Hydrologic Conditions Near Glendo, Platte County, Wyoming

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1791

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

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By GEORGE E. WELDER *and* EDWIN P. WEEKS

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By George E. Welder and Edwin P. Weeks

ABSTRACT

The Glendo area of Platte and Carbon Counties, Wyo., about 250 square miles in extent, is in the Great Plains physiographic province. It is bordered on the west by the Laramie Range and on the east by the Hartville uplift. The North Platte River and Horseshoe and Middle Bear Creeks are the principal streams that drain the area. Gentle to steep hills, which lie between 4,450 and 6,360 feet above sea level, characterize the topography. Approximately 7,600 acres of land is cultivated in the Horseshoe Creek valley and 1,000 or more acres in the Cassa Flats of the North Platte River and Middle Bear Creek valleys. The average annual precipitation of 13.15 inches and the streamflow diverted for irrigation from Horseshoe Creek and the North Platte River are usually inadequate to sustain crops during the entire growing season.

Sedimentary rocks, which underlie about 99 percent of the Glendo area, range in age from Cambrian(?) to Recent and in thickness from about 3,000 to 4,700 feet. Beds of Paleozoic and Mesozoic age dip steeply away from the Laramie Range and the Hartville uplift to form a large syncline, which is interrupted by the Elkhorn anticline in the central part of the area. Beds of Tertiary and Quaternary age that were deposited over the older structural features and later were partly removed by erosion have dips of less than 6°. The "Converse sand" of local usage at the top of the Hartville Formation of Mississippian(?), Pennsylvanian, and Permian age, the White River Formation of Oligocene age, and the flood-plain deposits of Recent age are the most important aquifers in the Glendo area.

The Hartville Formation consists predominantly of hard limestone and dolomite and of lesser amounts of sandstone and shale; its thickness ranges from 850 to 1,050 feet throughout most of the area. The "Converse sand" is an artesian aquifer consisting of fine- to medium-grained porous sandstone having an average thickness of about 80 feet.

Recharge to the Hartville Formation is mainly from seepage of surface water from Glendo Reservoir and Spring Creek; ground water is discharged from the formation to the overlying White River Formation and the alluvium in the North Platte River valley near Cassa and to four wells in the Horseshoe Creek valley. Flowing wells yielding from a few gallons per minute to 175 gpm (gallons per minute) or more from the "Converse sand" can probably be located in an area from ½ mile to 1½ miles wide and about 4½ miles long in the lower Horseshoe Creek valley. The depth to the "Converse sand" in this area depends upon the topographic relief and distance from the outcrop and ranges from 250 to about 1,000 feet. The discharge induced by pumping a well in the aquifier in the "Converse sand" would probably amount to about 2 gpm per foot of drawdown. Values

of 2,000, 2,100, and 10,300 gpd (gallons per day) per ft for the coefficient of transmissibility of the "Converse sand" were obtained from aquifer tests at three wells. The chemical analyses of samples from the Hartville Formation ("Converse sand" included) indicate that the water in the formation is of fairly good quality and adequate for domestic, stock, and irrigation uses, although the fluoride content is low and the water is hard.

The White River Formation is composed of as much as 575 feet of fractured siltstone and claystone, and the flood-plain deposits include up to 65 feet of silt, sand, and gravel. Precipitation is the main type of recharge to the rocks of Tertiary age. Recharge to the alluvium in the valleys of Horseshoe Creek and the North Platte River occurs mainly by seepage of ground water from underlying beds, by infiltration of irrigation water, and by infiltration of streamflow as bank storage. Ground water is discharged naturally from the area by seepage to streams, by underflow, and by evapotranspiration and artificially by wells. In 1961, the total discharge from 38 wells in the White River and Arikaree Formations and 29 wells in the flood-plain deposits was about 35 and 350 acre-feet, respectively. The water table in the alluvium is less than 20 feet below the surface in the Horseshoe Creek valley and is less than 35 feet in the North Platte River valley. The depth to the water table in the rocks of Tertiary age ranges from a few feet near the streams to as much as 140 feet along the stream divides.

Some wells in the White River and Arikaree Formations might yield as much as 50 gpm with relatively large drawdowns, although most wells would have a much smaller yield. Wells tapping the alluvium at locations several hundred feet from Horseshoe Creek would probably yield from 150 to 500 gpm, and wells near the stream might yield as much as 800 gpm. Wells in favorable parts of Cassa Flats would probably yield 500 gpm or more. The coefficient of transmissibility computed for the White River Formation in the Horseshoe Creek valley ranged from 450 to 650 gpd per ft. Coefficients of 80,000 and 240,000 gpd per ft were obtained for the alluvium in the Horseshoe Creek valley from aquifer tests at two wells.

The chemical analyses of samples collected from the White River and Arikaree Formations and from the alluvium indicate that the water in these formations is of fairly good quality and adequate for domestic, stock, and irrigation uses, although the fluoride content is low and the water is very hard. Some of the samples from the alluvium in the Horseshoe Creek valley have high salinities and are high in sulfate because of nearby gypsum outcrops.

If adequate amounts of surface water were available, better crops could be grown and relatively large quantities of irrigation water could be salvaged although considerable water would be lost to evapotranspiration. Much of the water would recharge the alluvium, return quickly to the stream, and become available for use a short distance downstream. Because wells tapping the alluvium derive much of their water from streamflow, the large-scale development of ground water for irrigation would diminish the surface-water supplies in the Horseshoe Creek valley and Cassa Flats. The decrease in streamflow, however, would not be equal to the amount of ground-water pumpage because much of the water applied for irrigation would quickly return to the stream. Wells drilled in most of the Horseshoe Creek valley and in most of Cassa Flats would not salvage efficiently the recharge to the alluvium from streamflow diverted for irrigation. Much of the water diverted from the streams and applied for irrigation would move rapidly back to the streams and would not be available for pumping.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

This study was conducted by the U.S. Geological Survey as part of the Department of the Interior's program for the development of the water resources of the Missouri River Basin (fig. 1). The main purposes were: (1) to determine the availability of ground water in the valleys of Horseshoe and Middle Bear Creeks and the North Platte River by ascertaining the water-bearing properties of the Hartville and White River Formations and the flood-plain deposits, and (2) to determine the feasibility of salvaging ground-water recharge that would occur if larger amounts of irrigation water were made available.

The study was made in conjunction with an investigation by the U.S. Bureau of Reclamation to determine the feasibility of trans-

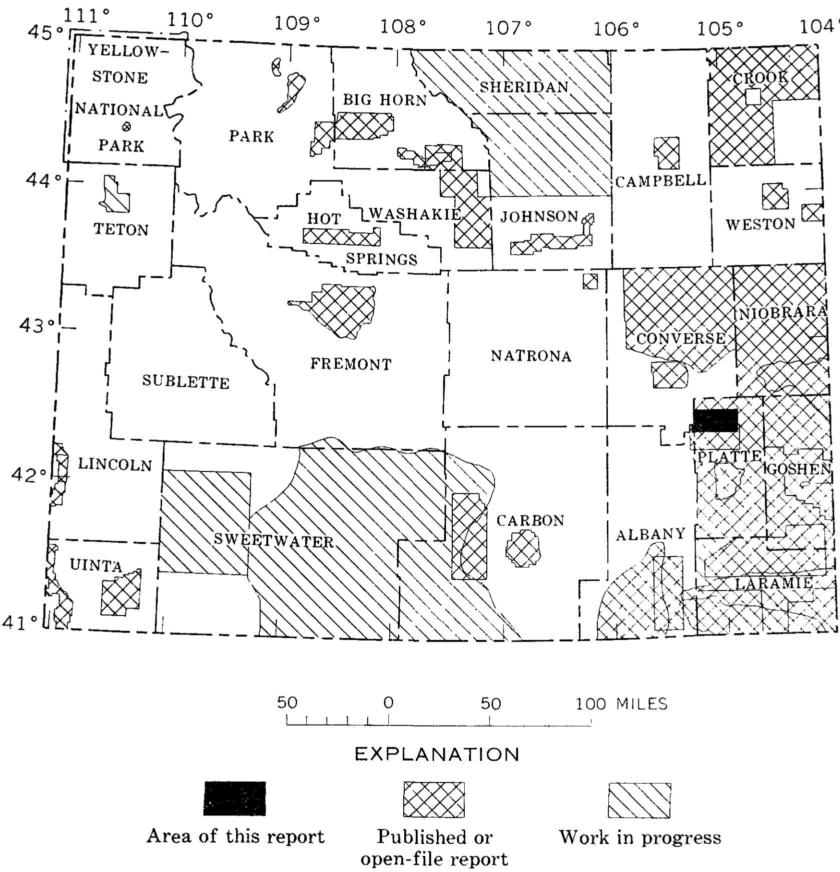

FIGURE 1.—Map of Wyoming showing the area covered by this report and other areas in which ground-water investigations have been made or are in progress.

ferring the water rights for inundated lands in the Glendo Reservoir area to the valleys of Horseshoe and Middle Bear Creeks and the North Platte River. The water that was being used in 1961 for irrigation in these valleys was diverted from Horseshoe Creek and the North Platte River. In the Horseshoe Creek valley, streamflow is usually inadequate to supply water for the entire growing season to all the water users.

The principal fieldwork upon which this report is based was done by D. A. Morris, E. P. Weeks, and G. E. Welder from May 15 to August 30, 1961. The work was under the general supervision of E. D. Gordon, district geologist of the Ground Water Branch for Wyoming. Water samples were analyzed by the Quality of Water Branch in Lincoln, Nebr.

LOCATION AND GENERAL GEOGRAPHY

The area described in this report is approximately 100 miles north of Cheyenne, Wyo., in the southeastern part of the State. Most of the area (240 sq mi) is in northwestern Platte County; however, the southwestern part (4 sq mi) extends 1 mile into Albany County (fig. 1 and pl. 1). The dimensions of the map area, which is rectangular in shape, are 21 miles from east to west and 12 miles from north to south. Former U.S. Highway 87, U.S. Interstate Highway 25, and the Chicago, Burlington, and Quincy Railroad transect the eastern part of the area in a north-south direction and serve Glendo, the only town in the area. The old railroad water station from which the cultivated land known as Cassa Flats was named is 6.5 miles southeast of Glendo. The North Platte River flows southward across the eastern part of the area whereas Elkhorn, Horseshoe, and North, Middle, and South Bear Creeks flow eastward and empty into the North Platte.

The area is in the extreme western part of the High Plains section of the Great Plains physiographic province and is bordered on the west by the Laramie Range and on the east by the Hartville uplift. Surface altitudes range from 4,450 feet above sea level in the southeast corner of the area to 6,360 feet in the southwest corner. Climatological data have been recorded at Wheatland, which is 37 miles south of Glendo, for 48 of the years between 1892 and 1962. Temperatures at Wheatland have ranged from $-38°$ to $109°$ F, and the annual mean temperature is $48.8°$ F. The average annual precipitation is 13.15 inches, and the wettest months are April, May, and June. Native hay, alfalfa, and wheat are the principal crops grown. The frost-free season ranged from 104 to 162 days for the period of record. Approximately 7,600 acres of farmland is irrigated from Horseshoe Creek when sufficient water is available. Usually in late summer there is not enough water even for the higher priority users who hold senior water rights for 2,719 acres in the lower Horseshoe Creek valley. More than 1,000 acres of land in the flood plain of the North Platte River in the Cassa area is irrigated by pump lifts from the river.

PREVIOUS GROUND-WATER INVESTIGATIONS

Parts, or all, of the Glendo area have been included in several previous ground-water studies. Rapp and Babcock (1953) conducted a reconnaissance of the geology and ground-water resources of the Glendo-Wendover area in 1949. This work included aquifer tests of the upper part of the Hartville Formation and an inventory of representative wells and well logs from the Glendo area. During the period 1952–56 studies were made throughout Platte County, and the results were published in a report by Morris and Babcock (1960). That résumé included the following new information pertaining to the Glendo area: results of aquifer tests of the alluvium along Horseshoe Creek, Bear Creek, and the North Platte River, additional well records, and general information about the geology. In August and September 1960, E. P. Weeks (1960) studied a 3-mile reach of Horseshoe Creek near U.S. Highway 87 to determine the effects of ground-water pumping on streamflow. All the mentioned investigations pointed to a need for additional ground-water study of the Glendo area.

WELL-NUMBERING SYSTEM

Wells and test holes shown on the accompanying map (pl. 1) are numbered according to the Federal system of land subdivision. The number shows the location of the well or test hole by township, range, section, and position within the section, as illustrated in figure 2.

The first numeral of a well number indicates the township; the second, the range; and the third, the section in which the well is located. The lowercase letters following the section number indicate the position of the well within the section. The first letter denotes the quarter section; the second letter, the quarter-quarter section; and the third letter, the quarter-quarter-quarter section (10-acre tract). The subdivisions of the sections are lettered a, b, c, and d in a counterclockwise direction beginning in the northeast quarter. Where more than one well is in a 10-acre tract, consecutive numbers beginning with 1 are added to the well number.

METHODS OF INVESTIGATION

The thicknesses and types of alluvium in the valleys of Horseshoe and Middle Bear Creeks and the North Platte River were determined

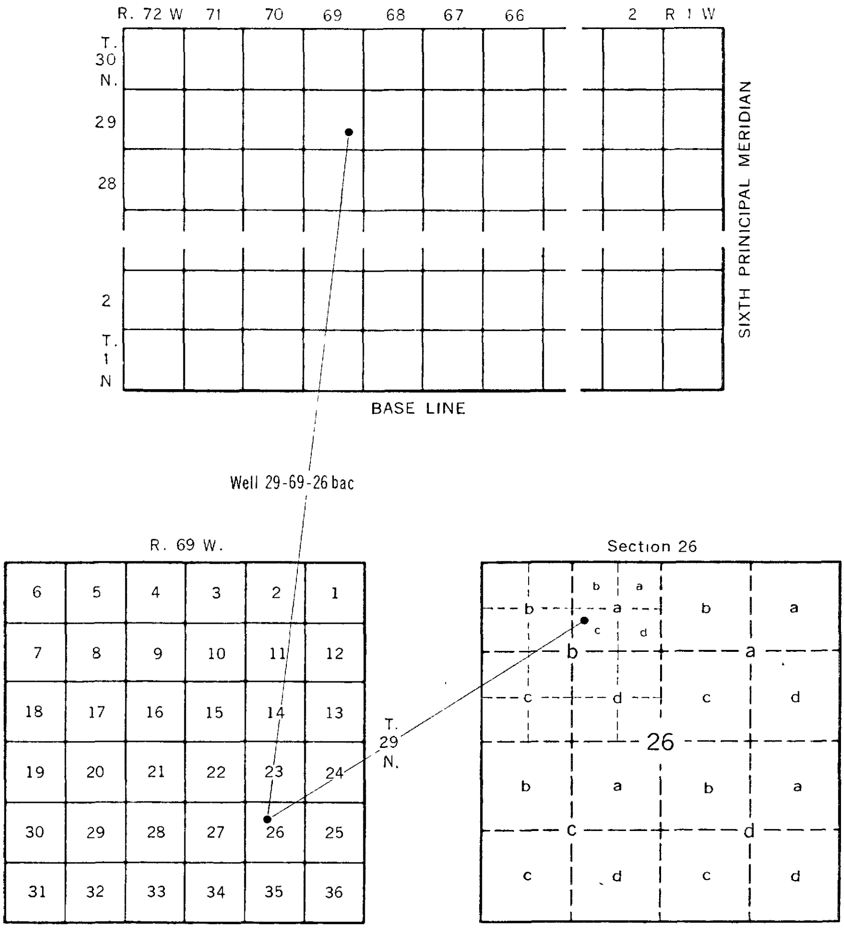

FIGURE 2.—Well-numbering system.

by drilling 49 test holes with a hydraulic rotary rig. From 3 to 6 holes were drilled in each of 10 lines across the stream valleys at strategic locations. Depths ranged from 18 to 71 feet, and a single hole was drilled to a total depth of 191 feet to test the Arikaree Formation. Samples, which were collected where major lithologic changes had occurred, were contaminated by cavings and drilling fluid; but, they yielded fairly reliable information regarding the thicknesses and general characteristics of the alluvium. The collected data were used in preparing sections of the stream valleys which show the relations between the alluvium, underlying beds, and water table. One-inch pipe was placed in 18 of the test holes so that water-level measurements could be made and hydrographs prepared.

Two test wells that penetrate the Hartville Formation were drilled to depths of 840 and 485 feet with a cable-tool rig. Samples collected where lithologic changes have occurred are representative of the materials penetrated, although they were somewhat contaminated by cavings. The deeper well was dually cased and perforated so that the water level in the "Converse sand" of local usage could be measured separately from the water level in that part of the Hartville Formation penetrated by the well below the "Converse sand." The shallower well was cased so that the water level in the White River Formation could be measured separately from that in the "Converse sand."

During the current investigation, 14 ground-water samples from the Glendo area were chemically analyzed: 3 samples came from that part of the Hartville Formation below the "Converse sand" that was penetrated by well 29–69–24dbc2; 4, from the "Converse sand"; 1 each, from the lower, middle, and upper part of the Opeche Shale; 1, from the Minnekahta Limestone and basal sequence of gypsum and red shale combined; 1, from the White River Formation; and 2, from the alluvium in the valley of Horseshoe Creek. Of the 14 samples, 11 were taken from test well 29–69–24dbc2 and 2, from test well 29–69–33bac during the course of drilling as successively deeper geologic formations were penetrated. The uncased interval of strata open to the well bore when each sample was collected could not always be restricted to a single aquifer. In each well, however, the overlying formations either were sealed off or they were too tight to yield enough water to significantly contaminate the water from the lower aquifer. Prior to the collection of each sample, the well was bailed for a sufficient time to allow fresh water from the formation to enter the well bore. One sample also was collected from the Horseshoe Cemetery well (29–68–19abb), which produces water from the alluvium in the valley of Horseshoe Creek.

Records were made of the important new wells and of the old wells not included in previous reports. The test holes and wells were located by means of aerial photographs and topographic maps, and their altitudes were determined from surveys by means of hand level, rod, and steel tape or were taken from the topographic maps. A water-level recorder was maintained throughout the study on a dug well (29–68–21acb) in the alluvium of the Horseshoe Creek valley, but the record was discontinuous because water in the well froze during some of the colder winter months.

A lithologic log was made as each test hole was drilled. Electric and gamma-ray logs were obtained for the deeper Hartville test well and for wells 29–68–20acd and 29–69–2aac, but the logs were poor in quality and, consequently, not very useful. To supplement the lithologic data from the two test wells that penetrated the Hartville Formation, three surface geologic sections of the upper part of the Hartville Formation were measured with the use of hand level, Brunton compass, and steel tape.

The water-bearing strata penetrated below the valley alluvium by the two deep holes were tested by bailing during the course of drilling. In addition to the bailing tests, one aquifer pumping test was made at the Horseshoe Cemetery well (29–68–19abb) and one at the W. H. Johnson well (28–67–18bcc1). These two wells produce water from the alluvium in the valleys of Horseshoe Creek and the North Platte River, respectively.

The geologic map prepared for this report was compiled from the following sources: J. J. Pennington (1947, unpublished thesis, University of Missouri), Love and others (1949), Rapp and Babcock (1953), Morris and Babcock (1960), and N. M. Denson (unpub. data). Topographic maps of the U.S. Geological Survey were used for the base, and contours of the land surface were included to facilitate the interpretation of hydrologic features. The contacts of geologic formations, however, are generalized with respect to altitude and caution should be used when making precise structural interpretations. A generalized structure contour map of the top of the "Converse sand" was constructed from the altitudes of points in wells and at surface exposures. In addition, generalized maps of the water tables in the White River and younger formations of Tertiary age and the alluvium of Recent age were drawn by utilizing the altitudes of water levels in wells and points on the surfaces of streams.

ACKNOWLEDGMENTS

The authors wish to acknowledge the fieldwork done by D. A. Morris at the beginning of the investigation. Mr. Morris helped direct all the rotary test-hole drilling and one of the cable-tool tests. The field assistance of N. M. Denson was of great help in determining the boundaries and extent of the Tertiary formations in the Glendo area.

Mr. Denson very generously offered the use of his field maps, which were useful in preparing the geologic map of the report area. The help of M. E. Lowry, who made many useful suggestions concerning the geology and hydrology, is gratefully acknowledged. Ranchers and farmers living in the region were very cooperative, and their assistance was greatly appreciated.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

GEOLOGIC SETTING

Igneous and metamorphic rocks of Precambrian age are exposed in the Laramie Range and the Hartville uplift in the southwestern and southeastern parts of the Glendo area, respectively; these rocks occur in less than 1 percent of the area. The sedimentary rocks underlying the area range in age from Cambrian(?) to Recent and in thickness from approximately 3,000 to 4,700 feet. (See table 1.) Limestone, dolomite, shale, siltstone, and sandstone of Devonian, Mississippian, Pennsylvanian, and Permian age and gypsum, shale, siltstone, and sandstone of triassic, Jurassic, and Cretaceous age are the predominant types of rocks which crop out in approximately 15 percent of the area. The remaining surface exposures consist mainly of claystone, siltstone, sandstone, and conglomerate of Tertiary age and of clay, sand, and gravel of Quaternary age.

The rocks that compose the three important aquifers in the Glendo area are the "Converse sand" of local usage at the top of the Hartville Formation, the fractured siltstone and claystone of the White River Formation, and the sand and gravel of the flood-plain alluvium.

The present structural framework, which partly controls the distribution of ground water in the Hartville Formation, is largely the result of orogenic movements that occurred when the Laramie Range and the Hartville uplift were elevated during Late Cretaceous and early Tertiary time. Paleozoic and Mesozoic beds, which were intensely folded and faulted in the vicinity of the Laramie Range and

TABLE 1.—*Generalized section of the geologic formations in the Glendo area, Wyoming*

[Adapted from Love and others (1949), Rapp and Babcock (1953), and Morris and Babcock (1960)]

System	Series	Subdivision	Thickness (feet)	Physical characteristics	Water supply
Quaternary	Recent	Dune sand	0–50±	Fine windblown sand.	Infiltration areas for recharge from precipitation.
		Slope wash	0–40	Clay, silt, sand, and gravel; small scattered outcrops.	Yields small amounts of water to a few wells.
		Flood-plain deposits	0–70	Fine to very coarse sand and gravel, containing lenses of silty and sandy clay; cobbles and boulders occur in some localities.	Yield as much as 800 gpm at favorable localities. Best aquifer in the area.
	? Pleistocene ?	Terrace deposits	0–30±	Sand, gravel, cobbles, and boulders, containing some lenses of clay and silt.	Generally lie above the water table. Not a known source of water in the Glendo area.
Tertiary	Pliocene and upper Miocene ?	Ogallala equivalent and rocks of late Miocene age	0–200±	Siltstone, sandstone, conglomerate, and boulders, interbedded or mixed with clayey sand or tuffaceous clay; loosely consolidated; form rounded topography.	Generally high and dissected but may yield stock water to a few wells in the area.
	Miocene	Arikaree Formation	200±	Sandstone, light-brown, fine-grained, massively- to erraticly-bedded, tuffaceous, and siltstone; contains beds of cemented sandstone and conglomerate.	Yields limited amounts of water to wells and springs.
	Oligocene	White River Formation	600±	Siltstone and claystone, buff, containing thin beds of volcanic material, sandstone, and conglomerate; many fractures.	Yields moderate amounts of water to stock, domestic, and municipal wells from fracture zones.

Cretaceous	Lower Cretaceous	Mowry Shale	40–90		Shale, dark-gray, siliceous, weathering silver-gray; contains fish scales and thin beds of yellow bentonite.	Ground-water possibilities not known.
		Thermopolis Shale	140–250	50–100	Sandstone, gray, medium-grained, moderately clean, hard; interbedded with dark sandy shale; called Muddy Sandstone Member.	
				90–150	Shale, black, soft, fissile, flaky; contains thin layers of bentonite and partings of ironstone.	
		Cloverly Formation	120–260		Sandstone, gray, fine-grained, clean, containing a sandy claystone layer in the middle.	Yields water to springs.
Jurassic	Upper Jurassic	Morrison Formation	150–220		Claystone, green, pink, and purple, siliceous; contains calcareous nodules, fresh-water limestones, and thin hard sandstones.	Ground-water possibilities not known.
		Sundance Formation	175–400	50–100	Shale, dull-green, grading downward into yellow, hard, limy, glauconitic, fossiliferous, siltstone; tan to gray hard basal sandstone; locally called "Upper Sundance."	Not a producing aquifer in the area but may contain water.
				125–300	Sandstone, red to buff, fine-grained, massive; underlain by interbedded tan, green, and purple beds of sandstone, siltstone, and shale; locally called "Lower Sundance."	
		Sandstone	30–75		Sandstone, white, tan, and yellowish, fine- to coarse-grained, massive to crossbedded, containing large rounded frosted grains; ammonites and pelecypods in middle part.	
Triassic		Chugwater Formation	275–500		Siltstone, red; contains red shale, fine-grained red silty sandstone, and a few thin beds of gypsum or anhydrite.	Yields very little water of poor quality.
Permian	?	Gypsum and red shale sequence	220–270		White gypsum interbedded with thin layers of red shale in upper two-thirds of the sequence; red shale in lower third, containing a thin purple to gray crinkled limestone at middle (Forelle Limestone). The red shale below the Forelle is the Glendo Shale of Condra, Reed, and Scherer (1950).	
		Minnekahta Limestone	20–41		Limestone, generally yellow to pink, hard, fine-grained, silty, thin-bedded; forms conspicuous slabby ledges.	
	?	Opeche Shale	25–120		Shale, bright red, becoming purple at top and yellow at base; contains yellow silty limy sandstones up to 2 ft thick in lower half.	Yields little or no water.

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TABLE 1.—*Generalized section of the geologic formations in the Glendo area, Wyoming*—Continued

[Adapted from Love and others (1949), Rapp and Babcock (1953), and Morris and Babcock (1960)]

System	Series	Subdivision				Thickness (feet)		Physical characteristics	Water supply
Permian—Con.	Lower Permian	Casper Formation (Laramie Range)	Hartville Formation (Hartville uplift)	Division I[1]	Cassa Member of Hoyt (1962)[2]	850–1,050	80±	Sandstone, white to yellow, fine- to medium-grained, subangular to subrounded; locally called "Converse sand."	"Converse sand" yields 75 to 175 gpm of water to four artesian wells in the area.
							170±	Shale, red, and siltstone, dolomitic sandstone, and breccia.	Lower dolomitic sandstones yield very little water.
					Broom Creek Member of Hoyt (1962)[2]			Interbedded gray limestone and red shale, siltstone, and sandstone.	Yields very little water.
Carboniferous: Pennsylvanian	Upper Pennsylvanian			Division II[1]	Wendover Member of Hoyt (1962)[2]		230±	Dolomite, light-gray, and light- to dark-gray limestone; cherty, fossiliferous; contains a few thin sandstone beds. Cannot separate members.	Yields little or no water.
					Meek Member of Hoyt (1962)[2]				
	Middle Pennsylvanian			Division III[1]	Hayden Member of Hoyt (1962)[2]		170±	Limestone, blue-gray, massive, cherty; contains lenticular beds of sandstone and siltstone.	
Carboniferous: Pennsylvanian or Mississippian	Lower Pennsylvanian or Upper Mississippian			Division IV[1]	Roundtop Member of Hoyt (1962)[2]		230±	Shale, red, pink, and green, interbedded with layers of limestone, dolomite, and siltstone.	Ground-water possibilities not known.
				Division V[1]	Reclamation Member of Hoyt (1962)[2]			Limestone, pink to gray, thin-bedded to massive, containing thin beds of red shale.	
				Division VI[1]	Fairbank Formation of Bates (1955)[3]		70±	Sandstone and quartzite, red to gray, grading upward into siltstone and shale. Deposited on a very irregular surface.	
Carboniferous: Mississippian and Devonian	?	Guernsey Formation				150–250		Limestone, gray, fine- to coarse-grained, cherty, interbedded with chalky dolomite; contains purple to gray fine-grained thin-bedded brittle dolomite in lower part and arkose at base.	
Cambrian(?)	?	Quartzite				0–50		Quartzite, brownish-red, coarse-grained. Present in adjacent areas; presence in Glendo area not determined.	
Precambrian		Igneous and metamorphic rocks							

[1] Divisions I–VI of Condra and Reed (1935, p. 10) were used by Love, Henbest, and Denson (1953).
[2] The group designations of Condra, Reed, and Scherer (1940, p. 3) were changed by Hoyt (1962, p. 47) to members that make up the Hartville Formation.
[3] Bates (1955, p. 1,986) and Hoyt (1962, p. 47) exclude the Fairbank Formation from the Hartville Formation.

the Hartville uplift, dip steeply away from these highs and form a large syncline. The Elkhorn anticline, a broad southwest-trending structural feature, interrupts the syncline in the central part of the area. (See pl. 1.)

Rocks of Tertiary and Quaternary age, which were deposited over the older structural features, have relatively uniform and small dips that are generally less than 6°. Ground-water distribution in these rocks, therefore, is related more to their varied thicknesses and the present topography than to their structural relief.

ROCKS OF PRE-TERTIARY AGE

Rocks of pre-Tertiary age exposed in the Glendo area include those from Precambrian to Early Cretaceous; rocks of Late Cretaceous age are not known to be present in the area. The age, thickness, physical characteristics, and water-bearing potential of these rocks are summarized in table 1. The Hartville Formation is the most important aquifer of pre-Tertiary age in the Glendo area; therefore, it is the only formation of pre-Tertiary age discussed further in this report.

HARTVILLE FORMATION

AGE AND CORRELATION

The sequence of rocks in the Hartville uplift overlying the Guernsey Formation of Devonian and Mississippian age and underlying the Opeche Shale of Permian age was named the Hartville Formation by Smith (1903, p. 2). Condra and Reed (1935, p. 10) separated the Hartville into six divisions, in which division VI is the oldest (table 1). Later, Condra, Reed, and Scherer (1940, p. 3) named seven groups that were equivalent to division I through division V and the Fairbank Formation that was equivalent to division VI. More recently, Hoyt (1962, p. 47) reduced the seven named groups of Condra, Reed, and Scherer to member rank and recognized the Hartville Formation as being composed of the seven members and the Fairbank Formation as being distinct from the Hartville (table 1).

Hoyt (1962, p. 47) suggested that the Fairbank Formation is correlative with beds of Early Pennsylvanian (Morrow) age in northeastern Colorado. The Hartville Formation as defined by Hoyt is considered by him to be Middle (Atokan, Des Moines) and Late (Missouri, Virgil) Pennsylvanian and Early (Wolfcamp, Leonard) Permian in age. However, fusulines of questionable Mississippian and Pennsylvanian age found in the Glendo area near the base of division V of the Hartville imply that the lowest part of division V, and all of division VI (Fairbank Formation), might be of late Mississippian age (Love and others, 1949).

Rocks in adjacent regions that are probably correlative with the Hartville Formation as defined by Smith (1903, p. 2) are as follows: Pennsylvanian and Permian equivalents in the subsurface of western Nebraska (Hoyt, 1962, p. 52), the Minnelusa Formation of the Black Hills uplift and the eastern Powder River Basin, the Amsden and Tensleep Formations of the western Powder River Basin and Bighorn Mountains, and the Casper Formation of the Laramie Range and the northwest Denver Basin (Agatston, 1954, p. 549). Outcrops of the Casper Formation in the western part of the Glendo area contain more sandstone than the Hartville Formation and may not include equivalents of the lower part of the Hartville (Bates, 1955, p. 1, 985); hence, the change in formation names from Hartville to Casper within the Glendo area.

Test well 29–69–24dbc2, which is near Horseshoe Creek on the southern part of Elkhorn anticline, was drilled to a total depth of 840 feet. The well penetrated 599 feet of the Hartville Formation. Although the contacts between the divisions of the Hartville are difficult to determine precisely, the general lithology indicates that the well was drilled through all of division I (241 to 497 ft) and division II (497 to 722 ft) and about two-thirds of division III (722 to 840 ft). A red shale bed penetrated by the well from 544 to 553 feet may be near the base of division I if this bed correlates with the subsurface marker bed at Lance Creek oil field, 43 miles northeast of Glendo (Agatston, 1954, p. 533). According to Hoyt (1962, p. 47) the Pennsylvanian-Permian contact is approximately 75 feet below this red shale marker.

The yellow to white sandstone immediately below the Opeche Shale in the Glendo area is probably correlative with the Lyons Sandstone of north-central Colorado (Hoyt, 1962, p. 47) and the Converse oil sand of commercial usage of the Lance Creek oil field (Love and others, 1949). Throughout this report the upper sandstone unit of the Hartville Formation is referred to as the "Converse sand" of local usage.

DISTRIBUTION AND THICKNESS

The Hartville Formation crops out on the Elkhorn anticline in the central part of the area and along the west edge of the Hartville uplift in the eastern part of the area (pl. 1). Exposures of the Hartville

Formation on the Elkorn anticline consist almost entirely of division I, II, and III; only small outcrops of divisions IV, V, and VI occur near the trace of the Elkhorn fault. In the western part of the area the "Converse sand" is mapped separately from the main body of the Casper Formation.

Love and others (1949) stated that the Hartville Formation thickens southeastward across the Glendo area from approximately 850 to 1,050 feet. More recently, Bates (1955, p. 1,987-1,991) measured a thickness of 1,179 feet for the Hartville (Fairbank Formation of Condra, Reed, and Scherer, 1940, which comprises division VI, included) near Sand Draw (sec. 28, T. 29 N., R. 67 W.) in the eastern part of the Glendo area.

The "Converse sand" is present throughout the Glendo area except where it has been removed by erosion from parts of the Laramie Range, Elkhorn anticline, and Hartville uplift. Maximum and minimum thicknesses of 96 and 63 feet were measured by the senior author on the east flank of the Laramie Range (28–70–18a) and the west edge of the Hartville uplift (29–67–28b), respectively. Thicknesses of 91, 84, 67, and 66 feet were obtained from test wells and outcrops in the southern and north-central parts of the mapped area. (See well logs and measured sections describing the lithology of the Hartville Formation, p. 17.) A reported thickness of 120 feet penetrated by well 29–68–20bac seems unusually great.

LITHOLOGY

Facies changes, complex lithologic types, and near-surface alterations by weathering tend to obscure the characteristics of the six divisions of the Hartville Formation outside of the Lake Guernsey type localities. The generalized lithologic descriptions of the divisions in the Glendo area are summarized by Love and others (1949) in their report on the geology of the Glendo damsite. According to that study division VI consists of 30 to 100 feet of red and gray sandstone and quartzite, the upper part of which grades southeastward into sandy siltstone. Divisions IV and V consist of about 230 feet of red shale, pink limestone, and thin white to pink dolomite beds. Division V is mostly limestone and division IV is mostly red shale and dolomite. Division III is composed of about 175 feet of hard bluish-gray limestone containing abundant red chert near the top and minor amounts of red shale, siltstone, and fine-grained sandstone. Division II is made up of about 225 feet of light-colored dolomite and small amounts of bluish-gray limestone. Chert occurs in the upper part and thin sandstone beds in the lower part. Division I consists of about 250 feet of sandstone, red shale, pink dolomite, and breccia.

Division II of the Hartville Formation and that part of division III penetrated by test well 29–69–24dbc2 are composed of 343 feet of hard cherty pink to gray limestone and dolomite, containing minor amounts of shale and fine-grained sandstone. Division I consists of 172 feet of pink dolomite and sandstone and of material that is probably brecciated limestone, dolomite, and sandstone and of 84 feet of overlying white to yellow fine- to medium-grained clean porous sandstone ("Converse sand").

The lithology of the "Converse sand" is nearly uniform throughout the area, as indicated by samples from test wells 29–69–24dbc2 and 29–69–33bac and by outcrops in the western, central, and eastern parts of the Glendo area. The unit was found to be composed almost entirely of white, yellow, and pink sandstone that is fairly well sorted and fine to medium grained. A single thin brown to pink limy dolomite bed was observed at each of three exposures at distances of 13, 36, and 44 feet below the top of the "Converse sand" in the eastern and central parts of the area. No dolomite or limestone beds were recognized in the two deep test wells when the "Converse sand" was penetrated.

The base of the "Converse sand" is commonly marked by a pink to lavender cherty dolomite which is usually less than 10 feet thick and is underlain by thick pink dolomitic sandstone and sandy dolomite. The yellow sandstone beds in the lower part of the Opeche Shale might be mistaken for the top of the "Converse sand." Generally, the sandstone beds in the Opeche are only a few feet thick and contain silt and clay, but one sandstone bed observed near the South Fork of Sand Draw was 14 feet thick and fairly clean.

The following well logs and surface sections of the "Converse sand" describe the character of the unit and adjacent beds. Corrections in the measured thicknesses of the sections were made for dip, which is different at each locality.

Description	Thickness (feet)	Depth (feet)
Sample log of test well 29-69-24dbc2 [Hole 3 in cross section *E-E'*. Alt 4,710 ft]		
Flood-plain deposits:		
Soil, brown to gray, sandy, silty	6	6
Sand, very fine to coarse, and fine to coarse gravel	32	38
Gypsum and red shale sequence:		
Dolomite, pink and gray; contains minor amounts of sandstone, red shale, and anhydrite; probably the Forelle limestone	12	50
Shale, red, silty, limy; contains thin beds of dolomite and limestone	29	79
Minnekahta Limestone:		
Limestone, buff, yellow, and pink, hard; contains red limy hard shale	41	120
Opeche Shale:		
Shale, red, soft; contains purple limestone	11	131
Shale, red, soft to hard; contains pink limestone	42	173
Shale, red, soft, and yellow fine- to medium-grained sandstone	15	188
Sandstone, yellow, fine- to medium-grained	5	193
Shale, red, soft	9	202
Sandstone, yellow, fine- to medium-grained	6	208
Shale, red and yellow, silty, soft; contains thin beds of yellow and white sandstone	33	241
Hartville Formation:		
Sandstone, yellow, white, and buff, fine- to medium-grained, subangular to subrounded, fairly well sorted, friable to indurated, porous, limy cement. Locally called the "Converse sand"	84	325
Dolomite, red, purple, and white, sandy; contains thin beds of red shale, siltstone, and sandstone	27	352
Sandstone, white and pink, fine- to medium-grained, limy; contains minor amounts of limestone and dolomite	23	375
Limestone, white to pink, and purple dolomite; contains sandstone and chert; probably brecciated	27	402
Sandstone, white and pink, fine- to medium-grained, limy; contains limestone and dolomite	10	412
Limestone, white, gray, and pink, dolomitic; contains sandstone and chert; probably brecciated	22	434
Sandstone, white and red, fine- to medium-grained, limy; contains limestone and dolomite; possibly brecciated	13	447
Limestone and dolomite, white and pink; possibly brecciated	7	454
Sandstone, pink and red, fine- to medium-grained, dolomitic, soft; possibly brecciated	9	463
Dolomite and limestone, gray, hard, cherty, possibly brecciated	15	478
Sandstone, pink and red, fine- to medium-grained, limy; contains limestone and dolomite	19	497
Dolomite and limestone, gray	3	500
Sandstone, pink and red, fine- to medium-grained; contains white and gray limestone and dolomite	10	510
Limestone, white and pink, and gray dolomite; sandy in upper 6 ft	31	541
Sandstone, red, and red shale	3	544
Shale, red, soft	9	553
Limestone and dolomite, white, pink, and gray, hard; contains chert in upper part and some sandstone from 610 to 616 ft	76	629

Sample log of test well 29-69-24dbc2—Continued

[Hole 3 in cross section *E-E'*. Alt 4,710 ft]

Description	Thickness (feet)	Depth (feet)
Hartville Formation—Continued		
Limestone, white, very hard	25	654
Limestone and dolomite, white, gray, and purple	22	676
Limestone, gray and white, fine to noncrystalline; sandy zones from 685 to 690 ft and 710 to 721 ft	59	735
Dolomite, white, limy; contains a small amount of red-brown chert in base	13	748
Limestone, gray and white, hard; contains much white, pink, and brown chert	4	752
Limestone and dolomite, white and gray; contains minor amounts of chert	17	769
Limestone and dolomite, gray and white; contains much dark-red to light-colored chert	9	778
Limestone, white and light-gray, hard; contains minor amounts of silt and dolomite	25	803
Limestone, dark-gray, crystalline to microcrystalline, silty; contains pink chert and minor amounts of sandstone and dolomite	20	823
Limestone, very dark-gray and limy dark shale	3	826
Limestone, white, slightly sandy, crystalline	2	828
Sandstone, white and pink, fine-grained, angular; clear quartz; limy cement, nonporous, very hard	12	840

Sample log of test well 29-69-33bac

[Alt 4,840 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt and soil	7	7
Sand, fine, to coarse gravel	10	17
White River Formation:		
Siltstone and claystone, buff, limy; a few thin sandstone beds	123	140
Siltstone and claystone, reddish-buff, limy	30	170
Siltstone and claystone, buff, limy	85	255
Siltstone and claystone, reddish-buff	45	300
Opeche Shale:		
Clay and shale, reddish-brown; contains scattered limy nodules and silty zones	65	365
Claystone and sandstone, yellow, limy, soft to firm	5	370
Shale, red	3	373
Claystone and sandstone, yellow, limy, soft to firm	5	378
Shale, red	1	379
Claystone and sandstone, yellow, limy	3	382
Shale, red	1	383
Claystone and sandstone, yellow, limy	5	388
Sandstone, yellow, clayey, limy	3	391
Hartville Formation:		
Sandstone, white, fine- to medium-grained, subrounded, well sorted, clean, slightly limy, containing clear quartz grains; a 7-ft bed of pink sandstone containing minor amounts of reddish-brown sandy limestone occurs at base. Locally called the "Converse sand"	91	482
Limestone, pink, white, and purple, dolomitic; contains red chert	3	485

Section of the "Converse sand" approximately 1 mile west of the Macfarlane ranch in the NE¼ sec. 18, T. 28 N., R. 70 W.

	Feet
Permian:	
Minnekahta Limestone	
Opeche Shale:	
Shale, purple	10
Shale, red with yellow sand beds in lower half	86
Total thickness of Opeche Shale	96
Casper Formation ("Converse sand"):	
Sandstone, white, buff, yellow, fine-grained, fairly well sorted, crossbedded, limy	13
Sandstone, white to buff, fine-grained, massive to crossbedded, limy; contains limonitic streaks and concretions (one-sixteenth of an inch in diameter)	24
Sandstone, buff, fine-grained, massive to crossbedded, limy	16
Sandstone, buff, fine-grained, massive, limy	14
Sandstone, buff, fine-grained, crossbedded, limy	19
Sandstone, yellow, fine-grained, massive to crossbedded; very friable	5
Sandstone, buff, fine-grained, massive to crossbedded, limy	5
Total thickness of "Converse sand"	96
Shale, red, silty, limy	9
Limestone, buff to yellow and pink (near top), thin-bedded	5
Sandstone, reddish-brown, dolomitic; thin crossbedded layers; weathered surface of zone 5 ft below top of unit contains many pea-sized projections	24
Sandstone and dolomite, buff to pink; irregular bedding	5
Shale and dolomite, dark reddish-brown, sandy	8
Limestone and dolomite, pink, gray, mottled, bedded to nodular and massive, cherty; may be partly brecciated	50±
Exposed thickness of part of Casper Formation underlying the "Converse sand"	101±

Section of the "Converse sand" along Spring Creek in the NE¼SE¼ sec. 14, T. 29 N., R. 69 W.

	Feet
Permian:	
Minnekahta Limestone	
Opeche Shale[1]:	
Shale, purple	9
Shale, red	36
Shale, red, yellow in lower 5 ft; contains eight beds of yellow sandy limestone and limy sandstone ranging in thickness from 1 to 3 ft	56
Total thickness of Opeche Shale	101

[1] This section of the Opeche Shale is 0.7 mile south of Spring Creek in the SW¼NW¼ sec. 23, T. 29 N., R. 69 W.

748-652—65——4

Section of the "Converse sand" along Spring Creek in the NE¼SE¼ sec. 14, T. 29 N., R. 69 W.—Continued

	Feet
Permian—Continued	
Hartville Formation ("Converse sand"):	
Sandstone, white to yellow, fine-grained, well-sorted, crossbedded to massive, friable to indurated, limy; contains a 2-ft brown silty dolomite and limestone bed 36 ft below top	59
Sandstone and dolomite, yellow to pink; massive to irregular bedding	7
Total thickness of "Converse sand"	66
Dolomite, pink, thin irregular beds; contains red chert nodules	5
Sandstone, dolomitic and sandy dolomite, red, massive to cross-bedded	26
Dolomite, buff, sandy	2
Shale, red, silty, limy	6
Limestone, dolomite, and sandstone, pink to gray, brecciated, cherty; irregular to massive beds	10+
Exposed thickness of part of Hartville Formation underlying the "Converse sand"	49+

Section of the "Converse sand" 3 miles northwest of Glendo in the NE¼ sec. 36, T. 30 N., R. 69 W.

	Feet
Permian:	
Minnekahta Limestone	
Opeche Shale:	
Shale, purple	10
Shale, red; thin platy yellow sandstone beds in lower 50 ft	56
Total thickness of Opeche Shale	66
Hartville Formation ("Converse sand"):	
Sandstone, white, yellow, pink (in upper part), fine-grained, well-sorted, massive to well-bedded, friable to firm, limy	44
Dolomite, pink to purple, sandy, massive	3
Sandstone, yellow, fine-grained, friable	20
Total thickness of "Converse sand"	67
Dolomite, gray, pink, purple, bedded; very irregular base	3
Sandstone, dolomitic, dull red, thin-bedded, cross-bedded to massive	20
Siltstone, shale, and dolomite, reddish-brown; alternating beds	12
Limestone, gray, irregular beds	4
Limestone, dolomite, and sandstone, gray, pink, purple, brecciated, massive, cherty	10+
Exposed thickness of part of Hartville Formation underlying the "Converse sand"	49+

WATER-BEARING CHARACTERISTICS

The "Converse sand" is the main water-bearing zone in the Hartville Formation. As previously mentioned, this sandstone is probably present in all parts of the Glendo area except where removed by erosion. Unfortunately, in about two-thirds of the Glendo area, it either lies at considerable depth below the surface or has been eroded away. Zones of minor importance are the pink dolomitic sandstones below the "Converse sand" in division I.

The rocks in that part of the Hartville Formation below division I are probably too tight to transmit very much water. Information from test well 29–69–24dbc2 indicates that divisions II and III consist mostly of dense impermeable limestone or dolomite; no cavernous zones were found in the well. An examination of outcrops in the area shows that most of the sandstones in the lower divisions of the Hartville are fine grained, cemented, and at some places quartzitic. The cavernous appearance of some exposures of the lower limestone and dolomite in divisions IV and V is probably the result of near-surface weathering and does not occur at the same horizon consistently; however, if solution cavities do exist in the subsurface, prospects of finding ground water in divisions IV and V should be good.

TERTIARY SYSTEM

Rocks of Tertiary age exposed in the Glendo area include Oligocene, Miocene, and Pliocene; rocks of Paleocene and Eocene age are not known to be present in the area. The age, thickness, physical characteristics, and water-bearing potential of these rocks are summarized in table 1. The White River Formation is the most important water-bearing formation of Tertiary age in the Glendo area; consequently, it is the only formation of Tertiary age discussed in detail in this report.

Rocks of Miocene and Pliocene age overlie the White River Formation at various places in the area (pl. 1). Test hole 28–68–17cba, which is near Middle Bear Creek, penetrated 131 feet of clayey siltstone and sandstone. Morris and Babcock (1960) mapped these beds, together with a discontinuous basal conglomerate, as the Arikaree Formation.

In the south-central and northwestern parts of the area, the character and stratigraphic position of coarse stream deposits infer that their age is late Miocene and Pliocene. These rocks have recently been recognized as being equivalent to the Ogallala Formation of southeastern Wyoming (N. M. Denson, oral commun., Nov. 7, 1962). In much of the area the Arikaree Formation has been removed by erosion and the Ogallala equivalent directly overlies the White River Formation.

WHITE RIVER FORMATION

AGE AND CORRELATION

Meek and Hayden (1858, p. 119, 133) first used the name White River for Tertiary deposits in Brule County, S. Dak. In 1862 (p. 433, 434), Meek and Hayden included in the White River the thick white to light-drab clay and sandstone overlying the Fort Union Formation that crop out in parts of Converse and Niobrara Counties, Wyo. The assignment of similar beds in the Glendo area to the White River Formation of Oligocene age is based upon stratigraphic position and lithologic similarity to White River strata in adjacent areas. To date, the lack of fossil and lithologic markers has prevented the division of the White River of the Glendo area into the Chadron and Brule Formations which are recognized to the south (Morris and Babcock, 1960, p. 31–33) and east (Wenzel and others, 1946, p. 59–70). Locally, water-well drillers refer to these beds as "the Brule clay."

DISTRIBUTION AND THICKNESS

Approximately 85 percent of the report area is underlain by the White River Formation, but little is known about the thickness and distribution of lithologic types that are contained in the formation. In most of the area the White River is covered by younger formations, terrace deposits, alluvium, slope wash, or soil. The maximum thickness of the formation in the area is not known, but 575 feet of sandy clay and silty sandstone was reported to have been penetrated by one of the Glendo townsite wells (29–68–9bcdl). A thickness of 283 feet of bluff to tan siltstone and claystone was penetrated by test well 29–69–33bac, which is just west of the Elkhorn fault on the south part of the Elkhorn anticline. The structurally low areas south and west of the Elkhorn anticline probably contain thick deposits of White River age.

Evidently, the surface on which the first Oligocene strata were deposited was very irregular. At least 550 feet of relief is present on the base of the White River Formation within a distance of 1.7 miles southeast from test well 29–69–33bac. The relationship between the thickness (575 ft) of the White River Formation in the Glendo townsite well (29–68–9bcdl) and the structural position of older formations indicates that pre-Oligocene strata either were eroded deeply or were down faulted in this vicinity.

LITHOLOGY

In the Glendo area most of the exposures of the White River Formation that were observed by the authors are composed of massive soft to moderately indurated buff-colored siltstone and claystone.

Particles of sand and gravel sizes are scattered sparsely throughout many of the siltstone and claystone beds. Adjacent to the Laramie Range in the upper valley of Horseshoe Creek, lenses of sandstone and conglomerate occur in the formation. (See logs of test holes in sec. 7, T. 28 N., R. 70 W.) Light-reddish brown zones were penetrated from 140 to 170 feet and 255 to 300 feet in test well 29–69–33bac. Reddish brown zones were observed at exposures, but it is not known if they are persistent and characteristic of a particular stratigraphic position in the formation. Minor amounts of pale-green plastic clay were found in the White River Formation in test well 29–69–33bac and the test holes in sec 7, T. 28 N., R. 70 W. Much of the constituent material of the White River Formation is calcareous volcanic ash that has been reworked and deposited by streams.

WATER-BEARING CHARACTERISTICS

Conchoidal fracturing is typical of the White River Formation in the Glendo area. The fine network of fractures enables the formation to yield small quantities of water in localities where a great enough thickness of saturated material is penetrated. In the vicinity of test well 29–69–33bac, a somewhat larger than normal yield from the White River Formation is probably the result of especially extensive fracturing near the Elkhorn fault.

During the drilling of test hole 28–70–7dbc, which is near the confluence of Three Cripples and Horseshoe Creeks, large quantities of drilling fluid flowed from the bore hole into several dry beds of coarse-grained sandstone and conglomerate in the White River Formation. (See table 6.) The combined fluid loss by gravity was about 40 gpm (gallons per minute). Unfortunately, these particular coarse-grained beds are above the water table. If similar zones occur below the water table in other parts of the Glendo area, wells tapping them might yield substantial quantities of water for domestic and stock uses and small quantities for irrigation.

QUATERNARY SYSTEM

Rocks of Quaternary age exposed in the Glendo area include deposits of Pleistocene and Recent age. Terrace deposits of Pleistocene age occur at several different positions above the flood plains of major streams; in most places these deposits are dissected and well drained. Flood-plain deposits, slope wash, and dune sand constitute the rocks of Recent age in the Glendo area. The flood-plain alluvium is the best aquifer in the area and is the only formation of Quaternary age discussed further in this report.

FLOOD-PLAIN DEPOSITS

AGE AND CORRELATION

Alluvial deposits occur at several terrace levels above the present flood plains of the major streams in the Glendo area. Their age is not known but they are similar to alluvial deposits of Pleistocene and Recent age described by Leopold and Miller (1954, p. 8–11) in the Powder River Basin. The coarse unconsolidated alluvium with which this report is particularly concerned was deposited after the higher terrace alluvium and probably is of Recent age.

DISTRIBUTION AND THICKNESS

The valleys of the North Platte River and Horseshoe Creek and the lower valley of Middle Bear Creek generally have well-defined flood plains that are underlain by alluvial deposits. South of the old Cassa railroad station near the mouth of Middle Bear Creek the flood plain of the North Platte River exceeds a mile in width (pl. 1); but in localities where the river has cut down through resistant rocks, there may be no flood plain at all. The width of the flood plain of Horseshoe Creek, between the Laramie Range and the North Platte River, ranges from 800 to 4,500 feet and averages approximately 2,200 feet. The flood plain of Horseshoe Creek widens slightly in the lower 6 miles of the stream; but, in general, the width of the flood plain is relatively uniform in the report area. The varied thicknesses of the alluvium do not increase or decrease in a particular pattern along the course of Horseshoe Creek. Maximum thicknesses of 38, 37, 58, 38, 43, 26, 33, 25, and 42 feet at respective distances of 1.6, 3.6, 5.0, 6.3, 7.8, 12.0, 13.1, 14.0, and 16.3 miles upstream from the mouth of Horseshoe Creek were penetrated during the test drilling (pl. 2). The greatest thicknesses of alluvium penetrated in the North Platte River and Bear Creek valleys were 65 and 37 feet, respectively.

LITHOLOGY

The valleys of Horseshoe Creek, Middle Bear Creek, and the North Platte River are partly filled with coarse alluvial deposits that are overlain by finer alluvium consisting mostly of permeable buff to gray silt and soil. The coarse alluvium consists of relatively clean sand and gravel and lenses of clay and silt. Subangular to rounded pieces of quartz, granite, gneiss, and schist are the chief constituents composing the sand and gravel; but reworked fragments of limestone, claystone, siltstone, and sandstone are also present. Large boulders (up to 4 ft in diameter) of igneous and metamorphic rocks from the Laramie Range were observed in the alluvium along the upper Horseshoe Creek valley in the southwestern part of the Glendo area. Near the edges of the flood plains, unsorted slope-wash deposits of clay, silt, sand, and gravel interfinger with or cover the alluvium. (See cross sections, pl. 2.)

METHOD OF DEPOSITION

Two very different types of alluvium occur in the major stream valleys of the Glendo area. Relatively clean deposits of sand and gravel are overlain by several feet of dark sandy silt and soil. (See sections, pl. 2.) Both types of alluvium are present for a distance of about 19 miles in the Horseshoe Creek valley between the Laramie Range and the North Platte River. Although the gradient of the stream decreases irregularly from 105 to 16 feet per mile along this 19-mile course of the stream, the overall thickness of the alluvium is fairly constant. The conditions of stream deposition that resulted in the deposition of coarser alluvium were evidently not the same as those that resulted in the deposition of the finer alluvium. According to Wooldridge and Morgan (1959, p. 158) many of the valley floors of the world indicate that active aggradation by coarse debris was in progress in the recent past, whereas in a still more recent period, extending into historical time, conditions of flood alluviation of finer debris have prevailed.

After a stream valley is sufficiently enlarged, the stream under certain conditions will erode a relatively flat floor by lateral corrasion. Then, if coarse debris becomes available from source areas, it will be deposited in, or near, the stream channel as the stream meanders across the flat valley floor; thus an extensive sheet of gravel will eventually accumulate. If active aggradation by coarse debris then ceases because of a shortage of coarse material, intermittent flooding can spread finer grained alluvium widely over the flood plain. This mode of deposition differs because each layer of deposit is contemporary over a wide area (Wooldridge and Morgan, 1959, p. 156).

The two processes of deposition just discussed were probably involved in the deposition of the coarse sand and gravel and the overlying sandy silt and soil that are found in the flood plains of streams in the Glendo area. The younger alluvium contains some windblown material, as well as humic constituents derived from decayed vegetation that once grew on the flood plain.

WATER-BEARING CHARACTERISTICS

Although the alluvial material underlying the flood plains of streams in the Glendo area is not too well sorted, it is sufficiently permeable to yield moderate to substantial quantities of water for stock, domestic, and irrigation uses. The permeability probably varies considerably within short distances, but probably no great difference in the average permeability occurs in the upstream and downstream deposits of the stream valleys.

The drilling of wells in the alluvium is made difficult by large boulders and the caving of loosely consolidated material. Boulders were found in most of the areas drilled, but they appear to be more prevalent in the upstream part of the Horseshoe Creek valley.

GROUND WATER

GROUND-WATER HYDROLOGY OF THE HARTVILLE FORMATION—AN ARTESIAN AQUIFER

AQUIFER GEOMETRY

An artesian aquifer contains water that is confined by relatively impervious beds. Water in an artesian aquifer is under sufficient pressure to rise above the base of the overlying confining bed when the bed is pierced or broken. In the Glendo area the "Converse sand" is an artesian aquifer that is confined by the Opeche Shale above and, usually, a dolomite bed below. Wells that penetrate the "Converse sand" downdip from the outcrop yield water under artesian pressure.

Plate 3, a generalized structure-contour map of the top of the "Converse sand," shows that the hydrologic conditions in the "Converse sand" aquifer are closely related to the structure of the area between the Hartville uplift and the Elkhorn fault. From its outcrop on the Elkhorn anticline and thence for a distance of about 7 miles, the "Converse sand" dips southeastward at an average gradient of 280 feet per mile into a syncline. The axis of the syncline plunges to the southwest into a narrow northern extension of the Denver basin. East of the syncline the beds rise steeply and crop out on the west flank of the Hartville uplift. This synclinal axis is considered to be the downdip limit of the segment of the aquifer in the "Converse sand" in the Horseshoe Creek area.

The northeast limit of the segment is probably in the vicinity of Glendo townsite. Thick strata of the White River Formation, penetrated by well 29–68–9bcd1, suggest that the "Converse sand" has been eroded or downfaulted in this area. Unfortunately, the physical limits of this interruption of the aquifer is not known.

The west limit of the Horseshoe Creek segment of the aquifer in the "Converse sand" is probably the Elkhorn fault. The structurally low position of the "Converse sand" in well 29–69–33bac indicates that the west side of the Elkhorn fault is downthrown from 100 to 300 feet. A comparison of the hydrographs of wells 29–69–33bac (west of the fault) and 29–69–24dbc2 (east of the fault) suggests that the wells are in two separate segments (fig. 3). Most of the movement along the Elkhorn fault occurred in pre-Tertiary time, but the tilted Tertiary beds on Elkhorn Creek (Love and others, 1949) and the extensive fracturing of the White River Formation near test well 29–69–33bac indicate that movement was probably recurrent in late Tertiary time.

The structural and ground-water conditions of the "Converse sand" in the areas northeast of Glendo and between Elkhorn fault and the Laramie Range are unknown. Well 29–69–33bac is the only well that has been drilled into the "Converse sand" within the mapped area (the "Converse sand" is probably absent in well 29–69–2aac) and outside of the segment just described.

PIEZOMETRIC SURFACE

The piezometric surface of an artesian aquifer is the imaginary pressure surface to which the water in the aquifer would rise under its full head. The general shape of the piezometric surface in the Horseshoe Creek segment of the aquifer in the "Converse sand" is shown in plate

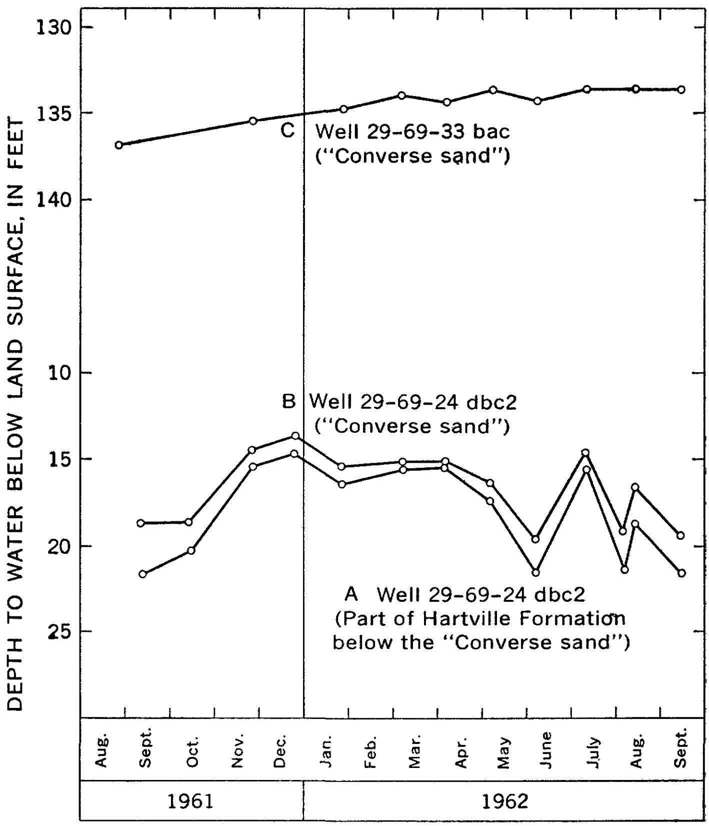

FIGURE 3.—Hydrographs of three wells that penetrate the Hartville Formation.

3. This map is very generalized, especially in the areas where there is no well control. When projecting the piezometric-contour lines outside of the areas of control, their strike was assumed to be about the same as the strike of the structure-contour lines. A more detailed piezometric map would probably indicate hydraulic gradients in relation to particular areas of recharge and discharge. Measurements of the static water level in wells that penetrate the "Converse sand" were used to determine the altitude and spacing of the isopiestic lines. The average hydraulic gradient shown on the piezometric map in the vicinity of Horseshoe Creek is approximately 20 feet per mile southeastward.

WATER-LEVEL FLUCTUATIONS

The fluctuations of the water level in a ground-water reservoir is caused by the increase or decrease in the amount of water in storage. If the addition of water to an aquifer is greater than the release of water from it, the water level in the aquifer will rise. When the addition of water to the aquifer is less than the release of water from it, the water level will decline. Normally, the water level in an artesian aquifer will respond quickly to recharge because pressures are transmitted rapidly in a hydraulic system.

During the present investigation, monthly water-level measurements were made in well 29–69–24dbc2 for the period September 1961 through September 1962. This well was cased and perforated so that water levels in the "Converse sand" and in a part of the Hartville Formation below the "Converse sand" could be measured separately. The similarity in the hydrographs indicates that the two zones are very closely related (fig. 3 *A*, *B*), although the lower zone yields much less water than the "Converse sand." In general, the water level in the Hartville Formation rises or lowers in an opposite direction from the water levels in the stream deposits (fig. 8). The high water levels in the Hartville during the winter months may be caused by the slow movement of water into the reservoir from distant recharge areas such as the Laramie Range, across relatively impermeable barriers such as the Elkhorn fault.

Pressure heads measured at well 29–68–20acd in 1962 and well 29–68–20abd in 1949 infer that the piezometric surface of the Horseshoe Creek segment of the aquifer in the "Converse sand" has changed very little since 1949. The difference between the highest and lowest water levels measured in well 29–69–24dbc2 during the period of observation was 7 feet (fig. 3*A*). The hydrograph of well 29–69–33bac (fig. 3*C*) shows an upward trend of the water level in the "Converse sand" west of the Elkhorn fault. At the end of the period of measurement, from August 30, 1961 to September 15, 1962, the water level in this well was 3 feet higher than at the beginning of the period.

RECHARGE

The addition of water to a ground-water reservoir is defined as recharge. Recharge to the Hartville Formation in the Glendo area comes from influent streams, overlying strata, and precipitation on the outcrop. Where Spring Creek and the North Platte River flow over the surface exposures of the Hartville on the Elkhorn anticline, water probably moves from the streams into the formation. Spring Creek flows most of the year along a 2-mile reach in secs. 14 and 15, T. 29 N., R. 69 W. The surface flow appears in the vicinity of the Elkhorn fault; ground water in the formations of Tertiary age west of the fault cannot be transmitted by the less permeable rocks of the Hartville Formation lying near the surface east of the fault. Surface flow disappears near the eastern boundary of sec. 14 into the permeable "Converse sand" and valley alluvium which are exposed in the bed of Spring Creek. The amount of recharge to the Hartville Formation from Spring Creek could not be measured, but it is probably less than 500 acre-feet per year.

Probably, considerable recharge to the Hartville Formation comes from the North Platte River in secs. 15 and 16, T. 30 N., R. 68 W. which are adjacent to the mapped area on the north. When the altitude of the water level in Glendo reservoir is about 4,580 feet, the impounded water inundates outcrops of the Hartville exposed in secs. 15 and 16.

A second type of recharge to the Hartville Formation is the ground water in overlying aquifers that is discharged into permeable zones in the Hartville. On the west flank of the Elkhorn anticline and on the Hartville uplift northeast of Glendo, the White River Formation was deposited across the former outcrops of the "Converse sand." If the White River Formation is fractured in these localities, large quantities of ground water could move into the "Converse sand" from the White River Formation.

The precipitation that falls directly on the surface exposures of the Hartville Formation and percolates into permeable zones is a third type of recharge to the formation. If as much as 3 inches of the average annual precipitation of 13.15 inches percolates into the outcrop area, which is approximately 10 square miles in extent, the annual recharge to the formation would be only about 1,600 acre-feet in the Glendo area. Because of the topographic relief and the low permeability of much of the Hartville, this much precipitation probably does not enter the formation.

DISCHARGE

Discharge, the opposite of recharge, constitutes the release of water from a ground-water reservoir. The combined discharge of the four wells that produce water from the "Converse sand" in the mapped area is estimated to be less than one-half of an acre-foot per day. Although conclusive data are lacking, it appears that the hydraulic gradient of the aquifer in the "Converse sand" is controlled by a relatively low elevation of the "Converse sand" in the vicinity of sec. 18, T. 28 N., R. 67 W. In this area it is very likely that ground water is being discharged into the overlying White River Formation and the alluvium in the North Platte River valley. Some ground water in the "Converse sand" could also be moving southward out of the Glendo area into the Denver basin.

Discharge from the Hartville Formation by means of evaporation, transpiration, and springs is probably negligible in the Glendo area.

HYDRAULIC PROPERTIES

The primary factors that determine the ground-water movement in an aquifer are the hydraulic gradient and the size, shape, quantity, and degree of interconnection of interstices in the formation. In general, gravel and coarse-grained sandstone will transmit larger volumes of water than fine-grained sandstone and siltstone. Shale, claystone, and dense limestone are relatively impermeable and transmit water primarily through fractures, solution channels, and similar features.

The hydraulic characteristics of an aquifer can be expressed as coefficients that are useful in estimating the availability of water in the aquifer. The reader is referred to the reports by Wenzel and Fishel (1942) and Ferris and others (1962) for excellent discussions on this subject.

The *coefficient of permeability* is the measure of a material's capacity to transmit water. The coefficient of permeability was expressed by Meinzer (Stearns, N. D., 1928) as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60°F. In field practice the adjustment to the standard temperature of 60°F is ignored because the temperature range in most aquifers is not large enough to significantly change the viscosity of the water; permeability is then considered to be a *field coefficient.* The *coefficient of transmissibility* is the product of the field coefficient of permeability and the full saturated height (in feet) of the aquifer (Theis, 1935, p. 520). The *coefficient of storage* of an aquifer is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface (Ferris and others, 1962).

The data obtained from various types of aquifer tests at wells can be used to calculate the aquifer coefficients just mentioned. A tabulation of the results of aquifer tests made at wells in the Glendo area is shown in table 2.

Aquifer tests made at a flowing well (29–68–20abd) that produces from the "Converse sand" in the Horseshoe Creek valley are discussed by Rapp and Babcock (1953, p. 12–18). Their average value for the coefficient of transmissibility calculated by the flow, nonequilibrium, and recovery methods was 10,300 gpd (gallons per day) per ft; their value for the coefficient of storage obtained by the nonequilibrium method was 0.0002. During the current investigation, bailing tests were made at the Wilson (29–69–24dbc2) and Twiford (29–69–33bac) test wells for periods of 24 and 12 hours, respectively. The values obtained for the coefficient of transmissibility of the aquifer in the "Converse sand" were 2,100 at the Wilson well and 2,000 at the Twiford well. In both tests the recovery method was used. No observation wells were available from which supplementary data could be obtained for calculation of the coefficient of storage.

The stratigraphic interval of the Hartville Formation below the "Converse sand" and from depths of 355 to 840 feet in the Wilson well was tested by bailing for 12 hours, and a relatively low coefficient of transmissibility of 340 was calculated by use of the recovery method. This value seems reasonable since the stratigraphic interval open to the well bore consisted of hard limestone and dolomite with minor amounts of impure sandstone.

The basal part of the gypsum and red shale sequence, the Minnekahta Limestone, and the Opeche Shale overlie the "Converse sand" in the vicinity of the Wilson test well. Bailing tests of short duration were performed as the well penetrated each of these formations. Evidently these formations have very low permeabilities because the well was quickly bailed dry during each test.

A useful, but limited, method for comparing the relative efficiencies of wells is based upon the *specific capacity* which is defined by Meinzer (1923, p. 62) as the rate of yield per unit of drawdown. Specific capacity is usually expressed in gallons per minute per foot. Any accurate statement of specific capacity must be based upon observations made after both the rate of discharge and the drawdown have become nearly constant. After long test periods, the specific capacities of well 29–68–20abd and test wells 29–69–24dbc2 and 29–69–33bac were 2.6, 2.2, and 2.5 gpm per foot of drawndown, respectively (table 2). All three wells penetrate the "Converse sand."

TABLE 2.—*Results of aquifer tests at wells near Glendo, Platte County, Wyo.*

Test data	Hartville [1] Formation	"Converse sand" of local usage			White River Formation
Well	29-69-24dbc2	29-68-20abd	29-69-24dbc2	29-69-33bac	29-69-33bac
Date of test	7-26-61	9-21-49	6-5-61	8-23-61	8-5-61
Duration of pumping or bailing ... hr	12	24	24	12	12
Well discharge ... gpm	38	78	60	14.6	78
Drawdown at discharging well ... ft	67	30	27.1	5.8	7.7
Specific capacity of discharging well ... gpm per foot of drawdown	.6	2.6	2.2	2.5	10.1
Saturated thickness of aquifer ... ft	485	120(?)	84	91	268
Coefficient of transmissibility ... gpd per ft	340	[3] 10,300	2,100	2,000	-------
Average field coefficient of permeability ... gpd per sq ft	.7	[3] 86	25	22	-------
Storage coefficient of aquifer	-------	.0002	-------	-------	-------

Test data	Flood-plain deposits					
	South Bear Creek	Horseshoe Creek				
Well	28-68-27abc	29-68-19abb	29-68-19cac	29-68-20acc	29-68-21bcc2	29-68-21bcc2
Date of test	7-6-55	6-22-61	7-21-60	8-16-60	7-20-55	8-16-60
Duration of pumping or bailing ... hr	1	72	360	1,800	3	1,800
Well discharge ... gpm	66	106	135	410	770	870
Drawdown at discharging well ... ft	5.3	[2] 2.4	17	10	5.3	12
Specific capacity of discharging well ... gpm per foot of drawdown	12.0	[2] 43	8	41	145	72
Saturated thickness of aquifer ... ft	6	20	34	17	25	24
Coefficient of transmissibility ... gpd per ft	6,500	80,000	-------	-------	240,000	-------
Average field coefficient of permeability ... gpd per sq ft	1,100	4,000	-------	-------	9,600	-------
Storage coefficient of aquifer	-------	-------	-------	-------	-------	-------

[1] Upper 485 ft of the Hartville Formation just below the "Converse sand."
[2] Drawdown in observation well 5 ft from pumped well.
[3] Average value.

GROUND-WATER HYDROLOGY OF THE WHITE RIVER FORMATION AND THE FLOOD-PLAIN DEPOSITS—UNCONFINED AQUIFERS

AQUIFER GEOMETRY

An unconfined, or nonartesian, aquifer is one in which the zone of saturation is overlain by permeable material that extends upward to the land surface. No confining barriers exist to prevent the percolation of water from ground level down to the zone of saturation.

An unconfined aquifer consisting primarily of the White River Formation and relatively minor thicknesses of younger beds of Miocene and Pliocene age is recognized in the Glendo area. Normally, the beds of Pliocene age and most of the beds of Miocene age are topographically high and well drained. Locally, however, the Arikaree Formation is partly saturated with ground water; in test well 28–68–17cba approximately 125 feet of the Arikaree Formation is saturated. Throughout most of the Glendo area the zone of saturation is within the White River Formation. More than 80 percent of the area is covered by this "aggregate" aquifer, which is known to be as much as 575 feet thick (well 29–68–9bcd1) near the town of Glendo. The aquifer is limited where it contacts the older impermeable rocks such as those exposed on the Laramie Range, the Hartville uplift, and the Elkhorn anticline.

A second unconfined aquifer in the Glendo area consists of the alluvial sand and gravel of Recent age that occur in the North Platte River and Horeshoe Creek valleys and in the downstream part of the valley of Middle Bear Creek. Both the maximum thickness (65 ft) that was penetrated during the test drilling and the maximum width (1.4 miles) of the alluvium are in the flood plain of the North Platte River near Cassa.

Although the ground-water conditions in the White River and younger formations of Tertiary age are closely related to the ground-water conditions in the alluvium, the two aquifers differ considerably because the alluvium has a much greater permeability.

WATER TABLE

The water table is defined by Meinzer (1923, p. 22) as the upper surface of the zone of saturation except where that surface is formed by an impereamable boundary. The slope of the water table is in the direction of the movement of water, and the gradient of the slope generally varies directly with the rate of movement and inversely with the permeability of the aquifer materials.

The slope of the water table in the White River and younger formations of Tertiary age is generally toward the North Platte River in the Glendo area (fig. 4). Locally, however, the slope is toward Horeshoe Creek and to a lesser degree toward Spring, Elkhorn, and

North, Middle, and South Bear Creeks. The comparatively steep slope of the water table (50 to 140 ft per mile) in the White River Formation is probably related to the low permeability of the formation.

The slope of the water table in the alluvium of the valleys in the Glendo area is controlled by the position of the streams and generally reflects the slope of the surface between the alluvium and the less permeable underlying bedrock. Because the thickness of the alluvium along Horeshoe Creek, a perennial stream, is relatively constant, the profile of the stream surface is approximately parallel to the contact between the alluvium and the underlying beds. The stream surface of Horeshoe Creek coincides with the water table in the alluvium, and its gradient decreases irregularly from approximately 105 feet per mile near the Laramie Range to 16 feet per mile near the North Platte River.

Water-level measurements in well 28–69–20adc indicates that the water table is about 100 feet below the land surface in the vicinity of the head of Middle Bear Creek. The valley fill in this area is dry and composed mostly of slope wash. Downstream the water table gradually becomes shallower until it is above the base of the alluvium. Test hole 28–68–17cca, just west of U.S. Interstate Highway 25 and north of Middle Bear Creek, penetrated about 20 feet of saturated alluvium. The slope of the water table in the alluvium of Middle Bear Creek decreases from approximately 100 feet per mile in the vicinity of former U.S. Highway 87 to 40 feet per mile near the North Platte River (fig. 5). In the area around Cassa the slope of the water table in the alluvium of the North Platte River valley is approximately 8 feet per mile.

The water table in the alluvium lies at a depth of less than 20 feet throughout most of the Horseshoe Creek valley and less than 35 feet in the Cassa Flats area. The depth to water in the White River and younger formations of Tertiary age ranges from a few feet near the streams to as much as 140 feet along the ground-water divides between the streams.

WATER-LEVEL FLUCTUATIONS

Water levels in the unconfined aquifers of the Glendo area are highest in spring and summer and lowest in fall and winter. Although little data is available concerning the annual fluctuation of the water table in the White River and younger formations of Tertiary age, the average annual fluctuation is probably about 5 feet. The maximum fluctuation of the water table in the White River Formation observed at test well 29–69–33bac was about 3 feet for the period August 2, 1961, to September 15, 1962 (fig. 6); but water levels in this

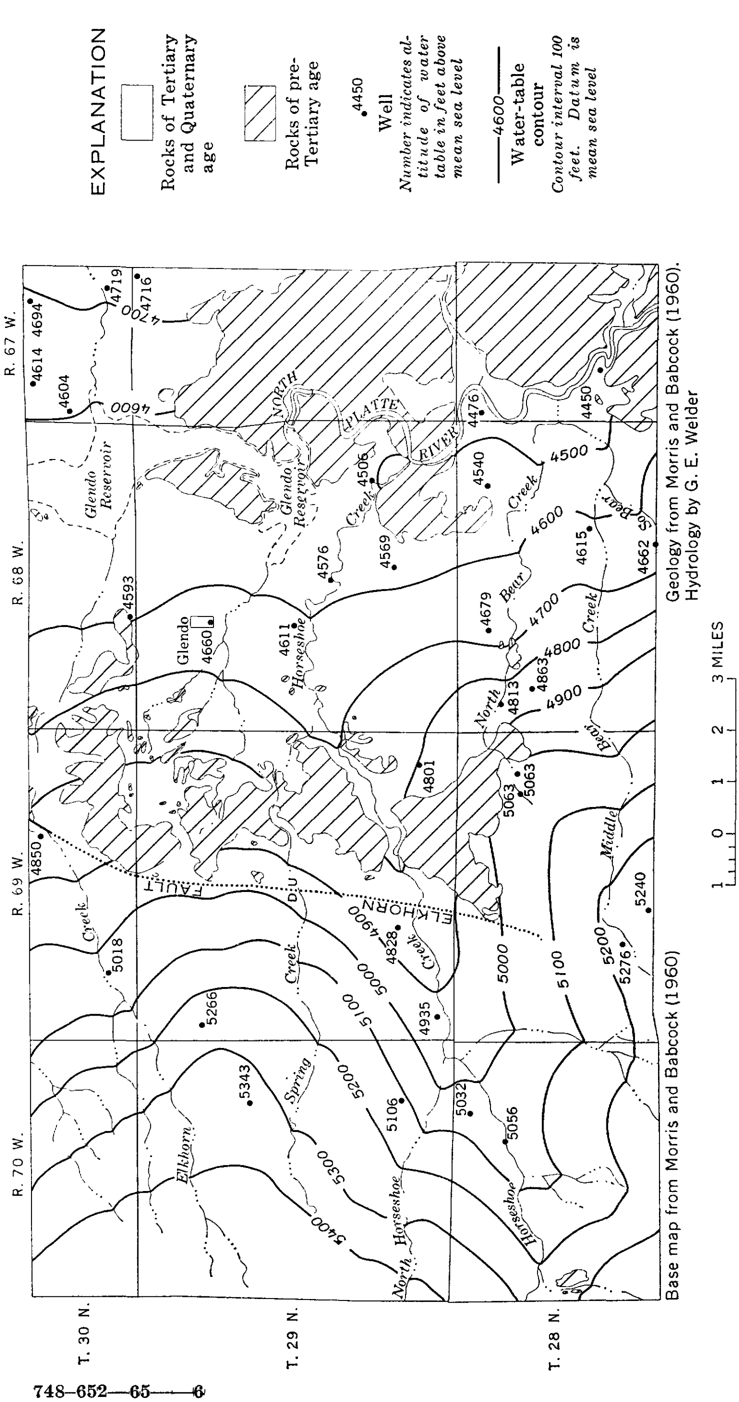

FIGURE 4.—Map of the Glendo area showing the general contour of the water table in the unconfined aquifers.

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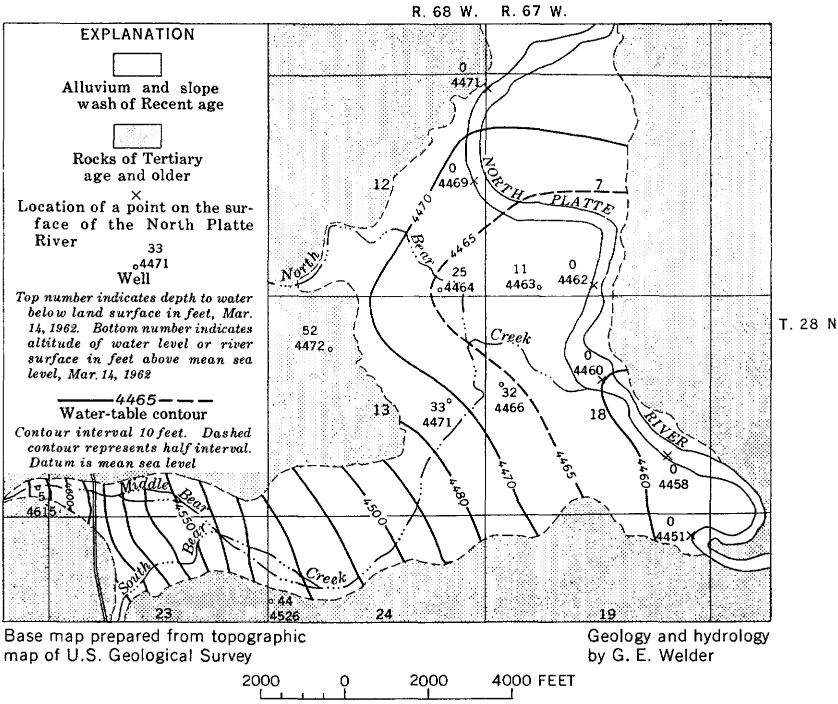

Figure 5.—Map of the Cassa Flats vicinity showing the configuration of the water table in the alluvium of part of Middle Bear Creek and the North Platte River valleys.

vicinity are probably affected by the amount of streamflow in Horseshoe Creek. The hydrograph of test well 28–68–17cba (fig. 6), which penetrates the Arikaree Formation, shows a decline of 5.7 feet from July 5, 1961, to September 15, 1962. Most of this decline was probably caused by pumping large quantities of water, for highway construction, from a nearby sump in Middle Bear Creek. Recent measurements of water levels in wells penetrating the formations of Tertiary age in the Glendo area indicate that very little change has occurred in the water table since 1953 when the measurements were last made at the same wells.

Water levels in the alluvium of the stream valleys of the Glendo area fluctuate in response to the stage of the stream and to the amount of water applied to the alluvial soils for irrigation. The relationship between the stream discharge measured at the U.S. Geological Survey stream-gaging station near the mouth of Horseshoe Creek and the water levels in the alluvium measured at well 29–68–21dad for the period 1950 through 1953 is shown in figure 7. Well 29–68–21dad is about 350 feet from the stream channel of Horseshoe Creek.

The hydrographs of 10 observation wells spaced along a 12.4-mile

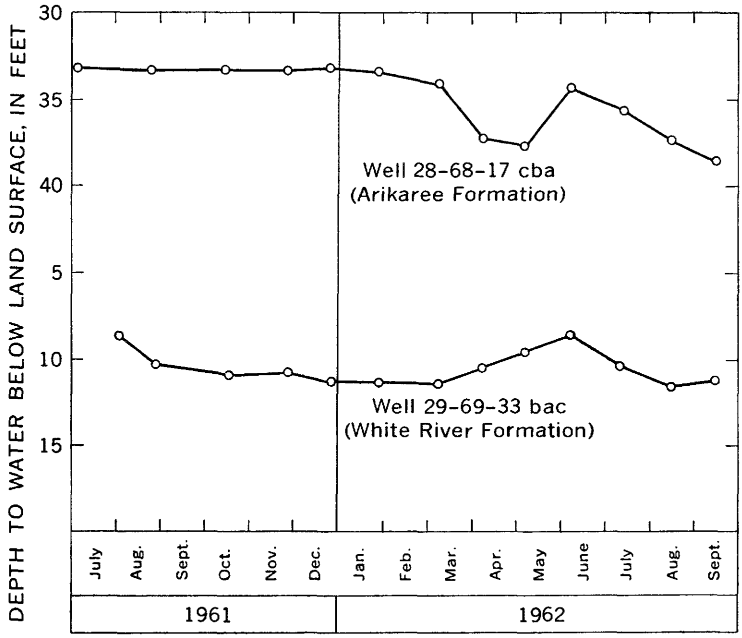

FIGURE 6.—Hydrographs of two wells that penetrate the White River and Arikaree Formations.

reach of Horseshoe Creek show a seasonal rise in the water table in the alluvium of the Horseshoe Creek valley during March, April, May, and June (fig. 8). The hydrographs of observation wells in areas that are not greatly affected by seepage from irrigation water show a decline in the water table during late June, July, and August after which the water table remains relatively steady until the following March (fig. 8*A*, *B*, *C*, *D*, *E*). Several of the hydrographs (fig. 8*F*, *G*, *H*, *I*) show irregular highs and lows that are related to water applied for irrigation in the vicinity of each well.

The irregular peaks on the hydrograph of observation well 28–67–7ccd (fig. 9*A*), which is in the alluvium of the valley of the North Platte River and 1,300 feet from the stream channel, are a definite response to the amount of flow in the river. Streamflow in the river is controlled by the amount of water released from Glendo reservoir. The water levels in observation wells 28–68–12ddc (fig. 9*B*) and 28–67–18bcc2 (fig. 9*C*), which also tap the alluvium of the North Platte River valley, do not fluctuate as readily with the changes in streamflow because these wells are farther away from the stream channel. The continued rise of the water table in the alluvium of the North Platte River valley into the fall of 1962 is probably due to the release of large quantities of water from Glendo reservoir during July, August, and September.

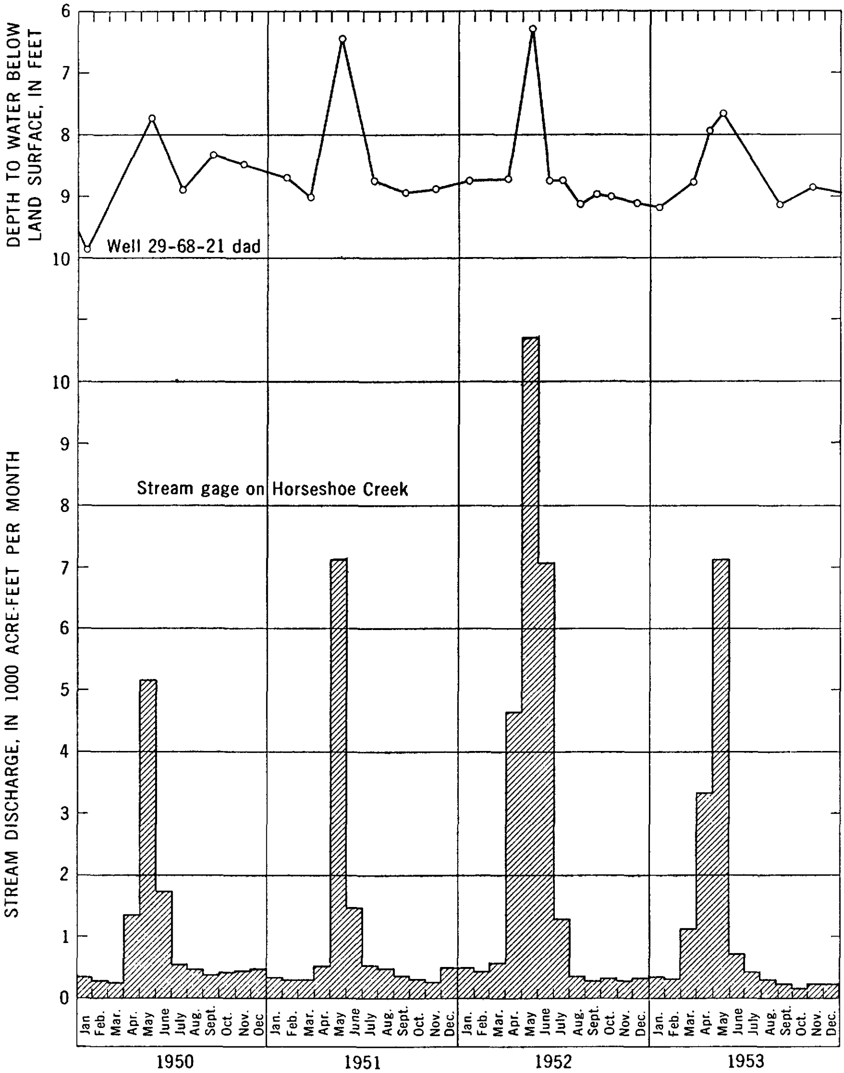

FIGURE 7.—Hydrographs showing the relation between the fluctuation of the water table in the alluvium of Horseshoe Creek valley (well 29-68-21dad) and the discharge of Horseshoe Creek (Geol. Survey stream-gaging station near the mouth of Horseshoe Creek).

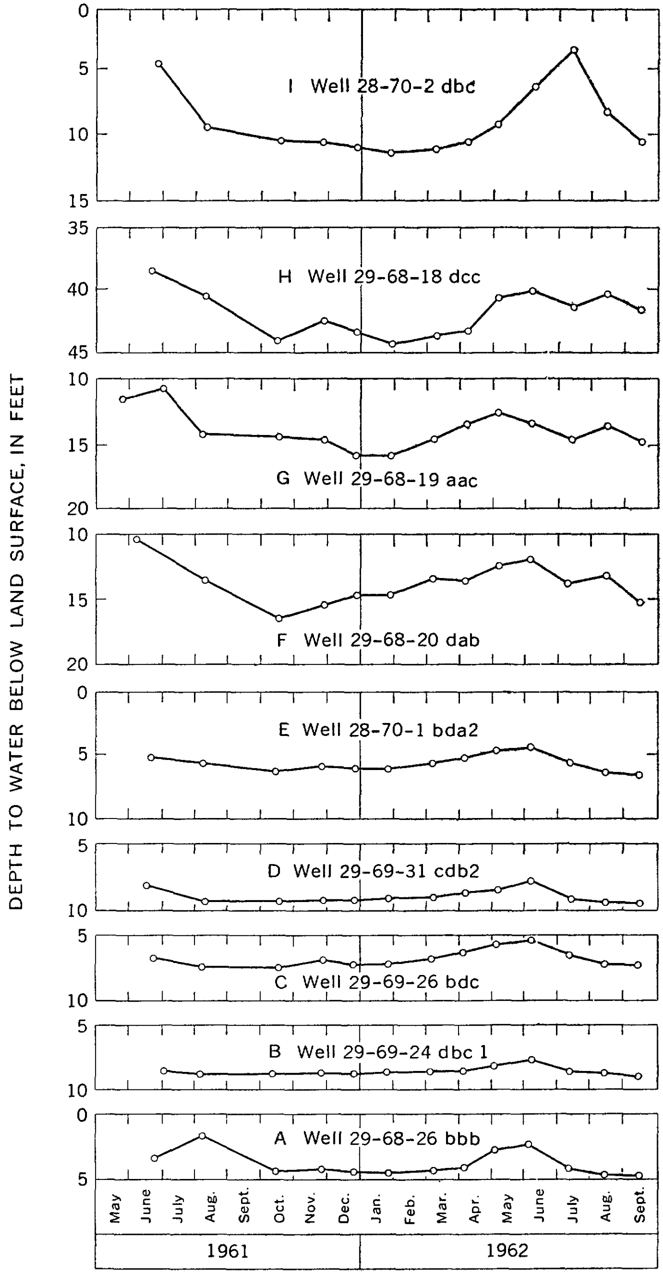

FIGURE 8.—Hydrographs of nine wells that penetrate the alluvium of Horseshoe Creek valley.

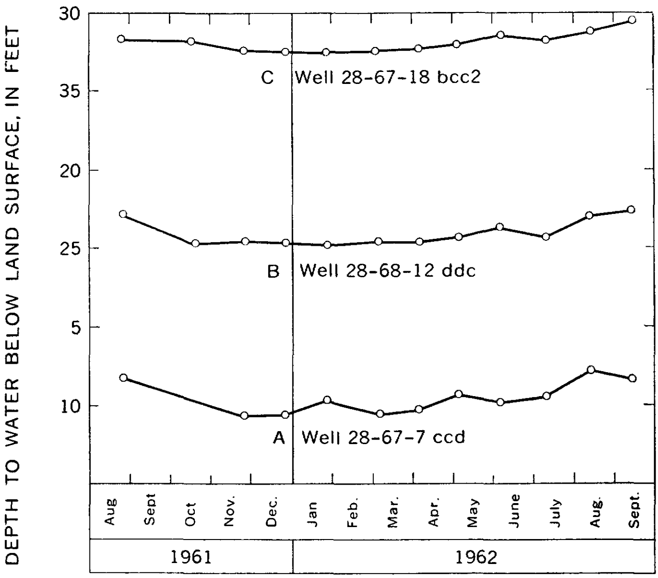

FIGURE 9.—Hydrographs of three wells that penetrate the alluvium of the North Platte River valley.

RECHARGE

RECHARGE TO THE WHITE RIVER FORMATION AND YOUNGER FORMATIONS OF TERTIARY AGE

The major source of recharge to the White River Formation and beds of Miocene and Pliocene age in the Glendo area is from precipitation. Locally, minor amounts of recharge from intermittent springs (pl. 1) that issue from perched zones in the beds of Miocene and Pliocene age seep downward to the water table. The largest spring in the area known to the authors is a perennial spring in sec. 35, T. 29 N., R. 68 W., that issues from the Cloverly Formation at about 33 gpm (Rapp and Babcock, 1953, p. 33). It recharges the White River Formation at a small rate as it flows over the formation into a small reservoir.

An estimate of the amount of recharge from precipitation to the rocks of Tertiary age in the Glendo area was made by dividing that part of the base flow of Horseshoe Creek, which is due to contributions from the White River Formation, by the size of the outcrop area that is drained by the stream. In this report *base flow* refers to that part of the streamflow maintained by ground-water discharge that originally came from the beds underlying the alluvium. The size of the outcrop area drained by the stream was determined by drawing flow lines on a water-table map from the point where the creek enters the North Platte

River westward to the Laramie Range. Contributions to the flow of Horseshoe Creek from the White River Formation were estimated from the stream hydrograph (fig. 10), which was prepared from data collected at the Geological Survey stream-gaging station near the mouth of Horseshoe Creek. (See the section on "Discharge to streams.") Increases in underflow (the ground water in the alluvium) were assumed to have accounted for all the ground-water discharge originating from the rocks of pre-Tertiary age; therefore, the base flow measured at the stream gage represented mostly ground water from the rocks of Tertiary age. The flow contribution in acre-inches per year per acre of outcrop area was divided by the precipitation in inches for the corresponding year, and the values were averaged to obtain a value of the recharge rate. According to these figures, about 4 percent of the precipitation that falls on the outcrop area recharges the White River Formation. This amounts to an average of about 0.45 inch per year for the 10-year period 1952–61.

The recharge rate obtained by analysis of streamflow in Horseshoe Creek was checked by an analysis of streamflow data for Cottonwood Creek, about 6 miles south of the report area. The geologic setting in the Cottonwood Creek basin is much simpler than the setting in the Horseshoe Creek basin. Streamflow data are available for the period 1947–50 for Cottonwood Creek from an upstream station near the outcrop of the pre-Tertiary rocks (U.S. Geol. Survey stream gage near Fletcher Park) and a station near the mouth of the stream (U.S. Geol. Survey stream gage at Wendover). These records were analyzed by determining the base flow at both gaging sites, and subtracting the base flow at the upper site from that at the lower site. Underflow in the alluvium at the lower site was estimated to be about 1 cfs (cubic feet per second), whereas that at the upper gage was estimated to be negligible; therefore, 1 cfs was added to the base flow that was calculated from the stream hydrographs for the lower gaging site. The base flow plus the estimated increase in underflow, converted to acre-inches per year, was divided by the size of the outcrop area of rocks of Tertiary age that is drained by the stream. The size of the outcrop area drained by the stream was determined by drawing, on a water-table map, flow lines through the point at which the downstream gage is located. About 0.5 inch per year, or about 3.5 percent of the annual rainfall for the period 1947–50, was the amount of recharge determined from this analysis. This amount is about equal to that obtained from the data gathered at Horseshoe Creek. The percentage of rainfall that became recharge was somewhat smaller, however, because the average annual rainfall for the period 1947–50 was greater than the average annual rainfall for the period 1952–61.

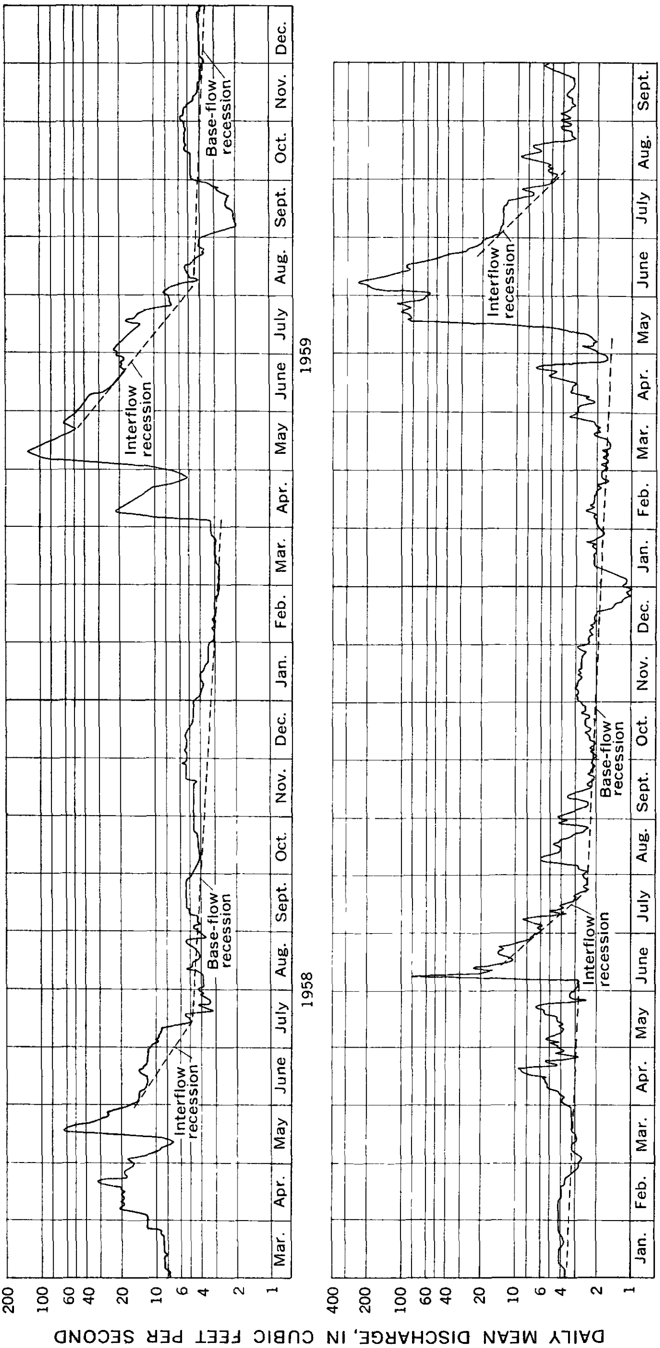

FIGURE 10.—Stream hydrograph of Horseshoe Creek for the water years 1958–61, showing interflow and base-flow recessions. (Drawn from data collected at Geol. Survey gaging station near the mouth of Horseshoe Creek.)

RECHARGE TO THE FLOOD-PLAIN DEPOSITS

The ground water in the alluvium of the valleys of Horseshoe Creek and the North Platte River is replenished partly by each of the following means of recharge: Infiltration of precipitation, seepage of spring water, infiltration of streamflow, infiltration of irrigation water that is diverted from streams, and seepage of gound water that its discharged from the underlying beds into the alluvium. Recharge to the alluvium in the valleys of North Bear, Middle Bear, and South Bear Creeks occurs by all these means except infiltration from irrigation water; adequate amounts of water for irrigation are not available in these streams.

The relatively small areal extent and the fine-grained character of the upper layer of the alluvium (pl. 2) tend to reduce the amount of recharge from precipitation to the flood-plain deposits in the Glendo area. The total amount of recharge by direct precipitation to all the alluvial deposits in the area is probably not more than 2,500 acre-feet per year. Recharge by seepage from springs to the alluvium is very much less.

In the vicinity of North Bear, Middle Bear, and South Bear Creeks, which are intermittent streams, the water table is lower than the stream channels. When the combination of snowmelt and rainfall in the drainage basin reaches the main stream channels, much of it seeps down to the saturated zone and causes the water table in the alluvium to rise; the remainder continues downstream as surface flow to the North Platte River. After recharge ceases, the water table gradually declines as ground water moves downstream in the form of underflow. Considerable precipitation would be necessary to maintain any surface flow in North Bear, Middle Bear, and South Bear Creeks except in a few places where the water table is very close to the surface. During dry periods, the underflow in the alluvium of the valleys of the Bear Creeks is maintained by ground-water discharge from the underlying beds of Tertiary age.

Most of the recharge to the alluvium in the valleys of Horseshoe Creek and the North Platte River occurs by the seepage of ground water from the underlying beds, the infiltration of irrigation water, and the infiltration of streamflow as bank storage. Recharge to the alluvium as bank storage is dependent upon the amount, duration, and distribution of runoff, and it varies greatly from year to year.

The amount of ground-water seepage from the underlying beds into the alluvium of the Horseshoe Creek valley is approximately equal to the amount of discharge of the stream during periods of low flow (base flow) plus the underflow that moves downstream. (See the section on "Underflow.") Estimates of base flow for the water years

1958–61 were made from the hydrograph of the discharge of Horseshoe Creek (fig. 10) and are given in table 3.

The amount of recharge to the alluvium from the infiltration of irrigation water and the infiltration of streamflow is approximately equal to the amount of discharge from the alluvium to the stream from these two sources. Estimates of the *interflow*—used in this report to refer to that part of the streamflow that is maintained by the discharge from the alluvium, which in turn originally came from infiltrating irrigation water and streamflow—also are given in table 3. Because most of the irrigating is done in the Horseshoe Creek valley during the time of high streamflow, separate estimates of recharge to the alluvium from irrigation and streamflow cannot be made; however, the percentage of irrigation water that seeps down to the water table is probably 50 percent or more.

DISCHARGE

Ground water is discharged naturally from the area by seepage to streams, by underflow, and by evapotranspiration and artificially by wells.

TABLE 3.—*Separation of streamflow at U.S. Geological Survey gaging station on Horseshoe Creek near Glendo, Wyo., into base-flow, interflow, and direct runoff components*

Water year [1]	Stream discharge (acre-feet)	Base flow (acre-feet)	Interflow contributions from bank storage (acre-feet)	Direct runoff (acre-feet)	Interflow as percentage of interflow plus direct ruuoff
1958	7,080	2,000	730	4,350	14
1959	9,480	1,850	2,400	5,230	31
1960	3,620	2,780	640	200	76
1961	10,270	2,150	1,800	6,320	22

[1] A water year extends from October 1 of the previous year to October 1 of the designated year.

DISCHARGE TO STREAMS

Ground water is discharged to the perennial streams of the area directly from the alluvium and indirectly from the White River and younger formations of Tertiary age. The contributions to the streamflow from each source may be determined by examining the stream hydrographs. The initial steep interflow recession show on the hydrograph of Horseshoe Creek (fig. 10) usually occurs in May, June, and July and represents discharge from the alluvium, which is recharged by seepage from irrigation water and bank storage during the period of high runoff in April, May, and June. Because the alluvium is very permeable, the water stored above the level maintained by the stream is discharged to the stream rather quickly. Within 2 or 3 months after the water levels are built up by spring recharge, they decline to the level maintained by the stream and remain near those levels until the next spring recharge. The approximate discharge from the alluvium of Horseshoe Creek was computed, by using an equation given by Butler (1957, p. 216–217), for the years 1958–61 from the interflow recession shown on the hydrograph of Horseshoe Creek (fig. 10). The results are given in table 3. The amount of interflow occurring from year to year depends upon the magnitude, duration, and distribution of direct runoff and upon the amount of streamflow diverted for irrigation.

The base-flow part of streamflow represents discharge from the alluvium, which is recharged by ground water from the underlying beds of Tertiary age. Base flow is represented on the hydrograph of Horseshoe Creek by the line connecting points of low flow for the period from August or September to March or April. During this time the stream discharges at a fairly stable rate, although some variation occurs in response to precipitation. Most of the base flow in Horseshoe Creek is probably contributed by the White River Formation; the rocks of pre-Tertiary age that underlie the alluvium have low permeabilities and contribute little water to the stream. Estimates of the volume of base flow in Horseshoe Creek for the years 1958–61 have been made from the stream hydrograph (fig. 10) and the results are shown in table 3. These values do not include all the water discharged from the strata underlying the alluvium because some of the discharge is carried downstream by underflow through the alluvium.

UNDERFLOW

Underflow is the downstream movement of water through a permeable deposit which underlies a surface streamway and is limited at its bottom and sides by rocks of relatively low permeability (Meinzer, 1923, p. 43, 44). The amounts of underflow near the mouths of Horseshoe and Middle Bear Creeks were computed, by use of Darcy's equation, to be approximately 0.6 and 0.5 cfs, respectively. Darcy's law states that the discharge of ground water in an aquifer is the product of the coefficient of permeability of the aquifer, the hydraulic gradient of the water table in the aquifer, and the cross-sectional area through which the water moves. An estimated field coefficient of permeability of 4,000 gpd per sq ft, hydraulic gradients near the mouths of the streams in feet per mile, and cross-sectional areas in mile-feet were used in making the calculations.

The rate of underflow will change seasonally as water levels rise and fall, but the thickness of the saturated part of the alluvial materials does not change greatly because the widths of the valleys are relatively large. Underflow from the alluvium of the North Platte River valley decreases to a very small amount in the southeast corner of the area because the river narrows in a steep canyon and has very little alluvium in its bed. Also, only little movement of water away from the area occurs through the White River and younger formations of Tertiary age because these formations thin to extinction against older and less permeable rocks in the down-gradient direction (pl. 1).

EVAPOTRANSPIRATION

Ground water is discharged to the atmosphere by evaporation in areas where the water table is near the surface and by transpiration by phreatophytes (plants whose root zones tap ground water). The principal phreatophytes in the Horseshoe Creek valley include cottonwood, boxelder, and willow. Alfalfa, also a phreatophyte, is extensively cultivated in the area.

An estimate of the amount of ground water discharged by evaporation and transpiration (evapotranspiration) was computed for the Horseshoe Creek valley from the stream hydrograph (fig. 11) for the year 1956. During that year, only little spring runoff occurred in the Horseshoe Creek basin, and the period of high water in Horseshoe Creek was extremely short (1 day). Recharge to the alluvium was little that year and streamflow throughout much of the summer was due to base-flow contributions from the White River Formation. Because of the high evapotranspiration rate in the summer, base flow was much less than in the winter.

The base flow without evapotranspiration losses for the summer months was projected by interpolating the base-flow curve between the spring and fall months (fig. 11). A smooth curve was drawn through values of the base flow observed during the summer, and the difference between the projected base flow and the observed base flow was attributed to evapotranspiration losses. The evapotranspiration losses determined from this analysis were about 500 acre-feet per year. Part of this loss represents evapotranspiration from ground water, and part represents evapotranspiration from water applied upstream for irrigation. Little water was available for irrigation in 1956, however, so the evapotranspiration losses from irrigation were probably less than half the total loss of 500 acre-feet. Thus, phreatophytes in the Horseshoe Creek valley probably consume from 250 to 350 acre-feet of water per year.

This method of determining evapotranspiration losses from the water table in alluvial valleys should be much more useful for streams where long-term discharge records are available at sites above the canal turnouts for the high-priority water users.

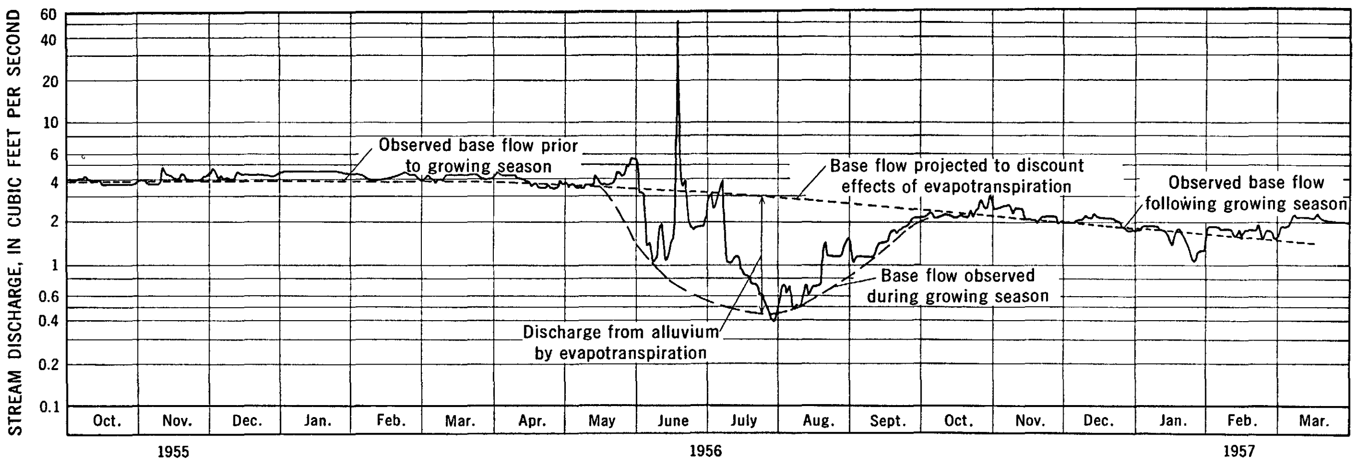

FIGURE 11.—Stream hydrograph of Horseshoe Creek for the water year 1956 showing the effects of evaporation losses. (Drawn from data collected at Geol. Survey gaging station near the mouth of Horseshoe Creek.)

Considerable quantities of ground water are discharged by evapotranspiration from the alluvium of the North Platte River in the Cassa Flats area by the cottonwood trees that grow near the banks of the river.

Evapotranspiration losses from ground water in the White River and Arikaree Formations are small in most of the area because the water table in these formations lies beneath the root zone of phreatophytes.

DISCHARGE TO WELLS

The quantity of ground water that is produced by wells from the unconfined aquifers in the Glendo area is relatively small. Discharge to wells from the White River and younger formations of Tertiary age amounts to about 35 acre-feet per year, and discharge to wells from the alluvium in the Horseshoe Creek valley was about 340 acre-feet in 1961. Pumpage from the alluvium in the valleys of Middle Bear Creek and the North Platte River is not known, but it probably does not exceed 5 acre-feet per year. Discharge to wells is discussed more thoroughly under the section on "Utilization of ground water."

HYDRAULIC PROPERTIES

The ability of a formation to yield water to wells is dependent upon the hydraulic properties of the aquifer materials, including the coefficients of transmissibility, permeability, and storage. Several methods have been developed for determining these properties in the field. The three general methods of analysis used in the report area were the analysis of drawdown and recovery tests, the analysis of regional water-level distributions, and the analysis of natural water-level declines.

HYDRAULIC PROPERTIES OF THE WHITE RIVER FORMATION

The coefficients of transmissibility of the White River and Arikaree Formations were computed from water-level altitudes in wells in the vicinities of Horseshoe and Cottonwood Creeks. Cottonwood Creek is about 6 miles south of the report area. Jacob's equation (1943, p. 566) for the distribution of head in a homogeneous aquifer that is recharged uniformly at a constant rate and lies between parallel drains was used. This equation, commonly called the piezometric parabola equation, is as follows:

$$T/W=\frac{ax}{h_0}-\frac{x^2}{2h_0},$$

where

T = coefficient of transmissibility,

W = accretion rate,

a=distance from ground-water divide to drain,

x=distance along perpendicular from observation well to drain, and

h_0=elevation of water level in well above level of drain.

Water levels in five wells near Horseshoe Creek and in two wells near Cottonwood Creek were analyzed to obtain the coefficient of transmissibility for the White River Formation. Distances from the ground-water divides to the streams were determined from the generalized water-table map (fig. 4), and the difference in altitude between the water levels in the wells and in the stream was determined from U.S. Geological Survey topographic maps. The accretion rate was determined to be about 0.04 foot per year, or 1.1×10^{-4} foot per day, from an analysis of base-flow contributions from the Tertiary formations to Horseshoe and Cottonwood Creeks. (See section on "Recharge.") According to these analyses, the coefficient of transmissibility for the White River Formation ranges from about 450 to about 650 gpd per ft near Horseshoe Creek and from about 750 to about 1,000 gpd per ft near Cottonwood Creek. The White River Formation is probably thicker near Cottonwood Creek than it is near Horseshoe Creek, and this increase in thickness probably accounts for the difference in the coefficients of transmissibility computed for the two areas.

The permeability of the White River Formation probably is largely due to fractures rather than to intergrain porosity and may vary a great deal over short distances. The coefficient of transmissibility determined by the piezometric parabola equation is an average figure for the region and does not account for local variations in permeability. Individual wells might behave as though they were drilled in a material of greater or lesser transmissibility than indicated by the regional analysis; however, the analysis of data from a large number of wells in the White River Formation would probably yield an average coefficient near the regional value.

A recovery test was attempted on the White River Formation at well 29–69–33bac in the Horseshoe Creek valley. The well penetrated 283 feet of the White River Formation, which is overlain by 9 feet of saturated alluvium. The test could not be analyzed for the aquifer coefficients, but it did indicate that recharge was being induced to the White River Formation from the alluvium. The specific capacity of the well, which was about 10 gpm per foot of drawdown after 12 hours of continuous bailing, indicated that the White River Formation is very permeable at this site. The Elkhorn fault is near the well, and the formation may be fractured more extensively here than in other parts of the area.

The combined transmissibility of the White River and Arikaree Formations was determined, by use of the piezometric parabola equation, from an analysis of water levels in two wells near Cottonwood Creek. This analysis indicated that the coefficient of transmissibility for the two formations is about 1,500 gpd per ft. If one assumes that the coefficient of transmissibility of the White River Formation is about 750 to 1,000 gpd per ft, as found previously, the transmissibility of the Arikaree Formation ranges from about 500 to 750 gpd per ft. This range is much lower than that obtained for the Arikaree Formation by H. A. Whitcomb (1962) in Niobrara County, Wyo.; the Arikaree Formation is much thinner here than in Niobrara County, however, and this fact may account for the difference.

HYDRAULIC PROPERTIES OF THE FLOOD-PLAIN DEPOSITS

Four aquifer tests on the alluvium in the area include two on the alluvium of Horseshoe Creek, one on the alluvium of the North Platte River, and one on the alluvium of South Bear Creek (table 2). The first test on the alluvium of Horseshoe Creek was performed by D. A. Morris and H. M. Babcock in 1955. During the test, well 29–68–21bcc2 was pumped for 3 hours at an average rate of 770 gpm, and water levels were observed in a test hole 48 feet east of the pumped well. This test gave a coefficient of transmissibility of about 240,000 gpd per ft (Morris and Babcock, 1960, p. 54) as determined by use of the Theis equation (Theis, 1935, p. 522). The coefficient of transmissibility for this test is much higher than that determined from other wells tapping comparable saturated thicknesses of alluvial materials in the area. The test was of such short duration that the accuracy of the values obtained using the Theis equation are somewhat suspect. However, a check of the data, by use of an equation derived by Boulton (1954, p. 564–579), as described by Stallman (1961, p. 24–27), indicated that the data gathered during most of the test could be analyzed satisfactorily by use of the Theis equation. The well is near Horseshoe Creek, and movement of water from the stream to the well may have altered the drawdown cone in such a way as to indicate an erroneously high coefficient of transmissibility.

Well 29–68–19abb, which also penetrates the alluvium of Horseshoe Creek, test pumped at a rate of about 100 gpm for 3 days beginning on June 22, 1961, and water levels were observed in three wells. Analysis of the data from this test, in which the Theis method was used, indicates that the coefficient of transmissibility of the alluvium at this site is about 80,000 gpd per ft and that the field coefficient of permeability is about 4,000 gpd per sq ft.

On June 28, 1961, a 24-hour aquifer test was begun at well 28–67–18bcc1. The well is 64 feet deep, and it penetrates 62 feet of alluvium in the flood plain of the North Platte River. The average pumping rate during the 24-hour period was about 100 gpm. Drawdown and recovery measurements could not be made at the pumped well, but measurements were made at an observation well located 275 feet to the west. Although the test did not provide data that could be used to compute coefficients for the aquifer properties, it did indicate that the alluvium would yield considerably more than 100 gpm in this area.

Morris and Babcock (1960, p. 46) reported a field coefficient of permeability of 1,100 gpd per sq ft that was calculated from the results of a 1-hour test at well 28–68–27abc in 1955. The well, which penetrates only 6 feet of saturated alluvium in the valley of South Bear Creek, was pumped at a rate of 66 gpm.

The hydraulic diffusivity (the coefficient of transmissibility divided by the storage coefficient) was determined for the alluvium of Horseshoe Creek in the vicinity of well 29–68–21acb from the water-level records for that well. For this determination, it was assumed that the well penetrated a rectangular aquifer bounded by drains. The right angle bends of the stream formed half the aquifer, and their image across the impermeable boundary (fig. 12) formed the other half. Although the downstream northeast-trending boundary is poorly defined, it is removed a considerable distance from the well and probably has little effect on the rate of water-level decline in the vicinity of the well. Two parts of the well hydrograph were analyzed, including periods of water-level decline following periods of application of water for irrigation ending on June 17 and July 27, 1961 (fig. 13). Recharge was assumed to be in equilibrium with discharge prior to the halting of irrigation because each time the water levels remained fairly constant for several days preceding the end of irrigation. The function giving the decline in head in a well at distances x, y from the nearest corner of the rectangular aquifer of dimensions l, w is given by the equation:

$$\frac{h}{h_0}=\left[\frac{\sum_{n=1,3,5}^{\infty}\frac{1}{n^3}e^{-n^2\pi^2\frac{Tt}{Sl}}\sin n\pi\frac{x}{l}}{\sum_{n=1,3,5}^{\infty}\frac{1}{n^3}\sin\frac{n\pi x}{l}}\right]\left[\frac{\sum_{n=1,3,5}^{\infty}\frac{1}{n^3}e^{-\frac{n^2\pi^2Tt}{Sw}}\sin n\pi\frac{y}{w}}{\sum_{n=1,3,5}^{\infty}\frac{1}{n^3}\sin\frac{n\pi y}{w}}\right],$$

where

h_0 = the initial height of the water table at the well above the level of the drain;

h = the height of the water table at the well at time t after recharge halted;

t = time, in days, since recharge halted;

T = coefficient of transmissibility, in consistent units; and

S = coefficient of storage

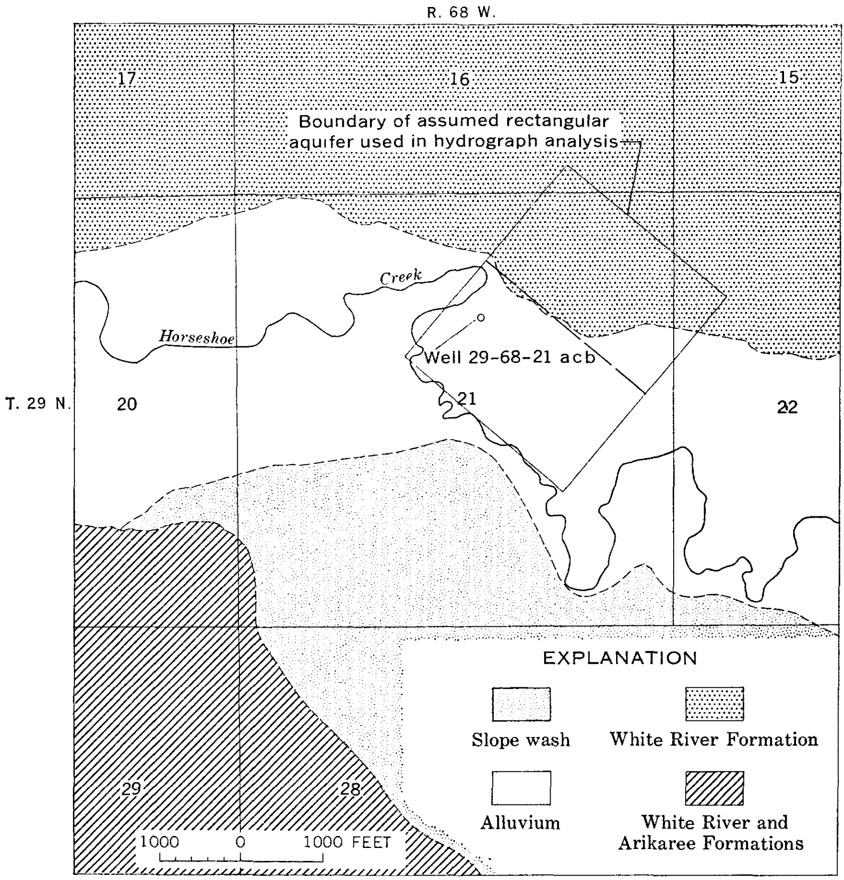

FIGURE 12.—Sketch showing the geohydrologic setting for well 29–68–21acb and its relation to the assumed rectangular aquifer used to determine the hydraulic diffusivity for the alluvium at this well site.

The expression enclosed between each set of brackets is a modification from Jacob (1943, p. 566). It represents the equation for head decline between one set of parallel drains following the end of recharge at an equilibrium rate.

A type curve of this function was prepared on log-log paper for the coordinates $\frac{x}{l}, \frac{y}{w}$. Actual values of $\frac{h}{h_0}$ in relation to time were determined from the well hydrograph, and these values also were plotted on log-log paper. The data was then analyzed by matching the data plot to the type curve, as described by Brown (1959, p. 1–22). Brown thoroughly described the method used here, although the equations used in his presentation are for head decline following instantaneous

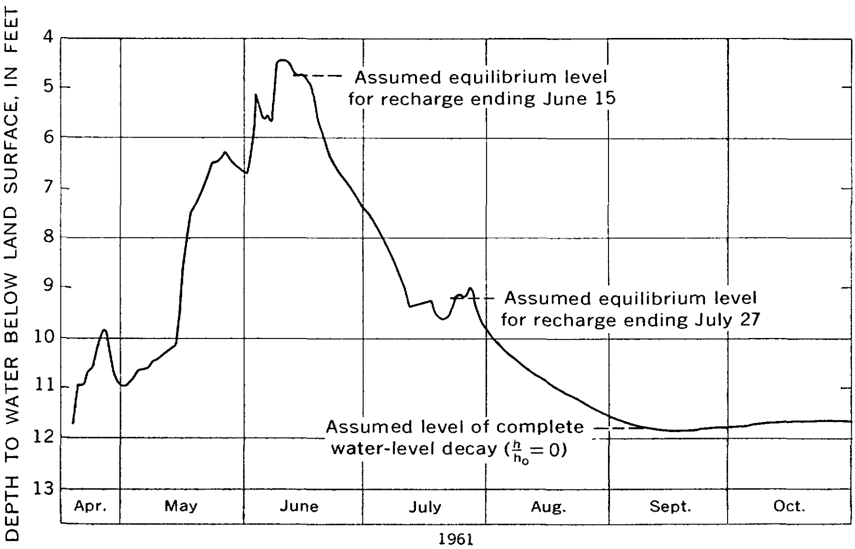

FIGURE 13.—Hydrograph of well 29–68–21acb showing water-level declines analyzed to determine hydraulic diffusivity for the alluvium at this well site.

slug recharge rather than head decline following cessation of recharge at an equilibrium rate.

The figure obtained for the hydraulic diffusivity determined for the alluvium in the vicinity of well 29–68–21acb by this method was about 20,000 square feet per day. If a storage coefficient for the aquifer of about 0.2 is assumed, the coefficient of transmissibility becomes about 4,000 square feet per day, or about 30,000 gpd per ft. This figure is smaller than that obtained for aquifer tests on other wells in the area. The alluvial materials at this site may contain more clay and silt than the alluvium elsewhere in the valley; hence, they may be less permeable. The well used for the determination was drilled as an irrigation well, but it was not equipped with a pump because the yield obtained was inadequate when the well was test pumped.

QUALITY OF GROUND WATER

Chemical analyses of 30 ground- and surface-water samples collected in the Glendo area are shown in table 4. The geologic units from which water samples were taken include the Hartville Formation, Opeche Shale, Minnekahta Limestone and gypsum and red shale sequence combined, Cloverly Formation, White River Formation, Arikaree Formation, and flood-plain deposits. Two samples from the North Platte River and one each from Middle Bear and Horseshoe Creeks were analyzed. The chemical analyses of water samples collected in the report area during previous investigations are discussed in reports by Rapp and Babcock (1953) and Morris and Babcock (1960). The reader is referred to the quality-of-water sections in these reports for more detailed explanations of the meaning of chemical analyses and the qualifications of suitable water for domestic, irrigation, and industrial uses.

STANDARDS FOR DOMESTIC USE

According to the standards set up by the U.S. Public Health Service (1962, p. 7), it is undesirable for the following chemical substances to be present in a water supply in excess of the listed concentrations:

Substance	*Concentration (ppm)*	*Substance*	*Concentration (ppm)*
Chloride (Cl)	250	Nitrate (NO_3)	45
Fluoride (F)	[1] 0.7–1.2	Phenols	0.001
Iron (Fe)	0.3	Sulfate (SO_4)	250
Manganese (Mn)	0.05	Total dissolved solids	500

[1] Recommended minimum and maximum limits based on an annual average of maximum daily air temperature at Wheatland, Wyo.

TABLE 4.—*Chemical analyses of water samples collected from*

[Results in parts per

Location	Depth or interval [1] (feet)	Yield (gpm)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
Hartville Formation (be												
29–69–24dbc2	355–385	20	6–14–61	------	19	0.01	------	29	7.7	26	12	42
Do	355–731	30?	7–10–61	------	13	.07	------	31	27	24	6.8	247
Do	355–840	35?	7–26–61	56	16	.00	0.03	33	18	20	4.4	230
"Converse sand" of												
29–68–20abb	410	160	9–21–49	54	18	0.12	------	46	11	21	3.2	244
29–68–20abd	442	78	7–20–49	54	21	.08	------	45	15	18	4.8	240
29–68–20bac	1,296	150	9–22–49	54	15	.20	------	45	13	18	3.2	240
29–69–24dbc2	44–268	60	6– 1–61	------	2.2	.02	0.03	56	14	20	5.2	230
Do	[2] 44–338	60	6– 5–61	------	20	.00	.02	55	12	18	4.5	233
Do	[3] 44–338	60	6– 6–61	------	20	.01	------	49	12	18	4.8	234
29–69–33bac	398–485	60	8–24–61	60	11	.10	------	23	7.9	44	8.7	183
Opeche												
29–69–24dbc2	44–173	0.5	5–24–61	------	16	0.02	0.09	484	95	77	10	164
Do	44–183	1.0	5–25–61	------	17	.07	.03	69	38	72	22	194
Do	44–208	2.0	5–26–61	------	8.2	.02	.01	82	29	66	7.8	180
Minnekahta Limestone and												
29–69–24dbc2	44–102	0.5	5–23–61	------	13	0.02	0.11	521	88	67	11	148

CLASSIFICATION OF WATER FOR IRRIGATION USE

The method of classifying water for irrigation that is used by the U.S. Salinity Staff (1954, p. 80) is based on the salinity and sodium (alkali) hazards of the water. The salinity hazard is related directly to the specific conductance which is a function of the total dissolved solids. Low-salinity water (specific conductance 0–250) can be used for irrigation of most crops on most soils. If a moderate amount of leaching occurs, medium-salinity water (specific conductance 250–750) can be used on plants having a moderate salt tolerance. High salinity water (specific conductance 750–2,250) can be used on certain plants having adequate drainage if special management for salinity control is practiced. Very high salinity water (specific conductance 2,250–5,000) is not suitable for irrigation under ordinary conditions.

The sodium (alkali) hazard is determined by the sodium-adsorption-ratio (SAR), which is related to the adsorption of sodium by the soil. Low-sodium water (SAR 0–10) can be used for irrigation on almost all soils with little danger of the development of harmful levels of ex-

wells, springs, and streams near Glendo, Platte County, Wyo.

million except as indicated]

Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Disolved solids: Calculated	Disolved solids: Residue or evaporation at 180°C	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Color
low the "Converse sand")														
0	118	8.5	0.6	0.4	0.07	------	234	104	70	32	1.1	357	8.1	4
0	35	7.7	1.0	.4	.07	------	261	189	0	21	.8	455	7.9	4
0	28	2.7	.7	.8	.05	------	231	172	0	20	.7	420	7.6	1
the Hartville Formation														
0	1.6	2.6	0.2	1.6	0.35	------	227	161	0	22	0.7	414	8.0	------
0	19	4.0	.4	.7	.13	------	248	174	0	18	.6	408	7.8	------
0	3.2	2.6	.2	1.5	.30	------	226	166	0	19	.6	416	7.8	------
0	47	2.6	.5	1.2	.04	------	280	198	9	18	.6	456	7.8	------
0	35	1.8	.4	.8	.04	------	263	185	0	17	.6	446	8.0	1
0	14	2.5	.5	1.1	.06	------	231	170	0	18	.6	395	7.4	2
0	34	7.3	.9	.1	.08	------	238	90	0	49	2.0	402	7.6	1
Shale														
0	1,530	7.6	0.4	0.7	0.27	2,300	2,510	1,600	1,470	9	0.8	2,520	7.5	------
0	302	17	1.1	2.9	.20	------	651	327	168	31	1.7	963	7.6	------
0	282	14	1.3	3.4	.15	------	615	322	174	30	1.6	883	7.6	------
gypsum and red shale sequence														
0	1,580	6.5	0.4	0.6	0.29	2,360	2,550	1,660	1,540	8	0.7	2,570	7.4	------

TABLE 4.—*Chemical analyses of water samples collected from*

[Results in parts per

Location	Depth or interval [1] (feet)	Yield (gpm)	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
Cloverly												
29-68-35cbb	Spring	33	9-13-49	53	19	0.12	------	49	7.5	40	8.0	296
White River												
29-68-9bcb	[4] 700	--------	8-5-46	55	------	------	------	42	4.6	58		214
29-68-9bcd1	[4] 793	84	9-14-49	------	28	0.12	------	43	20	21	5.6	234
29-68-9bcd2	145	10	8-5-46	54	64	.03	------	89	8.1	46		246
29-69-33bac	17-300	75	8-5-61	52	40	.00	0.00	79	9.5	25	6.7	256
Arikaree												
30-67-27ccb	Spring	50	8-20-50	53	53	0.25	------	61	11	67	16	376
Flood-plain												
28-67-18bcc1	64	100	9-24-49	52	39	0.05	------	70	6.7	15	7.2	276
28-68-13dcb	23	--------	7-20-49	54	19	.08	------	67	8.7	19	6.0	257
28-68-27abc	12	66	8-20-53	61	44	.03	------	64	6.7	34	3.8	287
29-68-19abb	60(?)	100	8-28-61	56	42	.02	0.26	155	19	25	8.5	258
29-68-21dad	58	10	9-14-49	52	38	1.20	------	153	17	34	2.4	252
29-69-24dbc2	9-35	100	5-19-61	------	29	.02	.11	293	28	32	4.9	286
Surface												
28-67-18d	(5)	--------	12-7-50	------	20	0.04	------	146	41	130	8.6	342
28-67-18d	(6)	--------	6-4-52	------	15	.04	------	49	11	31		141
28-68-14ccc	(7)	--------	9-25-49	------	37	.04	------	57	10	17	6.4	242
29-68-20ada	(8)	--------	9-25-49	------	38	.04	------	141	16	29	13	214

1 Uncased stratigraphic interval open to well bore when sample was collected.
2 Sample collected after well was bailed 6½ hr.
3 Sample collected after well was bailed 23½ hr.
4 Well also may produce from the Hartville Formation.

changeable sodium. Medium-sodium water (SAR 10–18) may be used on coarse-textured or organic soils having good permeability but will present an appreciable sodium hazard if used on fine-textured soils. High-sodium water (SAR 18–26) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions. Very high sodium water (SAR 26–31) is generally unsatisfactory for irrigation except under special soil conditions and salinity management.

wells, springs, and streams near Glendo, Platte County, Wyo.—Continued

million except as indicated]

Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium-adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Color
Formation														
0	4.0	3.6	0.2	1.7	0.35	------	296	154	0	35	1.4	515	7.7	------
Formation														
------	53	9.0	0.8	5.0	------	------	--------	124	0	50	2.2	463	------	------
0	33	4.0	1.2	1.1	0.2	------	--------	190	0	19	.7	439	7.8	------
0	88	33	.4	19	.02	------	--------	256	54	28	1.3	696	7.5	------
0	51	19	.3	3.2	.06	------	377	236	26	18	.7	557	7.2	1
Formation														
0	28	11	0.5	6.4	0.09	------	468	199	0	40	2.1	677	7.5	------
deposits														
0	9.6	3.0	0.2	4.7	0.20	------	302	202	0	13	0.5	449	7.5	------
20	9.2	4.0	.4	1.8	.20	------	284	203	0	16	.6	434	8.6	------
0	14	4.5	.4	.4	.03	------	326	187	0	28	1.1	486	7.3	------
0	286	9.5	.3	5.0	.04	------	700	465	253	10	.5	919	7.5	2
0	296	3.0	.4	1.2	.10	------	692	452	245	14	.7	939	7.5	------
0	634	8.2	.4	.5	.01	1,170	1,260	845	610	8	.5	1,470	7.1	------
water														
0	473	37	0.4	4.2	0.00	1,030	--------	534	254	34	2.4	1,450	7.9	------
0	103	7.5	.3	1.4	.07	------	312	168	52	29	1.0	460	7.7	------
14	2.4	1	.4	.8	.10	------	266	183	0	16	.5	427	8.2	------
0	296	3	.8	.7	.10	------	650	418	243	13	.6	875	7.7	------

[5] North Platte River during low flow; dissolved solids 1.48 tons per acre-foot.
[6] North Platte River during high flow; dissolved solids 0.42 ton per acre-foot.
[7] Middle Bear Creek; dissolved solids 0.36 ton per acre-foot.
[8] Horseshoe Creek during low flow; dissolved solids 0.88 ton per acre-foot.

HARDNESS CLASSIFICATION OF WATER

The hardness (calcium, magnesium) classification of water used by the Quality of Water Branch of the Geological Survey is as follows: 0–60 ppm (soft), 61–120 ppm (moderately hard), 121–180 ppm (hard), and 181+ (very hard).

SUITABILITY OF GROUND WATER

The samples of ground water from the Glendo area that were most suitable for domestic use came from the Hartville Formation (below the "Converse sand"), "Converse sand," Cloverly Formation, White River Formation, and flood-plain deposits. Seventeen of the 22 samples from these sources, however, contained less fluoride than the recommended lower limit. Three samples from wells (29–68–19abb, 29–68–21dad, 29–68–24dbc2) tapping the alluvium in Horseshoe Creek exceeded the limits for sulfate and total dissolved solids; two of these samples were very high in manganese. The high sulfate content in the ground water of the alluvium and the surface water in this part of the Horseshoe Creek valley is probably related to nearby outcrops of bedded gypsum ($CaSO_4 \cdot 2H_2O$). Upstream from the exposures of the gypsum the alluvium overlies the White River Formation, and the sulfate concentration in both the ground and surface water is much less.

The hardness of the samples listed in table 4 ranged from moderately hard (90 ppm) to very hard (1,660 ppm). Average hardnesses of water samples collected from each geologic unit were as follows: Hartville Formation (below the "Converse sand"), hard (155 ppm); "Converse sand," hard (164 ppm); Opeche Shale, very hard (750 ppm); Minnekahta Limestone and gypsum and red shale sequence, very hard (1,660 ppm); Cloverly Formation, hard (154 ppm); White River Formation, very hard (208 ppm); Arikaree Formation, very hard (199 ppm); and flood-plain deposits, very hard (393 ppm). The average hardness of four surface water samples was very hard (326 ppm).

Because all the sampled waters given in table 4 had low sodium-adsorption ratios, their use for irrigation would probably not cause harmful levels of exchangeable sodium to occur in the soils. The high salinity hazards of some of the waters sampled, however, would probably cause harmful effects to plants not having good salt tolerances. Most of the crops grown in the region—such as grains, sugar beets, and alfalfa—have a medium to high salt tolerance.

Sampled waters from the Hartville ("Converse sand" included), Cloverly, White River, and Arikaree Formations had medium salinities and would be suitable for the irrigation of plants having a moderate salt tolerance if a moderate amount of leaching occurs. The samples from the Opeche Shale and from the gypsum and red shale sequence had high to very high salinities; water from these formations would be poor for irrigation. The high salinities of samples from the alluvium in the Horseshoe Creek valley is probably a local condition that is related to the gypsum outcrops just mentioned. Outside of this vicinity the salinity of water from the alluvium is less. Samples of the ground water in the alluvium of South Bear Creek and the North Platte River valleys had medium salinities.

UTILIZATION OF GROUND WATER

Ground water is utilized in the Glendo area for domestic, stock, municipal, and irrigation purposes. The total amount of water that is used annually in the area is about 445 acre-feet.

The Hartville Formation yielded about 60 acre-feet to four wells in the Horsehoe Creek valley in 1961 for domestic, stock, and irrigation uses.

The town of Glendo, whose population in 1960 was 292, is supplied by three wells. One well is 793 feet deep and produces water from the White River Formation and possibly the Hartville Formation. The other two wells have depths of 145 and 160 feet and produce water from the White River Formation. In 1961, the combined discharge of the three wells was about 120 gpm, but the average daily consumption rate was only about 19 gpm. Glendo consumes about 30 acre-feet, or 9.8 million gallons, of ground water annually. Probably an additional 5 acre-feet per year of ground water is produced from the White River and Arikaree Formations at approximately 35 wells on farms and ranches in the area.

In 1961, about 340 acre-feet of ground water was pumped from four irrigation wells that produce from the alluvium in the valley of Horseshoe Creek; an additional 10 acre-feet of ground water from the alluvium in the stream valleys of the area was pumped at approximately 25 wells for domestic, stock, and irrigation purposes on farms and ranches in the area. A battery of three irrigation wells (28–68–15ddd1, 2, 3) that reportedly produced 375 gpm from the alluvium in Middle Bear Creek is no longer in use.

POSSIBILITIES OF ADDITIONAL GROUND-WATER DEVELOPMENT

The "Converse sand" will yield water for domestic, stock, municipal, and irrigation uses throughout much of the report area. Flowing wells yielding from a few gpm to 175 gpm or more may be obtained from the "Converse sand" in an area from ½ to 1½ miles wide and about 4½ miles long in the lower Horseshoe Creek valley (pl. 3). Wells tapping the "Converse sand" in areas outside of the lower Horseshoe Creek valley and between Glendo and Elkhorn fault (pl. 3) would probably not flow at the land surface and would require pumping equipment. The discharge of these wells, and additional discharge induced by pumping flowing wells in the "Converse sand," would probably amount to about 2 gpm per foot of drawdown. However, the theoretical drawdown curves computed from data gathered during tests at well 29–68–20abd by Rapp and Babcock (1953, p. 18) indicate that the cone of depression that would be formed by a well pumping from the "Converse sand" would extend out a great distance. Therefore, wells in the "Converse sand" should be located as far apart as practical to avoid excessive interference.

Because the "Converse sand" dips at a greater angle than the land surface, the depth to the top of the "Converse sand" becomes increasingly greater southeastward away from the outcrop area on the Elkhorn anticline (pl. 3.) Test well 29–69–24dbc2 topped the "Converse sand" at 241 feet below the land surface, but a well drilled near the mouth of Horseshoe Creek would probably top the "Converse sand" at a depth between 1,200 and 1,500 feet. The depth to the "Converse sand" can be approximated for a particular location by subtracting the altitude of the "Converse sand" (pl. 3) from the altitude of the land surface at that same location.

Supplies of water for domestic and stock uses and small supplies for municipal use are available in the White River and Arikaree Formations. Some wells might yield as much as 50 gpm with relatively large drawdowns, although most wells would have a much smaller yield. Wells of larger discharge might be obtained from the White River and Arikaree Formations near fault zones and other places where the rocks composing these formations are extensively fractured; these areas, however, are poorly exposed and difficult to locate.

Considerable quantities of ground water are available in the alluvium along the Horseshoe Creek valley. The amount of water held in storage in the alluvium in a 1-mile-long segment of the valley was computed to be about 700 acre-feet, based on an average thickness for the saturated part of the alluvial materials of 15 feet, an average width of the alluvium of 2,000 feet, and an assumed storage coefficient of 0.2. Wells tapping the alluvial deposits at locations some distance from the stream would probably yield from 150 to 500 gpm, and wells located near the stream might yield as much as 800 gpm.

Considerable ground water is available for development from the alluvium of the Platte River in the Cassa Flats area. The saturated thickness of the alluvial materials is as much as 30 feet in the area, and wells yielding 500 gpm or more could probably be obtained in many parts of the area. Probably test holes should be drilled before an irrigation well is installed in places where the thickness of saturated materials is unknown.

EFFECTS OF IRRIGATION DEVELOPMENT ON THE WATER SUPPLY

The natural streamflow in the Horseshoe Creek valley does not provide an adequate supply of water for the entire growing season. Water is applied in large quantities throughout the valley in the spring when water from spring runoff is available. Later in the season, streamflow is usually sufficient to supply only the high-priority users in the lower part of the valley. If adequate amounts of water become available because of future changes in the irrigation system, better crops can be raised and much of the irrigation water, which would recharge the alluvium and return to the stream, can be used downstream. Large quantities of irrigation water would probably be salvaged in this manner, although considerable water would be lost to evapotranspiration.

The rate at which recharge from water applied for irrigation would return to Horseshoe Creek was computed for a hypothetical ideal aquifer approximately representing the alluvium of Horseshoe Creek. The ideal aquifer was assumed to be 2,000 feet wide, to have parallel impermeable boundaries, and to be tapped by a straight stream that is parallel to and midway between the boundaries. The coefficients of transmissibility and storage for the ideal aquifer were assumed to be 75,000 gpd per ft and 0.2, respectively, which are approximately the same as the coefficients for the alluvium in the Horseshoe Creek valley. It also was assumed that the aquifer was uniformly recharged by irrigation at a rate of 0.1 foot per day for a time sufficient to produce equilibrium conditions before being halted instantaneously. The curve (fig. 14) shows the contribution to streamflow from each 1-mile strip of aquifer for 60 days after recharge has ceased. The ideal aquifer is a fairly close representation of the aquifer formed by the alluvium of Horseshoe Creek, and the curve should be useful in predicting return flows from irrigation diversions in the valley. Because water thus recharged returns very quickly to the stream, much of the water could be used for downstream irrigation a short time after it had been applied upstream.

These data also indicate that wells producing from the alluvium in the Horseshoe Creek valley and Cassa Flats would derive much of their water from the streams. The stream discharge would probably be decreased considerably in the vicinity of a heavily pumped area, but the surface-water supplies downstream would probably be diminished by a lesser amount because much of the water pumped by wells eventually would return to the stream. The irrigable area of Cassa Flats is very small in relation to the amount of water available from the North Platte River; therefore, a well-field in Cassa Flats would probably not appreciably decrease surface-water supplies downstream.

Wells would be of little benefit in most of the Glendo area in salvaging recharge to the alluvium from irrigation water because the water diverted for irrigation would return to the streams a short time after it was applied. However, along certain reaches of the streams, such as in secs. 20 and 21, T. 29 N., R. 68 W., where underflow is probably relatively great, wells might salvage ground water for irrigation that otherwise could not be used in these particular areas.

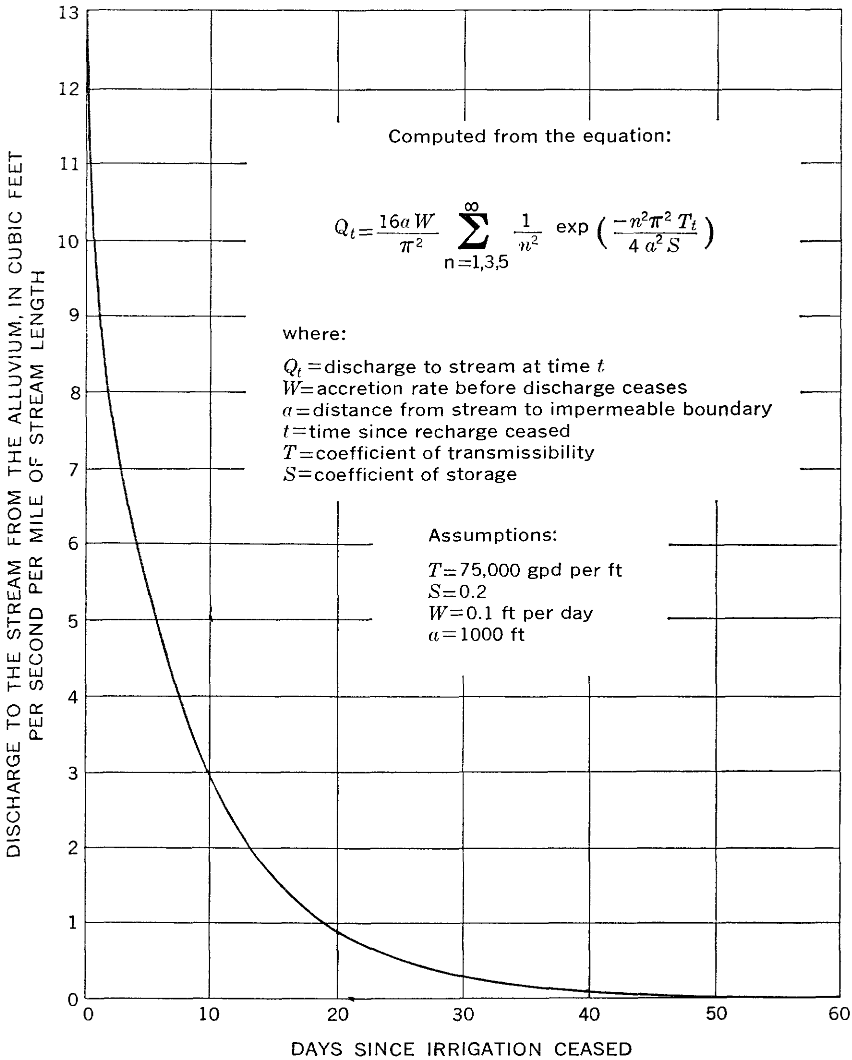

FIGURE 14.—Curve showing the return-flow contribution to Horseshoe Creek from recharge by irrigation water applied to land underlain by the valley alluvium, as determined from a mathematical model. Equation derived by R. W. Stallman (written commun., 1962).

RECORDS

RECORDS OF WELLS AND SPRINGS

The records of 83 wells and 7 springs shown in the following table are a combination of representative data taken from previous reports and data obtained during this investigation of the Glendo area.

TABLE 5.—*Records of wells and springs near Glendo, Platte County, Wyo.*

Well: See text for description of well-numbering system.
Type of well: Dn, driven well; Dr, drilled well; Du, dug well; Sp, spring.
Depth of well: Depths are given in feet below land surface; questionable depths are indicated by a question mark.
Type of casing: C, concrete, brick, or tile pipe; N, none; P, iron or steel pipe.
Character of material: Cg, conglomerate; Cls, claystone; G, gravel; Ls, limestone; S, sand; Sls, siltstone; Ss, sandstone.
Geologic source: PPMh, Hartville Formation; Pg, Gypsum and red shale sequence; Kc, Cloverly Formation; Tw, White River Formation; Ta, Arikaree Formation; Ts, Ogallala equivalent and rocks of late Miocene age; Qfp, flood-plain deposits including slope wash.
Type of pump: C, cylinder; F, flows; J, jet; N, none; T, turbine.
Type of power: E, electric; G, gasoline or diesel engine; H, hand operated; N, none; W, windmill.
Use of water: D, domestic; I, irrigation; N, none; O, observation; P, public; S, stock.
Description of measuring point: Bpb, bottom of pump base; Hpb, hole in pump base; Ls, land surface; Tc, top of casing; Twc, top of well cover.
Height of measuring point above mean sea level: Altitudes were interpolated from topographic maps.
Remarks: Ca, sample collected for chemical analysis; D, discharge in gallons per minute (B, bailed; E, estimated; M, measured; R, reported); DD, drawdown in feet; L, log of well in table of well logs; T, temperature in degrees Fahrenheit.

Well	Owner	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing unit: Character of material	Principal water-bearing unit: Geologic source	Type of pump and power	Use of water	Measuring point: Description of measuring point	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Distance to water level above (+) or below measuring point (feet)	Date of measurement	Remarks
28-67- 6acc	T. Van Buskirk		Dr	60	8	P	Sls	Tw	C, E	D, S	Ls		4,510	31.60	7-20-60	
6cca	Ivan Hooley		Dr	56	6	P	S, G	Qfp	J, E	D	Ls		4,495	19R	8-23-49	
7bac	Tony Pavlovitch		Dr	18			S, G	Qfp	C, E	S			4,480	9R		
18bcc1	W. H. Johnson		Dr	64	12	P	S, G	Qfp	T, E	D, I	Ls		4,494	28.95	6-28-61	Ca, D100, L, T52.
19aaa	Geo. Robb		Dr	24	2	P	S, G	Qfp	C, W	D, S	Ls		4,470	20R	8-23-49	T54.5.
28-68- 1cdc	Ivan Hooley		Dr	56	6	P	Sls	Tw	C, W	S	Ls		4,538	19R	8-22-49	T51.
2dcd	do		Du	35	84	N	Sls	Tw	N	N	Twc	0	4,570	29.93	8-24-49	
5caa			Dr	100(?)	6	P	Ss	Ta	W	N	Tc	1.0		57.28	9-15-62	
5ddd	J. Hughes	1951	Dr	74	5	P	Ss	Ta	N	N	Tc	.4	4,740	60.64	10-19-53	L.
7abc	W. H. Johnson		Dr	58	6	P	Sls	Tw	C, N	N	Tc	.2	4,866	53.17	10-19-53	
														53.85	4- 6-62	
7ddb	J. L. Jones		Dr	37	4	P	Ss, Sls	Tw, Ta	N	N	Tc	.8	4,871	7.95	10-19-53	
														6.55	4- 6-62	
10bbb	J. P. Hughes		Dr	48	6	P	Ss	Ta	C, E	D	Ls		4,680	38R	8-31-49	
12aac	C. B. & Q. RR	1942	Dr	42	12	P	S, G	Qfp	N	N	Ls		4,485	20R	10-28-42	D100R, L, destroyed.
13adc	W. H. Johnson		Dr	40(?)	7	P	S, G	Qfp	N	N	Tc	1.0	4,504	32.62	3-14-62	
13bac	do		Dr	65(?)	4	P	Sls	Twr	C, N	N	Ls		4,520	47.83	3-14-62	
13dad	do		Dr	34	4	P	S, G	Qfp	C, W	N	Ls		4,505	Dry	1-29-62	T53.
13dcb	B. A. Caster	1925	Dn	23	6	P	S, G	Qfp	C, W	S	Ls		4,552	15R	1948	Ca, T54.
15bbb	J. P. Hughes		Dr	217	6	P	Ss, Cg, Sls	Tw, Ta	C, W	S	Ls			182R	8-31-49	

See footnotes at end of table.

TABLE 5.—*Records of wells and springs near Glendo, Platte County, Wyo.*—Continued

Well	Owner	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing unit: Character of material	Principal water-bearing unit: Geologic source	Type of pump and power	Use of water	Measuring point: Description of measuring point	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Distance to water level above (+) or below measuring point (feet)	Date of measurement	Remarks
28-68-15ddd1	W. H. Johnson	1950	Dr	32	18	P	S, G	Qfp	T, E	N	Bpb-	3.0	4,623	5.37	10-24-53	D375E.
														9.66	9-15-62	
15ddd2	do	1950	Dr	28	18	P	S, G	Qfp	N	N	Hpb	3.0	4,623	9.98	10-24-53	
15ddd3	do	1950	Dr	24	18	P	S, G	Qfp	N	N	Hpb.	3.0	4,623	9.74	10-24-53	
16cdb	do		Du, Dr	20	6	P	S	Qfp	C, W	D	Ls		4,760	19R	11-3-48	
22baa	do		Sp				S, G	Qfp	F	I			4,665		9-15-62	D10E.
24bcb	do		Dr	65(?)	6	P	S, G, Sls	Tw, Qfp	C, W	S	Ls		4,570	44.41	3-14-62	T57.
27abb	D. W. Brown	1947	Dr	58	6	P	Ss	Ta	J, E	S, O	Ls		4,691	15.86	9-15-62	T54.
27abc	do	1919	Du	12	48	C	G	Qfp	C, E	D, I, S, O	Ls		4,668	4.73	9-15-62	Ca, D66M, DD5.3, T61.
28-69-11dba	Bess Panushka		Dr	98	5	P	Sls	Tw	N	N	Tc	0	5,130	67.00	10-23-53	
12bcd	F. J. Jones		Dr	63	5	P	Sls	Tw	N	N	Tc	0.3	5,082	19.40	10-19-53	
														19.05	4-6-62	
20adc	Donald Gordon	1950	Dr	128	4	P	Ss, G	Tw(?), Ts	C, W	S	Ls		5,374	98R	1950	
														103.00	4-14-62	D8B, L.
21cdd	do	1950	Dr	155	6-4	P	Ss, G	Tw(?), Ts	C, W	S	Ls		5,370	130R	1950	D5B, L.
28-70- 2dbb	Clayton Russell	1946	Dr	54	6	P	S, G	Qfp	C, H	D, S	Tc	.2	5,055	23.09	8-24-49	
2dbd1	do	1955	Dr	58	6	P	Sls, G	Tw, Qfp	J, E	D, S	Ls		5,040	36R	3-1-55	D25BR, L.
8dca1	Mrs. Macfarlane	1956	Dr	50		P	S, G	Qfp	J, E	D			5,202			
8dca2	do	1955	Dr	176	5.5	P	Sls	Pg	N	N	Tc	.2	5,206	12.77	8-14-61	
11bbc	Mr. Jacobsen		Dr	15	6	P	S, G	Qfp	N	N	Tc	.3	5,065	8.87	8-25-49	T54.
11dab	Clayton Russell	1960	Dr	227	6⅝	P	Cls, Sls, Ss.	Tw	C, W	S	Ls		5,220	104R	7-24-61	D10BR. DD96R.
29-67- 4aac			Dr	113	6	P	Ss	Ta	C, W	N	Tc	.6	4,791	75.70	7-8-52	
29-68- 9bcb	C.B. & Q. RR	1895	Du, Dr	[1]700			Sls, Ss	PPMh(?), Tw	C, E	D	Twc					Ca, T55.
9bcc	Town of Glendo	1960	Dr	160	12	P	Sls	Tw	T, E	P	Ls		4,714	32R	7-1-60	D35R, L.
9bcd1	do	1947	Dr	793		P	Sls, Ss	PPMh(?), Tw.	T, E	P	Ls		4,720		1954	Ca, D84R, L.
9bcd2	do	1933	Dr	145	8	P	Sls	Tw	T, E	P	Ls		4,720	92R	1946	Ca, D10E, DD55, T54.
9bdc	do	1940	Dr	225	6	P	Sls	Tw	C, E	N	Ls		4,750	90R	1954	D8R.

19abb	Town of Glendo (Horseshoe Cemetery).		Dr	60(?)			S, G	Qfp	T, E	P, I	Ls		4,695	38.00	5-24-61	Ca, D106M.
19cac	Fred Dilts	1956	Dr	52	14	P	S, G	Qfp	T, E	I	Ls		4,690	18R	1956	D135M, DD17, L.
20abb	A. M. Downey	1941	Dr	410	6	P	Ss	P ℙ Mh	F	S	Tc	.8	4,639	+32.46	9-21-49	Ca, D160M, DD33, L, T54.
20abd	do	1941	Dr	442	4	P	Ss	P ℙ Mh	F	D, S	Tc	.7	4,631	+40.40	9-21-41	Ca, D78M, DD30, L, T54.
20acc	do	1954	Du	41	72	C	S, G	Qfp	T, E	I	Ls		4,643	16.07	7-13-62	D410M, DD10, L.
20acd	do	1954	Dr	535	6	P	Ss	P ℙ Mh	F	S	Ls		4,640	+31.88	1-29-62	D70M.
20bac	J. R. Landcaster	1924	Dr	[2]1,296	4	P	Ss	P ℙ Mh	F	I, D	Ls		4,644			Ca, D150R, L, T54.
21acb	F. V. Waters	1958	Du	23	60	C	S, G	Qfp	N	N	Tc	2.0	4,608	8.70	8-14-62	L.
21bbb	Clark Coleman	1939	Dr	94	6	P	Sls, S, G	Tw, Qfp	C, H	D, O	Lc		4,646	30.41	8-29-55	Ca, L, T52.
21bcc2	J. R. Landcaster	1954	Dr	40.5	16	P	S, G	Qfp	T, E	I	Ls		4,625	7R	1954	D770M, DD5.3, L, T52.
21dad	F. V. Waters	1907	Dr	58	6	P	S, G	Qfp	C, H	D, O	Tc	.1	4,585	9.18 8.10	8-6-54 9-15-62	Ca, D10E, T52.
22cdc	T. R. Nida		Dr	40	6	P	S, G	Qfp	C, E	D, S	Ls		4,580	15R	11-5-58	
26adc	Mr. Thompson	1904	Dr	65		P	S, G	Qfp	J, E	D, S	Ls		4,520	14	1948	
27cca	Donald Summers	1948	Dr	75	6	P	Sls, S, G	Tw, Qfp	J, E	D	Ls		4,620	57R	10-22-48	
35cbb	Ivan Hooley		Sp				Ss	Kc	F	S			4,655		9-20-49	Ca, D33M, T53.
29-69- 2aac	C. E. Sanburn	1959	Dr	1,081	10¾	P	(?)	(?)	N	N	Tc	1.5	4,095	487.46	1-3-62	Dry oil test.
7bdb	W. Baxter	1952	Dr	110	5	P	Sls, Ss, Cg	Tw(?), Ts	C, E	D, S	Ls		5,243	77.00	4-14-62	D5R.
24dbc2	G. C. Wilson	1961	Dr	840	8-6½	P	Ss, Ls	P ℙ Mh	N	O	Ls		4,710	[3]19.47	9-15-62	Ca, D60BM, DD21, L, T55.
														[4]21.80	9-15-62	Ca, D40BM, DD68, L, T56.
26ada	R. W. Daly	1956	Dr	37	12	P	S, G	Qfp	N	N	Ls		4,735	11R	1956	L.
27dca1	Mrs. Eliz Conloque	1934	Dr	700	6	P	S, G	Qfp	N	N	Ls			20R	10-22-48	Destroyed.
27dca2	do		Dr	60			S, G	Qfp	J, E	D	Ls		4,795	20R	10-22-48	
28cdd	R. I. Twiford	1939	Dr	72	4	P	Sls, S, G	Tw, Qfp	J, E	D	Ls		4,850	22R	1948	
31 cad	Lewis Archie	1941	Dr	16			S, G	Qfp	N	N	Twc	.2	4,945	10.15 9.55	11-4-48 8-11-61	
32acc	Ralph McLeod	1958	Dr	35	4	P	S, G	Qfp	N	N	Ls		4,868	19R	12-15-58	D10R, L.
32bcb	do	1960	Dr	152	6	P	Sls	Tw	J, E	D			4,918			D4R, L.
33bac	R. I. Twiford	1961	Dr	485		P	Sls, Ss	P ℙ Mh, Tw	N	O	Ls		4,840	[5]11.08	9-15-62	Ca, D78BM, DD7.7, L, T52.
														[4]143.85	9-15-62	Ca, D14.6BM, DD5.8, T60, L.
34bca	Stella Martindale		Dr	70(?)	6	P	S, G	Qfp	C, W	D, S			4,825			
36bdc	Emmett Robb	1941	Dr	46	6	P	Sls	Tw	C, W	S	Ls		4,819	18R	1941	
29-70-14aab	R. I. Twiford	1943	Dr	150	6	P	Sls, Ss, Cg	Tw(?), Ts	C, W	S	Ls		5,481	138R	1943	
35aab	C. B. Harmon		Dr	48			Sls	Tw	C, H	D	Ls		5,137	30.97	8-24-49	T54.
36ddb	Lewis Archie		Du	12	112	C	S, G	Qfp	N	N	Tc	1.0	4,962	6.85	8-11-61	
30-67-27ccb	Glen Cundall		Sp				Ss	Ta	F	S			4,744			Ca, D50E, T53.
28bbd	Ray McCormick		Dr		6	P	Ss	Ta	C, H	N	Tc	.4	4,755	61.10	6-21-52	
30aac	L. Hytrek	1915	Dr	70	6	P	Sls	Tw	C, G	S	Tc	.8	4,661	47.50	6-23-52	
30cdc			Dr		6	P	Sls	Tw(?), Ta	C, W	N	Bpd	0	4,670	66.05	6-23-52	

See footnotes at end of table.

TABLE 5.—*Records of wells and springs near Glendo, Platte County, Wyo.*—Continued

Well	Owner	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Principal water-bearing unit		Type of pump and power	Use of water	Measuring point			Distance to water level above (+) or below measuring point (feet)	Date of measurement	Remarks
							Character of material	Geologic source			Description of measuring point	Distance above land surface (feet)	Height above mean sea level (feet)			
30-67-33aca	Glen Cundall		Sp				Ss	Ta	F	D, S			4,720			D30E, T50.
33acd	Roy McCormick		Dr		6	P	Ss	Tw	C, W	N	Tc	3.3	4,728	12.75	6-21-52	
30-68-31baa	Dick Cundall		Sp				S, G	Qfp	F	S			4,779			D2R.
33ccd	Mr. Hershberger	1955	Dr	78	6	P	Sls	Tw(?)	J, E	D	Ls		4,660	67	1955	L.
30-69-27adb	Dick Cundall	1940	Dr	50	6	P	Sls	Tw(?), Qfp	C, W	D, S	Tc	0	4,860	9.90	7-14-52	
27add	Jack Cundall		Sp				S	Qfp	F	S			4,830			D2E.
32cab	Mr. Foy		Dr	60	6	P	Sls	Tw	C, H	D	Ls		5,025	8.30	7-14-52	
36bdb	Jack Cundall		Sp					PPMh(?)	E	S			4,940			D1E.

[1] Well buried but connected to cistern 43.0 ft. deep.
[2] Well plugged back to 460 ft.
[3] Water level in the "Converse sand."
[4] Water level in the Hartville Formation below the "Converse sand."
[5] Water level in the White River Formation.

LOGS OF TEST HOLES AND WELLS

The logs of 54 test holes and 20 representative wells in the Glendo area are given in table 6. Forty-nine of the test holes were drilled during the summer of 1961 for the U.S. Geological Survey to gain information regarding the ground-water potential of formations underlying the area. Five of the test holes were drilled for damsite evaluation for the Bureau of Reclamation in 1962. The logs entitled "sample log" are those for which the well cuttings were collected and studied by personnel of the U.S. Geological Survey. Logs designated simply as "log" are driller's records that have not been changed. The test-hole and well logs are numbered according to the well-numbering system illustrated in figure 3, and their locations are shown on plate 1.

The altitudes given in table 6 are those of the land surface at the well or test-hole site and are given in feet above mean sea level; some were determined by interpolation between contours on topographic maps and others were surveyed by means of hand level and rod. The designation (O.W.) indicates that the well or test hole had pipe or casing installed in it so that water levels could be measured.

The sample logs of test wells 29–69–24dbc2 and 29–69–33bac, which penetrated the "Converse sand," are included in the section on lithology of the Hartville Formation.

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
28-67-7ccc [Sample log of test hole 4, section *J–J'*. Alt 4,475 ft]					
Flood-plain deposits:			White River Formation:		
Silt, sand, and soil	9	9	Siltstone and claystone, buff	10	41
Sand, coarse, to coarse gravel	22	31			
28-67-7ccd (O.W.) [Sample log of test hole 5, section *J–J'*. Alt 4,474 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil, sandy	6	6	Siltstone and claystone, buff	8	41
Sand, coarse, to coarse gravel	27	33			
28-67-7ccd [Sample log of test hole 6, section *J–J'*. Alt 4,470 ft]					
Flood-plain deposits:			White River Formation:		
Sand, medium, to coarse gravel	3	3	Siltstone and claystone, buff	4	31
Gravel, fine to coarse	24	27			
28-67-18bcc1 [Log of well. Alt 4,494 ft]					
Soil	22	22	Chalk	2	64
Sand and gravel	40	62			
28-67-18bcc2 (O.W.) [Sample log of test hole. Alt 4,498 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil, sandy	4	4	Siltstone and claystone, buff	6	71
Gravel, medium to coarse	24	28			
Clay, silty	4	32			
Gravel, fine to medium	33	65			
28-68-5ddd [Log of well. Alt 4,740 ft]					
Sandstone; water at 70 ft	70	70	Chalk rock, water-bearing	10	80
28-68-12aac [Log of destroyed well. Alt 4,490 ft]					
Soil and sand	24	24	Sand, fine	2	42
Gravel, water-bearing	16	40			
28-68-12cdc [Sample log of test hole 1, section *J–J'*. Alt 4,511 ft]					
Flood-plain deposits:			White River Formation:		
Silt and fine sand containing thin beds of coarse material; probably slope wash	20	20	Siltstone and claystone, buff	8	61
Clay, silty	2	22			
Sand, fine, to coarse gravel	31	53			

Table 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—**Con.**

28–68–12dcc

[Sample log of test hole 2, section *J–J′*. Alt 4,495 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt, sand, and soil	10	10
Gravel, medium, and clay	6	16
Clay, silty	7	23
Flood-plain deposits—Con.		
Sand, fine, to coarse gravel	15	38
White River Formation:		
Siltstone and claystone, buff	3	41

28–68–12ddc (O.W.)

[Sample log of test hole 3, section *J–J′*. Alt 4,489 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt, sand, and soil	20	20
Sand, coarse, to fine gravel; lenses of coarse gravel from 41 to 52 ft	32	52
White River Formation:		
Siltstone and claystone, buff	3	55

28–68–13ccb

[Sample log of test hole 4, section *I–I′*. Alt 4,558 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt and soil	2	2
Gravel, fine to medium	22	24
White River Formation:		
Siltstone and claystone, buff	7	31

28–68–17cba (O.W.)

[Sample log of test hole. Alt 4,923 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Gravel, fine to medium; mostly slope wash	23	23
Arikaree Formation:		
Sandstone, brown, fine-grained, clayey, limy, soft to hard	137	160
White River Formation:		
Siltstone and claystone, buff	31	191

28–68–17cca (O.W.)

[Sample log of test hole. Alt 4,889 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt and soil	22	22
Gravel, medium to coarse	13	35
Arikaree Formation:		
Sandstone, brown, fine-grained, clayey	6	41

28–68–24bac

[Sample log of test hole 2, section *I–I′*. Alt 4,548 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt and soil	1	1
Gravel, fine to medium	14	15
Gravel, medium to coarse	12	27
White River Formation:		
Siltstone and clay, buff	4	31

28–68–24bba

[Sample log of test hole 3, section *I–I′*. Alt 4,547 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt and soil	5	5
Gravel, fine to medium	10	15
Flood-plain deposits—Con.		
Gravel, medium to coarse	22	37
White River Formation:		
Siltstone and claystone, buff	4	41

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
28-68-24bdb					
[Sample log of test hole 1, section *I–I'*. Alt 4,540 ft]					
Flood-plain deposits:			White River Formation:		
Gravel, fine to medium	9	9	Siltstone and claystone, buff	12	21
28-69-20adc					
[Log of well. Alt 5,374 ft]					
Soil	4	4	Rock, cement, hard	6	95
Rock, cement	85	89	Gravel, water-bearing	33	128
28-69-21cdd					
[Log of well. Alt 5,370 ft]					
Soil	4	4	Rock, cement; alternating hard and soft layers	97	132
Gravel, dry	31	35	Gravel, water-bearing	13	145
			Rock, cement	10	155
28-70-1bac1					
[Sample log of test hole 6, section *B–B'*. Alt 5,017 ft]					
Flood-plain deposits:			White River Formation:		
Soil, sand, and gravel	6	6	Siltstone and claystone, buff	3	21
Sand, medium to coarse	12	18			
28-70-1bac2					
[Sample log of test hole 5, section *B–B'*. Alt 5,008 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	5	5	Siltstone and claystone, buff	4	25
Sand, fine, to coarse gravel	16	21			
28-70-1bda1					
[Sample log of test hole 4, section *B–B'*. Alt 5,000 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	3	3	Siltstone and claystone, buff	3	25
Clay, silty	15	18			
Gravel, medium to coarse	4	22			
28-70-1bda2 (O.W.)					
[Sample log of test hole 3, section *B–B'*. Alt 4,999 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil, sandy	2	2	Siltstone and claystone, buff	8	41
Sand, medium, to coarse gravel	31	33			
28-70-1bdd					
[Sample log of test hole 2, section *B–B'*. Alt 5,002 ft]					
Flood-plain deposits:			Sand, fine, to coarse gravel	25	32
Silt and soil	5	5	White River Formation:		
Clay and sand	2	7	Siltstone and claystone buff	2	34

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

28-70-1dbb (O.W.)

[Sample log of test hole 1, section *B-B'*. Alt 5,022 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Flood-plain deposits—Con.		
Clay and soil, sandy; contains minor amounts of sandstone and gravel	19	19	Gravel, medium to coarse	10	29
			White River Formation:		
			Siltstone and claystone, buff	4	33

28-70-2cac (O.W.)

[Sample log of test hole 1, section *A-A'*. Alt 5,057 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Clay, soil, sand, and gravel	12	12	Siltstone and claystone, buff	6	31
Sand, coarse, to medium gravel	13	25			

28-70-2dbc

[Sample log of test hole 2, section *A-A'*. Alt 5,042 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Silt and soil	5	5	Siltstone and claystone, buff	3	21
Sand, coarse, to medium gravel	13	18			

28-70-2dbd1

[Log of well. Alt 5,040 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Topsoil	4	4	Boulders	2	48
Chalk rock	28	32	Clay and cement rock	10	58
Gravel, water-bearing	14	46			

28-70-2dbd2

[Sample log of test hole 3, section *A-A'*. Alt 5,036 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Silt and soil	3	3	Siltstone and claystone, buff	5	21
Gravel, coarse	2	5			
Sand, fine, to medium gravel	11	16			

28-70-7cad

[Log of test hole drilled for Bur. of Reclamation to evaluate Three Cripples Creek damsite. Alt 5,399 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Slope wash and terrace deposits:			White River Formation—Con.		
Silt, dark-brown	4.9	4.9	Siltstone embedded with small gravel. Some large gravel and cobblestones	11.8	64.9
Silt and soft gravel	11.2	16.1	Siltstone, gravel, clay, and sand containing some cobbles	13.9	78.8
Sand, very coarse	4.7	20.8	Siltstone embedded with gravel and sand	23.6	102.4
Sand and gravel, coarse	2.0	22.8	Cobbles, gravel, and sand	7.6	110.0
Sandstone and siltstone, soft	2.5	25.3	Gravel, sand, siltstone, and some clay	13.5	123.5
Clay and gravel	2.1	27.4	Siltstone embedded with gravel, clay, and cobbles	9.7	133.2
Siltstone	1.8	29.2	Gravel, sand, and clay	16.9	150.1
Gravel, coarse sand, and siltstone	5.6	34.8			
White River Formation:					
Siltstone containing green seams and some gravel	18.3	53.1			

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

28–70–7cdd

[Log of test hole drilled for Bur. of Reclamation to evaluate Three Cripples Creek damsite. Alt 5,323 ft]

Description	Thickness (feet)	Depth (feet)
Slope wash and alluvial deposits:		
Silt and clay, light-brown, and fine sand	2.7	2.7
Silt, brown, and fine to coarse sand	7.3	10.0
Granite particles, weathered, and clay	1.5	11.5
Boulders	.9	12.4
Intermittent cobbles, layers		
Slope wash etc.—Continued		
of silt, sand, and gravel	20.5	32.9
White River Formation:		
Siltstone, light-brown, firm, limy, and clay and fine sand	37.6	70.5
Sand and coarse gravel, soft	5.3	78.8
Boulders	1.7	77.5
Siltstone, light tan, firm, limy, and fine sand	73.9	151.4

28–70–7dbc

[Log of test hole drilled for Bur. of Reclamation to evaluate Three Cripples Creek damsite. Alt 5,403 ft]

Description	Thickness (feet)	Depth (feet)
Slope wash and terrace deposits:		
Silt, dark-brown	2.0	2.0
Siltstone and gravel, green and red	1.2	3.2
Cobbles, sand, silt, and clay	5.9	9.1
Silt containing gravel and green sand	2.0	11.1
Siltstone, light-tan	4.0	15.1
Sand and gravel, coarse, and small amounts of clay and silt	16.9	32.0
Gravel	1.2	33.2
Cobbles and clay, light-tan	3.0	36.2
White River Formation:		
Siltstone, containing seams of sand and gravel	10.8	47.0
Gravel layer	1.0	48.0
Siltstone containing seams of sand and gravel	26.8	74.8
White River Formation—Con.		
Sandstone, light-tan, and green gravel	10.0	84.8
Sandstone, light-tan, and light-green gravel and cobbles	3.5	88.3
Siltstone, dark-brown, and cobbles and large boulders	9.3	97.6
Gravel, cobbles, and sand	2.4	100.0
Siltstone containing sand and gravel	9.9	109.9
Sand, fine, and cobbles, light-brown	4.9	114.8
Siltstone containing sand and gravel seams	18.2	133.0
Siltstone, fine soft sand, and blue-green cobbles	9.9	142.9

28–70–9bbd

[Sample log of test hole. Alt 5,190 ft]

Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:		
Silt and soil	2	2
Gravel, fine to medium, and boulders	40	42
White River Formation:		
Siltstone and claystone, buff	9	51

28–70–18abb1

[Log of test hole drilled for Bur. of Reclamation to evaluate Three Cripples Creek damsite. Alt 5,303 ft]

Description	Thickness (feet)	Depth (feet)
Alluvium:		
Topsoil, black, sandy	3.6	3.6
Boulders, gravel, and sand	16.4	20.0
Gypsum and red shale sequence:		
Siltstone and red shale, containing gypsum and sandstone	9.3	29.3
Clay, pink and buff	1.4	30.7
Minnekahta Limestone:		
Open cavern	2.8	33.5
Minnekahta Limestone—Con.		
Limestone, yellow to purple, hard	19.1	52.6
Open cavern	1.0	53.6
Opeche Shale:		
Shale, red, hard. containing light seams	29.0	82.6
Limestone, hard, massive	1.2	83.8
Shale, red, hard, light seams and red clay seams run across bedding	18.7	102.5

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

28-70-18abb2

[Log of test hole drilled for Bur. of Reclamation to evaluate Three Cripples Creek damsite. Hole drilled a 40° angle from vertical; bearing S. 36°10′ W. Alt 5,345 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
"Converse sand" of Hartville Formation:			"Converse sand" of Hartville Formation—Continued		
Sandstone, light-buff, soft, decomposed	4.7	4.7	Sandstone, buff, soft, fine-grained	15.0	95.7
Sandstone, light-buff, harder	3.6	8.3	Sandstone, light-pink, very soft, fine-grained	9.3	105.0
Sandstone, buff, soft	56.3	64.6			
Sandstone, dark-buff	24.1	80.7			

29-68-9bcc

[Log of well. Alt 4,714 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Topsoil	10	10	White River Formation:		
			Siltstone and claystone, buff	150	160

29-68-9bcd1

[Log of well. Alt 4,720 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Clay, bentonitic, brown, and coarse sand	80	80	Clay, brown, orange; contains fine sand	15	575
Clay, brown and gray	110	190	Sand, red, fine; contains orange shale and anhydrite	40	615
Clay, brown, and sand	40	230	Shale, red, anhydrite	15	630
Clay, brown and gray, sandy	160	390	Lime, purple; contains fine sand	20	650
Clay, white, brown, and gray, sandy	15	405	Sand, red, yellow; contains red and gray shale and anhydrite	25	675
Clay, white and brown, sandy	25	430	Anhydrite, white	8	683
Clay, vericolored, bentonitic	90	520	Sand, white; contains water	7	690
Clay, brown and gray; contains some gypsum and sand	10	530	Anhydrite, white	35	725
Clay, orange; contains some sand	15	545	Lime pink, and white anhydrite	5	730
Clay, chalky white, orange; contains fine sand	15	560	Anhydrite, white	63	793

29-68-18dcc (O.W.)

[Sample log of test hole 5, section *F-F′*. Alt 4,695 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Gypsum and red shale sequence:		
Clay, silty; streaks of gravel	32	32	Siltstone and red shale	3	61
Gravel, fine to medium	2	34			
Clay, silty, and gravel	9	43			
Gravel, and some fine sand	15	58			

29-68-19aac (O.W.)

[Sample log of test hole 3, section *F-F′*. Alt 4,664 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	6	6	Siltstone and red shale	3	51
Sand, fine, to coarse gravel	42	48			

29-68-19adb

[Sample log of test hole 4, section *F-F′*. Alt 4,675 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	4	4	Siltstone and red shale	6	51
Clay, sandy, and sand	10	14			
Gravel, fine to coarse	31	45			

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
29-68-19ada					
[Sample log of test hole 1, section *F–F'*. Alt 4,653 ft]					
Flood-plain deposits:			Gypsum and red shale sequence:		
Gravel, medium to coarse	40	40	Siltstone and red shale	5	45
29-68-19adb					
[Sample log of test hole 2, section *F–F'*. Alt 4,654 ft]					
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	4	4	Siltstone and red shale	8	51
Sand, fine to coarse gravel	39	43			
29-68-19cac					
[Log of well. Alt 4,690 ft]					
Overburden	8	8	Gravel, water-bearing	24	48
Clay mixed with sand	11	19	Clay, red, mixed with gravel	4	52
Sand, fine, mixed with clay	5	24			
29-68-20abb					
[Log of well. Alt 4,638 ft]					
White River Formation, pink	225	225	Shale, red	42	356
"Red beds"	25	250	Limestone, hard	2	358
Ledge, hard, red	6	256	Sandstone, white, ledgy	40	398
Shale, red	24	280	Sandstone, white, soft; contains water under artesian pressure	10	408
Ledge, red	2	282	Ledge, hard	2	410
Sand, red	28	310			
Sand, yellow	4	314			
29-68-20abd					
[Log of well. Alt 4,630 ft]					
Gravel and sand	37	37	Shale, tan	15	265
White River Formation	97	134	Shale, red	25	290
Lime shell	4	138	Ledge, red, hard	5	295
Shale, red	18	156	Shale, red	9	304
Lime shell	3	159	Ledge, red, hard	2	306
Shale, red	7	166	Shale, red	52	358
Lime shell	2	168	Sand, red	8	366
Shale, red	12	180	Shale, red, ledgy	37	403
Lime shell, hard	4	184	Limestone	2	405
Clay	7	191	Sandstone, white, water-bearing	9	414
Shale, red	18	209	Sandstone, yellow	28	442
Shell, hard	6	215			
Sandstone, red hard, water-bearing	35	250			
29-68-20acc					
[Log of well. Alt 4,643 ft]					
Alluvium:			Alluvium—Continued		
Soil and sand	17	17	Gravel, coarse	24	41

Table 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—**Con.**

29-68-20bac

[Log of well. Alt 4,644 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Soil and gravel, water-bearing	36	36	Sand, white; contains water and gas	3	643
Shale, gray	68	104	"Red bed," pink; contains lime shells	264	907
Limestone shells	61	165	"Red bed," light-pink	136	1,043
Shale, gray and pink, sandy	45	210	Limestone shells, sandy; contains some water	13	1,056
Chugwater Formation, pink	130	340	"Red bed," very sticky, red and pink	74	1,130
Sand, white; water under artesian pressure	9	349	"Red bed," sandy, red; contains lime shells	166	1,296
Limestone caprock, very hard; contains shells	1	350			
sand, light-brown	110	460			
"Red bed," pink and red, sandy; contains lime shells	180	640			

29-68-20dab (O.W.)

[Sample log of test hole 1, section *G–G′*. Alt 4,637 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Silt and soil	18	18	Siltstone and claystone, buff	6	35
Gravel, fine to medium	11	29			

29-68-21acb

[Log of well. Alt 4,608 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Topsoil	7	7	Chalk rock	2	25
Sand and gravel, coarse	16	23			

29-68-21bbb

[Log of well. Alt 4,646 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Soil	20	20	Shale	49	94
Sand	25	45			

29-68-21bbd

[Sample log of test hole 4, section *G–G′*. Alt 4,618 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Silt and soil	5	5	Siltstone and claystone, buff	8	41
Gravel, fine	28	33			

29-68-21bcb

[Sample log of test hole 3, section *G–G′*. Alt 4,620 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Silt and soil	7	7	Siltstone and claystone, buff	5	41
Gravel, fine to coarse	29	36			

29-68-21bcc1 (O.W.)

[Sample log of test hole 2, section *G–G′*. Alt 4,627 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Silt and soil	14	14	Siltstone and claystone, buff	4	41
Gravel, medium to coarse	23	37			

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
29-68-21bcc2					
[Log of well. Alt 4,625 ft]					
Sand	12	12	Gravel, very coarse at bottom	28.5	40.5
29-68-22ddd					
[Sample log of test hole 4, section *H-H′*. Alt 4,552 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	8	8	Siltstone and claystone, buff	6	41
Sand, coarse, to medium gravel	27	35			
29-68-23ccb					
[Sample log of test hole 5, section *H-H′*. Alt 4,563 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	12	12	Siltstone and claystone, buff	3	41
Sand, coarse, to coarse gravel	26	38			
29-68-23ccc					
[Sample log of test hole 3, section *H-H′*. Alt 4,550 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	12	12	Siltstone and claystone, buff	3	37
Gravel, fine to coarse	22	34			
29-68-26bbb (O.W.)					
[Sample log of test hole 2, section *H-H′*. Alt 4,540 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil, containing some gravel	5	5	Siltstone and claystone, buff	4	31
Sand, coarse, to coarse gravel	22	27			
29-68-26bbc					
[Sample log of test hole 1, section *H-H′*. Alt 4,535 ft]					
Flood-plain deposits:			White River Formation:		
Sand, coarse, to coarse gravel	16	16	Siltstone and claystone, buff	2	18
29-69-24dbb					
[Sample log of test hole 4, section *E-E′*. Alt 4,709 ft]					
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	4	4	Siltstone and red shale	4	23
Gravel, fine to coarse	15	19			
29-69-24dbc1					
[Sample log of test hole 3, section *E-E′*. Alt 4,710 ft]					
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	4	4	Siltstone and red shale	3	31
Gravel, medium to coarse	24	28			

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

29-69-24dbc3 (O.W.)

[Sample log of test hole 1, section *E-E'*. Alt 4,710 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	10	10	Siltstone and shale, red	7	31
Gravel, medium to coarse	14	24			

29-69-26ada

[Log of well. Alt 4,735 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Topsoil	7	7	Gravel and clay mixture	7	33
Sand	3	10	Clay, brown	4	37
Gravel, water-bearing	16	26			

29-69-26bca

[Sample log of test hole 4, section *D-D'*. Alt 4,762 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	4	4	Siltstone and shale, red	8	51
Clay and gravel	1	5			
Sand, coarse to medium gravel	38	43			

29-69-26bcd (O.W.)

[Sample log of test hole 3, section *D-D'*. Alt 4,758 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	5	5	Siltstone and shale, red	5	31
Sand, coarse, to coarse gravel	21	26			

29-69-26bdc (O.W.)

[Sample log of test hole 2, section *D-D'*. Alt 4,756 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Gypsum and red shale sequence:		
Silt and soil	3	3	Siltstone and shale, red	5	31
Sand, coarse, to coarse gravel	23	26			

29-69-26cab

[Sample log of test hole 1, section *D-D'*. Alt 4,763 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			Flood-plain deposits—Continued.		
Clay, soil, sand, and gravel	4	4	Clay, silty	6	18
Sand, coarse to medium gravel	8	12	Gravel, medium to coarse	18	36
			Gypsum and red shale sequence:		
			Siltstone and shale, red	5	41

29-69-31cac

[Sample log of test hole 4, section *C-C'*. Alt 4,950 ft]

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
Flood-plain deposits:			White River Formation:		
Silt and soil	9	9	Siltstone and claystone buff	9	31
Gravel, fine to medium	13	22			

TABLE 6.—*Logs of test holes and wells near Glendo, Platte County, Wyo.*—Con.

Description	Thickness (feet)	Depth (feet)	Description	Thickness (feet)	Depth (feet)
29–69–31cba					
[Sample log of test hole 5, section *C–C′*. Alt 4,954 ft]					
Flood-plain deposits:			White River Formation:		
Clay, soil, sand, and gravel	5	5	Siltstone and claystone, buff	5	31
Silt and soil	9	14			
Gravel, medium to coarse	12	26			
29–69–31cdb1 (O.W.)					
[Sample log of test hole 3, section *C–C′*. Alt 4,947 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	6	6	Siltstone and claystone, buff	6	25
Sand, fine, to fine gravel	13	19			
29–69–31cdb2 (O.W.)					
[Sample log of test hole 2, section *C–C′*. Alt 4,943 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	5	5	Siltstone and claystone, buff	6	21
Sand, coarse, to coarse gravel	10	15			
29–69–31cdc					
[Sample log of test hole 1, section *C–C′*. Alt 4,945 ft]					
Flood-plain deposits:			White River Formation:		
Silt and soil	4	4	Siltstone and claystone, buff	5	21
Sand, coarse, to coarse gravel	12	16			
29–69–32acc					
[Log of well. Alt 4,868 ft]					
Topsoil	12	12	Gravel and boulders, water-bearing	8	25
Conglomerate	5	17	Clay	10	35
29–69–32bcb					
[Log of well. Alt 4,918 ft]					
Clay	12	12	Shale, green; hard and soft layers	39	75
Gravel and boulders	9	21	Shale, brown; hard and soft layers	30	105
Cement rock, hard	8	29	Shale, hard	5	110
Clay, hard, mixed with lime rock	4	33	Clay, hard	42	152
Clay, soft, water-bearing	3	36			
30–68–33ccd					
[Log of well. Alt 4,660 ft]					
Soil	28	28	Siltstone, buff	50	78

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