Geology and Ground-Water Resources of the Owl Creek Area Hot Springs County Wyoming

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By Delmar W. Berry and Robert T. Littleton

ABSTRACT

About 250 square miles is included in the project area, which consists of relatively broad valleys and flat terraces grading into rugged folded and faulted uplands. The project area lies at the southern end of the Bighorn structural basin. The climate is semiarid; the normal annual precipitation is about 13 inches.

The exposed rocks range in age from Pennsylvanian to Recent; the younger deposits are exposed in and along the valleys, the older deposits in the uplands adjacent to the valleys. The alluvium and terrace deposits yield water to domestic and stock wells throughout the area and locally yield moderate to large quantities of water for irrigation. Large quantities of ground water can be obtained for only a short time, however, because recharge is not sufficient to sustain large yields for long periods. Some of the older formations that underlie the area (Madison limestone and Tensleep sandstone) yield large supplies of water to artesian springs. Other formations (the Cloverly and the Frontier formations and the Cody shale) can yield water under artesian pressure to domestic and stock wells.

The depth to the water table ranges from only a few feet in the river flood plain to about 70 feet at the margins of the valleys. The water in the terrace and alluvial deposits moves generally eastward toward the Bighorn River.

The ground-water reservoir is recharged principally by precipitation that falls either on the area or on adjacent areas and by percolation from irrigation water and streams. Ground water is discharged principally by evaporation and transpiration, by seepage into streams, and through springs and wells.

Most of the wells in the Owl Creek area were drilled, but some were dug and a few were bored or driven. Only eight wells in the area are used for irrigation. The yield of the irrigation wells ranges from about 50 to about 500 gallons per minute. Ground water for irrigation can be developed most practicably from the alluvium in the part of the valley that extends from the west side of Rose Dome to the vicinity of sec. 10, T. 43., R. 99 W., and from the terrace deposits north of Owl Creek in the central part of the area. The total amount of water that can be pumped from these aquifers is relatively small and depends on the amount of seepage from irrigation water applied to the land.

The relatively few data obtained during this investigation indicate that ground water from the principal aquifers in the Owl Creek area—the Chugwater and Frontier formations, the Cody shale, and the unconsolidated deposits—is of poor chemical quality; all the ground water is highly mineralized, and that from the unconsolidated deposits is very hard. The water is unsuitable for irrigation and

is objectionable for domestic use because of large amounts of dissolved solids (more than 2,000 parts per million), mostly sodium sulfate. However, some water from unconsolidated deposits might be classified as safe for supplemental irrigation if applied under carefully controlled conditions. Conversely, the surface water, especially in the upstream part of the area, is of generally good quality for irrigation, although at some times and in some places it is unsuitable.

INTRODUCTION

PURPOSE AND SCOPE

An investigation of the geology and ground-water resources of the Owl Creek valley and vicinity in Hot Springs County, Wyo., was begun in April 1946 by the U.S. Geological Survey as part of the program of studies undertaken by the Department of the Interior for the control, conservation, development, and use of the water resources of the Missouri River basin. In 1955, by cooperative agreement between the Wyoming Natural Resource Board and the U.S. Geological Survey, the studies of the Owl Creek valley were expanded to include a more detailed investigation of the geology and hydrology of the area. This investigation was made to determine the origin, movement, availability, and chemical quality of ground water for domestic, stock, irrigation, industrial, and municipal uses.

So little precipitation falls on the area that agriculture is restricted to localities where water for irrigation is available. Because streamflow varies greatly, both seasonally and annually, deficiencies of irrigation water occur from time to time. Supplemental water supplies, such as ground water, are needed because of these frequent surface-water shortages.

The studies were made under the immediate supervision of H. M. Babcock, district engineer of the Ground Water Branch of the Geological Survey for Wyoming. The quality-of-water investigations were made under the immediate supervision of P. C. Benedict, regional engineer, Quality of Water Branch.

LOCATION AND EXTENT OF AREA

The Owl Creek valley, in Hot Springs County, north-central Wyoming (figs. 1, 2), is at the southern end of the Bighorn structural basin. The area described in this report is about 36 miles long and about 7 miles wide; it includes the valley of Owl Creek, parts of the valleys of its two principal tributaries, a part of the Bighorn River valley near the confluence of the two streams, and the adjacent uplands. About 17,000 acres of the area is being considered for irrigation with water from the Anchor Reservoir, proposed to be built on the South Fork of Owl Creek. The geologic map (pl. 1) includes the

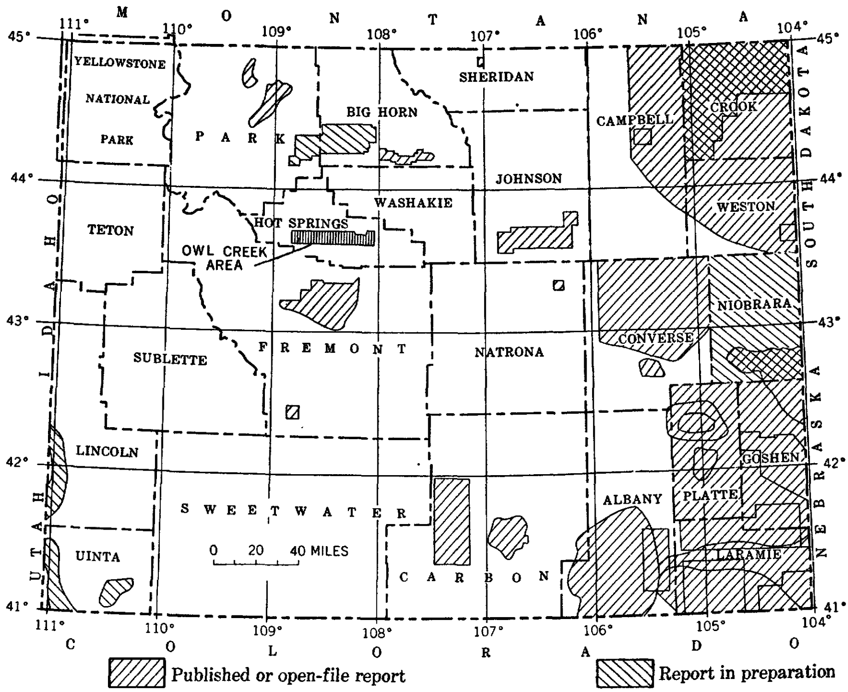

FIGURE 1.—Map showing area of this report and other areas of Wyoming for which ground-water reports have been published or are in preparation.

north flank of the Owl Creek Mountains, where the structural features and stratigraphy were such as to indicate the possible occurrence of artesian water in the formations underlying the area.

The report area lies within two systems of land subdivision (pl. 1). The southwestern part of the area was surveyed from the Wind River meridian and base line and lies within Tps. 8 and 9 N., Rs. 1 W to 4 E.; the remainder of the area was surveyed from the sixth principal meridian and base line and lies within Tps. 43 and 44 N., Rs. 94 to 100 W. The boundary between the two systems lies along Owl Creek and its South Fork.

PREVIOUS INVESTIGATION

Most previous studies of this region have not been concerned principally with the valley of Owl Creek, although several have covered areas that included the valley. Fisher (1906) described the geology and water resources of the Bighorn Basin, which includes the report area, and Darton (1906) prepared a report on the geology of the Owl Creek Mountains, including the Owl Creek valley. Anticlines in the southern part of the Bighorn Basin were described by Hewett and Lupton (1917). A geologic map of the Bighorn Basin was compiled

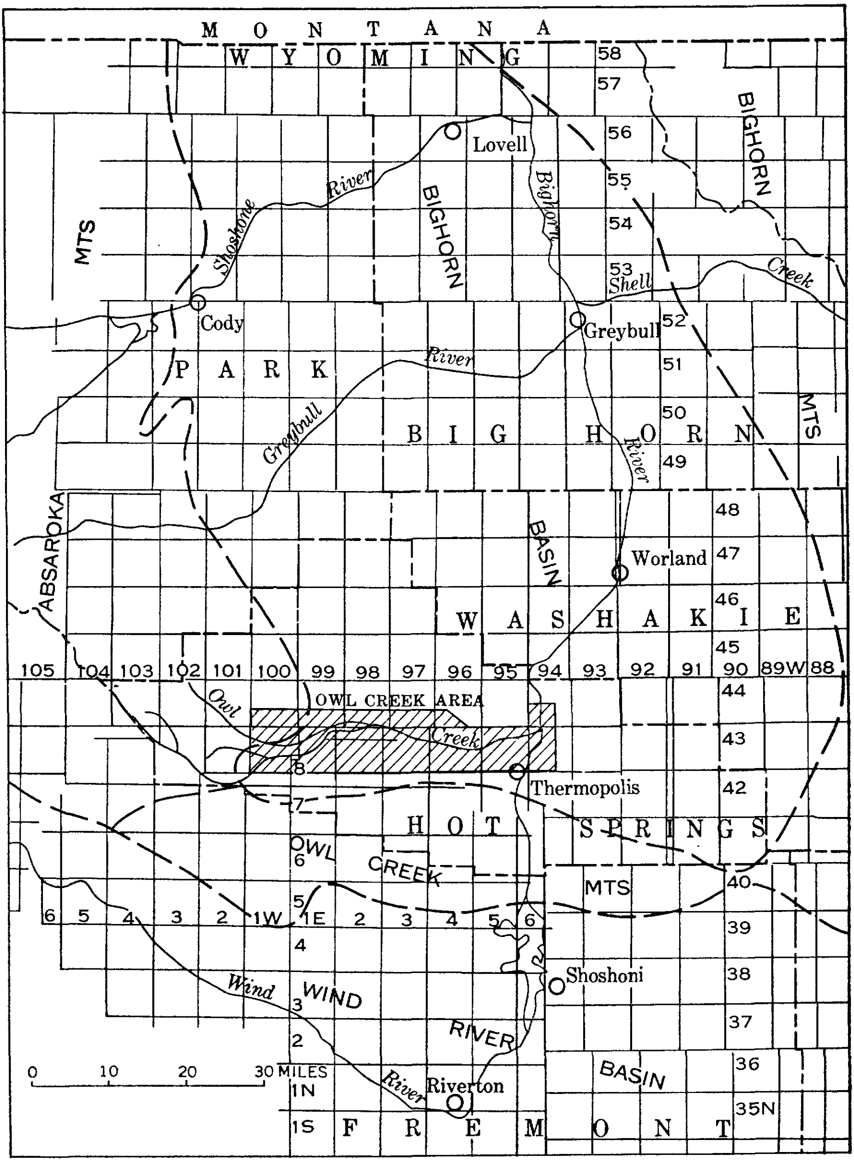

Figure 2.—Map of Bighorn Basin and part of Wind River Basin, Wyo., showing location of Owl Creek area.

by Andrews, Pierce, and Eargle (1947) from published and unpublished field data obtained by themselves and others, including Stippe and Heppe (1951). This map includes the Owl Creek area but is not as detailed as the geologic map (pl. 1) of the present report. Zapp (1956) prepared a structure contour map of the Tensleep sandstone in the Bighorn Basin. Detailed land classification, irrigation studies, and damsite investigations have been made in the Owl Creek area by the U.S. Bureau of Reclamation (1950).

METHODS OF INVESTIGATION

The fieldwork upon which this report is based was done from April to August 1946 and during June and July 1955. Records of 107 wells were obtained during the investigation. The depths of some of the wells and the water levels in most of them were measured with a steel tape from the top of the casing or some other fixed point. The reported depths of wells, the water levels in them, and other information were obtained from well owners, tenants, and drillers. Data on the character and thickness of water-bearing materials, on the yield and drawdown of wells, and on the quality of the water also were obtained. Nineteen test holes were put down. Acquifer tests were made to determine the specific capacities of three wells penetrating the terrace deposits and to determine the coefficients of transmissibility and permeability of the deposits.

Samples of water were collected from 12 wells and at 6 places from Owl Creek and its principal tributaries. The samples were analyzed in the Quality of Water laboratory of the U.S. Geological Survey, Lincoln, Nebr., by methods generally used by the Geological Survey (Am. Public Health Assoc., 1946).

Geologic mapping to supplement that of previous investigators was done on aerial photographs. The data were then transferred by use of a vertical sketchmaster to a base map adapted from township plats prepared by the U.S. Bureau of Land Management and from aerial photographs. Other data were recorded on the base map in the field.

W. P. Fulton of the Surface Water Branch made periodic measurements of water levels in observation wells and made streamflow measurements on the South Fork of Owl Creek to determine the seepage loss from the stream channel.

The wells shown on plate 1 were located with an automobile odometer and by inspection of aerial photographs; the locations are believed to be accurate to within 0.1 mile. They are numbered serially and arranged by townships and ranges in ascending order; thus well 1 is in T. 8 N., R. 2 E. Within a township the wells are listed in the order of the sections.

ACKNOWLEDGMENTS

Many residents supplied data on materials penetrated in the drilling of wells and test holes, the depth of wells, and other useful information. T. F. Stipp, U.S. Geological Survey, made available unpublished data that he collected on the geology of the western part of the Owl Creek valley; D. H. Eargle furnished unpublished geologic data on the whole area.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Owl Creek valley is at the southern end of the Bighorn structural basin (fig. 2), which is in the Middle Rocky Mountains physiographic province. The valley lies along the north side of the Owl Creek Mountains. It is bordered on the north by steep escarpments sculptured in soft Cretaceous rocks, on the west by the Absaroka Mountains, and on the east by the Bighorn River. The altitude of the area studied ranges from 6,500 feet on the Embar anticline (pl. 1) to 4,350 feet where Owl Creek joins the Bighorn River. The North and South Forks of Owl Creek rise in the Absaroka Mountains and flow eastward along the north side of the Owl Creek Mountains. The forks join in sec. 2, T. 43 N., R. 98 W., to form Owl Creek, which flows eastward to its confluence with the Bighorn River. The principal tributaries to Owl Creek that drain the southern part of the area along the north flank of the Owl Creek Mountains are Red Creek, which is a perennial stream, and Cottonwood Creek and the North Fork of Mud Creek, which are intermittent streams. The only drainage of the northern part of the area is through a few small draws and gullies.

CLIMATE

The climate of the Owl Creek area is semiarid and is characterized by large deviations from the normal precipitation. Although the area is well protected to the west and south by the Absaroka and Owl Creek Mountains, respectively, a wide variation in atmospheric conditions results in the localization of storms. Records of the U.S. Weather Bureau station at Thermopolis are incomplete but give a general indication of the climate of the valley (fig. 3). The station at Thermopolis (altitude 4,336 feet) is in a small, protected basin on the Bighorn River about 6 miles south of the east end of Owl Creek valley.

The normal annual precipitation at Thermopolis, computed in 1952, is 12.78 inches, and the average temperature for 1955 was 43.9° F, which was 1.5° F below normal. The length of the growing season in the valley ranges from about 109 to about 126 days.

DEVELOPMENT

The Owl Creek valley is in the central part of a livestock-grazing region, and the economy of the area is based primarily on the production of livestock. According to statistics compiled by the U.S. Bureau of Reclamation (1950, p. 63), the livestock raised in the area are principally sheep and range and dairy cattle. A few farmers fatten hogs for sale outside the area, but poultry and hogs are raised largely for local consumption. To support the livestock, more than 90 percent of the farmed area is used to raise grain and hay. Some row crops, chiefly sugar beets and potatoes, are grown at the lower

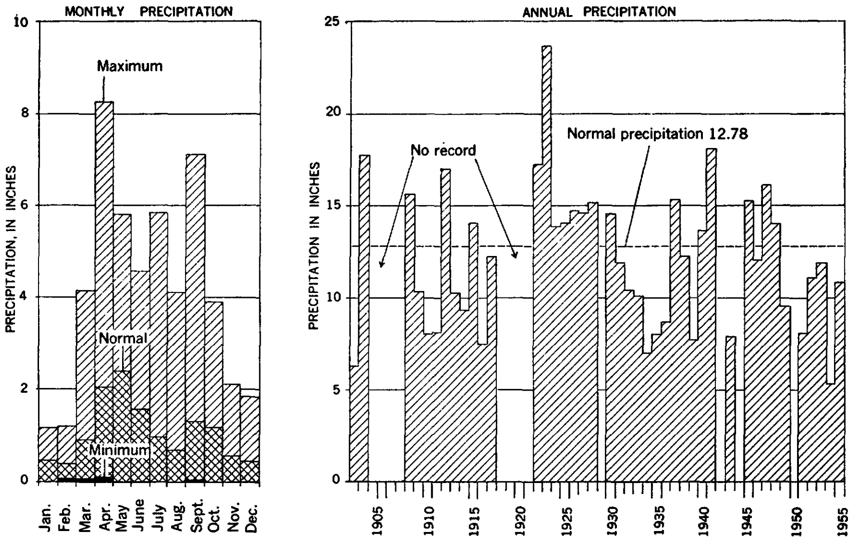

FIGURE 3.—Precipitation for period of record at Thermopolis, Wyo.

end of the valley. Because successful crop production is totally dependent on irrigation, the economy of the valley fluctuates with the availability of water for irrigation. There are large variations in the quantity of the natural flow of surface water available for irrigation; thus, development of additional water is needed to supplement the natural flow of surface water for irrigation. Storing surface water during periods when runoff exceeds demands and developing ground water of acceptable quality would improve the overall economy of the area, if provisions were made also for adequate drainage of the irrigated land.

Although the economy of the area is dependent primarily on agriculture and ranching, it is supplemented to a small extent by petroleum production and mining. Petroleum production in the area is small; however, adjacent areas produce considerable quantities of petroleum products, and exploration is continuing within the project area. Sulfur deposits within the Owl Creek area have been mined intermittently on a commercial basis; however, they were not being mined during the period of this investigation.

The Owl Creek area is served by a main line of the Chicago, Burlington, and Quincy Railroad, which passes through Thermopolis and the eastern part of the area. One Federal and two State highways serve the area. U.S. Highway 20 extends north and south through Thermopolis. State Route 116 extends about 25 miles westward from Thermopolis parallel to Owl Creek; State Route 120 passes northwestward through the eastern part of the area and connects Thermopolis with Cody.

PHYSIOGRAPHY

The physiography of the Owl Creek area is closely related to the structure and lithology of the exposed sedimentary rocks. The most striking physiographic feature in the area is the Owl Creek Mountains. Darton (1906, p. 26) described the Owl Creek Mountains as "an anticline or arch of the crust of the earth, which in the highest portion of the uplift has risen to 10,000 feet." Structurally, the mountains are a compound anticline, the north limb of which dips to the north-northeast. This dip slope is modified locally by smaller anticlinal, domal, and synclinal folds that were developed after the principal uplift of the mountains. The strike of the beds exposed on the north slope is generally west-northwest but deviates locally. The attitude of the strata ranges from horizontal to vertical, and in some places the beds are overturned. The north flank of the mountains is moderately dissected by small intermittent streams.

Agriculturally, the most important physiographic feature of the area is the valley occupied by Owl Creek and its main tributaries. The valley is broad where it traverses soft shale and narrow where it traverses more resistant rocks. The shape of the valley, a result of lateral planation by the streams in soft shale (principally the Cody shale), is such that the agricultural development has occurred in three rather distinct areas. The lower or Lucerne area is 0.5 to 3 miles wide; it parallels the Bighorn River and extends about 5 miles up Owl Creek. The middle area extends about 12 miles below the confluence of the North and South Forks of Owl Creek and ranges in width from 1 to 5 miles. The upper area extends along the South Fork upstream from the confluence of the North and South Forks; it is about 6 miles long and about 2 miles wide. Most of the irrigated land in the Owl Creek valley is in these three areas.

Smooth gently sloping terraces underlain by deposits of sand and gravel are present at some places within the main valley, chiefly on the north side of the present stream channel. These terraces were the flood plain of Owl Creek during early Quaternary time, before an increase of stream gradient caused the stream channels to shift and cut to their present levels. The sand and gravel underlying the terraces was derived chiefly from the upper reaches of the Owl Creek valley.

As the main drainage system developed, alluvial fans and pediments formed. (The alluvial fans and the veneer of colluvium on pediments are shown on plate 1 as slope deposits.) The alluvial fans are present at the mouths of several drywash tributaries of Owl Creek and are present in small areas on both sides of the creek. The pediments rise northward toward the southward-facing escarpments or southward toward the Owl Creek Mountains and generally are mantled by colluvium.

GEOLOGY

STRATIGRAPHIC SUMMARY

Most rocks that crop out in the Owl Creek area are of sedimentary origin, but some are igneous. The exposed sedimentary rocks range in age from Pennsylvanian to Quaternary; the igneous rocks are Tertiary. The outcrop areas of the formations are shown on plate 1. The oldest rocks exposed in the area are the Tensleep sandstone (Pennsylvanian), Phosphoria formation (Permian), Dinwoody and Chugwater formations (Triassic), and Sundance and Morrison formations (Jurassic). The Cretaceous deposits are the Cloverly formation, Thermopolis and Mowry shales, undifferentiated, Frontier formation, Cody shale, and Mesaverde formation. Tertiary rocks include the sedimentary Willwood formation and volcanic tuff and breccia. Rocks of Quaternary age include terrace deposits, slope deposits (alluvial fans and colluvium on pediments), and alluvium.

A generalized section of the geologic formations exposed at the surface and penetrated in the subsurface in the Owl Creek area is given in table 1.

GEOLOGIC HISTORY

The Owl Creek area is underlain by a thick section of sedimentary rocks, principally limestone, shale, and sandstone, which are overlain by a thin mantle of unconsolidated deposits—silt, sand, and gravel. Studies of well cuttings and outcrops have revealed much of the geologic history of the area. The following discussion of the geologic history is adapted in part from Thomas (1949).

PROTEROZOIC ERA

Precambrian rocks in Wyoming are exposed in the cores of most of the mountain ranges. The oldest known rocks began as great thicknesses of sediments deposited on an unknown foundation. After the rocks became consolidated they were folded and metamorphosed, and then they were invaded by batholiths that were mostly granitic. However, intrusive igneous rocks of many other types were formed. After this long Precambrian history of deposition of sediments, uplift, folding and regional metaporphism, and igneous intrusion, the region that now includes Wyoming was subjected to erosion, the old mountains were worn away, and by Cambrian time the region was reduced to a peneplain.

PALEOZOIC ERA

The Owl Creek area probably was being eroded at the beginning of the Paleozoic era; according to the available evidence the Early Cambrian sea was restricted to the Cordilleran trough west of Wyoming. Expanding eastward, this sea reached the western border of Wyoming

TABLE 1.—*Generalized section of geologic formations and their water-bearing properties, Owl Creek area, Hot Springs County, Wyo.*

Era	System	Series	Subdivision	Thickness (feet)	Physical character	Water supply
Cenozoic	Quaternary	Recent	Alluvium	0–38	Boulders, cobbles, pebbles, gravel, and sand; in places covered by and admixed with clay and silt; material coarse and well sorted at upper end of valley.	Contains zone of saturation that is recharged mainly by runoff in the Owl Creek drainage system. Supplies water chiefly for livestock use but locally for domestic use. Where deposits are thick and saturated, moderate to large supplies may be obtained.
			Slope deposits	?	Gravel, sand, silt, and clay, residual or transported; overlie chiefly parent bedrock.	Lie mainly above water table; hence, generally do not yield water to wells but serve as catchment for precipitation.
		(?) Pleistocene	Terrace deposits	0–40±	Mainly gravel, sand, and silt; locally mantled by slope wash.	Locally yield water for domestic, stock, and limited irrigation use. Where deposits are thick and saturated, moderate to large supplies may be obtained.
	Tertiary	Eocene	Volcanic rocks	?	Tuff and breccia.	Yield no water to wells.
			Willwood formation	?	Claystone, sandstone, and conglomerate, drab to brightly colored.	Ground-water possibilities not known.
Mesozoic	Cretaceous	Upper Cretaceous	Mesaverde formation	?	Sandstone, buff and gray, and carbonaceous shale; contains some coal.	Underlies too small an area to yield much water within report area.
			Cody shale	0–2, 500	Shale, gray to black; thin limy sandstone in upper part; contains zones of limy concretions.	Yields small supplies of water under artesian pressure; water occurs in sandy zones and zones of fractured shale. Suitable in quality for domestic use.
			Frontier formation	0–800	Sandstone, lenticular; contains thin layers of interbedded shale and of bentonite; thin coal beds occur sparcely in lower part.	Sandstone beds contain water under artesian pressure.
			Mowry shale	0–800	Shale, gray, siliceous; contains fossil fish scales, thin bentonite beds, and a few thin sandstone beds.	Yields little or no fresh water.
		Lower Cretaceous	Thermopolis shale		Shale, black, soft; contains gray to brown irregular Muddy sandstone member about 200 feet above base and about 40 feet thick.	Do.

			Cloverly formation	0–240	Three distinct units: upper silt and sandstone, middle shale, and lower sandstone. Sandstone at base lenticular and locally absent.	Lower sandstone yields small quantities of water.
	Jurassic		Morrison formation	0–300	Shale, variegated; contains lenticular conglomerate near the middle.	Yields little or no fresh water.
		Upper Jurassic	Sundance formation	0–400	Limestone, thin, brown, fossiliferous, and greenish-gray sandstone, green shale, and sandy shale; contains red shale and gypsum, the lateral equivalent of Gypsum Springs formation of Boysen area.	Do.
	Triassic		Chugwater formation	0–1,000	Siltstone, red, shaly in part, and red sandstone. Thin Alcova limestone member occurs in western part of area but is absent in eastern part.	Contains small amounts of water.
		Lower Triassic	Dinwoody formation	0–80	Shale, thin-bedded, yellow, silty; contains gypsiferous limestone at top.	Yields little or no fresh water.
Paleozoic	Permian		Phosphoria formation	0–270	Limestone, tan and gray; contains thin beds of siltstone and locally thin red shale at base.	Contains highly mineralized sulfurous (H_2S) water in Owl Creek anticline.
	Carboniferous: Pennsylvanian		Tensleep sandstone	350–375	Sandstone, tan, buff, gray, and white, in part crossbedded.	Reported to contain water of good quality under artesian pressure.
			Amsden formation	250±	Dolomite; contains shale partings; quartzitic sandstone (Darwin sandstone member) at base. Formation thins northward.	Ground-water possiblities not known.
	Carboniferous: Mississippian		Madison limestone	465–480	Limestone and dolomitic limestone, massive and in places brecciated. Locally may be cavernous at top.	Contains highly mineralized hot water under artesian pressure.
	Ordovician		Bighorn dolomite	140±	Dolomite, tan, gray, massive.	Contains little or no water.
			Gallatin limestone	455±	Limestone, impure; interbedded with thin beds of siltstone and silty shale.	Contains water in Embar anticline.
			Gros Ventre formation	400±	Sandstone and siltstone; contains impure limestone near top.	Do.
			Flathead quartzite	100–250	Quartzite and interbedded sandstone.	Reported to contain fresh water in Rose Dome.
Proterozoic	Precambrian				Granite, gneiss, and schist.	Weathered zone in granite may contain ground-water.

early in Middle Cambrian time and continued to advance eastward throughout that epoch. The Middle Cambrian rocks in the Owl Creek area are the Flathead quartzite and the Gros Ventre formation. The Flathead is a transgressive sandstone facies that becomes younger eastward. Continued expansion of the sea took place during Late Cambrian time, and sediments showing a gradation from near-shore sandstone (locally the Deadwood formation) to offshore limestone (the Gallatin limestone) were deposited. Some of these latest Cambrian rocks may have been removed by pre-Ordovician erosion during a period of emergence at the end of the Cambrian period. Emergent conditions continued until late in Ordovician time, when the northern and western parts of the region were submerged; during this submergence, the Bighorn dolomite was deposited in the Owl Creek area. The Wyoming area was emergent again at the end of Ordovician time, and it remained above the sea until late in Devonian time, when a sea again advanced from the west submerging only the northwestern and western parts of what is now Wyoming. Thus, no sediments of Silurian or Devonian age were deposited in the Owl Creek area.

Widespread submergence characterized Early Mississippian time, and large quantities of carbonate material were deposited to form the Madison limestone. Uplift at the end of Early Mississippian time resulted in the restriction of the Mississippian sea to the geosynclinal region west of Wyoming, and the Owl Creek area was eroded throughout the remainder of the period. During Early Pennsylvanian time the sea again advanced, and shaly, limy, and sandy sediments were deposited to form the Amsden formation and the Tensleep sandstone in the Owl Creek area. The sea then retreated eastward, the area being emergent during later Pennsylvanian and early Permian time.

In middle Permian time, an arctic sea expanded from the north over Wyoming and in it were laid down the limy sediments of the Phosphoria formation. After a period of instability during which the sea retreated and advanced several times and the sediments of the red-bed and limestone facies were deposited locally, the sea withdrew from Wyoming in late Permian time and the area was again emergent.

MESOZOIC ERA

Early in Triassic time a sea reached southeastern Idaho and later spread eastward into Wyoming and the Owl Creek area. The initial deposits in this sea were the tawny siltstone and shale of the Dinwoody formation. After the Dinwoody was deposited, the area was one of shallow basins and extensive mud flats and of arid climate, and the red shale, siltstone, and sandstone of the Chugwater formation were laid down. Marine conditions existed again over much of Wyoming during latest Chugwater time; during this time the Alcova limestone member of the Chugwater was deposited in the western part of the Owl Creek area. The area was emergent again from Late Triassic until Late Jurassic time.

Sediments accumulated under continental conditons during Early Jurassic time. An arctic sea then spread southward and covered Wyoming early in Late Jurassic time. During this submergence the limestone, sandstone, and shale of the Sundance formation were deposited in the Owl Creek area. Marine conditions terminated at the end of Sundance time, and the variegated continental shale of the Morrison formation was deposited.

At the beginning of Cretaceous time the Owl Creek area was a land surface. The Cretaceous sea then began to expand westward, and as it advanced over the area the near-shore silt and sand deposits of the Cloverly formation were laid down. The sea continued to advance, and during most of Cretaceous time a complicated series of several thousand feet of marine clay and sand were deposited to form the Thermopolis and Mowry shales, the Frontier formation, and the Cody shale. The sea began to retreat during Late Cretaceous time, and in its wake the clastic continental rocks of the Mesaverde formation were laid down. Minor oscillations of the sea during the major transgression and regression of the Cretaceous sea caused the abrupt changes in lithology characteristic of Cretaceous rocks in this area. The Cretaceous period ended with complete withdrawal of the sea and with the extensive mountain making of the Laramide revolution. During this and early Tertiary time, the ancestral Bighorn River basin and adjacent folded structures were formed, and the Owl Creek Mountains attained approximately their present form.

CENOZOIC ERA

During Paleocene time the Owl Creek area was uplifted and then, being topographically high, was eroded by streams. During Eocene time and possibly during Oligocene time, sediments completely filled the Bighorn Basin and covered the Owl Creek Mountains. Eocene igneous activity was centered in the Yellowstone Park area to the west and caused the accumulation of volcanic tuff and breccia in the area. In late Tertiary time, owing either to uplift or to climatic change in the Owl Creek area, active aggradation in the Bighorn River basin ceased and active degradation began. Erosion has been the dominant geologic process in the region since that time. The removal of most of the Tertiary sediments again exposed the more erosion-resistant mountain ranges and adjacent structures that had been buried. The Bighorn River was superimposed on the area from its position on the

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Tertiary sediments to form the deep Wind River Canyon in the Owl Creek Mountains. Minor interruptions in the last long cycle of erosion are reflected by the present topography of the basin. Streams flowing from the flanks of the mountains became entrenched; when the streams reached a temporary base level, they meandered from side to side and both widened and leveled their valley floors. As the valleys were widened and leveled, the streams deposited the gravel which now underlies the surface of the terraces. Downcutting and subsequent valley widening resulted in the development of the terraces and the present flood plain of Owl Creek and its tributaries. Concurrent with the action of the streams, direct erosion by precipitation has produced extensive badlands and, by contributing to escarpment retreat, has been an important factor in the formation of pediments at the base of escarpments. Wind has been an active agent of erosion in local areas.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Sedimentary rocks of Pennsylvanian to Recent age are exposed in the Owl Creek area. Formations older than the Tensleep sandstone of Pennsylvanian age do not crop out in the report area, but they have been penetrated in the subsurface during oil exploration. Although most of the formations that underlie the area may yield some water, only the most important aquifers are discussed in the following paragraphs. Table 1 summarizes the thickness, character of material, and water supply for each of the formations that either crop out or are known to be present in the subsurface within the report area.

MADISON LIMESTONE

In the Owl Creek area the Madison limestone, of Mississippian age, consists principally of limestone and dolomitic limestone. It does not crop out in the report area, but is exposed in the Wind River Canyon a few miles south of Thermopolis and in the Owl Creek Mountains on both sides of the canyon. The exposed limestone is generally massive, but in places it is cavernous or brecciated, or both. The lower part of the formation grades from a locally fossiliferous gray to brown oolitic limestone and crystalline dolomite into finely crystalline limestone and dolomite. In some places the basal beds are sandstone and shale. The lower part of the Madison generally is of lighter color than the middle and upper parts. The middle part of the formation is mostly massive limestone and dolomite and can be identified by its characteristic bluish-gray color. It generally contains a breccia zone which is underlain by a gray to tan cherty crystalline dolomite and limestone. The upper part of the Madison is composed of fossiliferous thin-bedded limestone and dolomite that locally contains lenses of sandstone and shale. In many places outcrops of the upper part are obscured by talus or slope deposits.

Data obtained from oil-well logs and deep test holes indicate that the formation is present in the subsurface throughout the report area, the thickness ranging from 465 to 480 feet. The Madison limestone is overlain by the Amsden formation and is underlain by the Bighorn dolomite.

Wells penetrating the Madison yield water under artesian pressure which is sufficient to cause the water to flow at the land surface in many places. The temperature of the water has been reported to be as much as 145°F, probably indicating that the water passes near a hot igneous intrusion. Large quantities of water issue from hot springs at Thermopolis. The water probably is derived principally from the Madison limestone.

TENSLEEP SANDSTONE

Most of the Tensleep sandstone, of Pennsylvanian age, is tan, buff, gray, and white fine- to medium-grained crossbedded sandstone. Pink sandstone, dolomite, limestone, some shale, and anhydrite are present locally within the formation. The quartz grains that make up the sandstone are fairly well sorted, subangular to subrounded, and frosted to translucent. The sandstone is generally porous and friable, though locally hard. The crystalline limestone and dolomitic limestone, which in places are interbedded with the massive sandstone, contain minor amounts of gray chert. Locally the contact between the limestone and sandstone is gradational.

The Tensleep sandstone is exposed only in the southwestern part of the Owl Creek area. The formation crops out in narrow bands along the Anchor and Embar anticlines; however, it undoubtedly underlies the remainder of the area. Sediments penetrated in deep oil-well tests indicate that the thickness of the formation ranges from 350 to 375 feet.

Water can be obtained from the Tensleep sandstone but the amount will differ from place to place, depending on the degree of cementation of the sandstone or the extent to which it is fractured. Within the report area, water from the Tensleep sandstone is under artesian pressure, and locally it may flow at the land surface.

CLOVERLY FORMATION

The Cloverly formation, of Cretaceous age, is composed of three distinct units, a lower sandstone, a middle shale, and an upper silt and sandstone. The lower unit is predominantly buff to gray sandstone and shaly sandstone, locally conglomeratic. The middle unit consists of medium- to drak-gray to reddish shale containing some plant fossils or imprints and locally containing some lenses of sandstone. The upper unit consists mostly of fine- to coarse-grained brown, buff, and grayish-brown dense sandstone, in part quartzitic, composed of subangular to subrounded quartz grains. The sandstone is locally overlain by a bed of siltstone. Because of its characteristic iron-stained appearance, the upper unit is frequently called the "rusty beds."

The Cloverly formation crops out along the flanks of the major structural domes and anticlines in the area. The formation dips sharply away from the uplifts and lies at considerable depth below the land surface elsewhere in the report area. The beds are nearly vertical on the steep sides of the anticlines, so that at these localities the Cloverly formation forms only a narrow band. The thickness of the formation ranges from 0 to about 240 feet.

The formation is known to contain water under artesian pressure on the flanks of the Owl Creek anticline, and it is probable that wells penetrating the formation downdip from the areas of outcrop also will yield water under artesian pressure. It is doubtful, however, that the yield would be more than enough for domestic and stock uses.

FRONTIER FORMATION

Most of the Frontier formation, of Cretaceous age, is composed of gray to gray-brown very fine to fine-grained sandstone interbedded with medium- to dark-gray sandy and bentonitic shale. Clayey sandstone, some of it bentonitic, is present sporadically throughout the formation. Locally, bentonite beds and thin beds or lenses of lignite separate the sandstone and shale beds.

The Frontier formation crops out on the north flank of the Owl Creek Mountains and along the flanks of domes and anticlinal structures in the report area. It overlies the Mowry shale and underlies the Cody shale. The Frontier has been eroded away along the crest of anticlines, but it attains a thickness of about 800 feet in the subsurface.

Water can be obtained from the Frontier formation in quantities sufficient only for domestic and stock use, as the sandstone is compact and the pores are small. The water is generally under artesian pressure, and locally it may flow at the land surface.

CODY SHALE

Most of the Cody shale, of Cretaceous age, in the Owl Creek area is composed of gray to black marine shale, but it contains thin limy sandstone beds in its upper part. Gray calcareous shale and a few thin bentonite lenses are present within the formation. The material weathers to grayish brown, chalky brown, and yellow. Throughout the area, the deposits are sandier toward the top of the formation, and where the Mesaverde formation is present they grade upward into the sandstone of that formation.

The Cody shale is exposed almost continuously along the north side of Owl Creek and in a few places along the flanks of the uplifts on the south side. Erosion following the uplift that formed the Owl Creek Mountains removed most of the Cody from the north flank of the mountains along the south side of Owl Creek. The Cody rests conformably on the Frontier formation, is overlain conformably by the Mesaverde formation, and is the bedrock beneath most of the central part of the Owl Creek valley. The Cody attains a thickness of 2,500 feet in the area.

Water for domestic and stock use is obtained from sandstone beds in the upper part of the Cody shale. Only small quantities of water can be obtained from the remainder of the formation because the permeability is low. Larger quantities of water can be obtained from fracture zones in even the fine-grained parts of the formation, but these are difficult to locate. The water from the Cody shale generally is under artesian pressure, but the pressure is not sufficient to cause the water to flow at the land surface in the area.

TERRACE DEPOSITS

The terrace deposits, of Quaternary age, consist mainly of gravel, sand, and silt, but pebbles and cobbles are present locally within the formation. As shown on plate 1 they do not include the first terrace above the present flood plains. The materials are well sorted, except locally where they are covered by or mixed with fine-grained slope deposits. In places there are deposits of caliche (calcium carbonate) 3 to 5 feet below the land surface. The presence of these evaporite deposits shows that the downward movement of water is locally retarded by fine-grained material within the terrace deposits.

The terrace deposits shown on plate 1 are 30 to 50 feet above Owl Creek. They are most conspicuous on the north side of Owl Creek but are present sporadically along both forks of the creek. Most of the deposits are relatively thin, but locally they are as much as 40 feet thick.

Water for domestic, stock, and some irrigation use is obtained from the terrace deposits. Moderate to large quantities of water can be pumped for short periods from wells in the terrace deposits, but prolonged pumping can be expected to deplete the supply of ground water because in most places the aquifer is thin and recharge is not sufficient to meet the demand. Ground water from the terrace deposits generally must be considered a supplemental rather than a principal supply for irrigation.

ALLUVIUM

The alluvium, of Quaternary age, that underlies the flood plains of the principal streams consists of clay, silt, sand, and gravel. The alluvial deposits at the upper end of the Owl Creek drainage system consist primarily of pebbles, cobbles, and boulders. Downstream, particularly in the irrigated areas, these coarser materials have been covered by and mixed with silt and clay that have been washed in from the valley sides. The texture of the alluvium in the valleys of tributary streams ranges from fine to coarse, depending on the character of the parent bedrock.

The alluvium along the major streams and tributaries, as shown on plate 1, includes the lower terrace, which is about 15 to 25 feet above the streams. Data obtained from well drillers and owners indicate that the thickness of the alluvium ranges from a featheredge to as much as 38 feet. The average thickness is probably about 20 feet.

Sufficient water for domestic and stock use can be obtained from the alluvium, but the water is used mainly for stock. Although tests have not been made of the water-bearing characteristics of the alluvium, the authors believe that, locally, where coarse materials occur, moderate quantities of irrigation water could be pumped. Except near perennial stretches of the streams, however, recharge is small and thus will limit the total quantity of water that could be pumped from the alluvium.

GROUND WATER

PRINCIPLES OF OCCURRENCE

The following discussion of the occurrence of ground water is adapted in large part from Meinzer (1923, p. 2–102), and the reader is referred to his report for a more detailed discussion of the subject.

All water beneath the surface of the earth is termed "subsurface water." The part of the subsurface water in the zone of saturation is termed "ground water" or, sometimes, "phreatic water," whereas subsurface water above the zone of saturation—that is, in the zone of aeration—is called "suspended subsurface water," or "vadose water." Vadose water is not available to wells or springs. It occurs in three zones, from the surface down (a) the zone of soil moisture, (b) the intermediate vadose zone, and (c) the capillary fringe. Water in the capillary fringe is held up from the water table by capillarity; it will not flow into a well, even though the material in the lower part of the fringe commonly is saturated. Ground water is available to wells and springs.

The rocks that form the outer crust of the earth are seldom totally solid but have numerous open spaces, called voids or interstices, which may contain air, natural gas, oil, or water. The interstices in rocks range from microscopic openings to the large caverns that are found in some limestone and volcanic rocks. Because the open spaces are generally connected, water may percolate from one to another, although in some rocks the interstices are isolated and the water has little or no chance to move. The occurrence of water in the rocks of any region is determined by the character, distribution, and structure of the rocks—that is, by the geological character of the region. All the rocks penetrated by wells in the Owl Creek area are sedimentary, but they include several types that differ greatly in lithologic character and in their ability to store and transmit water. The chief types of sedimentary rocks in the area are sand, gravel, sandstone, shale, and limestone.

The valleys of Owl Creek and its tributaries are underlain by alluvium consisting predominantly of sand, gravel, silt, and clay. Some of the beds contain well-sorted sand and gravel having a moderately uniform texture and a relatively high specific yield and permeability. Wells in this type of material yield adequate quantities of water to domestic and stock wells, and locally yield sufficient water for small-scale irrigation. Some of the alluvium and terrace deposits are thin and poorly sorted and contain silt and clay which tend to fill the pore spaces and reduce the permeability. Wells in this type of material yield only small quantities of water.

Most of the sandstone beds in the bedrock formations underlying the Owl Creek area are fine grained and have a relatively low permeability, owing to the adhesion of the water to the walls of the very small pore spaces, and to the absence of numerous or large fractures. In those sandstones in which the grains are held together by cementing material, the pore spaces are partly or mostly filled with the cement and little space is left for the movement of ground water. However, some saturated sandstone is uniformly grained and poorly cemented and will yield moderate supplies of water to properly constructed wells. The principal sandstone aquifers in the area are in the Tensleep sandstone, Cloverly formation, Frontier formation, and upper part of the Cody shale.

Shale is formed by the induration of clay or by mixture of sediments high in clay; it generally has a very low permeability. At some places, firm shale may have sufficient open joints and bedding planes to yield useful quantities of water to wells. At other places the shale may contain sufficient sand beds or lenses to make it moderately permeable. Many of the formations in the report area contain shale beds, but only those that are fractured or contain beds or lenses of sandstone are sufficiently permeable to yield water to wells.

The impermeability of shale is of value in some localities within the Owl Creek area. Shale overlies many of the sandstone beds; thus, water that enters the sandstone and passes beneath the shale is confined under artesian pressure and will rise in wells above the level at which it is tapped. The artesian pressure in some beds is sufficient to cause the water in wells to flow at the land surface throughout much of the area.

The limestone in the Owl Creek area is massive to thinly bedded; because some of it is dense and some has many openings or cavities, the limestone has a wide range in permeability. The large openings in the Madison limestone can be expected to yield large quantities of water to wells.

In many places in the Owl Creek area there is more or less continuous movement of water from one aquifer to another. It may move betweeen confined and unconfined aquifers (from bedrock to alluvium, for example), between different unconfined aquifers (from terrace deposits to alluvium), or between different confined aquifers. The movement of ground water from one aquifer to another is governed by the difference in pressure head or level of the water in the aquifers, the relative permeability of the aquifers, and the permeability of the confining beds or aquicludes. The movement probably is small except in localities where the different aquifers are in direct contact. However, this interchange of water does not represent a net addition to or withdrawal from the total ground-water supply of the area.

HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS

The hydrologic properties of water-bearing materials that are of primary concern in developing wells are their coefficients of permeability, transmissibility, and storage. Permeability is a measure of the ability of a unit cross section of material to transmit water (p. 21); transmissibility is the analogous property of a unit width of a whole aquifer; the coefficient of storage is a measure of the ability of a unit prism of the aquifer to release water from, or take water into, storage as a result of a change in head. The specific capacity of a well is the ratio of its yield to its drawdown and is governed by the transmissibility and storage coefficients of the aquifer and by the degree of thoroughness with which the well is developed. Specific capacity generally is expressed as the number of gallons per minute the well will yield per foot of drawdown of the water level in the well while it is being pumped.

The rate of movement of ground water is determined by the size, shape, number, and degree of interconnection of the interstices in the aquifer, by the density and viscosity of the water, and by the hydraulic gradient. The capacity of a water-bearing material for transmitting water under a hydraulic gradient is known as its permeability.

Meinzer's coefficient of permeability is the rate of flow of water, in gallons per day through a cross section of 1 square foot, under a hydraulic gradient of 100 percent, at a temperature of 60°F. (Wenzel, 1942, p. 7). It may be expressed as the number of gallons of water per day, at 60° F., that is conducted laterally through each mile of the water-bearing bed (measured at right angles to the direction of flow), for each foot of thickness of the bed and for each foot per mile of hydraulic gradient. The field coefficient of permeability is the same unit (expressed in either of the ways given above), except that it is measured at the prevailing temperature of the ground water in the area concerned. The coefficient of transmissibility is a similar measure for the entire thickness of the water-bearing formation and may be expressed as the number of gallons of water per day transmitted at the existing temperature through each 1-foot strip of the height of the aquifer, under a hydraulic gradient of 100 percent (or section of the aquifer 1 mile wide at a gradient of 1 foot per mile); it is the field coefficient of permeability multiplied by the thckness, in feet, of the aquifer.

The term "coefficient of storage" expresses the quantity of water released from storage in a column of the aquifer of unit cross section as the result of a unit decline in head. It is defined formally as the volume of water an aquifier releases from or takes into storage per unit surface area of the aquifier per unit change in the component of head normal to that surface. Under water-table conditons this quantity is approximately equal to the specific yield, which is the quantity of water, expressed as a ratio, that a given volume of the aquifer will yield under the pull of gravity if it is first saturated and then allowed to drain. Under artesian conditions the aquifer remains saturated, and the coefficient of storage represents either the water released from storage by the compression of the aquifer and by expansion of the water itself as the head declines or that added to storage by dilation of the aquifer and compression of the water as the head increases; it is proportional to the thickness of the aquifer.

The writers made aquifer tests, using the recovery method, on three wells penetrating the terrace deposits in the Owl Creek valley. The results of these tests are:

Well	Duration of test (minutes)	Discharge (gallons per minute)	Drawdown (feet)	Specific capacity (gallons per minute per foot of drawdown)	Coefficient of transmissibility (gallons per day per foot)	Saturated thickness of water-bearing material (feet)	Coefficient of permeability (gallons per day per square foot)
63	30	156	2.22	70	48,000	11	4,400
70	440	162	16.65	9.7	53,000	24	2,200
71	440	170	14.21	12	56,000	24	2,300

The method uses the following formula developed by Theis (1935):

$$T=\frac{264Q}{s}\log_{10}\left(\frac{t}{t'}\right)$$

in which

T=coefficient of transmissibility, in gallons per day per foot;
Q=discharge, in gallons per minute;
t=time since discharge began, in any unit;
t'=time since discharge stopped, in the same unit;
s=residual drawdown of the well, in feet, at time t'.

Values of residual drawdown (s), to linear scale, are plotted against corresponding values of the ratio of the time since discharge began and the time since discharge stopped (t/t'), to logarithmic scale. A straight line is then drawn through these points. The value Δs for one log cycle of t/t' (for which the value of $\log_{10}t/t'$ is unity) is determined and T is computed from the simplified formula

$$T=\frac{264Q}{\Delta s}$$

in which Q is the discharge, in gallons per minute, during the period of pumping.

ARTESIAN CONDITIONS

The pressure head of water at a given point in a body of water at rest has been defined as the height to which a column of water will rise above that point in a tightly cased well that has no discharge. Ground water that rises in wells above the level at which it is first penetrated is said to be "artesian" water, whether or not it rises high enough to flow at the land surface.

In many of the rock formations in the Owl Creek area, strata of relatively permeable rock, principally sandstone, alternate with strata of relatively impermeable rock, such as shale or clay. The strata in the area dip away from their outcrops, and water that enters the more permeable beds in their areas of outcrop moves down the dip of the beds and eventually passes between less permeable beds. Therefore the water in the saturated permeable beds that lie between the relatively impermeable confining layers is under artesian pressure.

The principal artesian aquifers in the area are in the Madison limestone, Tensleep sandstone, Cloverly and Frontier formations, and Cody shale. Water-bearing sandstone beds confined between relatively impermeable beds are present in all these formations except the Madison limestone. The Madison limestone locally contains solution channels that transmit water under artesian pressure. The general dip of the formations is northward from the Owl Creek Mountains, but in places local uplift and faulting have caused the strata to dip in other directions.

The piezometric surface is an imaginary surface to which water in a confined aquifer will rise in a well; it is analogous to the water table in an unconfined aquifer. The piezometric surface is not a plane surface but, like the water table, has irregularities and variations in slope. Likewise, it does not remain stationary but fluctuates more or less constantly in response to the same forces that affect the water table; in addition, it responds to forces such as loading and unloading of the aquifer as a result of changes in atmospheric pressure, to which the water table does not ordinarily respond. Obviously, each separate confined aquifer has its own piezometric surface.

The shape and slope of the piezometric surface of an aquifer determine the rate and direction of movement of ground water in the aquifer and are controlled by several factors. Irregularities in the shape and slope may be caused by (a) structure of the aquifer, (b) local differences in the permeability and thickness of the aquifer, (c) recharge to the aquifer, and (d) discharge of ground water through springs, seeps, and wells.

Data are not available to determine the extent of influence of each of the above factors on the piezometric surface of each of the artesian aquifers in the Owl Creek area. Each formation differs locally in structure, permeability, thickness, and location and amount of ground-water recharge and discharge, so that the shape and slope of its piezometric surface likewise differs locally.

In most of the area the confined water in the bedrock aquifers is under sufficient pressure to rise above the water table. Figure 4 illustrates the relation of the piezometric surface to the water table in an idealized cross section. Water enters the aquifer in the recharge area and moves downdip to become confined between the relatively impermeable shale beds. Water in the aquifer under the recharge area is under water-table conditions; downdip, the water is confined between the shale beds under artesian pressure. Wells penetrating the aquifer downdip from the recharge area obtain water under sufficient pressure to rise above the level at which it is found and, at some places, to flow at the land surface. The piezometric surface near the flowing wells is drawn down and forms a cone of depression around each well.

Water in the Madison limestone and the Tensleep sandstone is a part of an extensive artesian system. Water percolating through this system locally saturates permeable overlying and underlying strata. The intake or recharge areas are the exposures of the formations on the north slope of the Owl Creek Mountains. The ground-water reservoir is recharged by the direct penetration of precipitation and by seepage from small streams that flow across the outcrop areas. The natural discharge area for the artesian water that enters these forma-

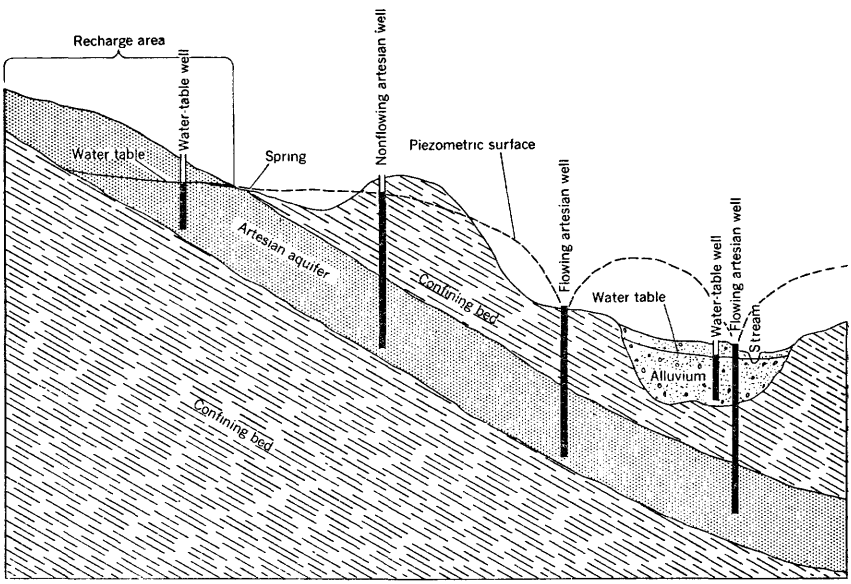

FIGURE 4.—Diagram showing water table and piezometric surface in unconfined and confined aquifers.

tions on the north slope of the Owl Creek Mountains appears to be chiefly along the axis of the Thermopolis anticline (Andrews, Pierce, and Eargle, 1947) south of the report area, where the strata have been broken by overthrust faulting and water issues from several large hot springs. The largest of these, Bighorn Hot Spring, is reported to yield about 13,000 gpm (gallons per minute). The temperature of the spring water was measured as 137°F. Hot water (about 145°F.) has been recovered from the Madison limestone in deep test wells on the White Rose and Rose Domes, both of which lie along the Thermopolis anticline.

The Cloverly and Frontier formations are recharged mainly by precipitation, which falls on extensive dip-slope exposures of the sandstone beds on the south side of the Owl Creek valley. Locally, the formations are recharged by water moving downward from overlying saturated alluvium.

The gently dipping Cody shale is recharged mainly from overlying zones of saturation in unconsolidated alluvium and terrace deposits. The thin sandstone beds and zones of fractured shale absorb water, which percolates down the dip of the strata. Thus, small supplies of water under artesian pressure can be obtained at moderate depths in the valley of Owl Creek. The artesian pressure, however, is not sufficient to cause the wells to flow at the land surface. Well 53, which is on the north side of the valley, penetrates sandy Cody shale at a depth of about 50 feet; the water from this depth rises to about 20 feet below the land surface. A few miles farther east a fractured zone in the Cody shale yields artesian water to well 37, in which the water rises to about 9 feet below the land surface.

WATER-TABLE CONDITIONS

Water in the terrace deposits and alluvium in the Owl Creek area occurs under water-table conditions. Meinzer (1923, p. 30, 31) discusses the water table in part as follows:

> The upper surface of the zone of saturation in ordinary permeable soil or rock is called the "water table." Where the upper surface is formed by impermeable rock the water table is absent. * * * The water table is not a level surface but has irregularities comparable with and related to those of the land surface, although it is less rugged. It does not remain in a stationary position but fluctuates up and down. The irregularities are due chiefly to local differences in gain or loss of water, and the fluctuations are due to variations from time to time in gain or loss.

The shape and slope of the water table (like those of a piezometric surface) indicate the rate, and direction of movement of ground water and are controlled by several factors. The gain or loss of water that contributes to the variations and differences in the shape and slope of the water table results from the differences from time to time in the amounts of ground-water recharge contributed by direct penetration of precipitation and by seepage from streams or from irrigation water applied to the land. Variations in the rates of discharge of ground water by seeps and springs, by direct evaporation from the zone of saturation, by transpiration from vegetation growing where the water table is shallow, and by pumping from wells likewise affect the water table. The shape and slope of the water table may be governed also by the configuration of the bedrock floor and by local differences in the thickness and permeability of the aquifer.

The general shape and slope of the water table in the terrace deposits and alluvium in the Owl Creek valley area are shown on plate 2 by contour lines. Contour lines drawn on the water table show the configuration of the water surface just as contour lines on topographic maps show the shape of the land surface. Each point on the water table along a contour line has the same altitude. The contour lines are based on measurements made of the water level in wells during the summer of 1946 and show the approximate shape and slope of the water table at the time the measurements were made. Fluctuations of the water table, particularly in the areas of shallow water, cause small seasonal changes in its shape and slope. The direction of movement of the ground water is down the slope of the water table and at right angles to the contour lines.

Although the slope of the water table and the direction of ground-water movement differ slightly from place to place, the general movement of the ground water in the terrace deposits and alluvium in the area is easterly. The slope of the water table is very nearly the same as the slope of the stream channel; it ranges from about 75 feet per mile in the western part of the area to about 30 feet per mile in the eastern part. The contour lines on the water table are nearly perpendicular to the stream in the eastern and western parts of the area, and thus they indicate very little ground-water movement from the adjacent formations to the stream. The contour lines in the central part of the area, where the Quaternary deposits are more extensive, bulge upstream and indicate much more movement of ground water from the adjacent terrace and alluvial deposits into the stream. The contour lines near the confluence of Owl Creek with the Bighorn River bulge downstream and indicate that ground water is moving from Owl Creek into the alluvium of the Bighorn River valley.

Except just above its confluence with the Bighorn River, the bed of the main stem of Owl Creek receives water from the underground reservoir; thus, Owl Creek is primarily a "gaining," or effluent, stream. The water table slopes gently downstream but also toward the stream. It also slopes from the outer to the inner edge of the terraces, where it dips rather sharply into the alluvium and again slopes gently toward the stream. These relationships are not shown by the generalized contour lines in figure 4 but are illustrated by the profile of the water table in figure 5. Along the inner edge of a terrace, the deposits are thin or are absent, and seeps occur near the base of the adjacent escarpment.

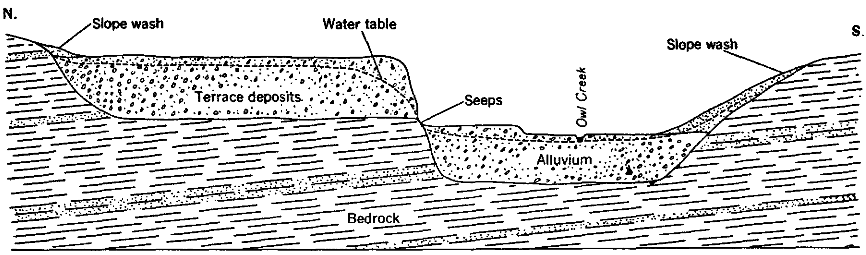

FIGURE 5.—Idealized cross section showing relation of the water table, the unconsolidated Quaternary deposits, and the underlying bedrock of Owl Creek valley.

Pumping from wells causes a drawdown of the water level and a pronounced distortion of the water table near the pumped wells. When irrigation wells are pumped heavily, relatively deep depressions are created in the water table around the pumped wells. However, the shape and slope of the water table as shown by plate 2 is too generalized to reflect changes in the water table that may have been caused by the removal of the relatively small amount of water pumped from wells in the area.

RECHARGE

The ground-water reservoir underlying the unconsolidated Quaternary deposits in the Owl Creek valley is recharged principally by direct penetration of precipitation, by seepage from irrigation canals and irrigated land, and by seepage from surface streams and depressions.

The direct penetration of precipitation is an unimportant source of recharge compared to the seepage from irrigation water. Of the precipitation that falls on the area, a part is returned to the atmosphere by evaporation and transpiration (evapotranspiration), a part runs off directly to surface streams, and a part infiltrates to the ground-water reservoir. The normal annual precipitation in the area is about 13 inches, of which only a small part, possibly no more than 1 inch, reaches the ground-water reservoir.

Precipitation that is not discharged immediately by evapotranspiration and by direct runoff to the streams percolates downward into the soil. The soil absorbs moisture until it can hold no more against the force of gravity; then, any excess moves downward to the zone of saturation. Such downward movement of water during the growing season may be prevented by transpiration, which may deplete the soil moisture more rapidly than it can be replenished by precipitation. Thus, at the end of the growing season, the soil moisture may be largely depleted. Precipitation during the fall and winter, at which time there is comparatively little evapotranspiration, tends to replenish the soil moisture and, after replenishing it, to move downward to the water table. Most of the ground-water recharge from precipitation in the Owl Creek valley occurs during the fall, winter, and early spring months. The high rate of evapotranspiration and the generally low rate of precipitation during the growing season probably permit very little recharge from precipitation during that season except where the water table is near the land surface.

Most of the water that reaches the ground-water reservoir seeps from the canals and laterals and from irrigated fields when applied in amounts excess to the soil-moisture requirements. This recharge is illustrated by the fluctuation of water levels in wells. It is interesting to note that the water levels fluctuate in response to the amount of precipitation. This fluctuation is due not to infiltration of the scanty precipitation but to the close relation between rainfall and the available supply of irrigation water. Irrigation water is diverted directly from Owl Creek, and the flow of the stream responds directly to precipitation. A hydrograph of the average water level in 13 wells in the irrigated part of the Owl Creek valley (fig. 6) shows a general seasonal fluctuation; the water level rises from March to

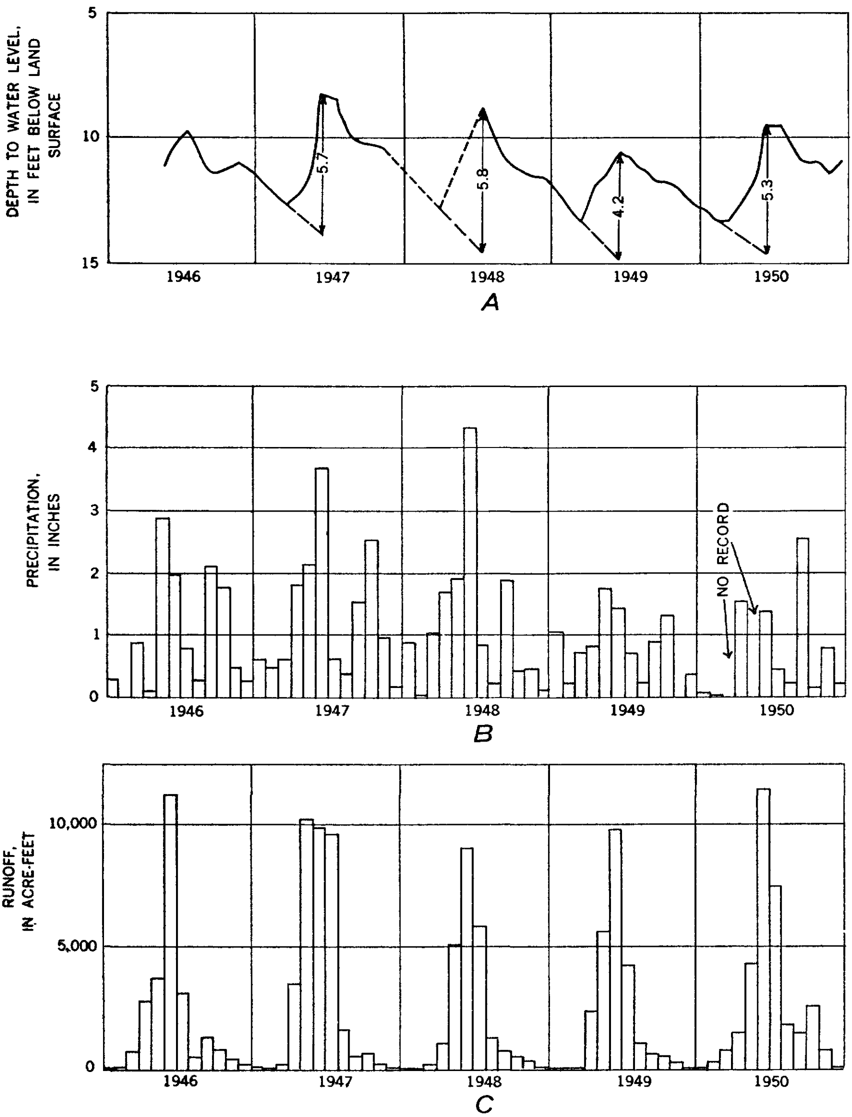

FIGURE 6.—Graphs showing *A*, average water level in 13 wells in Owl Creek valley, *B*, monthly precipitation at Thermopolis, Wyo., and *C*, combined flow of North and South Forks of Owl Creek above their junction.

July, when irrigation water is being applied to the land, and declines during the intervening months.

If the downward trend of the hydrograph during the winter months is projected each year until the time when the water levels actually reached the seasonal high (fig. 6), the average water level that presumably would have been reached if the winter discharge-recharge relation had continued to June or July would be about 14.4 feet below the land surface. However, recharge occurred or increased during the spring and early summer months, and the water level in the wells rose to an average depth of 9.2 feet below the land surface; this is a gross average rise of about 5.2 feet from the projected low. The projected low was based on the assumption that the rate of discharge during the winter continued through the spring and early summer. However, because of greater losses from evaporation and transpiration and because the hydraulic gradient is steeper, the discharge from the ground-water reservoir actually increases during the summer. Consequently, the gross average rise in water level probably is slightly greater than the 5.2 feet indicated. Therefore, if the average gross rise in water level is 5.2 feet and the storage coefficient is about 0.20, the annual recharge to the shallow ground-water reservoir is about 1 acre-foot of water per acre. Most of this recharge takes place by seepage from irrigation canals and ditches and irrigated land; only a very small part results from direct penetration of precipitation.

Although the shape of the water-table contour lines on plate 2 indicates that the movement of ground water generally is either from the unconsolidated alluvium and terrace deposits into the streams or parallel to the streams, the alluvium receives water from the streams at a few places along their courses during part of the year. For example, just below the Anchor Dam site segments of the channel of the South Fork of Owl Creek are dry during times of drought and low streamflow. This condition gave rise to speculation as to whether water is lost continuously from the stream by percolation through the alluvium to the underlying bedrock. To determine whether such a loss occurred, 6 sets of streamflow measurements were made at 4 locations within a 4½-mile section of the stream below the Anchor Dam site. The data obtained from these measurements (table 2) show that, in general, the losses are so small that they do not affect the streamflow appreciably. The appearance of dry sections during very low stages is, in the opinion of the writers, primarily the result of a transition from finer to coarser, well-sorted, highly permeable alluvium in this part of the valley; this transition allows for an increase in the amount of water that moves down the valley by underflow. However, it is possible that a part, perhaps a large part, of the loss of streamflow that occurs during the summer months is due to transpiration by

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TABLE 2.—*Variation in streamflow in South Fork of Owl Creek near Anchor Dam site, Owl Creek valley, Wyoming, 1946*

Date	Anchor Dam site	1 mile below damsite	Gain (+) or loss (−) in 1-mile section		3 miles below damsite	Gain (+) or loss (−) in 2-mile section		4½ miles below damsite	Gain (+) or loss (−) in 1½-mile section		Gain (+) or loss (−) in entire 4½-mile section	
1946	Cubic feet per second	Cubic feet per second	Cubic feet per second	Percent	Cubic feet per second	Cubic feet per second	Percent	Cubic feet per second	Cubic feet per second	Percent	Cubic feet per second	Percent
5/21	28.5	28.9	+0.4	+1.4	29.4	+0.5	+1.7	28.0	−1.4	−4.8	−0.5	−1.8
6/20	73.5	73.0	−.5	−.7	73.2	+.2	+.3	69.0	−4.2	−5.7	−4.5	−6.0
7/15	37.2	36.8	−.4	−1.1	34.3	−2.5	−7.0	29.9	−4.4	−12.8	−7.3	−20.0
9/4	6.9	7.6	+.7	+10.0	6.0	−1.6	−21.0	4.5	−1.5	−25.0	−2.4	−35.0
10/7	6.9	[a] 7.8	+.9	+13.0	6.9	−.9	−12.0	8.2	+1.3	+18.8	+1.3	+18.8
12/2	8.5	[a] 7.7	−.8	−9.4	[b] 4.4	−3.5	−45.5	3.7	−.7	−16.0	−5.0	−58.8

[a] Ice in channel above and below measurement section.
[b] Surface inflow between this and the preceding station estimated at 0.2 cfs.

vegetation along the stream valley and to evaporation and that a small amount of water may move into the underlying bedrock.

Depressions are present locally in the lowlands of the Owl Creek area. Some of the depressions, in the western part of the area where the unconsolidated deposits overlie the Chugwater formation, may have been formed by subsidence of surficial sediments into solution cavities in the Chugwater. Others, in the major terraces, possibly were caused by wind action. Part of the water that collects in these depressions evaporates, but a part percolates downward to the water table.

DISCHARGE

Ground water in the area is discharged from the zone of saturation by evaporation and transpiration and by discharge through seeps, springs, and wells.

Where the water table is shallow, plant roots obtain ground water directly from the zone of saturation or from the capillary fringe, and that water is discharged from the plants by transpiration. The depth from which plants will lift ground water varies with the species of plants and type of soil. The limit of lift by ordinary grasses and field crops is only a few feet; however, the roots of some plants may extend to depths of several tens of feet.

Discharge of ground water by evaporation and transpiration in the Owl Creek valley occurs throughout most of the area underlain by the alluvium and terrace deposits, but it is greatest in the alluvium where the water table is relatively shallow. Alfalfa, which is a user of large quantities of water and is capable of extending its roots to relatively great depths, is grown throughout the area on the terrace deposits and on the alluvium along the streams; consequently, much water is transpired by alfalfa in the area. In addition to the water discharged by crops, a rather large amount is transpired by the natural vegetation growing along the stream courses where the water table is near the land surface.

Water is discharged from the ground-water reservoirs of the area by seeps along the contact of the terrace deposits and the underlying consolidated rocks. During wet weather, some water is discharged from seeps along the sandstone outcrops in the southern part of the area and in gullies. Seepage along the terrace escarpments is relatively small, and the water either evaporates or is transpired at or near its place of issue; however, during periods of large recharge to the terrace deposits, some water from them moves into the alluvium.

Water is also discharged from the ground-water reservoir by wells. Most wells in the area supply water for domestic and stock use and yield only small quantities of water; however, a few irrigation wells yielding 50 to as much as 500 gpm have been developed. The combined discharge of the irrigation wells probably does not exceed 100 acre-feet per year.

WATER-LEVEL FLUCTUATIONS

The water table and piezometric surfaces of ground-water reservoirs rise and fall much like the surface of the water in a surface reservoir, in accordance with the relation between the rate of recharge to and the rate of discharge from the reservoirs. If the inflow exceeds the discharge, the surfaces will rise; conversely, if the discharge exceeds the inflow the surfaces will fall. The water table and piezometric surfaces fluctuate more as a result of the addition or removal of a certain quantity of water than does the water level of a surface reservoir, because ground water occupies only part of the volume of a ground-water reservoir. Thus, if an unconfined sand and gravel aquifer has an average storage coefficient of 0.20, the addition of 1 foot of water to the aquifer will raise the water table 5 feet.

The principal factors that cause a rise of the water table in the Owl Creek area are (a) infiltration of precipitation, (b) infiltration from streams, and (c) deep seepage of irrigation water. The principal factor that causes a rise of the piezometric surfaces in the area is the entrance of water into the artesian aquifers in areas where they crop out (a) by downward percolation from rainfall and (b) by infiltration from streams.

The principal types of ground-water discharge that cause declines in the water table in the area are (a) the discharge of ground water into streams or to the land surface through seeps and springs, (b) evaporation and transpiration, and (c) pumping from wells. Factors causing declines in the piezometric surfaces in the area are (a) discharge through seeps and springs and (b) discharge from wells.

The fluctuations of the water table and the piezometric surfaces in the Owl Creek area were studied by means of periodic measurements

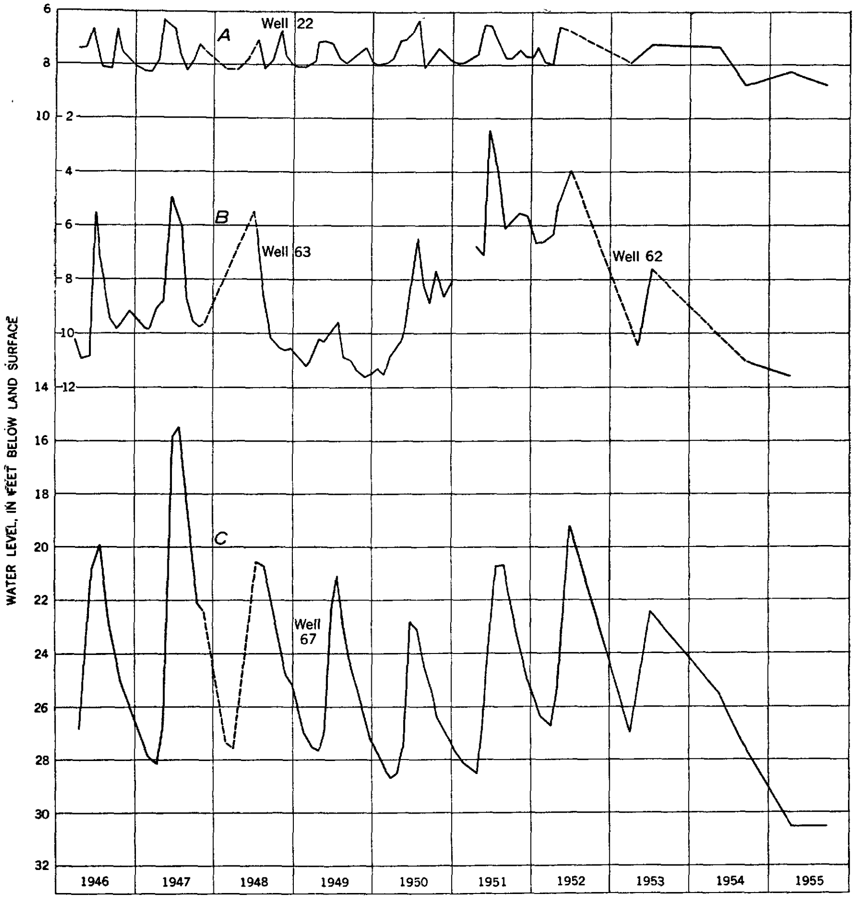

FIGURE 7.—Hydrographs showing changes in water level in wells in *A*, alluvium, caused by seasonal runoff; *B*, in terrace deposits, caused by recharge from irrigation; and *C*, in terrace and slope deposits, caused by recharge from irrigation.

of the depth to the water in wells. Although measurements were made of the water level in wells penetrating some of the artesian aquifers, the data were not conclusive, as the fluctuations appeared to follow no pattern; consequently, the following discussion of the water-level fluctuations is based principally on data pertaining to water-table conditions. Periodic measurements of water levels in wells in the area were begun in the summer of 1946. The water-level measurements are published in the water-supply papers of the U.S. Geological Survey.

Hydrographs in figure 7 show the fluctuations of the water level in 4 selected wells in the area. Well 22 obtains water from the alluvium of Owl Creek, and the water level in the well rises and falls in response to the flow in the stream. The flow of the stream generally is lowest during the winter months and highest during the summer months. The water level in well 22 generally fluctuates in a similar manner—it is low during the winter months and high during the summer. The minor peaks in the hydrograph probably reflect flood stages of the stream.

Wells 62 and 63 obtain water from the terrace deposits along Owl Creek and the water level fluctuates principally in response to infiltration of water from surface irrigation. The water level rises during the main irrigation season from May to August, inclusive, when most of the surface water is applied to the irrigated land. The water level generally declines during the nonirrigation season and reaches its lowest level during the winter months. Minor fluctuations probably reflect local conditions, such as precipitation or variations in amount of irrigation water applied to the land surface. When surface water is available during the fall months, hay crops are irrigated and small fluctuations of the water table result.

Well 67 penetrates terrace and slope deposits, and the water level in the well fluctuates in the same manner as does that in wells 62 and 63; however, the amount of change is much greater than in wells 62 and 63. Although the rise and fall of the water table in well 67 are caused principally by irrigation water, the increase in the range of fluctuation probably is due to a lower storage coefficient of the aquifer; that is, less water is required to fill the pore spaces of the aquifer than is required to fill the pore spaces in the aquifer penetrated by wells 62 and 63.

Fluctuations of the water levels in wells show a close relation to the fluctuations of precipitation because seasonal runoff and diversion of surface water for irrigation respond immediately to precipitation. Figure 6 shows the relation of the average water level in 13 wells in the area to precipitation and runoff. The peaks of the ground-water hydrographs are very nearly coincident with the periods of high precipitation and runoff.

RECOVERY

Pumping water from a well causes the water level in the well and in the aquifer surrounding the well to be drawn down to form a depression in the water table or piezometric surface that resembles an inverted cone, the apex of which is at the well (fig. 8). The surface area underlain by this cone of depression is known as the area of influence. The drawdown of the water level and the area of influence increase as the rate of pumping from a well increases. In artesian aquifers, owing to their lower coefficient of storage, the cone of depression enlarges faster than it does in water-table aquifers. If pumped wells are close together, their cones of influence may overlap so that pumping from one well will lower the water level in nearby wells.

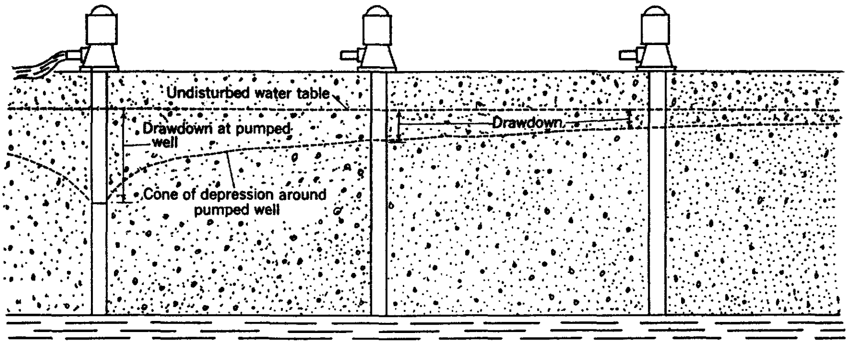

FIGURE 8.—Diagrammatic section of water table near well that is being pumped.

The specific capacity of a well (p. 20) is its rate of yield per unit of drawdown and is determined by dividing the discharge, in gallons per minute, by the drawdown, in feet. When a well discharges water, the water level declines, rapidly at first and then more slowly; it may continue to decline for several hours or days before the rate of decline becomes so small as to be negligible for the purpose of computing specific capacity. Conversely, when the discharge is stopped, the water level rises, rapidly at first and then more slowly; it may continue to rise long after the discharge has ceased. When wells 63, 70, and 71, which penetrate the terrace deposits, were pumped at rates of 156, 162, and 170 gpm, drawdowns of 2.22, 16.65, and 14.21 feet, respectively, resulted. Thus, the specific capacities of these wells were 70, 9.7, and 12 gpm per foot of drawdown, respectively; however, the specific capacity (70) determined for well 63 undoubtedly is too high, as the period of pumping was not long enough to allow the water level to become approximately stationary. No tests were made to determine the specific capacities of wells penetrating artesian aquifers in the area.

Much of the ground water recovered from the Owl Creek area is taken from drilled, dug, or bored wells. Wells that penetrate the consolidated deposits are drilled; those that penetrate the unconsolidated deposits are constructed by any one method or a combination of methods.

Many of the domestic and stock wells and most irrigation wells in the area have been drilled by the percussion (cable-tool) or the hydraulic-rotary methods, mostly the former. The drilled wells generally are cased with iron or steel, and their diameters range from 6 to 28 inches.

Dug wells are excavated with hand tools or power machinery, and their diameters generally range from 3 to 6 feet. Most of the dug wells were constructed during the early settlement of the area and are in localities where the water table is close to the land surface.

A few wells were bored in localities where the saturated deposits are only a few feet below the land surface. Bored wells generally are constructed with a hand auger.

Most wells in the area obtain water from unconsolidated alluvium and terrace deposits along the valley of Owl Creek. Drilled wells that obtain all their water from these deposits are cased the full depth of the hole to prevent caving. The casing generally is perforated opposite the aquifer. The casing in some of the older wells, however, is not perforated, and water can enter only through its open end; the quantity of water than can be obtained from such wells is materially reduced.

The selection of the correct size of perforation is important in constructing wells in unconsolidated deposits, particularly large-capacity wells such as may be used for irrigation or public supply; the yield, and at times even the life, of a well may be affected by the size of the casing perforation selected. If the perforations are too large, too much of the finer grained material may enter the well, perhaps filling it and damaging the pump; and if too much material is withdrawn, the ground may cave around the well. If the perforations are too small, they may become so clogged that water will not enter the well freely. The final development of a well to produce the most water with the least drawdown is easier and more certain where the casing perforations are of the correct size.

Good well-construction practice includes the selection of a well screen or perforated casing that will pass the fine-grained part (30 to 60 percent) of the material in the aquifer around the well. Retention of the coarser particles around the screen or perforated casing forms a natural gravel pack that greatly increases the effective diameter of the well and, hence, its specific capacity.

Gravel-walled (gravel-packed) wells generally are effective for obtaining large amounts of water from relatively fine grained unconsolidated deposits, and they are used widely for irrigation and public supply. A well of this type can be constructed by first drilling a hole 24 to 60 inches in diameter and then casing it temporarily with iron or steel pipe. A well screen or perforated casing of considerably smaller diameter than the hole then is lowered into place and centered in the larger pipe, screen or perforations being opposite the water-bearing beds. Unperforated casing extends above and between the perforated parts of the casing. The annular space between the inner and outer casings then is filled with sorted gravel, preferably of a grain size just a little larger than the openings in the screen or perforated casing and slightly larger than the grains of the water-bearing material. A medium- or coarse-grained gravel generally is used, but a fine-grained gravel or coarse-grained sand may be better in wells drilled in very fine grained deposits. The outer casing then is withdrawn far enough to allow the gravel packing to come in contact with the water-bearing material opposite the perforated sections of the casing.

Knowledge of the character of the water-bearing material is necessary to guide the choice of the type of well to be constructed. If the water-bearing material is a coarse gravel, as it is in parts of the Owl Creek area, gravel packing generally is unnecessary; wells of optimum efficiency can be constructed if a properly designed screen or perforated casing is used and the well is completely developed so that water will enter freely.

The above discussion deals only briefly with the construction and development of wells, and the reader is referred to Bennison (1947) for a more complete discussion of the subject.

Some ground water is discharged in the area through springs, most of which are artesian (springs that issue under artesian pressure). Most of the discharge from springs in and near the report area is from the thermal springs at Thermopolis and along the Bighorn River. The high temperature of the spring water can be reasonably assumed to be caused by heat from deep-seated igneous rock rather than by rise of the water from great depth. Neither the Tensleep sandstone nor the Madison limestone lies at sufficient depth to account for the high temperature of the water. To preserve the heat of the water in its course to the outlets, channels permitting rapid flow must exist; if the water rose slowly it would cool to the temperature of the adjacent rocks. That the water must be moving through large openings in the rocks is indicated also by the large flow of the springs. The Madison limestone is capable of providing such openings, and the spring water is similar in quality to water in the Madison elsewhere; these facts are strong evidence that the water is derived largely from the Madison. The total amount of water discharged through the springs is not known, but the flow from one of the largest springs is reported to be about 13,000 gpm.

A few contact springs and seeps occur along tributaries to Owl Creek, but only small amounts of water issue from them. These springs and seeps issue at the contact of the unconsolidated terrace deposits with the underlying consolidated rocks. Most of this water evaporates at or near the place of issue and causes salts to accumulate on the land surface.

POTENTIAL ADDITIONAL DEVELOPMENT

The feasibility of developing water from wells for irrigation depends, among other things upon the long-term yield of the ground-water reservoirs, the cost of drilling and pumping, the types of soil, the quality of water, the crops raised, and the market and price conditions. Most of these factors apply also to development of water for public supply or industrial use.

The ability of a ground-water reservoir to yield water over a long period of years is limited, like that of a surface reservoir, because it depends upon the relation of inflow to discharge and on the available storage. If the average annual amount of water discharged from a ground-water reservoir in a given area by pumping and by other means (underflow, seeps, springs, evaporation, and transpiration) persistently exceeds the average annual amount of water that enters the reservoir within the area, the water levels in wells will decline and the reservoir ultimately will be depleted.

The cost of drilling and pumping is determined in part by the depth to the aquifer, by the depth to the water level, and by the drawdown due to pumping. In areas where the water table or piezometric surface is relatively deep, the wells must be deep and the pumping lift correspondingly great. The cost of a well is also determined in part by the permeability and thickness of the water-bearing materials. Wells may penetrate relatively fine-grained materials that give a relatively small yield. Gravel packing may increase the yield of such wells, but it also adds to the cost. The character of the soil and the contour of the land surface also are important factors in the use of ground water for irrigation. A very sandy soil will cause excessive loss of water in ditches and perhaps will require the use of sprinkler systems. The land may be poorly drained, or it may require large expenditures for leveling.

The chemical quality of water also is an important factor to be considered. Water from some aquifers may be too highly mineralized or may contain certain minerals in amounts that are undesirable for domestic, irrigation, or industrial use.

Only the geologic and hydrologic factors that make feasible the development of ground water from the several aquifers will be discussed in this section. The chemical quality of the ground water in relation to use is discussed in the section "Chemical quality of the water" (p. 40).

ALLUVIUM

The thickness of the alluvium differs from place to place and can be determined only by test drilling or, under favorable conditions, by geophysical surveys. Additional ground water for domestic and stock supplies can be obtained from the alluvium; moderate to large supplies of water can be obtained where thick saturated deposits are present. In the widest part of the Owl Creek valley, from the west side of the Rose Dome to the vicinity of sec. 10, T. 43 N., R. 99 W., buried stream channels containing relatively thick sections of saturated deposits may be present almost anywhere. The water table lies relatively close to the land surface throughout the alluvial part of the valley, so that the pumping lift is relatively small.

Although the alluvium is permeable enough in places to yield large quantities of water to wells, the small amount of recharge to the alluvium limits the total amount of water that can be withdrawn.

If development of large quantities of ground water is undertaken in the future, a lowering of the water table will take place. The extent and persistency of that lowering will depend upon the average annual amounts of water withdrawn in relation to the average annual recharge. Discharge of ground water by wells is a new discharge that is superimposed on the natural balanced system. Before equilibrium of the water table under pumping conditions can be established, water levels must be lowered sufficiently to increase the natural recharge or to decrease the natural discharge, or both, by the net amount being discharged from the wells. If the average annual discharge should exceed the average annual recharge, water will be mined (removed from permanent storage in the aquifer), and the water table will be permanently lowered. However, because the alluvium and terrace deposits in the Owl Creek valley are not thick in comparison to those in many other parts of the country and because of the large drawdowns in wells necessary to obtain water at a high rate, extensive mining of ground water from the alluvium or terrace deposits of Owl Creek valley is not likely to occur. During periods of heavy pumping from the alluvium, water levels near the pumped wells will decline and can be expected to recover only when pumping is reduced seasonally and recharge is received from streams, underflow, precipitation, and seepage from irrigation. Withdrawal and consumptive use of water from the alluvium will cause a decrease in the flow of Owl Creek and, during periods of heavy withdrawal, could cause it to cease flowing in places.

If sufficient ground water is withdrawn to lower the water table below the reach of plant roots, water would be salvaged and be available for beneficial use; some of the water pumped for irrigation would percolate also back into the ground-water reservoir, and a part of this return flow could be reused. However, some water must be allowed to leave the area by underflow or seepage into the streams to prevent a troublesome accumulation of salts in the soil and the ground water.

TERRACE DEPOSITS

The areal extent (pl. 1), thickness, and permeability of the terrace deposits in the area are relatively small; thus the development of additional ground water from these deposits will be limited.

The principal terrace deposits are present in a narrow band along the north side of Owl Creek in the central part of the area, and between the North and South Forks of Owl Creek in the western part of the area. The total amount of water that can be withdrawn from the terrace deposits depends upon the amount of recharge to those deposits. Although some recharge is derived from precipitation on the terraces, most of it is seepage from irrigation water. The lower part of the terrace deposits throughout most of the central part of the area is saturated, and, where the deposits are sufficiently permeable, they will yield moderate to large quantities of water to wells. However, because the deposits are relatively thin and small in areal extent, their capacity to store water is small. Thus, even with normal recharge, only a limited amount of water can be pumped from them.

Other terrace deposits within the area are too small in areal extent and thickness to yield appreciable quantities of water.

CLOVERLY, FRONTIER, AND CODY FORMATIONS

The sandstone beds in the Cloverly, Frontier, and Cody formations will yield only relatively small quantities of water to wells because their permeability is low. Erosion following uplift has removed these formations from parts of the Owl Creek area, so that they are absent in the southwestern and southeastern parts and the central part of the eastern third of the area. The formations dip generally northward, but local disturbances have changed their direction of dip in places. Locally, near the Rose and White Rose Domes, the formations dip northeast and southwest, and near the Embar anticline they dip northeast. The formations lie below the younger deposits, and the depth at which they can be tapped by wells generally becomes progressively greater northward from their areas of outcrop.

The Cloverly and Frontier formations can be tapped by wells at reasonable drilling depths at most places on the south side of Owl Creek in the central part of the area and northeastward from the area of outcrop on the east flanks of the Rose and White Rose Domes.

The sandstone beds in the Cody shale can be tapped by wells in places within the area where the formation is exposed (pl. 1). The formation generally can be penetrated at reasonable drilling depths northward from the southern margin of the alluvium along the main stem and North Fork of Owl Creek.

TENSLEEP SANDSTONE

Although water can be obtained from the Tensleep sandstone throughout most of the Owl Creek area, the formation lies so far below the land surface in most places that the drilling of wells into it is not feasible. For example, the Tensleep sandstone is exposed at the surface on the crest of the Embar anticline (pl. 1, section *B–B′*), but the formation dips sharply and lies several thousand feet below the land surface only three-fourths of a mile northeastward. The best places at which to attempt development of wells at reasonable depths are on the gentle slopes of the anticlines and domes. Thus, prospecting for water in the formation probably would be most successful in localities northeast of the apexes of the Rose and White Rose Domes, southwest of the crest of the Embar anticline, and northeast of the crest of the Anchor anticline.

The Tensleep sandstone is rather permeable, especially near domes and anticlines where it is fractured; consequently, it probably will yield moderate amounts of water to wells. Wells penetrating the sandstone in localities adjacent to the report area have been reported to yield substantial quantities of water under artesian pressure.

MADISON LIMESTONE

The Madison limestone will yield water to wells, but throughout most of the report area the formation lies at even greater depths below the land surface than the Tensleep sandstone. The best places at which to prospect for water at the least depth in the Madison, as in the Tensleep, are on the gently sloping flanks of the domes and anticlines. However, the Madison limestone lies 600 to 700 feet below the Tensleep sandstone, and the shallowest depth at which the Madison could be tapped anywhere in the area is about 600 feet on the crests of the Anchor and Embar anticlines.

The Madison limestone is capable of yielding large quantities of water from solution cavities. However, the cavities occur sporadically within the formation, and a considerable risk is involved in attempting to develop water from the formation by drilling; furthermore, the water can be expected to be highly mineralized.

CHEMICAL QUALITY OF THE WATER

By HERBERT A. SWENSON

Water from the Chugwater and Frontier formations, the Cody shale, and the alluvium and terrace deposits in the report area was analyzed to determine its chemical quality and to aid in the evaluation of its suitability for irrigation and domestic use. Because ground water and surface water in the area are interrelated, water from the South and North Forks and the main stem of Owl Creek also was analyzed. Most of the 12 ground-water samples analyzed (table 3) were obtained in July 1946; the 7 surface-water samples (table 4), representing periods of high and low flow, were obtained in July and September 1947. The sampling points are shown on plate 1.

Because of the complex geology and hydrology of the area and because relatively few chemical-quality data are available, only a general description of the water quality and a general evaluation of the suitability of the water can be made for the report area as a whole. The sample of water from well 67 (unused well) was reported to contain sediment when collected and had extremely high concentrations of dissolved constituents; thus, the sample probably is not representative of ground water near the well. Although the analysis is shown in table 3, it is not considered in the following discussions.

Ground water in the Owl Creek area is highly mineralized; dissolved-solids concentrations ranged from 1,830 to 11,600 ppm (table 3). Conversely, surface water is less mineralized, especially in the upper reaches of the North and South Forks of Owl Creek; dissolved-solids concentrations ranged from 79 ppm in a sample from the South Fork near the Anchor Dam site to 3,960 ppm in a sample from Owl Creek near its mouth.

GROUND WATER

No samples of water from formations of Paleozoic age were obtained during this investigation. However, analyses of samples (Crawford, 1940) of water from 2 oil test wells in T. 44 N., Rs. 96 and 97 W., which tap the Tensleep sandstone in the Waugh Dome north of the report area, indicated that the water was of the sodium-sulfate type and contained about 2,300 ppm of dissolved solids. Because water from the overlying Phosphoria and Dinwoody formations may not have been properly cased off, these samples may represent a mixture of water from the Tensleep sandstone and the Phosphoria and Dinwoody formations. Water from the Phosphoria and Dinwoody formations at the Waugh Dome had a dissolved-solids concentration of about 2,400 ppm and was of the sodium-sulfate type.

The chemical character of dissolved solids in water from several different aquifers is shown graphically in figure 9, in which results of analyses are plotted in equivalents per million. (The concentration of a substance expressed in parts per million is converted to equivalents per million by dividing the number of parts per million by the equivalent weight of the substance.) Sulfate is the predominant anion in water from these aquifers, but the relative concentrations of cations are different in water from unconsolidated deposits and bedrock. Sodium predominates in water from bedrock, whereas calcium and magnesium predominate in water from unconsolidated deposits.

Water from 3 wells tapping aquifers in the Chugwater formation, Frontier formation, and Cody shale was relatively soft but contained more than 2,000 ppm of dissolved solids. Although these aquifers yield water differing in total concentration, the chemical characteristics of the water are relatively similar. Sodium and sulfate constituted more than 85 percent of the dissolved solids in the 3 samples

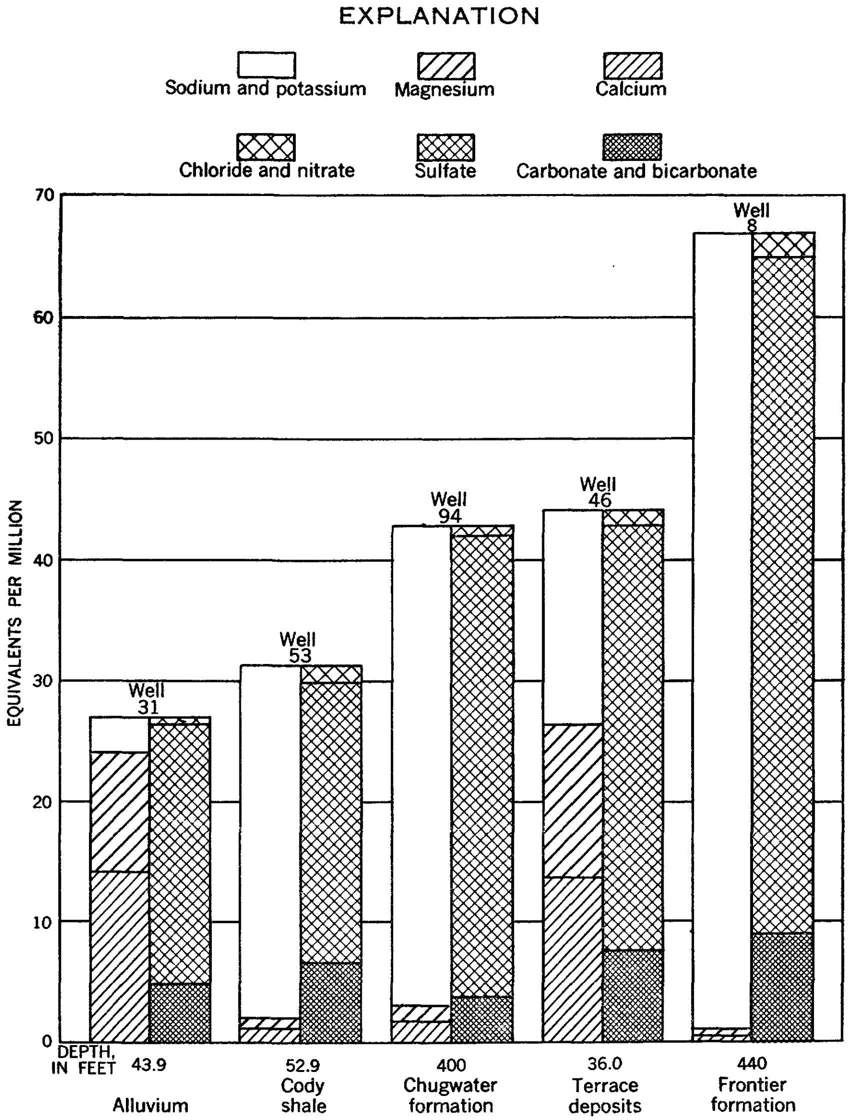

FIGURE 9.—Graphic representation of analyses of ground water in Owl Creek area, Wyo.

(table 3). The hardness of water from these consolidated rocks is lower than that of water from the unconsolidated alluvium and terrace deposits. This relatively low hardness probably results from natural softening, a reaction in which the calcium and magnesium in the water are partly exchanged for sodium and potassium derived from the rock material.

Water from two shallow wells (19 and 99) that produce from both bedrock and overlying unconsolidated deposits was analyzed. This mixed water was very hard; the concentrations of dissolved solids were 1,930 and 6,240 ppm (table 3). The chemical character of the bedrock water from these wells is altered by admixture with water from the overlying alluvium and terrace deposits. For example, the percent sodium (the ratio, expressed as a percentage, of sodium to the sum of the principal cations—sodium, potassium, calcium, and magnesium—all in equivalents per million) of water from bedrock was greater than 90, and that of water from unconsolidated deposits ranged from 11 to 44; the percent sodium of the mixed water was 43 and 68.

The quality of water from terrace deposits and alluvium is influenced by the quality of applied irrigation water. Analyses of water from six wells tapping these unconsolidated deposits indicate that, like water from Owl Creek and the lower reaches of its North and South Forks, calcium, magnesium, and sodium sulfates are the predominant dissolved salts. The water is very hard and most of the hardness is of the noncarbonate (permanent) type. Dissolved-solids concentrations ranged from 1,830 to 3,310 ppm in the 6 samples.

SURFACE WATER

Water draining from the more resistant rocks in the upper reaches of the North and South Forks of Owl Creek contains only small amounts of dissolved material. For example, in September 1947 during a period of low flow, water in the South Fork upstream from the Anchor Dam site had a dissolved-solids concentration of only 108 ppm; similarly, water in the North Fork upstream from the west edge of the report area had a concentration of 190 ppm. However, the quality of water near the confluence of the two forks differs considerably from that in the upstream reaches as a result of drainage from the less resistant rocks underlying the report area; dissolved-solids concentrations had increased to 642 and 1,380 ppm at the mouths of the South Fork and North Fork, respectively. Farther downstream, near the mouth of Owl Creek, the concentration was 3,960 ppm. The increase was due principally to the increase in concentrations of calcium, magnesium, sodium, and sulfate (table 4).

During the irrigation season, when flows were much higher, the downstream increase in dissolved solids was similar, though less pronounced. Data for the South Fork of Owl Creek near the Anchor Dam site and for Owl Creek near the mouth on July 1–2, 1947, show an increase in dissolved solids from 79 to 811 ppm, respectively (table 4). Part of the increase is due to ground-water inflow and part to the use and reuse of the creek water for irrigation.

TABLE 3.—*Chemical analyses of ground water, Owl Creek area, Hot Springs County, Wyo.*

[Data in parts per million except as indicated]

Well (pl. 1)	Depth of well (feet)	Date of collection	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium	Specific conductance (micromhos at 25°C)	pH
														Total	Noncarbonate			
Chugwater formation																		
94	400	July 22, 1946	0.50	38	15	913		232	1,830	26	1.3	2.7	3,040	157	0	93	3,950	8.0
Frontier formation																		
8	440	July 22, 1946	0.20	10	8.1	1,510		[a] 549	2,700	52	2.8	10	4,600	58	0	98	5,660	8.4
Frontier formation and alluvium																		
19	50	July 23, 1946	0.05	114	41	445		332	1,060	30	0.8	1.6	1,930	453	181	68	2,440	8.0
Cody shale																		
53	52.9	July 22, 1946	0.90	23	10	674		403	1,120	46	0.6	1.6	2,120	98	0	94	2,960	7.8
Cody shale and alluvium																		
99	42.5	July 23, 1946	0.10	446	335	868		448	3,650	87	0.8	100	6,240	2,490	2,120	43	5,760	7.8
Slope deposits and terrace deposits																		
67	44.0	July 25, 1946 [b]	0.40	211	352	2,870		495	7,250	186	1.3	0.1	11,600	1,970	1,560	76	11,300	7.9

Terrace deposits

46	36.0	July 22, 1946	0.10	275	155	408		472	1,690	26	1.0	25	3,120	1,320	933	40	3,230	8.0
72	64	do	.20	235	108	269		444	1,120	42	1.3	25	2,270	1,030	666	36	2,460	8.0
76		do	.05	183	81	282		573	802	44	1.1	40	1,830	790	320	44	2,200	7.9
63		Oct. 28, 1949 [c]	.10	350	134	460	5.6	442	1,880	37	1.2	7.9	3,310	1,420	1,060	41	3,620	7.4

Alluvium

31	43.9	July 22, 1946	0.80	285	121	65		300	1,040	16	0.2	0.0	1,960	1,210	964	11	2,010	7.3
55	42	July 23, 1946	.20	248	88	287		282	1,270	28	.4	8.0	2,280	981	750	39	2,540	7.5

[a] Includes equivalent of 33 ppm of carbonate (CO_3).
[b] Unused well. Sample contained sediment and probably is not representative.
[c] Silica (SiO_2), 32 ppm; boron (B), 0.53 ppm.

TABLE 4.—*Chemical analyses of surface water, Owl Creek area, Hot Springs County, Wyo.*

[Data in parts per million except as indicated]

Source	Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium	Specific conductance (micromhos at 25°C)	pH
																Total	Noncarbonate			
South Fork Owl Creek one-quarter mile upstream from Anchor Dam site	*1947* July 1	[a] .97	17	0.02	11	6.1	3.4		57	10	1.6	0.1	0.5	0.01	79	53	6	12	116	8.3
	Sept. 2	[a] 2.2	19	.65	12	5.4	10	2.0	77	8.7	1.5	.7	.5		108	52	0	28	148	7.0
South Fork Owl Creek 400 yds upstream from confluence with North Fork	do		17	.02	92	44	51		254	293	5.0	.2	.4		642	410	202	21	904	7.8
North Fork Owl Creek 0.6 mile upstream from gaging station, which is in NE¼ sec. 18, T. 43 N., R. 100 W.	do	[b] 4.6	36	.80	21	6.8	28		128	33	.4	.4	.5		190	80	0	43	283	7.5
North Fork Owl Creek 100 yds upstream from confluence with South Fork	do		33	.02	158	70	190		392	723	13	.7	.6		1,380	682	361	38	1,790	7.6
Owl Creek one-quarter mile upstream from mouth	July 2	[c] 140	18	.02	102	38	102	6.8	[d] 207	432	13	.3	2.0	.17	811	411	241	34	1,170	8.5
Owl Creek 15 ft upstream from mouth	Sept. 2	[c] 1.0	26	.02	370	186	610		359	2,530	59	.8	.7		3,960	1,690	1,400	44	4,240	7.8

[a] At gaging station in NW¼ sec. 11, T. 8 N., R. 1 E., about 6 miles downstream from sampling site.
[b] At gaging station NE¼ sec. 18, T. 43 N., R. 100 W.
[c] At gaging station in sec. 7, T. 43 N., R. 94 W., 1 mile upstream from mouth of Owl Creek.
[d] Includes equivalent of 2 ppm of carbonate (CO_3).

SUITABILITY

Ground water in the report area is used mostly for domestic needs and stock watering. However, because of its high mineral content, much of the ground water is not potable by ordinary standards. Most of the water used for irrigation in the area is diverted from Owl Creek and its two principal tributaries, although some ground water is pumped for irrigation, principally in T. 43 N., R. 96 W.

Of the ground-water samples obtained for this study, 3 were from domestic wells, 5 from stock-watering wells, 1 from an irrigation well, and 3 from unused wells. Two of the seven surface-water samples represent water that was available for irrigation during a period of high flow in July 1947.

DOMESTIC USE

Although ground water in the report area generally is highly mineralized, the palatability of drinking water is largely a matter of personal opinion. Persons who have become accustomed to drinking water that contains relatively large amounts of dissolved salts generally consider water of low mineral content to be flat tasting.

Standards for drinking water used on interstate common carriers have been established by the U.S. Public Health Service (1946) and have been accepted by the American Water Works Association for all public water supplies. Although, except for fluorides, they are not mandatory even on common carriers, they are generally accepted as a basis for evaluating drinking-water supplies. The standards for some of the chemical constituents are given in the following table:

Constituent	*Maximum concentration recommended (ppm)*
Iron and manganese	0.3
Magnesium	125
Sulfate	250
Chloride	250
Fluoride	1.5
Dissolved solids	[a] 500

[a] 1,000 ppm may be permitted if water of better quality is not available.

In the report area the ground water contained more than the recommended maximum concentrations of sulfate and dissolved solids. Several wells produced water having excessive amounts of magnesium or iron; well 8, which taps the Frontier formation, produced water having an excessive amount of fluoride (2.8 ppm). Highly mineralized water containing large amounts of sodium sulfate (Glauber's salt) and magnesium sulfate (Epsom salt) can be disagreeable for drinking because of its taste and cathartic action. When present in concentrations greater than about 0.3 ppm iron can cause stains on clothing, fixtures, and utensils, and when in concentrations of 0.5 to 1.0 ppm it can be tasted. Recent investigations indicate that fluoride in concentrations greater than about 1.5 ppm in drinking water has been associated with mottled enamel of the teeth of children, although in concentrations less than about 1.5 ppm it tends to reduce tooth decay. (California Inst. Technology, 1952, p. 257.)

Although specific limits for hardness cannot be set, water having a hardness of 60 to 120 ppm generally is considered to be moderately hard, of 120 to 200 ppm to be hard, and of more than 200 ppm to be very hard. By these criteria, water in the report area from bedrock aquifers would be classed as moderately hard to hard, and that from unconsolidated deposits as very hard.

IRRIGATION

According to Wilcox (1948, p. 25–27) the characteristics that determine the suitability of water for irrigation are total concentration (expressed in his paper in terms of electrical conductivity or dissolved solids), percent sodium, and concentration of boron. Specific conductance (electrical conductivity) is a measure of the ability of a water to conduct an electrical current and is directly related to the dissolved solids in the water. High concentrations of dissolved solids in irrigation water may adversely affect plant growth and may cause the soil to become saline. Sodium in irrigation water may replace the calcium and magnesium absorbed on soil colloids; the soil then becomes less permeable to water and air. Boron in concentrations greater than about 0.5 ppm in irrigation water is toxic to some plants. Boron concentrations were not determined for most samples from the report area; however, boron is not known to be present in objectionable amounts in water in this general area.

Water having a specific conductance much in excess of 2,000 micromhos and a percent sodium above 60 would be classed as doubtful to unsuitable for irrigation. Ground water in the report area had a specific conductance of more than 2,000 micromhos in all 12 samples and a percent sodium of more than 60 in 4 samples. Therefore, because of a high specific conductance or high percent sodium, or both, ground water in the area, insofar as the samples are representative, is classed as doubtful to unsuitable for irrigation.

Water in the upper reaches of the North and South Forks of Owl Creek is classed as excellent for irrigation by the method of Wilcox. During high-flow periods, the water in the downstream reach of Owl Creek is rated as good to permissible; however, during low-flow periods, it is rated as unsuitable for irrigation because of a high content of dissolved solids.

As with all other systems for classification of water for irrigation, that of Wilcox is largely empirical and assumes average conditions of soil, crops, drainage, permeability, and climate. The reader is referred to recent studies of the U.S. Salinity Laboratory Staff (1954) for a more complete discussion of systems of classifying water for irrigation.

In parts of the report area ground water is used for supplementary irrigation (p. 17). If data in table 3 are representative, ground water from consolidated rocks should not be used for irrigation because of high dissolved solids and high percent sodium; however, some water from terrace deposits and alluvium might be classified as safe for supplemental irrigation because, although dissolved solids are relatively high, percent sodium is relatively low. Even so, the water from the Quaternary deposits would have to be applied under carefully controlled conditions to prevent salinization of soils. Supplementary use of these waters probably is better adapted to the upper reaches of the basin, where water of good quality from the North and South Forks is available for flushing salts from the soils, than to the lower reaches, where water from Owl Creek sometimes is highly mineralized.

Releases from Anchor Dam should improve the quality of water available to downstream users. Application of the reservoir water to the lands is likely to cause changes in the quality of the shallow ground water; therefore, periodic studies of the quality of water from selected wells should be made to provide data for measuring and evaluating the changes.

LOGS OF WELLS AND TEST HOLES

The logs of 19 wells and test holes in the Owl Creek area, including 5 that were jetted for use as observation wells, are given in table 5. The locations of the test holes and wells are shown on plate 1.

TABLE 5.—*Logs of wells and test holes*

Description	Thickness (feet)	Depth (feet)
Well 10		
[Drilled. SW¼SW¼ sec 10, T. 8N., R. 4 E.]		
Quaternary:		
Alluvium:		
Silt, sand, and gravel	32	32
Sand; contains water	6	38
Cretaceous:		
Frontier formation:		
Shale	23	61
Well 11		
[Jetted. SW¼SE¼ sec. 10, T. 8 N., R. 4 E.]		
Quaternary:		
Alluvium:		
Clay	10	10
Clay, tight	3	13
Gravel	1.4	14.4
Test hole 1		
[Jetted. SE¼SW¼ sec. 36, T. 9 N., R. 1 E.]		
Quaternary:		
Alluvium:		
Sand and gravel	7.5	7.5
Gravel	4.2	11.7
Test hole 2		
[Drilled 1954. SE¼SW¼ sec. 33, T. 9 N., R. 2 E. Depth to water below land surface, 14 feet]		
Quaternary:		
Alluvium:		
Silt and clay	20	20
Gravel	12	32
Cretaceous:		
Cody shale:		
Shale	13	45

TABLE 5.—*Logs of wells and test holes*—Continued

Well 32

[Jetted. NE¼NE¼ sec. 35, T. 9 N., R. 2 E.]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Alluvium:		
Clay	11	11
Sand	1.6	12.6

Well 37

[Drilled. NE¼SE¼ sec. 5, T. 43 N., R. 94 W.]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Alluvium:		
Soil	7	7
Gravel, with water (cased off)	14	21
Cretaceous:		
Cody shale:		
Shale, blue; contains soft water in a zone of fracturing at 27 to 29 feet; water rises to 9 feet below land surface	9	30

Test hole 3

[Jetted. NE¼SE¼ sec. 7, T. 43 N., R. 94 W.]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Terrace deposits:		
Soil	3	3
Gravel	2	5
Sand	3	8
Gravel	5.6	13.6

Well 60

[Drilled. NE¼NW¼ sec. 21, T. 43 N., R. 95 W.]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Alluvium:		
Soil	15	15
Gravel	18	33
Triassic:		
Chugwater formation:		
Red beds	22	55
Sandstone	6	61
Red beds	6	67
Sandstone, coarse, hard	5	72
Red beds	12.3	84.3

Well 62

[Jetted. SW¼SW¼ sec. 7, T. 43 N., R. 96 W.]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Terrace deposits:		
Soil, clayey	4	4
Gravel and sand; contains caliche layers	8.3	12.3

Test hole 4

[Drilled 1954. NW¼SW¼ sec. 8, T. 43 N., R. 96 W. Depth to water below land surface, 5.50 feet]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Terrace deposits:		
Clay	3	3
Gravel	9	12
Clay	9	21

Test hole 5

[Drilled 1954. SW¼SW¼ sec. 8, T. 43 N., R. 96 W. Depth to water below land surface, 5.70 feet]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Terrace deposits:		
Clay	6	6
Gravel	22	28
Clay	3	31

Well 66

[Drilled. NW¼SE¼ sec. 13, T. 43 N., R. 96 W.]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Alluvium:		
Soil	15	15
Gravel	20	35
Cretaceous:		
Mowry and Thermopolis shales:		
Shale; lower 3 feet is sandy	17	52

Unnumbered test holes

[Drilled 1954. Site of well 69, NW¼NW¼NW¼ sec. 17, T. 43 N., R. 96 W. Depth to water below land surface, 9 feet]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Terrace deposits:		
Soil	7	7
Gravel	25	32
Sand rock	2	34
(?)	6	40

Unnumbered test hole

[Drilled 1954. Site of well 71, NW¼NW¼ sec. 17, T. 43 N., R. 96 W. Depth to water below land surface, 8 feet]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Terrace deposits:		
Soil	7	7
Gravel	26	33

Unnumbered test hole

[Drilled. Site of well 73, NW¼NE¼ sec. 18, T. 43 N., R. 96 W. Depth to water below land surface, 11.5 feet]

Description	Thickness (feet)	Depth (feet)
Quaternary:		
Terrace deposits:		
Clay	9	9
Gravel	30	39
Clay	2	41

TABLE 5.—*Logs of wells and test holes*—Continued

Description	Thickness (feet)	Depth (feet)
Test hole 6		
[Drilled. NE¼NW¼ sec. 18, T. 43 N., R. 96 W.]		
Quaternary:		
Terrace deposits:		
Soil	8	8
Gravel	12	20
Cretaceous:		
Cody(?) shale:		
Shale, yellow	15	35
Shale, blue	5	40
Test hole 7		
[Drilled. SE¼SE¼ sec. 31, T. 44 N., R. 94 W. Depth to water below land surface, 6.3 feet]		
Quaternary:		
Alluvium:		
Soil, clayey	9	9
Sand, fine and silt; contains some clay	5	14
Sand, fine to coarse; contains some clay	3	17
Gravel	3	20
Cretaceous:		
Cody shale:		
Shale, black	12	32
Test hole 8		
[Drilled. SW¼NE¼ sec. 32, T. 44 N., R. 94 W.]		
Quaternary:		
Alluvium:		
Soil, silty	10	10
Clay, and silt	6	16
Sand, medium to coarse, dark-gray	6	22
Sand, coarse; contains some pebbles	8	30
Test hole 9		
[Drilled. NW¼SW¼ sec. 32, T. 44 N., R. 94 W. Depth to water below land surface, 11.0 feet]		
Quaternary:		
Alluvium:		
Soil	2	2
Clay, brown; contains some silt	17	19
Cretaceous:		
Cody shale:		
Shale, clayey, dark-brown	15	34

RECORDS OF WELLS

Information pertaining to the wells inventoried in the Owl Creek area is tabulated in table 6. The well numbers shown in table 6 correspond to those on plate 1 and in table 3.

TABLE 6.—*Records of wells in Owl Creek area, Hot Springs County, Wyo.*

Well: Number in parentheses indicates that an analysis of the water is given in table 3.
Type of well: B, bored; Dr, drilled; Du, dug; J, jetted.
Depth of well: Reported depths below land surface given in feet; measured depths given in feet and tenths below measuring points.
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, sandy or fractured shale; Ss, sandstone.
Geologic source: Trc, Chugwater formation; Kt, Thermopolis shale; Kmr, Mowry shale; Kf, Frontier formation; Kc, Cody shale; Kmv, Mesaverde formation; Qt, terrace deposits; Qs, slope deposits; Qa, alluvium.
Method of lift and type of power: C, centrifugal; Cy, cylinder; N, none; T, turbine; E, electric motor; G, gasoline engine; H, hand operated; W, windmill.
Use of water: D, domestic; I, irrigation; N, none; S, stock.
Measuring point: Bp, base of pump; Hc, hole in casing; Hp, hole in pump; Ls, land surface; Tc, top of casing; Tcc, top of cribbing; Tpb, top of pump base; Twc, top of well cover.
Depth to water: Measured depths to water are given in feet, tenths, and hundredths.

Well (pl. 1)	Location	Owner or tenant	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed		Method of lift and type of power	Use of water	Measuring point			Depth to water level measuring point (feet)	Date of measurement	Remarks (Yield in gallons per minute, draw-down in feet)
							Character of material	Geologic source			Description	Distance above (+) or below (−) land surface (feet)	Height above mean sea level (feet)			
	T. 8 N., R. 2 E.:															
1	SW¼NW¼ sec. 5	Mary Merril	Du	-----	36	R	S, G	Qa	Cy, G	D	Twc	−8.7	---------	17.89	4-24-46	
	T. 8 N., R. 3 E.:															
2	SW¼NW¼ sec. 1	Fred Ostberg	Dr	73	6	P	Sh	Kc	Cy, H	D	Tc	+1.0	5,001.24	16.93	4-26-46	Dry after pumping 150 gallons. Water in fractured zone.
3	SE¼SW¼ sec. 1	George Scholz	Dr	40	8	P	S, G	Qa	Cy, G	S	Tc	+.2	4,982.56	15.55	8-11-45	
4	SE¼NE¼ sec. 2	Melvin Love	Dr	-----	6	P	S, G	Qa	N	N	Tpb	+3.6	5,016.74	14.81	4-19-46	
5	SW¼NW¼ sec. 2	Glen Fleiman	Dr	73.0	6	P	S, G	Qa	Cy, G	D	Tc	+.6	5,060.96	26.03	4-19-46	
6	NE¼NE¼ sec. 3	Harry Miller	Dr	69.4	6	P	S, G	Qa	N	N	Tc	+.2	5,079.45	19.95	4-20-46	
7	NE¼NE¼ sec. 4	Jack David	Dr	95	6	P	Ss	Kf	Cy, G	S	Tc	+.4	5,171.51	32.33	4-19-46	
	T. 8 N., R. 4 E.:															
(8)	NE¼SW¼ sec. 7	George Burnap	Dr	440	8	P	Ss	Kf	Cy, H	S	Tc	+5.5	4,969.22	.44	5-2-46	Reported to flow periodically.
9	NW¼SW¼ sec. 7	Arapahoe Ranch	Dr	-----	8	P	Ss	Kf	Cy, G	N	Tc	+.8	4,949.38	17.95	8-11-45	
10	SW¼SW¼ sec. 10	Fred Lawrence	Dr	61	6	P	S, G	Qa	Cy, G	D	Tc	+1.2	4,800.55	10.88	4-19-46	Log.
11	SW¼SE¼ sec. 10	U.S. Geol. Survey	J	14.4	1	P	S, G	Qa	N	N	Tc	+2.3	---------	12.48	4-16-51	Log.
12	SW¼SW¼ sec. 11	Roy Collins	Dr	88.6	6	P	Ss	Kf	Cy, H	D	Tc	+.6	4,764.22	17.04	4-18-46	
13	NW¼NW¼ sec. 14	do	Dr	40	8	P	Ss	Kf	Cy, H	S	Tc	+1.1	4,774.06	22.75	8-11-45	
14	SW¼NE¼ sec. 15	Harry Collins	Dr	-----	6	P	Ss	Kf	Cy, H	S	Tc	+.9	---------	25.32	5-15-46	
15	SE¼NE¼ sec. 15	R. G. Mayfield	Dr	175	6	P	Ss	Kf	Cy, H	D, S	Tc	+.7	4,853.95	55.10	5-14-46	

16	NE¼NW¼ sec. 15	Ray Thornburg	Dr	-----	6	P	S, G	Qa	Cy, H	S	Hp	+2.7	4,789.09	6.69	5-14-46	Reported to be good water prior to surface-water contamination.
17	NE¼NW¼ sec. 15	Thornburg Bros.	Du	20.9	30	C	S, G	Qs	C, G	I	Twc	-5.0	---------	9.17	5-23-55	
18	SW¼NW¼ sec. 15	do	Dr	80	6	P	Ss	Kf	N	N	Tc	+.5	4,862.22	27.42	5-15-46	
(19)	NE¼NE¼ sec. 16	School district	Dr	50	6	P	S, G, Ss	Qa, Kf	Cy, H	D	Twc	+.2	4,797.38	7.45	5-14-46	
20	NW¼NE¼ sec. 16	James Thornburg	Dr	71.5	6	P	S, G, Ss	Qa, Kf	Cy, W	N	Tc	+.8	4,808.49	8.31	4-19-46	
21	SW¼NE¼ sec. 16	do	Dr	250	8	P	Ss	Kf	Cy, W	S	Tc	+2.0	---------	16.30	4-19-46	Reported to be flowing when drilled.
	T. 9 N., R. 1 E.:															
22	SW¼SW¼ sec. 36	D. B. Whetstone	Dr	21	28	P	S, G	Qa	N	N	Tc	+.8	5,765.39	8.23	4-26-46	
23	SE¼SW¼ sec. 36	do	Dr	20.5	28	P	S, G	Qa	N	S	Tc	+2.9	5,732.21	8.24	4-26-46	
24	NE¼SE¼ sec. 36	do	Dr	88	6	P	S, G, Sh	Qa, Kc	Cy, H	D	Twc	+.3	5,695.28	9.62	4-26-46	
	T. 9 N., R. 2 E.:															
25	NW¼SW¼ sec. 32	Forrest Daniels	Dr	75	6	P	S, G, Sh	Qa, Kc	Cy, H	D	Hc	+3.1	5,626.42	9.01	4-26-46	Can be pumped dry.
26	SE¼SW¼ sec. 33	Arthur Miller	Dr	42.5	14	P	S, G	Qa	T, E	I	Tc	+.3	---------	21.82	5-20-55	
27	SW¼SE¼ sec. 33	T. C. Todd	Dr	90	6	P	S, G, Sh	Qa, Kc	Cy, H	D	Twc	+.5	5,532.95	14.20	4-25-46	
28	SE¼NE¼ sec. 34	H. O. Davis	Dr	120	6	P	S, G, Sh	Qa, Kc	Cy, H	D	Tc	+.4	5,447.72	9.07	5-20-46	
29	NE¼SW¼ sec. 34	Clyde Duncan	Dr	80	6	P	S, G, Sh	Qa, Kc	Cy, H	D	Tc	+.1	5,481.39	13.34	4-25-46	
30	NW¼SW¼ sec. 34	Art Miller	Dr	-----	6	P	Sh	Kc	Cy, H	D	Tc	+.2	5,496.79	15.11	4-25-46	
(31)	NE¼NE¼ sec. 35	Arapahoe Ranch	Dr	43.9	10	P	S, G	Qa	Cy, H	S	Tc	+.2	5,372.35	10.75	8-10-45	
32	NE¼NE¼ sec. 35	U.S. Geol. Survey	J	12.6	1	P	S	Qa	N	N	Tc	+1.7	---------	11.32	4- 6-51	Log.
33	SW¼NW¼ sec. 35	John Graboski	Dr	53	8	P	Sh	Kc	Cy, H	D	Tc	+.5	5,438.74	9.77	4-25-46	
	T. 9 N., R. 3 E.															
34	NW¼SW¼ sec. 30	Arapahoe Ranch	Dr	-----	6	P	Sh	Kc	Cy, W	S	Twc	+.7	5,291.19	13.80	4-25-46	
35	SE¼SE¼ sec. 32	do	Dr	-----	8	P	Ss	Kf	Cy, H	D, S	Tc	+.9	---------	22.90	8-10-45	
36	SE¼NE¼ sec. 33	Harry Miller	Du	28	72	R	S, G	Qa	Cy, H	D	Tcc	+.1	5,129.03	12.65	4-20-46	
	T. 43 N., R. 94 W.:															
37	NE¼SE¼ sec. 5	Hans Nielson	Dr	30	8	P	Sh	Kc	Cy, H	D	Tc	0	---------	9.00	1-10-47	Log.
38	NW¼NE¼ sec. 6	Rose Allen	Dr	108.4	5	P	Sh	Kc	N	N	Tc	+.5	4,365.09	58.34	4-15-46	
39	NE¼SE¼ sec. 6	A. C. Melton	Dr	76	8	P	Sh	Kc	Cy, G	S	Tc	+.8	4,362.23	27.44	5- 2-46	
40	SE¼NE¼ sec. 7	Melvin Shaffer	Dr	31.5	6	P	S, G	Qa	Cy, H	D, S	Tc	+1.7	4,315.99	4.65	4-29-46	
41	SW¼NW¼ sec. 7	Joseph Kohielusz	Dr	36	3	P	S, G	Qa	Cy, H	D	Tc	+.2	4,349.39	6.75	4-22-46	
42	NE¼SW¼ sec. 7	School district	Dr	100	8	P	S, G, Sh	Qt, Kc	Cy, H	D	Tc	+4.1	4,352.64	30.90	4-22-46	
43	SE¼SW¼ sec. 7	J. B. Smith	Dr	63	6	P	S, G, Sh	Qt, Kc	Cy, G	D	Tc	+.4	5,353.35	20.85	4-29-46	
44	SE¼SE¼ sec. 7	Clyde Harvey	Dr	41.5	6	P	S, G, Sh	Qt, Kc	Cy, H	S	Tc	+.8	4,336.52	32.51	4-29-46	
45	SW¼NE¼ sec. 8	I. N. Harvey	Dr	78	8	P	S, G	Qt	Cy, H	D, S	Tc	+1.2	4,308.40	27.46	4-29-46	
(46)	SW¼SW¼ sec. 8	Frank Webb	Dr	36.0	6	P	S, G	Qt	Cy, H	S	Tc	+1.5	4,326.37	23.57	4-29-46	
47	NE¼NE¼ sec. 18	Mark Lesher	Dr	-----	6	P	Sh	Kc	Cy, G	S	Tc	+.4	4,349.06	52.32	5-27-46	
	T. 43 N., R. 95 W.:															
48	SW¼SE¼ sec. 1	Setty estate	Dr	50.5	8	P	Sh	Kc	Cy, W, H	S	Tc	+.7	4,360.37	9.03	4-15-46	
49	SE¼SW¼ sec. 11	Cleve Vannoy	Dr	12	-----	-----	S, G	Qa	Cy, H	D	Twc	+.4	4,403.64	5.63	4-17-46	
50	SW¼NE¼ sec. 12	G. D. Shaffer	Dr	60	6	P	S, G, Sh	Qa, Kc	Cy, H	D	Tc	+.3	4,370.18	7.26	4-22-46	Reported to be good water until contaminated by surface water.
51	SW¼NE¼ sec. 12	M. L. Smith	Dr	52	8	P	S, G, Sh	Qt, Kc	Cy, H	D, S	Tc	+.9	4,367.03	9.74	4-29-46	
52	NW¼NW¼ sec. 12	S. R. Buchanan	Dr	-----	-----	P	Sh	Kc	Cy, W	N	Tc	+.2	4,385.76	19.89	5- 2-46	
(53)	SW¼NW¼ sec. 12	do	Dr	52.9	8	P	Sh	Kc	Cy, E	D	Tc	+.5	4,389.34	20.05	4-17-46	
54	SW¼SW¼ sec. 15	Ira Foulk	B	12.6	-----	P	S, G	Qa	N	N	Tc	+.5	4,480.13	5.11	4-17-46	

TABLE 6.—*Records of wells in Owl Creek area, Hot Springs County, Wyo.*—Continued

Well (pl. 1)	Location	Owner or tenant	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift and type of power	Use of water	Measuring point: Description	Measuring point: Distance above (+) or below (−) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield in gallons per minute, drawdown in feet)
	T. 43 N., R. 95 W.—Continued															
(55)	SE¼SE¼ sec. 16	Henry Freudenthal.	Dr	42	6	P	S, G	Qa	Cy, H	S	Bp	+1.3	4,487.27	16.14	4-22-46	
56	NW¼NE¼ sec. 19	Charles McComber.	Du	-----	48	R	S, G	Qa	N	N	Twc	+.2	-----	11.27	8-11-45	
57	SW¼NE¼ sec. 19	School district	Dr	85	6	P	Sh	Kmr	Cy, H	D	Bp	+.5	4,625.48	46.46	4-17-46	
58	NE¼NW¼ sec. 19	Floyd Ready	Dr	-----	6	P	Sh	Kmr	Cy, H	D	Twc	+.8	-----	8.87	5- 2-46	
59	NE¼NW¼ sec. 20	Leo Duncan	Dr	53.0	6	P	S, G, Sh	Qt, Trc	Cy, H	D	Tc	+.4	-----	26.16	5- 2-46	
60	NE¼NW¼ sec. 21	Henry Freudenthal.	Dr	84.3	6	P	S, G, Sh	Qa, Trc	Cy, H	D	Tc	+1.0	4,509.43	31.62	4-17-46	Log.
	T. 43 N., R. 96 W.:															
61	NE¼NE¼ sec. 7	Thomas Sanford	Du	-----	48	R	S, G	Qt	Cy, H	S	Tcc	+.6	4,961.63	18.75	8-11-45	
62	SW¼SW¼ sec. 7	U.S. Geol. Survey	J	12.3	1	P	S, G	Qt	N	N	Tc	+3.0	-----	9.78	4- 6-51	Log.
(63)	NW¼SE¼ sec. 7	Willis Bianacci	Du, Dr	-----	48	W	S, G	Qt	C, G	I	Twc	+.2	4,901.20	9.87	8-11-45	Yield 156; drawdown 2.22.
64	NW¼NW¼ sec. 9	Thomas Sanford	Dr	155	8	P	Sh	Kc	Cy, H	S	Tc	+1.2	-----	54.59	4-19-46	
65	SW¼NW¼ sec. 13	Mark Plasters	Dr	203	6	P	Sh	Kt	Cy, H	N	Tc	+.5	4,674.41	61.05	4-23-46	Yield only a few hundred gallons per day.
66	NW¼SE¼ sec. 13	Floyd Ready	Dr	52	6	P	Sh	Kmr, Kt	Cy, H	D, S	Tc	+.5	4,629.89	20.64	4-23-46	Log.
(67)	SE¼NW¼ sec. 14	Leonard Thornton.	Dr	44.0	6	P	S, G, Sh	Qt, Qs	N	N	Tc	+.7	4,699.31	27.53	4-23-46	
68	SE¼SW¼ sec. 14	Chester Ready	Dr	60	-----	-----	S, G, Sh	Qa, Kc	Cy, H	D, S	Bp	+.6	-----	10.15	4-23-46	
69	NW¼NW¼ sec. 17	Tom Sanford	Dr	42.1	15	P	S, G	Qt	T, E	I	Bp	+2.0	-----	19.23	6-24-55	Log; yield 332; drawdown 2.88.
70	NW¼NW¼ sec. 17	do	Dr	42.0	14	P	S, G	Qt	T, E	I	Hc	+.4	-----	18.25	6-21-55	Yield 162; drawdown 16.65.
71	NW¼NW¼ sec. 17	do	Dr	42.6	14	P	S, G	Qt	T, E	I	Hc	+.2	-----	18.84	6-21-55	Log; yield 170; drawdown 14.21.
(72)	NW¼NE¼ sec. 18	Bruce Gwynn	Dr	64	6	P	S, G	Qt	Cy, H	D, S	Tc	+.8	4,885.93	10.01	4-23-46	
73	NW¼NE¼ sec. 18	Tom Sanford	Dr	50.0	15	P	S, G	Qt	C, G	I	Tc	+.4	-----	25.52	5-20-55	Log.
74	NW¼NE¼ sec. 23	Jess Ready estate	Dr	-----	10	P	S, G	Qa	N	N	Tc	+.5	4,667.63	7.42	4-18-46	

75	SE¼NE¼ sec. 23	Leonard Shumway.	Du, Dr	68.8	6	P	S, G, Sh	Qa, Kc	Cy, H	D	Tc	−9.2	4,663.92	21.08	4-18-46	
	T. 43N., R. 97W.:															
(76)	SW¼SW¼ sec. 3	Arapahoe Ranch	Dr	-----	8	P	S, G	Qt	N	N	Tc	+1.1	5,106.21	17.30	4-24-46	
77	SW¼NW¼ sec. 5	do	Dr	98	6	P	S, G, Sh	Qa, Kc	Cy, G	D	Twc	−5.6	5,170.76	15.07	4-24-46	
78	SW¼NW¼ sec. 5	do	Dr	-----	----	----	S, G	Qa	Cy, W	S	Twc	0	5,178.63	7.94	4-24-46	Reported to pump only 30 gallons per day.
79	NW¼NE¼ sec. 11	Jess Perkins	Dr	25	10	P	S, G, Sh	Qt, Kc	N	N	Tc	+1.0	5,021.71	7.59	4-23-46	
80	SW¼SW¼ sec. 11	Luke McNeil	Dr	68	6	P	S, G	Qa	Cy, H	D	Tc	+.4	---------	21.38	4-19-46	
81	SE¼SW¼ sec. 11	do	Dr	48.5	6	P	S, G	Qa	N	N	Tc	+.2	4,989.11	5.54	5-13-46	
82	NE¼NE¼ sec. 12	Jess Perkins	Dr	122	6	P	S, G, Sh	Qs, Kc	Cy, G	S	Tc	+.4	4,972.92	30.37	4-23-46	
83	SE¼SW¼ sec. 12	Clair Rush	Dr	140	8	P	S, G, Sh	Qs, Kc	N	N	Tc	+.2	4,951.77	9.23	4-20-46	
84	SE¼SE¼ sec. 12	L. W. Mortis	Dr	30	6	P	S, G, Sh	Qs, Kc	Cy, H	S	Twc	+.2	4,932.39	9.89	4-20-46	
85	NE¼NW¼ sec. 14	A. R. Merrill	Dr	21.6	8	P	S, G	Qa	N	N	Tc	+2.3	4,991.19	11.14	4-20-46	
86	NW¼ sec. 14	Melvin Love	Dr	30	10	P	S, G	Qa	N	N	Twc	+.1	4,988.49	12.42	4-19-46	
	T. 43 N., R. 98 W.:															
87	SW¼NE¼ sec. 3	Arthur Miller	Dr	60	6	P	Sh	Kc	Cy, H	D	Tc	+.6	5,371.91	12.04	4-25-46	
88	NE¼SW¼ sec. 3	do	Dr	31.4	10	P	S, G	Qt	T, E	I	Tc	+.9	---------	5.48	6-3-55	Battery of 3 wells.
89	NW¼NW¼ sec. 7	Ellis Merrill	Dr	-----	6	P	S, G	Qa	N	N	Tc	+.6	5,618.56	5.27	5-22-46	
	T. 43 N., R. 99 W.:															
90	SE¼SW¼ sec. 7	Lloyd Woody	Du	12	36	R	S, G	Qa	Cy, H	D, S	Twc	+.5	---------	7.56	5-2-46	
91	SW¼SW¼ sec. 8	Martin Johnson	Du	18	36	R	S, G	Qa	N	D	Twc	+.6	---------	14.66	5-3-46	Reported to be dry during winter months.
92	SE¼SW¼ sec. 8	C. S. Anderson	Dr	60	8	P	S, G	Qa	N	N	Tc	+.9	5,974.39	6.85	8-10-45	
93	NE¼SW¼ sec. 9	J. Brown	Du	18	60	R	S, G	Qa	N	N	Twc	0	---------	8.65	5-3-46	
(94)	NW¼SE¼ sec. 10	H. D. Curtis	Dr	400	8	P	Ss	Trc	N	N	Tc	+.7	5,782.69	11.95	8-10-45	
95	NW¼NW¼ sec. 18	Arley Hart	Du	-----	36	R	S, G	Qa	N	N	Twc	+1.1	6,094.18	5.70	5-3-46	
	T. 43 N., R. 100 W.:															
96	NE¼NE¼ sec. 13	do	Du	35	----	----	S, G	Qa	N	N	Twc	+.7	---------	6.20	5-3-46	
97	SE¼SW¼ sec. 14	Landis Merrill	Du	15	----	----	Ss	Trc	Cy, H	S	Twc	0	---------	7.41	5-3-46	
	T. 44 N., R. 94 W.:															
98	SW¼NW¼ sec. 20	Albert Fisher	Dr	140	6	P	Ss	Kmv	Cy, E	S	Twc	+.7	4,396.39	67.44	5-28-46	
(99)	SW¼SW¼ sec. 20	Elmer Tanner	Dr	42.5	6	P	S, G, Sh	Qa, Kc	Cy, G	S	Twc	+.9	4,307.38	28.49	5-28-46	
100	SW¼SE¼ sec. 20	Blake Palmer	Du	-----	36	R	S, G	Qa	N	N	Twc	0	4,271.48	6.56	5-27-46	
101	NE¼SW¼ sec. 29	Gwynn estate	Dr	24	6	P	S, G	Qa	N	N	Tc	+.7	4,295.15	16.69	5-28-46	
102	NE¼NE¼ sec. 30	do	Dr	59	6	P	S, G, Sh	Qa, Kc	N	N	Ls	0	4,322.84	39.26	5-28-46	
103	SE¼NE¼ sec. 31	Andrew Karol	Dr	42	6	P	Sh	Kc	Cy, H	S	Tc	+.8	4,329.87	28.98	5-28-46	
104	SE¼SE¼ sec. 31	George Wortham	Dr	75	----	P	Sh	Kc	Cy, H	S	Twc	0	---------	17.18	5-28-46	
105	NW¼NW¼ sec. 32	R. W. Jones	Dr	30	6	P	Sh	Kc	Cy, H	D, S	Twc	+.6	4,308.19	41.69	5-28-46	
106	SE¼SW¼ sec. 32	Jose Murillo	Dr	38	----	P	S, G	Qa	Cy, H	D, S	Twc	+.6	4,295.70	15.96	5-28-46	
	T. 44 N., R. 98 W.:															
107	NW¼SE¼ sec. 31	R. W. Philburn	Dr	60	6	P	S, G	Qa	Cy, H	D	Tc	+1.3	---------	4.61	5-13-46	

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