Geology and Ground-Water Resources of the Greybull River-Dry Creek Area Wyoming

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1596

Prepared in cooperation with the Wyoming Natural Resource Board and Wyoming State Engineer, and as part of the program of the Interior Department for the development of the Missouri River basin

Robinove and Langford—GEOLOGY, GROUND-WATER, GREYBULL RIVER-DRY CREEK AREA, WYO.—Geological Survey Water-Supply Paper 1596

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By CHARLES J. ROBINOVE *and* RUSSELL H. LANGFORD

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By Charles J. Robinove and Russell H. Langford

ABSTRACT

The Greybull River–Dry Creek area, in the central part of the Bighorn Basin, Wyo., is underlain by Quaternary and Tertiary alluvial and terrace deposits and Tertiary and older bedrock formations. Part of the Emblem Bench, the Greybull terrace, and the alluvial flats of the Greybull River valley are irrigated with water diverted from the Greybull River. The applied irrigation water has increased the recharge to previously saturated permeable alluvial deposits and has created zones of saturation in some hitherto dry deposits. Some irrigation wells constructed in the deposits yield as much as 1,000 gpm (gallons per minute) and have specific capacities of more than 50 gpm per foot of drawdown. Domestic and stock water is obtained from the terrace and alluvial deposits and from the Willwood formation, which underlies most of the area.

The YU Bench, which is underlain by 10 to 60 feet or more of deposits of the Rim terrace and the thick Willwood formation, is now dry and is used only for grazing. In order to obtain ground water on the YU Bench, it would probably be necessary to drill wells to aquifers below the level of the Greybull River valley at depths of about 400 to 550 feet or more. The nonirrigated part of the Emblem Bench also is dry, and wells would have to be drilled to depths of about 100 to 200 feet or more.

The Bureau of Reclamation has investigated the possibility of irrigating the YU Bench and the upper part of the Emblem Bench with water from Buffalo Bill Reservoir, diverted from the Shoshone River through Oregon Basin. If these benches are irrigated, the applied water will recharge the terrace deposits, which will then be capable of yielding small to moderate amounts of water to wells.

Studies of the chemical quality of ground water from the Willwood formation, deposits of the Sunshine and Greybull terraces, and alluvium indicate that the mineralization and chemical characteristics of the water vary widely. Most of the ground water contains more than 800 ppm (parts per million) of dissolved solids and is very hard. Some water from the Willwood formation, although highly mineralized, is soft. Sodium and sulfate are the predominant ions in most water in the area, but calcium and bicarbonate are the predominant ions in some water from alluvium. The proportion of sulfate increases approximately from 30 to 50 percent of the dissolved solids as the dissolved-solids content increases from about 500 to 2,000 ppm. Water from some wells changed appreciably in quality during an 8-month period.

The chemical quality of surface water also varies widely. In the upper reaches of the Greybull River and in Buffalo Bill reservoir on the Shoshone River, the water is only slightly mineralized. However, in the lower reaches of the Greybull River, return flows from irrigation and drainage from the Willwood formation cause an increase in the mineralization of the river water. Conversely,

return flows from irrigation cause a decrease in mineralization of water in Dry Creek.

The classification as to suitability of water for irrigation shows that ground water from deposits of Quaternary age has a high to very high salinity hazard and a low to medium sodium hazard. Water from the Greybull River near Meeteetse and from Buffalo Bill Reservoir has a low to medium salinity hazard and a low sodium hazard. Despite the salinity hazard, the ground water from Quaternary deposits is suitable for irrigating most crops grown in the area, provided drainage is good so that soil salinity can be controlled. Concentrations of boron and residual sodium carbonate are low in ground and surface waters used for irrigation at the time of this investigation.

The ground water generally does not meet the recommended standards for drinking water because of excessive concentrations of fluoride, sulfate, and dissolved solids. The water is classed as good for stock watering because it contains less than 2,500 ppm of dissolved solids.

If the YU and upper Emblem Benches are developed for irrigation, the resulting ground water in the newly irrigated terrace deposits probably will be very highly mineralized and very hard. In time and with good drainage, however, the quality of the ground water should improve. The additional development probably would adversely affect the quality of water in the Greybull River and in lower Dry Creek.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The investigation of the Greybull River–Dry Creek area was made during 1956–58 by the U.S. Geological Survey, partly under the program of the Department of the Interior for the development of the Missouri River basin and partly in cooperation with the Wyoming Natural Resource Board and the Wyoming State Engineer. The purposes of the investigation were to determine the origin, occurrence, availability, and chemical quality of ground water for domestic, stock, and supplemental irrigation use in the irrigated area; to evaluate the suitability of the ground water for the various uses; and to determine the possibility that water supplies for domestic use on the YU Bench and the upper part of the Emblem Bench would result from the irrigation proposed for these benches. The Bureau of Reclamation has investigated the possibility of irrigating the YU Bench and the upper part of the Emblem Bench with Shoshone River water from Buffalo Bill Reservoir, diverted through Oregon Basin.

The fieldwork upon which this report is based was done in the summers of 1956 and 1957. The geologic map (pl. 1) is adapted from that of Andrews, Pierce, and Eargle (1947). The base map was compiled from topographic maps, which cover the part of the area west of Otto and south of Emblem, and from aerial photographs, which cover the eastern and northern parts of the area. The geologic formations and important hydrologic features are shown on the map.

Records of 180 wells and springs were obtained during the investigation and are summarized in table 8. The depth of wells and depth to water were measured with a steel tape where possible; other depths were reported by well owners and users, and drillers. Information on the character and thickness of water-bearing materials, yield and drawdown of wells, and general quality of water also was obtained from these sources. The logs of 15 test holes drilled by the U.S. Bureau of Reclamation on the YU Bench gave information on the thickness and character of the deposits of the Rim terrace. Tests were made to determine the discharge, drawdown, and specific capacity of several wells of large discharge.

Data pertaining to the chemical quality of ground water, applied irrigation water, and water draining from irrigated lands were obtained by chemical analysis of samples of water from 29 wells and springs and from major streams and irrigation canals in the report area.

The sections of this report concerning the geology, ground water, and water-bearing properties of the stratigraphic units were prepared by Charles J. Robinove. The section on the chemical quality of the water was prepared by Russell H. Langford. The ground-water studies were directed by H. M. Babcock and E. D. Gordon, successive district supervisors for the ground-water studies in Wyoming. The quality-of-water studies were directed by P. C. Benedict, D. M. Culbertson, and T. F. Hanly, successive district supervisors for the quality-of-water studies.

LOCATION AND EXTENT OF THE AREA

The Greybull River–Dry Creek area, about 350 square miles in extent, is in the Bighorn Basin in northwestern Wyoming. The area lies between long 108°03′ and 108°48′ W. and lat 44°17′ and 44°33′ N., and includes parts of Tps. 50–53 and Rs. 93–99 W. The index map (fig. 1) shows the areas of this report and other ground-water reports in Wyoming. Figure 2 shows the location of the report area within the Bighorn Basin.

PREVIOUS INVESTIGATIONS

The geology and water resources of the Bighorn Basin have been the subject of many investigations. In the preparation of this report, free use has been made of data on stratigraphy, general geology, and water resources gathered by other investigators. The following annotated bibliography describes reports containing information on the regional geology and water resources:

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174.

Describes glacial geology and correlates terraces.

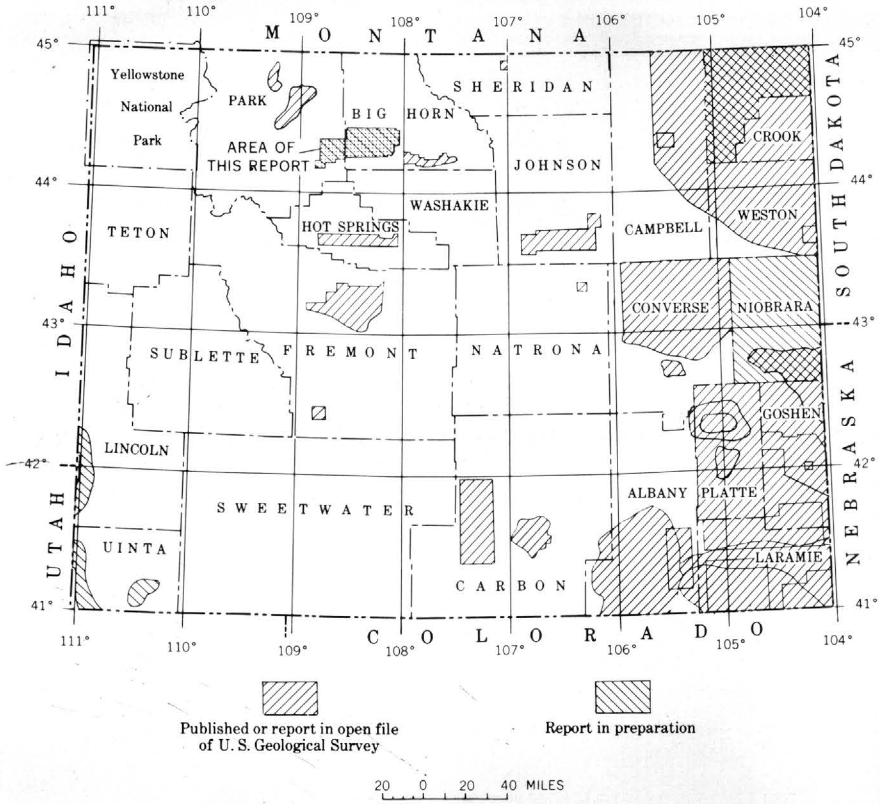

FIGURE 1.—Map of Wyoming showing the area described in this report and other areas for which ground water reports have been released or are in preparation.

Andrews, D. A., Pierce, W. G., and Kirby, J. J., 1944, Structure contour map of the Bighorn Basin, Wyoming and Montana: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 3.

Shows structure contours on top of Frontier formation.

Andrews, D. A., Pierce, W. G., and Eargle, D. H., 1947, Geologic map of the Bighorn Basin, Wyoming and Montana, showing terrace deposits and physiographic features: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 71.

Shows bedrock geology, named and unnamed terraces, alluvium, sedimentary rocks, and structure.

Fisher, C. A., 1906, Geology and water resources of the Bighorn Basin, Wyoming: U.S. Geol. Survey Prof. Paper 53.

Contains general information on artesian water in bedrock formations and some data on surface-water irrigation.

Hewett, D. F., 1926, Geology and oil and coal resources of the Oregon Basin, Meeteetse, and Grass Creek Basin quadrangles, Wyoming: U.S. Geol. Survey Prof. Paper 145.

Contains data on terraces of the Greybull River and an interpretation of the erosional history in the vicinity of Meeteetse.

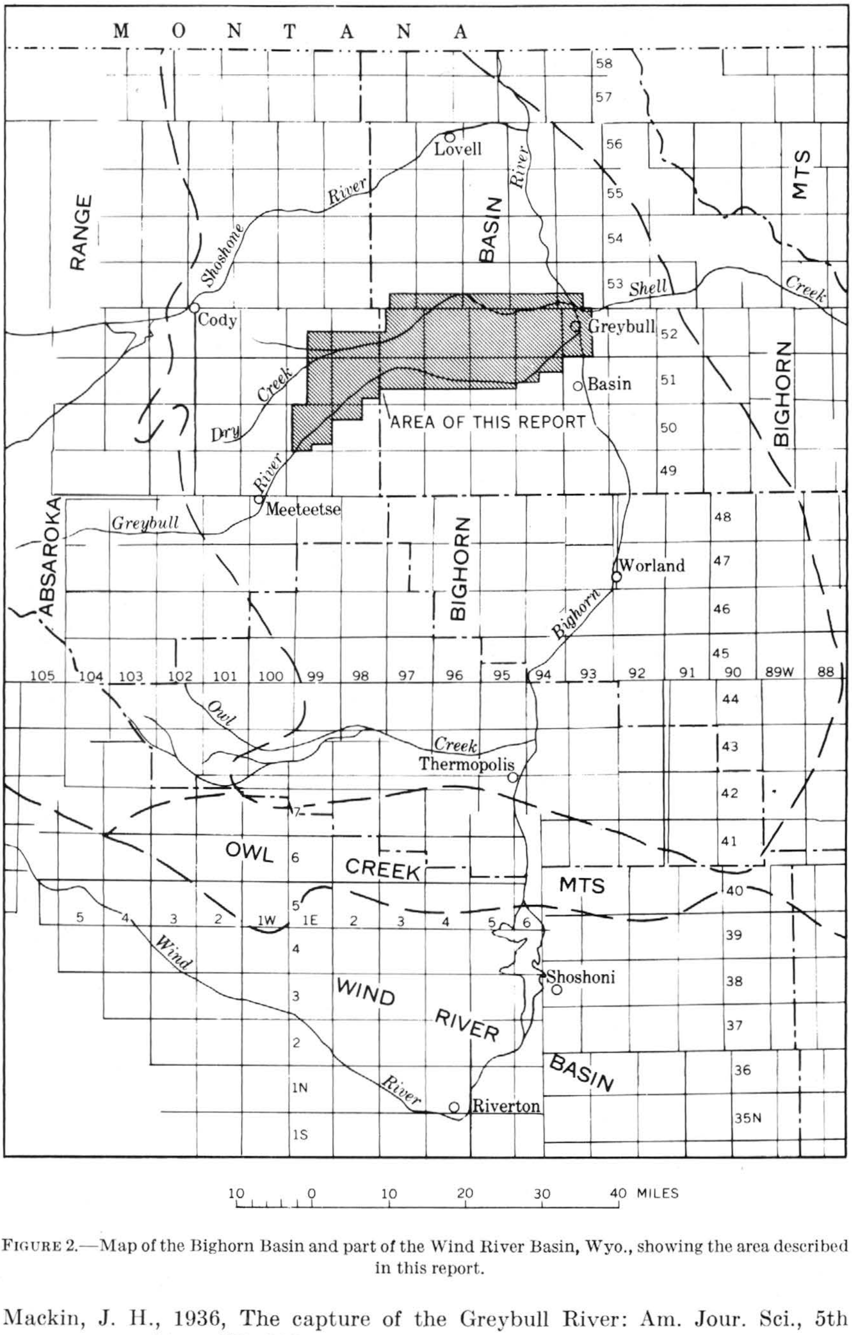

FIGURE 2.—Map of the Bighorn Basin and part of the Wind River Basin, Wyo., showing the area described in this report.

Mackin, J. H., 1936, The capture of the Greybull River: Am. Jour. Sci., 5th ser., v. 31, p. 373–385.

Describes the Tertiary and Quaternary history of the Greybull River area with special reference to capture of graded streams.

Mackin, J.H., 1937, Erosional history of the Bighorn Basin, Wyoming: Geol. Soc. America Bull., v. 48, p. 813–894.

Describes the Tertiary and Quaternary history of the Bighorn Basin with reference to terrace and stream features. Outlines theories of pulsational downcutting of basin streams.

——— 1947, Altitude and local relief of the Bighorn area during the Cenozoic, *in* Wyoming Geol. Assoc. Guidebook [2d Ann.] Field Conf., Bighorn Basin, Wyoming, 1947.

Describes the development of geomorphic features during the Cenozoic.

Sinclair, W. J., and Granger, Walter, 1911, Eocene and Oligocene of the Wind River and Bighorn Basins: Am. Mus. Nat. History Bull., v. 30, p. 83–117.

Describes stratigraphy, paleontology, and geomorphic history of the Tertiary rocks in the Bighorn Basin.

——— 1912, Notes on the Tertiary deposits of the Bighorn Basin: Am. Mus. Nat. History Bull., v. 31, p. 57–67.

Continuation of the previous study.

Swenson, F. A., 1957, Geology and ground-water supply of the Heart Mountain and Chapman Bench divisions, Shoshone irrigation project, Wyoming: U.S. Geol. Survey Water-Supply Paper 1418.

Describes the occurrence of ground water in terrace gravels along the Shoshone River.

Van Houten, F. B., 1944, Stratigraphy of the Willwood and Tatman formations in northwestern Wyoming: Geol. Soc. America Bull., v. 55, p. 165–210.

Describes the Willwood and Tatman formations. Proposes the name "Willwood" in place of "Big Horn Basin Wasatch."

Wyoming Geological Association, 1947, Guidebook [2d Ann.] field conference, Bighorn Basin, Wyoming, 1947.

Contains road logs of field trips, stratigraphic sections, and special papers on physiography, stratigraphy, structure, and oil fields of the Bighorn Basin.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to all those who aided in this study. Well drillers in the area supplied logs of many of the wells, and oil companies made available their records of logs of test holes drilled during seismic surveys. The residents of the area furnished information about and access to their wells. Mr. Earl Lloyd, State Engineer of Wyoming, permitted access to records of irrigation wells. Personnel of the U.S. Bureau of Reclamation provided logs of test holes, and the Greybull Valley Irrigation District permitted access to records of streamflow and irrigation diversions.

The Department of Geology of Wayne State University allowed the use of data from an unpublished thesis by M. G. Marlian.

CLIMATE

The climate of the Greybull River–Dry Creek area is semiarid. The normal annual precipitation at Basin, 8 miles south of Greybull, is 6.86 inches; in 1956, which was one of the years of low precipitation, it was only 2.79 inches. Winter precipitation generally is heavier on the west side of the Bighorn Basin, near Meeteetse, than farther east, near Greybull. Great quantities of snow in the headwaters of the Greybull River in the Absaroka Range provide most of the irrigation water used in the valley. Precipitation during the growing season is insufficient to support agriculture without irrigation. The growing season averages about 130 days in the area.

Figure 3 shows the annual precipitation and monthly distribution of precipitation at the station at Basin.

WELL-NUMBERING SYSTEM

The wells, springs, and test holes are numbered according to their location within the Bureau of Land Management's system of land

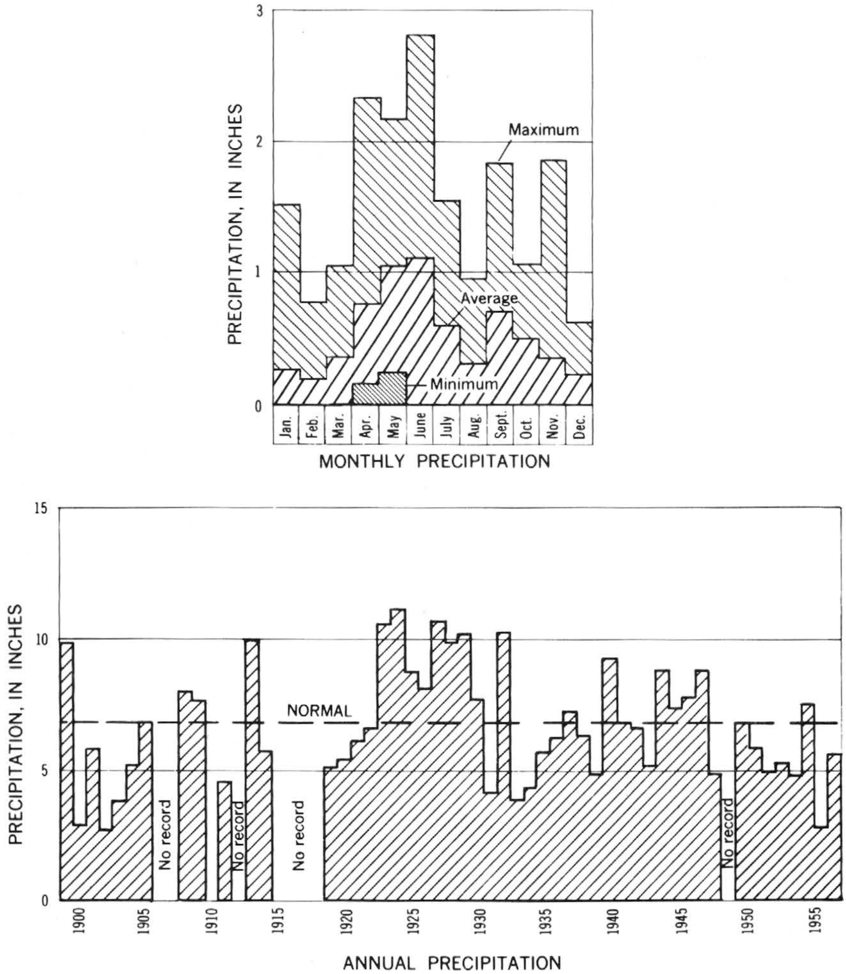

FIGURE 3.—Precipitation at Basin, Wyo., 1898–1957. (Data from records of the U.S. Weather Bureau.)

subdivisions. The report area is in the sixth principal meridian and base line system. The well number shows the location of the well by township, range, section, and position within the section. The well-numbering system is illustrated in figure 4. In the report area all townships are north of the base line and all ranges are west of the principal meridian. 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 first letter after the section number denotes the quarter section, the second letter the quarter-quarter section, and the third letter the quarter-quarter-quarter section (10-acre tract). The subdivisions of the sections are lettered a, b, c, and d in a counterclockwise direction, beginning in the northeast quarter. Where more than one well is listed in a 10-acre tract, consecutive

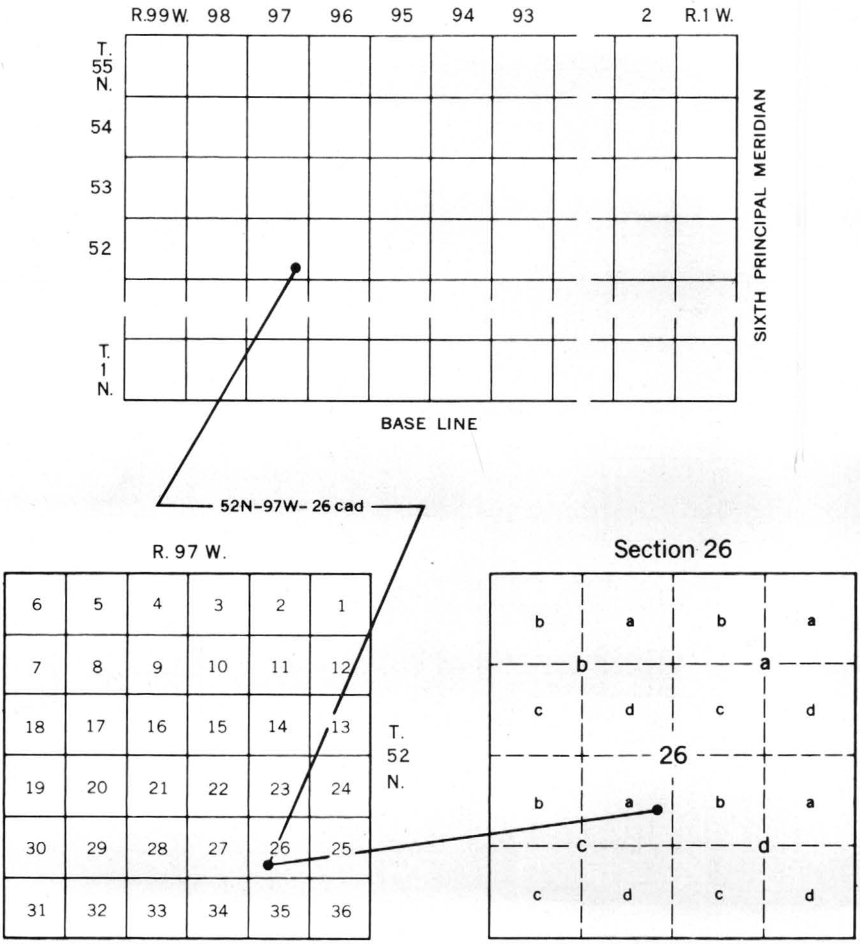

FIGURE 4.—Well-numbering system.

numbers beginning with 1 are added to the well number. Thus, well 52–97–26cad is in the SE¼NE¼SW¼ sec. 26, T. 52 N., R. 97 W. The same numbering system is used to designate localities where surface water was sampled for analysis.

LANDFORMS AND DRAINAGE

Three main elements make up the landscape of the Greybull River–Dry Creek area: the stream valleys and low terraces, the bedrock slopes and badlands, and the flat-topped interstream divides.

The floor of the Greybull River valley ranges in width from less than half a mile to more than 3 miles. Low terraces flank the alluvial valley in places.

Rising above the valley floor are low terraces and bedrock slopes, which are gently sloping and smooth in some places near Otto and are eroded into rugged badlands below the YU Bench.

The YU Bench, the south edge of the Emblem Bench east of the YU Bench and west of Table Mountain, Table Mountain, and the high areas east of Table Mountain form the divide between the Greybull River and Dry Creek. Table Mountain and the Emblem and YU Benches represent former flood plains of the Greybull River. Figure 5 shows the YU Bench and part of the Greybull River valley.

Altitudes in the area range from about 3,780 feet where Dry Creek enters the Bighorn River to 5,742 feet at the west end of the YU Bench. The total relief is about 1,960 feet.

The Greybull River drains the major part of the report area. It rises in the Absaroka Range and flows northeastward and eastward across the Bighorn Basin to its junction with the Bighorn River between Basin and Greybull. The drainage area of the Greybull River at Meeteetse, near the base of the Absarokas, is approximately 690 square miles and, at its mouth, is approximately 1,130 square miles. The average discharge of Greybull River at Meeteetse for the period 1920–56 was 346 cfs (cubic feet per second) and the discharge ranged from 28 to 10,500 cfs. The average discharge recorded at the gaging station near Basin for the period 1930–56 was 178 cfs, or 129,000 acre-feet per year; the discharge ranged from 0 to 5,390 cfs. Water from the Greybull River has been used for irrigation for more than 50 years. In 1957 water was diverted for irrigation of about 39,000 acres in the Greybull River and Dry Creek valleys.

Dry Creek drains the northern part of the report area. Upstream from the irrigated area of the Emblem Bench the stream flows only in direct response to precipitation, but downstream it receives waste water from irrigation of the Emblem Bench. Some water is diverted from Dry Creek for irrigation of about 800 acres on the Agrarian Bench and the bottom lands along Dry Creek near Greybull. The

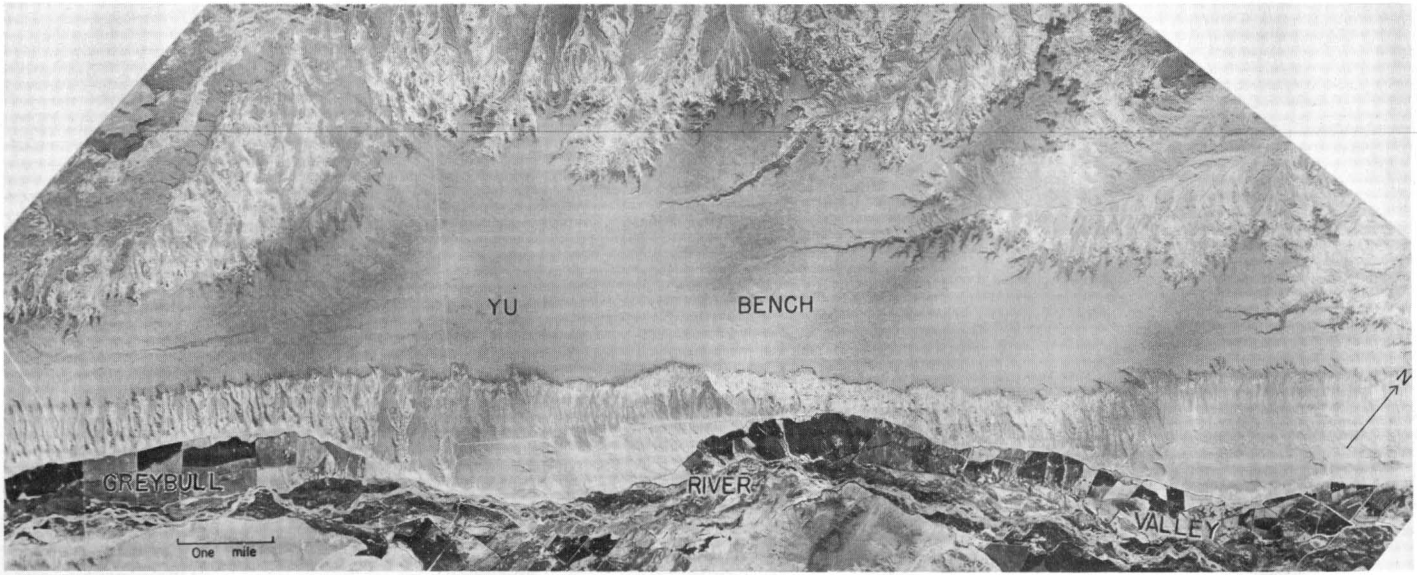

FIGURE 5.—Aerial photograph showing part of the Greybull River valley and the YU Bench. Photograph by Army Map Service.

average discharge of Dry Creek, measured near the mouth, for October 1952 to September 1953 was 14.9 cfs, or 10,800 acre-feet. During the periods April 1951 to December 1953 and October 1955 to September 1956 the discharge of Dry Creek at Greybull ranged from 0 to 860 cfs, although the daily mean discharge seldom was more than 100 cfs.

The Greybull River and Dry Creek (below the Emblem Bench) are the only perennial streams in the area. Minor ephemeral and intermittent streams drain the highlands bordering the valleys and are tributary to the Greybull River and Dry Creek.

Water is diverted from the Greybull River at many points for irrigation. Canals on the lower terraces return a part of the water to the Greybull River, but water diverted from the river to the Emblem Bench eventually is discharged into Dry Creek.

GENERAL GEOLOGY

SUMMARY OF STRATIGRAPHY

The rocks exposed in the Greybull River–Dry Creek area range in age from Triassic to Recent. They include, in ascending order, the Chugwater formation of Triassic age; the Gypsum Spring, Sundance, and Morrison formations of Jurassic age; the Cloverly formation, Thermopolis and Mowry shales, Frontier formation, Cody shale, Mesaverde, Meeteetse, and Lance formations of Cretaceous age; and the Fort Union and Willwood formations of Tertiary age. Tertiary and Quaternary alluvial sediments overlie the bedrock in many places. Plate 1 shows the location and extent of the geologic formations. The stratigraphic section given below summarizes the descriptions and water-bearing properties of the Upper Cretaceous and younger rocks in the area. The Cody shale and Frontier formation may be penetrated at shallow depths just west of the Bighorn River but they are too deeply buried in the western part of the area to be drilled economically. Further discussion of formations above the Cody shale is in the section on "Stratigraphic units and their water-bearing properties."

POST-PALEOZOIC GEOLOGIC HISTORY

MESOZOIC ERA

At the beginning of the Triassic period, an eastward-advancing sea deposited the siltstone and shale of the Dinwoody formation in what was to become the Bighorn Basin. The red beds of the Chugwater formation were deposited on the Dinwoody.

Jurassic sediments including the marine Gypsum Spring and Sundance formations were then laid down. As the sea retreated, the continental variegated shale of the Morrison formation was deposited.

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Generalized stratigraphic column of Upper Cretaceous and younger rocks in the Greybull River-Dry Creek area, including water supply and geologic events

System	Series	Subdivision	Lithology	Approximate thickness (feet)	Water supply	Major geologic events
Quaternary	Recent	Colluvium (slope wash)	Gravel, sand, and clay	0–20±	May yield small amounts of water to wells.	Degradation of basin by streams. Pulsational downcutting forming gravel-capped terraces. "Reversal" of topography—high terraces left as interstream divides. Superposition of drainage across structural barriers.
		Alluvium	Gravel, sand, and silt	0–30±	Moderate to large yields obtained.	
	Pleistocene	Terrace deposits	Gravel, sand, and silt	0–60+	Moderate to large yields obtained from Pleistocene terrace deposits where saturated.	
Tertiary	Pliocene					
	Eocene	Tatman formation	Sandstone and carbonaceous shale	650–870	Crops out just south of report area. Not water bearing.	Bighorn Basin filled with continental sediments conformable on older rocks in center of basin and overlapping them on the margins.
		Willwood formation	Variegated mudstone, sandstone, and conglomerate	2,500±	Small to moderate yields obtained.	
	Paleocene	Fort Union formation	Sandstone and shale	1,500+	Probably capable of small to moderate yields.	Continued diastrophism and deposition of continental clastic sediments and coal.
Cretaceous	Upper Cretaceous	Lance formation	Sandstone and shale	850–1,400		Continued deposition of clastic sediments. Period ended with folding and faulting.
		Meeteetse formation	Shale, sandstone, coal, and bentonite	450–1,150		Retreat of sea. Deposition of continental clastic sediments and coal.
		Mesaverde formation	Sandstone, shale, and coal	900–1,400		
		Cody shale	Shale, sandstone, and bentonite	2,600–3,500	Probably capable of small yields.	Marine invasion and deposition of marine sediments.
		Frontier formation	Sandstone, shale, coal, and bentonite	425–465	Probably capable of small to moderate yields.	Fluctuating emergence and marine submergence of land.

Marine conditions again prevailed from Early Cretaceous time into the Late Cretaceous, and the Thermopolis and Mowry shales, Frontier formation, and Cody shale were deposited. As the sea regressed, marine sandstone and shale gave way to the continental sandstone, shale, and coal-bearing strata of the Mesaverde, Meteetse, and Lance formations.

The Bighorn Basin and its bounding mountain ranges were formed during the Laramide revolution, which began in Late Cretaceous time and lasted into Eocene time. The pre-Laramide sediments in the basin were folded into anticlines and synclines along the mountain flanks, generally parallel to the edges of the basin.

CENOZOIC ERA

In Tertiary time, continental sandstone, shale, and coal were deposited to form the Fort Union, Willwood, and Tatman formations. The Fort Union is tilted at the edges of its outcrop area but is nearly flat in the center of the basin. The Willwood formation reaches a maximum thickness of 2,500 feet in the basin and, together with the overlying Tatman formation, represents a time during which the basin was being filled with continental sediments. The Tatman formation was deposited in the forested swamps and open waters of a shallow lake. It is not present in the report area but is exposed on Tatman Mountain, a few miles south of the Greybull River where it is covered by Tertiary terrace gravels, and in Squaw Buttes, west of Worland where it is overlain by Tertiary volcanic rocks.

Subsequent to the deposition of the Tatman formation, the volcanic rocks, which are exposed in the Absaroka plateau and Yellowstone Park, were formed. Eastward-flowing streams eroded the volcanic rocks, carried the rock debris into the basin, and deposited it over the Tatman and older formations. During several stages of deposition and subsequent erosion, the Greybull River cut a succession of terraces. The names applied locally to remnants of these terraces differ from the names that have been used for the more extensive terraces and their deposits. The list below gives the names of the features from youngest to oldest, and shows their relations.

Name of alluvial terrace	*Local name applied to terrace surface*	*Name of sedimentary deposit underlying terrace surface*
Greybull terrace	No local name	Deposits of the Greybull terrace.
Sunshine terrace	Emblem Bench, Agrarian Bench.	Deposits of the Sunshine terrace.
Numbered terraces	No local names	Deposits of the numbered terraces.
Rim terrace	YU Bench, Bridger Butte, Table Mountain.	Deposits of the Rim terrace.
Tatman Mountain terrace.	Tatman Mountain (south of the report area).	Deposits of the Tatman Mountain terrace.

Mackin (1936, 1937) discussed the late Tertiary and Quaternary physiographic history of the Bighorn Basin with special reference to the Greybull River–Dry Creek area. The following discussion is adapted from his papers.

The gravel-capped terraces represent former flood plains of the Greybull River. The ancestral Greybull River originally flowed on the Tatman Mountain surface. The point at which the ancestral river emptied into the Bighorn River is unknown because the only remnant of Tatman Mountain gravel is more than 20 miles from the Bighorn River. Gravel underlying the Tatman Mountain terrace is preponderantly volcanic rock, showing that the Absaroka volcanic plateau to the west was the source of sediment. The gravels of the lower terraces and alluvium are also of volcanic orgin and are all very similar in composition and size. Mackin (1937) estimates the valley floor, now represented only by the gravel cap on Tatman Mountain, to have been at least 14 miles wide and possibly double or triple that width.

After the deposition of the Tatman Mountain gravel and subsequent cutting of the terrace, the Greybull River formed another flood plain at a lower level, the deposits of which are now represented by the deposits of the Rim terrace on YU Bench, Bridger Butte, and Table Mountain. The width of the valley at that time is estimated to have been 6 miles (Mackin, 1937).

After renewed downcutting, the Greybull River flowed at the level of the Sunshine terrace surface, which is locally represented by the Emblem and Agrarian Benches. The surface is well preserved on the Emblem Bench and indicates that, when the river was at this level, its mouth was where Dry Creek now flows into the Bighorn River. While the Greybull River was flowing at the level of the Emblem Bench, a tributary of the Bighorn River flowed in the valley now occupied by the lower Greybull River, eroded headward, and captured the ancestral Greybull River at a point east of the northeast end of the YU Bench. The Emblem Bench surface probably was not wider than at present. Most of the northern edge of the Emblem Bench abuts Dry Creek valley but south of the YU Bench it lies along the Greybull River valley. This "crossover" of a terrace from one valley to another is evidence of a stream capture (Mackin, 1936).

The capture, according to Mackin (1936), was possible because the gradient of the graded capturing stream, which was adjusted to the transportation of fine sand and silt, was lower than the gradient of the graded ancestral Greybull River, which was adjusted to the transportation of coarse rock waste.

After the capture, the Greybull River formed a flood plain south of the Emblem Bench and at a lower altitude. Subsequently, the river cut the flood plain and formed the Greybull terrace, and the river now flows on a still lower flood plain. The Greybull terrace is not present west of the point of capture (approximately at the Big Horn–Park County line).

The deposits underlying Rim terrace were laid down as channel and flood-plain deposits. Successive lateral movement of the river and attendant downcutting resulted in the river flowing at successively lower levels, the lowest of which is the present valley. The oldest terraces now are on the interstream divides and are the highest points on cross-valley profiles. This is illustrated by the profile sections on plate 1. Figure 6 shows the geology in the vicinity of Burlington and Emblem. Parts of all the major terraces and the alluvium are shown on the photographs. Figure 7 shows topographic profiles across and along the valley and terraces.

GROUND WATER

PRINCIPLES OF OCCURRENCE

The fundamental principles governing the occurrence and movement of ground water have been set forth by Meinzer (1923) and many others, so will be discussed briefly here.

Ground water in the Greybull River–Dry Creek area is derived chiefly from the infiltration of irrigation water and from precipitation that falls as rain or snow. A part of the water on the land surface runs off directly into streams, a part evaporates, a part is consumed by vegetation, and a part percolates through pore spaces in the soil and underlying rocks to the water table, where it enters the zone of saturation—the zone in which the rocks are saturated with water under hydrostatic pressure. Some of the water in the zone of saturation eventually returns to the surface through seeps and springs or is discharged by wells, drains, and evaporation. Most of the water, however, percolates through the stream beds and banks directly into surface streams.

The porous rocks below the water table are saturated except, in some rocks, for isolated pores. Rocks that are sufficiently permeable can yield water to wells. In the more permeable rocks, such as the deposits of unconsolidated sand and gravel, the individual pores are interconnected and are large enough that the water moves rapidly through them under the force of gravity, but in less permeable rocks, such as the siltstone and clay of some of the bedrock formations, the pores are so small that water moves through them very slowly.

WATER TABLE

The water table is defined as the top of the zone of saturation. It is the surface at which the pressure is atmospheric and below which

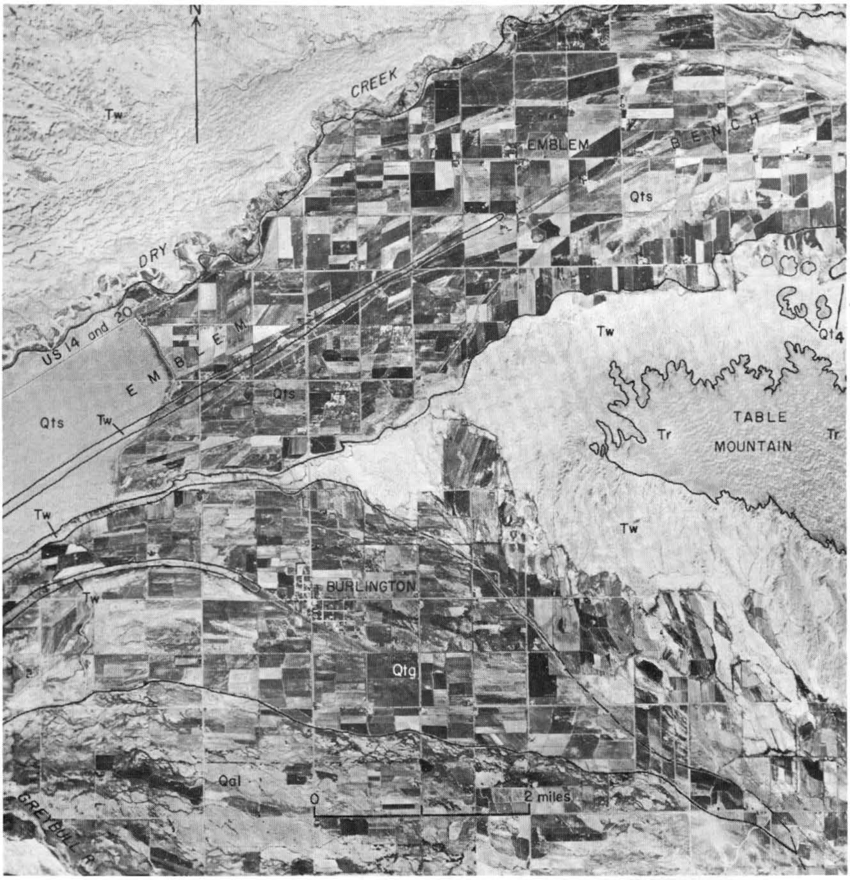

FIGURE 6.—Photogeologic map of the central part of the Greybull River–Dry Creek area showing the Willwood formation, terraces, and alluvium. Qal, alluvium; Qtg, deposits of Greybull terrace; Qts, deposits of Sunshine terrace; QT_4, deposits of numbered terrace; Tr, deposits of Rim terrace; Tw, Willwood formation. Photograph by Army Map Service.

the pressure is greater than atmospheric; that is, hydrostatic pressure exists. Above the water table the pressure is less than atmospheric, and water is held up by capillary force, forming what is known as the capillary fringe. In the lower part of the capillary fringe the interstices may be full of water, but this is not a part of the zone of saturation as defined.

The water table is represented by the water level in shallow wells in the terrace and alluvial deposits in the report area. It generally is not level or uniform but is a sloping surface conforming in a general way to the configuration of the land surface. In the irrigated terrace deposits and alluvium the water table is commonly within a few feet of the surface; in that part of the area in Big Horn County it is rarely

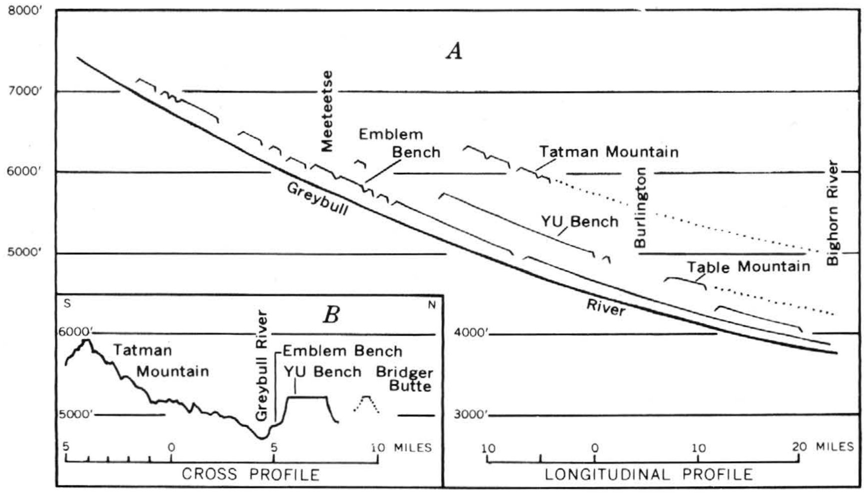

FIGURE 7.—Longitudinal (*A*) and cross profiles (*B*) of major benches formed by the Greybull River. (Modified from Mackin, 1947, fig. 5)

deeper than 10 feet, but in the alluvium of the Greybull valley in Park County it is generally deeper. The depth to water in the Willwood formation ranges from about 20 to about 75 feet. The depths to water are discussed further in the sections on the individual aquifers.

The water table is not a stationary surface but fluctuates up and down as water is added to or withdrawn from the underground reservoirs. In the Greybull River–Dry Creek area, the water table begins to rise as water enters the ground when irrigation begins in the spring. Minor fluctuations during the irrigation season are caused chiefly by the consumptive use of water by plants (evapotranspiration). When the application of irrigation water ceases in the fall, the water levels begin to decline and continue declining until irrigation water is applied in the following spring. The fluctuations range from a fraction of a foot to several feet.

Periodic measurements of the depths to water in a number of wells in various alluvial aquifers and the Willwood formation are tabulated in the sections on the individual aquifers.

Figure 8 shows diagrammatically the types of occurrence of ground water in the alluvial deposits of the report area. *A* represents the occurrence of ground water in terrace deposits, such as those capping the Emblem Bench, bounded by a valley on one side and a rising escarpment on the other. Water enters the ground by seepage from irrigation ditches, irrigated fields, and from precipitation on the land surface. The water table is close to the land surface and slopes toward the valley. Water is discharged along the contact of the water table and the valley side.

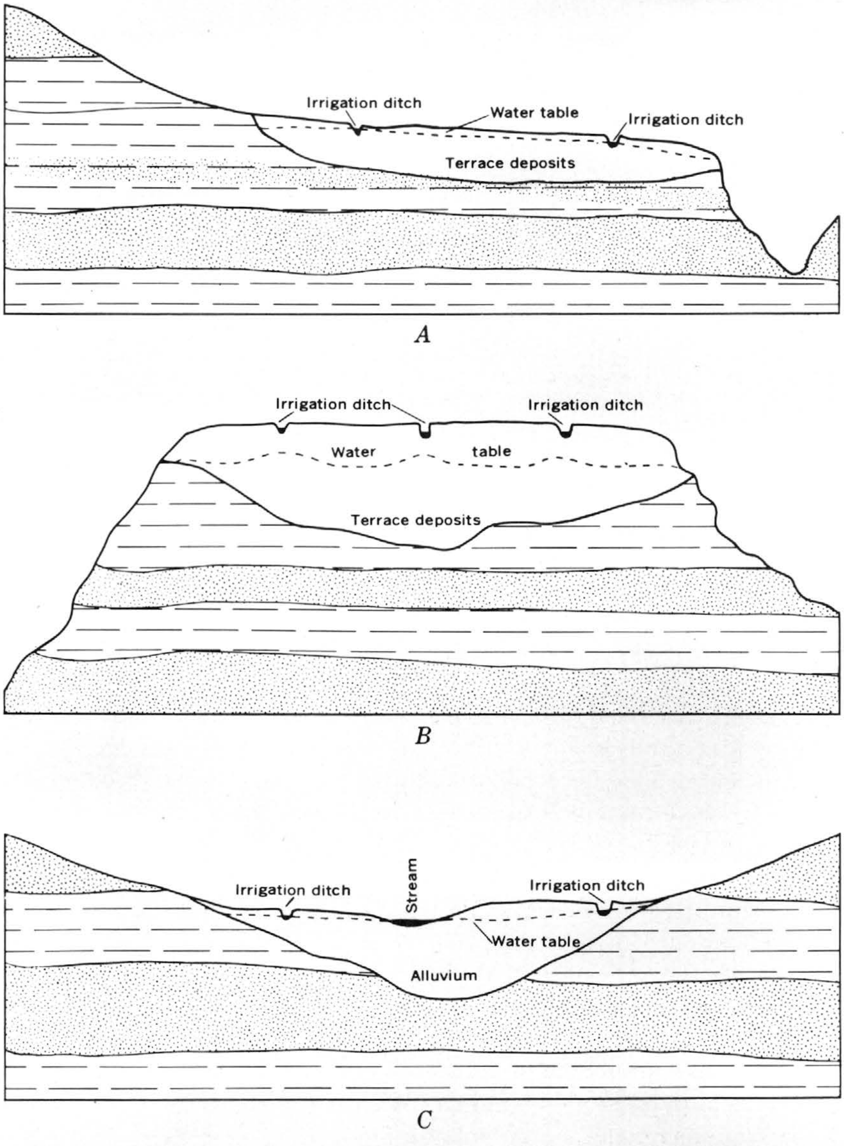

FIGURE 8.—Occurrence of ground water in the alluvial deposits in the Greybull River–Dry Creek area.

B illustrates the occurrence of ground water in a terrace deposit underlying a mesa and exposed on all sides. Water seeps into the ground from irrigation ditches and recharges the terrace deposit. Ground-water mounds form under the areas where recharge occurs; the water moves laterally away from the mounds and is discharged at low points on the contact of the terrace deposit and the underlying bedrock along the sides of the bench. Similar conditions might be expected in the YU Bench if it is irrigated.

C illustrates the occurrence of ground water in the alluvium of a stream such as the Greybull River. Water is recharged to the ground-water reservoir from irrigation ditches, irrigated fields, and precipitation on the land surface. The water table slopes toward the stream and the water moves toward, and is discharged into, the stream.

RECHARGE

Recharge is the addition of water to the ground-water reservoir and it may be accomplished in several ways. In the nonirrigated part of the area, seepage from precipitation that occurs as rain and snow is the principal source of recharge. Under favorable conditions of soil moisture, a part of the precipitation seeps through the soil and is added to the ground-water reservoir. The average annual precipitation in the area is less than 10 inches, and of this amount only a small fraction percolates to the ground-water reservoirs. In the irrigated part of the area, recharge by seepage from precipitation is small in comparison to the amount of recharge from irrigation water.

DISCHARGE

Ground water may be discharged from the zone of saturation into the atmosphere by evaporation and transpiration, and to the land surface through seeps, springs, wells, or drains.

EVAPORATION AND TRANSPIRATION

Ground water may evaporate directly from the soil where the water table is near the surface. It may also be taken into the roots of plants directly from the zone of saturation, or from the capillary fringe, and be discharged from the plants by transpiration. The depth from which plants will lift ground water varies with the species of plant and the type of soil. Ordinary grasses and field crops can lift water only a few feet; however, alfalfa and certain types of desert plants may send their roots to depths of several tens of feet to reach the water table.

Discharge of ground water by evaporation and transpiration in the Greybull River–Dry Creek area probably is limited to the irrigated areas underlain by permeable material in which the water level generally is less than 10 feet below the surface. No estimate of the loss of water by evaporation or transpiration was made.

SEEPS, SPRINGS, AND DRAINS

Some water is discharged from the ground-water reservoirs by seeps, springs, and drains. The seeps and springs in the area of this report occur mainly where the water table intersects the land surface at the edge of a terrace or a depression in an alluvial flat. In the valley bottoms, water enters the streams by seepage through the bed and banks.

Underground drains in the Sunshine terrace deposits underlying the Emblem Bench discharge water into the Dry Creek valley. Some drains flow continuously; others flow only during and shortly after the irrigation season.

The water from a few springs is utilized for livestock. The water that discharges from the Emblem Bench is diverted from Dry Creek for irrigation on the Agrarian Bench.

WELLS

Most of the water discharged by wells in the Greybull River–Dry Creek area comes from wells in the alluvial and terrace deposits. Some domestic and stock wells obtain small amounts of water from the Willwood formation.

Yields of most irrigation wells in the alluvial and terrace deposits range from 100 to 1,000 gpm (gallons per minute). In years when the supply of surface water for irrigation is small, the wells are pumped heavily; in years when the surface water supply is adequate, only a few of the irrigation wells are used and they may be pumped only for short periods. No farmed areas are irrigated solely by ground water.

SUBSURFACE OUTFLOW

Water in the alluvial deposits moves in a generally eastward direction toward the Bighorn River and is discharged either into the river or into the alluvial deposits underlying the Bighorn River valley. The amount of outflow has not been computed.

UTILIZATION OF WATER

PUBLIC SUPPLIES

Ground water is not used for municipally owned public supply in any of the communities in the area. The town of Greybull obtains water from Shell Creek, which flows west from the Bighorn Mountains and empties into the Bighorn River at Greybull.

Privately owned wells supply water to residents of Otto, Burlington, and Emblem.

DOMESTIC AND STOCK SUPPLIES

Ground water is used almost exclusively for rural domestic supplies. Shallow dug, bored, or drilled wells in saturated alluvial or terrace gravels supply nearly all the stock and domestic water. Yields are reported to be generally adequate except in a few places where water levels decline greatly during winter and early spring. The water generally is potable but in a few places it is too highly mineralized to be used for domestic supply.

Drilled wells in the bedrock formations supply some domestic and stock water. Supplies generally are adequate and the water is reported by most users to be soft.

IRRIGATION SUPPLIES

Until 1955 little ground water was used for irrigation. A few irrigation wells had been drilled but most were unused. The sparsity of precipitation in the vicinity of the headwaters of the Greybull River in 1955 diminished the surface-water supply for irrigation, and therefore spurred several farmers and ranchers to attempt the construction of irrigation wells. In 1957 there were 14 irrigation wells equipped with pumps, 4 not equipped with pumps, and 1 under construction. Of the 14 wells, 9 have electrically powered pumps; the others are powered by tractors.

All the irrigation wells obtain water from alluvial or terrace deposits. They are generally drilled or dug to bedrock (usually not more than 35 feet) and the casings are perforated. Figure 9 illustrates three types of wells used in the area. The small-diameter drilled wells range in diameter from 8 to 12 inches. The large-diameter dug wells are generally 36 to 48 inches in diameter. Two wells (52-96-3cbc and -3dbc) are constructed with casings of perforated corrugated culvert pipe and have a horizontal gallery which extends northward 200 and 300 feet respectively from the wells. Well 52-96-3cbc is reported to produce 900 gpm; well 52-96-3dbc is reported to produce more than 1,000 gpm.

STRATIGRAPHIC UNITS AND THEIR WATER-BEARING PROPERTIES

Below the Mesaverde formation is a thick sequence of Cretaceous shale and some sandstone. These rocks hold little promise for development of large amounts of ground water of good quality and therefore were not studied during the investigation.

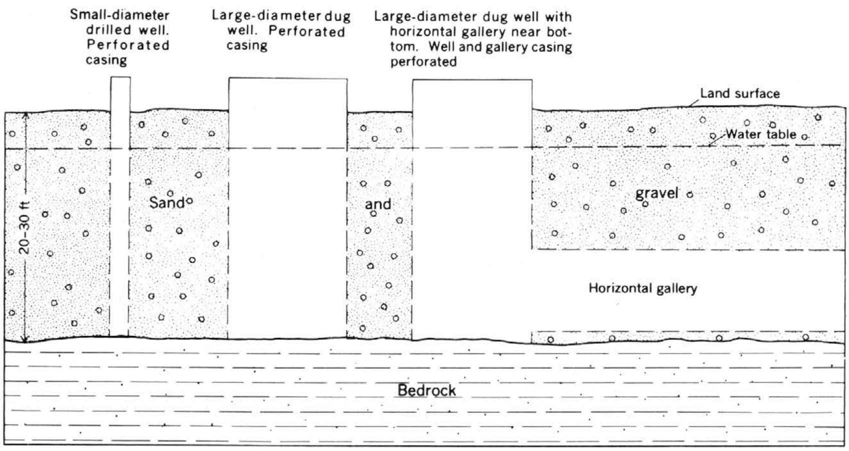

FIGURE 9.—Typical irrigation wells in the alluvial deposits.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

MESAVERDE FORMATION

The Mesaverde formation is exposed near the east border of the report area. It consists of massive and thin-bedded sandstone, shale, and coal. The thickness is about 1,000 feet near Greybull (Pierce, 1948). It strikes slightly west of north and dips westward into the basin. No wells are known to obtain water from the Mesaverde formation in the report area, but small to moderate supplies probably could be obtained west of the area of outcrop.

LANCE AND MEETEETSE FORMATIONS

The Lance and Meeteetse formations crop out west of the Mesaverde outcrop and dip southwestward into the basin. They consist of shale, sandstone, coal, and bentonite. Figure 10 is a stratigraphic section of the Lance formation and part of the Meeteetse, measured along Antelope Creek about 2 miles southwest of Basin.[1] The strike of the beds shown in the section ranges from N. 40° W. to N. 51° W. and they dip 24°–30° SW. The variegated red and gray shale at the top of the section is thought to be Cenozoic (John T. Sanford, written communication, May 31, 1957). The total thickness of the two formations near Greybull is about 1,140 feet (Pierce, 1948).

The water-bearing properties of the Lance and Meeteetse formations are probably similar to those of the Mesaverde.

TERTIARY SYSTEM

PALEOCENE SERIES

FORT UNION FORMATION

The Fort Union formation crops out to the west of the Lance formation in a northwest-southeast band 1 to 4 miles wide. It lies with slight angular unconformity on older beds. Sandstone and shale make up most of the formation. The thickness is about 1,500 feet near Greybull (Pierce, 1948).

Only one well (52–94–2bcd) in the area is reported to obtain water from the Fort Union formation. The water is not used for drinking.

Adequate supplies of water for domestic and stock use can be obtained from the Fort Union in the eastern and extreme southwestern parts of the area; it is deeply buried beneath the Willwood formation in the central part of the area.

EOCENE SERIES

WILLWOOD FORMATION

Character.—The Willwood formation is composed of variegated mudstone, sandstone, and locally abundant conglomerate.

[1] Marlian, M. G., 1957, Stratigraphic position of the Lance formation near Basin, Wyoming: Unpublished M.S. thesis, Wayne State University.

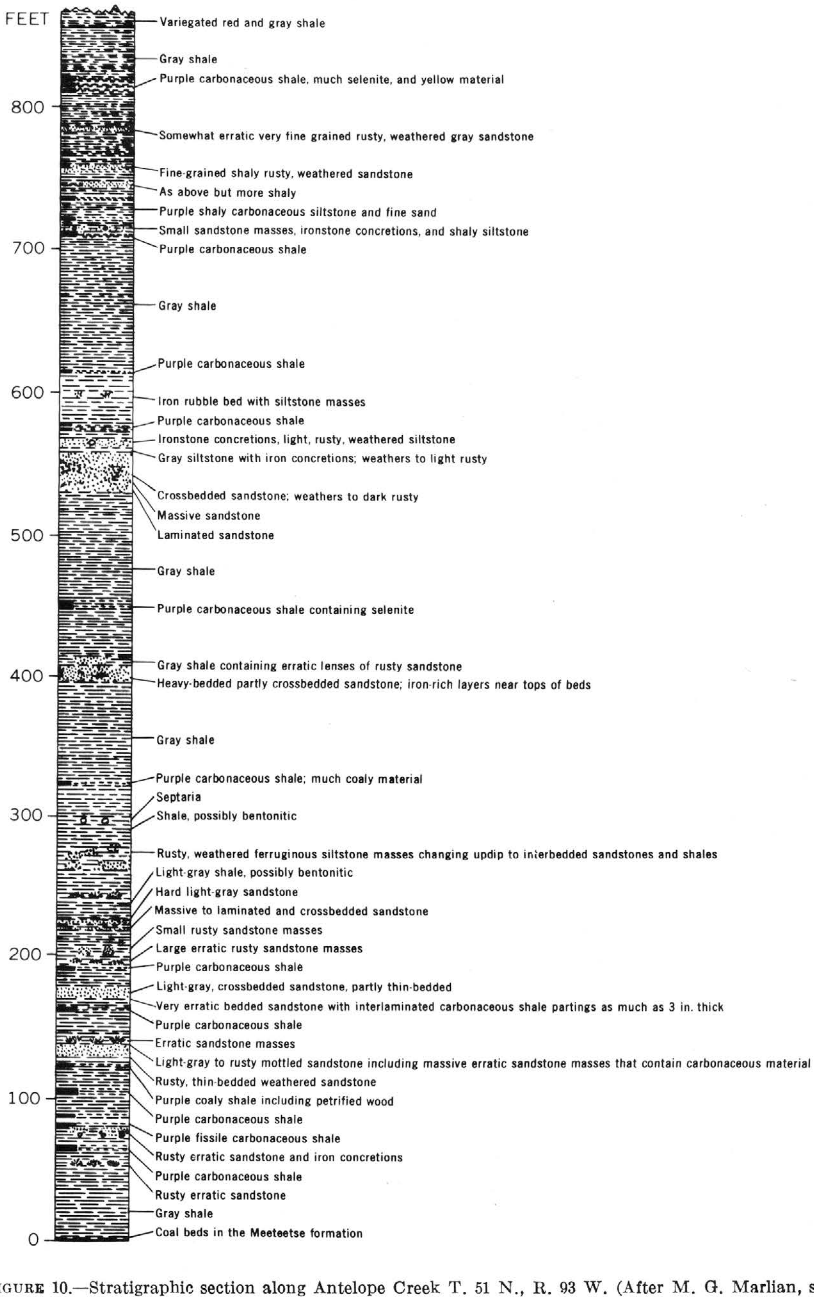

FIGURE 10.—Stratigraphic section along Antelope Creek T. 51 N., R. 93 W. (After M. G. Marlian, see footnote 1, p. 22.)

Claystone and siltstone in the Willwood are commonly variegated, and the dominant color is red. The formation is locally called the "red-banded Willwood." The unweathered beds are poorly indurated. Weathering breaks up the beds into small, thin flakes. The claystone and siltstone beds commonly weather to concave slopes where they are overlain by more resistant beds and to convex slopes where no capping bed is present. Locally, as along the YU Bench, badlands are well developed in interbedded sandstone and mudstone.

The sandstone and conglomerate beds are composed principally of poorly sorted quartz grains and minor amounts of dark minerals, and are generally yellow or brown in color. Most of the beds are well indurated and stand out as prominent ledges, but some are poorly indurated and weather rapidly to steep slopes.

Figure 11 is a stratigraphic section of part of the Willwood formation exposed in secs. 15 and 22, T. 51 N., R. 98 W. The base of the section is a few feet above the road between Burlington and Meeteetse; the Willwood formation is overlain by the deposits of the Rim terrace underlying YU Bench. The Willwood was deposited in a fluviatile environment by streams whose sediments were deposited in channels, giving rise to very lenticular beds.

Extent and thickness.—The Willwood formation underlies the central part of the Bighorn Basin. Where it is not covered by alluvial deposits it directly underlies most of the surface of the report area. Near the edges of its outcrop it lies unconformably on the Fort Union, Lance, and Meeteetse formations. In the middle of the basin it lies conformably on the Fort Union.

The thickness of the Willwood ranges from zero on its margin to more than 2,500 feet in the center of the Bighorn Basin.

Age and correlation.—The name Willwood was proposed by Van Houten (1944) for beds lying above the Fort Union (Polecat Bench) formation of Paleocene age and underlying the Tatman formation of Eocene age in the Bighorn Basin. These beds had previously been described as "Wasatch" (Fisher, 1906; Sinclair and Granger, 1911, 1912; Hewett and Lupton, 1917; Hewett, 1926). Inasmuch as the term "Wasatch" has been variously used for all the Bighorn Basin Tertiary, or for the Eocene alone, and has been divided into formations on the basis of faunal units, the use of the term has become so confused that its application in the Bighorn Basin is meaningless. The following table (after Van Houten, 1944) shows the correlation of formations and faunal units.

Water supply.—The Willwood formation is capable of yielding small amounts of water of reportedly poor to good quality throughout most of the area that it underlies. Forty-four wells inventoried during this investigation are believed to obtain water solely from the

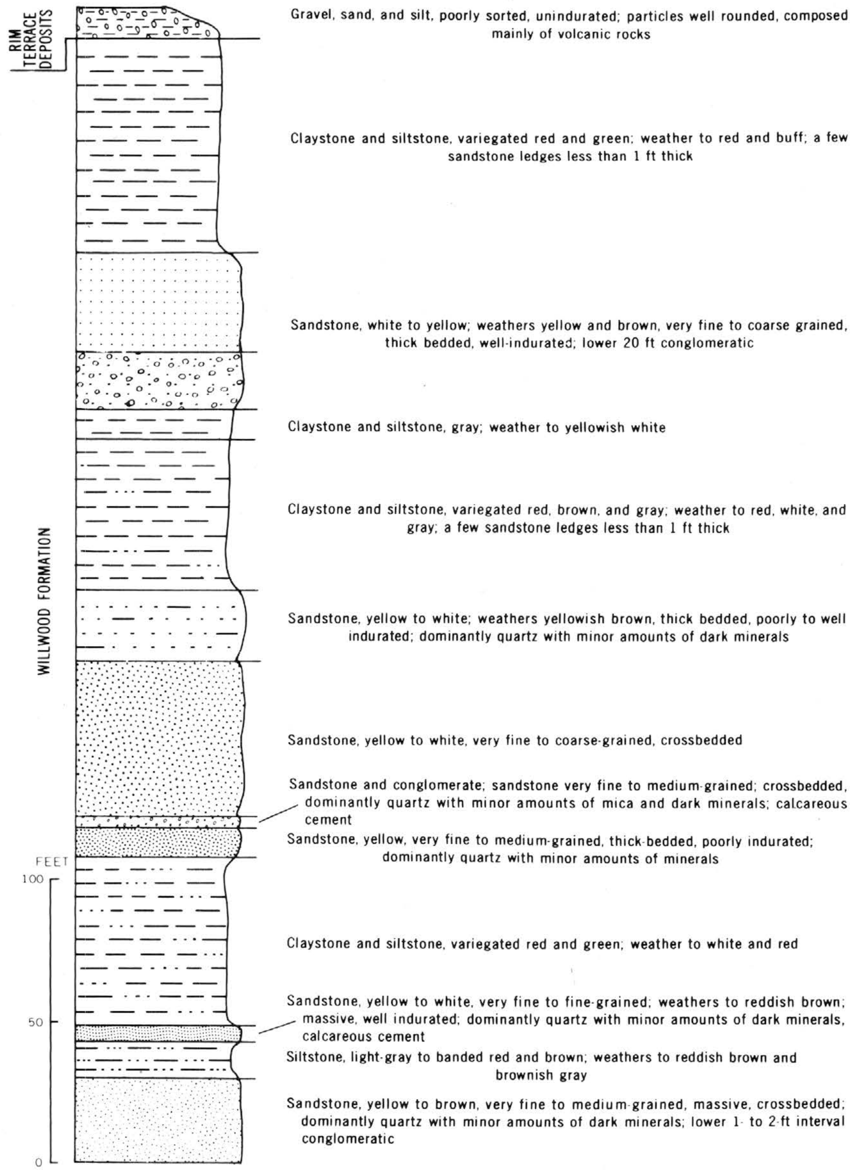

FIGURE 11.—Stratigraphic section of part of the Willwood formation and the deposits of the Rim terrace underlying YU Bench in secs. 15 and 22, T. 51 N., R. 98 W.

Willwood formation. A few other wells may obtain water from both the Willwood and overlying saturated alluvial material. All the inventoried wells are used for domestic or stock supplies and generally are equipped with either jet or cylinder pumps. Yields are small, ranging from 3 to 6 gpm. Users report that some supplies are inadequate for domestic use and that the water is of poor quality at many places.

Correlation of faunal units and formations in the early Tertiary of the Bighorn Basin
[Modified from Van Houten, 1944]

Age	Faunas	Formation
Eocene Bridgerian	?	Early Basic Breccia 60 feet
Wasatchian	(Green River flora)	Tatman formation 870 feet
		Transitional beds
	Lost Cabin Lysite Gray Bull	Willwood formation 2,500 feet
Paleocene	Clark Fork Silver Coulee Rock Bench Mantua	Fort Union formation (Polecat Bench formation) 3,500 feet

Water in the Willwood formation generally is under artesian conditions, and rises in wells to levels of a few feet to more than 70 feet below the land surface. No flowing wells were found in the report area.

Wells along the Greybull River south of the YU Bench range in depth from 34 to 205 feet; water levels range from 8 to 73 feet. East of the YU Bench water levels range generally from 5 to 50 feet below the land surface. Table 1 shows the water levels in selected observa-

TABLE 1.—*Water levels in feet below land surface in observation wells in the Willwood formation.*

Date \ Well	50-99-21aac	51-95-15ccb2	52-95-33ccc
1956			
July 21	----	----	20.53
August 3	----	5.30	----
August 13	----	----	20.52
September 17	----	----	20.30
December 1	----	5.30	19.86
1957			
January 29	----	7.96	19.75
April 4	73.56	----	20.26
May 1	73.87	----	----
June 11	72.75	----	----
August 11	69.37	----	----
October 9	66.45	----	----
December 11	68.33	----	----
1958			
April 11	73.86	----	----
September 28	66.84	----	----

tion wells in the Willwood. The water levels all show small range of fluctuation; the highest levels occur in the late summer and autumn, the lowest levels occur in the spring.

A few small springs occur in the Willwood on the escarpment below the YU Bench. Discharges are very small and the springs occur as wet areas on the rock or as small pools with no drainage.

Development of quantities of water larger than required for normal domestic and stock use probably is not feasible in the area.

The upper part of the Willwood underlying the YU Bench probably is almost completely drained of water, and wells drilled in the bench (none have been drilled up to 1957) probably must penetrate to below the level of the Greybull River valley before obtaining sufficient water for stock and domestic use.

PLIOCENE SERIES

DEPOSITS OF THE RIM TERRACE

Character.—The deposits of the Rim terrace are composed of rock debris deposited by the degrading Greybull River. Figure 12 illustrates the character of the material making up the deposit. The material is poorly sorted, and ranges in size from silt to small boulders. A mechanical analysis of material from the deposit in the NW¼ sec. 16, T. 50 N., R. 99 W., made by the U.S. Bureau of Reclamation, shows that 30 percent by weight of the particles are less than 4.76 mm

FIGURE 12.—Deposit of the Rim terrace on south edge of YU Bench in sec. 36, T. 51 N., R. 99 W. Photograph by C. J. Robinove.

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in diameter and 70 percent are larger. Sixty-five percent of the particles are between 9.52 mm and 76.2 mm in diameter.

The deposits are predominantly subangular to rounded fragments of volcanic rocks derived from the Absaroka volcanic plateau to the west.

Extent and thickness.—The deposits of the Rim terrace extend along the uplands bordering the Greybull and Wood Rivers from the eastern edge of the Absaroka volcanic plateau to about the longitude of the town of Otto. The deposits were originally part of a great sheet of terrace gravels; they have been eroded into the small patches and tablelands that make up the "Meeteetse Rim" along the Greybull River near Meeteetse, and into the large remnants that make up the YU Bench and Table Mountain. Mackin (1937) estimated that the deposits of the Rim terrace originally were about 6 miles wide. At the present time the widest part is near the eastern end of the YU Bench where the terrace is about 3½ miles wide.

The Rim terrace slopes about 40 feet per mile; the gradient is approximately equal to the gradient of the Greybull River. The surface of the terrace is 400 to 550 feet above the river. (See pl. 1.) On the YU Bench the surface is flat and is broken only by gullies that slope gently where they are underlain by the gravels and steepen abruptly in the underlying bedrock. Figure 13 shows the eastern end of the YU Bench and the next lower terrace level, the Emblem Bench.

The U.S. Bureau of Reclamation in 1949–52 drilled 15 test holes in the YU Bench to determine the character and thickness of the

FIGURE 13.—YU Bench (upper skyline at left) and Emblem Bench (lower skyline at right). View north across Greybull River valley from NE¼ sec. 10, T. 51 N., R. 97 W. Willwood formation in foreground. Photograph by C. J. Robinove.

deposits of the Rim terrace. The logs of the test holes are included in the table of logs of wells and test holes at the end of this report. Measurements of the thickness of the terrace deposits have been made at 35 points on the edges of the bench. Elevations of the top of the bedrock have been determined from the elevation of the surface of the bench and the thickness of the gravel deposit. Elevations at measured points on the edge of the bench were determined from topographic maps and the test-hole elevations were determined by instrumental leveling by the Bureau of Reclamation.

The accuracy of the test hole data is good; however, the determinations of bedrock elevation on the edges of the bench may be in error by $\pm$ 10 feet because of the difficulty of measuring the thickness of the terrace deposits. As the slopes are eroded the gravel slumps and in many places covers and hides the gravel-bedrock contact. Plate 2 shows contours on the top of the Willwood formation underlying the YU Bench.

An estimated minimum of 20 additional test holes would furnish additional data on the thickness of the deposits of the Rim terrace and, hence, a more accurate outline of the bedrock topography. The test holes should be drilled through the full thickness of the deposits of the Rim terrace and should be cased and equipped with screens to permit their use for water-level and chemical quality observations when a body of ground water is built up in the deposits of the Rim terrace.

Age and correlation.—The following discussion is adapted from Mackin (1937). The terrace gravels of the Bighorn Basin have yielded no fossils; their age must be determined by comparison with features of known age in other regions. The no. 2 terrace of Alden (1932) is Pleistocene in age as shown by comparison with glacial deposits in the Upper Missouri drainage basin. This age may be accepted for terraces correlating with no. 2 in the Bighorn Basin. The terrace levels in the Bighorn Basin and their correlations are shown in the table below. Fossils found in the Cypress Hills Plateau of southwestern Saskatchewan and in the Flaxville gravel of Montana indicate a middle or late Tertiary age for these deposits (Alden, 1932). As shown below, the YU Bench is correlated with the no. 1 or Flaxville terrace and is therefore considered to be Tertiary. Closer assignment of the surfaces to epochs within the Tertiary must await more definitive dating of the gravels of the Northern Plains.

Origin of terraces and benches.—Two types of flat, gently sloping surfaces are found in the Greybull River–Dry Creek area: (a) the planed bedrock surface that truncates bedrock structures and is overlain with a very thin veneer of gravel, and (b) the terrace surfaces that are underlain by appreciable thicknesses of unconsolidated alluvial

Correlation of the Bighorn Basin terrace levels

[After Mackin, 1937. Chart shows relative heights of the projected levels of the terraces and benches of the Bighorn Basin above the present levels of the Yellowstone and Bighorn Rivers. Names and numbers in parentheses indicate correlations assigned by W. C. Alden, 1932]

Feet	Bighorn River		Yellowstone River	
	Greybull valley	Shoshone valley	Pryor Creek valley	Rock Creek valley
1, 200				
	Tatman 1190±100 (Cypress)			
1, 000				
800			Polecat 625±50 (No. 1 Flaxville)	
600				
	YU 440±50 (No. 1 Flaxville)	Kane 420±5		Mesa 450±100 (No. 1 Flaxville)
400				Roberts 210±100 (No. 2)
200				
	Emblem 110±10 (No. 2)	Powell 80±10 (No. 2)		Red Lodge 20±20 (No. 2)
0		Cody 20±5 (No. 3)		

material. The first of these surfaces is properly called a "bench," the second, a "terrace." However, the terrace surfaces underlain by thick gravel deposits, the most prominent of which are YU Bench, Table Mountain, Emblem Bench, and Agrarian Bench, have been termed "benches" both locally and in the geologic literature for long periods of time so that it is deemed necessary to continue the use of the term even though such usage may not be strictly correct.

The planed bedrock floors overlain with only small amounts of gravel and the bedrock floors underlying thick alluvial deposits have been described as pediments. Mackin (1937, p. 879–881) points out that pediments sloping from a mountain range into a closed basin are controlled by a rising base level which is caused by the continuing accumulation of alluvium on the basin floor. Pediments in the Bighorn Basin are different, however, in that a through-flowing master stream is capable of carrying the erosional debris beyond the limits of the basin and can provide a stable or slowly lowering base level for the pediment-forming agents. Thus, the surfaces formed are concave upward. The longitudinal stream profiles closely parallel the pediment surfaces. (See fig. 7.)

Water supply.—As of 1957 there were no wells on the YU Bench, and no diversions of surface water had ever been made to the bench. The average annual precipitation on the bench is about 8 inches and this is the only source of recharge to the terrace deposits. Test drilling by the U.S. Bureau of Reclamation in the YU Bench showed that no water was present in the terrace deposits. This discussion, therefore, is based upon the ground-water conditions that may be expected when the bench is irrigated. Stockmen in the area report that until 1951, they were able to water stock at small springs on the north side of the YU Bench, but that the springs dried up at that time and have not flowed since.

Prior to application of irrigation water, development of domestic ground-water supplies on the YU Bench would be difficult. As there is little or no ground water in the gravel deposits underlying the YU Bench, it would be necessary to drill into the Willwood formation below the terrace deposits to obtain water. The wells probably would penetrate below the level of the base of the bench before reaching saturated permeable sandstone beds. Yields from these sandstone beds probably would be low, depths to water would be great and the water probably would be highly mineralized.

The application of irrigation water to the YU Bench would result in recharge to the terrace deposits and the development of a perched ground-water body under the bench. The water would initially move downward until it reached the top of the bedrock and then would move laterally to points of discharge at the sides of the bench. Development of the ground-water body could be accelerated and construction of domestic wells made more feasible by spreading water from the canals and allowing it to recharge the terrace deposits before the land is settled.

The contour map (pl. 2) indicates that when large amounts of water enter the terrace deposits, the water will move to the northeast and will be discharged along the gravel-bedrock contact. The difference in permeability of the terrace deposits and the Willwood formation is so great that a perched body of ground water will lie in the terrace deposits above the Willwood formation.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT SERIES

DEPOSITS OF THE SUNSHINE TERRACE

Character.—The deposits of the Sunshine terrace are composed of the same type of rock material as the deposits of the Rim terrace; that is, poorly sorted gravel, sand, and silt, predominantly rounded fragments of volcanic rocks derived from the Absaroka Range to the west.

Extent and thickness.—The deposits of the Sunshine terrace underlie the Emblem Bench, the Agrarian Bench, and small remnants of the Sunshine terrace along the Greybull River valley upstream from the

Emblem Bench. Plate 3 shows points where the thickness of the deposits was measured in outcrops or determined from well logs in the irrigated part of the Emblem Bench. The point at which the greatest thickness of gravel of the deposits of the Sunshine terrace was penetrated is in sec. 10, T. 52 N., R. 96 W. where a well was bottomed in the gravel at a depth of 57 feet. The thinnest deposits, less than 10 feet, are at the north edge of the bench. Figure 14 shows the relation of the Emblem Bench to the Dry Creek valley and Table Mountain.

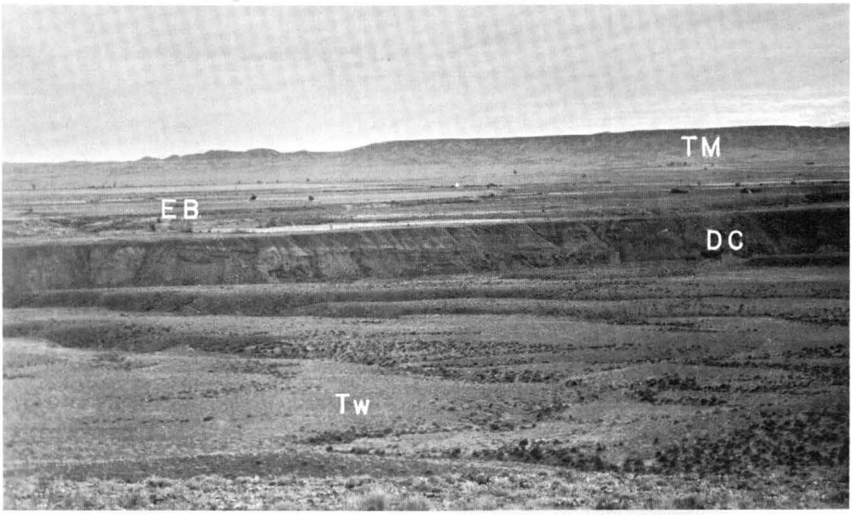

FIGURE 14.—View of Table Mountain (*TM*), Emblem Bench (*EB*), south wall of the Dry Creek valley (*DC*), and Willwood formation covered with a thin veneer of gravel (*TW*). View south from sec. 3, T. 52 N., R. 95 W. Photograph by C. J. Robinove.

Water supply.—The deposits of the Sunshine terrace underlying the Emblem Bench constitute an important aquifer in that they yield water to many wells, some of which are used for irrigation; the deposits are very permeable and receive large quantities of recharge from surface water from canals, laterals, ephemeral streams, and irrigated lands, and from precipitation. Throughout the bench the deposits are capable of yielding moderate to large quantities of water to either drilled or dug wells. Drilled wells may be constructed where the saturated thickness of the deposits is fairly large; no dug wells have been put down in the bench but they could be constructed where the water table is close to the surface and the saturated thickness is not great.

Specific capacities of irrigation wells in the deposits of the Sunshine terrace range from about 25 to about 55 gpm per foot of drawdown. Well 52–96–8cbc has a specific capacity of only 2.3 gpm per foot of drawdown but this probably is due to plugging of the casing perforations. Discharges of more than 1,000 gpm from irrigation wells have been reported.

Water levels in the irrigated part of Emblem Bench are within a few feet of the surface except in places near the southern edge. (See pl. 1.) Measurements of water levels in selected wells began in July 1956 and continued through September 1958, and are given in table 2. Water levels in some wells show very small fluctuations, others fluctuate as much as 10 feet. The fluctuations are dependent upon the application of irrigation water.

DEPOSITS OF THE GREYBULL TERRACE

Character, extent, and thickness.—The deposits underlying the Greybull terrace are of the same type as the other terrace and alluvial materials. They border the Greybull River alluvium on the north in the central part of the area and are exposed in two localities south of the Greybull River about 5 miles east of Otto. The maximum reported thickness of the deposits is 47 feet in well 52–96–31dca. The deposits are about 15 feet thick under the terrace east of Otto and probably are nearly the same thickness in most of their extent north of the Greybull River.

Water supply.—The deposits of the Greybull terrace are capable of yielding water in sufficient quantities for domestic and stock use throughout their extent, and moderate to large quantities where the saturated thickness is fairly large. Well 52–96–31dca is capable of producing 590 gpm with a drawdown of 10.4 feet, a specific capacity of 57 gpm per foot of drawdown.

Water levels in the deposits of the Greybull terrace range from less than 1 foot below land surface in one well to more than 20 feet below land surface in another; depths to water in observation wells are shown in table 3.

DEPOSITS OF THE NUMBERED TERRACES

The deposits underlying the numbered terraces (pl. 1) are not water bearing, except for the deposits of Qt_1 and Qt_2 south of the Greybull River and east of the Bighorn River. These terraces are irrigated and the applied irrigation water recharges the terrace deposits. The numbered terraces are correlated with the named terraces on the basis of height above the Greybull River. The correlation is indicated in the explanation of the geologic map (pl. 1). No information was collected on the thickness and water-bearing properties of these terrace deposits.

ALLUVIUM

Character.—The alluvium in the Greybull River valley is similar in composition to the higher terrace deposits; the alluvium of the Dry

TABLE 2.—Water levels in feet below land surface, in observation wells in deposits of the Sunshine terrace.

Date \ Well	[1] 52-94-2bcd	52-95-6ccc	52-95-9dad2	52-95-10cbc	52-95-10dbd1	52-96-2cbc	52-96-3cbc	52-96-3cbc	52-96-7dad	52-96-8cbc	52-96-9ada2	52-96-9cbc	52-96-10dcd	52-96-16aad	52-96-18bcc	52-96-18cbc
1956																
July 21	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	4.94	--------	--------	3.43	--------
Aug. 3	--------	7.22	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	39.29	--------	--------	--------
Aug. 6	--------	--------	13.29	--------	--------	--------	--------	--------	4.62	5.75	6.33	--------	--------	22.89	--------	3.73
Aug. 11	--------	--------	--------	5.91	--------	5.59	--------	4.20	--------	--------	--------	--------	--------	--------	--------	--------
Aug. 13	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	6.02	--------	--------	4.01	--------
Sept. 19	5.75	7.24	13.35	6.88	4.82	8.22	8.35	6.80	5.70	6.68	6.21	5.40	37.58	21.35	5.15	5.19
Dec. 1	6.10	7.44	15.45	8.02	5.34	10.40	8.50	7.36	7.06	6.90	7.72	11.73	38.73	22.91	5.14	6.56
1957																
Jan. 29	7.78	7.58	16.93	--------	7.47	12.30	--------	12.96	8.80	7.26	11.87	--------	40.12	28.04	6.27	7.32
Apr. 4	--------	7.52	17.78	9.52	5.60	13.26	13.79	13.57	--------	7.28	10.04	13.72	41.57	26.78	6.60	9.95
May 1	--------	7.48	17.48	9.28	3.64	7.59	13.55	13.58	--------	6.68	9.39	11.36	42.03	27.09	5.37	6.42
June 11	--------	7.37	14.55	5.93	4.82	5.74	9.08	4.78	--------	6.40	7.04	7.81	40.53	25.52	4.97	4.25
Aug. 11	--------	7.32	13.05	5.53	4.01	5.36	6.64	4.10	--------	5.70	6.26	6.48	--------	--------	4.58	3.87
Oct. 9	--------	7.34	--------	6.95	--------	--------	--------	6.08	--------	6.37	--------	--------	--------	21.44	--------	4.47
Dec. 11	--------	7.37	--------	7.99	--------	--------	--------	10.26	--------	6.95	--------	--------	--------	22.41	--------	5.92
1958																
April 11	--------	7.24	--------	9.48	--------	--------	--------	13.30	--------	7.08	--------	--------	--------	26.12	--------	8.32
Sept. 28	--------	7.09	--------	5.65	--------	--------	--------	3.98	--------	6.52	--------	--------	--------	20.14	--------	3.88

[1] Well penetrates both deposits of the Sunshine terrace and Fort Union formation; measurements probably are indicative of water-level fluctuations in deposits of the Sunshine terrace.

TABLE 3.—*Water levels, in feet below land surface, in observation wells in deposits of the Greybull terrace*

Date \ Well	[1] 51-94-8dbb1	[1] 51-94-8dcb	51-94-10aaa	51-96-1cbc	52-96-28ccb	52-96-31bcb	52-96-31dca	52-96-33ccb	52-97-26dbd	52-97-35dbc	52-97-36caa
1956											
July 21	--------	--------	--------	--------	--------	1.57	--------	--------	--------	--------	--------
July 25	--------	--------	--------	5.22	--------	--------	--------	--------	--------	--------	--------
Aug. 3	--------	--------	--------	--------	--------	1.37	5.90	3.68	4.06	4.17	--------
Aug. 6	--------	--------	--------	--------	4.99	--------	--------	--------	--------	--------	--------
Aug. 13	--------	--------	--------	--------	--------	--------	--------	--------	5.84	--------	--------
Sept. 19	11.13	4.44	1.95	7.66	5.87	2.16	6.82	5.91	3.76	6.31	4.60
Dec. 1	14.02	8.76	4.85	8.17	7.16	2.74	10.24	5.37	6.34	6.82	6.22
1957											
Jan. 29	17.73	14.01	--------	9.59	8.04	--------	13.62	7.17	8.60	8.09	8.55
Apr. 4	20.30	14.65	--------	9.75	8.18	--------	16.51	7.40	8.78	8.67	9.05
May 1	17.09	7.37	4.65	9.50	7.33	2.98	15.76	5.44	8.58	8.41	7.02
June 11	9.73	3.61	--------	.00	5.74	3.21	8.95	5.54	5.97	7.57	5.05
Aug. 11	3.58	3.09	--------	3.40	3.25	2.74	6.11	4.57	6.34	7.36	4.34
Oct. 9	10.53	--------	--------	7.17	--------	--------	8.86	5.18	6.22	--------	--------
Dec. 11	16.11	--------	--------	9.47	--------	--------	11.73	6.50	6.83	--------	--------
1958											
Apr. 11	20.99	--------	--------	9.02	--------	--------	16.88	7.58	8.52	--------	--------
Sept. 28	5.85	--------	--------	8.40	--------	--------	7.45	4.57	5.17	--------	--------

[1] Wells penetrate both deposits of the Greybull terrace and Willwood formation; water levels probably indicate fluctuations in deposits of the Greybull terrace.

Creek and Bighorn River valleys is composed mainly of sand and has much smaller amounts of gravel than the Greybull River valley alluvium. Alluvium of the Greybull River is shown in figure 15. The Dry Creek valley is shown in figure 16.

Extent and thickness.—Alluvium underlies the valleys of the Bighorn and Greybull Rivers throughout their extent in the report area. The Dry Creek valley is underlain by alluvium from a point about a mile north of Emblem to its confluence with the Bighorn River at Greybull. The logs of a few wells indicate that the thickness of the alluvium in the Greybull valley is about 30 feet but precise data are lacking in many localities. The alluvium of the Dry Creek valley is probably not over 15 feet thick.

Water supply.—Water in the alluvium of the Greybull River valley is derived from the infiltration of surface water applied for irrigation, and from precipitation on the alluvium. Water levels range generally from 1 foot to 20 feet below land surface and fluctuate in response to application of water for irrigation. Table 4 lists depths to water in selected observation wells in the alluvium.

Four irrigation wells have been constructed in the alluvium of the Greybull River valley; well 51-97-1bcb1 as a reported discharge of 250 gpm, and well 51-95-15ccb1 discharges 140 gpm with a drawdown of 9.5 feet. The other two wells were not in use at the time of the investigation.

FIGURE 15.—View of Greybull River downstream from bridge in sec. 6, T. 50 N., R. 98 W., June 1957. The river is in flood and has cut its channel next to the bedrock at the left. Coarse alluvial gravel is exposed at the right. Photograph by C. J. Robinove.

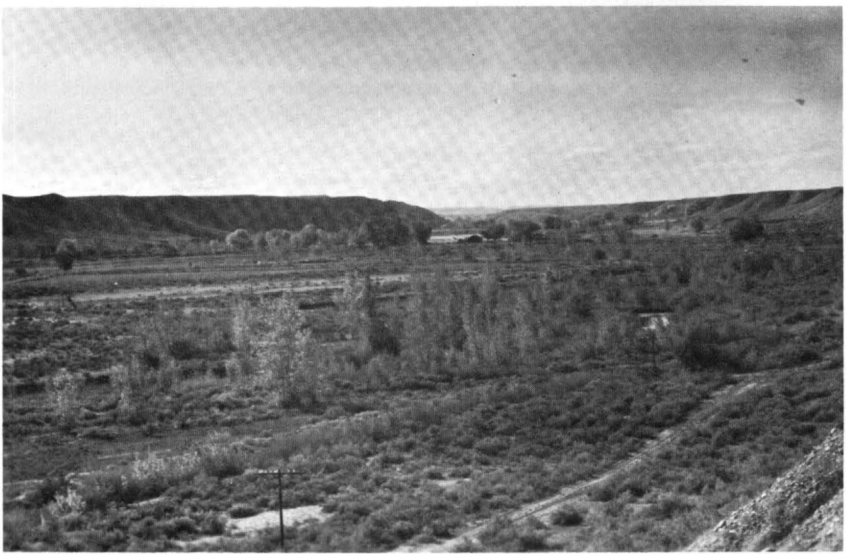

FIGURE 16.—View of Dry Creek valley west from sec. 6, T. 52 N., R. 94 W. Agrarian Bench surface in foreground, Dry Creek valley in center, Emblem Bench on skyline at left, terrace Qt_4 on skyline at right. Photograph by C. J. Robinove.

TABLE 4.—*Water levels, in feet below land surface, in observation wells in Greybull River alluvium*

Date \ Well	50-98-5aac	51-95-15ccb1	51-95-21aca	51-96-4aac	51-96-4dcb	51-96-5bcc	51-96-6bda	51-96-6cbb	51-96-7cac	51-96-8bbb	51-97-2cbb	51-97-12abc1	51-98-23aad2	52-93-20abc	52-96-31ccc
1956															
July 21	------	------	------	------	------	------	------	------	------	------	7.53	------	------	------	------
July 25	------	------	3.05	------	------	------	------	------	6.18	5.75	------	4.30	------	------	------
Aug. 3	------	6.60	------	1.61	5.31	2.88	------	------	------	------	------	------	------	------	4.68
Aug. 11	------	------	------	------	------	------	3.65	10.96	------	------	------	------	------	------	------
Aug. 13	------	------	3.29	------	4.65	------	------	------	------	------	------	------	------	------	------
Sept. 19	------	------	5.00	4.10	6.00	5.10	5.20	13.07	6.51	5.39	5.44	5.77	------	5.19	4.62
Dec. 1	------	7.03	4.31	5.43	6.47	7.71	8.48	18.06	7.06	7.93	10.62	9.80	------	7.40	7.84
1957															
Jan. 29	------	7.45	5.48	6.19	7.16	------	12.27	22.80	7.78	8.83	------	12.69	------	------	11.01
Apr. 4	19.79	7.65	5.71	5.95	7.29	------	16.96	28.42	7.80	11.20	------	15.36	15.23	------	16.93
May 1	20.22	7.60	5.03	5.76	4.37	------	17.81	28.17	5.88	11.54	------	16.56	15.98	------	17.87
June 11	------	5.44	2.93	3.49	4.35	------	9.47	22.10	------	8.26	------	6.62	12.52	------	8.74
Aug. 11	16.66	------	------	2.11	5.40	------	4.55	13.34	------	3.91	------	5.34	12.83	------	4.41
Oct. 9	15.73	6.96	------	------	5.28	------	------	15.07	------	------	------	------	9.53	------	------
Dec. 11	17.42	6.96	------	------	6.94	------	------	19.38	------	------	------	------	10.61	------	------
1958															
Apr. 11	19.94	7.40	------	------	7.42	------	------	31.73	------	------	------	------	15.54	------	------
Sept. 28	13.87	6.30	------	------	3.87	------	------	11.93	------	------	------	------	9.60	------	------

CHEMICAL QUALITY OF THE WATER

The suitability of a water for various uses—agricultural, domestic, and industrial—depends to a large extent on the chemical quality of the water. The chemical quality of a water is determined by the kind and amount of substances that are dissolved in the water. Water that meets the quality requirements of one user may be unsatisfactory for another. Agricultural users of water need to know what effect, if any, the water will have on livestock and on irrigated crops and soils. Domestic users of water are primarily interested in the palatability and potability of their drinking water and in the suitability of the water for laundering and washing. Industrial users of water are concerned with the suitability of the water for cooling purposes and various other processes, and with the type and degree of treatment needed to make the water suitable for their particular use.

As part of the ground-water investigation of the Greybull River–Dry Creek area, a study was made to determine the chemical quality of the ground water, to relate the chemical quality of the water to the geology and hydrology of the area, and to evaluate the suitability of the water for various uses. The chemical quality of applied irrigation water and of water draining from irrigated lands also was studied.

Because proposed development may result in irrigation of additional acreages in the report area and in diversion of water from the Shoshone River basin, consideration was given in the water-quality study to the following questions: What is the chemical quality and suitability for irrigation of the available water from the Greybull and Shoshone Rivers? What would be the quality and suitability for use of ground water resulting from the irrigation development of presently unirrigated terrace deposits? What effect would the proposed irrigation development have on the quality of water in Greybull River and Dry Creek?

METHOD OF STUDY

As part of the program of the Department of the Interior for development of the Missouri River basin, the Geological Survey made studies during the period 1947–56 of surface-water quality in the vicinity of the report area. Rather comprehensive studies were made during 1947–53 of the quality of water released from Buffalo Bill Reservoir and the quality of water in Greybull River at Meeteetse, Greybull River near Basin, and Dry Creek at Greybull. Reconnaissance studies were made in 1955–56 at various sites on streams in the Greybull River and Dry Creek basins.

The intensive study of water quality in the Greybull River-Dry Creek area was begun in August 1957. In this report, the results of the field and laboratory aspects of the study are summarized; the water quality of the area is related to the geologic, hydrologic, and cultural environment; and the suitability of the water is evaluated for agricultural and domestic uses.

Samples of ground water were obtained from representative wells and springs yielding water from the Willwood formation, deposits of the Sunshine and the Greybull terraces, and the alluvium. Wells were pumped before sampling so the sample would represent, as nearly as possible, water directly from the aquifer rather than water that had been standing in the well. The samples were collected in chemically resistant glass or polyethylene bottles, and turbid samples were filtered through filter-paper pulp soon after collection. Water temperature was determined at the time of sampling; however, some temperatures, which were not representative because the water had passed through considerable piping and a tank, were not recorded.

Most samples of surface water were collected near the center of flow of the stream. A few samples were dipped from flowing water near the stream bank. Chemically resistant glass or polyethylene bottles were used.

The samples were analyzed within about 4 weeks of collection by the U.S. Geological Survey, by methods common to the field of water chemistry (Am. Public Health Assoc., 1955). For most samples the concentrations of the major dissolved constituents (silica, calcium, magnesium, sodium, bicarbonate and carbonate, sulfate, and chloride) and many of the important minor constituents (iron, potassium, fluoride, nitrate, and boron) were determined. The concentration of selenium, an important minor constituent, was determined on a few samples of ground water. Dissolved solids were determined for most samples, as were some important characteristics of the water such as hardness, specific conductance, and pH. Percent sodium and sodium-adsorption ratio, which are useful in evaluating the suitability of water for irrigation, were calculated for most samples.

Concentration of individual dissolved constituents and of dissolved solids, and the hardness given in tabular form in this report, are expressed 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, a measure of the ability of the water to conduct an electrical current, is expressed in reciprocal ohms (mhos) per centimeter $\times 10^6$, and is referred to as micromhos per centimeter at 25° C. For brevity, "micromhos" or "micromhos at 25° C" is used in this report. Because it is related to the concentration and chemical types of dissolved material, the specific conductance can be used for estimating the dissolved-solids content of the water. For ground and surface waters in the report area the dissolved solids in parts per million are approximately equal to 0.7 times the specific conductance in micromhos. The term "mineralization," as used in this report, refers to the amount of dissolved material in the water, whether expressed as parts per million of dissolved solids or as specific conductance in micromhos.

The pH indicates the degree of acidity or alkalinity of a water. A pH of 7 indicates that the water is neither alkaline nor acid, values progressively higher than 7 denote increasing alkalinity, and values progressively lower than 7 denote increasing acidity.

Percent sodium and sodium-adsorption ratio (SAR) are calculated with concentrations in equivalents per million (epm) as follows:

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

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

"Equivalents 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 equivalents per million of the cations is approximately equal to the total equivalents per million of the anions. Silica is considered to be in the colloidal state and therefore not ionized. Normally iron, selenium, and boron are present in such small amounts that they are not included as ionized constituents. Parts per million can be converted to equivalents per million by multiplying by the following factors:

Cation	*Factor*	*Anion*	*Factor*
Calcium (Ca^{++})	0. 04990	Bicarbonate (HCO_3^-)	0. 01639
Magnesium (Mg^{++})	. 08224	Carbonate (CO_3^{--})	. 03333
Sodium (Na^+)	. 04350	Sulfate (SO_4^{--})	. 02082
Potassium (K^+)	. 02558	Chloride (Cl^-)	. 02820
		Fluoride (F^-)	. 05263
		Nitrate (NO_3^-)	. 01613

FACTORS AFFECTING WATER QUALITY

A complete description of the occurrence and significance of the dissolved substances in water is beyond the scope of this report. For such a description the reader is referred to one of the annual series of U.S. Geological Survey Water-Supply Papers entitled "Quality of

Surface Waters of the United States." In the following section several of the more important factors affecting water quality in general and for the report area in particular will be discussed.

Alkali and alkaline earth bicarbonates, sulfates, and chlorides are the principal dissolved substances in natural waters. Silica, iron, manganese, potassium, fluoride, nitrate, boron, and gases—such as hydrogen sulfide and carbon dioxide—are present also, but usually in small amounts.

The amount and kind of chemical constituents in water depend on the environments 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 containing carbon dioxide is a particularly effective solvent for such carbonate rocks as limestone and dolomite, 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 in or containing these fine-grained rocks usually yield highly mineralized water. Conversely, granitic and volcanic rocks and leached sand and gravel are more resistant to the solvent action of water and, therefore, yield water of low mineralization. Generally, however, in arid and semiarid regions such as the Bighorn Basin, sand and gravel contain large amounts of soluble material; some sand stone contains cementing material that is very soluble in water.

The longer the water is in contact with the rocks, the more mineralized it becomes. Thus, water that infiltrates the earth's crust is usually more highly mineralized than overland runoff.

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

1. Evapotranspiration concentrates the salts in the water, 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 clays (such as bentonite) or natural zeolites. The exchange of calcium and magnesium in the water for sodium from the clay causes the water to gain sodium and to lose 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:

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

CHEMICAL CHARACTERISTICS OF THE WATER

An understanding of the chemical quality of ground water in the Greybull River–Dry Creek area requires knowledge of the chemical quality of recharge and drainage water. Because irrigation water in the area, as in other arid and semiarid parts of the country, is a major source of ground water, the quality of the ground water is related to the quality of the applied water.

APPLIED IRRIGATION WATER

Data pertaining to the chemical characteristics of surface water in the vicinity of the report area for the period July 1955 to April 1958 are summarized in table 5. Additional available data are given in the annual series of water-supply papers entitled "Quality of Surface Waters of the United States;" most additional data are referred to in footnotes on the table.

Figure 17 is a map of the Greybull River, Dry Creek, and part of the Shoshone River basins showing sites where chemical-quality data have been obtained. Also, the chemical type and mineralization of the water at representative sites are shown by means of patterns (Stiff, 1951). Patterns representing periods of both high and low flow are shown if data were available, and the water discharge at the time of sampling is shown above each pattern. The patterns are constructed by plotting the concentrations in equivalents per million of the ionized constituents to the right and left of a vertical axis and connecting the consecutive plots with straight lines. The resultant pattern not only depicts the chemical type of the water but also, by its relative size, the mineralization of the water.

GREYBULL RIVER

Greybull River and its principal tributary, Wood River, rise in the high Absaroka volcanic plateau to the west of the report area and much of their flow is from melting ice and snow. Upstream from the streamflow gaging stations near Pitchfork and Sunshine, the streams drain areas underlain by volcanic rocks of Tertiary age. Water in the upper reaches of these streams is, as expected, only slightly mineralized (less than 100 ppm of dissolved solids) and is of the calcium bicarbonate type. Although analyses in table 5 for Greybull River near Pitchfork and Wood River at Sunshine are for high-flow periods in summer, they probably also represent fairly well the chemical quality of water in the streams during periods of lower flow in spring and fall.

Downstream from the confluence with the Wood River, water in the Greybull River at Meeteetse contains more dissolved solids (100 to 500 ppm) and has higher concentrations of mainly calcium, sodium, and sulfate than the water in the upper reaches of the Greybull and Wood

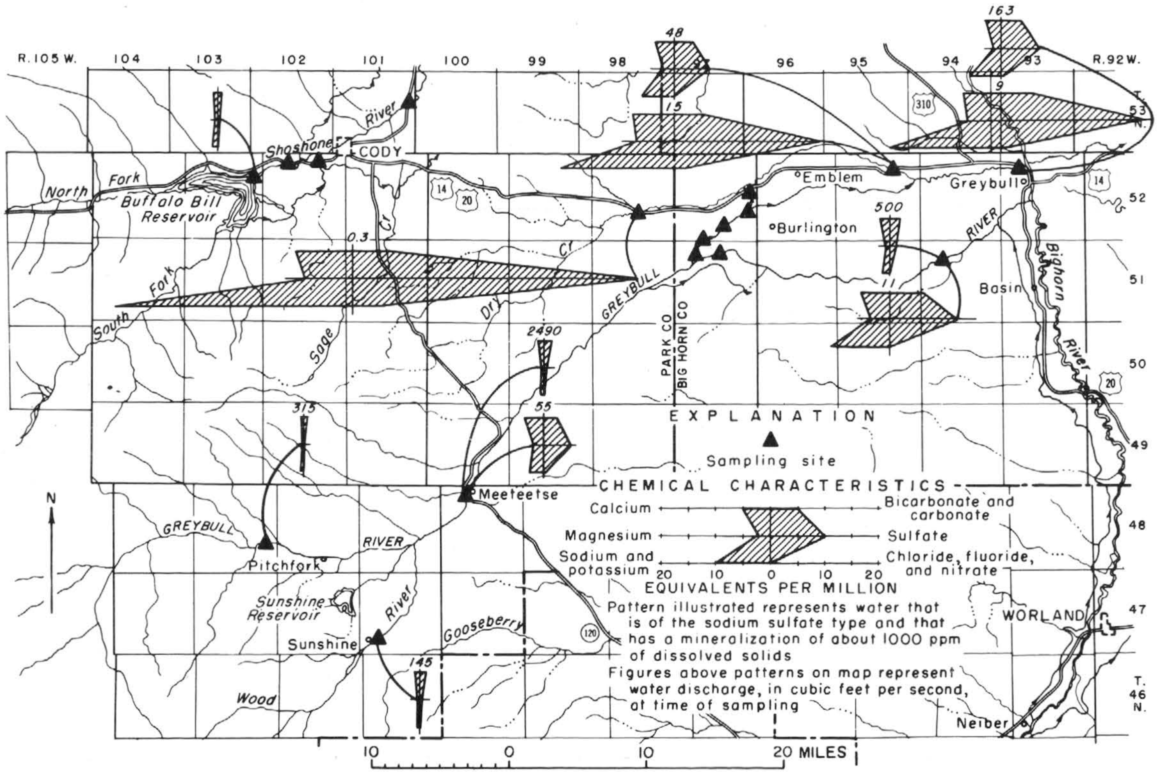

FIGURE 17.—Map of part of northwestern Wyoming showing chemical characteristics of surface water in Greybull River and Dry Creek basins and in Buffalo Bill Reservoir.

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TABLE 5.—*Chemical analyses of surface water,*

[Results in parts per

Date	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
Greybull River near Pitchfork										
June 4, 1956	1,870	15	0.18	10	2.7	4.2	0.9	50	0	5.0
July 24	315	13	.01	8.5	1.2	4.8	.4	41	0	5.0
Wood River at Sunshine										
June 4, 1956	530	15	0.14	11	2.3	4.8	0.9	50	0	8.0
July 24	145	12	.00	17	3.6	6.4	.8	67	0	15
Greybull River at Meeteetse										
July 24, 1955	820	--------	------	28	10	18	2.4	--------	--------	--------
June 4, 1956	1,530	16	0.07	16	4.2	8.3	.9	70	0	20
July 24	670	13	.03	23	7.0	13	1.1	91	0	38
Aug. 9, 1957	947	--------	------	33	11	17	--------	134	0	52
Greybull River near Burlington										
Aug. 9, 1957	----------	--------	------	35	12	25	--------	146	0	68
Greybull River near Basin										
June 5, 1956	500	17	0.03	31	7.9	24	1.6	121	0	61
July 24	15	18	.01	86	31	164	3.4	312	0	425
Aug. 9, 1957	59	--------	------	72	27	132	--------	274	0	315
Dry Creek above Emblem										
June 21, 1956 [3]	[4] 10	19	1.5	56	84	1,020	12	360	0	2,180
Nov. 6, 1957	[4] .5	13	.02	169	165	1,220	54	498	0	3,010
Dec. 5	[4] .3	12	.00	210	107	1,000	9.2	424	0	2,510
Mar. 4, 1958	1.7	--------	------	--------	--------	--------	--------	--------	--------	2,310
Dry Creek below Emblem										
July 24, 1956	29	21	0.01	93	38	172	3.8	296	0	505
Apr. 17, 1957	[4] 15	16	.01	150	82	467	10	356	0	1,290
May 6	35	19	.01	89	32	203	9.0	320	0	484
June 1	65	18	.02	89	33	235	9.0	278	0	598
July 1	48	21	.03	66	24	123	4.5	215	0	330
Aug. 5	39	--------	.01	93	35	--------	--------	302	7	--------
Aug. 8	[4] 40	24	.02	85	31	146	4.0	283	4	385
Sept. 9	31	23	.02	97	40	190	3.7	332	0	495
Sept. 30	27	21	.02	89	41	175	3.9	334	0	458
Nov. 6	9.9	26	.00	127	64	294	4.5	398	0	847
Dec. 5	7.8	28	.00	145	68	324	4.1	426	0	915
Jan. 7, 1958	2.1	28	.01	157	66	300	4.3	468	10	860
Feb. 4	[4] 5	28	.01	153	64	299	4.0	462	0	845
Mar. 4	5.4	--------	------	--------	--------	--------	--------	--------	--------	1,060

See footnotes at end of table.

Greybull River–Dry Creek area, Wyoming

million except as indicated]

Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25° C)	pH
(sec. 24, T. 48 N., R. 103 W.)											
0.0	0.0	0.9	0.00	--------	77	36	0	20	0.3	96.5	7.6
.0	.1	.6	.02	--------	56	26	0	28	.4	80.3	7.2
(sec. 29, T. 47 N., R. 101 W.)											
0.0	0.0	0.9	0.00	--------	86	37	0	22	0.3	106	7.1
.0	.2	.7	.02	--------	93	57	2	19	.4	149	7.4
(sec. 4, T. 48 N., R. 100 W.) [1]											
--------	--------	--------	--------	--------	213	112	--------	25	0.7	308	------
0.0	0.0	0.9	0.00	--------	108	57	0	24	.5	158	7.7
.0	.1	.7	.03	--------	147	86	11	24	.6	233	8.0
.0	--------	--------	--------	--------	--------	128	18	22	.7	322	8.0
(sec. 3, T. 51 N., R. 97 W.)											
0.2	--------	--------	--------	--------	--------	138	18	28	0.9	370	8.0
(sec. 8, T. 51 N., R. 94 W.) [2]											
0.0	0.0	1.5	0.02	--------	218	110	11	32	1.0	334	7.6
17	.5	1.7	.12	--------	925	340	84	51	3.9	1,330	8.0
12	--------	--------	--------	--------	--------	292	67	50	3.4	1,060	8.0
(sec. 21, T. 52 N., R. 98 W.)											
80	1.2	0.2	0.65	3,630	3,720	486	191	82	20	4,820	8.0
250	.9	.3	1.4	5,130	5,170	1,100	692	69	16	6,290	8.2
164	.9	.3	.49	4,220	4,400	965	617	69	14	5,360	7.8
--------	--------	--------	--------	--------	--------	1,100	--------	--------	--------	5,300	------
(sec. 3, T. 52 N., R. 95 W.)											
13	1.4	9.7	0.22	1,000	1,040	390	147	49	3.8	1,440	8.2
55	1.8	5.2	.43	2,250	2,330	712	420	58	7.6	3,010	7.8
18	1.3	.5	.22	1,010	1,040	352	90	55	4.7	1,450	7.5
25	.9	6.0	.28	1,150	1,180	358	130	58	5.4	1,650	7.6
13	.9	5.7	.16	--------	720	264	88	50	3.3	1,030	7.9
--------	--------	--------	--------	--------	975	376	117	--------	--------	1,340	8.3
.0	1.8	6.7	.20	--------	863	341	102	48	3.4	1,200	8.3
12	1.6	8.3	.20	1,030	1,060	408	136	50	4.1	1,460	8.1
15	1.6	4.0	.19	--------	987	392	118	49	3.9	1,380	8.1
23	2.0	11	.31	1,600	1,650	579	253	52	5.3	2,160	8.1
27	1.9	14	.34	1,740	1,780	642	293	52	5.6	2,320	7.9
24	1.8	16	.29	1,700	1,760	663	263	49	5.1	2,280	8.3
24	1.9	16	.29	1,660	1,730	645	266	50	5.1	2,240	8.0
--------	--------	--------	--------	--------	--------	724	--------	--------	--------	2,590	------

TABLE 5.—*Chemical analyses of surface water, Greybull*

[Results in parts per

Date	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
Dry Creek at Greybull (sec										
July 24, 1956	8	9.8	0.01	104	63	320	4.6	212	0	1,000
Aug. 8, 1957	52	------	------	84	35	154	------	262	0	430
Sept. 30	36	17	.03	------	------	204	3.9	278	0	593
Nov. 6	12	20	.00	158	85	444	5.7	371	0	1,310
Dec. 5	14	26	.00	178	87	448	4.7	418	0	1,290
Jan. 7, 1958	9	26	.02	211	101	500	5.4	481	6	1,520
Feb. 4	5	24	.00	199	96	466	4.8	473	0	1,440
Mar. 4	10	20	.10	180	89	465	6.9	418	0	1,390
Apr. 4	12	17	.00	174	99	532	13	396	0	1,580
Apr. 30	20	15	.01	162	100	577	20	381	0	1,580
Buffalo Bill Reservoir										
June 5 1956 [7]	3,600	16	0.09	8.5	10	8.9	1.1	74	0	22
July 24 [7]	1,580	15	.01	28	5.9	9.6	1.4	95	0	35
Sept. 5, 1957 [8]	----------	17	.03	10	3.9	16	1.2	57	0	26

[1] Analyses of 30 samples collected in 1951–53 water years given in Water-Supply Papers 1198, 1251, and 1291.

[2] Analyses of 31 samples collected in 1951–53 water years given in Water-Supply Papers 1198, 1251, and 1291.

[3] Sample represents initial flow in creek after rains. Suspended-sediment concentration at time of sampling was 25,900 ppm. Analysis probably includes salts dissolved from dry stream bed.

[4] Estimated.

Rivers. The drainage basins of the two streams between the Pitchfork and Sunshine gaging stations and the Meeteetse gaging station are underlain by shale of Cretaceous age, which characteristically contributes sodium, calcium, and sulfate to water. The difference in chemical character during high- and low-flow periods is illustrated in figure 17.

Downstream from Meeteetse the Greybull River drains the Willwood formation of Tertiary age and its water is used extensively for irrigation of terrace and alluvial deposits. As a result, the water in the Greybull River near Basin generally is moderately mineralized (500 to 1,000 ppm of dissolved solids) and, during relatively low-flow periods, is of the sodium sulfate type. (See table 5 and fig. 17.) Comparative data indicate that the mineralization of the water near Basin is about 1½ to 6 times the mineralization of the water at Meeteetse.

DRY CREEK

Water in the lower reaches of Dry Creek is derived largely from drainage from irrigated lands of the Emblem Bench. Upstream from the Emblem Bench the creek drains areas underlain by Cretaceous shales and by the Willwood formation of Tertiary age. Data obtained

River–Dry Creek area, Wyoming—Continued

million except as indicated]

Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25° C)	pH
5, T. 52 N., R. 93 W.)[5]											
25	1.2	7.4	0.34	1,640	1,740	520	346	57	6.1	2,280	8.1
9.8	--------	--------	--------	--------	--------	352	137	49	3.6	1,270	7.7
15	1.2	3.6	.21	--------	1,140	414	186	51	4.4	1,560	8.1
34	1.6	11	.40	2,250	2,320	744	440	56	7.1	2,910	8.0
35	1.7	16	.41	2,290	2,390	802	459	55	6.9	2,970	7.9
37	1.9	20	.42	2,670	2,770	940	536	53	7.1	3,380	8.3
37	1.6	19	.47	2,520	2,640	892	504	53	6.8	3,220	7.9
42	1.4	15	.35	2,420	2,470	814	471	55	7.1	3,100	8.1
64	1.3	8.7	.39	2,680	2,830	843	518	57	8.0	3,510	8.1
74	1.0	7.3	.42	2,720	2,840	816	504	60	8.8	3,570	7.9
near Cody[6]											
0.5	0.1	0.5	0.03	--------	117	63	2	23	0.5	177	7.1
1.5	.1	.7	.06	--------	142	94	16	18	.4	240	7.0
.8	.1	.5	.03	--------	105	41	0	45	1.1	150	7.5

[5] Analyses of 11 samples collected in 1951 water year are given in Water-Supply Paper 1198.
[6] Many analyses of samples collected in 1947–49 water years from Shoshone River 2 to 3 miles downstream from Buffalo Bill Reservoir given in Water-Supply Papers 1102, 1132, and 1162.
[7] Samples collected from Shoshone River in sec. 3, T. 52 N., R. 102 W., ½ mile downstream from Trail Creek and 5½ miles downstream from Buffalo Bill Reservoir.
[8] Sample collected from Buffalo Bill Reservoir at face of dam.

in 1956–58 for Dry Creek above Emblem (table 5 and fig. 17) indicate that water draining the upper part of the basin is moderately saline (3,000 to 10,000 ppm of dissolved solids). The water is of the sodium sulfate type.

Downstream from the Emblem Bench the water, although it is of lower mineralization than the water upstream from the bench, also is of the sodium sulfate type. Analyses of samples collected on the same days both above and below Emblem Bench indicate that the low flow in Dry Creek above Emblem has little effect on the chemical characteristics or mineralization of Dry Creek below Emblem.

Mineralization of water in Dry Creek

Date	Above Emblem: Discharge (cfs)	Above Emblem: Specific conductance (micromhos at 25°C)	Below Emblem: Discharge (cfs)	Below Emblem: Specific conductance (micromhos at 25°C)
Nov. 6, 1957	0.5	6,290	9.9	2,160
Dec. 5	.3	5,360	7.8	2,320
Jan. 7, 1958	No flow	----------	2.1	2,280
Mar. 4	1.7	5,300	5.4	2,590

Some water is diverted from Dry Creek between Emblem and Greybull for irrigation on the Agrarian Bench. (See pl. 4.) Data for Dry Creek (table 5 and fig. 17) indicate that the chemical characteristics of the water at Greybull closely resemble those of the water below Emblem, although the water is generally more highly mineralized at Greybull than below Emblem.

BUFFALO BILL RESERVOIR

Snowmelt in the high Absaroka volcanic plateau in northwestern Wyoming is the principal source of the water entering Buffalo Bill Reservoir. Because the water has been in contact with the rocks and soils for a relatively short time and because the major part of the drainage basin upstream from Buffalo Bill Reservoir is underlain by chemically resistant volcanic rocks, the water in the reservoir is only slightly mineralized. Data in table 5 along with data obtained 2 to 3 miles downstream from Buffalo Bill Dam during the period April 1947 to September 1949 indicate that dissolved solids rarely exceed 200 ppm. The water is of the calcium bicarbonate type, and silica constitutes about 10 to 20 percent of the dissolved solids. Percent sodium generally ranges from 20 to 40. Average (weighted with water discharge) hardness as $CaCO_3$ of water released from the reservoir during 1947–49 was 50 to 70 ppm.

RELATION OF CHEMICAL CHARACTERISTICS AND MINERALIZATION TO WATER DISCHARGE

Generally, high flows resulting from melting of ice and snow and from heavy rains are less mineralized and may be of a different chemical type than low flows in a stream. For example, water in the Greybull River at Meeteetse is of the calcium bicarbonate type and specific conductance is generally less than 400 micromhos when streamflow is greater than about 200 cfs, but it is of the calcium sodium sulfate type and specific conductance is from about 400 to 750 micromhos when streamflow is less than about 200 cfs. Impoundment and release of water from Sunshine Reservoir (fig. 17) probably affect the relation of water discharge to chemical characteristics of water in the Greybull River below its confluence with the Wood River. The relation of mineralization to water discharge for the Greybull River and Dry Creek is illustrated in figure 18. The lines drawn on figure 22 are not intended to indicate that straight-line relation exists between discharge and mineralization but rather to indicate the general trend of the relation.

WATER DIVERTED FROM GREYBULL RIVER

In addition to data given in table 5 and depicted on figure 17, data were obtained to determine how much change, if any, occurs in the chemical characteristics of diverted water as it flows through a canal system. On Aug. 8, 1957, samples were collected at intervals along

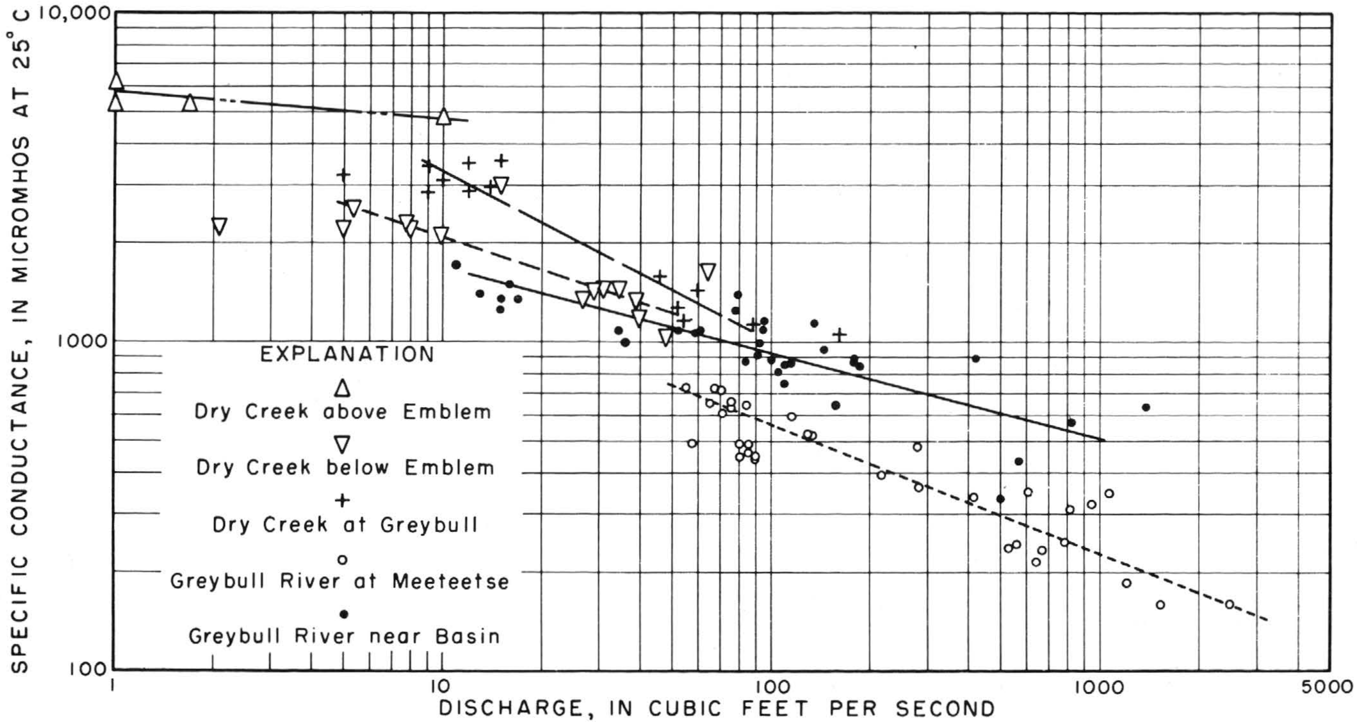

FIGURE 18.—Relation of specific conductance to discharge of Greybull River and Dry Creek.

the Bench Canal from near the point of diversion to near the end of the canal. The canal is in Tps. 51 and 52 N., R. 97 W. (See fig. 17.) Chemical analyses of these samples, which are summarized in table 6, indicate that the chemical characteristics of diverted water changed only slightly as the water flowed through the canal; calcium, magnesium, and bicarbonate concentrations increased slightly in the reach between the bridge near the diversion and a point about 2 miles below the diversion, but they remained fairly constant from that point to the end of the canal. Although the samples were collected within a period of about an hour, normal variations in the chemical characteristics of diverted water could account for the slight changes in characteristics, or perhaps calcareous material is dissolved from the bed and banks of the canal near the diversion. The Willwood formation, which crops out in the canal (see pl. 1) from about location 2 to location 4 (see table 6), apparently contributes essentially no dissolved solids to the canal water. Also, influent seepage of ground water does not contribute dissolved solids to the canal water because the canal loses water to the ground-water reservoir, probably throughout most of its length.

TABLE 6.—*Chemical analyses, in parts per million, of water from Bench Canal, Greybull River-Dry Creek area, Wyoming, Aug. 8, 1957*

	1	2	3	4	5
Calcium (Ca)	27	32	33	30	30
Magnesium (Mg)	11	12	14	13	13
Sodium (Na)	21	22	21	25	21
Bicarbonate (HCO_3)	115	132	140	132	136
Sulfate (SO_4)	66	66	62	63	66
Chloride (Cl)	.3	.2	.2	.4	.0
Hardness as $CaCO_3$	111	130	140	130	138
Noncarbonate hardness as $CaCO_3$	17	22	25	22	26
Percent sodium	29	27	25	30	25
Sodium-adsorption ratio	0.9	0.8	0.8	1.0	0.8
Specific conductance (micromhos at 25°C)	317	342	347	340	343
pH	8.2	8.1	7.8	8.1	8.0

1. At bridge on Burlington-Meeteetse road near diversion (51-97-8ba).
2. About 2 miles below diversion (51-97-4bbb).
3. About 4 miles below diversion (52-97-27c).
4. About 6 miles below diversion (52-97-24c).
5. About 8 miles below diversion near end of canal (52-97-13ab).

GROUND WATER

Ground water from the Willwood formation of Eocene age and the Greybull and Sunshine terrace and alluvial deposits of Quaternary age in the report area is characterized generally by relatively high mineralization and variability in chemical composition. Dissolved solids in water from 29 wells or springs ranged from 265 to 2,180 ppm but in most was more than 800 ppm. Sulfate was the predominant anion (on the basis of equivalents per million) in water from more than half the wells and springs, and sodium was the predominant cation in water from two-thirds of them. However, calcium was the predominant cation or ranked close to sodium as the predominant cation, in water from about half the wells and springs. Whereas water from Quaternary deposits generally contains more than 25 ppm of silica and is hard, water from the Willwood formation generally contains relatively minor amounts of silica and is relatively soft.

Data pertaining to the chemical characteristics of ground water of the major aquifers are given in table 7. In addition, the location of sampled wells and springs is shown on plate 4 along with patterns (Stiff, 1951) that represent the chemical type and mineralization of the water. The patterns illustrate the variability in chemical composition of the ground water from place to place in the report area.

Although the concentrations of most of the major dissolved constituents in the ground water cannot be correlated directly with the mineralization of the water, the concentration of sulfate is directly related. The relation shown in figure 19 indicates that the percentage

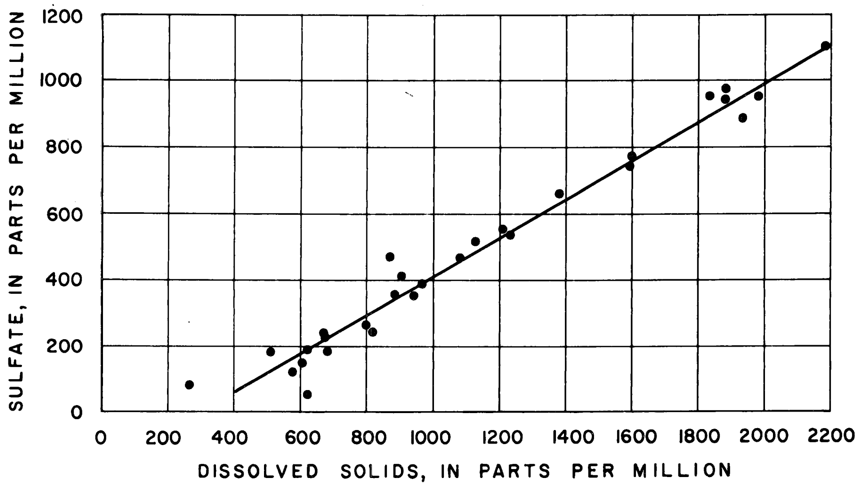

FIGURE 19.—Relation of concentration of sulfate to mineralization of ground water.

by weight of sulfate increases from about 30 to 50 percent of the dissolved solids as the mineralization of the water increases from about 500 to 2,000 ppm. This relation is probably the result of two independent factors: (a) the precipitation of bicarbonates, principally as calcium and magnesium carbonates and (b) the solution of sulfates from rocks. Because the solubility of carbonates is much less than that of sulfates, carbonates tend to precipitate from bicarbonate waters and sulfates increase in concentration as evaporation and transpiration cause the mineralization of ground water and applied irrigation water to increase. The calcareous nature of the soils and the calcareous coating on gravel in terrace deposits in the irrigated

TABLE 7.—*Chemical analyses of ground water,*

[Results in parts per

Well (location)	Depth of well (feet)	Date of collection	Water temperature (°F)	Silica (SiO_2)	Iron (Fe)	Selenium (Se)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
Alluvium											
50-98-5aac [1]	41.9	8- 9-57	48	2.8	0.13	------	9.0	6.2	276	2.1	193
-99-14bac	Spring	8- 9-57	56	31	------	------	83	43	65	8.1	447
51-94-2bbd1	15	8-10-57	52	30	.39	------	188	50	380	3.0	577
-95-15ccb1	24	8-10-57	55	30	.02	------	203	54	236	3.7	516
-96-3cda	25	8-10-57	55	32	.02	------	85	19	115	3.1	374
		4-11-58	55	------	------	------	------	------	------	------	370
-97-12abc2	16	8-10-57	58	32	.02	------	96	25	70	1.7	443
-98-23aaa	9.2	8- 9-57	54	28	.23	------	115	29	74	11	464
52-94-24dda	8	8-10-57	--------	29	.06	------	235	53	290	5.0	614
Deposits of											
51-94-8dbb3 [2]	40	8-10-57	--------	29	0.49	------	145	22	109	3.8	316
-98-13aad2	Spring	8- 9-57	52	23	.01	------	178	50	74	4.4	392
		4-11-58	48	------	------	------	------	------	------	------	414
52-96-32ccb	30	8- 9-57	53	28	.05	------	72	19	128	3.9	334
-33dcb	22	8- 9-57	57	28	.03	0.00	59	18	130	3.7	363
-97-25dbc	19	8- 9-57	49	31	.11	------	50	14	247	3.7	386
			--------	31	.05	------	102	26	130	2.9	439
-26dbb	16	4-11-58	47	------	------	------	122	37	176	------	388
Deposits of											
-95-5cbd	9	8- 9-57	55	39	0.02	------	185	38	352	4.6	516
-10dbd2	27	8- 8-57	55	35	.19	------	102	27	232	3.0	386
-96-1cbc	19	8- 9-57	--------	38	.12	------	114	41	272	1.9	425
-2cbc	26	8- 8-57	49	37	.22	0.01	79	32	169	2.0	376
		4-11-58	49	------	------	------	101	41	188	------	426
-3cbc	36	8- 8-57	53	44	.20	------	96	35	248	1.7	428
-8cbc	50	8- 8-57	50	31	.22	------	140	126	336	3.5	492
		4-11-58	46	------	------	------	108	69	330	------	486
-9ada2	16	8- 8-57	58	20	.05	------	35	11	35	1.7	157
-10dcd	57	8- 8-57	56	30	.13	------	44	13	109	3.2	246
		4-11-58	51	------	------	------	------	------	------	------	222
-16aad	44	8- 8-57	49	28	.03	------	128	36	143	2.9	391
-97-13bad	16	8- 8-57	--------	52	.06	------	95	54	99	1.9	486
Willwood											
50-99-21adc	97.2	8-10-57	51	15	0.07	0.01	120	139	72	5.5	546
51-95-15ccb2	124	10- 9-57	56	6.8	.95	------	22	4.4	610	3.3	268
-98-13aad1	100	8- 9-57	--------	8.9	.13	------	13	6.7	532	2.7	541
52-95-8cbb	147	8-10-57	55	17	.13	------	118	48	400	4.3	459
		4-11-58	--------	------	------	------	71	29	380	------	384
-97-26cad	180	8- 9-57	55	8.9	.12	.01	4.0	.0	245	1.3	476

[1] Well used only for observation of water level. Water colored and turbid when sampled. Part of the water from this well may be from Willwood formation.

part of the report area attest to the fact that carbonates are precipitated from the percolating water. Sulfate minerals such as gypsum (calcium sulfate) are present in the water-bearing formations and are dissolved by the percolating ground water.

ROCKS OF TERTIARY AGE

The chemical characteristics of water from the Willwood formation of Eocene age were determined from analyses of water from 5 wells, *Greybull River-Dry Creek area, Wyoming*

million except as indicated]

Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C	Dissolved solids: Calculated	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Alluvium													
0	472	9.5	0.5	0.2	0.08	869	--------	48	0	92	17	1,340	8.0
0	153	3.5	.6	2.7	0.1	605	--------	384	17	26	1.4	921	7.5
0	950	30	.5	3.4	.10	1,980	1,920	675	202	55	6.4	2,560	7.5
0	770	30	.3	4.1	.02	1,600	1,590	730	307	41	3.8	2,050	7.8
0	223	4.5	.6	6.8	.06	673	--------	291	0	46	2.9	988	7.7
0	-----	-----	-----	-----	-----	--------	--------	294	0	-----	-----	960	7.8
0	123	.1	.4	4.8	.04	576	--------	341	0	31	1.7	872	7.5
0	186	4.5	.4	1.2	.04	679	--------	408	28	28	1.6	1,020	7.2
0	880	36	.4	5.5	0.7	1,930	1,840	804	301	44	4.4	2,390	7.4
Greybull terrace													
0	410	8.5	1.0	21	0.08	904	--------	452	193	34	2.2	1,220	7.8
0	468	5.0	.9	13	.01	1,080	1,010	648	327	20	1.3	1,340	7.6
0	-----	-----	-----	-----	-----	--------	--------	686	347	-----	-----	1,370	7.8
0	238	6.4	.7	13	.11	670	--------	258	0	51	3.5	982	7.7
0	187	2.7	.8	4.6	.15	620	--------	222	0	56	3.8	915	7.8
0	355	6.8	2.0	34	.17	940	--------	184	0	74	7.9	1,360	7.8
0	268	5.8	1.4	3.4	.18	795	--------	362	2	44	3.0	1,140	7.6
0	482	11	-----	3.6	-----	--------	--------	458	140	46	3.6	1,470	7.7
Sunshine terrace													
0	940	22	2.5	5.6	0.34	1,880	1,840	618	195	55	6.1	2,380	7.6
0	515	14	1.9	18	.19	1,130	1,140	366	49	58	5.3	1,580	7.7
0	660	24	2.6	12	.19	1,380	1,370	452	103	57	5.6	1,850	7.9
0	355	8.0	3.1	16	.07	882	--------	330	22	53	4.0	1,260	7.8
0	425	-----	-----	-----	-----	--------	--------	422	73	49	4.0	1,490	7.9
0	550	9.5	4.2	15	.22	1,210	1,210	384	33	58	5.5	1,660	7.7
0	1,100	31	2.9	18	.27	2,180	2,030	868	465	46	5.0	2,650	7.9
0	750	-----	-----	-----	-----	--------	--------	552	153	57	6.1	2,190	7.9
0	80	.0	.4	.6	.04	265	--------	134	5	36	1.3	411	7.8
0	180	4.0	1.2	5.9	.16	508	--------	164	0	59	3.7	761	7.9
0	-----	-----	-----	-----	-----	--------	--------	156	0	-----	-----	733	8.1
0	390	17	1.0	15	.22	973	--------	468	147	40	2.9	1,340	7.6
0	243	3.4	2.1	4.3	.29	815	--------	459	60	32	2.0	1,140	7.4
formation													
0	538	15	0.6	5.7	0.01	1,230	1,180	870	422	15	1.1	1,640	7.4
0	974	135	2.5	3.4	.13	1,880	1,890	73	0	95	31	2,790	7.8
10	740	12	1.5	2.3	.27	1,590	1,600	60	0	95	30	2,360	8.4
0	950	22	2.8	23	.44	1,830	1,810	492	116	64	7.9	2,440	7.8
0	745	-----	-----	-----	-----	--------	--------	298	0	73	9.5	2,120	8.0
16	50	47	4.3	1.2	.18	621	--------	10	0	98	34	1,030	8.6

[2] Part of the water from this well may be from Willwood formation.

ranging in depth from 97 to 180 feet. All these wells are in irrigated parts of the report area and all but one were drilled through alluvial or terrace deposits into the Willwood. Most of the water from these wells probably was once applied as irrigation water. Two other wells (50–98–5aac and 51–94–8dbb3) shown in table 7 under alluvium and deposits of the Greybull terrace probably obtain part of their water from the Willwood.

Water from the Willwood formation in the report area generally is slightly saline; dissolved solids in water from the 5 sampled wells ranged from 621 to 1,880 ppm.

Sulfate generally is the principal anion in water from the Willwood, although bicarbonate is the principal anion in water from well 52–97–26cad near Burlington. (See pl. 4.) This bicarbonate type water was of lower mineralization than any of the sulfate type water yielded by the other wells tapping the Willwood and may have resulted from sulfate reduction by organic matter. (See table 7.) Concentrations of chloride, nitrate, and boron were relatively low; however, fluoride was present in relatively high concentrations in the water. In contrast to water from overlying deposits, water from the Willwood contained less than 20 ppm of silica.

Sodium generally is the principal cation in water from the Willwood. (See table 7 and pl. 4.) Water users in the area report that water from most deep wells is relatively soft. However, calcium and magnesium, ions that cause water to be hard, were present in significant concentrations in water from 3 of the 7 sampled wells that derive part or all their water from the Willwood. Well 50–99–21adc, in the extreme western part of the report area, yielded water of the magnesium sulfate type. Differences in hardness (calcium and magnesium content) may be caused by differences in the local base-exchange capacity of the clay minerals in the formation. Decomposing feldspathic volcanic rocks and volcanic glass provide the clay minerals necessary for reactions of this kind.

Water from well 52–95–8cbb was sampled in August 1957 and again in April 1958. The well was not pumped during the intervening months. Although the water sampled in April was of the same chemical type (sodium sulfate) as that sampled in August, the concentrations of all the major dissolved constituents were lower in April than in August. Probably chemical reactions, in which principally calcium and magnesium sulfate precipitated out of the water standing in the well, are the major causes of the changes. However, the relatively high nitrate content (23 ppm) suggests that part of the water yielded by the well may have seeped downward from adjacent overlying deposits of the Sunshine terrace or drained from the surface into the well.

DEPOSITS OF QUATERNARY AGE

The chemical characteristics of water from deposits of the Sunshine and Greybull terraces and from alluvium in the Greybull River valley were studied. All the wells and springs selected for sampling are in irrigated parts of the report area, and most were used regularly for irrigation, domestic supply, or stock watering. A few of the wells and springs sampled in August 1957 were selected for resampling in April 1958 to determine seasonal changes in water quality.

DEPOSITS OF THE SUNSHINE TERRACE

The chemical characteristics of water from deposits of the Sunshine terrace in T. 52 N., Rs. 95, 96, and 97 W. are illustrated on plate 4. Ten wells, used principally for irrigation or domestic supply on the Emblem Bench, were sampled in August 1957, and three of the ten were resampled in April 1958. Results of chemical analyses of the samples are given in table 7.

The mineralization of water from the deposits of the Sunshine terrace differs widely from place to place. Dissolved solids ranged from 265 to 2,180 ppm in water from the 10 wells and was more than 1,000 ppm in water from 5 of them. Of the irrigated part of Emblem Bench, water from the southwestern edges was of lower mineralization than that from the central and eastern part. (See pl. 4.) Of the 5 wells yielding water of relatively low mineralization, 4 are on the upgradient side of the water table underlying Emblem Bench and, therefore yield water that has recharged the terrace deposits recently in relation to water from wells farther downgradient; water from well 52–96–9ada2 closely resembled chemically the applied irrigation water from the Greybull River. (See pl. 4 and fig. 17.)

Water from the six wells on the downgradient side was of the sodium sulfate type. Calcium, magnesium, and bicarbonate also were principal ions in water from these wells. The water from Sunshine terrace deposits is very hard and, in relation to water from the Willwood, is siliceous and contains high concentrations of nitrate. Like water from the underlying Willwood, however, the water from Sunshine terrace deposits contains fluoride in relatively high concentrations.

DEPOSITS OF THE GREYBULL TERRACE

Water from four wells tapping deposits of the Greybull terrace near Burlington was moderately mineralized; dissolved solids ranged from 620 to 940 ppm. The water was of the sodium bicarbonate sulfate type and, like water from deposits of the Sunshine terrace, was very hard and siliceous.

The percentage of calcium in water was higher from well 52–97–26dbb in the upper terrace than from the three wells in the lower terrace. However, analysis of a sample collected from the well in April 1958 revealed that the chemical characteristics of the water had changed appreciably since the preceding August; concentrations particularly of sodium and sulfate but also of calcium and magnesium were higher and concentration of bicarbonate was lower in April than in August. (See table 7.) Because this well is used regularly for domestic purposes, the data should be representative of the chemical characteristics of the water from the aquifer and should not be affected by chemical reactions, such as precipitation of some constituents resulting from stagnation of water standing in the well. Probably, most of the water pumped from the well during and shortly after the irrigation season has recently recharged the ground-water reservoir from irrigated lands, whereas water pumped in late winter and spring has been in contact longer with the rocks in the terrace deposits and has thus become more mineralized.

A spring (51–98–13aad2), issuing from the base of the deposits of the Greybull terrace that is irrigated with water from the Greybull River, yielded water that varied only slightly in mineralization from August to April. (See table 7.) In contrast to water from the Greybull terrace near Burlington, the water from this spring was of the calcium sulfate type and contained more than 1,000 ppm of dissolved solids. Data for this spring indicate that solution of salts in the terrace deposit and evapotranspiration have increased the mineralization of applied irrigation water about 3 to 5 times.

Well 51–94–8dbb3, on the south side of Greybull River in the eastern part of the report area, yields water from the deposits of the Greybull terrace and perhaps also from the underlying Willwood formation. As in water from the spring, calcium and sulfate are the major dissolved constituents; this fact suggests that most of the water from this well is yielded by the terrace deposits.

ALLUVIUM

Ground water from alluvium along the Greybull River in Rs. 96–99 W. is generally of the calcium bicarbonate type and contains less than 700 ppm of dissolved solids. In contrast, water from the alluvium in Rs. 94 and 95 W. is of the sodium calcium sulfate type and contains more than 1,500 ppm of dissolved solids. (See pl. 4 and table 7.) These differences in chemical type and mineralization probably result from differences in chemical composition of applied irrigation water and in drainage. Whereas water of relatively low mineralization is diverted from the river in the western part of the report area, water of relatively high mineralization is diverted in the eastern part. On Aug. 9, 1957, for example, water in the Greybull River at Meeteetse had a specific conductance of 322 micromhos; near Burlington the specific conductance was 370 micromhos; but farther downstream near Basin the specific conductance was 1,060 micromhos This threefold increase in mineralization was accompanied by increases principally in concentrations of sodium and sulfate (table 5) and probably was due to accretion of ground water and return flows from irrigated lands. In addition, drainage in the lower part of the

Greybull Valley is poor in relation to drainage in the upper part of the valley. As a result of the poorer drainage, ground water probably moves out of the alluvium more slowly and thus is in contact with the rocks longer in the lower part of the valley than in the upper part.

The water from well 50–98–5aac is believed to be from both the alluvium and the underlying Willwood formation. Because the chemical characteristics of water from this well resembled closely the characteristics of water from the Willwood in the western part of the report area, the contribution of water from the alluvium to this well apparently is slight. (See pl. 4.)

Like water from the deposits of the Sunshine and Greybull terraces, water from alluvium is siliceous and very hard; however, unlike water from the terrace deposits, it contains less than 0.7 ppm of fluoride.

DEPOSITS OF THE RIM TERRACE AND UNIRRIGATED DEPOSITS OF THE SUNSHINE TERRACE

Although, at the time of this investigation (1957), no significant ground-water bodies were present in the deposits of the Rim terrace underlying YU Bench and the deposits of the Sunshine terrace underlying the upper unirrigated part of the Emblem Bench, irrigation on the benches could result in the development of ground-water bodies in the terrace deposits. The chemical characteristics of water in these potential ground-water bodies can be estimated from knowledge gained during the water-quality study in the irrigated part of the report area.

The chemical characteristics and mineralization of water in Buffalo Bill Reservoir are similar to those of waters in the Greybull River near Meeteetse during the irrigation season. Therefore, regardless of whether irrigation water from Buffalo Bill Reservoir or from Greybull River is applied on the benches, the major factors affecting the quality of ground water formed as a result of irrigation will be the solubility of the rocks and soils in the deposits and the drainage from the deposits underlying the benches.

Drainage of the deposits of the Rim and Sunshine terraces is good, so the solubility of the rocks and soils will be the major determining factor. Surface soils on YU Bench are slightly calcareous, and subsoils are moderately to highly calcareous. Because deposits of the Rim terrace represent first-cycle sedimentation, soluble salts and minerals are probably prevalent in the gravels. Thus, ground water percolating through the deposits of the Rim terrace may be expected to bring into solution principally sulfate and carbonate salts. The same probably will be true for the upper part of the Emblem Bench, as materials in deposits of the Sunshine terrace closely resemble those in deposits of the Rim terrace.

The resultant ground water in the terrace deposits thus will be highly mineralized, very hard, and unsuitable for most uses; dissolved solids greater than 3,000 ppm and hardness greater than 1,000 ppm might be common. However, continued recharge by downward percolating irrigation water should tend to leach the terrace deposits and lower the mineralization and hardness of the ground water. More than 50 years of irrigation of similar deposits on Emblem Bench has resulted in ground water with a mineralization as high as about 2,000 ppm of dissolved solids and a hardness of as high as about 900 ppm, although most ground water is of better quality.

Drainage of highly mineralized water from newly irrigated terraces will have an adverse effect on the quality of water in the Greybull River and lower Dry Creek. Whereas the water in the Greybull River upstream from the major irrigated lands near Burlington is now of relatively good quality, after irrigation is developed on YU Bench the quality of the water in the river south of the bench probably will deteriorate and will resemble that of the water now in the river near Basin. Water that flows in upper Dry Creek is very highly mineralized and should improve somewhat in quality as a result of drainage from the YU and upper Emblem Benches. The water now used for irrigation of Agrarian Bench, however, will probably be of poorer quality than at present.

SUITABILITY OF THE WATER

Water suitable for agricultural use may not be at all suitable for domestic or industrial use because water-quality requirements vary widely. In the following section the suitability of the water is evaluated only for agricultural and domestic uses because the report area is not developed industrially. However, the chemical-quality data for the report area can be compared with water-quality tolerances for various industrial application given in publications such as "Water Quality Criteria" (Calif. Inst. Tech., 1952) if the suitability of the water for industrial use is of interest.

AGRICULTURAL USE

Both surface water and ground water are used for irrigation in the report area, and the suitability of the water resources for irrigation are evaluated by methods currently used by the U.S. Salinity Laboratory Staff of the Department of Agriculture. Characteristics that determine the suitability of water for irrigation are mineralization, relative concentrations of the cations, and concentrations of boron and residual sodium carbonate. In the classification of water for irrigation, the methods of the U.S. Salinity Laboratory Staff are based on the assumption that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quality of water used, climate, and salt tolerance of crops; any deviation from average conditions may change the classification.

Highly mineralized water when 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 mineralization of irrigation water is usually referred to as 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 is a first step in the formation of stable soil aggregates and in the development of soil having 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 a water is directly related to the adsorption of sodium by soil and thus is a criterion for determining the suitability of an irrigation supply. It is, therefore, a measure of the sodium (alkali) hazard of the water.

The sodium-adsorption ratio and specific conductance of both ground and surface water (tables 5 and 7) are plotted on the diagram for classification of irrigation water (fig. 20). Only the approximate extremes in salinity and sodium hazards are shown for the Greybull River at Meeteetse, Dry Creek below Emblem, and Buffalo Bill Reservoir. The water from other sites can be classified by plotting the data in figure 20. The interpretation of the diagram by the U.S. Salinity Laboratory Staff (1954) is as follows:

SALINITY HAZARD

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.

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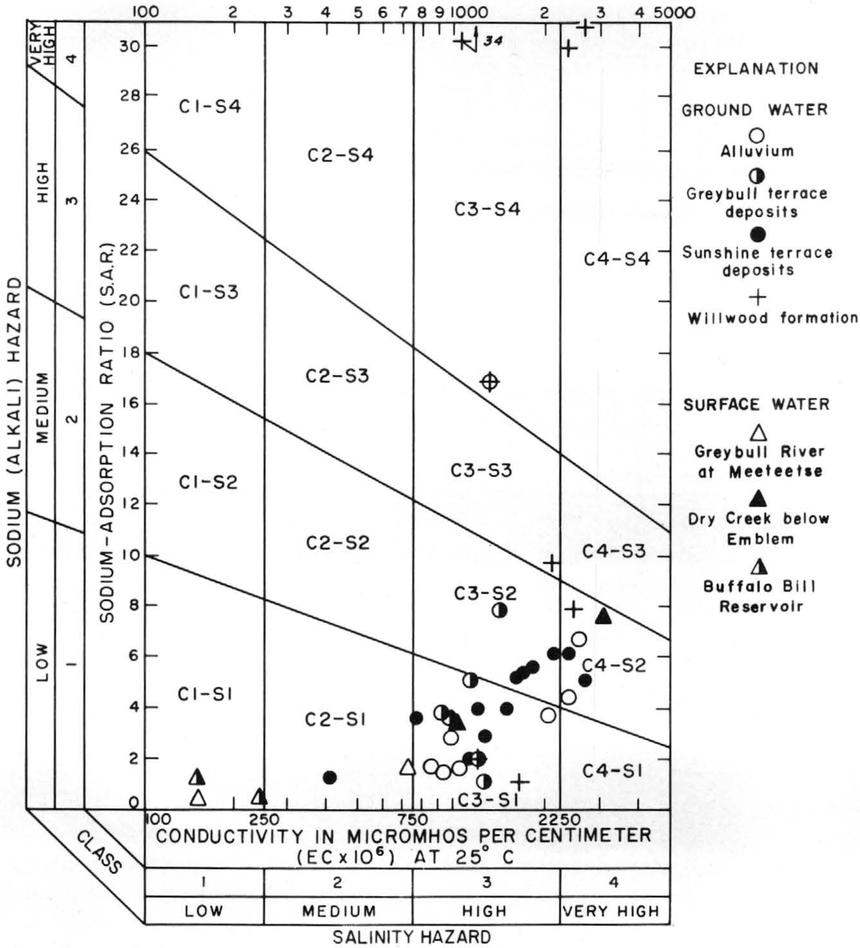

FIGURE 20.—Classification of the water for irrigation. (Diagram from U.S. Salinity Laboratory staff, 1954.

SODIUM (ALKALI) HAZARD

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 avocados 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 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.

Most ground water from deposits of Quaternary age in the report area has a high to very high salinity hazard and a low to medium sodium hazard. Water from some wells tapping the Willwood formation of Tertiary age, although not used for irrigation, has a very high sodium hazard.

Of the 6 irrigation wells sampled in the report area, 5 tapped the deposits of the Sunshine terrace, and 1 tapped the alluvium; the water from these wells had a specific conductance ranging from 761 to 2,650 micromhos and a sodium-adsorption ratio ranging from 2.9 to 6.1.

Although the plots in figure 20 for Greybull River at Meeteetse indicate that the water has, at times, a low salinity hazard, the curve on figure 18 indicates that the specific conductance of the water is less than 250 micromhos only when the flow is greater than about 800 cfs. Conversely, although the plots in figure 20 for Dry Creek below Emblem indicate that the water has, at times, a very high salinity hazard, the curve on figure 22 indicates that the specific conductance of the water is less than 2,250 micromhos when the flow is greater than about 10 cfs. During the period when water from Dry Creek is being diverted to irrigate the Agrarian Bench, the flow in Dry Creek below Emblem usually exceeds 10 cfs (see table 5) and the specific conductance of the water is generally between 1,000 and 1,500 micromhos. Buffalo Bill Reservoir contains water that has low salinity and sodium hazards.

Most crops, such as small grains, alfalfa, sweet clover, sugar beets, and potatoes, grown on irrigated lands in the report area have a medium to high salt tolerance; therefore, water having a high salinity hazard can be used to irrigate them providing drainage is good. Because most terraces now under irrigation or proposed for irrigation are underlain by zones of coarse gravel and have soils that are predominantly loams and sandy loams, which have high permeability, drainage should be adequate. However, in areas such as the lower Greybull River valley, where drainage is a major problem, use of water having a high salinity hazard may result in development of saline soils.

Boron in small amounts is an essential plant nutrient, although concentrations of boron that are required for optimum growth of certain plants are toxic to others. For boron-sensitive plants, concentrations of less than about 0.7 ppm in irrigation water are recommended (Wilcox, 1948, table 8). In the report area, ground and surface waters studied contained less than 0.7 ppm of boron except for very low flow in Dry Creek above Emblem. By the time these low flows have been diluted by return flows from irrigated lands on Emblem Bench, the boron concentration is reduced to less than 0.7 ppm. The maximum concentration of boron observed in lower Dry Creek was 0.47 ppm. (See table 5.)

"Residual sodium carbonate" is a property of water defined as (bicarbonate + carbonate) minus (calcium + magnesium), concentrations being expressed in equivalents per million (Eaton, 1950, p. 127). It is a measure of the tendency of irrigation water to become more alkaline when calcium and magnesium carbonates precipitate as the water is subjected to evaporation and transpiration. Irrigation water containing predominantly sodium and carbonate or bicarbonate has a high pH and may cause alkaline soils to develop; the soil condition referred to as "black alkali" has been attributed to the presence of sodium carbonate in the soil solution. Waters having residual sodium carbonate of more than 2.5 epm are considered to be unsuitable for irrigation (U.S. Salinity Lab. Staff, 1954, p. 81). Of the surface and ground waters studied in the report area, only water from the Willwood formation contained more than 2.5 epm of residual sodium carbonate.

Many of the water samples obtained during this investigation came from wells that are used for stock watering, which is an important agricultural use of water in the report area. Although not much is known regarding the relation of quality of water to health and growth of stock, in Montana water having a mineralization of less than 2,500 ppm is considered to be good for stock watering; 2,500 to 3,000 ppm, fair; 3,500 to 4,000 ppm, poor; and more than 4,000 ppm, unfit (Calif. Inst. Tech., 1952, p. 155). Even low concentrations of some substances, such as nitrate, fluoride, selenium, and molybdenum, are toxic to animals.

Because the ground water and surface water in the area (except for upper Dry Creek) generally contained less than about 2,500 ppm of dissolved solids, the water would be classed as good for stock watering. Concentrations of fluoride, although somewhat high for human consumption, and of nitrate were low enough to be considered safe for most livestock. (See tables 5 and 7.) Selenium in water from several representative wells was determined to be present only in concentrations of less than 0.02 ppm. Although molybdenum was not determined in water samples from the area, it probably is present only in very small amounts.

DOMESTIC USE

The U.S. Public Health Service (1946) 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 recommended concentrations for some of the chemical constituents are given below.

Constituent	*Maximum in ppm*	*Constituent*	*Maximum in ppm*
Iron and manganese (Fe+Mn)	0.3	Fluroide (F)	[1] 1.5
Magnesium (Mg)	125	Selenium (Se)	[1] .05
Sulfate (SO_4)	250	Dissolved solids	[2] 500
Chloride (Cl)	250		

[1] Mandatory limit.
[2] 1,000 ppm permitted if water of better quality is not available.

Iron in water tends to stain fixtures and laundry and concentrations higher than about 0.5 ppm affect the taste of the water. Persons accustomed to drinking water that contains high concentrations of sulfate, chloride, 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, and chloride imparts a saline taste to water. Concentrations of fluoride higher than about 1.5 ppm in drinking water have been associated with a dental defect known as "mottled enamel;" however, concentrations of about 1.0 to 1.5 ppm are considered to be beneficial in the prevention of tooth decay, especially for children. Selenium in relatively low concentrations in food and drinking water is harmful to some people; therefore, a mandatory limit of 0.05 ppm has been established.

Except for excessive concentrations of sulfate, fluoride, and dissolved solids, most ground water from the report area contains less than the recommended maximum concentrations. Concentrations of sulfate exceeded 250 ppm in water from about two-thirds of the wells and springs sampled, and concentrations of dissolved solids were greater than 500 ppm in water from all but one. Some wells tapping deposits of the Sunshine terrace, particularly those along the northern part of Emblem Bench, and some wells tapping the Willwood formation yielded water containing fluoride in concentrations higher than 1.5 ppm. Seven of the ten sampled wells in deposits of the Sunshine terrace, three of the seven tapping Willwood formation, and one of the five tapping deposits of the Greybull terrace yielded water containing 1.9 to 4.3 ppm of fluoride.

Specific limits are not established for hardness, but water having a hardness of less than 60 ppm is generally considered to be soft; of 60 to 120 ppm, moderately hard; of 120 to 200 ppm, hard; and of more than 200 ppm, very hard. Soft water is suitable for most uses without further softening, and very hard water usually requires softening for most uses in the home. In the report area, ground water generally is hard to very hard, and most of the water has noncarbonate or permanent hardness. Permanent hardness, in contrast to temporary (or carbonate) hardness, cannot be removed by boiling the water. Water from some wells tapping the Willwood formation is soft. (See table 7.)

The limits for nitrate are not established by the U.S. Public Health Service; however, high concentrations of nitrate in drinking water have caused cyanosis in infants. Some investigators recommended that nitrate in infants' drinking water should not exceed about 45 ppm (Calif. Inst. Tech., 1952, p. 301). Concentrations of nitrate were lower than 45 ppm in ground water from the report area. However, water from wells tapping deposits of the Greybull and Sunshine terraces generally contained more nitrate than water from wells tapping the Willwood formation or the alluvium. (See table 7.)

SUMMARY

Water for domestic and stock use is available from the Willwood formation and the alluvial deposits throughout most of the Greybull River–Dry Creek area. Water for supplemental irrigation is available from the alluvium of the Greybull River valley, and from the terrace deposits, with the exception of the deposits of the Rim terrace underlying YU Bench.

The amount of water now in the terrace deposits underlying the YU Bench and the nonirrigated part of the Emblem Bench probably is insufficient for even domestic requirements. The terrace deposits underlying the irrigated part of the Emblem Bench probably contained little, if any, ground water before they were irrigated. After irrigation was begun on the bench, influent seepage of applied irrigation water recharged the terrace deposits, and they now will yield sufficient water to wells for domestic and stock use and some supplemental irrigation. If water is applied to the nonirrigated parts of the terraces, some of it will seep into the terrace deposits and form perched ground-water bodies above the bedrock in those areas. The amount of water thus stored in the terrace deposits will vary with the amount and rate of application of irrigation water and the amount and rate of discharge of water from the terrace deposits. When the rate and volume of influent seepage is large enough, the water table will rise to a level where water will be discharged along the edges of the bench.

According to the amount and rate of application of water on the terraces, water for domestic use probably will become available in all parts of the irrigated benches except along their edges. Water may be obtained from wells penetrating the Willwood formation only if the sandstone beds are saturated. Wells probably would need to be drilled to depths below the level of the Greybull River valley to penetrate saturated beds in the Willwood formation; wells in the YU Bench probably will need to be at least 400 and possibly more than 550 feet deep; wells in the Emblem Bench south of the YU Bench probably will need to be 100 to more than 225 feet deep. Quantitative determination of ground-water conditions when irrigation begins will require more sources of information than are presently available. Additional test holes should be drilled through the terrace deposits and completed so that they can be used as water-level and chemical-quality observation wells. Data from the test holes also will aid in determining the topography of the bedrock surface and the volume of the terrace deposits.

The chemical quality of the ground water varies widely. Water from the Willwood formation, deposits of the Sunshine and Greybull terraces, and alluvium generally contains from 250 to 2,000 ppm of dissolved solids; and a large percentage by weight of the dissolved solids is sulfate. Whereas water from the Willwood formation generally is soft and contains minor amounts of silica, water from terrace deposits and alluvium is hard and siliceous. Water from half the sampled wells tapping the deposits of the Greybull and Sunshine terraces and the Willwood formation contains more than 0.7 ppm of fluoride, whereas water from wells tapping alluvium contains less than 0.7 ppm. The water from alluvium in the lower part of Greybull valley is of the sodium calcium sulfate type and contains about 1,600 to 2,000 ppm of dissolved solids; however, the water from alluvium in the upper part of the valley is of the calcium bicarbonate type and contains about 500 to 1,000 ppm.

In most of the ground water, sodium and sulfate are the predominant ions; however, calcium and bicarbonate also are principal ions. In some of the water of relatively low mineralization, calcium and bicarbonate are the predominant ions. Concentrations of selenium in water from selected wells were 0.01 ppm or less, and concentrations of boron in water from all sampled wells were less than 0.5 ppm. The quality of water from some wells changed appreciably from August 1957 to April 1958, and that from others changed only slightly.

The chemical quality of surface water also varies. Water in the upper Greybull River and in Buffalo Bill Reservoir contains less than 150 ppm of dissolved solids and is of the calcium bicarbonate type. Return flows from irrigated lands downstream from Meeteetse and drainage from the Willwood formation cause the water in Greybull River near its mouth to be more mineralized and of the sodium sulfate type. Data indicate that the water in the river near Basin is 1½ to 6 times as mineralized as it is at Meeteetse.

Water draining from the upper Dry Creek basin is moderately saline (3,000 to 6,000 ppm of dissolved solids) and of the sodium sulfate type. Downstream from irrigated lands on Emblem Bench the water also is of the sodium sulfate type, although it is somewhat less mineralized than in the upper reaches.

The relation of mineralization to discharge shows a definite change in water quality as the water in Greybull River and Dry Creek moves downstream.

Most ground water from deposits of Quaternary age has a high to very high salinity and a low to medium sodium hazard for irrigation use. Water from wells tapping the Willwood formation is not used for irrigation; however, it has a high to very high salinity hazard, and water from some of the wells has a very high sodium hazard. Water in Buffalo Bill Reservoir and in the Greybull River at Meeteetse has a low to medium salinity hazard. However, water from Greybull River near Basin has a medium to high salinity hazard, and that from Dry Creek below Emblem, which is used for irrigation on Agrarian Bench, has a high to very high salinity hazard. Most surface water used for irrigation in the area generally has a low sodium hazard. Because most irrigated crops grown in the report area have a medium to high salt tolerance, water having a high salinity hazard can be used providing drainage is good. Concentrations of boron in ground water and in surface water used for irrigation are below 0.5 ppm, and residual sodium carbonate is present only in water from a few wells tapping the Willwood formation.

The ground water is classed as good for stock watering because the water generally contains less than 2,500 ppm of dissolved solids and low concentrations of nitrate and selenium.

Except for excessive concentrations of sulfate, fluoride, and dissolved solids, most ground water contains less than the recommended maximum concentrations of dissolved constituents in drinking water. Concentrations of nitrate in ground water are less than the 45 ppm recommended maximum. The water is hard to very hard, and most of the water has permanent (non-carbonate) hardness.

Because the water in Buffalo Bill Reservoir and the water in Greybull River near Meeteetse during the irrigation season are chemically similar and are of good quality, the quality of water in the ground-water body that may develop beneath YU and upper Emblem Benches as a result of new irrigation will be affected principally by the solubility of rocks and soils in the terrace deposits. The soils are calcareous, and the deposits contain sulfate salts; therefore, the potential ground water probably will be highly mineralized and very hard. Mineralization of more than 3,000 ppm of dissolved solids and hardness in excess of 1,000 ppm may be common. However, with time and good drainage, the quality of the ground water should improve.

If YU Bench and upper Emblem Bench are developed for irrigation, much valuable information regarding the rate of leaching of the soils and terrace deposits and the changes with time of the quality of ground water can be obtained from a continuing study of the quality of ground water and drainage water. During the early phases of development on YU and upper Emblem Benches, the chemical quality of water from newly drilled wells should be determined periodically to ascertain the suitability of the water, particularly for drinking and culinary purposes. Such a study, made in conjunction with a continuing study of the ground-water hydrology of the benches, would provide a basis for predicting more accurately the influence prospective irrigation developments would have on ground-water conditions and nearby lands and streams in similar areas of Western United States.

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TABLE 8.—*Records of wells, springs, and test holes in the Greybull River–Dry Creek area, Wyoming*

Well (location): See text for description of well-numbering system.
Type of supply: B, bored well; Dn, driven well; 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, brick or tile pipe; P, iron or steel pipe; R, rock; W, wood.
Character of material: G, gravel; S, sand; Sh, shale; Ss, sandstone.
Geologic source: Klm, Lance and Meeteetse formations; Qal, alluvium; Qtg, deposits of the Greybull terrace; Qts, deposits of the Sunshine terrace; Tfu, Fort Union formation; Tw, Willwood formation.
Method of lift and type of power: C, cylinder; Cf, centrifugal; J, jet; N. none; T, turbine; S, submersible; E, electric motor; G, gasoline or diesel engine; H, hand operated; N, none.
Use of water: D, domestic; I, irrigation; N, none; O, observation; S, stock.
Altitude of land surface at well: Determined from topographic maps; altitudes of USBR test holes determined by instrumental leveling.
Depth to water: Measured depths to water level are given in feet, tenths, and hundredths; reported depths are given in feet.
Remarks: Ca, sample collected for chemical analysis, results given in table 7; D, discharge in gallons per minute (E, estimated; M, measured; R, reported); DD, drawdown in feet while discharging at preceding rate; L, log of well given in table of well logs; T, temperature of water in degrees Fahrenheit; Th, time in hours for stated drawdown at stated discharge; Cond, conductivity in micromhos per centimeter at 25° C.

Well (location)	Owner or user	Year drilled	Type of supply	Depth of well below land surface (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed		Method of lift and type of power	Use of water	Depth to base of alluvial or terrace materials	Altitude of land surface at well (feet)	Depth to water level below land surface (feet)	Date of measurement	Remarks
							Character of material	Geologic source							
50-98- 5aac	Sheets Flat School		Dr	41.9	6	P		Qal	C, H	O		4,970	19.79	Apr. 9, 1957	Ca, T48.
- 5abd	Wellington Snyder.		Dr	35.0	6	P		Qal	C, E	S		4,975	17.30	do	
- 5bad	do		Dr	88.0	6	P		Tw	U, E	D		4,980	39.41	do	
- 6cac	R. M. Mullins		Dr	60.0	8	P		Tw(?)	U, E	D, S		5,020	12.87	do	
- 6dbc	Thomas B. Florida.		Dr	87	6	P		Tw(?)	U, E	D		5,010	12	do	
-99- 1dcb	Frank W. Scott		Dr	50.0				Qal(?)	J, E	D		5,070	25.82	Apr. 8, 1957	Water reported hard.
- 2ccc	USBR test hole 3	1950	Dr	67.5	1½	P					61.0	5,592.4	Dry	1950	L.
- 3(cen.)	USBR test hole 2	1952	Dr	64.2							53.0	5,585.7	Dry	1952	L.
-10ccb	USBR test hole 1	1950	Dr	66.0							62.0	5,654.6	Dry	1950	L.
-14bac	O. V. Asay		Sp				G	Qal	N	N		5,137			D5E, Ca, T56.
-14bad	do		Dr	85	3	P		Tw(?)	J, E	D		5,125			
-15dbd	do		Du	10.0			G	Qal	C, E	S		5,162	9.39	Apr. 9, 1957	
-21aac	William Petersen		Dr	205.0	6	P		Tw	N	O		5,280	73.56	do	
-21aad	do		Dr	80	6	P		Tw	J, E	D, S		5,270	51.30	do	Pumping measurement.
-21adc	Morris Stoddard		Dr	97.2	6	P		Tw	J, E	D, S		5,280	55.53	Apr. 10, 1957	Ca, T51.
-28bab	Sam Osborne		Dr	82	12-6	P	G, Ss	Qal, Tw	J, E	D, S	20	5,280	31	do	Water softened for domestic use.
51-94- 2bbd1	Victor Boelens		Du	15			G, S	Qal	C, H	S					Ca, T52.
- 2bbd2	do		Dr	60	6	P	Sh	Tw	C, H	D					Supply inadequate, water reportedly soft.

- 8dbb1	Alvin Mills		Dr	39	12	P	G, Ss	Qtg, Tw	T, E	I, O	16		11.13	Sept. 17, 1956	D24OR, DD26R, L(50 ft), T54.
- 8dbb2	do		Dr	65	8	P	G,Ss	Qtg, Tw	C, H	S	14		10.08	do	L.
- 8dbb3	do		Dr	40	9	P	G,Ss	Qtg,Tw	J,E	D			6.53	Aug. 10, 1957	Ca.
- 8dcb	do		Dr	44	12	P	G,Ss	Qtg,Tw	N	O			4.44	Sept. 17, 1956	
-10aaa	Ora J. Gould		Du	10.5	30	W	G,S	Qtg	C,E	S,O			1.95	do	
-95- 5bac	L. L. Gunnels		Dr	150	8-4	P		Tw	C, H	D		4,285	53.13	July 23, 1956	Water reported poor quality.
-10cad	C. E. Neddeau		Dr	180	3	P		Tw	C, H	D, S		4,142			Water reported soft.
-14adb	John Bullinger		Dr	80			Ss	Tw	C, E	D					Water reported hard.
-14bac	M. H. English		Dr	18	6	P	G	Qal	C, H	S			6.17	Aug. 13, 1956	Well reported dry in 1955.
-14bcd	F. R. Hammond		Dr	18	6	P	G	Qal	J, E	D, S			6.50	do	
-15bcd1	T. W. Swenson		Du	12	36x36	W	G	Qal	C, E	S		4,139	6.70	July 23, 1956	
-15bcb2	do		Dr	85	8-4	P		Qal, Tw	T, E	D		4,139	7.86	do	Water reported soft.
-15ccb1	Merlin Wardell		Du	24	18	C	G	Qal	C, E	I, O	24	4,130	6.60	Aug. 8, 1956	L, Ca, D141M, DD9.55, TH¼, T55.
-15ccb2	do		Dr	124	6	P	Ss	Tw	S, E	D, O		4,130	5.30	Aug. 1, 1956	Ca, T56.
-16ddc	Wesley Thorley	1956	Dr	110	6½	P		Tw	C, H	D		4,135	8.38	July 23, 1956	
-19cad	D. J. Geertsen		Dr	105	4	P, C		Tw	N	N		4,225	8	July 1956	
-20aac	Bob Sawyer	1953	Dr	43				Qal	J, E	D		4,170	3	do	Water reported soft.
-20bdd1	Ira Ilg		Dr	60	8	P		Qal		D, S		4,185			
-20bdd2	do		Dr	27				Qal		S	27	4,185	6.62	July 24, 1956	L, Stock will not drink water.
-21aca			Du	10	5-1	P	G	Qal	N	O		4,138	3.05	July 25, 1956	
-21ada	Charles Harp		Dr	40		P	G	Qal	T, E	D		4,132	6.30	do	Water reported soft.
-22aab	M. L. Shepard		Dr	60	8	P	G	Qal	T, E	D	40	4,110	6.93	July 23, 1956	L.
-22baa	R. F. Boyd	1940	Dr	80	6	P		Tw(?)	C, H	D		4,115	19.88	do	
-23bbd	Glenn Hopkins		Dr	70	6	P		Tw(?)	C, H	D			6.73	Aug. 13, 1956	
-96- 1cbc			Dn	12	1½	P	G	Qtg	N	N, O		4,270	5.22	July 25, 1956	
- 1cca	O. W. Horton		Dr	100				Tw	C, H	D		4,265			Water reported soft.
- 2acc	J. F. Pederson	1948	Dr	55				Tw	J, E	D		4,290	10.34	July 25, 1956	Water reported soft, well can be pumped dry.
- 2dac	Harlan Mayland		Dr	86				Tw	C, H	D		4,275			Water reported hard.
- 3cda	Frank Pearce		Dr	25	6	P	G	Qal	J, E	D		4,325	6.53	July 26, 1956	L, Ca, T55.
- 4aac	Lyle Johnson		Dn	14	2	P	G	Qal	Cf, E	S, O		4,348	1.61	Aug. 1, 1956	
- 4bcc	Jack Loveland		Du		30	W	G	Qal	C, H	D		4,370	4.68	do	Dry in winter 1955-56.
- 4dcb	Frank Pearce		Du	9.0	24	C	G	Qal	N	O		4,350	5.31	July 25, 1956	
- 5bcc	T. E. Riley		Du	20	36	P, R	G	Qal	Cf, E	D, O		4,410	2.88	Aug. 1, 1956	Dry in spring 1956.
- 5ccb			Du	9.0	12	C	G	Qal	N	N		4,408	4.74	July 26, 1956	
- 5dac	L. Basinger		Du	16			G	Qal	C, H	D		4,385	3.70	Aug. 1, 1956	
- 5dda	O. W. Peterson		Du	12			G	Qal	C, H	S	56(?)	4,377	3.52	Aug. 25, 1956	
- 6bda	Elmer G. Frandson		Du	32	28	P	S, G	Qal	C, G	I, O	32	4,435	3.65	Aug. 11, 1956	L.
- 6cbb	do	1955	Dr	37.0	8	P	S, G	Qal	N	I, O	37	4,450	10.96	Aug. 11, 1956	L.
- 7cac			Du	10.0	24x24	C	G	Qal	C, H	O		4,425	6.18	July 26, 1956	
- 7ccd1	John Michaels	1950	Dr	103	6	P		Tw(?)	T, E	D		4,415			
- 7ccd2	do		Du	10(?)			G	Qal				4,415	4.50	July 26, 1956	
- 7dda	Douglas Reid		Du	12			G	Qal	C, H	D, S		4,398	4.85	do	Water reported hard.
- 8bbb			B	21	6	P		Qal	C, H	O		4,408	5.75	July 26, 1956	
- 8cba	E. S. Maller		Du	38				Qal	C, H	S		4,389	3.33	do	Water reported soft.
- 8dcc	Con Williams		Du	8.0	24	W	G	Qal	T, E	D, S		4,372	5.00	do	Water reported hard.
-10cba1	Chas. Ondracek	1944	Dr	240	6	P		Tw	C, E	D		4,325			T52, supply reported inadequate.
-10cba2	do		Du				G	Qal		S		4,325	3.56	July 25, 1956	
-12dbc			B	14.5	3	P	G	Qal	N	N		4,243	6.76	July 21, 1956	
-20bbb			Dr		3	P		Tw	C, H	N		4,435	5.74	July 25, 1956	
-24 add	Ralph Heath	1952	Dr	85			Ss	Tw	C, H	D		4,235	10.30	July 23, 1956	

TABLE 8.—*Records of wells, springs, and test holes in the Greybull River–Dry Creek area, Wyoming*—Continued

Well (location)	Owner or user	Year drilled	Type of supply	Depth of well below land surface (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power	Use of water	Depth to base of alluvial or terrace materials	Altitude of land surface at well (feet)	Depth to water level below land surface (feet)	Date of measurement	Remarks
-24bab	Frank Dent, L. Haley.	1946	Dr	60	--	--	--	--	C, H	D	--	4,258	--	--	Water reported soft but unfit for drinking.
-97- 1bcb1	Don Schlaf	1934	Dr	56	12	P	G	Qal	T, G	I	48	4,483	4	July 1956	L, D250R, could be pumped dry.
- 1bcb2	do	1920	Dr	27.0	6	P	G	Qal	J, E	D	--	4,483	5.19	July 26, 1956	Water reported hard.
- 2bdd	Louis Dobson	--	Du	20	24	P	G	Qal	C, E	D	--	4,508	--	--	Do.
- 2cbb	Avent School	--	Dr	29	3	P	G	Qal	C, H	O	--	4,525	7.53	July 21, 1956	
- 2dca	Edgar Aagard	--	Dr	204	6	P	--	Tw	N	N	17	4,490	9.29	do	Well caved below 58 feet, reported inadequate supply for domestic use.
- 7aba	--	--	Dr	51.0	6	P	--	Tw(?)	C, H	N	--	4,700	23.64	July 24, 1956	
- 7add	Archie Crichton	--	Dr	128	4	P	--	Tw	C, H	D	--	4,695	120	July 1956	Water reported soft.
- 7dbd	A. J. Blackstone	--	Dr	100	--	--	--	Tw	C, H	D	--	4,680	--	--	Water reported soft, well can be pumped dry.
- 8adb	Everett Renner	--	Dr	34	4	P	--	Tw	C, G	D	--	4,605	8.14	July 22, 1956	Water reported hard.
-12abc1	Orlando Aagard	--	Du	16	36 x 36	W	G	Qal	C, H	S, O	--	4,460	4.30	July 26, 1956	
-12abc2	do	--	Du	16	--	--	G	Qal	J, E	D	--	4,460	--	--	Ca, T58.
-98- 2dcb	USBR test hole 15	1952	Dr	57.5	--	--	--	--	--	--	45.5	5,197.7	Dry	1952	L.
-10dbb	USBR test hole 14	1952	Dr	61.0	--	--	--	--	--	--	45.5	5,249.9	Dry	1952	L.
-13aad1	Ed C. Allen	--	Dr	100	6-4	P	Ss	Tw	J, E	D	--	4,715	--	--	Ca, T56.
-13aad2	do	--	Sp	--	--	--	G	Qtg	--	S	--	4,705	--	Apr. 5, 1957	Ca, T48, D30E.
-13da	George H. Renner	--	Dr	15	--	--	G	Qal	C, H	D	--	4,702	11	Apr. 1957	Water has slightly reddish color.
-14dba	Don Schlenker	--	Dr	20	6	P	S	Qal	J, E	S	--	--	18	do	
-16bcd	USBR test hole 12	1952	Dr	40.2	--	--	--	--	--	--	29.7	5,317.2	Dry	1952	L.
-17aba	USBR test hole 13	1952	Dr	39.5	--	--	--	--	--	--	29.0	5,317.5	Dry	1952	L.
-18cbd	USBR test hole 10	1952	Dr	41.5	--	--	--	--	--	--	31.5	5,355.0	Dry	1952	L.
-18ddd	USBR test hole 11	1952	Dr	34.5	--	--	--	--	--	--	24.5	5,366.1	Dry	1952	L.
-21dcd	Alden Avent	--	Dr	88.6	6	P	Ss	Tw	J, E	D	--	4,850	25.80	Apr. 9, 1957	
-22aad	--	--	Dr	60	3	P	--	Qal	N	N	--	4,810	0.45	Apr. 5, 1957	
-22bbb	Charles Dooley	--	Dr	50	6	P	G	Qal	J, E	D, S	--	4,880	42.05	Apr. 6, 1957	L.
-23aaa	Hoover Renner	--	Du	9.2	--	--	G	Qal	J, E	S	--	4,760	4.87	Apr. 10, 1957	Ca.
-23aad1	do	--	Dr	27.6	6	P	G	Qal	J, E	D	--	4,762	13.39	do	
-23aad2	do	--	Du	20.4	36 x 36	W	G	Qal	J, E	S, O	--	4,765	15.23	do	
-32cdc	E. R. Hague	--	Dr	40.6	6	P	--	Qal	C, H	D	--	4,962	5.02	Apr. 9, 1957	

-32dcd	Leslie Ward		Dr	77.0	6	P		Tw	C, H	D		4,950	19.17	do	
-99-23ccc	USBR test hole 6	1951	Dr	31.0							28.0	5,474.6	Dry	1951	L.
-24bcc	USBR test hole 8	1951	Dr	25.4							18.0	5,349.5	Dry	1951	L.
-24cda	USBR test hole 5	1952	Dr	62.0							52.0	5,436.1	Dry	1952	L.
-25aad	USBR test hole 9	1952	Dr	38.2							27.0	5,435.5	Dry	1952	L.
-35abc	USBR test hole 4	1952	Dr	75.2							61.0	5,512.8	Dry	1952	L.
-36bcc	USBR test hole 7	1950	Dr	39.0	1½	P					34.0	5,512.6	Dry	1950	L.
52-93-19bda	John Schmer		Dr	32	6	P		Qal(?)	J, E	D, S					Water reported very hard.
-19cbd	W. F. Jones		Du	15				Qal(?)	C, H	D			5.36	Sept. 17, 1956	Water has laxative effect.
-20abc	Paul F. Mau		Du	17	18	P	G	Qal	C, H	D,O			5.19	do	L, Cond. 1,450.
-20acb	H. R. Unterzuber.		Du	20			G	Qal	C, E	D	20.0				L, Cond. 2,300.
-94- 1ddd	M. S. Brinkerhoff.		Du	13	12	C	G,S	Qal	C, H	S					Well reported to pump dry after 15 gals.
- 2bcd	Henry Fiene		Dr	50	4	P		Qts(?) Tfu(?)	C, H	S, O			5.75	Sept. 17, 1956	
- 2dad	James Yates		Dr	135				Klm(?)	J, E	S			20	Sept. 1956	
-24dda	Robert Harvey		Du	8			G	Qal	C, E	S			2.99	Sept. 17, 1956	T61, Ca.
-95- 3ccc	James Roberts		Dr	10.5			G	Qts	C, H	S			4.76	Aug. 8, 1956	Supply reported inadequate in winter, water unfit for drinking.
- 4cac	C. H. Trumbull		Dr	25	4	P			J, E	D			8.44	Aug. 9, 1956	Water not used for drinking.
- 4cad	J. G. Davis	1910	Du	14		R	G	Qts	Cf, E	S	14				L, water turns, blue-green when lye is added.
- 4cbc1	John Menzel		Dr	18	4	P	G	Qts	C, E	S	18		5.69	Aug. 10, 1956	L.
- 4cbc2	do		Dr	110	6	P		Tw		D					Pumps dry after 75 gals.
- 4dca	John Oleson	1950	Dr	18				Qts	J, E	D, S					Water reported to be good quality.
- 5bcb	Harold W. Cooper		Dr	118	6	P	Ss	Tw	C, E	D			40.88	Aug. 10, 1956	Water reported to have alkali taste.
- 5cbd	Heard Fales		Du	9			G	Qts	J, E	D, S			5.27	do	L, Ca, T55.
- 5dcb	Vern Harrison		Du	8	18	C	G	Qts	J, E	S			5.22	do	L.
- 6ccc	Eley Peterson		Dr	33	12	P	G	Qts	T, E	I, O	30(?)		7.22	do	L, well connected to subsurface tile drain.
- 6dac	Mrs. Edna Miller	1946	Dr	100	8	P		Tw(?)	J, E	D			7.20	do	Water reported hard.
- 8bcc	John Fink		Dr	57			G	Qts	J, E	S		4,325			Well reported dry in fall 1955.
- 8cbb	Christ Marcus		Dr	147	4	P		Tw	J, E	D, S		4,350	33.25	Aug. 8, 1957	Ca, reported inadequate supply.
- 8dac	Earl Madson		Dr	100				Tw	C, E	S		4,295			Reported inadequate supply, unfit for drinking.
- 8dad	Fred Funke		Du, Dr	45	8	P			C, E	S		4,290			Reported soft water.
8dbb			Du	11.0	60	C		Qts	N	N		4,308	7.90	July 20, 1956	
- 9cad	Harry Peterson		Dr	38				Qts	C, E	S		4,265	18.93	Aug. 8, 1956	
- 9dad1	do		Dr	23	2	P	G	Qts	J, E	D		4,235			D3R.
- 9dad2	do		Dr	40	6	P	G	Qts	C, E	S, O		4,235	13.29	Aug. 8, 1956	
- 9dbd	M. H. Oleson	1953	Dr	17			S	Qts	J, E	D		4,240			Water reported hard.
-10abb	Felix Saldana	1948	Dr	105	5	P	Ss	Tw	C, H	D	50(?)		30	Aug. 1956	L, can be pumped dry.
-10cbc	Axel Lilja	1955	Dr	49	12	P	G	Qts	T, E	I, O	18	4,222	5.91	Aug. 9, 1956	49 ft casing, perforated.
-10dbd1			Dr	38.2	4	P		Qts	N	O		4,200	4.42	July 20, 1956	
-10dbd2			Dr	27	12	C		Qts	C, H	D		4,200			Ca, T55.

TABLE 8.—*Records of wells, springs, and test holes in the Greybull River–Dry Creek area, Wyoming*—Continued

Well (location)	Owner or user	Year drilled	Type of supply	Depth of well below land surface (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power	Use of water	Depth to base of alluvial or terrace materials	Altitude of land surface at well (feet)	Depth to water level below land surface (feet)	Date of measurement	Remarks
-33ccc			Dr	84	6	P		Tw	C, H	D, O		4,235	20.53	July 21, 1956	
-96- 1cac	Chris Link		Dr	28	6	P	G	Qts	C, E	S					Water reported hard.
- 1cbc	Martin Mayland		Dr	19	6	P		Qts	J, E	D			5.40	Aug. 10, 1956	Ca, T62.
- 2bbd	Elmer Blank		Dr	21	6	P	G	Qts	J, E	D, S	21		8.02	do	L.
- 2cbc	Zion Evangelical Lutheran Church.		Dr	26	8	P	G	Qts	T, E	I, O	26		5.59	do	L, Ca, T50, D300M, DD7.87M, Th1.5.
- 2cbd	Wm. K. Schmoldt.		Dr	23	6	P	G	Qts	Cf, E	D, S			5.90	do	Water reported hard, highly mineralized.
- 3cbc	Arnold Wamhoff		Dr	36	48	P	G	Qts	T, E	I, O	21(?)		8.35	Sept. 18, 1956	L, D900R, 48 in. casing perforated 10–36 ft., connected to 200 ft long perforated 12 in. diameter culvert buried 18 to 22 ft deep, Ca, T53.
- 3dbc	Harry Grabbert		Du	28	36	P	G	Qts	T, G	I, O	28		4.20	Aug. 11, 1956	L, 36 in. casing perforated and connected to 300 ft long 12 in. diameter perforated culvert buried at 28 ft.
- 4cbc	Lester Werbelow		Dr	26			G	Qts	C, E	S					Hardness reported about 270 ppm.
- 5cca	Joe Davis		Dr	23	6	P	G	Qts	J, E	D	20		6.48	Aug. 11, 1956	Supply reported almost inadequate.
- 7cad	N. G. Brown		Du	12	3	P	G	Qts	C, H	O		4,550	4.62	Aug. 6, 1956	Water reported unfit for drinking.
- 7dad	J. O. Neff		Dr	24	4	P	G	Qts	C, H	D	20	4,530	4.55	do	L, water cloudy, brown.
- 8bbc	Carl Wagner		Dr	31	8	P	G	Qts		D	31	4,515			L.
- 8cbc	Chris Simon	1955	Dr	50	20	P	G	Qts	T, E	I, O	37	4,530	5.75	Aug. 6, 1956	Ca, T50, D94M, DD40.-80M, Th¼, perforations plugged with bentonite.
- 8dbd	Frank Wardell		Dr	22	3	P	G	Qts	C, H	D		4,508	5.81	do	L.
- 8dca	do	1956	Du		36	P	G	Qts	N	N		4,510	4	do	Under construction.
- 9ada1	Effie H. and Cal Crosby.		Dr	26	8	P	G, S	Qts	J, E	D		4,455			L, casing perforated in lower gravel.

- 9ada2	do		Du	16	36	P	G	Qts	N	O		4,455	6.33	Aug. 7, 1956	Ca.
- 9bbb	Rollin and Donald Stearns.	1944	Dr	20	6	P	G	Qts	J, E	D	12		4.70	Aug. 11, 1956	L.
- 9cbc			B	21.3	4	P		Qts	C, H	O		4,492	4.94	Aug. 20, 1956	
-10ccb	William Edwards		Du	10	6	P	G	Qts	C, E	D		4,448	8.41	Aug. 7, 1956	
-10cda	Adam Preis		Dr	44			G	Qts	J, E	D, S		4,455	24	Aug. 1956	
-10dcd	Nahne Jensen	1934	Dr	57	15	P	S, G	Qts	T, E	I, O	57+	4,470	39.29	Aug. 2, 1956	L, D200E, DD5E, Th160, Ca, T56.
-11cbd	Paul Werbelow		Dr	35				Qts	J, E	D, S		4,430	21.03	Aug. 8, 1956	
-11dac	Louis Schultz		Dr	60	6	P		Qts (?), Tw(?).	J, E	D		4,442	13.10	do	Supply reported inadequate, water laxative.
-11dbc	Marie Moeller		Dr	50	4	P	G	Qts	J, E	D, S		4,435	27.09	do	Pumping measurement.
-16aad	William Edwards		Dr	44	12	P	G	Qts	T, E	I, O	42+	4,475	22.89	Aug. 7, 1956	D225M, DD9.09M, Th1, L, Ca, T52 casing perforated 22-42 ft.
-16abb	Jim Kelso	1956	Dr	30	6	P	G, S	Qts	J, E	D		4,465	5.95	do	L, hardness reported 255 ppm.
-16cbc	R. W. Cauffman		Dr	16			G, S	Qts	C, H	S	16	4,491	5.80	Aug. 6, 1956	L, waters 300 sheep.
-16dac	William Edwards	1955	Dr	114	10	P	Ss	Tw	N	N		4,490	47	Aug. 1956	L, D120R, DD63R.
-17bbb	Harry A. Johnson		Du	14			G	Qts	C, H	D		4,540	4.30	Aug. 6, 1956	L, well can be pumped dry.
-17bbc	Loren Johnson		Dr	45			G	Qts	C, E	D		4,530	7.87	do	
-18bcc	Irving Jensen		Du	9.5	12	C		Qts	C, H	S, O		4,575	3.43	July 20, 1956	
-18cad	Ferrel Riley	1950	Dr	28	3	P	G	Qts	C, E	D	28	4,548	4.21	Aug. 6, 1956	L.
-18cbc	Ivan Briggs		Du	14	12	P	G	Qts	C, H	S, O		4,582	3.73	do	
-19bcb	Alfred Allen		Dr	43	6	P	Ss	Tw	C, H	D, S		4,565	4.46	do	
-20bbc	Pete Mileski		Du	20	3	P	G	Qts	C, E	S		4,530	5.03	do	
-28ccb			Du	10.0	24	C	G	Qtg	N	O		4,390	4.99	do	
-29bba	L. M. Johnson		Dr	65				Tw	J, E	D		4,210			Can be pumped dry.
-29ccb	Wesley Johnson		Dr	30			G	Qtg		D		4,430			L.
-31bcb			Du	7.0	24 x 24	W		Qtg	C, H	O		4,450	1.57	July 21, 1956	
-31ccb	Levi Johnson		Dr	18	6	P	Ss	Tw	C, E	D, S		4,448	3.67	Aug. 2, 1956	Dry in spring 1956.
-31ccc	Don Schlaf		Dr	28	8	P	G	Qal	C, H	O		4,450	4.68	Aug. 2, 1956	L.
-31dbc	A. F. McIntosh	1932	Du	41	24	P	G	Qtg	T, E	I	41+	4,435	5.22	Aug. 4, 1956	L.
-31dca	Wesley Johnson	1936	Du	47	24	P	G	Qtg	T, G	I, O	47	4,430	5.90	Aug. 1, 1956	L, D590M, DD10.38M, T53.
-32ccb	Jack Hibbert		Dr	30	6	P	G	Qtg	J, E	D		4,418	2.00	Aug. 3, 1956	Ca, T53.
-32ccc	Wesley Johnson		Dr	17	4	P	G	Qtg	C, H	S		4,418	1.00	Aug. 1, 1956	
-33ccb	Jim McNiven	1955	Du, Dr	31	3	P	G	Qtg	T, G	I, O		4,380	3.68	do	L, pumps dry after 6 minutes pumping 1070 gpm. Casing connected to drain with pipe and gate.
-33dcb	W. J. McNiven		Dn	22	1½	P	G	Qtg	C, H	D, S		4,363	5.50	do	Ca, T57.
-97-13bad	Cecil Cline		Du	16	24	C	G	Qts	J, E	D	16	4,590	9.73	Aug. 6, 1956	Ca, L.
-13ddb	S. E. Rasmussen		Du	15	18	P	G	Qts	C, H	S		4,590	3.13	do	
-25dbc	Bob Yorgason	1951	Dr	19	6	P	G	Qtg	C, H	D, S		4,470	4.01	Aug. 2, 1956	Ca, T49.
-26cad	Richard Gormley		Dr	180	8	P		Tw	J, E	D		4,530	18.98	do	Ca, T55.
-26dbb	Eugene Lewis		Du	16	36	P	G	Qtg	Cf, E	D		4,525	5.66	do	Ca.
-26dbd	do		Dr	10	8	P	G	Qtg	C, E	S, O		4,495	4.06	do	
-35cbb	E. E. Meyers		Dr	60				Tw	C, H	S		4,530			Quality reported very poor.
-35dbc			Dr	70	6	P		Qtg	C, H	O		4,505	7.04	July 24, 1956	
-36caa	Glen Nicholson		Du	16	16	C	G	Qtg	C, H	S, O	16	4,475	4.17	Aug. 2, 1956	L.

Logs of test holes and wells in the Greybull River–Dry Creek area

SAMPLE LOGS

	Thickness (feet)	Depth (feet)
50-99-2ccc. U.S. Bureau of Reclamation test hole 3. Altitude 5,592.4 feet.		
Deposits of the Rim terrace:		
Silt and some boulders	3	3
Gravel, silt, sand, and boulders	58	61
Willwood formation:		
Sandstone, soft, coarse grained, brown	5	66
Shale, soft, brownish-gray	1. 5	67. 5
50-99-3(center). U.S. Bureau of Reclamation test hole 2. Altitude 5,585.7 feet.		
Deposits of the Rim terrace:		
Silt, sandy	1. 5	1. 5
Sand, silt, and gravel	9. 5	11
Sand and gravel	7. 5	18. 5
Sand, gravel, and boulders	19. 5	38
Sand and gravel	15	53
Willwood formation:		
Siltstone, soft, buff to red	7	60
Siltstone, hard, sandy, light-gray	4. 2	64. 2
50-99-10ccb. U.S. Bureau of Reclamation test hole 1. Altitude 5,654.6 feet.		
Deposits of the Rim terrace:		
Silt and gravel	3	3
Gravel, sand, silt, and some boulders (dynamite used to get through boulders)	59	62
Willwood formation: Shale, soft, brownish gray and shaly sandstone	4	66
51-98-2dcb. U.S. Bureau of Reclamation test hole 15. Altitude 5,197.7 feet.		
Deposits of the Rim terrace:		
Silt and sand	1	1
Sand and gravel	23	24
Sand, gravel, and boulders	8	32
Sand and gravel	13. 5	45. 5
Willwood formation:		
Sandstone, soft, friable, medium to very coarse-grained, brown to gray	7. 8	53. 3
Siltstone, soft, drab	4. 2	57. 5

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
51-98-10dbb. U.S. Bureau of Reclamation test hole 14. Altitude 5,249.9 feet.		
Deposits of the Rim terrace:		
Silt and sand	1. 5	1. 5
Sand and gravel	10. 5	12. 0
Sand, gravel and boulders	31. 0	43. 0
Willwood formation: Sandstone, soft, very soft at top, silty, buff	18	61
51-98-16bcd. U.S. Bureau of Reclamation test hole 12. Altitude 5,317.2 feet.		
Deposits of the Rim terrace:		
Sand, gravel, and silt	10	10
Sand and gravel	19. 7	29. 7
Willwood formation: Siltstone, soft, red and green	10. 5	40. 2
51-98-17abc. U.S. Bureau of Reclamation test hole 13. Altitude 5,317.5 feet.		
Deposits of the Rim terrace: Sand and gravel	29. 0	29. 0
Willwood formation:		
Siltstone, soft, buff to drab; sandstone 32.5 to 32.6 ft, 33.9 to 34.5 ft	5. 7	34. 7
Sandstone, soft fine, buff to gray	4. 3	39. 0
Sandstone, coarse, medium-hard	. 5	39. 5
Sandstone, soft, fine, buff to gray	. 4	39. 9
51-98-18cbd. U.S. Bureau of Reclamation test hole 10. Altitude 5,355.0 feet.		
Deposits of the Rim terrace:		
Sand, gravel, and silt	8	8
Sand, gravel, and boulders	11	19
Sand and gravel	6	25
Clay, red, and gravel	6. 5	31. 5
Willwood formation:		
Siltstone, soft, drab to buff	3. 6	35. 1
Sandstone, fine-grained, soft, buff	3	38. 1
Siltstone, soft, buff	1. 7	39. 8
Sandstone, soft, fine, buff	1	40. 8
Siltstone, soft, buff	. 7	41. 5

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
51-98-18ddd. U.S. Bureau of Reclamation test hole 11. Altitude 5,366.1 feet.		
Deposits of the Rim terrace:		
Silt and sand	2. 5	2. 5
Sand and gravel	22	24. 5
Willwood formation: Siltstone, soft, slightly sandy, buff; red from 29.4 to 30.6 ft	10	34. 5
51-99-23ccc. U.S. Bureau of Reclamation test hole 6. Altitude 5,474.6 feet.		
Deposits of the Rim terrace: Silt and sandy gravel	28	28
Willwood formation: Siltstone, soft, red	3	31
51-99-24bcc. U.S. Bureau of Reclamation test hole 8. Altitude 5,439.5 feet.		
Deposits of the Rim terrace: Gravel, sandy, and silt	18	18
Willwood formation: Siltstone, medium-hard, light-gray	7. 4	25. 4
51-99-24cda. U.S. Bureau of Reclamation test hole 5. Altitude 5,436.1 feet.		
Deposits of the Rim terrace:		
Sand and silt	2	2
Sand and gravel	50	52
Willwood formation:		
Sandstone, soft, medium-grained, friable, buff	2. 1	54. 1
Sandstone, coarse, friable, soft	7. 1	61 2
Siltstone, soft, dark-gray	. 8	62. 0
51-99-25aad. U.S. Bureau of Reclamation test hole 9. Altitude 5,435.5 feet.		
Deposits of the Rim terrace:		
Silt and sand	1. 5	1. 5
Sand and gravel	25. 5	27. 0
Willwood formation:		
Sandstone, medium-grained, very soft, buff	4. 6	31. 6
Siltstone, medium-hard to soft, buff	3. 7	35. 3
Sandstone, soft, friable, fine, silty, buff	2. 9	38. 2

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
51-99-35abc. U.S. Bureau of Reclamation test hole 4. Altitude 5,512.8 feet.		
Deposits of the Rim terrace:		
Silt and sand	2.5	2.5
Sand and gravel	8	10.5
Sand, gravel, and boulders	50.5	61
Willwood formation:		
Siltstone, soft, variably sandy, light-gray	7.6	68.6
Sandstone, soft, silty, buff	2.6	71.2
Siltstone, soft, greenish-gray to red	4.0	75.2
51-99-36bcc. U.S. Bureau of Reclamation test hole 7. Altitude 5,512.6 feet.		
Deposits of the Rim terrace:		
Silt	3	3
Gravel, silt, sand, and some boulders	31	34
Willwood formation: Sandstone, soft, very fine grained, silty, gray	5	39

DRILLERS' LOGS

51-94-8dbb1. Alvin Mills.

	Thickness (feet)	Depth (feet)
Soil	2	2
Deposits of the Greybull terrace:		
Gravel, black	8	10
Sand and gravel	6	16
Willwood formation:		
Sand, brown, little water	8	24
Sand	2	26
Sand, water	8	34
Shale, limy, hard	1	35
Sand, black and white, water	5	40
Clay, sandy, blue	10	50

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
51-94-8dbb2. Alvin Mills.		
Topsoil	3	3
Deposits of the Greybull terrace: Gravel	11	14
Willwood formation:		
Sand	9	23
Clay, yellow	3	26
Sand, water	3	29
Clay, yellow	2	31
Shale, very hard	2	33
Clay, yellow	3	36
Sand, water	2	38
Sand and gravel	2	40
Clay, sandy, blue	8	48
Shale, sandy, dark	2	50
Shale, black and brown	5	55
Shale, gray	10	65
Shale, sandy, gray	--------	at 65
51-95-15ccb1. Merlin Wardell. Altitude 4,130 feet.		
Soil	1. 5	1. 5
Alluvium: Gravel	22. 5	24
Willwood formation: Shale	--------	at 24
51-95-20bdd2. Ira Ilg. Altitude 4,185 feet.		
Soil	2	2
Alluvium:		
White sand	14	16
Gravel	11	27
Willwood formation: Bedrock	--------	at 27
51-95-22aab. M. L. Shepard. Altitude 4,110 feet.		
Alluvium: Gravel	60	60
51-96-3cda. Frank Pearce. Altitude 4,325 feet.		
Alluvium: Gravel	25	25

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
51-96-6bda. Elmer G. Frandson. Altitude 4,435 feet.		
Soil	2. 5	2. 5
Alluvium: Sand and gravel	29. 5	32
Willwood formation: Shale	--------	at 32
51-96-6cbb. Elmer G. Frandson. Altitude 4,450 feet.		
Soil	2. 5	2. 5
Alluvium: Sand and gravel	34. 5	37
Willwood formation: Shale	--------	at 37
51-97-1bcb1. Don Schlaf. Altitude 4,483 feet.		
Alluvium: Gravel	48	48
Willwood formation: Sandstone	8	56
51-98-22bbb. Charles Dooley. Altitude 4,880 feet.		
"Dirt"	46	46
Alluvium: Gravel	4	50
52-93-20abc. Paul F. Mau.		
Soil	4	4
Alluvium: Gravel	13	17
52-93-acb. H. R. Unterzuber.		
Alluvium: Gravel	20	20
Cody shale: Shale, brown	--------	at 20
52-95-4cad. J. G. Davis.		
Soil	4	4
Deposits of the Sunshine terrace: Gravel	10	14
Willwood formation: Shale	--------	at 14

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
52-95-4cbcl. John Menzel.		
Deposits of the Sunshine terrace: Gravel	18	18
Willwood formation: Shale	--------	at 18
52-95-5cbd. Heard Fales.		
Soil	4	4
Deposits of the Sunshine terrace: Gravel	5	9
52-95-5dcb. Vern Harrison.		
Deposits of the Sunshine terrace:		
Clay	4	4
Gravel	4	8
52-95-6ccc. Eley Peterson.		
Soil	9	9
Deposits of the Sunshine terrace:		
Gravel	21	30
Hardpan	3	33
52-95-10abb. Felix Saldana.		
Deposits of the Sunshine terrace:		
Gravel	50	50
No record	40	90
Willwood formation: Sandstone	15	105
52-96-2bbd. Elmer Blank.		
Soil	5	5
Deposits of the Sunshine terrace: Gravel	16	21
Willwood formation: Shale	--------	at 21
52-96-2cbc. Zion Evangelical Lutheran Church.		
Soil	6	6
Deposits of the Sunshine terrace: Gravel	20	26

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
52-96-3cbc. Arnold Wamhoff.		
Soil, sandy loam	4	4
Deposits of the Sunshine terrace:		
Clay, cream	1. 5	5. 5
Gravel	15. 5	21
Willwood formation:		
Sandstone, gray	1	22
Sand, black, water-bearing	4	26
Gravel and black sand	10	36
Clay, white	--------	at 36
52-96-3dbc. Harry Grabbert.		
Soil	3	3
Deposits of the Sunshine terrace: Gravel	25	28
Willwood formation: Shale	--------	at 28
52-96-7dad. J. O. Neff. Altitude 4,530 feet.		
Deposits of the Sunshine terrace: Gravel	20	20
Willwood formation: Bedrock	4	24
52-96-8bbc. Carl Wagner. Altitude 4,515 feet.		
Deposits of the Sunshine terrace: Gravel	31	31
Willwood formation: Shale	--------	at 31
52-96-8dbd. Frank Wardell. Altitude 4,508 feet.		
Deposits of the Sunshine terrace: Gravel	22	22
52-96-9adal. Effie H. and Cal Crosby. Altitude 4,455 feet.		
Deposits of the Sunshine terrace:		
Gravel with hard alkali water	12	12
Clay or sand	3	15
Gravel with soft water	3	18
Sand, white	8	26

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
52-96-9bbb. Rollin and Donald Stearns.		
Deposits of the Sunshine terrace: Gravel	12	12
Willwood formation: Shale	8	20
52-96-10dcd. Nahne Jensen. Altitude 4,470 feet.		
Soil(?)	25	25
Deposits of the Sunshine terrace:		
Sand	15	40
Gravel	17	57
52-96-16aad. William Edwards. Altitude 4,475 feet.		
Deposits of the Sunshine terrace:		
Dirt, sandy, red	28	28
Gravel	14	42
52-96-16abb. Jim Kelso. Altitude 4,465 feet.		
Deposits of the Sunshine terrace:		
Gravel	24	24
Sand with little gravel	6	30
52-96-16cbc. R. W. Cauffman. Altitude 4,491 feet.		
Deposits of the Sunshine terrace: Gravel and sand	16	16
Willwood formation: Shale	--------	at 16
52-96-16dac. William Edwards. Altitude 4,490 feet.		
Willwood formation:		
Sandstone	13	13
Shale, brown	no record	
Shale, blue	--------	99
Sandstone	15	114
Shale, blue	--------	at 114
52-96-17bbb. Harry A. Johnson. Altitude 4,540 feet.		
Deposits of the Sunshine terrace: Gravel	14	14

Logs of test holes and wells in the Greybull River–Dry Creek area—Continued

	Thickness (feet)	Depth (feet)
52-96-18cad. Ferrel Riley. Altitude 4,548 feet.		
Deposits of the Sunshine terrace: Gravel	28	28
Willwood formation: Shale		at 28
52-96-29ccb. Wesley Johnson. Altitude 4,430 feet.		
Deposits of the Greybull terrace: Gravel	30	30
52-96-31ccc. Don Schlaf. Altitude 4,450 feet.		
Alluvium: Gravel	28	28
52-96-31dbc. A. F. McIntosh. Altitude 4,435 feet.		
Deposits of the Greybull terrace: Gravel	41	41
52-96-31dca. Wesley Johnson. Altitude 4,430 feet.		
Soil	2. 5	2. 5
Deposits of the Greybull terrace: Gravel	44. 5	47
Willwood formation: Shale		at 47
52-96-33ccb. Jim McNiven. Altitude 4,380 feet.		
Deposits of the Greybull terrace: Gravel	31	31
52-97-13bad. Cecil Cline. Altitude 4,590 feet.		
Deposits of the Sunshine terrace: Gravel	16	16
Willwood formation: Shale		at 16
52-97-36caa. Glen Nicholson. Altitude 4,475 feet.		
Deposits of the Greybull terrace: Gravel	16	16

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