Geology and Ground-Water Resources of the Lower Bighorn Valley Montana

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1876

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

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By L. J. HAMILTON *and* Q. F. PAULSON

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A reconnaissance investigation of the geology and ground-water hydrology of the area as they relate to the availability and quality of ground water and as they affect drainage of land presently irrigated and land proposed for irrigation

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GLOSSARY

Aquifer.—A formation, group of formations, or part of a formation that is water bearing.

Artesian water.—Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.

Confining bed.—A bed overlying or underlying an aquifer which, because of its impermeability or low permeability relative to that of the aquifer, gives the water in the aquifer artesian head.

Drawdown.—The lowering of the water table or piezometric surface caused by pumping or artesian flow.

Effluent flow.—Flow of water from the ground into a surface-water body.

Evapotranspiration.—That portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation, no attempt being made to distinguish between the two.

Flowing well.—A well that discharges water at the land surface by artesian pressure without the application of a pump or other lifting device.

Ground water.—That part of subsurface water which is in the zone of saturation.

Hydraulic gradient.—As applied to ground water, the rate of change of pressure head per unit of distance of flow at a given point and in a given direction.

Influent flow.—Flow of water into the ground from a surface-water body.

Permeability.—The capacity of an aquifer to transmit water.

Permeability, field coefficient of.—The rate of flow of water, in gallons per day, under prevailing conditions, through a cross section of aquifer 1 foot high and 1 mile wide, under a hydraulic gradient of 1 foot per mile.

Piezometric surface.—An imaginary surface that everywhere coincides with the static level of water in an aquifer. It is the surface to which the water from a given aquifer will rise under its full head.

Pressure head.—The hydrostatic pressure at a point in an aquifer. Expressed as the height of a column of water that can be supported by the pressure.

Seismograph shothole.—A hole drilled into bedrock, at the bottom of which an explosive charge is detonated as a source of seismic energy for geophysical measurements.

Specific capacity.—The discharge of a well expressed as rate of yield per unit drawdown, generally gallons per minute per foot of drawdown.

Transmissibility, coefficient of.—The quantity of water, in gallons per day, under prevailing conditions, that is transmitted through each mile of an aquifer under a hydraulic gradient of 1 foot per mile. It is equal to the average field coefficient of permeability multiplied by the thickness of the aquifer, in feet.

Underflow.—The movement of ground water in a conduit-shaped aquifer.

Water table.—The upper surface of the zone of saturation, except where that surface is formed by an impermeable body.

GEOLOGY AND GROUND-WATER RESOURCES OF THE LOWER BIGHORN VALLEY, MONTANA

By L. J. Hamilton and Q. F. Paulson

ABSTRACT

The Bighorn River has incised a deep, broad valley in Cretaceous strata along its 65-mile lower reach below the mouth of Bighorn Canyon in south-central Montana. It ceased downcutting at six different levels 100–200 feet apart, widening its flood plain and alluviating each level with about 30 feet of sandy gravel. These deposits are the only economic source of ground water in large areas of the valley where the underlying bedrock consists of relatively impermeable shale to great depths. Ground water in the alluvium is hard and in the irrigated lowlands is highly mineralized at those places where drainage is slow and discharge by evapotranspiration is great.

Three bedrock sandstone aquifers are present at moderate depths along three separate reaches of the valley. The sandstones yield soft, moderately to highly mineralized water that contains a high percent sodium.

Wells in alluvial gravel of the irrigated lowlands can yield 100 gallons per minute at many places because the alluvium is fairly permeable and is readily recharged by infiltration of applied irrigation water, canal seepage, and ground water moving into the lowlands from the alluvium of tributary coulees. Seepage from the Two Leggins Canal in the central area probably is large.

Alluvial gravel deposits have been mantled by thick alluvial and colluvial deposits of silty clay or silt that thin riverward. These fine-grained deposits drain slowly and confine ground water in alluvial gravel under artesian pressure at many places in the irrigated lowlands of the central and southern areas. The piezometric surface is close to the land surface at many places in the central area, and capillary rise and evapotranspiration in waterlogged ground has produced agriculturally harmful alkali deposits.

Waterlogging of presently irrigated land in the central area will become more widespread if irrigation is extended to higher terraces to the west unless drainage ditches are installed along the base of high-terrace alluvium to intercept increased seepage and spring discharge. Additional provisions also may be required to intercept water moving through the alluvium of coulees.

INTRODUCTION

LOCATION AND DESCRIPTION OF AREA

The area included in this investigation extends along the valley of the Bighorn River from the mouth of the canyon in T. 6 S., R. 31 E., to the confluence with the Yellowstone River in T. 5 N., R. 34 E. (fig. 1). The valley crosses parts of Big Horn and Yellowstone Counties, Mont., and much of it is within the Crow Indian Reservation. The area is 65 miles long and ranges in width from 10 miles at the south end to 3 miles at the north end. It includes the flood plain of the Bighorn River, the adjacent stream terraces, and a part of the bordering shale and sandstone hills.

The area lends itself to a three-fold division (fig. 1). The southern area is characterized by a broad irrigated lowland east of the river and a steplike sequence of upland terraces west of the river. It extends from the mountain front to Two Leggins Creek. The central area extends from Two Leggins Creek to 15 miles north of Hardin, where the river is along the eastern edge of the valley and a broad irrigated lowland lies west of the river. The northern area extends from the central area 10 miles to the Yellowstone River valley; it is a narrow lowland between high sandstone hills.

PURPOSE AND SCOPE OF INVESTIGATION

This report is the result of one of a series of investigations in the U.S. Department of the Interior's program for the development of the natural resources of the Missouri River basin. The U.S. Geological Survey was requested by the U.S. Bureau of Reclamation and the U.S. Bureau of Indian Affairs to investigate the geology and ground-water hydrology of the area as they are related to the availability and quality of ground water for domestic and stock use and as they may affect drainage of presently irrigated land and lands proposed for irrigation. It has been proposed to irrigate about 43,500 acres of additional land on high terraces with water stored behind Yellowtail Dam.

Geologic and hydrologic investigations were begun in 1957 by Q. F. Paulson. He was assisted in 1958 by L. J. Hamilton, who completed the field investigations and prepared this report. The geology was mapped on aerial photographs and later transferred to a base map. Altitudes of observation wells were obtained by spirit leveling in T. 5 S. and T. 6 S., and from quadrangle maps elsewhere in the valley.

Most wells and numerous springs were inventoried. The depths to water in 60 observation wells were measured periodically for 4 years and have been measured in 20 selected wells to the present (1966). Pumping tests were made at the sites of five wells to determine the hydrologic characteristics of the aquifers. The chemical quality of water from 19 wells was determined, and the conductivity of water from 145 wells was measured.

PREVIOUS INVESTIGATIONS

A summary of the geology and natural resources of Big Horn County by Thom, Hall, Wegemann, and Moulton (1935) was based,

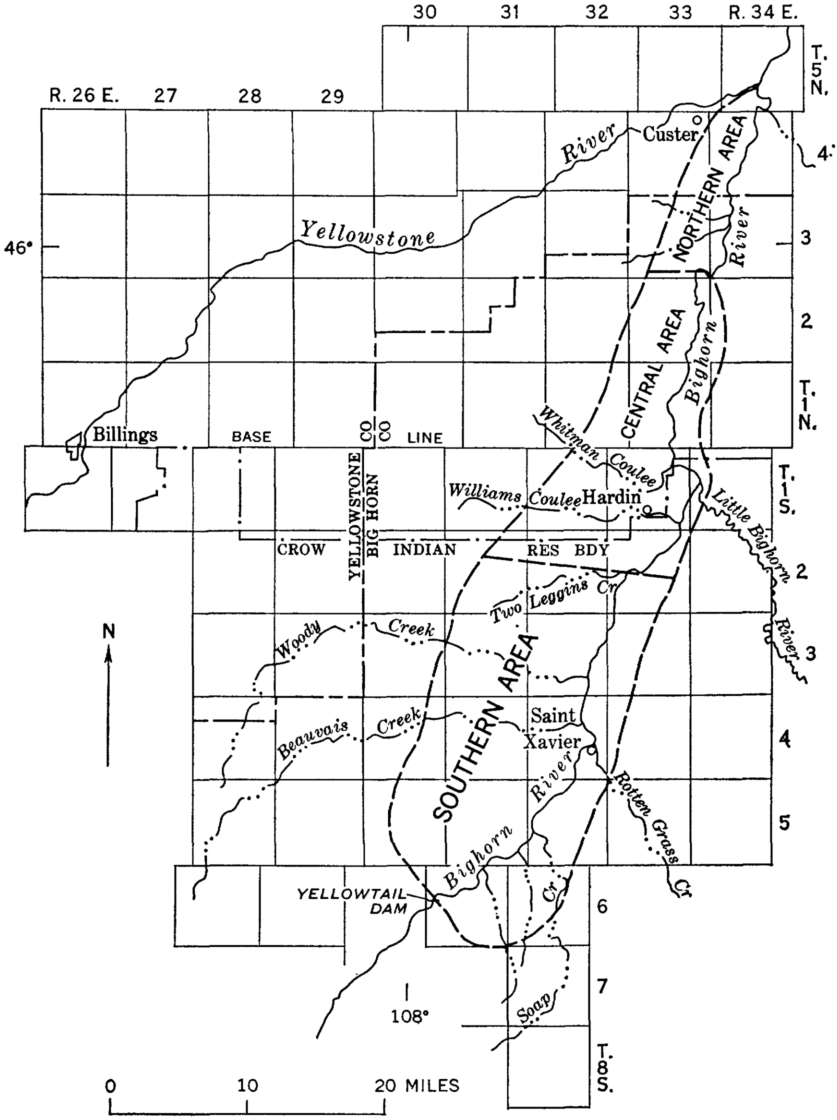

FIGURE 1.—Drainage and the three divisio s of the area studied.

for the most part, on 12 reconnaissance field investigations. A detailed report on the geology and the oil, gas, and mineral resources of the southern part of the valley and of the canyon area was made by Richards (1955). The bentonitic clay deposits of the Bighorn and Little Bighorn River valleys were studied in detail by Knechtel and Patterson (1956). The geology and ground-water resources of the lower Little Bighorn River valley were studied by Moulder, Klug, Morris, and Swenson (1960), with special emphasis on drainage of waterlogged lands. A reconnaissance of the geology and ground-water hydrology of lands above Two Leggins Canal was made by Swenson and Zimmerman (1958).

ACKNOWLEDGMENTS

Much valuable information on wells was obtained from farmers and ranchers of the area, and these people were most cooperative in all phases of the investigation. Engineers and geologists of the U.S. Bureau of Reclamation participated in field conferences and supplied maps and logs of their exploratory drilling. Mr. Henry Kray, well driller from Hardin, supplied logs of wells which he had drilled between 1956 and 1961, and several oil companies provided numerous seismograph shothole logs that were useful for determining the thickness and extent of alluvial aquifers.

NUMBERING SYSTEM FOR LOCATION OF WELLS AND OTHER SITES

Well and other locations are numbered according to a system based on surveys of the area by the U.S. Bureau of Land Management. Each location number begins with a capital letter that indicates the quadrant of the principal meridian and base-line system for Montana. The quadrants are designated A, B, C, and D, beginning with thc northeast quadrant and continuing in a counterclockwise direction. The first numeral of a well number indicates the township, the second the range, and the third the section. The lowercase letters following the section number indicate the location within the section and are lettered a, b, c, and d in a counterclockwise direction beginning in the northeast corner. The first lowercase letter denotes the quarter section, the second letter the quarter-quarter section. A diagram illustrating this method of locating and well numbering is shown in figure 2.

HISTORY AND GENERAL FEATURES OF THE AREA

The economic development of the area has been closely related to the utilization of the water resources. Because present and future growth patterns depend to some extent on past experiences, the history of settlement, the climate, and the economic resources as factors affecting past development are reviewed.

The settlement of the area and the development of agriculture is closely associated with recent Indian history. The first treaty between the U.S. Government and the Crow Indian Tribe was signed in 1851. It established the right of the Indians to a tract of land 185 miles long and 90 miles wide, extending from the 45th parallel of

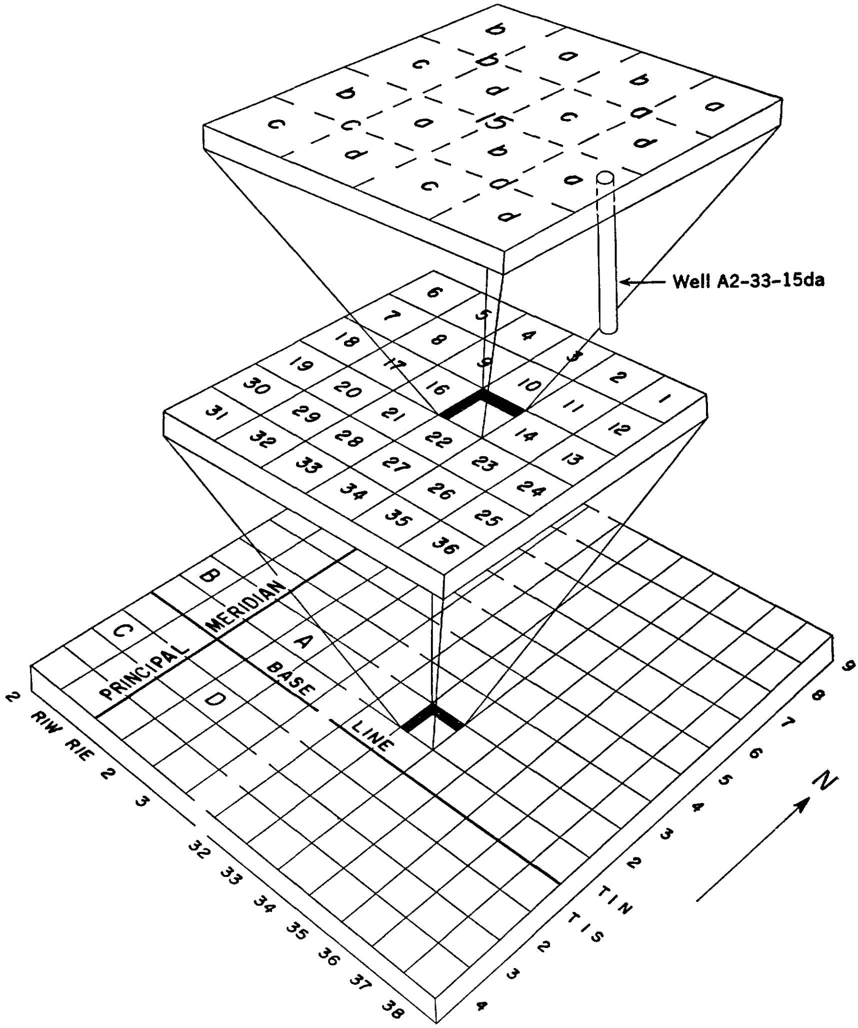

FIGURE 2.—System used in numbering wells and other field locations.

north latitude northward through the Bighorn and Pryor Mountains to the Yellowstone River and between the 107th and 111th meridians of west longitude. Another treaty in 1868 reestablished the right of the Crow Tribe to the reservation and provided for construction of Indian Agency schools, storage sheds, and flour mills, and for distribution of implements and seed for those Indians interested in farming. Little farming was done by the tribe during the following decade because the Crows obtained sufficient food and clothing by hunting buffalo. During this period the Crows were employed as scouts in the long U.S. Army campaign to return hostile Sioux and Cheyenne

Indians to their assigned Dakota reservation. The hostile tribes united under the leadership of Sitting Bull and Chief Crazy Horse to annihilate five troops of the U.S. Army 7th Cavalry, commanded by General George A. Custer, in the battle of the Little Bighorn. This battle was fought on June 25, 1876, about 12 miles southeast of Hardin. In 1877 the Government established Fort Custer at the confluence of the Bighorn and Little Bighorn Rivers to discourage further Indian uprisings. With the wanton destruction of the buffalo herds by white hunters, the Crow Tribe was obliged to turn to agriculture for a living.

The tribe leased reservation lands to cattle companies, and large herds of cattle began moving onto the reservation in 1880. Grazing of sheep was introduced about 1900. Agitation for opening parts of the reservation to homesteading resulted in treaties in 1880, 1890, and 1904, which reduced the size of the reservation to 3,300 square miles. The tribe received schools, livestock, fences, and irrigation projects in return for ceded land. Eight irrigation systems were constructed by the Government between 1892 and 1910. An additional payment of $9 million was made to the tribe in 1962 for the ceded land.

The northern, ceded part of the original reservation, was opened to homesteading in 1906. Dryland grain farming on 160-acre tracts was generally profitable between 1906 and 1917 under favorable rainfall and market conditions. The numerous droughts and crop failures that followed forced many dryland grain farmers into bankruptcy. Farmers who had sufficient savings to carry them over these hard times were later able to buy abandoned farms and develop economic units. They were able to increase their production and profits during wet years, and by planting newly developed drought-resistant varieties of grain and by strip cropping and summer fallowing they were successful at dryland farming.

The Indians originally raised much livestock, building up a cooperative herd of several thousand cattle before 1920. Rustlers stole the entire herd, and the Federal Government subsequently discouraged the tribe from rebuilding the herd (Medicine Crow, 1939). The Indians also reserved large tracts of the reservation for grazing wild horses, which totaled 30,000 by 1920. Horses were the principal item of wealth and means of barter for the Indians and were much easier to keep than cattle. However, commercial ranching interests influenced the Government to rid the range of these horses, and the Indians were forced to sell their horses at low prices or have them shot (Medicine Crow, 1939).

The Indians leased increasing acreages of land; by 1937 only 7 percent of the reservation land was operated by Indian owners, and only 60 of the 522 families of the Crow Tribe supported themselves entirely by farming or ranching (Medicine Crow, 1939).

The climate of the area played an important role in the agricultural development. The lower Bighorn Valley has a continental, semiarid climate characterized by abundant sunshine, low relative humidity, moderate to strong winds, and wide daily and seasonal variations in temperature. One-half to one-third of the yearly precipitation falls in the late spring or early summer as short rainstorms occasionally accompanied by hail. The average annual precipitation and altitude increase toward the south end of the valley, Hardin (2,885 ft) averaging about 12 inches for the period of record 1941–66, and Campbell Farm 4 (3,650 ft) at the south end of the valley averaging about 15 inches for the period of record from 1942–61. In some years there are large deviations from these averages, however, and Hardin has received as little as 8 inches and as much as 21 inches of annual precipitation.

The mean annual temperature at Hardin is 46°F, but there are large daily temperature fluctuations, and winter temperatures as low as −46°F and summer temperatures as high as 110°F have been recorded. The growing season at Hardin averages 150 days and is about a week longer at Campbell Farm 4, nearer the Bighorn Mountains. The earliest and latest recorded dates of killing frosts are September 27 and May 3 at Hardin and October 5 and May 9 at Campbell Farm 4.

The occasional moderate to strong winds from the west and northwest are generally of short duration, but during hot dry weather they dry the soil rapidly and damage crops.

The economy of the area is mostly dependent on irrigation. The production and processing of livestock and other agricultural products are the principal occupations. Most of the livestock is shipped to marketing centers outside Big Horn County. A beet sugar refinery capable of processing 1,500 tons of beets per day is located 1 mile north of Hardin. A small creamery supplies local demand.

Resources not related to agriculture that contribute to the economy are oil, gas, and sand and gravel. Oil is produced from the Soap Creek dome at the south end of the valley (D6–32–34). The Hardin gas field supplies some natural gas for local domestic use from 50 scattered wells 600–700 feet deep. Sand and gravel plants supply local demands. Resources not yet developed include bentonite, gypsum, limestone, and timber.

GEOLOGIC SETTING

OLDER BEDROCK

The 8,000 feet of rocks exposed in the lower Bighorn Valley range in age from Mississippian at the mouth of Bighorn Canyon to Recent on the flood plains of the large streams (pl. 1). Shale and sandy shale, which do not yield water readily to wells, make up more than 75 percent of this thickness. The rocks and their water-bearing properties are described in table 1.

In Late Mississippian time extensive erosion and weathering widened joints and developed caverns in the upper few hundred feet of the Madison Limestone. A karst topography developed as the roofs of caverns collapsed and filled the caverns with limestone breccia. Breccia zones and caverns were partly filled by red clay, deposited in Amsden time. The Tensleep Sandstone was deposited in Middle and Late Pennsylvanian time and partly eroded in Permian time. This sandstone thins gradually northward from the Bighorn and Pryor Mountains and is absent in the northern part of the valley (Rogers and others, 1945).

During the Cretaceous Period about 2,000 feet of shale accumulated in the study area, which was part of the Rocky Mountain geosyncline. Toward the end of the Cretaceous Period, mountain building in the Rocky Mountain area was widespread. The Bighorn uplift formed a broad northwest-trending anticline with steeply dipping strata along its flanks. Scattered doming and faulting of gently dipping strata occurred many miles beyond the mountains.

The strata adjacent to the northeast flank of the Bighorn Mountains were bowed into northwest-elongated domes, most of which have closures of less than 300 feet. Soap Creek dome (D6–32–34, pl. 1), 10 miles east of the mountains, has a surface closure of 500 feet and is the only dome in the study area from which commercial amounts of oil had been obtained as of 1966.

Tensional stresses in the uplifted strata of the Bighorn Mountains were relieved by normal faults of large vertical displacement. Numerous normal faults of small vertical displacement are concentrated mainly along three en echelon bands in the study area. One band is along the flank of the mountains, mostly in the silicious Mowry Shale north of the canyon mouth (Richards, 1955, pl. 1). Another band trends northward from Woody Creek dome (D3–31), and the third band occurs in the outcrop of Parkman Sandstone about 6 miles northeast of Hardin (pl. 1). This latter band of en echelon faults may form the east end of the Huntley-Lake Basin fault zone.

YOUNGER BEDROCK AND ALLUVIUM

In Late Cretaceous time, the geosyncline was filled with sediment derived from the rising Rocky Mountains. The humid climate of Late Cretaceous and early Tertiary time gradually became more arid as the rising mountains obstructed the movement of moist westerly winds from the Pacific Ocean (Mackin, 1937, p. 819). To adjust to gradually decreasing precipitation and runoff, streams draining the Bighorn Mountains changed their gradient by depositing great thicknesses of Tertiary alluvium in the Bighorn Basin southwest of the study area, and in the Great Plains just east of the Bighorn Mountains. By late Tertiary time, these deposits had engulfed all but the highest parts of the Bighorn Mountains.

The flood of debris from the Bighorn Mountains diminished by the end of Tertiary time, and streams began incising and removing Tertiary alluvium. Northeastward-flowing streams radiating from the Absaroka and Wind River Ranges of western Wyoming were superimposed from the high upper Tertiary plain onto resistant granite and Paleozoic strata of the Bighorn Mountains. These streams deposited a veneer of pediment gravel over large areas.

The ancestral Bighorn River, having a larger drainage area and a greater discharge, downcut more rapidly than the neighboring streams. It cut its canyon to a depth of 1,000 feet and a width of one-fourth mile at the mountain flanks and to a depth of more than 2,000 feet and a width of 1½ miles where it crossed the mountain crest (Richards, 1955, pl. 1). Its tributaries cut headward and intercepted and diverted much of the original northeastward drainage. Such stream piracy is continuing, as indicated by the capture of the headwaters of Hay Creek by a tributary of Beauvais Creek at D5–30–1b (Richards, 1955, p. 80). As Beauvais Creek had a larger drainage basin and greater discharge than Hay Creek, it incised terrace deposit 2 more rapidly and established a moderate gradient of 30 feet per mile well into its headward drainage. Its tributary has downcut 100 feet below the dry channel of Hay Creek near the point of capture.

ALLUVIAL TERRACES

The sequence of six steplike, broad alluvial terraces in the southern part of the lower Bighorn Valley affords striking evidence that the river did not continuously deepen its valley during Cenozoic time. This cyclic erosion and deposition has occurred at least six times during Cenozoic time. At the beginning of a cycle, the river incised its channel through the 20- to 40-foot-thick layer of sandy gravel and 100–200

TABLE 1.—*Generalized section and water-bearing characteristics of stratigraphic units in the lower Bighorn Valley*

System	Series	Stratigraphic unit	Thickness (feet)	Lithologic character	Water-bearing properties
		Alluvial fans	0–40	Consist of silt and fine sand in northern area of valley and of silty clay in central and southern areas.	Yield to wells will be small unless wells also penetrate underlying coarse-grained alluvium. Recharged principally by canal leakage, infiltrating irrigation water, and underflow from coulees.
	Recent	Alluvium	5–40	Consists of as much as 30 feet of sandy gravel overlain by thin deposits of silty clay underlying flood plain of Bighorn River and low terraces. Deposits of tributary streams are thinner.	Well yields of as much as 100 gpm (gallons per minute) can be developed locally. Water varies widely in chemical quality. Recharged by canal leakage, infiltrating irrigation water, underflow from coulees, and precipitation.
Quaternary	? Pleistocene	Colluvial and eolian(?) deposits	0–50	Principally slope wash consisting of silty clay with some thin layers of gravel. Present as wedge-shaped deposits which thin away from base of river bluffs and scarps of terraces. Deposits are thickest in southern part of valley.	Relatively impermeable. Recharged by precipitation and by seepage from higher ground.
? Tertiary	? Pliocene	Alluvial terrace deposits	5–40	River deposits consisting of 20–40 feet of sandy gravel overlain by thin layer of silty clay except where covered by colluvium. Terraces are 100 to as much as 600 feet above river level.	Deposits are permeable but saturated only in lower half. Wells may yield up to 30 gpm of slightly or moderately mineralized water. Recharged by precipitation and by underflow from coulees.
		Hell Creek Formation	600	Massive yellow to tan arkosic sandstone and greenish-gray sandy shale. Sandstone beds 30 feet thick in lower half; 10 feet thick and separated by greater thicknesses of shale in upper half.	Excellent aquifer. Water suitable for domestic and stock use. Soft, slightly mineralized water is unsuitable for irrigation because of high percentage of sodium salts.
		Bearpaw Shale	600	Dark-gray concretionary shale. Upper part contains thin siltstone beds and fossiliferous brown-weathering calcareous concretions. Lower part contains concretions and bentonite beds. Basal zone contains 10-foot-thick lenticular bentonite bed and large closely spaced concretions.	Relatively impermeable. Contains some highly mineralized water.
		Parkman Sandstone	250	Upper part contains massive lenticular brown and yellowish-gray arkosic sandstone, which at places contains numerous limonite-cemented sandstone concretions. Lower part is gray silty shale and sandy siltstone. Southeast of Bighorn Valley upper part becomes more shaly and lower part grades into massive sandstone.	Good artesian aquifer. Transmissibility variable because of different amounts of cement in different localities and ranges from 6,000 to 20,000 gpd per ft. Contains moderately mineralized water unsuitable for irrigation because of high percentage of sodium salts (Moulder and others, 1960).

Cretaceous	Upper Cretaceous	Claggett Shale	350	Dark-gray shale. Top part contains tan- and brown-weathering fossiliferous calcareous concretions with septarian veins of calcite. Lower part has bentonite beds and a few beds of calcareous concretions.	Relatively impermeable. Contains some highly mineralized water.
		Gammon Shale	370	Brown-weathering sandy shale. Changes eastward into gray silty shale with scattered thin sand layers. Several bentonite beds with calcite veins. Numerous zones of large ferruginous calcareous concretions which weather tan, brown, and reddish brown and contain some fossils and septarian calcite veins. Eagle Sandstone equivalent.	Slightly permeable. May yield small quantity of mineralized water.
		Telegraph Creek Formation	850	Tan- and brown-weathering silty shale and sandy siltstone. Upper part has several zones of scattered calcareous concretions which weather tan or orange brown.	Relatively impermeable. Contains some highly mineralized water.
		Niobrara Shale	400	Tan-weathering, gray, bentonitic, gypsiferous shale. Zone of sandy calcareous shale, at top and base, contains calcareous fossiliferous concretions and weathers light gray and light tan.	Do.
		Carlile Shale	300	Dark-gray concretionary gypsiferous, ferruginous shale. Upper part contains 20 beds of tan-weathering calcareous septarian concretions. Lower part is silty shale and contains beds of orange-brown- to red-brown-weathering ironstone concretions.	Relatively impermeable. May contain some highly mineralized water.
		Greenhorn Shale	60–100	Dark-gray calcareous shale. Weathers light tan. Lenticular bentonite bed at base. Contains scattered calcareous concretions and a thin bed of limestone. Formation is thickest along east side of valley.	Do.
		Belle Fourche Shale	200–300	Upper member. Gray silty ferruginous, gypsiferous shale. Upper part has many light-gray- and tan-weathering calcareous concretions. Zone of brown-weathering ferruginous "dolostone" concretions in middle. Lower part is silty bentonitic shale with thin layers of sand with black chert pebbles. Fewer concretions along east side of valley where member is thinner. Lower part contains a basal sandstone that thickens to 5 to 10 feet near Hardin, where it is called the Frontier gas sand of economic usage.	Slightly permeable. May contain some highly mineralized water.

TABLE 1.—*Generalized section and water-bearing characteristics of stratigraphic units in the lower Bighorn Valley*—Continued

System	Series	Stratigraphic unit	Thickness (feet)	Lithologic character	Water-bearing properties
Cretaceous	Upper Cretaceous	Belle Fourche Shale	200–300	Lower member. Dark-gray sandy bentonitic shale. Upper part has thin pebbly sandstone layers, which thicken to several feet locally. Sandstone is fine- or medium-grained arkose. Thick lenticular bentonite bed at top. Lower part is silty bentonitic shale with several beds of purplish-grey- or reddish-brown-weathering ironstone concretions. Member thickens along east edge of valley.	Slightly permeable. May contain highly mineralized water. Where sandstone beds are recharged at base of alluvial aquifers, they may serve as local source of soft potable water.
	Lower Cretaceous	Mowry Shale	350–400	Dark-gray hard silicious fissile shale and thin-bedded siltstone. Numerous thin bentonite beds. Many fish-scale and vertebrae impressions.	Relatively impermeable except perhaps along joints and bedding surfaces. May yield some highly mineralized water.
		Thermopolis Shale	400	Dark-gray concretionary shale. Upper part contains numerous thin bentonite beds and manganese-stained black siltstone concretions. Lower part of shale is bentonitic with numerous thin brown siltstone beds.	Relative impermeable. Probably contains highly mineralized water.
		Cloverly Formation	300–400	Birdhead Sandstone Member. Interbedded dark-gray shale and brown-weathering thin-bedded siltstone and flaggy sandstone.	Do.
				Unnamed middle member. Variegated red and gray shale and some thin sandstone, siltstone, limestone, and widely scattered coal beds.	Do.
				Pryor Conglomerate Member. Lenticular massive fine- and medium-grained well-sorted ferruginous quartzose sandstone with thin layers of sandy pebble conglomerate. Lower part mostly conglomeratic quartzose sandstone with black chert pebbles up to 1 inch in diameter. Varies in thickness up to 150 feet, but is missing in upper reaches of Soap Creek.	Good aquifer in southern part of valley. May yield flows up to several hundred gallons per minute of moderately mineralized water. Water unsuitable for continuous irrigation because of high percentage of sodium salts. Sandstones thin and are lenticular in central part of valley and yield no water, or else highly mineralized water, at great depths.
Jurassic	Upper Jurassic	Morrison Formation	140–280	Greenish-gray siltstone, shale, and sandstone. Lenticular tan-weathering fine-grained sandstone at top. Sandstone is arkosic.	May be a fair aquifer where sandstone is present, yielding moderately to highly mineralized water. Underlying siltstone and shale is relatively impermeable.

		Ellis Group	Swift Formation	180	Greenish-gray shale, siltstone, and glauconitic fossiliferous sandstone containing small chert pebbles.	Sandstone beds may be permeable if not tightly cemented. Possibly would yield small quantities of water to wells.
		Ellis Group	Rierdon Formation	300	Mostly greenish-gray shale with thin-bedded light-brown-weathering siltstone and oolitic sandy limestone at top.	Relatively impermeable. May contain some highly mineralized water.
	Middle Jurassic	Ellis Group	Piper Formation	150	Thin-bedded gray argillaceous limestone, red shale, and siltstone. Contains thin-bedded white gypsum in lower part.	Do.
Triassic and Permian			Chugwater Formation	450–650	Mostly red fine-grained sandstone and siltstone with a thin bed of white hard limestone in top part and numerous thin gypsum beds in lower part.	Do.
Pennsylvanian			Tensleep Sandstone	0–100	Thin-bedded fine- to medium-grained well-sorted quartzose sandstone with a few thin beds of siltstone and limestone. Cemented at many places by silica, calcite, or anhydrite. Lower sandstone beds are brecciated at several localities. Thins gradually northward and is absent in northern part of valley.	Excellent aquifer locally in southern part of valley where sandstone is less cemented and probably brecciated. Yields flows of 200 gpm of slightly mineralized water at D6–31–7a. Large initial flows of up to 2,000 gpm from Tensleep Sandstone and underlying Amsden Formation at D4–29–9bd, –15d and –28ac. Poor aquifer in central and northern parts of valley where sandstone is thinner. Cemented by anhydrite and carbonate.
Pennsylvanian			Amsden Formation	250–300	Heterogeneous sequence of thin beds of sandstone, limestone, shale, and siltstone. Colors range from white, yellow grey, and pink to brown, red, purple, and green. Much reddish-brown-weathering shale and siltstone in lower part. Thin gray chert beds in middle part.	Excellent aquifer locally in southern part of valley where limestone is thick bedded and cavernous or where sandstone beds are thicker and sandstone is not cemented. Large yields reported along Beauvais Creek (D4–29–9bd, –15d, and –28ac), near Soap Creek dome (D6–32–16dd and D7–32–2bb), and west of Hardin (D1–32–23bd). Water may be transmitted upward through breccia zones from underlying Madison Limestone. Water is probably highly mineralized except close to mountains. Yields oil at Soap Creek dome.
Mississippian			Madison Limestone	700–1, 200	Massive light-gray to brownish-gray finely crystalline limestone. Contains a few thin beds of dolomite. Upper 200 feet contains small caverns along joints and fissures and layers of limestone breccia. Red clay and silt cement in breccia zones partially removed by ground-water solution.	Yields moderate to large amounts of warm highly mineralized water from caverns and breccia zones. Initial yield of 15,000 gpm reported at D1–32–23bd. Water is an unpotable saturated solution of calcium and magnesium sulfate (table 5). After storage and cooling in surface reservoirs, used for irrigating alfalfa. Water can be used for continual irrigation of permeable, well-drained soils and for treatment of alkali soils. Yields oil and water at D6–32–34 on Soap Creek dome.

feet into the underlying soft Cretaceous shale. It subsequently ceased downcutting and began cutting laterally, and deposited sandy gravel on its newly established flood plain. Seismograph shothole logs suggest that the river is presently underlain by gravel that ranges from 10 to 30 feet thick. The river does not seem to be alluviating its flood plain or incising its channel at present.

Sandy gravel of terrace deposit 2 (pl. 1) is exposed 100–150 feet above the river along undercut bluffs and at numerous small gravel pits. The deposit generally consists of thick beds of sandy poorly sorted pebble and cobble gravel interbedded with thin, lenticular beds of well-sorted medium- to coarse-grained quartz sand. The deposit is overlain by a few feet of silty clay, except where it is mantled by thicker colluvial deposits below the scarps of higher terraces. The gravel consists in large part of rounded pebbles and cobbles of basalt, andesite, granite, chert, quartzite, limestone, and dolomite that have been eroded from the mountains. The deposits underlying higher older terraces, although not as well exposed, seem to be similar in thickness, composition, and sorting to those of terrace deposit 2; but in places they have been extensively cemented. The gravelly sand near the base of terrace deposit 4 contains much volcanic pumice and glass shards and has been thoroughly and extensively cemented. Carbonate cement seems to bond firmly to the sharp edges of these materials.

Strong northwesterly winds have removed silt, clay, and fine sand from terraces, leaving a pebbly desert pavement at scattered locations. This eolian material and colluvial silty clay have been deposited with thin lenticular layers of alluvial and colluvial gravel along east-facing terrace scarps. Broad wedge-shaped deposits of these materials have accumulated to a thickness of as much as 50 feet along the scarps of higher terraces in the southern area. The deposits thin eastward over the surface of lower terraces, giving them a general riverward slope of 10–20 feet per mile. The deposits form bluffs of well-sorted silty clay, resembling loess, where they have been eroded by gullies. Eolian, colluvial, and alluvial deposits along the scarps of terrace deposit 2 have a combined thickness of 10–30 feet.

The flood plains of tributary streams are underlain by thin deposits of lenticular silty gravel derived from reworking of pediment and terrace gravel. The gravel is usually mantled with deposits of silt or silty clay that are thicker than the underlying gravel and were derived from sheetwash and gully erosion of soft shale. Flash floods pick up a heavy load of this fine material and deposit much of it at the mouths of creeks as alluvial fans. These fans extend over broad areas around the mouths of creeks but have not been mapped in the central and southern areas because they merge imperceptibly with silty clay of the terraces and the flood plain. Conspicuous alluvial fans in the northern area (pl. 1) are composed of silt and fine gravelly sand derived from the Hell Creek Formation and terrace gravel. The fans extend about one-half mile from the mouths of coulees and have slopes of about 70 feet per mile. Fan deposits in the northern and central areas have a maximum thickness of about 30 feet. Those in the southern area, along the east side of the valley, have a maximum thickness of about 50 feet. Numerous steep-gradient ephemeral creeks draining badlands east of the valley in the southern area have built thick coalescing fan deposits on the original flood plain, and these fans have forced the river to migrate slowly westward to its present position.

AGE OF TERRACE DEPOSITS

The remnants of the two highest terrace deposits in the southern part of the valley, designated 6 and 5, respectively, are 650 and 550 feet above the Bighorn River (table 2). They have been correlated by Alden (1932, p. 28) with the late Tertiary Flaxville Formation (late Miocene or Pliocene) of northern Montana on the basis of their height above present river level.

TABLE 2.—*Description of lower Bighorn River terrace deposits*

Deposit	Map symbol (pl. 1)	Height above Bighorn River (feet)	Thickness of gravel underlying topsoil (feet)	Geologic age	Areal extent (sq mi)	Occurrence along valley (X, extensive; O, remnants)		
						North area	Central area	South area
Flood plain.	Qfp	2–15	12–20	Late Recent	85	X	X	X
1	Qt_1	15–40	10–30	Late Pleistocene	150	O	X	X
2	Qt_2	130–150	12–40	do	100	X	X	X
3	Qt_3	250	20–30	Middle Pleistocene	5	O	O	X
4	Qt_4	330	20–35	Early Pleistocene	8		O	X
5	Tt_5	550	20	Late Tertiary	20		O	X
6	Tt_6	650	20	do	6			X

Although the age of the terrace deposits cannot be determined without specialized studies, some age estimates have been made by considering the possible causes of changes in the regimen of the river. It has been suggested (Thom and others, 1935, p. 84; Mackin, 1937, p. 890) that the Bighorn River and its tributaries incised their channels in response to renewed mountain uplift and the resultant regional steepening of the gradient of streams. If this were true, streams would cut more deeply near uplifted areas than farther downstream, and there would be a gradual downstream convergence of terraces. There is no noticeable downstream convergence of terraces in the lower Bighorn Valley; however, the mountain uplift may have caused climatic changes that caused the streams to downcut in the lower valley as well as in the mountains.

The river increases its gradient near the mouth of Dry Head Creek, about 20 miles upstream from the mouth of the Bighorn Canyon. The increase in gradient does not seem to be the result of bedrock structure or recent mountain uplift. The increase in gradient from 6 to 13 feet per mile along that reach results from boulders being carried into the river by relatively short, high-gradient tributaries that head 2,800 feet above the river along the crest of the Bighorn Mountains. The river also receives much landslide debris below the mouth of Dry Head Creek, where it has widened its canyon in Cambrian shale and has undercut cliffs of massive Bighorn Dolomite of Ordovician age.

The lowest two of the major terrace deposits of the lower Bighorn River are respectively 15–40 and 130–150 feet above the river. If they are of the same ages as the Cody and Powell alluvial terraces of the Shoshone River in Wyoming, they may be, in part, outwash from mountain glaciers. The Cody terrace, 22–25 feet (Mackin, 1937) above the Bighorn River near Kane, Wyo., has been traced up the Shoshone River into a terrace complex which ranges in height from 120 to 190 feet above the river at Cody (Mackin, 1937, pl. 2). The Powell terrace, possibly equivalent to terrace deposit 2 and 80 feet (Mackin, 1937) above the river near Kane, also has been traced upstream along the Shoshone River roughly parallel to the Cody terrace. Both terraces, underlain by more than 50 feet of gravel at many places (Swenson, 1957, p. 42; Moss and Bonini, 1961, p. 548), have been traced farther upstream to where the terrace gravel seems to merge with valley-train deposits that extend downstream from the Ishawooa moraines of Wisconsin age (Moss and Bonini, 1961, p. 551).

The coarse- to fine-grained sandy pumicite in the alluvium of terrace deposit 4 contains a lens of stream-rounded pebbles of pumice. An attempt was made to correlate this pumice with a dated volcanic ash. The coarseness of this material suggests that it came from a nearby volcano, possibly in the Absaroka Range of Wyoming. A coarse-grained specimen of this pumicite was identified in the petrographic laboratory of the State Geological Survey of Kansas as "* * * relatively fresh glass, and loaded with sanidine and some quartz and other volcanic crystalline material. The normal refractive index, $1.497 \pm .001$, is somewhat lower than that of the Pearlette [Pearlette Ash (late Kansan age) of Frye and others, 1948] and there are minor differences in shard shape and other characters. The total absence of biotite is also different from Pearlette" (Ada Swineford, written commun., 1961). The pumicite may prove useful in correlating alluvial terrace deposits in Montana and Wyoming, but the age of the deposit is not known.

WATER RESOURCES

SURFACE WATER

The Bighorn River and its tributaries drain about 19,000 square miles in Wyoming and 3,900 square miles in south-central Montana. The average annual discharge of the Bighorn during the period of record (1934–66) was about 2.5 million acre-feet at the mouth of Bighorn Canyon. Damaging spring floods have occurred along the Bighorn in the past, and a maximum discharge of more than 37,000 cfs (cubic feet per second) was recorded on June 16, 1935. Since completion of Boysen Dam in October 1951, annual peak flows have ranged from 4,000 to 17,000 cfs. Regulation for irrigation and hydroelectric power generation generally results in flows of 1,000 to 3,000 cfs. Yellowtail Dam further regulates the flow for irrigation and power.

The Little Bighorn River had an average discharge of 240 cfs during the period of record (1953–66), and an occasional spring flood ranging from 1,000 to 4,500 cfs. Other perennial tributaries that empty into the Bighorn River in the study area are Beauvais, Rotten Grass, Soap, Lime Kiln, and Grapevine Creeks.

The Bighorn River is the source of water for 95 percent of the 43,000 acres of irrigated land in the valley, 80 percent of this acreage being irrigated from two main canals. In the southern area the Big Horn Canal, with a headgate capacity of 720 cfs, diverts water from the Bighorn River near the mouth of the canyon and carries it 35 miles north along the east side of the valley (pl. 1). In the central area the Two Leggins Canal, with a headgate capacity of 400 cfs, diverts water from the Bighorn River at the mouth of Two Leggins Creek, 6 miles south of Hardin, and carries it 30 miles north along the west side of the valley. Some small acreages are irrigated from tributary streams. Water stored in Yellowtail Reservoir can be used for the irrigation of about 43,500 acres of land in the proposed Hardin unit. The irrigable land in the Hardin unit is located on the high terraces flanking the west side of the Bighorn Valley.

The city of Hardin obtains its water supply from the Bighorn River. A screened concrete intake with a maximum capacity of 2 mgd (million gallons per day) is located one-half mile upstream from the railroad bridge. The water is pumped from riverside settling basins through a 12-inch main to a rapid sand filter basin and then is chlorinated and pumped into two elevated storage tanks that have a combined storage capacity of 570,000 gallons. The average water use by the city has increased from 180,000 gpd (gallons per day) in 1921 to 460,000 gpd in 1966. The maximum use during the summer is about 1.25 mgd.

The sugar beet refinery north of Hardin during its 2 months of operation pumps about 5 mgd from the Bighorn River. The larger stores and creamery in Hardin use from 8,000 to 20,000 gpd of municipal water during the summer.

GROUND WATER

Ground water is an important part of the hydrologic cycle (fig. 3) and obeys certain physical laws and principles. These laws and principles are, in general, simple and easily understood, although they may be complex in detail.

Rocks contain many voids or interstices. Below a certain level these voids are filled with water and form underground reservoirs. Such reservoirs are replenished by downward percolation of precipitation and of irrigation water and by seepage from streams and canals. They are depleted by discharge of ground water at the earth's surface through springs and wells, by seepage to streams, or by evaporation and plant transpiration to the atmosphere. Water in an underground reservoir may be under either artesian or water-table conditions. (See "Glossary.")

The hydrologic properties of an aquifer (see "Glossary") are governed by the size, shape, and degree of interconnection of voids. These properties determine the amount of water that an aquifer can store and affect the rate of movement of ground water from areas of recharge to areas of discharge. A bed of fine silt or clay may have a high porosity but may transmit water slowly because the voids are small. Thin films of water in the voids are held firmly to the surface of silt or clay particles by molecular attraction and obstruct movement of water through any remaining void space. In the lower Bighorn Valley, silty alluvial clay and shale bedrock transmit water slowly. At many places they serve as confining beds for artesian aquifers.

THE WATER TABLE AND MOVEMENT OF GROUND WATER

The water table or piezometric surface of a ground-water reservoir does not remain stationary but fluctuates in response to recharge to, or discharge from, the reservoir. It is not a smooth plane but has irregularities comparable with and related to those of the land surface, although much more subdued. The configuration of the water surface can be shown by lines connecting points of equal altitude (contours) on the water table or piezometric surface. The direction of ground-water movement and the hydraulic gradient can be determined from the contours.

Ground-water movement from areas of recharge to areas of discharge is at right angles to the contours in the direction of the hydraulic gradient. In places where recharge is exceptionally high,

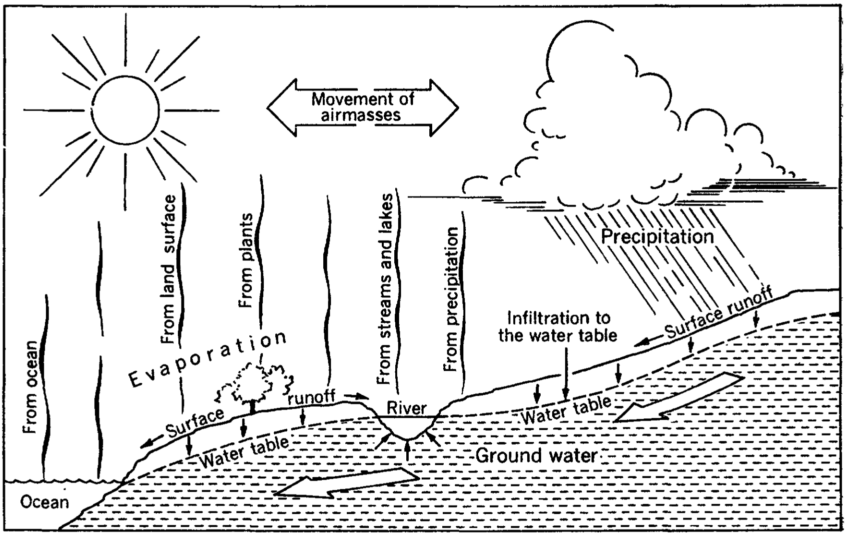

FIGURE 3.—The hydrologic cycle.

the water table or piezometric surface may form a mound from which ground water slowly spreads outward. The surface may have a depression in an area where ground water is discharging, as along effluent streams or at places where water is being pumped from the reservoir by wells or is being withdrawn by vegetation. The direction of water movement is toward the lowest part of a depression. The mounds or depressions may be pronounced in materials of low permeability but barely detectable in very permeable materials.

Although the contours are not shown because of inadequate areal coverage, a generalized contour map was made for part of the area. The map showed that the direction of ground-water movement in the irrigated terrace deposits coincides with the direction of slope of the land surface. Movement is generally northeastward and eastward in the central area and northward or northwestward in the southern area. In the nonirrigated terraces west of the Bighorn River in the southern and central areas, the direction of movement is generally northeastward. Movement through the alluvium in the coulees is generally parallel to the surface streams.

The rate of movement of ground water is low in comparison with that of surface water. Under a hydraulic gradient of 10 feet per mile, the rate of movement may range from less than 1 foot per year in clay to about 4 miles per year in clean coarse gravel. At the gradients extant and in the type of material underlying the flood plain and terraces, the rate of movement of ground water in the area is probably less than 350 feet per year.

FIELD TESTS OF ALLUVIAL AQUIFERS

Two shallow privately owned wells and three shallow wells installed by the Geological Survey were tested to determine the hydraulic characteristics of the alluvial aquifers (table 3). The wells were pumped at a steady rate for at least 1.5 hours, and water levels were measured during the recovery periods. The data were analyzed by the methods described by Theis (1935), Wenzel (1942), and Cooper and Jacob (1946).

The coefficient of transmissibility at one location in the alluvial gravel of terrace deposit 1 was 55,000 gpd per ft (gallons per day per foot). The test well did not fully penetrate the aquifer, so the value of transmissibility is probably low. Coefficients of transmissibility at other places in terrace deposit 1 would vary in accordance with the thickness of the deposits and the amount of fine materials included in the gravel. A coefficient of transmissibility of 22,000 gpd per ft was calculated at one location in the alluvial gravel of terrace deposit 2. Transmissibility at other places in the deposit would vary in accordance with the criteria listed for terrace deposit 1.

Coefficients of transmissibility for the alluvium along three coulees ranged from 2,000 gpd per ft to 24,000 gpd per ft. Part of the difference was caused by differences in thickness of saturated material at the test sites, but most of the difference was due to geologic conditions. Whitman Coulee has only about half the drainage area of Williams Coulee, but its alluvium has greater coefficients of permeability and transmissibility where tested. The greater coefficients are due to a larger percentage of coarse-grained material in the alluvium of Whitman Coulee, whose headward tributaries are eroding sandstone and siltstone of the Parkman Sandstone and the Hell Creek Formation. The alluvium of Williams Coulee has a high percentage of clay eroded from soft weathered outcrops of Carlile Shale and Niobrara Shale. The coefficients of transmissibility and permeability of the alluvium at the mouth of a short unnamed coulee were low because the fine materials have not been winnowed out.

Estimates were made of the discharge of ground water through the three coulees (table 3). The approximations, based on the coefficients of transmissibility, cross-sectional areas, and gradients that were assumed to be the same as that of the land surface in the coulees, ranged from 14,000 gpd to 220,000 gpd (table 3, last line).

RECHARGE AND DISCHARGE

NONIRRIGATED TERRACE DEPOSITS

Rain and snowmelt recharges the alluvium of the nonirrigated terraces during long periods of wet cloudy weather in late winter and early spring, when evapotranspiration losses are low. This is the only

TABLE 3.—*Summary of aquifer-test data, well information, and computations*

Location of well or test hole	A2-33-35cd	A1-33-20cd	A1-33-31dc	D1-33-10cd	D1-33-33ab.
Aquifer	Alluvial gravel of terrace deposit 1.	Alluvial gravel of unnamed coulee.	Alluvial gravel of terrace deposit 2.	Alluvial gravel of Whitman Coulee.	Alluvial gravel of Williams Coulee.
Depth of well (ft)	11	34	17	46	37.
Diameter of casing (in.)	18.0	4.0	30.0	4.5	4.0.
Depth to base of aquifer (ft.)	20[1]	34.0	25[1]	46.0	37.5.
Depth interval of slotted casing (ft.)		24-34		31-46	22-37.
Previous well development	Pumped for domestic and stock use.	None	Pumped for lawn irrigation.	Pumped 90 minutes at 12 gpm.	Pumped 120 minutes at 30 gpm.
Date of test	10-3-58	12-5-57	12-6-57	10-1-58	10-2-58.
Yield (gpm)	23	3	27	10	31.
Length of test (minutes)	180	100	240	210	300.
Depth to water before test (ft.)	5.42	24.23	13.05	13.60	6.52.
Maximum drawdown (ft.)	2.01	1.30	1.75	5.59	6.38.
Saturated gravel thickness (ft.)	15[1]	10.0	12[1]	9.0	12.0.
Coefficient of transmissibility (gpd per ft.)	55,000[2]	2,000	22,000	24,000	19,000.
Average field coefficient of permeability	3,700	200	1,800	2,700	1,600.
Estimated slope of water table or piezometric surface (ft per mi).	12	90±10	10	30±5	30±5.
Estimated discharge per foot width of aquifer (gpd per ft).	120	34±4	40	130±30	110±20.
Estimated width of coulee alluvium (ft)		400		1,000	2,000.
Estimated total ground-water discharge through coulee (gpd).		14,000±1,600		135,000±30,000	220,000±40,000

[1] Seismograph shothole log.
[2] Transmissibility shoud be greater because the well penetrates only part of this aquifer.

source of recharge, and it is small; therefore, only the lower $\frac{1}{3}$–$\frac{1}{2}$ of the alluvial gravel of the nonirrigated terraces in the central area is saturated.

The water table in the alluvium of the nonirrigated terraces west of the river in the southern and central areas generally slopes northeastward, parallel to the surface slope of the underlying shale. Ground water is discharged along seep zones where the base of the terrace alluvium has been exposed by erosion. The largest springs in the central area discharge less than 1 gpm (gallon per minute), but those in the southern area discharge several gallons per minute.

ALLUVIUM ALONG COULEES

Recharge to alluvium along coulees is derived from infiltration of precipitation, surface runoff from higher ground, and seepage from higher terraces. Recharge to this alluvium is greatest in the southern area west of the river because of the higher annual precipitation and the greater expanse of high terrace deposits that discharge ground water along the south sides of coulees. The alluvium underlying Hay Creek has a high water table at several places (D4–31–26cc and D4–32–32db).

Ground water moves downstream through the alluvium in the coulees at gradients of 30–90 feet per mile. Ground water in the thin gravel aquifer at the base of the alluvium is under artesian pressure near the mouths of several coulees in the central area. Ground water moving through the alluvium in the coulees is discharged into flood-plain alluvium and overlying alluvial-fan deposits along the back edge of the irrigated terraces.

IRRIGATED TERRACE DEPOSITS

Aquifers underlying the irrigated terraces are recharged by underflow from coulees, infiltration of irrigation water, and leakage from irrigation canals. Leakage from the main irrigation canals probably is great. Leakage from the Agency Canal at Crow Agency, Mont., in the Little Bighorn Valley was computed to be between 100 and 400 gpd per lineal foot of canal (Moulder and others, 1960, p. 60). Although the Agency Canal is comparable in many ways to the Two Leggins Canal, the large suspended-sediment load of water from the Bighorn River may partly seal the Two Leggins Canal.

Ground water in alluvial gravel underlying irrigated terraces in the central area is under artesian pressure, being confined beneath a broad wedge-shaped deposit of slightly permeable silty clay or silty sand. The deposit thickens to as much as 40 feet toward the back edge of the irrigated terrace. The piezometric surface is as much as 15 feet above the top of the alluvial gravel and is close to the land surface at many places. In the northern area, data from logs of widely scattered seismograph shotholes suggest that alluvial sand and gravel is present at the land surface in irrigated terraces. Sparse well information in the southern area indicates that the piezometric surface there is as much as 10 feet above the top of the alluvial gravel in some places. Ground water there is confined beneath thick deposits of alluvial and colluvial silty clay. At other places the water table is a few feet below the top of the gravel.

FLUCTUATIONS OF WATER LEVELS

Periodic water-level measurements were made from 1957 through 1961 in 60 observation wells in both nonirrigated and irrigated areas during the investigation for this report. Since completion of fieldwork, periodic measurements have been continued in 20 selected wells. The water levels fluctuated in response to changes in rate and quantity of recharge to, and discharge from, the ground-water reservoir. Many of the observation wells were not pumped or else were pumped sparingly, so most of the water-level fluctuations are due to factors other than pumping.

Water levels in two unused wells on nonirrigated terraces were characterized by virtual lack of fluctuations from 1957 to 1962. The water level rose about one-half foot in 1958 and 1959, probably in response to recharge from heavy precipitation during June 1958 and from heavy late-winter snowmelt in 1959 (fig. 4, wells A1–33–31cd and D1–33–8bc). Differences in the rate of rise of the water levels probably were a result of differences in the rate of infiltration, due to differences in the type of soil and in the slope of the land surface. The half-foot decline of water levels in these two wells in 1960–61 probably was a result of drought, which became severe during 1959 and 1960. Increased precipitation in 1963 and 1964 caused water levels to rise.

Water levels rise 4–8 feet during spring and summer in wells in alluvium at the mouths of coulees (fig. 5, wells A1–33–20cd and D1–33–10cd). The rise is in response to recharge to the alluvium from precipitation, seepage from higher ground, and leakage from the Two Leggins Canal. Although the canal is downslope from the coulees, leakage probably causes a mounding of water under the canal and a consequent blocking of underflow from the coulees. The water level in well A1–33–20cd in midsummer of 1960 was about 3 feet lower than the maximum of previous years because of drought in 1959 and 1960.

The water levels in many wells on the irrigated terraces fluctuate similarly to water levels in wells in coulees. Recharge is rapid and the rise in water level is sharp when water is diverted into canals

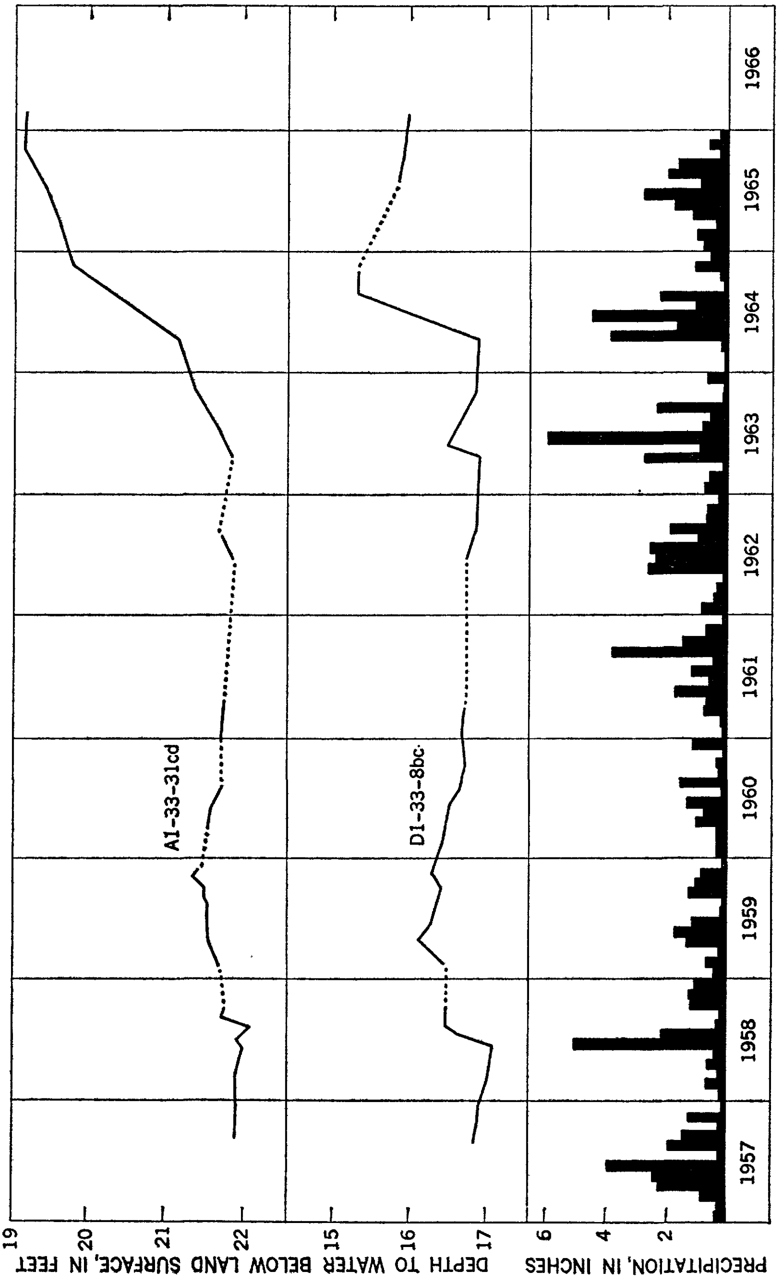

FIGURE 4.—Water levels in two wells located on nonirrigated terraces, and precipitation at Hardin, Mont.

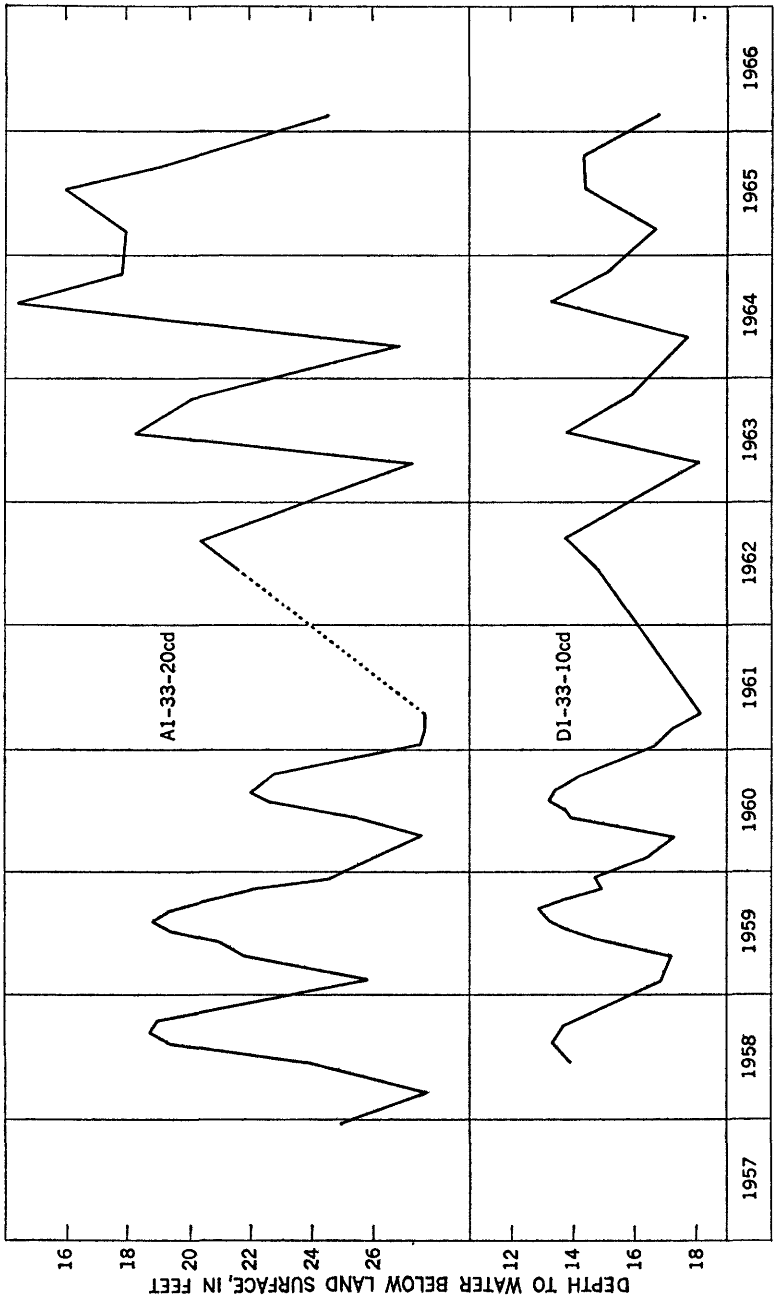

FIGURE 5.—Water levels in two wells in alluvium at the mouths of coulees.

and laterals and onto fields in the spring. Water levels generally begin to decline in September, when irrigation is less and less water is in the canals (fig. 6, wells A1–33–33dc, D1–33–34aa, D5–32–9aa, and D5–32–17cc).

The hydrograph of well A1–33–33dc is characterized by a marked declining trend of water levels from 1957 to 1961. Both the summer peaks and the late winter lows show this declining trend. This trend is caused by a deep interception drainage ditch, which was constructed in 1954 three-fourths of a mile east of the well.

In marked contrast to the above-discussed trend is the rising trend of the water level in wells D1–33–34aa and D5–32–9aa (fig. 6). This rising trend indicates that the areas near these wells are in danger of waterlogging, unless the recharge is reduced or better drainage is provided.

The hydrograph of well D5–32–17cc (fig. 6) is characteristic of wells on waterlogged land. During the summer, evapotranspiration lowers the water level and causes the annual low in the summer.

WATERLOGGING IN IRRIGATED LAND

Waterlogging of irrigated land is caused by one, or a combination, of several geologic and hydrologic factors. The factors in the lower Bighorn Valley include:

1. Poor surface and internal drainage of soils. Surface drainage is poor on the nearly flat land adjacent to the river flood plain, along the foot of terrace scarps, and along barrow pits adjacent to roads. Drainage of soils by downward percolation is slow over large areas where the soil is clayey.
2. Merging of a gently sloping water table with a steeply sloping land surface. This occurs commonly along the base of steep colluvial slopes below terrace scarps.
3. Thinning of the alluvial gravel aquifer where underlying bedrock is mounded or where erosion by the river or its tributaries has removed the upper part of the alluvial gravel and fine alluvium has been deposited. Meager data from seismograph shotholes and soil-test borings suggest that this thinning may cause waterlogging at several places. Such constrictions in the aquifer will produce a damming effect on ground-water movement and a locally higher water table or piezometric surface.

If irrigation water is applied to terraces west of the presently irrigated land in the Hardin area, the water table will rise under the terraces until ground-water discharge balances the increased recharge from irrigation. Discharge will be largely from springs and by seepage at the base of terrace alluvium where it has been exposed by erosion along the sides of gullies and coulees cut back into the terraces and

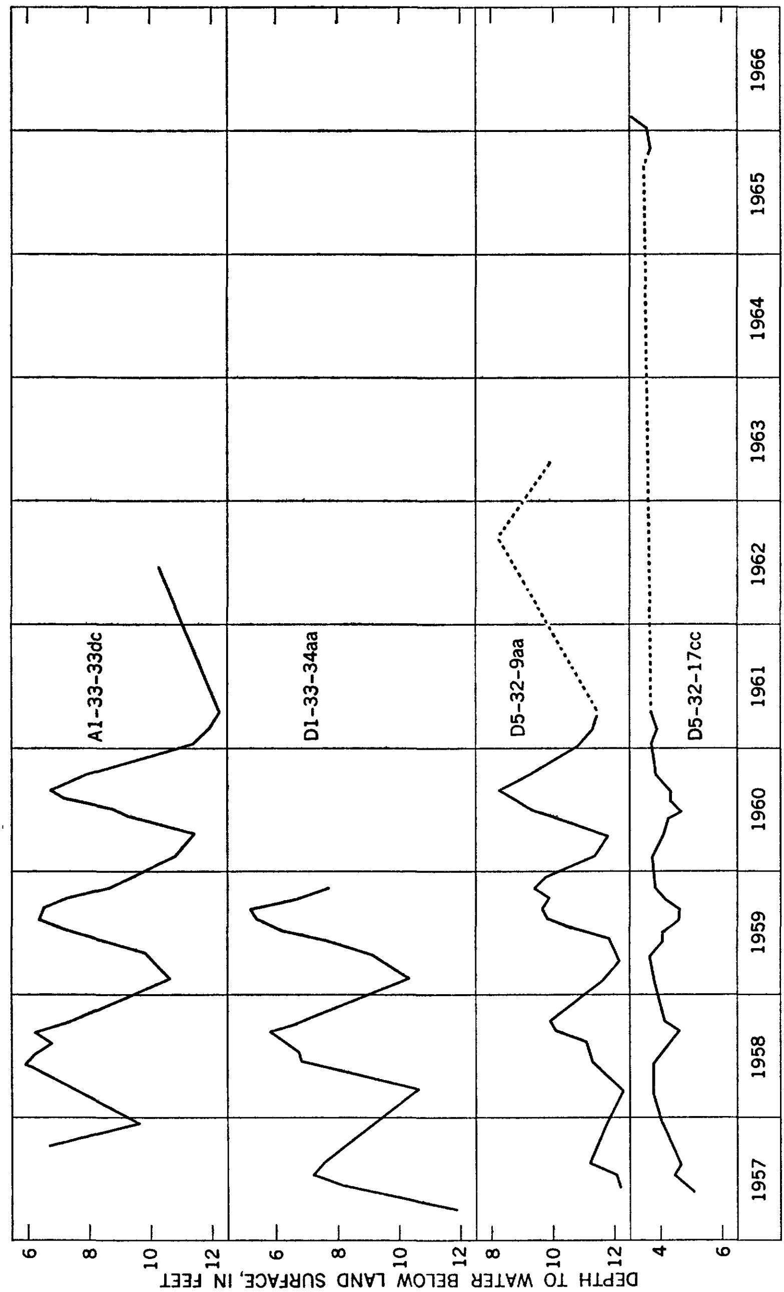

FIGURE 6.—Water levels in four wells located on irrigated terraces.

along terrace scarps. Where these scarps are mantled by colluvium, ground water may move through these deposits into alluvium of the coulees and lower terraces. Unless this discharge is controlled, drainage problems of the presently irrigated land will be aggravated. Interception drains constructed along terrace scarps so that they are bottomed in shale, with provisions to carry water across the valley bottom to the river, will be required. Some additional provisions to intercept water moving through coulees may be necessary.

CHEMICAL QUALITY OF THE GROUND WATER

The constituents dissolved or suspended in water are usually reported in parts per million by weight. Commonly, the chemical equivalence as well as the weight concentrations of ionized constituents is taken into account. This equivalence may be obtained from data expressed in parts per million by dividing the weight concentration of each ion by its combining weight. The combining weight of an ion is obtained by dividing its atomic or molecular weight by its ionic charge. The converted data are expressed in equivalents per million, an expression that has been contracted for the sake of convenience from milligram equivalents per kilogram.

The chemical quality of ground water in the lower Bighorn Valley was determined from laboratory analyses of 6 water samples from wells in bedrock and of 27 water samples from wells in alluvium (tables 4 and 5 and pl. 1). Concentrations of total dissolved solids in samples from bedrock ranged from 499 ppm (parts per million) for a well in sandstone of the Pryor Conglomerate Member of the Cloverly Formation (table 4, analysis 30) to 4,770 ppm for a well in the Bearpaw Shale (analysis 6). Concentrations in samples from alluvium ranged from 605 ppm for a well on a nonirrigated terrace (analysis 20) to 7,240 ppm for a well on an irrigated terrace (analysis 22).

The analyses of nine water samples, obtained between 1914 and 1921 (tables 4 and 5), are from Geological Survey Bulletin 856 (Thom, and others, 1935, p. 152–155), which is out of print. Analyses 15, 16, and 23, obtained from the records of well owners, were made by the Montana State Board of Health.

The concentration of dissolved solids in ground water from alluvium decreased during a 4-month period at one well (analyses 12 and 13) and increased during the same period at another well (analyses 28 and 29). Such changes probably result from seasonal changes in the source and rate of recharge to the alluvium. The concentration of dissolved solids at some places on the irrigated terraces has increased as a result of poor drainage and evapotranspiration. A large increase in concentration of magnesium and sulfate ions at one place (analyses 7 and 8) in 40 years may have been due to precipitation of less soluble calcium sulfate (gypsum) in waterlogged soil along with an increase of total dissolved solids through evapotranspiration.

Calcium and magnesium.—Calcium is dissolved principally from limestone, dolomite, gypsum, gypsiferous shale, and alluvium derived from these rocks; magnesium is dissolved mainly from dolomite, dolomitic limestone, and alluvium derived from these rocks. Ground water in alluvium and in the Madison Limestone in the study area is very hard (hardness as $CaCO_3 > 180$ ppm, table 4) because it has appreciable concentrations of dissolved compounds of calcium and magnesium. Calcium in water samples from the alluvium ranges from 55 to 524 ppm; magnesium in water samples from the alluvium ranges from 23 to 282 ppm. These constituents produce insoluble compounds with soap and form mineral crusts in boilers and hot-water pipes. Water having a high ratio of calcium and magnesium to sodium (analysis 11) can be used to help reclaim saline soil containing large amounts of sodium provided the soil is sufficiently permeable and good drainage can be established.

Sodium and potassium.—Sodium, generally present in large quantities (14–1,706 ppm in samples analyzed) in the groun l water of the area, is dissolved from many types of rocks. Although water yielded by wells in sandstone aquifers contains lower concentrations of sodium ions than that yielded by many wells in alluvium, it is unsuitable for irrigation because it has a high sodium-adsorption-ratio (table 5, fig. 7). Unless it is highly mineralized, it is more suitable than water from alluvium for domestic uses because it has a lower hardness.

Potassium is present in low concentrations (0.9–24 ppm in samples analyzed) in natural ground water and therefore has little effect on its quality.

Carbonate and bicarbonate.—Carbonate and bicarbonate are dissolved from limestone, dolomite, and alluvium derived from these rocks. Bicarbonate is generally present in ground water in amounts ranging from 300 to 600 ppm in the area. High concentrations of both bicarbonate and sodium ions in irrigation water will harm many types of soil, if irrigation is continued for several years. Sodium bicarbonate (black alkali) precipitated from irrigation water deflocculates soil clay and increases the alkalinity of soil solutions so that plant nutrients are less soluble and, therefore, unavailable for plant use (Eaton, 1950).

Sulfate.—Sulfate, dissolved from gypsum beds and veins and gypsiferous shale and alluvium, is the principal anion in highly mineralized ground water in the area. Sulfate in water samples from the alluvium ranges from 202 to 4,400 ppm. In combination with calcium it forms a hard scale in hot-water pipes and boilers.

TABLE 4.—*Chemical analyses of ground*

[In parts per

Analysis	Well location	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
1	A3-34-18dc1		33	0.07	27	18	[1] 295		431
2	18dc2		24	[2] 1.20	123	89	[4] 804		1,160
3	A2-33-10dd	52	25	.07	73	50	372	5.6	521
4	15bb		[3] 48		33	22	[4] 427		654
5	35cd	57	24	.42	175	59	304	6.1	432
6	A1-33-16ad1		18	[2] 11	62	18	[4] 1,706		396
[8] 7	27b		22	[2] 2.4	183	23	[4] 72		317
8	27bb	39	17	.21	202	143	410	5.7	583
9	28cd	48	25	.17	190	101	1,060	18	338
10	32ad1	47	21	.12	188	81	193	4.1	347
11	D1-32-23bd	103	18	1.5	665	136	14	24	180
12	D1-33-14ab	47	26	.11	470	235	1,020	13	603
13	14ab	50	27	.03	439	198	908	13	602
14	15dd	44	27	.13	249	124	410	8.8	290
15	19da		20	Tr.	138	58	[4] 109		316
16	19da		37	1.2	112	28	[4] 122		406
17	24bc	52	28	.82	315	137	1,380	20	415
18	26cb	52	26	2.0	142	50	300	7.8	347
[8] 19	27d		28	.12	103	39	[1] 329		325
[8] 20	30a		30	1.3	74	35	[1] 70		270
[8] 21	D-2-32-26a		35	.12	91	54	[1] 215		285
22	D3-33-8bd	52	28	.08	428	273	1,290	19	493
[8] 23	D3-35-18dc		11	1.0	12	9	[4] 625		393
24	D4-32-2aa	55	27	.09	524	249	1,000	10	455
25	23dc		21	1.6	286	114	[1] 275		425
26	23dc	54	22	1.3	419	84	200	6.8	446
27	26bd	50	26	.14	213	189	490	9.2	471
28	36bd	51	20	.34	259	82	168	5.9	457
29	36bd	53	24	.17	377	121	197	6.8	516
30	D5-31-35cc2	68	10	.23	0.3	0.4	186	0.9	319
31	36db	48	25	.08	55	41	148	3.3	304
32	D5-32-11bb	50	30	.16	458	282	775	14	430
33	20ba	48	27	.18	168	71	118	4.5	458

[1] Calculated Na and K undifferentiated.
[2] Fe and Al undifferentiated.
[3] Si, Al and Fe undifferentiated.
[4] Analysis by Montana State Board of Health. Calculated Na and K undifferentiated

Chloride.—Chloride, dissolved from nearly all types of rocks, is generally present in small amounts in ground water in the area (table 5). It ranged from 11 to 280 ppm in water samples from the alluvium. Relatively high concentrations of chloride in shallow ground water may indicate pollution by sewage (analysis 17). The high concentration of dissolved sodium chloride in water from a well in the Bearpaw Shale (analysis 6) makes the water impotable. It may have been derived from solution of thin beds or veins of salt in the shale.

Fluoride.—Fluoride is present in most ground water in the area in concentrations of less than 1 ppm. Where it is present in drinking water in concentrations of about 1 ppm it may reduce the incidence *water in the lower Bighorn Valley*

million; Tr., trace]

Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$		Percent sodium	pH	Specific conductance (micromhos at 25°C)
						Residue on evaporation at 180°C	Sum	Calcium, magnesium hardness as $CaCO_3$	Noncarbonate			
28	338	15	--------	Tr.	------	965	--------	[5] 141	--------	[6] 82	------	--------
0	1,340	48	--------	18	------	2,970	--------	[5] 672	--------	[6] 72	------	--------
0	725	20	0.6	11	0.42	1,560	1,550	389	0	67	7.4	2,160
0	527	12	--------	--------	------	1,440	--------	[5] 173	--------	[6] 84	------	--------
0	933	31	.7	0.3	.27	1,820	1,750	680	326	49	7.2	2,320
0	105	2,480	--------	--------	------	4,770	--------	[5] 229	--------	[6] 94	------	--------
0	392	28	--------	.06	------	864	--------	[5] 552	--------	[6] 22	------	--------
0	1,390	86	.3	.5	.29	2,750	2,540	1,090	612	45	7.4	3,320
0	2,700	135	.5	4.9	.92	4,470	4,400	890	613	72	7.5	5,470
0	900	21	.5	3.3	.49	1,660	1,580	804	519	34	7.3	2,010
0	1,980	4	4.0	0	.14	3,260	2,940	2,220	2,070	1	7.6	3,040
0	3,580	143	.3	9.3	1.6	6,120	5,800	2,140	1,650	51	7.1	6,590
0	3,250	116	.4	7.5	1.6	5,580	5,260	1,910	1,420	51	7.0	5,830
0	1,730	33	.4	.1	.65	2,950	2,730	1,130	892	44	7.3	3,380
0	365	80	--------	0	------	1,050	--------	[5] 583	--------	29	------	[7] 1,600
0	249	43	--------	0	------	850	--------	[5] 395	--------	40	------	[7] 1,200
0	3,580	280	.8	.6	1.0	6,060	5,950	1,350	1,010	69	7.2	7,010
0	885	30	.7	.3	.52	1,670	1,620	562	277	53	7.2	2,190
0	771	43	--------	Tr.	------	1,490	--------	[5] 417	--------	[6] 63	------	--------
0	202	20	--------	3.0	------	605	--------	[5] 328	--------	[6] 34	------	--------
0	630	22	--------	1.3	------	1,230	--------	[5] 449	--------	[6] 51	------	--------
0	4,400	111	.5	13	1.5	7,240	6,810	2,190	1,790	56	7.1	7,520
35	954	32	--------	--------	------	1,890	--------	[5] 67	--------	[6] 96	------	--------
0	3,930	155	.5	8.8	.81	6,570	6,130	2,330	1,960	48	7.0	6,670
0	1,380	22	--------	Tr.	------	2,550	--------	[5] 1,180	--------	[6] 34	------	--------
0	1,360	24	.6	.6	.45	2,500	2,340	1,390	1,030	24	7.0	2,720
0	1,930	38	.7	9.3	1.1	3,390	3,140	1,310	924	45	7.3	3,780
0	938	16	.5	3.3	.53	1,810	1,720	982	607	27	7.1	2,130
0	1,330	19	.6	7.2	.83	2,530	2,340	1,440	1,020	23	6.9	2,690
0	125	7.9	1.4	.1	.08	499	489	2	0	99	8.0	825
0	365	11	.7	4.8	.23	806	804	304	55	51	7.5	1,180
0	3,450	65	.6	122	1.3	5,850	5,410	2,300	1,950	42	7.1	6,030
0	550	17	.4	22	.24	1,270	1,200	712	336	26	7.2	1,640

[5] Calculated as $CaCO_3$.
[6] Percent sodium and potassium.
[7] Field measurement of conductivity.
[8] Well not on map showing locations.

of tooth decay, but where it is present in larger amounts it may cause mottling and discoloration of children's teeth. The highest concentration of fluoride detected in ground water in the area was 4 ppm in a sample from a flowing artesian well in the Madison Limestone and Amsden Formation (analysis 11). Fluoride may be leached from superphosphate fertilizer by infiltrating precipitation and irrigation water and may be leached in trace amounts from fragments of igneous rocks in alluvial gravel.

Nitrate.—Nitiate was present in water sampled from several wells in the area. The concentrations ranged from 0 to 122 ppm, but most were less than 10 ppm. Nitrate in shallow ground water may indicate pollution. The water in one well (analysis 32) was undoubtedly

TABLE 5.—*Chemical analyses and sodium-adsorption-ratio of ground water in the lower Bighorn Valley*

[In equivalents per million]

Analysis	Well location	Geologic source [1]	Well depth (ft)	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Sodium-adsorption-ratio (SAR)
1	A3-34-18dc1	Khc	62	10-17-21	1.35	1.48	[2] 12.83		7.06	0.93	7.03	0.42			[4] 10.9
2	18dc2	Qt_1	18	9-18-16	6.15	7.32	[3] 35.00		18.95	0	27.82	1.35		0.29	[4] 13.5
3	A2-33-10dd	Qt_1	43	8-25-60	3.65	4.11	16.20	0.14	8.54	0	15.10	.56	0.03	.18	8.2
4	15bb		81	12-2-14	1.65	1.81	[3] 18.58		10.72	0	10.98	.34			[4] 14.1
5	35cd	Qal	11	8-25-60	8.73	4.85	13.20	.16	7.09	0	19.43	.87	.04	0	5.1
6	A1-33-16ad1	Kb	190	9-9-16	3.09	1.48	[3] 74.20		6.48	0	2.18	70.50			[4] 49.1
[5] 7	27b	Qal	12	9-18-16	9.13	1.89	[3] 3.13		5.20	0	8.16	.79		0	[4] 1.3
8	27bb	Qal	10	4-14-60	10.09	11.76	17.84	.15	9.56	0	28.90	2.43	.02	.01	5.4
9	28cd	Qt_1	17	4-14-60	9.48	8.31	46.10	.46	5.54	0	56.20	3.81	.03	.08	15.9
10	32ad1	Qt_1	24	4-14-60	9.38	6.66	8.40	.11	5.19	0	18.74	.59	.03	.05	3.0
11	D1-32-23bd	Mm, Pa	4,000	11-17-60	33.20	11.18	0.61	.61	2.95	0	41.20	.11	.21	0	0.1
12	D1-33-14ab	Qt_1	20	4-14-60	23.45	19.32	44.40	.33	9.89	0	74.50	4.03	.02	.15	9.6
13	14ab	Qt_1	20	8-25-60	21.90	16.28	39.50	.33	9.87	0	67.70	3.27	.02	.12	9.0
14	15dd	Qt_1	28	4-14-60	12.43	10.19	17.80	.23	4.76	0	36.00	.93	.02	0	5.3
15	19da	Qt_2	25	1-11-35	6.88	4.77	[3] 4.74		5.18	0	7.59	2.26			[4] 2.0
16	19da	Qt_2	24	5-31-45	5.58	2.30	[3] 5.30		6.58	0	5.18	1.21			[4] 2.7
17	24bc	Qt_1	28	8-25-60	15.73	11.26	60.00	.51	6.81	0	74.50	7.90	.04	.01	16.4
18	26cb	Qt_1	16	8-25-60	7.09	4.11	13.50	.20	5.68	0	18.43	.85	.04	0	5.7
19 [5]	27d	Qt_1	37	10-20-21	5.15	3.21	[2] 14.30		5.32	0	16.05	1.21			[4] 6.8
20 [5]	30a	Qt_2	18	10-10-21	3.69	2.88	[2] 3.44		4.43	0	4.21	.56		.05	[4] 1.9
21 [5]	D2-32-26a	Qt_2	21	10-11-21	4.54	4.44	[2] 9.35		4.67	0	13.12	.62		.02	[4] 4.4
22	D3-33-8bd	Qt_1	28	8-25-60	21.40	22.45	56.20	.49	8.08	0	91.56	3.13	.03	.21	12.0
23 [5]	D3-35-18dc	Kp	120	12-19-45	0.60	0.74	[3] 27.20		6.44	1.17	19.87	.90			[4] 33.3
24	D4-32-2aa	Qt_1	52	8-24-60	26.19	20.46	43.50	.26	7.46	0	81.80	4.37	.03	.14	9.0
25	23dc	Qt_1	45	10-18-21	14.29	9.37	[2] 11.95		6.96	0	28.63	.62			[4] 3.5
26	23dc	Qt_1	30	8-24-60	20.92	6.92	8.70	.17	7.31	0	28.31	.68	.03	.01	2.3
27	26bd	Qt_1	35(?)	4-15-60	10.63	15.53	21.30	.24	7.72	0	40.15	1.08	.04	.15	5.9
28	36bd	Qt_1	38	4-15-60	12.93	6.75	7.31	.15	7.49	0	19.55	.45	.03	.05	2.3
29	36bd	Qt_1	38	8-24-60	18.83	9.95	8.57	.17	8.46	0	27.68	.53	.03	.12	2.3
30	D5-31-35cc2	Kcv	1,033	8-24-60	.01	.03	8.08	.02	5.23	0	2.60	.22	.07	0	57.3
31	36db	Qt_1	44	4-15-60	2.74	3.37	6.44	.08	4.98	0	7.60	.31	.04	.08	3.7
32	D5-32-11bb	Qt_1	35	4-15-60	22.85	23.19	33.65	.36	7.05	0	71.80	1.83	.03	1.97	7.0
33	20ba	Qt_1	47	4-15-60	8.40	5.84	5.13	.12	6.50	0	11.45	.48	.02	.35	1.9

[1] Geologic source: Mm, Madison Limestone; Pa, Amsden Formation; Kcv, Cloverly Formation; Kp, Parkman Sandstone; Kb, Bearpaw Shale; Khc, Hell Creek Formation; Qt_1 and Qt_2, terrace deposits 2 and 1; Qal, alluvium.
[2] Calculated Na and K undifferentiated.
[3] Analysis by Montana State Board of Health. Calculated Na and K undifferentiated.
[4] Sodium-adsorption-ratio (SAR) includes sodium plus potassium.
[5] Well not on map showing locations.

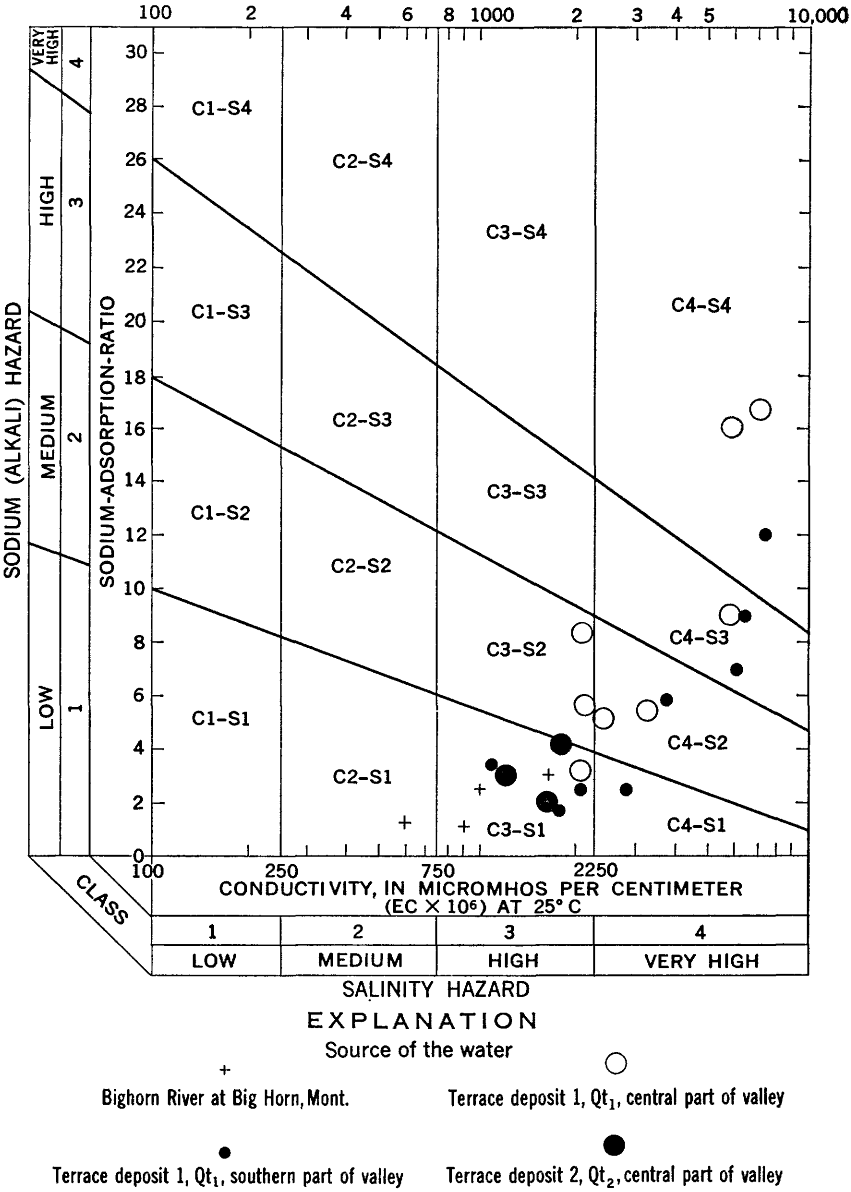

FIGURE 7.—Classification of irrigation water.

polluted at the time it was sampled, and other wells (analyses 2, 3, 22, 23) also may be polluted. Water containing more than about 45 ppm nitrate, if used in making infant-feeding formulas, may cause a serious blood condition (Comly, 1945, p. 112–116).

Boron.—Boron is one of the elements essential for plant growth. However, if it is present in irrigation water in concentrations of 2–3 ppm, it is harmful to most crops. Boron is present in ground water in the area in concentrations ranging from 0.08 to 1.6 ppm.

PHYSICAL PROPERTIES OF THE GROUND WATER

Color.—Most ground water is clear and colorless whether or not it is highly mineralized or bacterially contaminated. Well water may appear black or reddish brown when the well is first pumped owing to the accumulation of colloidal and suspended iron from a corroded pump or well casing. It is usually cleared after it has been pumped a few minutes. Water pumped from a shallow well at D1–33–19da contained gas and reddish-brown colloidal iron that may have come from a nearby leaking gas well which has a corroded casing. The concentration of gas and colloidal iron in the water does not appear to decrease after long periods of pumping.

Taste.—Sodium and bicarbonate ions give water a "soda" or "alkali" taste that is not unpleasant when these ions are not highly concentrated. A sodium chloride concentration of 200–300 ppm gives water a noticeably salty taste. A similar concentration of calcium or magnesium sulfate may have a bitter taste and a laxative effect. Much of the water in the area has sufficient sulfate to give a perceptible taste.

Temperature.—The temperature of water from wells in alluvium generally varies only a few degrees above or below the mean annual air temperature of 46°F. Temperature of water from the alluvium ranged from 39° to 57°F. The temperature of water from wells in bedrock is higher, increasing with the depth of the well. Water from well D5–31–35cc (1,033 ft deep) had a temperature of 68°F; that from well D1–32–23bd (4,000 ft deep) had a temperature of 103°F.

Specific conductance.—As the concentration of dissolved constituents in water increases, the ability of the water to conduct an electric current also increases. To supplement the chemical-quality data, the specific conductance of water samples from 145 wells was measured with a portable meter. The results are shown in table 6. The conductivity of ground water from wells in the alluvium ranged from 700 to more than 8,000 micromhos per centimeter. Water from the Tensleep Sandstone and sandstone of the Pryor Conglomerate Member of the Cloverly Formation has a conductivity of less than 1,000 micromhos per centimeter near their area of outcrop at the southern

TABLE 6.—*Specific conductance of water samples from wells*

Well	Depth (feet)	Geologic source [1]	Specific conductance (micromhos at 25°C)
A1-33-4cb	20	Qt_1	1,560
10cb	17.6	Qt_1	5,900
11bb2	11	Qt_1	3,600
16ad2	65	Kb & Qt_1	[2] 8,000
16cc	65	Qt_1	2,550
16dd	65	----------	6,000
20ad	75	Kb	6,000
21ad			5,100
21ba	44	Kb	5,000
27bb	10	Qal	3,320
27cc	20	Qal	[2] 8,000
28ca	21.1	Qt_1	6,000
28, cd	18	Qt_1	5,470
31cd	27	Qt_2	700
32ad1	24	Qt_1	2,010
32dd1	60	Kb	1,380
33bd	21	Qt_1	[2] 8,000
33cd			2,900
33dd	30	Qt_1	[2] 8,000
A2-33-2bd	55	Qt_1	1,400
2cc1	42	----------	2,350
3dd	120	Kb	6,100
10dd	43	Qt_1	2,160
11ac	20	Qal	3,400
11bb	45	Qt_1	1,490
14bd	40	Qt_1	4,000
15aa	47	Qt_1	2,100
15bb	81	----------	2,100
15cc	54	Qt_1	2,100
21dd	65	Qt_1	1,500
22aa	40	Qt_1	3,400
22dc	55	Qt_1	2,400
27bb	45	Qt_1	2,500
27cd	15	Qt_1	3,000
28dd	15	Qt_1	1,800
33cc	80	Kb(?)	1,950
34ab	28	Qt_1	[2] 8,000
34da	25	Qt_1	[2] 8,000
35cd	11	Qal	2,320
A3-33-36bc	120	Khc	1,150
A3-34-18aa	30	Qal	2,500
18db	48	----------	940
18dc2	17	Qt_1	2,200
19dd	100	Khc	3,900
31ba1	38	Khc	1,600
A4-34-17da1	10	Qal	1,400
D1-32-23bd	4,000	Mm & P	3,040
D1-33-2ca	30	Qt_1	5,500
2cd	27	Qt_1	4,400
3ad	21	----------	5,000
3dd	33	Qt_1	3,900
10ba	12	Qt_1	1,250
10ca			1,650
10db	32	Qt_1	3,900
10cd2	55	----------	1,100
14ab	20	Qt_1	5,830
14db	28	Qt_1	3,000
15dd	28	Qt_1	3,380
19da	25	Qt_2	1,200
23dd			[2] 8,000
24bc	28	Qt_1	7,010
25bc	7	Qal	3,200
D1-33-26aa	20	----------	[2] 8,000
26cb	16	Qt_1	2,190
27ad	32	Qt_1	3,000
33cd	26	Qt_1	2,000
34cb	24	Qt_1	1,300
35cb	16	----------	3,200
35dc	9	Qt_1	1,900
36cc	16	Qal	2,900
D1-34-18bb1	20	Qal	3,500
19bb	10	Qal	1,300
D2-32-12dd	55	Qt_2	1,600
D2-33-2ba2	24	Qt_1	1,850
2bb	18	Qt_1	3,200
2cd	11	Qt_1	2,400
3bb	50	Qt_1	2,000
3cc	16	Qt_1	3,400
5bb	30	Qt_2	1,900
9dd	20	Qt_1	1,100
10bc	21	Qt_1	3,600
10cd			2,500
10dc	9	Qt_1	3,300
10dd	50	Qal	4,300
11ba	22	Qal	2,500
15ba	17	Qt_1	2,100
16ca1	9	Qt_1	1,250
18bb	55	Qt_2	1,400
20dc	26.2	Qal	2,000
29dc	11	Qal	1,950
32db	13	Qal	2,600
D3-32-36dd	70	----------	[2] 8,000
D3-33-5cd	20	Qal	6,200
8bd	28	Qt_1	7,520
8da			6,500
9ba	70	Qt_1	6,500
20ab			600
29ab	80	Qt_1	2,200
29bb	49	Qt_1	[2] 8,000
30aa	49	Qt_1	[2] 8,000
D4-32-1ad	40	Qt_1	6,200
2aa	52	Qt_1	6,670
12dd	56	Qt_1	[2] 8,000
13cc			4,800
23ad1	26	Qt_1	3,000
23dc	30	Qt_1	2,720
24aa	29	----------	4,000
24cc	55	Qt_1	2,900
24dc	7	Qt_1	4,600
25bb	55	Qt_1	2,500
26ad	60	Qt_1	2,600
26bd	35	Qt_1	3,780
26da	45	Qt_1	2,800
35aa	38	Qt_1	2,600
35ab	34	Qt_1	2,000
36bd	38	Qt_1	2,690
36db	66	Qt_1	2,500
D4-33-6aa	60	----------	2,600
6cc	50	Qt_1	5,900
7ab	70	Qt_1	1,900
7bb	66	Qt_1	3,800
7db	50	Qt_1	3,100
18ca	80	Qt_1	4,700

See footnotes at end of table.

TABLE 6.—*Specific conductance of water samples from wells*—Continued

Well	Depth (feet)	Geologic source [1]	Specific conductance (micromhos at 25°C)	Well	Depth (feet)	Geologic source [1]	Specific conductance (micromhos at 25°C)
D5-31-35bd	50	----------	2,400	D5-32-17cc	33	Qal	1,750
35cc2	1,033	Kcv	825	19da	32	Qal	2,300
36ad	50	----------	1,450	20ba	47	Qt1	1,640
36db	44	Qt1	1,180				
				29aa	65	Qt1	1,400
D5-32-2aa	38	Qt1	3,100	30aa1	45	Qt1	2,400
2ad	43	Qt1	5,900	30aa2	25	Qt1	2,000
9ba	25	Qt1	2,200	30bb	8	Qal	2,300
10bc	100	Qt1	2,300	30dd	60	Qt1	2,400
10bd	45	Qt1	2,300	31aa	37	Qt1	3,200
11bb	35	Qt1	6,030	D6-31-11dc	30	Qt2	1,000
16dd	80	Qt1	1,800	16cd	395	Kcv	840

[1] Geologic source:
Qal Alluvium.
Qt1 Quaternary Terrace deposit 1.
Qt2 Quaternary Terrace deposit 2.
Khc Hell Creek Formation.
Kb Bearpaw Shale.
Kcv Cloverly Formation.
Pa Amsden Formation.
Mm Madison Limestone.
[2] Meter scale goes only to 8,000.

end of the valley. The conductivity of the water from these aquifers is much higher at Soap Creek dome (D6–32–34) and Woody Creek dome (D3–31–33). Water yielded by the Tensleep Sandstone at those places had a concentration of total dissolved solids of about 2,800 ppm (Crawford, 1942). These aquifers become thinner and more lenticular farther north and are reported to yield only small amounts of highly mineralized water from great depths in the central area. Water from wells in the Hell Creek Formation in the northern area has conductivities between 1,150 and 3,900 micromhos. The arkosic sandstones of the Hell Creek Formation are not as "clean" and well sorted as the Tensleep Sandstone and the sandstone of the Pryor Conglomerate Member of the Cloverly Formation, and ground water probably moves more slowly through them, dissolving part of the fine-grained material in the process.

AVAILABILITY AND UTILIZATION OF THE GROUND WATER

DOMESTIC AND STOCK USE

Ground water in sufficient quantities for domestic and stock needs is furnished by shallow wells in alluvial gravel of the terraces in the central area. Shallow ground water in the lower Bighorn Valley is very hard (hardness as $CaCO_3 > 180$ ppm). At places in the southern area, the water is too highly mineralized to be potable (pl. 1). The chemical quality of ground water in the alluvium under irrigated land would gradually improve if better drainage could be developed.

Water from alluvial gravel near the Two Leggins Canal is usually less mineralized than ground water in other parts of the central area because it is derived in large part from seepage of relatively unmineralized river water from the canal.

Ground water in amounts sufficient for domestic and stock use is difficult to find outside of the irrigated valley. Alluvium in the larger coulees can provide small supplies of water, but in some coulees this water is of poor chemical quality. Small to moderate quantities of potable water can be obtained from alluvial gravel underlying the more extensive remnants of nonirrigated terraces.

It is nearly impossible to get potable water in quantities sufficient even for stock use from shale bedrock, which underlies large areas of the valley. It is necessary to drill to depths of more than 1,000 feet throughout much of the central and southern areas to penetrate a sandstone aquifer which some drillers call the "Lakota sand" at the base of the Cloverly Formation. This sandstone yields highly mineralized water to wells in the central area. Farther south, nearer the recharge area of the sandstone, the water is less mineralized. The Parkman Sandstone, which crops out about 6 miles north of Hardin and dips under the valley (pl. 1), yields moderate supplies of soft, moderately mineralized water from depths of less than 200 feet. Farther north and downdip, the Parkman is reported to yield highly mineralized water. Thin sandstone aquifers in the Hell Creek Formation yield soft, moderately mineralized water from depths of less than 200 feet in the northern area.

INDUSTRIAL AND MUNICIPAL USE

Wells in alluvium could furnish water for industrial and municipal use if they were located so as to induce recharge to the alluvium from the Bighorn River or the Two Leggins Canal. Although the water initially would be very hard and mineralized, its chemical quality would gradually improve with use, as recharge from surface water increased. Wells on the irrigated terraces away from a source of recharge could not be expected to yield more than 100 gpm when pumped continuously for long periods.

In the southern area, bedrock aquifers are generally accessible at depths of less than 1,000 feet near the mountain flanks. Wells of large yield can usually be developed in these aquifers. Cavernous zones in the Madison Limestone have yielded large quantities of water to wells (table 1), but such zones may be narrow, and it is impossible to predict that a well will penetrate such a zone. The Madison Limestone lies at great depths throughout most of the valley.

IRRIGATION USE

Shallow ground water from alluvial gravel is used for irrigating gardens on terraces where surface water is not available. Because only a few feet of the gravel is saturated, well yields are insufficient for more extensive irrigation. Alluvium of the irrigated terraces can yield water in amounts sufficient for irrigating small tracts, but at some places the water is too highly mineralized for this use (pl. 1; fig. 7).

Water from bedrock aquifers is not used extensively for irrigation except at D1–32–23bd, 4 miles west of Hardin, where warm water from a flowing well tapping the Amsden formation and Madison Limestone is used to irrigate alfalfa. Although the water contains little sodium (table 5, analysis 11), it is unsuitable for irrigation of poorly drained soil. The water is highly saline, being a saturated solution of calcium and magnesium sulfate.

Water from sandstone aquifers is generally unsuitable for irrigation because it has a high percentage of sodium ions and a high sodium-adsorption-ratio (table 5; fig. 7). The sodium percentage of water from Cretaceous sandstone aquifers can be reduced by dissolving gypsum in the water or by mixing the water with hard water from the Amsden Formation or Madison Limestone.

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