops out over much of the surface of the northern Black Hills, where it caps many of the high ridges and broad plateaus which make up the Bear Lodge Mountains. On the flanks of the uplifted area, sandstone of the Fall River underlies dip slopes and, where cut by erosion, forms prominent hogback ridges. The formation has been penetrated at depth in both water wells and oil-test holes drilled on the adjacent plains.

Lithology and thickness.—The Fall River Formation is composed mainly of light-brown tabular sandstone interbedded with dark-gray to black siltstone and claystone. The siltstone and claystone, which in places may make up most of the formation, locally contain thin carbonaceous layers and coal beds. The sandstone is light to yellowish brown, fine to medium grained, poorly cemented, thin to very thick bedded, and is commonly crosslaminated and ripple marked. Weathered surfaces show a jointed or blocky structure, and commonly have a gnarly appearance due to the presence of numerous iron concretions, which are more resistant to weathering than the sandstone.

The Fall River Formation, as seen in exposures in the northern part of the Black Hills, ranges in thickness from about 100 to 150 feet. Logs of wells drilled in the western part of the mapped area show the apparent thickness of the Fall River Formation to be as much as 250 feet, but this is probably exaggerated because of the greater thickness penetrated vertically where strata are inclined.

Water supply.—The Fall River Formation yields water to many domestic and stock wells in the northern part of the Black Hills and to a few deep wells on the adjacent plains. In most places, the water is under artesian pressure, but near the outcrop areas, where the aquifers are at shallow depths, the artesian head is low and wells generally do not flow. Where the aquifers are more deeply buried, the artesian pressure is greater; and, at many places in the valley of the Little Missouri River and the valley of the Belle Fourche River southeast of the "Big Bend," wells tapping the Fall River and the underlying Lakota Formation flow. The yields generally are small, ranging from 2 to 10 gpm. Darton (1909) reported flows of 10 to 100 gpm from wells drilled into the Fall River and Lakota in the vicinity of Belle Fourche, S. Dak.

The results of shut-in-pressure tests made at wells 55–61–8dc and 56–62–28bb, which tap both the Fall River and Lakota Formations, are given in table 1. A test hole drilled at location 55–67–4ac (log, table 12) reportedly penetrated about 140 feet of the Fall River and Lakota Formations without obtaining water. Faulting in the area (pl. 2) may have created a system of ground-water barriers by interrupting the continuity of water-bearing beds. Because of the lack of quantitative data, no conclusions can be drawn regarding the water-bearing potential of the Fall River Formation. However, the Fall River and Lakota Formations combined probably are potential sources of moderate supplies of ground water, and, at many places in Crook County, properly constructed wells may yield sufficient water for small community or industrial needs.

Wells drilled in areas of outcrop of the Fall River Formation generally yield at least small quantities of water, and moderate quantities may be expected where the formation is thick and composed in large part of sandstone. However, in deeply dissected areas, such as on the crest of the Bear Lodge Mountains and on the northeastern flank of the Black Hills where deep canyons have been eroded into the formation, sandstone of the Fall River may be almost completely drained. Prospecting for water in these areas should be done as far as possible from the margins of the Bear Lodge plateau and canyon rims. Any water found will probably be near the base of the formation and will be under little or no artesian pressure. Where the Fall River Formation is dry, most wells can be completed successfully by drilling into the underlying Lakota Formation. On the gentler northwestern slope of the Black Hills, the Fall River Formation is relatively undissected, and ground water is more easily obtained. The saturated thickness of the formation and artesian pressures increase toward the outcrop of the overlying Skull Creek Shale (pl. 2).

Because the Fall River and Lakota Formations are the principal source of ground water in the report area, 500-foot contour lines were drawn on the geologic map (pl. 2) to indicate the approximate depths to the top of the Fall River to a maximum of 1,000 feet below the land surface. The depths are based on elevations on the top of the Fall River, as shown by structure contours (pl. 2), and land-surface elevations, determined from topographic maps. The contours are generalized and do not reflect local differences in surface elevations, but the depths indicated probably are sufficiently accurate to permit estimations of drilling depths to the formation within the limits of the contour lines. For example, a well drilled midway between the 500- and 1,000-foot contours generally may be expected to penetrate the top of the Fall River Formation at a depth of 700 to 800 feet. Depths will differ locally, depending upon the topographic position of the well site. Approximate depths to formations lying above or below the Fall River may be estimated by referring to the thickness of formations given on plate 2 or in stratigraphic descriptions contained in the text.

SKULL CREEK SHALE

The Skull Creek Shale consists of 200 to 250 feet of black marine shale that grades vertically into the underlying Fall River Formation and the overlying Newcastle Sandstone. The formation is relatively impermeable and is not considered to be an aquifer in the area.

NEWCASTLE SANDSTONE

Outcrop and extent.—The Newcastle Sandstone forms a sinuous hogback ridge extending along the western border of Crook County from the southern margin to the Little Missouri River. North of the

Little Missouri, about 4 miles northwest of New Haven, the hogback swings abruptly northeastward and becomes a series of asymmetrical hills that dip gently northward. At the Montana State line, the outcrop is deflected sharply to the southeast, and the hills decrease in prominence as the formation thins and disappears in the northeastern part of the mapped area. The formation extends for some distance north and west of the outcrop area, where it has been penetrated at depth in several oil-test holes. It is familiarly known to oil-well drillers as the "Muddy."

Lithology and thickness.—The Newcastle Sandstone consists of light-gray slabby sandstone interbedded with darker gray shaly siltstone and claystone containing a few bentonite and lignite beds. In some areas either the sandstone or the shale may compose a major part of the sequence. The sandstone is characteristically light to yellowish gray, fine to medium grained, generally calcareous, and rather soft. The beds are lenticular, ranging in thickness from a few inches to several feet, and commonly exhibit crossbedding and ripple marks on weathered surfaces. The sandstone usually weathers to form weak benches between softer siltstone and claystone.

The formation is reported to be about 60 feet thick in the northwestern part of the area; it thins eastward, and the sandstone disappears in the southern part of T. 56 N., R. 61 W. Locally, it is absent or the dominance of shale causes it to be indistinguishable from the underlying Skull Creek Shale and overlying Mowry Shale. The average thickness is about 40 feet; however, it may differ greatly within short distances. The following stratigraphic section describes a part of the Newcastle sandstone, as exposed near the middle of the area of outcrop in Crook County. The formation becomes increasingly silty and shaly northward.

Stratigraphic section of part of the Newcastle Sandstone 2 miles west of New Haven, in sec. 27, T. 55 N., R. 67 W., Crook County, Wyo.

[Generalized from Grace, 1952, p. 36]

	Feet
Newcastle Sandstone (top removed by recent erosion):	
Sandstone, light-gray, fine-grained, calcareous, very hard; top half irregular and thin bedded; bottom half massive	5
Sandstone, light-brown, fine-grained, slightly friable; top half massive; lower half thin bedded	3. 25
Sandstone, white, fine-grained, massive	4
Sandstone, light-yellow, fine-grained, slightly friable	4
Sandstone, light-gray, fine-grained, calcareous, hard, thin- to medium-bedded, crossbedded in part	2. 50
Siltstone, light-gray, clayey, interbedded with gray to yellow clayey sandstone	15
Exposed thickness, Newcastle Sandstone	33. 75

Water supply.—Only a few wells in Crook County obtain water from the Newcastle Sandstone. Of three wells inventoried during the investigation, one is reported to yield a small quantity of water for stock use, and the other two are unused because of excessive pumping lifts. According to Grace (1952), the Newcastle Sandstone, except in the vicinity of New Haven, Wyo., is principally siltstone and claystone. Consequently, in most areas, it should not be expected to yield more than small quantities of water to wells. West of New Haven, where the formation attains a thickness of 25 to 40 feet and consists mostly of fine-grained sandstone, the yields may be somewhat greater than elsewhere. The steep westerly dip of beds in the area causes the Newcastle Sandstone to lie at a prohibitive drilling depth only a short distance west of the outcrop area.

The Newcastle Sandstone is poorly exposed in the report area, but wells drilled in areas underlain by the more easily distinguishable Mowry Shale should penetrate the Newcastle at depths no greater than about 200 feet near the contact of the Mowry Shale and the Belle Fourche Shale (pl. 2). The rate of increase in depth is very rapid along the west side of the Black Hills uplift but more gradual to the northwest, where the dip of beds is much less steep. Before a production well is constructed in the Newcastle Sandstone, test drilling is advisable. Where the Newcastle is dry, or where the pumping lift is excessive, the well might be drilled an additional 200 to 300 feet to penetrate the Fall River Formation. Water in the Fall River probably will not flow, but artesian pressure should raise it to within a few feet of the surface.

SHALES OF CRETACEOUS AGE

Overlying the Newcastle Sandstone is 3,000 to 5,000 feet of predominantly dark-gray and black shale that comprises, in ascending order, the Mowry Shale, Belle Fourche Shale, Greenhorn Formation, Carlile Shale, Niobrara Formation, and Pierre Shale. The formations are described briefly on plate 2. This sequence of shale is only locally sandy and, except possibly for the Groat Sandstone Bed (Rubey, 1930, p. 4) of the Gammon Ferruginous Member of the Pierre Shale, generally yields little water.

GROAT SANDSTONE BED OF THE GAMMON FERRUGINOUS MEMBER OF THE PIERRE SHALE

Outcrop and extent.—The Groat Sandstone Bed lies approximately 700 feet above the base of the Pierre Shale and about 150 feet below the top of the Gammon Ferruginous Member. The unit crops out in the northwestern part of the area as a low discontinous ridge rising above the softer shale underlying the plains. Exposures may be traced from a point 3 miles west of New Haven northward into Montana.

Lithology and thickness.—The Groat Sandstone Bed consists of a sequence of yellowish-gray ferruginous sandstone and interbedded thin gray siltstone and claystone. The sandstone is very fine to fine grained, silty, calcareous, and friable. It is generally thin bedded, crosslaminated, and ripple marked, and characteristically weathers to soft slabby rather poorly exposed outcrops. The unit thickens northward from a thin edge west of New Haven to a reported 125 feet in southern Montana. The maximum thickness of the Groat Sandstone Bed in the report area is not know. The following stratigraphic section indicates the formation is predominantly sandstone in southern Carter County, Mont., about 5 miles north of the report area, but the proportion of claystone and siltstone increases southward, and the sandstone becomes much less dominant in Crook County.

Stratigraphic section of part of the Gammon Ferruginous Member of the Pierre Shale including the Groat Sandstone Bed in sec. 4, T. 9 S., R. 56 E., Carter County, Mont.

[Generalized from Robinson and others, unpub. data]

	Feet
Pierre Shale (in part):	
Gammon Ferruginous Member:	
Upper part (in part):	
Shale, gray and brownish-gray; silty at base; weathers light gray	15
Groat Sandstone Bed:	
Partly covered; mostly medium-gray fine-grained to silty soft sandstone; upper part grades into overlying unit	5
Sandstone, medium-gray to light brownish-gray with a slight greenish tinge, fine-grained, calcareous, glauconitic, arkosic, micaceous	6
Sandstone, medium-gray and yellowish-gray, very fine grained in middle and upper parts, silty and clayey in lower 20 ft, friable	70
Thickness, Groat Sandstone Bed	81
Lower part (in part):	
Claystone and shale, dark- to medium-gray, locally brownish-gray, silty, increasingly silty near top; grades into overlying unit	40

Water supply.—None of the wells inventoried in Crook County penetrate the Groat Sandstone Bed, thus the water-yielding capacity of the formation is not known. It is possible that the thicker and less silty units will yield small quantities of water to stock and domestic wells. The Groat Sandstone Bed, with the possible exception of the alluvium of the Little Missouri River valley, is perhaps the only potential source of ground water in the area between the outcrop of Newcastle Sandstone and the Fox Hills Sandstone to the west. Because of the steep westerly dip of the beds in the area, however, the Groat Sandstone Bed lies at excessive drilling depths for most purposes except in, or a short distance west of, the outcrop area.

In the area of outcrop of the Groat Sandstone Bed in the northwestern part of Crook County, where sandstone becomes more dominant, water might be obtained from relatively shallow wells drilled near the contact with the overlying shale (pl. 2). Depth to the formation increases northwestward, and drilling depths become excessive, for most purposes, a short distance from the outcrop. Generally it is advisable to drill test holes to determine the water-bearing potential of the aquifer before drilling a more expensive well, because the Groat Sandstone Bed differs greatly in thickness and composition from place to place.

FOX HILLS SANDSTONE

Outcrop and extent.—The Fox Hills Sandstone crops out as a narrow band of generally steeply dipping strata outlining the western margin of the Black Hills dome. The formation generally is poorly exposed, and outcrops in most of the area appear as low grassy ridges.

Lithology and thickness.—The Fox Hills is predominantly a grayish marine sandstone but commonly contains beds of gray shale and siltstone, which become more abundant near the base and locally may constitute a large part of the formation. The sandstone is gray to light brown, generally fine to medium grained, soft, and thin bedded. The rock has a slabby appearance on weathered surfaces and locally contains numerous calcareous and ferruginous concretions.

The formation is reported to range in thickness from 150 to 200 feet; but the lack of good exposures in the area and the gradational contact with, and the similarity to, the overlying Lance Formation makes it difficult to obtain accurate measurements. The contact is placed arbitrarily at the base of the lowest beds of carbonaceous shale or gray bentonitic clay in the Lance Formation. The description of a partial section of the Fox Hills measured just south of the map area is included here.

Stratigraphic section of part of the Fox Hills Sandstone 3 miles south of the report area in sec. 17, T. 48 N., R. 66 W., Weston County, Wyo.

[Generalized from Robinson and others, unpub. data]

	Feet
Top of ridge.	
Fox Hills Sandstone (in part):	
Sandstone, yellowish-gray, fine-grained, locally crossbedded	40
Shale, gray; thin (1 ft) fine-grained sandstone bed in lower part	26
Sandstone, light-gray, fine-grained; gray sandy shale in middle part	8
Shale, gray; some yellowish-gray sandy shale; thin (1 ft) fine-grained sandstone bed near middle and at base	43.5

Stratigraphic section of part of the Fox Hills Sandstone 3 miles south of the report area in sec. 17, T. 48 N., R. 66 W., Weston County, Wyo.—Continued

	Feet
Fox Hills Sandstone—Continued	
Shale, gray, sandy; a few thin light-gray fine-grained sandstone beds in upper part	34
Measured thickness, Fox Hills Sandstone, rounded	152

Water supply.—Little is known about the water-bearing possibilities of the Fox Hills Sandstone in the report area because only one well was inventoried that obtains water from the formation. A pumping test indicated that this well has a specific capacity of 0.2 gpm per foot of drawdown. (See table 1.) Low specific capacities (about 0.4 gpm per foot of drawdown) of two wells reportedly drilled into the Fox Hills Sandstone at Gillette, about 20 miles west of the report area, indicate a generally low permeability for the formation in that area. At most places, however, the formation probably will yield sufficient water for stock and domestic use.

Wells drilled in the area of outcrop of the Fox Hills Sandstone east of the Little Missouri River probably will be unsuccessful. The steep dip of the beds in this area also causes the formation to lie at great depths a short distance west of the outcrop. Water may be available where the outcrop broadens and is crossed by the intermittent Prairie Creek, which may provide additional recharge to that received from direct precipitation. A moderately thick section of water-saturated Fox Hills Sandstone may underlie the broad area of outcrop in the extreme northwest corner of Crook County. The Colgate Member of the Fox Hills, which consists of a massive sandstone in the upper part of the formation in Carter County, Mont., is probably represented here, and should be a potential source of ground water. The dip of beds in this area continues to be moderately steep, and depths to the formation increase rapidly northwestward (pl. 2). West of the outcrop area the formation is overlain by generally more permeable sandstone of the Lance Formation.

LANCE FORMATION

Outcrop and extent.—The Lance Formation is exposed only in the western part of Crook County. The outcrop extends in a broad band from the southern border to the north line of T. 55 N., R. 68 W., where it is deflected westward into Campbell County by the Rocky Point anticline. The outcrop swings northward and then northeastward in Campbell County and reappears in the extreme northwest corner of the mapped area (pl. 2). Poor exposures prevent a precise determination of formational boundaries at many places.

Lithology and thickness.—The Lance Formation consists of a nonmarine sequence of interbedded yellowish-gray sandstone and darker gray shaly siltstone and sandy claystone containing a few beds of black carbonaceous shale near the base.

Sandstone of the Lance Formation is yellowish gray, fine to medium grained, silty, and friable. The sandstone units are commonly lenticular, thin to thick bedded, and crosslaminated, and range in thickness from only a few inches to several feet. The thicker beds locally contain calcareous concretions, which in places attain diameters of several feet. The formation is reported to range in thickness from about 500 to 1,000 feet and is thinnest in the northern part of the county. Because of the difficulty of establishing the contact between the Lance and the overlying Fort Union Formation, some writers place the contact between the Cretaceous and Tertiary strata at the horizon above the highest dinosaur-bearing beds, where the first coal seams occur (Brown, 1958, p. 112). The following is a description of a partial section of the Lance Formation measured north of Oshoto, Wyo.

Stratigraphic section of part of the Lance Formation in the SW¼ sec. 7, T. 54, N., R. 67 W., Crook County, Wyo.

[Generalized from Robinson and others, unpub. data]

	Feet
Top of hill.	
Lance Formation (in part):	
Sandstone, light yellowish-gray to light-gray, medium- to fine-grained, friable	60+
Shale, medium-gray, silty, slightly carbonaceous	8
Sandstone, light-gray, fine-grained, crossbedded, very friable; weathers olive gray	2
Shale, brown, carbonaceous	8
Sandstone, light-gray, fine-grained, friable	20
Claystone, medium-gray, sandy, carbonaceous	16
Sandstone, light-gray, fine- to medium-grained, friable; weathers light brownish gray	15
Shale, medium-gray to olive-gray, slightly sandy	3
Sandstone, light-gray, fine- to medium-grained, friable, crossbedded; weathers light yellowish brown	95
Shale, medium-gray, slightly carbonaceous	12+
Measured thickness, Lance Formation, rounded	240

Water supply.—In areas of outcrop of the Lance Formation, water is generally easily obtainable. Yields differ from well to well throughout the area, depending upon the number, thickness, and extent of water-bearing sandstone penetrated. (See table 1.) The quantity of water available generally increases from the eastern margin of the outcrop, where the formation is thin, westward to the contact with the overlying Fort Union Formation, where the Lance attains its full thickness of about 1,000 feet. Wells normally yield adequate supplies of water for stock and domestic use at depths ranging from 100 to 150 feet and larger quantities probably can be obtained from deeper wells in most areas. The two community wells at Moorcroft penetrated about 300 feet of saturated Lance strata to obtain water for a public supply. Water in the Lance is under some artesian pressure at most places, and consequently water levels in wells are generally relatively near the surface; however, depths to water differ with differences in elevation of the land surface.

TERTIARY SYSTEM

Tertiary rocks lying within Crook County, except for a few small isolated remnants of the White River Formation of Oligocene age, are of early Paleocene age and are represented by the Tullock Member of the Fort Union Formation. The younger Lebo Shale and Tongue River Members of the Fort Union Formation and the overlying Wasatch Formation of Eocene age crop out in Weston and Campbell Counties a short distance south and west of the mapped area.

TULLOCK MEMBER OF THE FORT UNION FORMATION

Outcrop and extent.—The Tullock Member of the Fort Union Formation is exposed only in the westernmost part of the mapped area˙ The eastern boundary of the outcrop in most of its length lies only 2 to 4 miles east of the Campbell–Crook County line. The topography of the area underlain by the Tullock Member is characterized by sharp-crested and gullied ridges and narrow, twisting, ravinelike valleys that contrast sharply with the rolling topography of the Lance Formation to the east.

Lithology and thickness.—The Tullock Member is composed of a thick sequence of interbedded gray sandstone, siltstone, and claystone containing thin beds of subbituminous coal. The presence of thin coal beds distinguishes the Fort Union Formation from the lithologically similar strata of the underlying Lance Formation, upon which it rests conformably. The contact is generally established at the base of the lowest coal-bearing strata in the Tullock Member. The sandstone beds are light to yellowish gray, generally fine to medium grained, friable, commonly lenticular, and massive. The following description of an outcrop of the Tullock Member 1 mile west of the report area probably is representative of exposures in Crook County.

Stratigraphic section of part of the Tullock Member of the Fort Union Formation 1 mile west of the report area in sec. 35, T. 56 N., R. 69 W., Campbell County, Wyo.

[Generalized from Robinson and others, unpublished data]

	Feet
Top of hill.	
Fort Union Formation (in part):	
Tullock Member (in part):	
Sandstone, very light-gray, medium- to fine-grained, friable; contains calcareous sandstone concretions as much as 5 ft thick, 25 ft wide, and 50 ft long	10
Shale, dark-brown to black, coaly	2
Sandstone, light-gray, very fine grained, friable; weathers yellowish gray	9
Claystone, medium-gray	11
Siltstone, light-yellowish-gray, shaly	3
Claystone, medium-gray to brown	7
Sandstone, very light gray, very fine grained, locally shaly to slabby, friable	21
Shale, gray to brown, carbonaceous	5
Sandstone and siltstone, light-gray, very fine grained	8
Claystone and shale interbedded, light-gray to dark-brown and black, sandy and carbonaceous	12
Sandstone, light-gray, fine-grained, friable; weathers yellowish-gray; contains beds of gray to brownish-gray carbonaceous shale	22.5
Shale, gray to dark-brown; contains thin coal seams	13
Measured thickness, Tullock Member, Fort Union Formation, rounded	123
Lance Formation.	

The Tullock Member increases in thickness westward from an eroded edge along the eastern margin of its outcrop to approximately 1,000 feet about 6 miles west of the Crook–Campbell County line in the vicinity of Rozet. It apparently thins to the north, because only about 500 feet is reported near the Montana State line.

Water supply.—The Tullock Member of the Fort Union Formation yields water to a few stock and domestic wells in the extreme western part of Crook County. During the investigation, four wells were tested to determine their specific capacities, and the coefficients of transmissibility and permeability of the aquifer. (See table 1.) In 1954 the Geological Survey made a study of the availability of ground water at the Wyodak Coal Mine in Campbell County, about 20 miles west of Moorcroft. The results of pumping tests indicated that the Fort Union Formation in that area has an average coefficient of permeability of about 3 gpd per square foot and an average coefficient of transmissibility of about 1,000 gpd. The specific capacities of the four wells used in the Wyodak test ranged from 0.5 to 1 gpm and averaged about 0.9 gpm per foot of drawdown. An 840-foot well drilled in the Fort Union Formation at Gillette, about 25 miles west of Moorcroft, had a specific capacity of 0.7 gpm per foot of drawdown when tested (Littleton, 1950, p. 14).

In areas of outcrop of the Tullock Member, wells generally yield sufficient water for stock and domestic use. Larger yields may be obtained from deep wells in areas where the saturated thickness is great, but pumping lifts will increase proportionately and may become excessive for many purposes. The saturated thickness is least along the eastern margin of the outcrop and increases rapidly westward owing both to the dip of the beds and rising surface elevations. Depth to water, which is relatively small in the eastern part of the outcrop area, becomes greater westward because of higher surface elevations and the drainage of the beds in the upper part of the formation by the many deep, narrow valleys that dissect the area. Owing to the irregularity of the terrain, it is difficult to predict the depth to water at any particular site. It is advisable to drill one or more small-diameter test holes to determine the availability of, and depth to water in areas where more than a small stock or domestic supply is desired. If not enough water is available from the Tullock Member, additional supplies generally can be obtained from the underlying Lance Formation.

WHITE RIVER FORMATION

Rocks of the White River Formation occur as isolated remnants of Oligocene strata that at one time may have covered much of the northern Black Hills. Outcrops are confined principally to the high divides in the vicinity of Missouri Buttes and along the northern and western sides of the Bear Lodge Mountains, where, at most places, they may rest unconformably on either the Fall River Formation or Skull Creek Shale. The deposits are more than 150 feet thick in some areas, but because of their small areal extent they are not considered to be a potential source of ground water. A brief description of the White River Formation is given on plate 2.

QUATERNARY SYSTEM

ALLUVIAL DEPOSITS

Outcrop and extent.—Deposits of stream-laid clay, silt, sand, and gravel underlie most of the stream valleys of Crook County. They range in thickness from only a veneer in the upland valleys and narrow canyons to several tens of feet in places in major stream valleys. Only the thicker and more extensive alluvial deposits are considered to be potential sources of large supplies of ground water in the area. They are shown on the geologic map (pl. 2) as occupying the valleys of the Belle Fourche and Little Missouri Rivers and their major tributaries.

Lithology and thickness.—Alluvial deposits in the report area are composed of unconsolidated or semiconsolidated clay, silt, fine sand, and lesser amounts of coarse sand and gravel. In areas where streams are entrenched in shaly sedimentary rocks, the valley fill is composed mainly of clay and silt and minor amounts of sand and gravel. In areas where stream channels cross coarser grained and more resistant bedrock, the proportion of coarse sand and gravel is greater. The Little Missouri flows almost entirely upon soft shale of Cretaceous age, and consequently relatively small amounts of coarser material have been deposited. The Belle Fourche River, on the other hand, crosses several sandstone outcrops in its southwestern reach, and the alluvium of its valley and those of its major tributaries probably contains a considerable amount of sand and gravel in some places. Logs of water wells and logs of test holes drilled along the Belle Fourche River (table 4) indicate that the clay, silt, and sand are interbedded, and that the deposits generally become coarser with depth.

The thickness of the alluvium underlying the valley of the Belle Fourche River was determined by augering a series of test holes across the valley at four different locations. (See pl. 2.) The locations of the lines of test holes are shown on plate 2, and the logs are given in table 4. The thickness of the alluvium at Keyhole Reservoir was obtained from logs of test holes drilled by the Bureau of Reclamation in 1947 preparatory to the construction of the dam.

TABLE 4.—*Logs of test holes*

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Test hole 1, section *B–B′*					
Alluvium:			Lance Formation:		
Silt, brown, sandy	5	5	Sandstone, gray, very fine to fine-grained, soft	15	28
Sand, brown, fine, silty (water at 7 ft)	8	13			
Test hole 2, section *B–B′*					
Alluvium:			Gravel(?) no sample	5	24
Silt, brown (water at 7 ft)	10	10	Clay, gray, plastic	3	27
Silt, dark-brown; contains some fine to coarse sand grains	2	12	Clay and silt, gray	6	33
Sand and fine to coarse gravel	7	19	Lance Formation:		
			Sandstone, brownish-gray, very fine grained, soft	2	35
Test hole 3, section *B–B′*					
Alluvium:			Sand, gray, fine to medium; more coarse grains than above	3	18
Sand, light-brown, very fine (water at 7 ft)	10	10	Clay and silt, gray, sandy	14	32
Sand, grayish-brown, fine to medium	2	12	Lance Formation:		
Sand, gray, very fine to fine, some coarse grains	3	15	Claystone, gray, sandy	35	67

TABLE 4.—*Logs of test holes*—Continued

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Test hole 4, section *B–B′*					
Alluvium:			Sand, gray, very fine to fine	4	24
Sand, light-brown, very fine (water at 7 ft)	8	8	Clay and silt, brownish-gray	6	30
Sand, grayish-brown, very fine	7	15	Lance Formation:		
Sand, gray, very fine, some coarse grains	4	19	Claystone, gray and green	17	47
Gravel(?) no samples	1	20			
Test hole 5, section *B–B′*					
Alluvium:			Sand, grayish-brown, fine to coarse; some clay and silt; lenses of fine to medium gravel	10	30
Sand, brown, very fine to fine, silty	6	6	Lance Formation:		
Sand, brown, very fine to coarse; coarser below 12 feet with some medium gravel (water at 8 ft)	14	20	Claystone, gray, sandy	12	42
Test hole 6, section *B–B′*					
Alluvium:			Lance Formation:		
Sand, brown, fine to coarse; contains clay or clay lenses (water at 10 ft)	24	24	Claystone, gray, silty	23	47
Test hole 7, section *B–B′*					
Alluvium:			Lance Formation:		
Clay and silt, dark-brown (no water)	15	15	Siltstone, brown, hard	2	17
Test hole 1, section *C–C′*					
Alluvium:			Fox Hills(?) Sandstone and Pierre Shale:		
Silt and fine sand, light-brown	5	5	Claystone, gray to black, sandy in upper part, plastic	21	42
Sand, light-brown, very fine (water at 7 ft)	6	11			
Sand, brown, fine to medium; contains lenses of fine to medium gravel	10	21			
Test hole 2, section *C–C′*					
Alluvium:			medium; contains lenses of fine gravel	13	25
Silt, brown	5	5	Pierre Shale:		
Silt, brown, sandy (water at 6 ft)	7	12	Claystone, dark - gray, plastic	12	37
Sand, brown, fine to					
Test hole 3, section *C–C′*					
Alluvium:			of fine to medium gravel	8	19
Silt and fine sand, brown (water at 7 ft)	11	11	Pierre Shale:		
Sand, brown, fine to coarse; contains lenses			Claystone, gray, plastic	18	37
Test hole 4, section *C–C′*					
Alluvium:			fine to coarse, contains large percentage of clay and some fine to medium gravel	11	31
Silt and fine sand, brown	11	11	Pierre Shale:		
Sand, dark-brown, fine to coarse; contains clay and fine gravel lenses (water at 13 ft)	9	20	Claystone, dark-gray	11	42
Sand, dark-brown, very					

TABLE 4.—*Logs of test holes*—Continued

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Test hole 5, section *C–C′*					
Alluvium:			Alluvium—Con.		
Clay and silt, dark brown, sandy, sticky (water at 23 ft)	23	23	Sand, dark-brown, fine to coarse; clayey; contains fine to medium gravel	17	40
			Pierre Shale:		
			Claystone, dark-gray	7	47
Test hole 1, section *D–D′* [Data for section *D–D′* obtained from records of Bureau of Reclamation, 1948]					
Alluvium:			Lakota Formation:		
Silt and sandstone fragments	8	8	Sandstone, medium- to coarse-grained, hard	94	102
Test hole 2, section *D–D′*					
Alluvium:			Morrison Formation:		
Silt, sand, and gravel (water at 6 ft)	23	23	Shale and siltstone, soft, calcareous	44	143
Lakota Formation:					
Sandstone, very fine-grained to coarse-grained, friable	76	99			
Test hole 3, section *D–D′*					
Alluvium:			Morrison Formation:		
Silt, sand, and gravel (water at 5 ft)	31	31	Shale and siltstone, soft, calcareous	40	132
Lakota Formation:					
Sandstone, fine- to coarse-grained, friable	61	92			
Test hole 4, section *D–D′*					
Alluvium:			Lakota Formation—Con.		
Sand	10	10	Conglomerate	5	110
Sand, fine, and gravel (water at 14 ft)	45	55	Morrison Formation:		
Sand and boulders	20	75	Shale, soft	19	129
Lakota Formation:			Interbedded siltstone and sandstone, calcareous	78	207
Sandstone, coarse-grained, friable	30	105			
Test hole 5, section *D–D′*					
Alluvium:			Lakota Formation—Con.		
Sand, silty	11	11	Conglomerate	6	100
Sand and gravel (water at 12 ft)	65	76	Morrison Formation:		
Lakota Formation:			Shale and siltstone, calcareous	29	129
Sandstone, coarse-grained, friable	18	94			
Test hole 6, section *D–D′*					
Alluvium:			Morrison Formation:		
Sand, silty	17	17	Interbedded shale and siltstone	90	188
Sand and gravel (water at 23 ft)	18	35			
Lakota Formation:					
Sandstone, coarse-grained, friable	63	98			
Test hole 7, section *D–D′*					
Lakota Formation:			Morrison Formation:		
Sandstone, coarse-grained, moderately hard (water at 50 ft)	134	134	Shale, siltstone, and limestone	40	179
Conglomerate	5	139			

TABLE 4.—*Logs of test holes*—Continued

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Test hole 1, section *E–E'*					
Alluvium:			Alluvium—Con.		
Silt, light-brown	10	10	Gravel, fine to medium	4	24
Sand, light-brown, very fine, silty	4	14	Sundance Formation (Stockade Beaver Shale Member):		
Sand, medium-brown, very fine to medium; contains a few coarse sand grains and pebbles (water at 15 ft)	6	20	Claystone, dark-gray, hard	8	32
Test hole 2, section *E–E'*					
Alluvium:			Alluvium—Con.		
Silt, light-brown	11	11	Sundance Formation (Hulett Sandstone Member):		
Sand, light-brown, fine to medium; contains some coarse sand grains and fine gravel; clayey near bottom (water at 15 ft)	10	21	Sandstone, yellowish-brown, very fine grained, soft	4	25
Test hole 3, section *E–E'*					
Alluvium:			Alluvinm—Con.		
Sand, medium-brown, very fine to fine, silty (water at 11 ft)	11	11	Sundance Formation (Stockade Beaver Shale Member):		
Sand, medium-brown, fine to medium, clayey; contains some coarse to very coarse grains	13	24	Claystone, grayish-green, hard	18	42
Test hole 1, section *F–F'*					
Alluvium:			Spearfish Formation:		
Sand, medium-brown, fine to coarse; some silt; contains lenses of fine to medium gravel (water at 7 ft)	24	24	Siltstone, red	3	27
Test hole 2, section *F–F'*					
Alluvium:			Alluvium—Con.		
Silt, dark-brown	9	9	Gravel(?); no samples	15	32
Sand, dark-gray, fine to medium, silty, some coarse grains (water at 10 ft)	8	17	Spearfish Formation.		
Test hole 3, section *F–F'*					
Alluvium:			Spearfish Formation:		
Clay and silt, dark-brown; contains some fine to medium sand and a small amount of fine gravel (water at 27 ft)	27	27	Siltstone, red	7	34
Test hole 4, section *F–F'*					
Alluvium:			Alluvium—Con.		
Silt and fine sand, light-brown	12	12	Clay, silt, and fine sand, mixed, light-brown, sticky (water at 24 ft)	4	24
Sand, medium-brown, very fine to fine, some coarse grains and few pebbles	8	20	Spearfish Formation:		
			Siltstone, red	10	34

Water supply.—The alluvium of the Belle Fourche and Little Missouri Rivers and major tributaries contains ground water in quantities that differ locally with the permeability of the alluvium and the availability of recharge. Where the valley fill consists of saturated material composed in large part of coarse well-sorted sand and gravel, yields to wells may be relatively large; however, the total amount of water available is limited by the thickness and areal extent of the aquifer. Alluvial deposits composed of very fine material or a poorly sorted mixture of fine and coarse material, even though extensive and saturated, may yield water very slowly to wells. A comparison of the results of laboratory tests of samples of alluvium (tables 2 and 3) reveals that permeability is greatest in materials in which most of the grains lie within a relatively narrow size range, such as samples from test hole 50–68–25ca.

The results of pumping tests made on six wells are given in table 1. The differences in specific capacity and permeability obtained are probably due primarily to differences in the composition of the valley fill, although well construction may be a factor in the case of the three large-capacity wells. All are of relatively large diameter and two are gravel packed.

Most of the water developed from the alluvium of the Belle Fourche and Little Missouri River valleys is used domestically and for stock; relatively little is used for irrigation. The yields of these wells range from less than 10 to nearly 300 gpm. Water supplies are generally adequate to meet stock and domestic needs. Test drilling in the valley of the Belle Fourche River may reveal other areas underlain by deposits capable of supplying water for small-scale irrigation.

The more productive aquifers commonly occupy buried stream channels, concealed beneath more recent alluvial deposits, and probably are not directly related to present stream channels. The only reliable method of locating these buried channels is by test drilling. Right and wrong methods of locating buried channels in valley fill by test drilling are illustrated in figure 6. To insure success with a minimum amount of drilling, a series of regularly spaced holes should be drilled across the trend of the valley, as along line *B–B′* rather than along line *A–A′* or at random. It may be advisable to decrease the spacing between drill holes where the depth to bedrock appears to be increasing. For example, holes 3 and 4 show an increasing thickness of alluvial fill; therefore, hole 5 was drilled between them to locate the deepest part of the channel.

Fluctuations of the ground-water level in the valley fill generally may be correlated with variations in the flow of the adjacent stream. The general nature of fluctuations of the water table in the alluvium

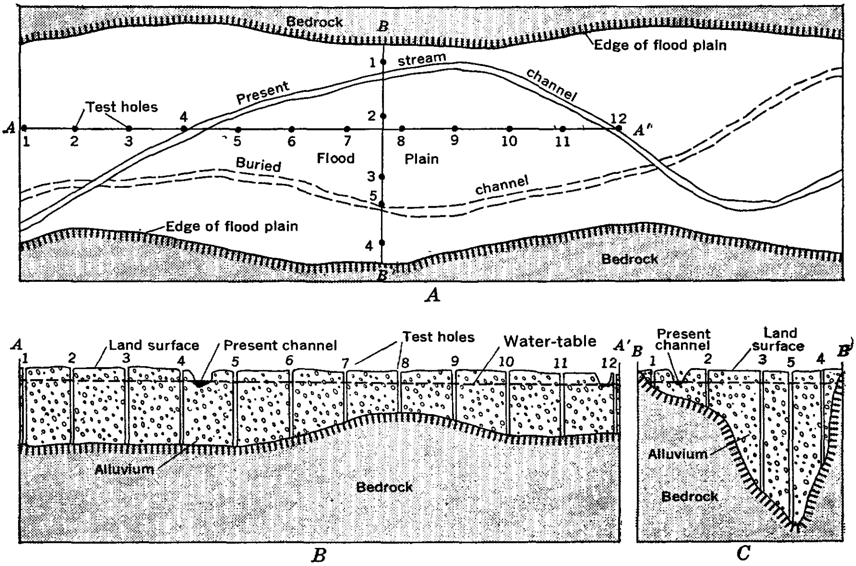

FIGURE 6.—Method of locating a buried channel in a stream valley by test drilling. *A*, Map of test-drilling programs. *B*, Section *A–A′*, none of the 12 test holes located the buried channel. *C*, Section *B–B′* test holes 3 and 4 outlined the buried channel. (After McLaughlin, 1954.)

is shown by a hydrograph of the water level in a shallow observation well (54–65–12ad) in the Belle Fourche River valley at Hulett (fig. 7). The hydrograph shows that the water table in the alluvium generally reaches its maximum height in early spring, when snow melt and spring rains produce heavy runoff in the Belle Fourche River. The water level declines gradually through the summer and fall, when rains are infrequent and the rate of evapotranspiration is high. Throughout the period of record, however, the average water level has remained fairly constant.

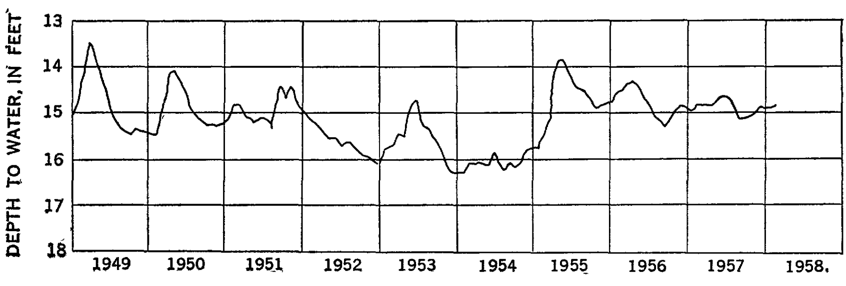

FIGURE 7.—Hydrograph of observation well 54–65–12ad, 19 feet deep, in alluvium of Belle Fourche River at Hulett, Wyo, showing water-level fluctuations in 1949–58.

UNDERFLOW IN THE ALLUVIUM OF THE BELLE FOURCHE VALLEY AT THE SOUTH DAKOTA STATE LINE

The purpose of the underflow study was to estimate the quantity of ground water moving through the alluvium of the Belle Fourche valley at the South Dakota State line. The stream valley is deeply intrenched in the nearly impermeable Skull Creek and Mowry Shales, and little lateral movement of ground water outside the valley fill is possible. The ground water in the alluvium moves southeastward, in the direction of the slope of the water table and in the direction of the gradient of the stream. The amount of ground water transmitted through the aquifer is proportional to the cross-sectional area through which the water moves, the permeability of the aquifer, and the slope of the water table.

The cross-sectional area of the aquifer was determined by augering test holes across the Belle Fourche valley, 0.3 mile east of the South Dakota State line. Seven test holes were spaced at 100-foot intervals, where possible, and were drilled to the underlying Skull Creek Shale. The augering was done with equipment and a drilling crew provided by the Eastern Clay Products Division of the International Mining and Chemicals Co. at Belle Fourche, S. Dak. Representative samples of the material penetrated were analyzed in the Hydrologic Laboratory of the Geological Survey at Denver, Colo., and the results are shown in tables 2 and 3. The slope of the water table in the alluvium was assumed to be comparable to the gradient of the stream, as determined from a topographic map of the area.

The width of the alluvial fill, measured at right angles to the movement of ground water, is about 650 feet, and the average thickness of the saturated material is 8.5 feet, giving a cross-sectional area of about 5,500 square feet.

The coefficients of permeability, as determined in the laboratory, ranged from 0.1 to 2 gpd per sq ft, and the average was 0.8 gpd per square foot. The average coefficient of permeability is the calculated average number of gallons per day that would pass through each square foot of the saturated material if the hydraulic gradient (slope of the water table) were 1 foot for each foot of horizontal measurement. Because the slope is roughly about 6 feet in 6,000 feet the amount of water passing through each square foot of alluvium is $6/6{,}000 \times 0.8$ gpd, or about 0.0008 gpd. Thus, the total estimated amount of ground water crossing the South Dakota State line in the valley (5,500 square feet$\times$0.0008 gpd$=$4.4 gpd) is less than 5 gpd.

Of the three factors involved in computing the underflow (cross-sectional area through which the ground water moves, coefficient of permeability, and hydraulic gradient), the coefficient of permeability is the most difficult to determine and affords the greatest possibility of error. Mechanical errors in collecting representative samples of the aquifer may have resulted in an appreciable error in the calculation of the average permeability; however, it is apparent that the underflow across the State line is extremely small.

AVAILABILITY OF GROUND WATER FOR IRRIGATION

The development of successful irrigation wells in northern and western Crook County probably will be confined principally to the valley of the Belle Fourche River. Relatively large amounts of water may be obtained from water-table wells drilled at favorable locations in the alluvium and from artesian wells tapping the Minnelusa Formation.

Permeable beds in the alluvial deposits of the Belle Fourche valley are relatively thin and are likely to be of small areal extent. Generally they will not support heavy sustained pumping without a resulting decrease in the amount of water in storage and a serious decline in water level. If the recharge during the nonpumping period replaces the pumped water, however, the discharge can exceed the average rate of recharge for short periods of time without causing serious lowering of the water level. In this way the aquifer can be used as a storage reservoir, to which water can be added or from which water can be withdrawn. To develop the maximum amount of ground water from the valley fill, water must be pumped in excess of the rate of recharge during the growing season, thus providing the maximum amount of storage for water that otherwise would be lost as surface runoff if the ground-water reservoir were permitted to remain filled.

Ground water discharging from seeps and springs in water-bearing formations cut by the valley of the Belle Fourche River locally maintain water levels in the alluvium that are higher than the stream bed. The resulting surface flow in these short reaches of channel is utilized for irrigation by pumping from sumps dug in the stream bed. The quantity of water available is generally small and is used principally to supplement that supplied by precipitation.

The generally high mineralization of water in alluvial deposits limits its application to plants with a moderately high salt tolerance. It is suitable for most hay and grain, alfalfa, sugar beets, and the more salt-tolerant vegetables.

The Minnelusa Formation lies at a minimum depth of about 600 feet in the Belle Fourche River valley between Devils Tower and Hulett. The depth to the formation increases to the northeast and southwest. Wells in the vicinity of Hulett were reported to have flows ranging from about 180 to 375 gpm when drilled. These wells penetrate only the upper part of the Minnelusa, and larger flows may be expected from deeper wells. Most of the wells probably would yield appreciably more water if suitable pumps were installed.

Water in the Minnelusa Formation, though normally very hard, has a relatively low concentration of dissolved solids, and is suitable for the cultivation of most farm crops and vegetables.

SUMMARY OF GROUND-WATER CONDITIONS

In summarizing the ground-water conditions in northern and western Crook County, the discussion is confined principally to the areas within the drainage systems of the Belle Fourche and Little Missouri Rivers. It is within these lowland areas that additional supplies of water can be utilized most profitably and that moderate to large supplies possibly may be developed. The upland region between the two rivers holds little promise for the development of more than small amounts of ground water.

BELLE FOURCHE RIVER DRAINAGE AREA

Oshoto-Moorcroft area.—Wells drilled west of a line extending from a point about 3 miles east of Moorcroft to Oshoto obtain water from the Fort Union Formation, Lance Formation, Fox Hills Sandstone, or from the alluvium of the Belle Fourche River valley and its major tributaries. The great thickness of shale underlying the Fox Hills Sandstone and the steep dip of the beds along the western limb of the Black Hills monocline causes other aquifers in the area to lie at depths ranging from 3,000 to 5,000 feet. Yields of wells generally range from a few gallons per minute from the Fort Union and Fox Hills to perhaps as much as 150 gpm from sufficiently deep wells in the Lance.

East of this imaginary line, the area between the outcrop of the Fox Hills Sandstone and the Fall River Formation is underlain by a sequence of shale ranging in thickness from an eroded edge against the Black Hills to more than 4,000 feet where the entire sequence is present. Successful wells generally must be drilled to the Fall River and, perhaps, to the underlying Lakota Formation. Drilling depths become excessive for most purposes only a short distance west of Fall River outcrops because of the steep dip of beds in the area. (See pl. 2.) Water in the Fall River and Lakota Formations is under artesian pressure and generally will flow or rise to within a short distance of the surface when tapped by wells. Flows of wells are generally small, but yields from pumping probably would be somewhat greater. Wells penetrating a sufficiently thick section of shale may yield adequate supplies suitable for stock use, but the chemical quality of the water probably will limit its domestic use.

The development of ground water in alluvial deposits in the Oshoto-Moorcroft area has been confined principally to the valleys of the

Belle Fourche River, and of Donkey and Buffalo Creeks. Supplies normally are adequate for stock and domestic use, and, where the saturated sand and gravel deposits are sufficiently thick and extensive, moderate to large quantities of ground water might be developed.

Keyhole Reservoir to the "Big Bend" of the Belle Fourche River.—The Morrison, Sundance, and Spearfish Formations, which underly the Belle Fourche valley in this area generally are capable of yielding only small quantities of water to wells. The Hulett Sandstone Member of the Sundance Formation may yield moderate supplies of water where the sandstone is thick and saturated.

The Minnelusa Formation yields relatively large quantities of water to several flowing wells in the vicinity of Hulett. It is the only potential source of domestically acceptable water, within an economic drilling depth, in that part of the Belle Fourche valley in which the Spearfish Formation crops out. The depth to the formation ranges from about 550 feet at Devils Tower to perhaps as much as 700 feet where the entire Spearfish is present. Successful wells would be appreciably deeper where the Minnelusa contains a large proportion of evaporite deposits in its upper part.

The alluvium underlying the Belle Fourche valley in this area is very permeable in places and capable of yielding sufficient water for small-scale irrigation. However, as elsewhere, the composition of alluvial deposits differs greatly, and the success of a well depends upon the thickness of saturated permeable material penetrated.

"Big Bend" of the Belle Fourche River to the South Dakota State line.—Several flowing wells in and adjacent to the valley of the Belle Fourche River in this part of the report area tap the Fall River and Lakota Formations. The wells are generally only 300 to 400 feet deep, although some are deeper and a few are shallower. Flows are characteristically small, but yields of most wells probably could be increased by the installation of pumps. Northeast of the Belle Fourche valley drilling depths to the Fall River increase markedly; wells generally do not flow, but water levels will normally be near the land surface.

The alluvium of the Belle Fourche River in this area contains a large proportion of clay and silt. Laboratory analyses of alluvial samples indicate that the permeability of the valley fill is very low. The possibility of constructing water wells that will yield more than stock or domestic supplies is not favorable.

LITTLE MISSOURI RIVER DRAINAGE AREA

Several flowing wells have been drilled in the Fall River and Lakota Formations in, or a short distance east of, the Little Missouri River valley between Oshoto and the Montana State line. The wells generally yield only small quantities of water (3–10 gpm) but, as elsewhere, larger quantities probably can be obtained by installing pumps. West and northwest of the Little Missouri River, the Fall River and Lakota Formations lie too deep to be considered potential aquifers. The Newcastle Sandstone may contain some water but wells tapping the sandstone will probably not flow, and yields are expected to be small. West of R. 67 W., the Groat Sandstone Bed may yield small quantities of water to wells.

The alluvial deposits underlying the valley of the Little Missouri River in Crook County are probably composed chiefly of intermixed clay, silt, and very fine sand. Careful prospecting may locate more permeable sand and gravel deposits, but they are probably neither thick nor extensive. At most places yields of wells would be small and would fluctuate in response to recharge.

AREA BETWEEN THE BELLE FOURCHE AND LITTLE MISSOURI RIVERS

In the high divide area separating the drainage of the Belle Fourche River system from that of the Little Missouri, the prospects of obtaining more than small quantities of ground water from drilled wells generally are poor. Because the area lies near the crest of the Black Hills uplift and has been deeply dissected, ground water is usually at a considerable depth. Supplies adequate for stock and domestic use may be expected from most of the consolidated rocks of the area, but pumping lifts at most places will be relatively great.

The alluvium of the narrow stream valleys is generally thin and coarse and thus provides little opportunity for the storage of large supplies of ground water. Shallow dug wells are the best means of collecting alluvial water in most places.

THE CHEMICAL QUALITY OF THE GROUND WATER

By Russell H. Langford

The suitability of water for its many uses depends to a large extent on its chemical quality. As part of the investigation, a study was made to determine the chemical quality of the ground water, to relate the chemical characteristics to the geology and hydrology of the area, and to evaluate its suitability for different uses. Samples of water were collected during August and October 1956 from representative wells that tap the Minnelusa Formation of Pennsylvanian and Permian age; the Spearfish Formation of Permian and Triassic age; the Gypsum Spring, Sundance, and Morrison Formations of Jurassic age; the Lakota, Fall River, and Lance Formations of Cretaceous age; the Fort Union Formation of Tertiary age; and alluvium of Quaternary age. The samples were analyzed by the U.S. Geological Survey using methods common to the field of water chemistry (Rainwater and Thatcher, 1960), and the results of the analyses are given in table 5; the locations of the sampled wells are shown on plate 2.

EXPRESSION OF DATA

The concentrations of dissolved constituents in the water are reported in parts per million (ppm). A part per million is a unit weight of a constituent in a million unit weights of water. The specific conductance of water, which is expressed in micromhos per centimeter at 25°C, is a measure of the ability of the water to conduct an electrical current and is related to the amount and the chemical types of dissolved material. Because it is related to the amount of dissolved material, specific conductance can be used for approximating the total mineralization. The pH indicates the degree of acidity or alkalinity. A pH progressively higher than 7 denotes increasing alkalinity, and a pH progressively lower than 7 denotes increasing acidity.

Percent sodium and sodium-adsorption ratio are useful in evaluating the suitability of water for irrigation. They are calculated, with concentrations in equivalents per million (epm), as follows:

$$\text{Percent sodium} = \frac{100Na^{+1}}{Ca^{+2}+Mg^{+2}+Na^{+1}+K^{+1}}$$

$$\text{Sodium-adsorption ratio} = \frac{Na^{+1}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$$

An equivalent per million is a unit for expressing concentrations of chemical constituents in terms of the interreacting values of the ions. One epm of a positively charged ion (cation) will react with one epm of a negatively charged ion (anion). Because the positive and negative charges are balanced in a solution, the total of the equivalents per million of the predominant cations (calcium, magnesium, sodium, and potassium) is approximately equal to the total of the equivalents per million of the predominant anions (bicarbonate, carbonate, sulfate, chloride, fluoride, and nitrate). Parts per million are converted to equivalents per million by multiplying by the following factors:

Constituent	*Factor*	*Constituent*	*Factor*
Calcium (Ca^{+2})	0.04990	Bicarbonate (HCO_3^{-1})	0.01639
Magnesium (Mg^{+2})	.08224	Carbonate (CO_3^{-2})	.03333
Sodium (Na^{+1})	.04350	Sulfate (SO_4^{-2})	.02082
Potassium (K^{+1})	.02558	Chloride (Cl^{-1})	.02820
		Fluoride (F^{-1})	.05263
		Nitrate (NO_3^{-1})	.01613

TABLE 5.—*Chemical analyses, in parts per million, of*

[Color: units in platinum-

Well location	Depth of well (ft)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
Alluvium												
		1956										
50-67-4 cc	39.2	Oct. 2	49	19	11	------	52	19	281	7.1	648	0
53-67-8 cc	60	Nov. 5	------	14	.36	------	70	37	332	5.6	733	0
54-65-13ba	38	Oct. 18	49	19	3.0	------	365	73	27	6.8	305	0
55-64-32cb	32.0	Aug. 16	49	19	.21	------	260	60	69	6.2	256	0
57-65-22ca2	80	Oct. 3	52	3.9	1.3	------	34	28	970	17	367	6
(1)	32	Aug. 16	51	13	5.8	------	240	66	202	7.5	276	0
Fort Union Formation,												
49-68-29bc	155.1	Aug. 16	51	7.4	0.18	------	10	4.6	400	3.3	480	0
Lance												
50-67-31dd2	406	Oct. 2	53	9.3	0.02	0.00	6.0	3.2	440	1.6	722	0
68-14cd	97.0	Aug. 16	50	6.7	.69	------	11	6.2	315	3.6	550	0
Lakota and Fall												
55-61-8 dc	315	Aug. 16	57	8.0	2.0	------	113	49	70	15	356	0
56-62-28bb	333	Aug. 16	52	9.0	.23	0.08	38	16	68	9.2	258	0
66-11ca	125	Oct. 28	------	9.6	.74	------	58	21	486	10	339	0
57-64-3db	390	Oct. 30	56	8.8	.87	------	39	15	206	12	385	0
58-64-35ac	280	Oct. 30	------	8.2	5.5	------	74	32	232	19	356	0
Morrison												
56-63-7bd	300	Aug. 16	51	9.2	0.32	0.00	23	10	276	8.7	250	0
Sundance Formation, Redwater												
56-63-15ad	60	Oct. 2	54	11	0.36	------	37	19	222	7.2	231	0
Gypsum Spring Formation and Stockade												
54-65-11ab	52	Aug. 16	49	24	0.36	------	318	130	129	13	310	0
Spearfish												
55-64-21cd	150	Aug. 16	52	36	1.9	------	518	94	59	7.0	304	0
Minnelusa												
54-64-7 bc1	663	Oct. 2	56	12	0.49	0.00	113	36	4.1	2.2	280	0
(2)	1,180	Oct. 31	61	14	.02	------	137	36	2.4	1.4	260	0

[1] In South Dakota, 5 miles southeast of point where Belle Fourche River crosses Wyoming-South Dakota boundary.
[2] In South Dakota, about 5 miles south of Belle Fourche.

ground water in northern and western Crook County, Wyo.

cobalt scale (Hazen, 1892)]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Color (units)	Turbidity (as ppm SiO_2)
Alluvium—Continued														
295	9.0	0.4	0.3	0.33	1,010	1,020	206	0	74	8.5	1,640	7.8	------	------
450	7.5	.4	.8	.28	1,280	1,310	326	0	68	8.0	1,890	7.7	1	------
970	3.5	.5	.0	.26	1,620	1,770	1,210	960	5	.3	1,940	7.2	4	------
815	4.5	.4	.1	.21	1,360	1,450	895	685	14	1.0	1,720	7.6	------	------
1,950	6.0	.6	.1	.95	3,200	3,340	200	0	90	30	4,450	8.2	------	------
1,060	8.0	2.8	.2	.35	1,740	1,840	870	644	33	3.0	2,200	7.4	------	------
Tullock Member														
510	8.5	1.6	4.2	0.18	1,190	1,200	44	0	95	26	1,810	8.2	------	------
Formation														
365	4.0	0.0	2.4	0.19	1,190	1,210	28	0	97	36	1,830	8.1	3	0.5
275	10	.8	.1	.23	------	922	53	0	92	19	1,440	8.2	------	------
River Formations														
350	5.0	0.2	0.1	0.07	------	822	484	192	23	1.4	1,160	7.3	------	------
105	2.0	.3	.1	.18	------	377	162	0	46	2.3	624	8.0	------	------
1,020	7.0	.4	.0	.27	1,780	1,820	231	0	81	14	2,530	7.6	1	------
305	5.0	.4	.0	.21	------	794	159	0	72	7.1	1,200	7.7	1	------
545	8.0	.4	.0	.22	1,100	1,120	318	26	60	5.6	1,600	7.6	1	------
Formation														
460	6.0	0.8	0.7	1.8	------	933	100	0	84	12	1,400	8.2	------	------
Shale and Lak Members														
475	3.0	0.3	0.4	0.22	------	894	169	0	73	7.4	1,330	8.0	------	------
Beaver Shale Member of Sundance Formation														
1,310	7.0	1.3	1.0	0.31	2,090	2,310	1,330	1,080	17	1.5	2,500	7.7	------	------
Formation														
1,490	13	0.9	3.7	0.47	2,370	2,590	1,680	1,430	7	0.6	2,620	7.7	------	------
Formation														
203	1.0	1.8	0.1	0.05	------	551	431	201	2	0.1	794	7.5	2	2
270	.0	.2	.6	.05	------	625	492	279	1	.0	864	7.7	1	------

GEOCHEMISTRY

The principal solutes of natural water are alkali and alkaline earth, bicarbonate, sulfate, and chloride. Silica, iron, manganese, potassium, fluoride, nitrate, boron, and gases—such as hydrogen sulfide and carbon dioxide—are present also, but generally in small amounts.

The amount and kind of chemical constituents depend on the past environment of the water. Rainwater contains only small amounts of dissolved salts and gases; however, as water infiltrates the earth's crust, it dissolves gases—principally carbon dioxide—and soluble minerals. Water charged with carbon dioxide is a particularly active solvent for carbonate rocks, and water in contact with gypsiferous rocks may dissolve large amounts of calcium sulfate. Fine-grained rocks, such as shale, expose considerable surface area to the solvent action of the water, and aquifers containing these fine-grained rocks usually yield highly mineralized water. Conversely, sandstone and sand and gravel expose less surface area, are more resistant to the solvent action of water, and, therefore, yield water of low mineralization. However, in semiarid regions, such as in eastern Wyoming, some sand and gravel may contain large amounts of soluble material, or some sandstone may contain cementing material that is very soluble.

The longer water is in contact with rocks, the more mineralized it becomes. Rainwater or snowmelt that runs off quickly is usually of low mineralization, but water that infiltrates the earth's crust is in contact with rocks for longer periods of time and thus is usually more highly mineralized than overland runoff.

Chemical reactions can cause changes in the chemical characteristics of water as it moves through rocks. Some of these reactions and changes are as follows:

1. Evapotranspiration concentrates the water solution, and some of the least soluble salts, such as calcium carbonate, may precipitate.
2. Cation-exchange softening can occur when water is in contact with clay (such as bentonite) or natural zeolites. Calcium and magnesium from the water may be exchanged for sodium from the clay. As a result, the water tends to become enriched with sodium and depleted of calcium and magnesium.
3. Reduction of sulfate in the water results in an equivalent increase in carbonate. The reaction takes place in the presence of organic matter, such as methane gas, and is reported by Riffenburg (1925, p. 39), as follows:

$$CaSO_4 + CH_4 = CaCO_3 + H_2S + H_2O$$

Riffenburg (1925, p. 39–41) experimented with samples of sandstone from the Lance Formation, the Fort Union Formation, and the

Eagle Sandstone and with samples of shale from the Lance Formation from Rosebud and Fergus Counties, Mont. The experiments consisted of infiltrating natural water through, or allowing it to remain in contact with rock samples and comparing the analyses of the water before and after contact. Although the rock samples probably were somewhat weathered, Riffenburg concluded that the results of the experiments illustrate the kinds of exchange and sorption that take place as water moves through these formations. The experiments showed that the hardness (as $CaCO_3$) of water in contact with sandstone from the three formations decreased by as much as 300 ppm (parts per million) for lengths of time between 5 minutes and 2 months. Although the hardness of the water in contact with shale from the Lance Formation increased during the first 40 hours of the experiment, the hardness had decreased to an amount less than that of the original water after 40 days of contact. The concentration of chloride in the water remained about the same in all the tests, but the concentrations of bicarbonate decreased and that of sulfate increased in most of the tests with sandstone. Bicarbonate and sulfate concentrations were not determined for water in contact with shale.

The results of Riffenburg's experiments probably are fairly representative of the cation-exchange softening of water moving through some of the water-bearing formations in the report area. Many of these water-bearing formations are calcareous or gypsiferous and would normally yield very hard water (more than 200 ppm hardness as $CaCO_3$) to wells. The fact that some of these formations yield soft water (less than 60 ppm hardness as $CaCO_3$) is evidence that cation-exchange reactions are occuring as the water moves through the formations.

Oxidation-reduction reactions involving sulfate and carbonate probably do not occur extensively in the report area, because most ground water in the area is of the sulfate type. However, because some formations of Cretaceous age contain coal and other carbonaceous materials, oxidation–reduction reactions probably occur locally.

CHEMICAL CHARACTERISTICS OF THE WATER

The chemical characteristics of the water can be described only in a general way, because a relatively small number of samples were obtained for analysis. However, the specific conductances of water from many wells, determined in the field during the summer of 1956, aided in selecting wells from which representative samples could be obtained. Data from previous reports describing the quality of water in areas south and west of the report area are used to augment the data obtained for this study. Information concerning the geologic source of the water and the depths of wells near Newcastle and Osage was obtained from Williams (1948.)

The chemical characteristics of water from aquifers in the different formations in the report area are illustrated by bar diagrams in figures 8 and 9. The height of each bar diagram is proportional to the total

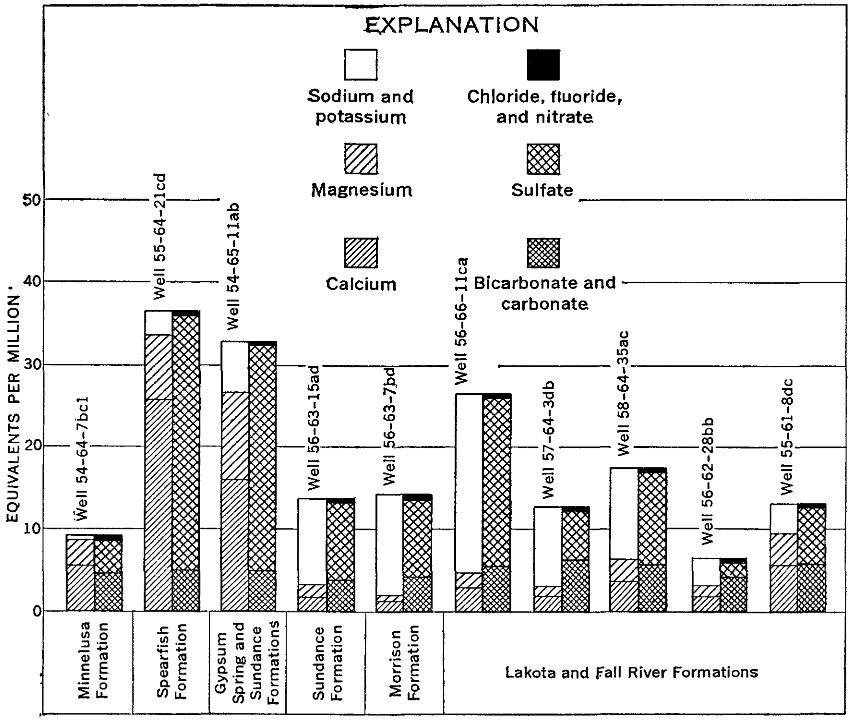

FIGURE 8.—Chemical characteristics of water from rocks of Pennsylvanian, Permian, Triassic, Jurassic, and Early Cretaceous age, Crook County, Wyo.

mineralization of the water, and the relative height of each of the bar diagrams indicate the chemical type of the water. For example, water from well 50–67–31dd3 (fig. 9) is of the sodium bicarbonate type and contains about 1,200 ppm of dissolved solids, whereas water from well 55–64–21cd (fig. 8) is of the calcium sulfate type and contains about 2,500 ppm of dissolved solids. The chemical characteristics of water are described by major water-bearing formation in the following section.

PAHASAPA LIMESTONE

No data regarding the chemical characteristics of water from the Pahasapa Limestone in the report area are available, because the Pahasapa generally lies at a depth too great for economic water development. However, in the event that water from this source is

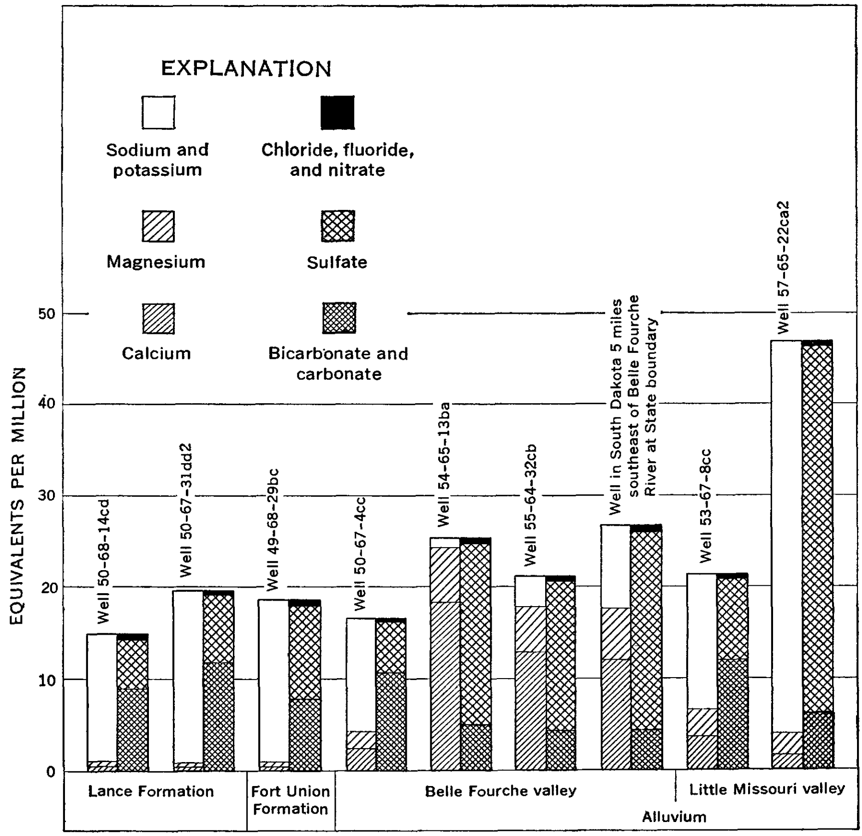

FIGURE 9.—Chemical characteristics of water from rocks of Late Cretaceous, Tertiary, and Quaternary age, Crook County, Wyo.

utilized in the future, data for water from wells southeast of the report area provide information that may be applicable in the report area.

Crawford (1940, p. 1304, 1308) gives an analysis of water from a well at Sundance, Wyo., which enters the Pahasapa at a depth of 750 feet and which produces water from a depth of 1,260 feet. The analysis, shown below, may not truly represent the chemical characteristics of water from the Pahasapa, as the sample may have been contaminated by drilling mud.

Constituent	*Parts per million*	*Constituent*	*Parts per million*
Calcium (Ca)	16	Bicarbonate (HCO_3)	310
Magnesium (Mg)	104	Sulfate (SO_4)	194
Sodium plus potassium as sodium (Na)	33	Chloride (Cl)	58
		Dissolved solids	577

The analysis does indicate, however, that the water from the lower part of the Pahasapa near Sundance is of relatively low mineralization, is of the magnesium bicarbonate sulfate type and is very hard.

724-488—64——5

Data regarding the chemical characteristics of water from the upper part of the Pahasapa Limestone south of the report area are given in table 6. The water from a deep (1,178 ft) flowing well northeast of Newcastle, Wyo., came from a zone 80 feet below the top of the Pahasapa. The analysis showed that the water is of relatively low mineralization, is of the calcium bicarbonate type, and is hard. Farther downdip, a 2,638-foot flowing well at Newcastle produces water from the upper part of the Pahasapa Limestone that is warmer and harder, although of the same type and mineralization as water from the well northeast of the city. The water from two other deep flowing wells near Newcastle came both from the upper part of the Pahasapa Limestone and the lower part of the Minnelusa Formation. Water from these two wells is similar in chemical characteristics to that from the wells tapping only the upper part of the Pahasapa, although it is slightly more mineralized.

Any wells that may be drilled to the Pahasapa Limestone in the Belle Fourche or Little Missouri River valleys would be much farther from the recharge area than the wells at Sundance and near Newcastle. As a result, water from wells in the two river valleys probably would be more highly mineralized than that from the wells nearer the recharge area in the Black Hills, although both sources probably would supply water of the calcium magnesium bicarbonate type. The increase in mineralization of water with increasing distance from the recharge area is indicated by data from Littleton (1950, p. 15). He reported that water from the Pahasapa at Gillette contained about 3,000 ppm of dissolved solids. However, Gillette is somewhat farther from the recharge area of the Pahasapa than are the Little Missouri and Belle Fourche River valleys.

MINNELUSA FORMATION

The water used for public supply in Hulett (well 54–64–7bc1 in table 5 and fig. 8) is representative of water from the Minnelusa Formation only in that part of the Belle Fourche River valley near Hulett. Here the water is of the calcium bicarbonate sulfate type, is very hard, and is of relatively low mineralization (551 ppm of dissolved solids). Field measurement of specific conductance indicated that water from nearby well 54–65–13bd (640 ft deep) contained approximately 500 ppm of dissolved solids. Although water from a well in the Redwater Creek valley south of Belle Fourche, S. Dak., (table 5) is similar in chemical characteristics to that from the Hulett well, water from wells near Devils Tower, Sundance, and Newcastle is much more highly mineralized and is of the calcium sulfate type. Analyses of water from the Minnelusa Formation south of the report area and at Devils Tower, within the report area, are given in table 7.

TABLE 6.—*Chemical analyses, in parts per million, of water from the upper part of the Pahasapa Limestone and the lower part of the Minnelusa Formation*

Geologic source of water	Upper part of Pahasapa Limestone		Upper part of Pahasapa Limestone and lower part of Minnelusa Formation	
Well location	Northeast of Newcastle	At Newcastle	Southeast of Newcastle	At Osage
Well	46-60-31d	45-61-20dc	44-60-6ad	46-63-10dc
Depth feet	1,178	2,638	1,300	2,592
Date of collection	Dec. 9, 1947	Apr. 1, 1957	Dec. 10, 1947	Dec. 9, 1947
Temperature °F	60	76	58	76
Silica (SiO_2)	11	14	7.6	5.6
Iron (Fe)	.05	.01	.00	.05
Calcium (Ca)	58	64	55	70
Magnesium (Mg)	9.8	28	13	19
Sodium (Na)	36	2.8	37	18
Potassium (K)	6.8	2.2	7.6	2.4
Bicarbonate (HCO_3)	306	290	300	296
Sulfate (SO_4)	16	38	27	47
Chloride (Cl)	1.8	2.0	2.8	1.2
Fluoride (F)	.5	.2	.7	.6
Nitrate (NO_3)	1.5	1.9	1.8	1.0
Boron (B)	.10	----------	.14	.07
Dissolved solids	290	297	298	346
Hardness as $CaCO_3$	185	274	191	252
Noncarbonate hardness as $CaCO_3$	0	37	0	9
Percent sodium	29	2	29	14
Sodium-adsorption ratio	1.2	.1	1.2	.5
Specific conductance micromhos at 25°C	492	504	504	529
pH	7.1	7.4	7.2	7.1

Comparison of the data in tables 6 and 7 indicates that the dissolved-solids content (principally calcium, magnesium, and sulfate) is higher in water from the upper part of the Minnelusa Formation than in that from the lower part. The presence of more gypsiferous rocks in the upper part of the Minnelusa than in the lower part may account for the high concentrations of calcium and sulfate in water from the upper part of the formation.

SPEARFISH FORMATION

Because the Spearfish Formation contains beds of gypsum, water from it is of the calcium sulfate type, and is very hard and highly mineralized. (See table 5 and fig. 8). Although only one sample of water from this formation was analyzed, a field measurement of specific conductance indicated that water from well 54–64–7cb has about the same dissolved-solids content (2,000–3,000 ppm) as that from well 55–64–21cd.

During periods of above-normal runoff, the Spearfish Formation may receive some water from the Belle Fourche River in the reach from about Devils Tower northeastward to T. 56 N., R. 63 W. Thus, the analysis in table 5 may represent the quality of water available from the Spearfish only in that reach of the Belle Fourche River valley. Water from wells that tap the Spearfish Formation in other parts of the report area might be even more highly mineralized than that from the two wells described in the preceding paragraph.

TABLE 7.—*Chemical analyses, in parts per million, of water from the Minnelusa Formation at Devils Tower and south of the report area*

[Some data rounded off to agree with Survey style]

Geologic source of water	Upper and middle sandstones of Minnelusa Formation.[1]	Lower part of Opeche and upper part of Minnelusa Formation.[2]	Upper part of Minnelusa Formation.[3]	Upper(?) part of Minnelusa Formation.[4]	Lower part of Minnelusa Formation.[3]
Well location	Southeast of Newcastle	North of Newcastle	East of Upton	At Devils Tower	At Sundance
Well	44-60-6ad	45-61-3a	47-64-12c	53-65-18ba	
Depth (ft)	1,010	720	1,560	608	----------
Date of collection	Dec. 10, 1947	Dec. 10, 1947	----------	June 1956	----------
Temperature °F	57	58	----------	----------	----------
Silica (SiO_2)	5.0	6.0	----------	----------	----------
Iron (Fe)	.05	.05	----------	0.55	----------
Calcium (Ca)	474	504	723	[5] 255	160
Magnesium (Mg)	84	142	252	[5] 124	94
Sodium (Na)	9.7	29	} 81	[5] 23	2
Potassium (K)	14	8.4			
Bicarbonate (HCO_3)	222	136	110	[5] 351	280
Sulfate (SO_4)	1,310	1,720	2,760	820	532
Chloride (Cl)	11	3.8	36	40	5
Fluoride (F)	1.8	2.4	----------	----------	----------
Nitrate (NO_3)	2.2	1.8	----------	>10	----------
Dissolved solids	2,190	2,760	3,910	1,880	931
Hardness as $CaCO_3$	1,530	1,840	[5] 2,840	1,150	[5] 786
Noncarbonate hardness as $CaCO_3$	1,350	1,730	[5] 2,750	860	[5] 556
Percent sodium	1	3	6	[5] 4	[5] 0
Sodium-adsorption ratio	.1	.3	.6	[5] .3	[5] .0
Specific conductance micromhos at 25° C	2,230	2,680	----------	----------	----------
pH	7.2	7.5	----------	7.0	----------

[1] Williams, 1948, p. 19. Water encountered between 305 and 1,010 ft flows from the well through the annular space between 10- and 6-in. casings. Water from the lower part of Minnelusa and upper part of Pahasapa flows from the same well through the 6-inch casing. (See analysis for well 44-60-6ad in table 6.)
[2] Williams, 1948, p. 9.
[3] Analysis by Crawford (1940, p. 1297, 1302).
[4] Analysis by Wyoming State Chemist.
[5] Calculated by Russell H. Langford.

GYPSUM SPRING AND SUNDANCE FORMATIONS

The Gypsum Spring Formation, like the Spearfish, contains beds of gypsum and yields highly mineralized water of the calcium sulfate type. (See table 5 and fig. 8). Water from well 54-65-11ab, near Hulett, contains more than 2,000 ppm of dissolved solids, of which about 80 percent (by weight) is calcium sulfate.

Unlike the Gypsum Spring Formation, the Sundance Formation yields water of the sodium sulfate type. The bar diagram for water from well 56-63-15ad (fig. 8) illustrates the chemical characteristics of water from the Lak and Redwater Shale Members of the Sundance Formation in the northern part of the report area. Farther south, near Keyhole Reservoir, a well 690 feet deep and probably tapping the Lak and Redwater Shale Members yields more highly mineralized water, also of the sodium sulfate type; an analysis by the U.S. Bureau of Reclamation of a water sample collected in April 1948 from well 51-66-27bd is as follows:

Iron (Fe)ppm	1.2	Fluoride (F)ppm	0.3
Calcium (Ca)do	35	Dissolved solidsdo	1,700
Magnesium (Mg)do	14	Hardness as $CaCO_3$do	145
Sodium (Na)do	524	Sodiumpercent	87
Bicarbonate (HCO_3)do	381	Specific conductance micromhos at 25°C	2,320
Sulfate (SO_4)do	927		
Chloride (Cl)do	9.6	pH	7.7

Field measurements of specific conductance indicate that water from well 53–65–35bd, which taps the Hulett Sandstone Member and the Stockade Beaver Shale Member of the Sundance Formation, contained only about 500 ppm of dissolved solids and that water from wells 52–66–14ba and 54–60–4bb, which probably penetrate the Hulett Member, contained, respectively, about 1,800 and 500 ppm of dissolved solids. Cation-exchange reactions, whereby calcium and magnesium in the water are exchanged for sodium from clay and shale, probably result in a water type that is predominantly sodium rather than calcium and magnesium.

MORRISON FORMATION

Water from the Morrison Formation is similar in chemical characteristics to that from the Lak and Redwater Shale Members of the Sundance Formation. (See fig. 8.) Sodium and sulfate are the principal dissolved constituents, and the dissolved-solids content of the water is only slightly higher than that from well 56–63–15ad in the underlying Sundance. (See table 5.) A field conductivity measurement indicated that water from well 56–63–26da, which also taps the Morrison, contained about 700 ppm of dissolved solids.

LAKOTA AND FALL RIVER FORMATIONS

Field measurements of specific conductance indicate that the dissolved-solids content of water from the Lakota and Fall River Formations in the report area ranges from about 100 to 2,500 ppm. Wells in the Little Missouri River valley yield water with the highest dissolved-solids content, and wells in the Belle Fourche River drainage basin in the northeastern part of Crook County yield water with the lowest dissolved-solids content.

Williams (1948, p. 7) states that the mineralization of water from the Lakota and Fall River Formations near Newcastle, Wyo., also varies widely. He cites, as an example, that the dissolved-solids content (principally sodium and sulfate) of water from 12 wells in the Osage oil field northwest of Newcastle (T. 46 N., Rs. 63 and 64 W.) ranged from about 650 to 5,000 ppm.

In figure 8, the diagrams for water from wells 56–66–11ca, 57–64–3db, and 58–64–35ac illustrate the chemical characteristics of water from the Lakota and Fall River Formations in the Little Missouri River valley. The diagrams for water from wells 55–61–8dc and 56–

62–28bb illustrate the chemical characteristics of water from the two formations in the lower part of the Belle Fourche River basin in Crook County. The more highly mineralized water is of the sodium sulfate type, whereas the water of lower mineralization is of mixed type.

The Lakota and Fall River Formations contain iron-bearing sandstone and iron concretions; therefore, water from them would be expected to contain troublesome amounts of iron. Iron was present in relatively high concentrations in samples of water collected from this study. Of 5 samples, 4 contained from 0.74 to 5.5 ppm of iron. A well at the Grayco refinery on the west edge of Newcastle also produced water having a high concentration of iron; in fact, when a sample was obtained in 1947, an iron oxide stain around the discharge area of the well was observed. The concentration of precipitated iron in the sample was determined to be 54 ppm at the time of analysis. Whether all of this precipitated iron was in solution or whether it was in colloidal form when the sample was obtained is not known. Although the concentration of iron in the sample obtained in 1941, before the well was deepened, was not determined, iron was reported to be present. The results of the chemical analysis of water samples collected from the well at Newcastle are given in table 8.

TABLE 8.—*Chemical analyses, in parts per million, of water from a well tapping the Lakota Formation at Newcastle, Wyo.*

Depth of well feet	[1] 830	[2] 930?
Date of collection	Aug. 15, 1941	Dec. 10, 1947
Temperature °F		61
Silica (SiO_2)		3.0
Iron (Fe)		[3] 54
Calcium (Ca)	308	286
Magnesium (Mg)	138	118
Sodium (Na)	128	59
Potassium (K)		14
Bicarbonate (HCO_3)	140	24
Sulfate (SO_4)	1,413	1,250
Chloride (Cl)	21	14
Fluoride (F)		1.8
Nitrate (NO_3)		.0
Dissolved solids	2,077	1,940
Hardness as $CaCO_3$	[4] 1,340	1,200
Noncarbonate hardness as $CaCO_3$	[4] 1,230	1,180
Percent sodium	[4] 17	10
Sodium-adsorption ratio	[4] 1.5	.7
Specific conductance micromhos at 25°C		2,080
pH		6.5

[1] Analysis by J. G. Crawford (Williams, 1948).
[2] Water also from sandy beds in the upper part of the Sundance.
[3] Precipitated iron at time of analysis.
[4] Calculated by Russell H. Langford.

LANCE AND FORT UNION FORMATIONS

Water from the Lance and Fort Union Formations in southwestern Crook County is moderately to highly mineralized, soft, and of the sodium bicarbonate sulfate type. (See fig. 9.) Field measurements of specific conductance indicated that the dissolved-solids content of water from wells 49–68–36db, 50–67–31dc, and 50–68–24cd2, which tap the Lance Formation is about 1,200 to 1,400 ppm. Chemical analyses (table 5) of water from nearby wells 50–67–31dd2 and 50–68–14cd showed that the dissolved-solids content of water from these wells is about 1,200 and 900 ppm respectively. Water from the Fort Union is more highly mineralized than that from the Lance. Field measurements of specific conductance of water from wells 49–68–16ca, –27bc, and –28ab, and chemical analyses of water from well 49–68–29bc indicated that the dissolved-solids content of water from wells tapping the Fort Union Formation ranges from about 1,200 to 3,500 ppm.

Hardness of water from the Lance and Fort Union Formations ranged from 28 to 53 ppm in the 3 samples collected for this study; this low hardness probably results from cation-exchange reactions. The 3 wells sampled ranged in depth from 97 to 406 feet. Swenson (Littleton, 1950) observed that water from 3 deep (387–840 feet) wells tapping the Fort Union in the Gillette area also contained principally sodium bicarbonate and sulfate, although the hardness ranged from 38 to 330 ppm.

ALLUVIUM

Ground water from alluvium in the Belle Fourche and Little Missouri River valleys is very hard, contains relatively high concentrations of iron, and is moderately to highly mineralized. However, the chemical characteristics of the water differ from place to place. The differences are related to the type of rocks underlying the alluvium. Comparison of bar diagrams in figure 9, for water from wells 54–65–13ba and 55–64–32cb, with the diagram in figure 8, for water from well 55–64–21cd, demonstrates the similarity in chemical characteristics of water from the Spearfish Formation with that from alluvium overlying the Spearfish. Similarly, the chemical characteristics of water from wells 50–67–4cc and 53–67–8cc are like those from wells tapping the Lance Formation. In the western part of Crook County, the alluvium underlying the valley of the Belle Fourche River is probably recharged principally by water from springs and seeps issuing from the Lance and Fort Union Formations. Farther downstream toward the "Big Bend" of the Belle Fourche River, the alluvium is probably recharged principally by water similarly derived from the Spearfish, Sundance, Lakota, and Fall River Formations. The alluvium in the Little Missouri River valley is probably recharged in part by water seeping from shale of Cretaceous age. Well 57–65–22ca2 taps the alluvium in the Little Missouri River valley and penetrates the underlying Skull Creek Shale. Water from this well contains more than 3,000 ppm of dissolved solids, of which about 90 percent (by weight) is sodium and sulfate.

The relation of the chemical characteristics and mineralization of water from the alluvium to the type of rocks underlying the alluvium in the vicinity of the sampled wells is shown in the following table. Generally, where underlain by formations such as the Spearfish and Sundance Formations and shale of Cretaceous age, which contain highly mineralized water, the alluvium can be expected to yield highly mineralized water to wells. Where underlain by the Lance and Fort Union Formations (and perhaps the Lakota and Fall River Formations), the alluvium would probably yield water of moderate mineralization to wells.

Relation of geology to chemical characteristics of water from alluvium

Well in alluvium	Formation underlying alluvium	Type of water	Dissolved-solids content (ppm)
50-67- 4cc	Lance Formation	Sodium bicarbonate	1,020
51-67-31dd	do		[1] 1,000
53-67- 8cc	do	Sodium bicarbonate	1,310
54-65-12da	Spearfish Formation		[1] 2,300
13ba	do	Calcium sulfate	1,770
55-64-32cb	do	do	1,450
57-65-13ca	Skull Creek Shale		[1] 2,000
22ca2	do	Sodium sulfate	3,340
9- 1-26ba [2]	Belle Fourche Shale	Calcium sulfate	1,840

[1] Approximate. Based on field measurement of specific conductance.
[2] In South Dakota about 5 miles southeast of point where Belle Fourche River crosses State boundary.

BELLE FOURCHE AND LITTLE MISSOURI RIVERS

As part of the program of the Department of the Interior for development of the Missouri River basin, studies of the chemical quality of surface water in the Belle Fourche and Little Missouri Rivers have been made by the U.S. Geological Survey. From May 1949 to July 1951, samples representing flows of 0.1 to 408 cfs (cubic feet per second) were obtained from the Little Missouri River at the bridge on U.S. Highway 212, 1 mile northwest of Alzada, Mont. From May 1946 to August 1956, samples representing flows of 0.1 to 990 cfs were obtained from the Belle Fourche River downstream from Donkey Creek near Moorcroft. Chemical analyses of all these samples are given in the annual series of water-supply papers of the Geological Survey entitled "Quality of surface waters of the United States." Analyses of water from the rivers during representative high- and low-flow periods are given in table 9, together with an analysis of water from Keyhole Reservoir. The chemical characteristics of the water are shown graphically in figure 10.

The drainage basin of the Belle Fourche River upstream from the station near Moorcroft is underlain principally by rocks of the Fort Union and Wasatch Formations of Tertiary age and the Lance Formation of Cretaceous age. During low-flow periods the water is of the sodium sulfate type, is very hard, and is highly mineralized. During high-flow periods the water is of a mixed type and of low

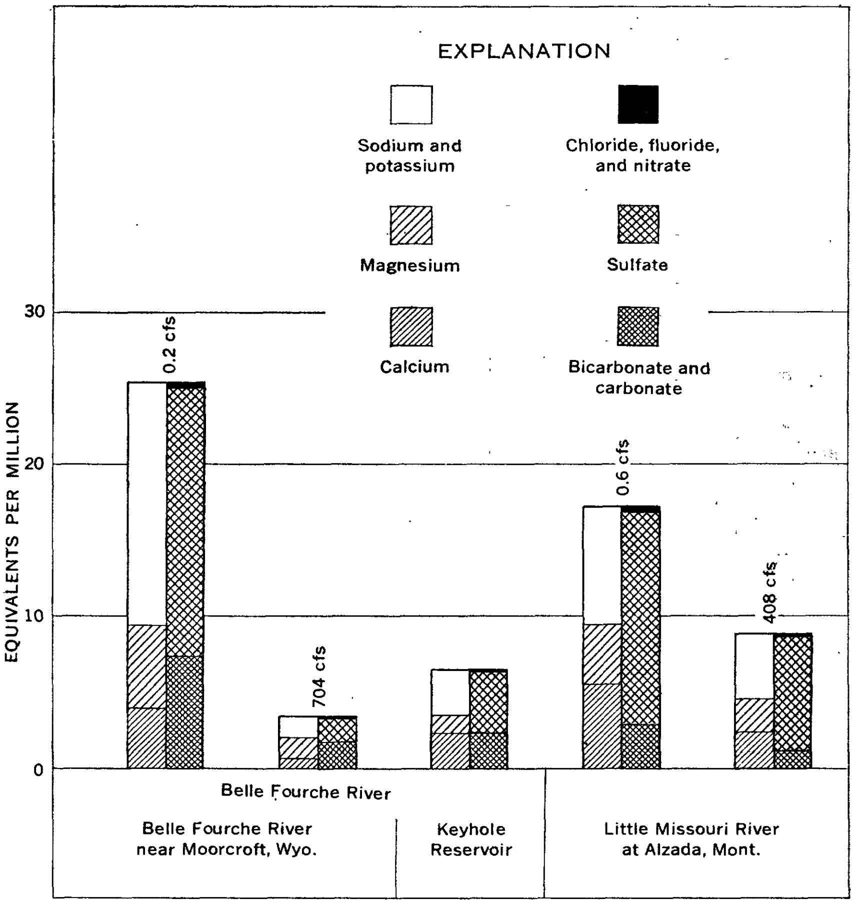

FIGURE 10.—Chemical characteristics of water from the Belle Fourche and Little Missouri Rivers, Wyo. and Mont. Figure above bar diagram represents discharge at time of sampling.

mineralization. (See table 9 and fig. 10.) During high-flow periods the water is about one-tenth as mineralized as it is during low-flow periods.

The drainage basin of the Little Missouri River upstream from Alzada is underlain principally by shale of Cretaceous age. During low-flow periods the water is of the sodium sulfate type, is very hard, and is moderately mineralized. However, during high-flow periods the water retains its basic type and is only about half as mineralized as it is during low-flow periods.

The runoff rates in the two drainage basins are dissimilar. The Belle Fourche River drainage basin upstream from the gaging station near Moorcroft contributed runoff to the Belle Fourche River at annual rates ranging from about 1 to 16 acre-feet per square mile of

TABLE 9.—*Chemical analyses, in parts per million, of water from Belle Fourche and Little Missouri Rivers, during both high- and low-flow periods*

	Belle Fourche River			Little Missouri River	
	Near Moorcroft, Wyo.		Keyhole Reservoir near Moorcroft, Wyo.	At Alzada, Mont.	
Date of collection	Apr. 5, 1951	Aug. 12, 1956	Oct. 2, 1956	Apr. 6, 1951	May 5, 1950
Water discharge cfs	0.2	704	(1)	0.6	408
Silica (SiO_2)	3.1	13	4.3	4.1	12
Iron (Fe)	.10		.01	.20	.04
Calcium (Ca)	78	14	45	113	49
Magnesium (Mg)	67	17	15	47	28
Sodium (Na)	368	26	61	177	96
Potassium (K)		6.7	9.0		
Bicarbonate (HCO_3)	424	109	148	184	80
Carbonate (CO_3)	12	0	0	0	0
Sulfate (SO_4)	852	73	190	672	360
Chloride (Cl)	9.5	3.5	3.0	6.0	2.0
Fluoride (F)	.8	.5	.4	.4	.4
Nitrate (NO_3)	.5	1.5	2.9	.5	2.7
Boron (B)	.12	.06	.08	.26	.30
Dissolved solids:					
Calculated	1,600			1,110	
Residue on evaporation at 180° C	1,670	248	437	1,180	638
Hardness as $CaCO_3$	470	105	174	476	238
Noncarbonate hardness as $CaCO_3$	103	16	53	325	172
Percent sodium	62	33	42	45	47
Sodium-adsorption ratio	7.4	1.1	2.0	3.5	2.7
Specific conductance micromhos at 25°C	2,260	365	628	1,550	860
pH	8.3	7.3	7.9	7.5	7.0

[1] Reservoir storage on date of collection was about 13,000 acre-feet.

drainage area during the period 1947–54. During the same period, the Little Missouri River drainage basin upstream from the gaging station near Alzada contributed runoff to the Little Missouri River at annual rates ranging from about 7 to about 120 acre-feet per square mile. Differences both in geology and in climate of the two drainage basins probably cause the different runoff characteristics and chemical quality of water of the two streams.

SUITABILITY OF THE WATER

Water-quality requirements differ for various uses. Water suitable for irrigation may not be at all suitable for domestic or industrial use, and water suitable for one industrial application may not be suitable for another. The suitability of ground water in the report area is discussed, therefore, in terms of requirements for each use.

DOMESTIC USE

The U.S. Public Health Service (1946, p. 371–384) has established drinking water standards for sanitary, bacteriological, and chemical requirements of water used for drinking and culinary purposes on interstate common carriers. The standards have been adopted by the American Water Works Association for all public water supplies. Although the standards are not compulsory for water that is used locally, they are measures of the suitability of water for domestic use. The maximum permissible concentrations for some of the chemical constituents are as follows:

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

[1] 1,000 ppm permitted if no other water is available.

Iron in water tends to stain porcelain fixtures and laundry and, when present in concentrations higher than about 0.5 ppm, can be tasted. Persons accustomed to drinking water that contains high concentrations of sulfate and dissolved solids often prefer such water to less mineralized water. However, sulfate in concentrations higher than about 250 ppm may have a laxative effect. Concentrations of fluoride higher than about 1.0 ppm in drinking water have been associated with a dental defect known as "mottled enamel," although concentrations ranging from 0.8 to 1.5 ppm are considered to be beneficial in the prevention of tooth decay, especially for children (California Institute of Technology, 1952, p. 257).

In the report area, concentrations of iron, sulfate, and dissolved solids exceeded the recommended limits in water from most wells, and concentrations of fluoride exceeded the limit in water from a few wells. (See table 5.) Water from the alluvium and the Fall River and Lakota Formations contained excessive amounts of iron, and water from most of the water-bearing formations contained excessive amounts of sulfate and dissolved solids. Except for water from three wells, the ground water analyzed contained nearly 1.5 ppm fluoride. Of these 3 wells 2 are used for stock watering, but the third (54–64–7bcl), which taps the Minnelusa Formation, is used for public supply in Hulett. The use of water from this third well for drinking, especially by children, might result in mottled tooth enamel, although the concentration of fluoride was only slightly higher than the recommended limit. (See table 5.) Data in table 7 show that fluoride concentrations in excess of 1.5 ppm also occur in water from the Minnelusa Formation near Newcastle, Wyo.

Although no official specific limits are established for hardness, water having a hardness of less than 60 ppm generally is considered to be soft and, therefore, suitable for most uses without further treatment. Water having a hardness of 60 to 120 ppm is considered to be moderately hard; 120 to 200 ppm, hard; and more than 200 ppm, very hard. Very hard water usually requires softening for most uses in the home and in industries. Thus, by these limits, water from the Lance and Fort Union Formations is soft, but water from most water-bearing formations in the report area is moderately hard to very hard.

AGRICULTURAL USE

Stock watering is an important agricultural use of water in the report area, and most of the water samples obtained for this investigation were from wells that have been used for stock watering for many years. Although little is known of the relation of quality of water to health of stock, in Montana water containing less than 2,500 ppm of dissolved solids is considered to be good for stock watering; 2,500 to 3,500 ppm, fair; 3,500 to 4,500 ppm, poor; and more than 4,500 ppm, unfit (California Institute of Technology, 1952, p. 155). Because the dissolved-solids content of ground water in the report area generally is less than about 2,500 ppm, the water would be classed as good for stock watering. Some substances, such as selenium and molybdenum, even when present in low concentrations, are toxic to animals. Although these substances were not determined in water samples from the report area, they are probably present in the ground water in only very small amounts.

Irrigation in the report area is practiced in only parts of the Belle Fourche River valley, and water from the river is used. Nevertheless, the suitability of the water resources of the area can be evaluated by current methods (U.S. Salinity Laboratory Staff, 1954) for supplementary irrigation. Characteristics that determine the suitability of water for irrigation are (1) concentration of boron, (2) total mineralization, and (3) relative cation concentrations.

Boron, although an essential plant nutrient, is toxic to some plants; concentrations of less than about 0.7 ppm in irrigation water are recommended (Wilcox, 1948, table 8) for boron-sensitive plants. All except two of the sources sampled in the report area yielded water that contained less than 0.7 ppm of boron. Well 56–63–7bd, which taps the Morrison Formation, and well 57–65–22ca2, in the alluvium, yielded water that contained 1.8 and 0.95 ppm, respectively.

Highly mineralized water used for irrigation may adversely affect plant growth. Plants absorb water and essential minerals and nutrients by the process of osmosis; when the concentration of salts in the soil solution becomes too high, the osmotic pressure balance between the soil solution and the plant roots is upset and growth is retarded. The total mineralization of irrigation water is usually referred to as its salinity, and the specific conductance of the water is a measure of the salinity hazard of the water.

When sodium is present in irrigation water in relatively higher concentrations than those of calcium and magnesium, it may replace the calcium and magnesium ions adsorbed on the soil colloids. Calcium and magnesium when adsorbed on soil particles tend to flocculate the colloids; flocculation results in soil of good tilth and permeability. However, if adsorbed calcium and magnesium are replaced by sodium, the colloids disperse, and a puddled, structureless soil of poor tilth is the result. The sodium-adsorption ratio of water is directly related to the adsorption of sodium by soil and is a valuable criterion for determining the suitability of an irrigation supply. (See p. 53.) It is, therefore, a measure of the sodium (alkali) hazard of the water.

The classification of irrigation water by the method of the U.S. Salinity Laboratory Staff (1954) is based on the salinity and sodium hazard of the water. (See fig. 11.) The classification is based on the assumption that the water will be used under average conditions of drainage, soil texture, infiltration rate, quantity of water used, salt tolerance of crops, and climate. Large deviations from average conditions may change the classification. The interpretation of the diagram by the U.S. Salinity Laboratory Staff is as follows:

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avacados may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels

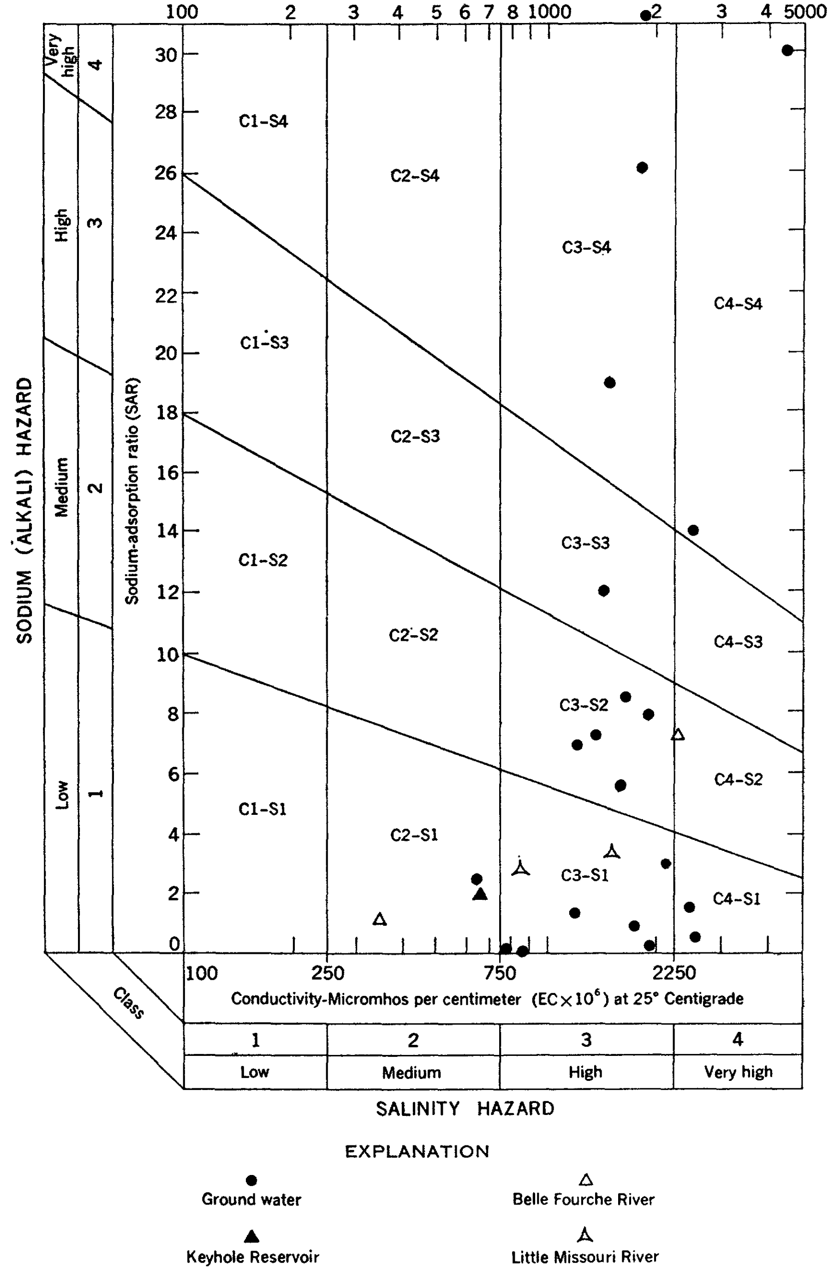

FIGURE 11.—Classification of water for irrigation. (Diagram from U.S. Salinity Laboratory Staff, 1954.)

of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Sodium-adsorption ratios and specific conductances (tables 5 and 9) for both ground and surface waters in the report area are plotted in figure 11. Most ground water has a high to very high salinity hazard and a low to medium sodium hazard; however, water from the Lance and Fort Union Formations has a very high sodium hazard. During high-flow periods, water in the Belle Fourche River near Moorcroft has a medium salinity and a low sodium hazard, but during periods of low flow, the water has a very high salinity and a medium sodium hazard. Keyhold Reservoir contains water having a medium salinity and a low sodium hazard. The water from the Little Missouri River near Alzada is classed as having high salinity and low sodium hazards at both high and low flows.

Most crops in the report area, such as grains, sugar beets, and alfalfa, have a medium to high salt tolerance and water classed as C3–S1 or C3–S2 could be used to irrigate them if drainage is good.

INDUSTRIAL USE

Industrial water-quality criteria vary widely. A compilation of water-quality tolerances for several different industrial applications is shown in table 10. The suitability of a water supply for industrial use can be evaluated by comparing the chemical analyses with the tolerances. Generally, the alkalinity, the iron content, the dissolved-solids content, and the hardness of the ground water in the report area exceed the tolerance limits that are recommended for most industrial applications. Most samples collected for this study were clear and colorless; results of color and turbidity determinations for a few of the samples are shown in table 5.

SUMMARY

The mineralization and chemical characteristics of the ground water vary widely from place to place, and the water-bearing formations each yield water having rather distinctive characteristics. The Pahasapa Limestone south of the report area yields a hard, bicarbonate type of water whose dissolved-solids content is 300 to 600 ppm. Any wells that may be drilled to the Pahasapa in the report area probably would produce a more highly mineralized water than do the wells near Sundance and Newcastle, because of the differences in distance from the recharge area of the Pahasapa.

Water from the Minnelusa Formation near Hulett, Wyo., and south of Belle Fourche, S. Dak., is of the calcium bicarbonate sulfate type; its dissolved-solids content is 500 to 600 ppm and its hardness

TABLE 10.—*Water-quality*

[From California Institute of Technology, 1952. Range of

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)
Baking	10	10	None	Low	--	--	--	(1)	--	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=more than 400 psi.	1	2	--	--	3	.00	50	2	--	--
Brewing:										
Light beer	0-10	0-10	None	Low	--	--	500	--	75-80	.1
Dark beer	0-10	0-10	do.	Low	--	--	1,000	--	80-150	.1
Carbonated beverages.	1-2	5-10	do.	Low	1.5	--	850-855	200-250	50-128	.1-.2
Confectionery	--	--	Low	Low	--	--	50-100	--	--	.2
Cooling water	50	--	--	--	--	--	--	50	--	.5
Food canning and freezing.	1-10	--	None	Low	--	--	--	50-85	--	.2
Food-equipment washing.	1	5-20	do.	None	--	--	850	10	--	--
Food processing, general.	1-10	5-10	Low	Low	--	--	850	10-250	30-250	.2
Ice manufacturing	1-5	5	None	Low	3	--	170-1,300	70-72	30-50	.03-.2
Laundering	--	--	--	--	--	--	--	0-50	60	.2-1.0
Plastics	2	2	--	--	--	--	200	--	--	.02
Pulp and paper:										
Ground wood pulp.	50	30	--	--	--	--	500	200	150	.3
Soda and sulfate pulps.	25	5	--	--	--	--	200	100	75	.1
Kraft paper (bleached).	40	25	--	--	--	--	300	100	75	.2
Kraft paper (unbleached).	100	100	--	--	--	--	500	200	150	1.0
Fine paper	10	5	--	--	--	--	200	100	75	.1
Rayon (viscose):										
Pulp	5	5	--	--	--	--	100	8	50	.05
Manufacture	0.3	--	--	--	--	--	--	55	--	.0
Steel manufacture	--	--	--	--	--	--	--	50	--	--
Sugar manufacture	--	--	--	--	--	--	--	--	--	.1
Tanning operations	20	10-100	--	--	--	--	--	50-513	128-135	.1-2.0
Textile manufacture	.3-25	5-70	--	--	--	--	--	0-50	--	.1-1.0

[1] Some hardness desirable.
[2] Presence of $CaSO_4$ advantageous.
[3] Sodium chloride, NaCl, 1,000-1,500.

tolerances for industrial applications

recommended threshold or limiting values in parts per million]

Manganese (Mn)	Fe + Mn	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
0.2	0.2	------	------	------	------	------	------	------	------	------	------	H_2S, 0.2
------	------	5	40	------	50	200	50	------	------	------	>8.0	H_2S, 5
------	------	.5	20	------	30	100	40	------	------	------	>8.4	H_2S, 3
------	------	.05	5	------	5	40	30	------	------	------	>9.0	H_2S, 0
------	------	.01	1	------	0	20	15	------	------	------	>9.6	H_2S, 0
.1	.1	------	50	100–200	------	50–68	------	(2)	------	1	6.5–7.0	NO_3, 30; H_2S, 0.2
.1	.1	------	50	200–500	------	50–68	------	(2)	------	1	------	NO_3, 30; H_2S, 0.2
.2	.1–1.5	------	------	------	------	------	------	250	250	.2–1.0	------	H_2S, 0–0.2
.2	.2	------	------	------	------	------	------	------	------	------	>7.0	H_2S, 0.2
.5	.5	------	------	------	------	------	------	------	------	------	------	
.2	.2	------	------	------	------	------	------	------	(3)	1	>7.5	H_2S, 1
------	.2	------	------	------	------	------	------	------	250	1	------	
.2	.2–.3	------	------	------	------	------	------	------	------	1	------	
.2	.2	------	10	------	------	------	------	------	------	1	------	
.2	.2	------	------	------	------	------	------	------	------	------	6.0–6.8	
.02	.02	------	------	------	------	------	------	------	------	------	------	
.1	------	------	50	------	------	------	------	------	75	------	------	CO_2, 10
.05	------	------	20	------	------	------	------	------	75	------	------	CO_2, 10
.1	------	------	50	------	------	------	------	------	200	------	------	CO_2, 10
.5	------	------	100	------	------	------	------	------	200	------	------	CO_2, 10
.05	------	------	20	------	------	------	------	------	------	------	------	CO_2, 10
.03	.05	<8	<25	------	------	------	------	------	------	------	------	Cu<5
.0	.0	------	------	------	------	------	------	------	------	------	7.8–8.3	
------	------	------	------	------	------	------	------	------	175	------	6.8–7.0	
------	------	------	------	20	100	------	------	20	20	------	------	Mg, 10
.1–.2	.2	------	------	------	------	------	------	------	------	------	6.0–8.0	
.05–1.0	.2–1.0	------	------	10	200	------	------	100	100	------	------	Mg, 5

400 to 500 ppm. The meager data available indicate that water from the upper part of the Minnelusa is more highly mineralized than that from the lower part. The dissolved-solids content of water from wells tapping the upper part of the Minnelusa at Devils Tower and south of the report area ranges from about 1,880 to 3,900 ppm; calcium and sulfate are the principal dissolved constituents.

The Spearfish and Gypsum Spring Formations yield water of the calcium sulfate type; its hardness exceeds 1,300 ppm and its dissolved-solids content is 2,000 to 3,000 ppm. Beds of gypsum in the two formations undoubtedly contribute to the quality of the water. The Sundance and Morrison Formations, on the other hand, yield water of the sodium sulfate type that has a hardness of 100–200 ppm and that contains generally from 500 to as much as 2,000 ppm of dissolved solids.

The iron content of water from the Lakota and Fall River Formations exceeded 0.7 ppm in four of five samples collected for this study, and the dissolved-solids content ranged from 100 to 2,500 ppm. Water from wells in the Little Missouri River valley has the highest mineralization, and that from wells in the Belle Fourche drainage basin in northeastern Crook County, the lowest. The more highly mineralized water is of the sodium sulfate type, whereas the water of lower mineralization is a mixed type.

The Lance and Fort Union Formations yield water of the sodium bicarbonate sulfate type. Cation-exchange reactions probably account for the low hardness of the water from these formations. Whereas water from the Lance Formation contained about 900 to 1,400 ppm of dissolved solids, water from the Fort Union Formation contained about 1,200 to 3,500 ppm. Water from the river alluvium is very hard and is moderately to highly mineralized; it contains relatively high concentrations of iron and differs in chemical characteristics from place to place. The differences are related to the type of rocks underlying the alluvium.

The mineralization and chemical characteristics of the water from the Belle Fourche River near Moorcroft, Wyo., and the Little Missouri River near Alzada, Mont., also vary. During low-flow periods, the water in both streams is of the sodium sulfate type, although the mineralization of water in the Little Missouri is less than that in the Belle Fourche. During high-flow periods, the mineralization of water in the Belle Fourche is about one-tenth that during low-flow periods, and that in the Little Missouri is about half. During high-flow periods, however, the water in the Little Missouri River retains its basic type, whereas water in the Belle Fourche River is of mixed type.

Because the chemical quality of the ground water differs greatly, the suitability of the water for domestic, agricultural, and industrial uses also differs. Most ground water in the area has a hardness greater than 200 ppm and contains iron in excess of 0.2 ppm, sulfate in excess of 250 ppm, and dissolved solids in excess of 500 ppm. The water, therefore, would be unsuitable for many industrial applications and domestic uses. Water from a few wells in the area contains fluoride in excess of the recommended limit of 1.5 ppm for drinking water.

Because the water generally contains less than 2,500 ppm of dissolved solids, it generally is suitable for stock watering. When classified for irrigation, the water generally has a high to very high salinity hazard and a low to medium sodium hazard. The water having a high salinity and a low sodium hazard could be used to irrigate salt-tolerant crops if drainage is good, so that water can be applied in excess of crop needs.

REFERENCES CITED

Brady, F. H., 1958, Evaporite deposits in the Minnelusa Formation in the Sundance-Beulah area, Crook County, Wyo.: Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf., Powder River Basin, p. 45-47.

Brown, R. W., 1958, Fort Union Formation in the Powder River Basin, Wyo.: Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf., Powder River Basin, p. 111–113.

California Institute of Technology, 1952, Water quality criteria: California Water Pollution Control Board pub. 3, 512 p.

Crawford, J. G., 1940, Oil-field waters of Wyoming and their relation to geological formations: Am. Assoc. Petroleum Geologists Bull., v. 24, no. 7, p. 1214–1329.

Darton, N. H., 1905, Description of the Sundance quadrangle, Wyoming: U.S. Geol. Survey Geol. Atlas, Folio 127, 12 [1] p., 1 sheet of illus., 5 maps.

——— 1909, Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey Prof. Paper 65, 105 p., 24 pls.

Darton, N. H., and O'Harra, C. C., 1905, Description of the Aladdin quadrangle, Wyoming, South Dakota, and Montana: U.S. Geol. Survey Geol. Atlas, Folio 128, 8 [1] p., 4 maps.

——— 1907, Description of the Devils Tower quadrangle, Wyoming: U.S. Geol. Survey Geol. Atlas, Folio 150, 10 p., 4 maps.

Dobbin, C. E., and Reeside, J. B., Jr., 1929, The contact of the Fox Hills and Lance Formations: U.S. Geol. Survey Prof. Paper 158-B, p. 9–25.

Grace, R. M., 1952, Stratigraphy of the Newcastle Formation, Black Hills region, Wyoming and South Dakota: Wyoming Geol. Survey Bull. 44, 44 p., 1 pl., 2 figs.

Hazen, Allen, 1892, A new color standard for natural waters: Am. Chem. Soc. Jour., v. 12, p. 427–428.

Imlay, R. W., 1947, Marine Jurassic of Black Hills area, South Dakota and Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 2, p. 227–273.

Knetchel, M. M., and Patterson, S. H., 1955, Bentonite deposits of the Northern Black Hills district, Montana, Wyoming, and South Dakota: U.S. Geol. Survey Mineral Inv. Field Studies Map MF 36.

Littleton, R. T., 1950, Ground-water conditions in the vicinity of Gillette, Wyo.: U.S. Geol. Survey Circular 76, 43 p., 3 pls., 2 figs.

Love, J. D., and Weitz, J. L., 1951, Geologic map of the Powder River Basin and adjacent areas, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM 122.

Mapel, W. J., and Bergendahl, M. H., 1956, Gypsum Spring Formation, northwestern Black Hills, Wyoming and South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 1, p. 84–93.

Mapel, W. J., Robinson, C. S., and Theobald, P. K., 1959, Geologic map of the northern and western flank of the Black Hills uplift, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Oil and Gas Inv. Map OM 191.

McLaughlin, T. G., 1954, Geology and ground-water resources of Baca County, Colo.: U.S. Geol. Survey Water-Supply Paper 1256, 232 p., 2 pls., 54 figs.

Meinzer, O. E., 1923, The occurrence of ground water in the United States, with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489, 321 p., 31 pls.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p., 17 figs.

Riffenburg, H. B., 1925, Chemical character of ground waters of the Northern Great Plains: U.S. Geol. Survey Water-Supply Paper 560B, p. 31–52.

Rubey, W. W., 1930, Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U.S. Geol. Survey Prof. Paper 165–A, p. 1–54.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., 16th Ann. Mtg., p. 519–524.

Thomas, Harold E., 1951, The conservation of ground water: New York, N.Y., McGraw-Hill Book Co., Inc., 1st ed., 327 p.

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

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

Waagé, K. M., 1959, Stratigraphy of the Inyan Kara Group in the Black Hills: U.S. Geol. Survey Bull. 1081–B, p. 11–90.

Wilcox, L. V., 1948, The quality of water for irrigation use: U.S. Dept. Agriculture Tech. Bull. 962, 40 p.

Williams, C. C., 1948, Water-supply possibilities from wells at Newcastle, Wyo.: U.S. Geol. Survey open-file report, 19 p.

BASIC DATA

724-488—64——7

TABLE 11.—*Records of wells, springs, and oil-test holes in northern and western Crook County, Wyo.*

Well or spring number: 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; reported depths are given in feet below land surface
Type of casing: C, concrete; P, iron or steel pipe; R, rock; W, wood
Character of material: Cls, claystone; G, gravel; L, limestone; S, sand; Sh, shale, Sls, siltstone; Ss, sandstone
Geologic source (in alphabetical order): Jm, Morrison Formation: Jsg, Stockade Beaver Shale Member of Sundance Formation and Gypsun Spring Formation; Jsh, Hulett Sandstone Member of Sundance Formation; Jsrl, Redwater Shale and Lak Members of Sundance Formation; Kfh, Fox Hills Sandstone; Kfr. Fall River Formation; Kl, Lance Formation; KlK, Lakota Formation; Km, Mowry Shale; Knc, Newcastle Sandstone; Kp, Pierre Shale; PPml, Minnelusa Formation; Qal, alluvium; Tft, Tullock Member of Fort Union Formation; TRPs, Spearfish Formation
Method of lift; C, cylinder; Cf, centrifugal; F, flows; J, jet; N, none; T, turbine; E, electric; G, gasoline; H, hand operated; W, windmill
Use of water: D, domestic; I, irrigation; In, industrial; N, none; P, public; S, stock
Distance to water: Measured distances to water are given in feet and hundredths; reported distances 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; L, log of well given in table of well logs, depth in parentheses () when different from measured depth; T, temperature in degrees Fahrenheit

Well No.	Owner or tenant	Type of supply	Depth of well (ft)	Diameter of well (in.)	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	Distance to water level above (+) or below land surface datum	Data of measurement	Remarks
48-69-1ad	Russell Krause	Dr	360	6	P	Ss	Tft	C, W	S			Adjacent to report area.
1bd	do	Dr	321	6	P	Ss	Tft	C, W	S	10.70	May 31, 1952	L, D25R Do.
48-68-2ac	E. Stevenson	Dr	62.0	6	P	S	Qal	C, W	S	14.98	June 4, 1956	
2ba	do	Dr	75	6	P	S, G	Qal	C, W	D	16.60	June 2, 1956	T50
14ac	Mary Butler	Dr	131.0	6	P	Ss	Kl	C, W	D, S	18.40	June 4, 1956	L (138), D25R
14dd	do	Dr	140	6	P	Ss	Kl	C, H	N	28.80	do	
15aa	Keeline Ranch	Dr	176.0	6	P	Ss	Kl	C, W	S	82.38	do	
16ca	Mary Butler	Dr	153.0	6	P	Ss	Tft	C, W	S	80.10	do	T51, D2.3M, DD4.1
24aa	do	Dr	97.0	6	P	Ss	Kl	C, W	S	57.04	do	L(103)
27bc	Joe Watts	Dr	127.0	10	P	Ss	Tft	C, W	S	17.88	June 1, 1956	T51, D3.2M, DD17.3
28ab	Russell Krause	Dr	61.0	6	P	Ss	Tft	C, W	S	12.70	June 2, 1956	T49, D5.0M, DD12.2
28bb	do	Dr	114.0	6		Ss	Tft	C, W	S	61.40	do	L(115)
29bc	do	Dr	155.1	10	P	Ss	Tft	C, W	S	83.92	do	T51, Ca, D1.3M, DD14.0
31bd	do	Dr	53.1	6	P	S, G	Qal	C, W	S	12.40	May 31, 1956	
33ba	do	Dr	158.0	6	P	Ss	Tft	N	N	37.50	June 1, 1956	
36db	E. Stevenson	Dr	60.1	6	P	Ss	Kl	C, W	S	16.15	June 4, 1956	T51, D1.4M, DD3.4
49-69-36aa	Russell Krause	Dr	200.0	6	P	Ss	Tft	C, G	S	23.05	May 31, 1956	L(220) (adjacent to report area)
50-67-4cc	John Schuricht	Dr	39.2	8	P	S, G	Qal	C, W	S	20.06	June 18, 1956	T49, Ca, D5.5M, DD0.3
5dc	do	Dr	35.0	8	P	S, G	Qal	N	N	10.70	do	D8M, DD9.2
31dc	P. Hall	Dr	350		P	Ss	Kl	-, E	I	104.80	June 25, 1956	L, T54
31dd1	City of Moorcroft	Dr	406	8	P	Ss	Kl	T, E	P			D40R
31dd2	do	Dr	406	8	P	Ss	Kl	T, E	P	100		Ca, T53
50-68-12db	Bob Wood	Dr	42.0	6	P	S, G	Kl	C, W	S	14.38	June 18, 1956	T50

13ca	L. Anderson	Dr	225	10	P		Kl	N	N	30.90	June 25, 1956	
14cd	L. McCullough	Dr	97.0	8	P	Ss	Kl	C, W	S	14.40	June 5, 1956	T50, Ca, D4.4M, DD2.6
23ba	do	Dr	36.2	5	P	S, G	Qal	C, W	S	7.60	do	
50-68-23dc	L. McCullough	Dr	137	6	P	Ss	Kl	C, G	S	43.50	June 5, 1956	L
24cd1	do	Dr	16.0	4	P	S, G	Qal	C, H	D	10.60	do	
24cd2	do	Dr	180	5	P	Ss	Kl	C, E	D, S	21.00	do	T49, D5.8M, DD3.8
27aa	D. Lester	Dr	82.0	6	P	Ss	Kl	C, W	S	59,05	June 4, 1956	T50
32da	E. Stevenson	Dr	41.0	4	P	Ss	Tft	C, W	S	21.10	do	
34bc	D. Lester	Dr	147	8	P	Ss	Kl	J, E	D	22.90	June 5, 1956	L
51-66-11ca	A. C. Waters	Dr	355	6	P	Ss	Jsh(?)	C, W, F	D			D2E
27bd	U.S. Bureau of Reclamation.	Dr	690	6	P	Ss	Jsrl(?)	C, E	D	175	Apr. 26, 1948	D19.6R, DD311.8R, Ca
51-67-25ca	Central States Drilling Co.	Dr	2,827	6	P	Ss						Oil test, L
31dd	John Schuricht	Dr	40	6	P	S, G	Qal	C, W	S	14.80	June 18, 1956	T49, D4.1M, DD8.3
52-66-1dd	David Roberts	Dr	60	6	P	Ss	Jsg	J, E	D, S	26		
12cd	G. D. Carr	Dr	135	6	P	Ss	Jsg(?)	J, E	D, S			
13ac	F. Schleining	Du	36.1	36	R	S, G	Qal	C, H	D, S	17.60	June 19, 1956	
14ba	G. D. Carr	Dr	107	6	P	Ss	Jsh(?)	C, W	S			T51, L
22cd	Lyle Griffith	Dr	260	6	P	Ss	Klk	C	N	150.10		L
24ca1	R. E. Mills	Du	56.0	48	S	S, G	Qal	C, H	D	30.05	June 19, 1956	
24ca2	do	Dr	120	6	P	Ss	Jsh	C, E	D, S	30		
53-65-4bc	E. V. Ike	Dr	600	18	P	Sls	₸ Ps	N	N	145.00	July 16, 1956	Oil test.
7cc	National Park Service	Sp				Sls	Jsrl(?)		P			D10R
8dc	J. B. Driskill	Du	30.1	22	P	S, G	Qal	J, E	D, S	21.50	July 12, 1956	
18ba	National Park Service	Dr	608	4	P	Ss	Pml	J, E	D	14.55	July 22, 1956	T55, L, Ca
18bc	Clifford Thurman	Dr	40	6	P	S, G	Qal	N	N	14.50	July 13, 1956	Abandoned.
35bd	Glen Conzelman	Dr	160	7	P	Ss	Jsh, Jsg	C, H	D	93.75	Aug. 11, 1956	T52, L
53-66-12da	National Park Service	Sp					Jsg		P		July 12, 1956	D1R
13ab	do	Sp					₸ Ps		N		do	D1R
53-67-3ca	Fred Sehn	Dr	525	6	P	Ss	Kfr	F	S			L, D0.2R
8ba	Bill Svoboda	Dr	90	6	P	S, G	Kp	J, E	D, S	11		D12R
8bb	H. Berger	Dr	140	6	P	Ss	Kfh	C, W	S	21.20	Nov. 6, 1956	D5.5M, DD26.4M
8cc	E. Wesley	Dr	60	8	P	S, G	Qal	J, E	D	20		Ca
34bc	H. Berger	Dr	730	6	P		Kfr, Klk	C, W	S	60	Nov. 7, 1956	D7R
53-68-14cd	S. Woods	Dr	125	5	P	Ss	Kl	C, W	D, S	50		D15R
15cd	J. Hahn	Dr	180	5	P	Ss	Kl	C, G	D	130		D10R, DD50R
54-60-4bb	George Osloond	Dr	780	7	P	Ss(?)	Jsh(?)	F	S		May 29, 1956	D0.5R, L
54-61-1bb	E. Bunney	Dr	336	2	P	Ss	Kfr	F	S			T57, L, D1.3M
3aa	A. Bunney	Dr	292	2	P	Ss	Kfr	F	S			T56, D0.5E
54-64-6ac	Perry Roberts	Dr	64	7	P	Sls	₸ Ps	J, E	D, S	14		
6db	Hulett Cemetery Assoc.	Dr	105	8	P	Sls	₸ Ps	J, E	D	60.00	July 17, 1956	
7bc1	City of Hulett	Dr	663	8	P	Ss	Pml	F	P	+80	1934	T56, L, Ca, D375R
7bc2	do	Dr	690	6	P		Pml	F	P	+80		T56, D350R
7cb	Hulett Rodeo Grounds	Dr	35.0	6	P	Sls	₸ Ps	J, E	S	17.33	July 18, 1956	T49, D6.4M, DD11.8
18bb	Carl Husby	Dr	105	4	P		₸ Ps	J, E	D, S	21.84	July 13, 1956	L
54-65-11ab	L. Davis	Dr	52	6	P	Sls	Jsg	C, W	S	20		T49, Ca
12ad	Charles Martin	Du	19	60		S, G	Qal	N	N	15.20	July 16, 1956	
12da	Hulett Cooperative	Dr	70	8	P	Sls	Qal	J, E	D	20.00	July 13, 1956	T52, D6.8, DD.6
13ba	D. Steiger	Dr	38	16	P	S, G	Qal	T, G	I	7.50	do	T49, L(46), Ca, D266M, DD18.3

TABLE 11.—*Records of wells, springs, and oil-test holes in northern and western Crook County, Wyo.*—Continued

Well No.	Owner or tenant	Type of supply	Depth of well (ft)	Diameter of well (in.)	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	Distance to water level above (+) or below land surface datum	Data of measurement	Remarks
54-65-13bd	D. Steiger	Dr	640	6	P	Ss	Pml	F	D, I		July 13, 1956	T56, D180M
27db	R. Singleton	Dr	40.0	5	P	Sls	Ꞧ Ps	C, H	D, S	17.60	do	L(50)
29dd	E. V. Ike	Dr	792	6	P	Ss	Pml	Cf, E	D, S	7	July 17, 1956	T58, L
34ba	R. Singleton	Dr	85	7	P	Sls	Ꞧ Ps	N	N	19.60	Aug. 11, 1956	
54-67-22da	M. Fowler	Dr	800	7	P	Ss	Kfr, Klk	F	S			D150R
55-60-7ca	Lillian Jensen	Dr	390	2	P	Ss	Kfr	F	S			T56, L, D15R
18dc	do	Dr	215	2	P	Ss	Kfr	F	S			T55, L, D1E
28ba	L. W. Budmayr	Dr	394	2	P	Ss	Kfr, Klk	F	S			T57
33cc	E. A. Osloond	Dr	396	6	P	Ss	Kfr, Klk	F	S			T53, D2.8M
55-61-3ad	Lillian Jensen	Dr	389	2	P	Ss	Kfr, Klk	F	S			T58, D1.6M
8dc	Herman Kruger	Dr	315	2	P	Ss	Krf, Klk	F	S	+33.5		T57, L, Ca, D3.2M, DD33.5
20da	do	Dr	512	4	P	Ss	Kfr, Klk	C, E	D, S	2		
22dc	T. W. Mowery	Dr	613	4	P	Ss	Kfr, Klk	F	D, S			T58, L, D3.7M
23bb	A. Leitner	Dr	500	2	P	Ss	Klk	F	S		Aug. 3, 1956	T57, D2.8M
55-62-2ad	J. D. Hejde	Sp				Ss	Kfr					
55-64-11aa	E. Neilson	Sp				Sls	Jsg		N			D50±E
11dd	E. Gontz	Dr	115	6	P	Sls	Ꞧ Ps	J, E	D, S	80		
13cd	C. S. McAmis	Sp				Ss	Jsg					D1E
21ab	W. T. Dirks	Dr	90	6	P	Sls	Ꞧ Ps	C, E	S			
21cd	do	Dr	150	6	P	Sls	Ꞧ Ps	C, E	S	103.95	Aug. 11, 1956	L, T52, Ca, D3.7M, DD6.1
24bb	C. S. McAmis	Dr	75	6	P	Sls	Ꞧ Ps	J, E	S	35		
32ab	Earl Wilson	Dr	80	5	P	Sls	Ꞧ Ps	J, E	D, S	15		
32cb	A. P. Meike	Dr	32.0	6	P	S, G	Qal	C, W	D, S	26.10	July 14, 1956	T49, Ca, D2.7M, DD3.7
55-65-24bc	Helen Hutton	Dr	151	6	P	Ss	Jsrl	C, W	S	66.60	Aug. 11, 1956	
55-67-3ca	Henry Hauber	Dr	554		P	Ss	Klk, Jm	C, W	S	40		
4ac	do	Dr	325		P	Ss	Kfr	N	N			Dry hole, L
8db	L. F. Dennis	Dr	50		P	Cls	Qal	C, W	D, S	20		
9cc	Gulf Oil Co.	Dr	4,108		N			N	N			Oil test, L(4047)
10ac	Henry Hauber	Dr	235	6	P	Ss	Kfr, Flk	F	S			D12R
14db	V. H. Simmons	Dr	2,350		N			N	N			Oil test, L(1921)
56-61-11ac	National Lead Co.	Dr	939	6	P	Ss	Kfr, Klk	T, E	In	140		T64, L, D20R
13bd	E. Brontley	Dr	720	6	P	Ss	Kfr, Klk	C, E	D, S	20		T52
14ba	Hunt Oil Co.	Dr	3,793									Oil test, L(810)
20bc	T. Jensen	Dr	345	2	P	Ss	Kfr, Klk	F	S			T58, D11R
29dd	do	Dr	500	2	P	Ss	Kfr, Klk	F	D, S			T58, D5R
56-62-1ca	do	Dr	554	2½	P	Ss	Klk, Jm	F	S, I			T63, D70M

20cd	Charles Phillips	Dr	250	4	P	Ss	Klk, Jm	C, H	D, S	59.70	June 20, 1956	
21ac	do	Dr	300	4	P	Ss	Kfr, Klk	F	S			T55, D1E
24cc	D. L. Owens	Dr	219.0	2	P	Ss	Klk	F	S			T53, D10E
27bb	Charles Phillips	Dr	166.0	3	P	Ss	Kfr, Klk	F	S			T52, D1.7M
28bb	Ben Phillips	Dr	333	4	P	Ss	Kfr, Klk	F	S	+21.2		T52, L, Ca, D9.9M, DD21.2
29dd	do	Dr	115	5	P	Ss	Klk	C, G	D, S	90.40	July 11, 1956	T50, D2.9M, DD12.3
56-63-2cc	I. Moore	Du	40	36	S	S, G	Qal	N	N	30.50	July 23, 1956	
7bd	do	Dr	300	4	P	Ss	Jm	J, E	D, S	26.23	Aug. 2, 1956	T51, Ca, L, D3.5M, DD17.3
10ca	do	Dr	400	5	P	Ss	Jsh	F	S			L, D5R
15ad	Jim McClure	Dr	60	6	P	Ss, Cls	Jsrl	J, E	D, S	16.30	July 20, 1956	T54, Ca, L
56-63-26aa	W. Carr	Dr	34	6	P	Ss, Cls	Jm	C, H	D, S	11.20	July 23, 1956	T49, D5R
26da	W. Bunney	Dr	132	6	P	Ss, Cls	Jm	C, E	S	22.03	July 20, 1956	T50, D6.2M, DD23.7
32ab	Joe Svoboda	Dr	82	6	P	S, G	Qal	J, E	D, S	25		L
32cb	E. Holcomb	Dr	50	6	P	Ss, Cls	Jsg	C, E	D	20.07	July 16, 1956	
56-64-12cc	I. Moore	Dr	180	6	P	Ss, Cls	Jsrl	C, N	N	20		
56-65- 8cc	Dick Ackerman	Dr	200	3	P	Ss	Klk	F	D, S			D25R, DD20R
10ac	E. Davison	Dr	167	4	P	Ss	Kfr, Klk	C, W	S	50		D10R
56-66- 2bc	F. Bush	Dr	232	6	P	Ss	Klk	F	S			D3R
3ca	do	Dr	250	5	P	Ss	Kfr, Klk	F	D, S			D5E
11bb	do	Dr	200		P	Ss	Kfr, Klk	F	S			D5E
11ca	R. S. Jolley	Dr	125		P	Ss	Kfr, Klk	F	S			L, Ca, D2.7M
13bc	do	Dr	153		P	Ss	Kfr	F	D			
56-67-26ab	A. C. Moore	Dr	295	8	P	Ss	Kfr	C, W	S	30		D10R
26bb	do	Dr	95	6	P	Ss	Knc	C, W	S	30		
33dd	Henry Hauber	Dr	174		P	Ss	Kfr	J, G	D	40		D5R
57-62-29cc	M. M. Coburn	Dr	610	4	P	Ss	Kfr	C, H	S	107.70	July 23, 1956	T54, L, D3R
57-63- 2ab	C. Raber	Dr	40	7	P	Cls	Qal	N	N	18.25	Aug. 15, 1956	
24aa	R. Robinson	Dr	400	4	P	Ss	Kfr, Klk	J, E	D, S	50		L, D5R
57-64- 3bc	Hugh Harney	Dr	34	4	P	S, G	Qal	C, H	S	20.80	Oct. 30, 1956	L, D5R
3db	Roy Foster	Dr	390	4	P	Ss	Kfr, Klk(?)	C, G	D, S	153		T56, Ca, D4E
4bb	Chester Whitney	Du	36	48	W	S, G	Qal	N	N	19.90	Aug. 13, 1956	L
10ca	Bill Lobbins	Dr	234		P	Ss	Kfr	C, W	S	220	Nov. 4, 1956	
21ac	Floyd Mitchell	Dr	300	6	P	Ss	Kfr, Klk	N	N	248		
57-64-31aa	Charles Moore	Dr	141	6	P	Ss	Klk	C, G	S	70.50	Oct. 29, 1956	L
57-65-13ca	Harry Scoggins	Du	33	48	C	S, G	Qal	J, E	D, S	26.10	Aug. 13, 1956	L
15bb	L. A. Bergman	Dr	1,765									Oil test, L
22ca1	Morris Madden	Dr	350	4	P	Ss	Kfr, Klk	J, E	D	250		T54, L
22ca2	do	Dr	80	4	P	S, G	Qal	C, H	S	26.90	Aug. 13, 1956	T52, Ca
33da	E. Davidson	Dr	115	4	P	Ss	Kfr	F	D, S		Nov. 3, 1956	
57-66- 6dc	Amerada Petroleum	Dr	1,678									Oil test
33ab	F. Bush	Dr	600			Ss	Knc	N	N	150		
33cc	C. Storms	Dr	810			Ss	Knc	N	N	300		L
57-67-23cc	Amerada Petroleum	Dr	1,510			Ss						Oil test, L
58-64-33bc	Chester Whitney	Du	13	36	R	S	Qal	C, H	S	7.58	Aug. 13, 1956	
35ac	G. Harney	Dr	280	4	P	Ss	Kfr, Klk	J, E	S	45		Ca, D2.5M

TABLE 12.—*Drillers' logs of water wells and oil-test holes*

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
48-69-1bd (adjacent to map area)					
Alluvium:			Alluvium—Con.		
Sand and gravel	30	30	Shale, sandy; contains coal beds	200	300
Fort Union Formation:			Sandstone	21	321
Sandstone, fine	70	100			
49-68-14ac					
Alluvium:			Lance Formation:		
Sand and gravel	38	38	Shale	60	98
			Sandstone, dark-gray	40	138
49-68-24aa					
Alluvium:			Lance Formation:		
Sand and gravel	50	50	Shale	30	80
			Sandstone, contains water	23	103
49-68-28bb					
Alluvium:			Fort Union Formation:		
Sand, yellow	30	30	Shale	50	90
Sand, fine	10	40	Sandstone (water)	25	115
49-69-36aa					
Alluvium:			Fort Union Formation:		
Sand, yellow	40	40	Shale, sandy	140	180
			Sandstone (water)	40	220
50-67-31dc					
Lance Formation:			Lance Formation—Con.		
Shale, blue, sandy	150	150	Shale, blue	80	290
Sandstone, gray (water from 170 to 200 ft)	50	200	Shale; contains several thin sandstone beds	60	350
Shale, brown	10	210			
50-68-23dc					
Alluvium:			Lance Formation:		
Sand, yellow	50	50	Shale	65	115
			Sandstone (water)	22	137
50-68-34bc					
Alluvium:			Lance Formation—Con.		
Soil	5	5	Shale, blue	10	85
Sand, brown	10	15	Sandstone, blue	2	87
Sand, fine	5	20	Shale, blue	5	92
Gravel	5	25	Sandstone, blue	5	97
Lance Formation:			Shale, blue	33	130
Sandstone (water)	25	50	Sandstone (water)	15	145
Shale, blue	3	53	Shale, blue	2	147
Sandstone	22	75			

TABLE 12.—*Drillers' logs of water wells and oil-test holes*—Continued

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
		51-67-25ca			
(Tops of formations only)					
Fall River Formation		310	Opeche Formation		1,840
Lakota Formation		490	Minnelusa Formation		1,880
Morrison Formation		610	Pahasapa Limestone		2,790
Minnekahta Limestone		1,810	Bottom of hole		2,827
		52-66-14ba			
Alluvium:					
Sand and gravel	26	26	Sundance Formation—Con.		
Sundance Formation:			Stockade Beaver Shale Member:		
Hulett Sandstone Member:					
Sandstone and siltstone	71	97	Shale, green	10	107
		52-66-22cd			
Skull Creek Shale	50	50	Minnekahta Formation—Con.		
Fall River Formation	170	220			
Lakota Formation	40	260			
Minnelusa Formation:					
Sandstone; upper part			coarse and dark, becoming finer grained and lighter in color with depth	48	608
		53-65-18ba			
Alluvium:			Minnekahta Limestone—Con.		
Soil and fine sand	22	22			
Sand, red, cemented	3	25			
Gravel	3	28	Limestone and sandstone; contains water and gas	20	468
Spearfish Formation:			Opeche Formation:		
Shale, red; contains beds of gypsum	352	380	Shale, blue	3	471
Shale, red	65	445	Shale, red	20	491
Minnekahta Limestone:			Shale, red, and thin limestone, interbedded	59	550
Limestone, dark	3	448	Limestone, gray	10	560
		53-65-35bd			
Sundance Formation:			Sundance Formation—Con.		
Redwater Shale and Lak Members:			Stockade Beaver Shale Member:		
Shale, variegated gray, blue, and pink, sandy	50	50	Shale, red	10	120
			Shale, gray, sandy	25	145
			Sandstone, gray	5	150
Hulett Sandstone Member:			Shale, gray, sandy	10	160
Sandstone	10	60			
Limestone(?)	3	63			
Sandstone	47	110			
		53-67-3ca			
Mowry Shale, Newcastle Sandstone, and Skull Creek Shale:			Fall River Formation:		
			Sandstone, silty and clayey (water flow)	125	525
Shale	400	400			

TABLE 12.—*Drillers' logs of water wells and oil-test holes*—Continued

54-60-4bb

Material	*Thickness (ft)*	*Depth (ft)*
Fall River Formation:		
Sandstone, soft	70	70
Shale	10	80
Sandstone, hard	50	130
Lakota(?) Formation:		
Shale	50	180
Sandstone, white	20	200
Shale	10	210
Sandstone	30	240
Shale, black	20	260
Sandstone	20	280
Shale	10	290
Sandstone	20	310
Morrison and Sundance Formations:		
Shale	220	530
Morrison and Sundance Formations—Continued		
Shale, sandy	10	540
Shale, sandy, red	60	600
Sandstone (water at 600 ft.)	10	610
Sandstone, and thin beds of shale	80	690
Shale, blue	60	750
Hard rock(?)	10	760
Gypsum	10	770
Shale, red	10	780

54-61-1bb

Material	*Thickness (ft)*	*Depth (ft)*
Skull Creek Shale:		
Shale	200	200
Fall River Formation:		
Sandstone	20	220
Fall River Formation—Con.		
Shale	65	285
Sandstone	45	330
Shale	6	336

54-64-7bc1

Material	*Thickness (ft)*	*Depth (ft)*
Alluvium:		
Soil, red	15	15
Spearfish Formation:		
Sandstone, red	10	25
Limestone, sandy, hard	15	40
Gypsum (water)	2	42
Sandstone, red	35	77
Sandstone, red, conglomeratic (water)	3	80
Shale	34	114
Gypsum	8	122
Shale, red	108	230
Shale, red, and gypsum	90	320
Shale, red, with beds of gypsum and pink limestone	22	342
Limestone, pink	4	346
Shale, red, sandy, and beds of gypsum	59	405
Limestone, red, sandy	11	416
Shale, red, sandy	64	480
Spearfish Formation—Con.		
Limestone, red, sandy	10	490
Shale, bright-red	25	515
Minnekahta Limestone:		
Limestone, gray	3	518
Sandstone, gray (flows 15 gpm)	5	523
Limestone, sandy	22	545
Opeche Formation:		
Shale, purple	5	550
Shale, dull-red	70	620
Minnelusa Formation:		
Sandstone, red, and red shale partings	8	628
Sandstone, dark-gray (water flow increased to 75 gpm)	17	645
Shale, red, sticky	1	646
Sandstone, light-gray, soft, (flow increased to 375 gpm)	17	663

54-64-18bb

Material	*Thickness (ft)*	*Depth (ft)*
Alluvium:		
Sand and gravel	30	30
Spearfish Formation:		
Shale and sandstone, red	75	105

54-65-13ba

Material	*Thickness (ft)*	*Depth (ft)*
Alluvium:		
Sand and silt	15	15
Sand and gravel	27	42
Spearfish Formation:		
Siltstone and sandstone	4	46

54-65-27db

Material	*Thickness (ft)*	*Depth (ft)*
Alluvium:		
Sand and gravel	30	30
Spearfish Formation:		
Sandstone and shale, red	20	50

TABLE 12.—*Drillers' logs of water wells and oil-test holes*—Continued

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
54-65-29dd					
Alluvium:			Minnekahta Limestone:		
Soil(?)	28	28	Sandstone, limy	7	580
Sand and gravel	54	82	Limestone, hard	30	610
Spearfish Formation:			Opeche Formation:		
Sandstone, siltstone, and claystone, red; contains gypsum	317	399	Shale, red	64	674
Gypsum	46	445	Minnelusa Formation:		
Sandstone, claystone, red; contains gypsum	128	573	Sandstone	118	792
55-60-7ca					
Alluvium:			Fall River Formation:		
Soil and sand	25	25	Sandstone	15	310
Skull Creek Shale:			Shale, gray	55	365
Shale, blue, containing a few thin beds of hard sandstone	250	275	Sandstone	15	380
Shale, gray	20	295	Lakota(?) Formation:		
			Shale, green	10	390
55-60-18dc					
Alluvium:			Fall River Formation—Con.		
Soil and sand	42	42	Shale, gray	23	128
Skull Creek Shale:			Sandstone	26	154
Shale, blue, containing a few thin beds of hard sandstone	49	91	Shale, gray	16	170
Fall River Formation:			Sandstone	39	209
Sandstone and clay	14	105	Lakota(?) Formation:		
			Shale, red	6	215
55-61-8dc					
Skull Creek Shale:			Fall River Formation and upper part of Lakota Formation:		
Shale	200	200	Sandstone	115	315
55-61-22dc					
Mowry and Skull Creek Shales:			Fall River and Lakota Formations—Continued		
Shale, black	430	430	Shale	100	580
Fall River and Lakota Formations:			Sandstone	30	610
Sandstone	50	480	Shale	3	613
55-64-21cd					
Alluvium:			Spearfish Formation:		
Slope wash	75	75	Siltstone, red	75	150
55-67-4ac					
Skull Creek Shale:			Fall River Formation—Con.		
Shale	185	185			
Fall River Formation:					
Sandstone and shale (bot-			tom of hole in very hard quartzite)	140	325

TABLE 12.—*Drillers' logs of water wells and oil-test holes*—Continued

55-67-9cc

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
(Tops of formations only)			Minnekahta Limestone		1,995
Newcastle Sandstone		178	Opeche Formation		2,033
Fall River Formation		476	Minnelusa Formation		2,042
Lakota Formation		619	Pahasapa Limestone		2,778
Morrison Formation		810	Englewood Limestone		3,674
Sundance Formation		1,084	Whitewood Dolomite		3,682
Spearfish Formation		1,383	Deadwood Formation		4,047

55-67-14db

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
(Tops of formations only)			Spearfish Formation		1,248
Inyan Kara Group		316	Minnekahta Limestone		1,842
Morrison Formation		508	Minnelusa Formation		1,921
Gypsum Spring Formation		1,173			

56-61-11ac

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
Mowry and Skull Creek Shales:			Lakota Formation—Con.		
Shale (bentonite at 160 feet)	600	600	Shale, dark	25	760
Fall River Formation:			Sandstone, white (water)	20	780
Sandstone, white	10	610	Shale	20	800
Shale, black	10	620	Sandstone, white, and beds of shale	45	845
Shale, hard, sandy	30	650	Morrison(?) Formation:		
Sandstone, yellow, hard	20	670	Shale, dark	45	890
Shale and some sandstone	10	680	Sandstone and shale, interbedded	15	905
Shale	50	730	Shale, limy, hard	34	939
Lakota Formation:					
Sandstone, white (water)	5	735			

56-61-14ba (partial log)

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
(Tops of formations only)			Morrison Formation		560
Fall River Formation		400	Sundance Formation		810
Lakota Formation		490			

56-62-28bb

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
Skull Creek Shale:			Fall River and Lakota Formations—Continued		
Shale	60	60	Shale	90	260
Fall River and Lakota Formations:			Sandstone	60	320
Sandstone	110	170	Shale	13	333

56-63-7bd

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
Alluvium:			Morrison and Sundance Formations—Continued		
Sand	30	30	Shale and sandstone, interbedded	40	300
Morrison and Sundance Formations:					
Shale	230	260			

56-63-10ca

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
Alluvium:			Sundance(?) Formation:		
Silt	25	25	Shale, green	110	260
Morrison Formation:			Sandstone, white	25	285
Sandstone, yellow	20	45	Shale, green	90	375
Shale, red and green	105	150	Sandstone	25	400

TABLE 12.—*Drillers' logs of water wells and oil-test holes*—Continued

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
56-63-15ad					
Alluvium:			Sundance Formation:		
Sand and gravel	35	35	Shale, red, and white sandstone	25	60
56-63-32ab					
Alluvium:			Sundance Formation (lower part):		
Silt	40	40	Sandstone, siltstone, and claystone	5	82
Gravel	7	47			
Clay	20	67			
Gravel	10	77			
56-66-11ca					
Fall River Formation:			Lakota Formation:		
Sandstone	40	40	Shale	40	70
			Sandstone	70	125
57-62-29cc					
Mowry Shale:			Skull Creek Shale:		
Shale	20	20	Shale	360	510
Bentonite	60	80	Fall Fiver Formation:		
Shale	10	90	Sandstone	30	540
Bentonite	30	120	Shale	30	570
Newcastle Sandstone:			Sandstone	40	610
Sandstone	30	150			
57-63-24aa					
Allnvium:			Fall River Formation—Con.		
Sand and gravel	25	25	Sandstone	10	325
Skull Creek Shale:			Shale, dark	10	335
Shale, black, sticky	255	280	Shale interbedded with layers of sandstone	25	360
Fall River Formation:			Lakota(?) Formation:		
Shale, sandy	5	285	Sandstone	40	400
Sandstone (water)	10	295			
Shale, dark, sandy, hard	20	315			
57-64-3bc					
Alluvium:			Skull Creek Shale:		
Clay, sticky	10	10	Shale, black	14	34
Sand and gravel	10	20			
57-64-4bb					
Alluvium:			Alluvium—Continued		
Clay, sticky	10	10	Gravel and sand	3	30
Sand, fine	17	27	Skull Creek Shale:		
			Shale, black	6	36
57-64-31aa					
Alluvium:			Lakota Formation—Con.		
Soil	10	10	Sandstone (water)	20	95
Lakota Formation:			Morrison(?) Formation		
Sandstone	65	75	Shale, blue (some water)	46	141

TABLE 12.—*Drillers' logs of water wells and oil-test holes*—Continued

Material	*Thickness (ft)*	*Depth (ft)*	*Material*	*Thickness (ft)*	*Depth (ft)*
57-65-13ca					
Alluvium:			Alluvium—Continued		
Silt	23	23	Sand and gravel	10	33
57-65-15bb					
(Tops of formations only)			Morrison Formation		385
Fall River Formation		220	Sundance Formation		550
Lakota Formation		370	Bottom of hole		1,765
57-65-22ca1					
Alluvium:			Fall Fiver Formation and part of Lakota Formation:		
Silt, sand, and gravel	40	40	Sandstone	50	225
Skull Creek Shale:					
Shale, black	135	175	Shale, black	125	350
57-66-33cc					
Belle Fourche and Mowry Shales:			Newcastle Sandstone:		
Shale, black	550	550	Sandstone	50	600
			Skull Creek Shale:		
			Shale, black	210	810
57-67-23cc					
(Tops of formations only)			Fall River Formation		1,223
Mowry Shale		717	Lakota Formation		1,379
Newcastle Sandstone		928	Bottom of hole		1,510

INDEX

[Italic page numbers indicate major references]

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

Whitcomb, Harold A., 1913–

Ground-water resources and geology of northern and western Crook County, Wyoming, by Harold A. Whitcomb and Donald A. Morris. With a section on the chemical quality of the ground water, by Russell H. Langford. Washington, U.S. Govt. Print. Off., 1964.

v, 92 p. illus., maps (1 col.) diagrs., tables. 24 cm. (U.S. Geological Survey. Water-supply paper 1698)

Part of illustrative matter fold. in pocket.

Prepared in cooperation with the State Engineer of Wyoming.

(Continued on next card)

Whitcomb, Harold A., 1913– Ground-water resources and geology of northern and western Crook County, Wyoming. 1964. (Card 2)

Bibliography: p. 77–78.

1. Water, Underground—Wyoming—Crook Co. 2. Water-supply—Wyoming—Crook Co. 3. Geology—Wyoming—Crook Co. 4. Borings—Wyoming—Crook Co. 5. Water—Analysis. I. Morris, Donald Arthur, 1918– joint author. II. Langford, Russell Hal, 1925–. III. Wyoming. State Engineer. (Series)