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PRELIMINARY REPORT ON THE GEOLOGY AND GROUND-WATER RESOURCES OF THE SOUTHERN PART OF THE DEER LODGE VALLEY, MONTANA

By

R. L. Konizeski, R. G. McMurtrey, and Alex Brietkrietz

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CONTENTS

ILLUSTRATIONS

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TABLES

PRELIMINARY REPORT ON THE GEOLOGY AND GROUND-WATER RESOURCES OF THE SOUTHERN PART OF THE DEER LODGE VALLEY, MONTANA

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ABSTRACT

The study area is the southern (upper) part of the Deer Lodge Valley, a north-southward-trending intermontane basin in western Montana. The valley is bounded by relatively low, rounded mountains to the east and south, and the higher, rugged Flint Creek Range to the west. It is drained by the northward-flowing Clark Fork and its tributaries. The climate is semiarid-temperate as contrasted to subhumid-temperate in the highlands to the west. Agriculture and ore refining are the leading industries. Both are dependent on large supplies of water.

The basement rocks marginal to and underlying the valley include consolidated sedimentary, igneous, and metamorphic rocks ranging in age from Precambrian to early Tertiary. These are overlain within the valley by a considerable thickness of Tertiary sediments that are in turn mantled by a thin cover of Quaternary alluvium.

The basement rocks are relatively impermeable and are not considered to be potential aquifers. The Tertiary sediments are mostly fine grained, but some in the central part of the valley consist of well-sorted permeable gravel. These gravel deposits generally yield adequate amounts of water for stock and domestic use and, locally, for irrigation of small areas. The Quaternary deposits generally consist of gravel and coarse sand and usually yield adequate amounts of water to wells for stock and domestic use, and for irrigation of small areas.

The ground-water reservoir is recharged mostly by infiltration of water from streams, irrigation, and precipitation. It discharges mostly by evapotranspiration and effluent streamflow. Ground water generally moves in the same direction as surface water. In the northern part of the study area, ground water moves eastward from the west side of the valley and northwestward just east of the river. In the southwestern part of the study area, ground water moves northeastward with localized components of flow toward one or another of the tributary streams.

INTRODUCTION

PURPOSE AND SCOPE

This investigation of the geology and ground-water resources of the southern part of the Deer Lodge Valley was begun in 1960 as a part of the continuing study of the ground-water resources of Montana, begun in 1955 by the U.S. Geological Survey in cooperation with the Montana Bureau of Mines and Geology. The areas studied or presently being studied are located in various parts of the State. (See fig. 1.) The objectives of this study were to determine (1) the character, thickness, and extent of water-bearing materials; (2) the source, occurrence, and movement of the ground water; (3) the quantity and availability of the ground water; and (4) the annual and seasonal fluctuations of the water table.

LOCATION AND EXTENT

The area described in this report includes about 200 square miles in the southern part of the Deer Lodge Valley. It extends northward for 17 miles from about 2 miles south of Gregson Hot Springs to the Deer Lodge-Powell County line. (See fig. 2.) It is bounded on the west by the rugged Flint Creek Range and on the south and east by a group of relatively low-lying mountains, which form the Continental Divide.

METHODS OF INVESTIGATION

The geologic relations were studied in the field and mapped on aerial photographs. A geologic map was then compiled (pl. 1, in pocket) and was used to interpret the hydrologic phenomena.

An inventory of 124 wells was made to obtain additional geologic and hydrologic data. Altitudes were determined for 88 of these wells by instrumental leveling; pertinent data regarding these wells are given in table 2, page 20. About 40 wells were measured monthly. Pumping tests were made of some of the observation wells to determine the hydrologic properties of the water-bearing materials. A hydrologic map (pl. 2, in pocket) was compiled on the basis of all the geologic and hydrologic information available.

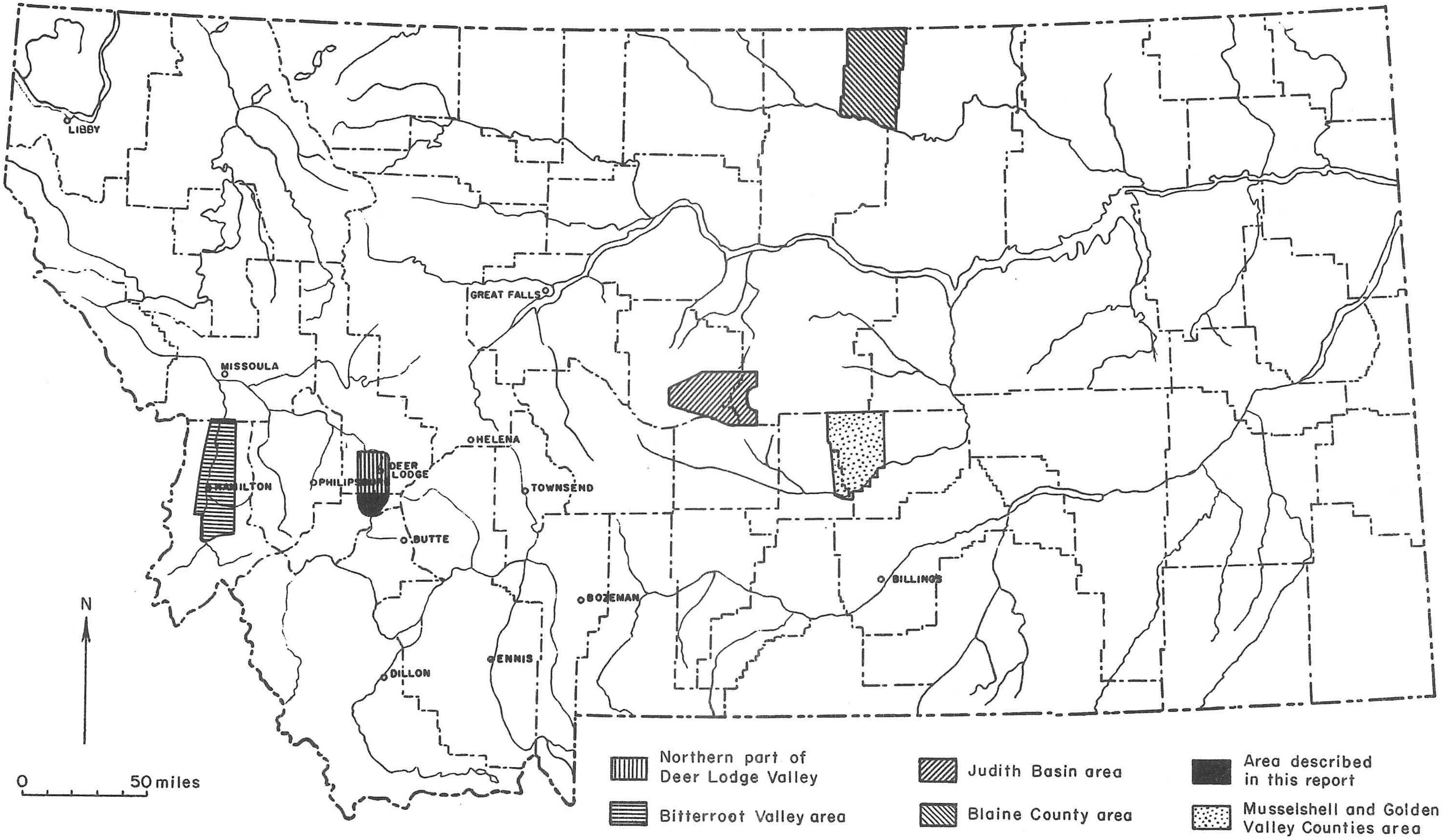

Figure 1.--Map of Montana showing the location of cooperative ground-water investigations, 1955-1962.

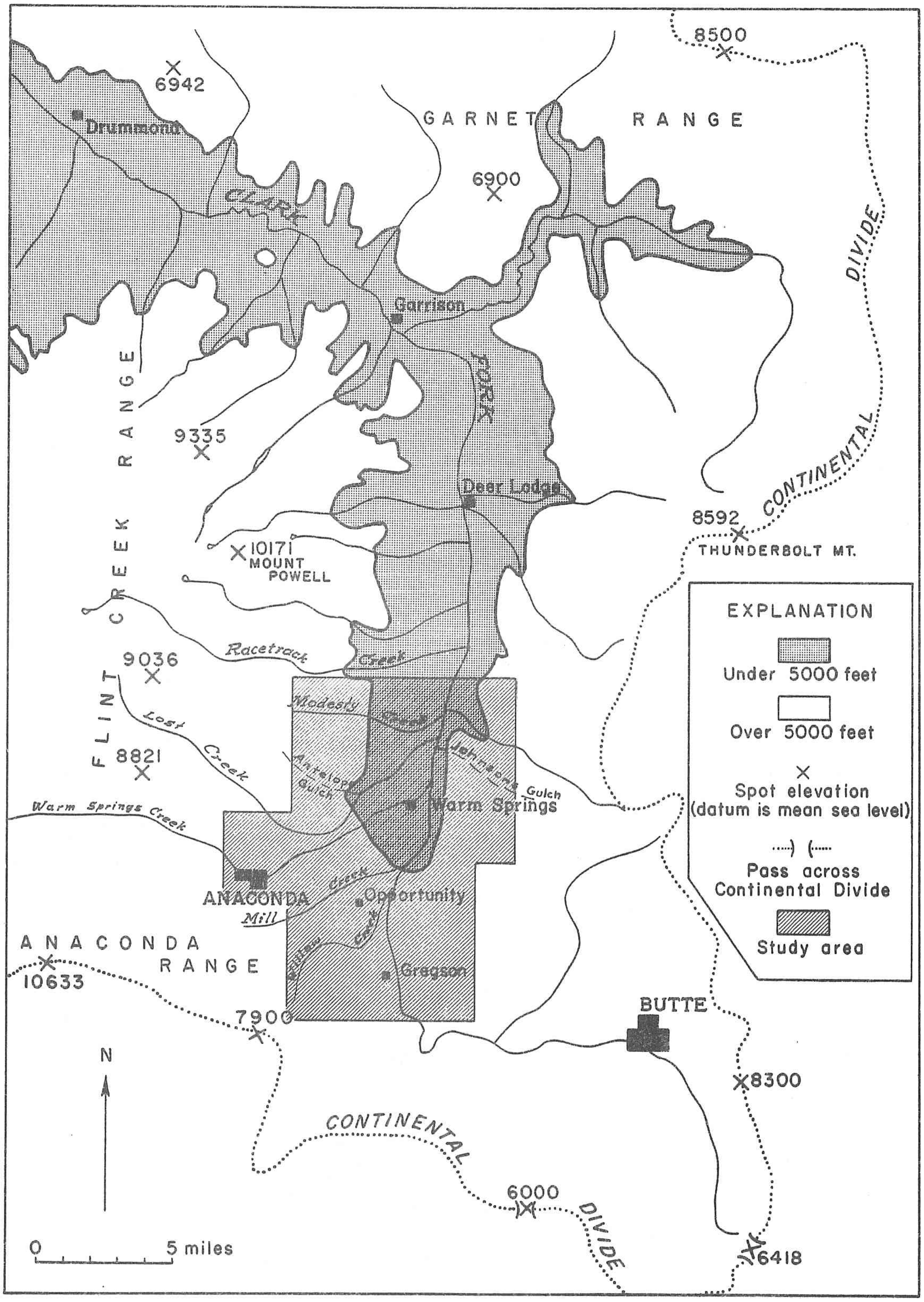

Figure 2.--Areal map showing location, topography, and drainage of study area.

PREVIOUS INVESTIGATIONS

Various phases of the geology of the area have been described by Earl Douglass (1902), J.T. Pardee (1913), Paul Billingsley (1915), W.C. Alden (1953), R.L. Konizeski (1957), and T.A. Mutch (1960). The ground-water resources have been briefly described by E.S. Perry (1933).

ACKNOWLEDGMENTS

Appreciation is expressed to the residents of the area and to the public agencies and private companies that contributed to the investigation. Special thanks are extended to the individuals who supplied information about their wells and permitted access to their lands.

WELL-NUMBERING SYSTEM

The wells described in this report are assigned numbers based on their location within the system of land subdivision used by the U.S. Bureau of Land Management. (See fig. 3.) Because all the wells lie within the northwest quadrant of the Montana Principal Meridian and Base Line System, the prefix letter B is omitted for convenience. The first numeral of the well number indicates the township, the second the range, and the third the section. Lower-case letters that follow the section number indicate the position of the well within the quarter section (160 acre tract) and the quarter-quarter section (40 acre tract). The subdivisions are designated a, b, c, and d in a counter-clockwise direction beginning in the northeast quarter. If more than one well is visited within the same 40-acre tract, consecutive digits beginning with 1 are added to the well number.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Deer Lodge Valley lies west of the Continental Divide near the center of the Northern Rocky Mountain physiographic province. It trends in a north-south direction between relatively low, rounded mountains to the east, and the higher, glacier-scoured Flint Creek Range to the west. Valley-floor altitudes decrease from about 5,100 feet at Gregson Hot Springs, near the head of the valley, to about 4,300 feet at Garrison near its mouth (18 miles north of the study area). The highlands to the east reach a maximum altitude of 8,592 feet at the rounded summit of Thunderbolt Mountain. The Flint Creek Range reaches a maximum altitude of 10,171 feet at the knife-edged crest of Mount Powell. The mountain slopes east of the valley are incised by numerous shallow draws, and the flanks of the Flint Creek Range west of the valley, by deep U-shaped glaciated canyons.

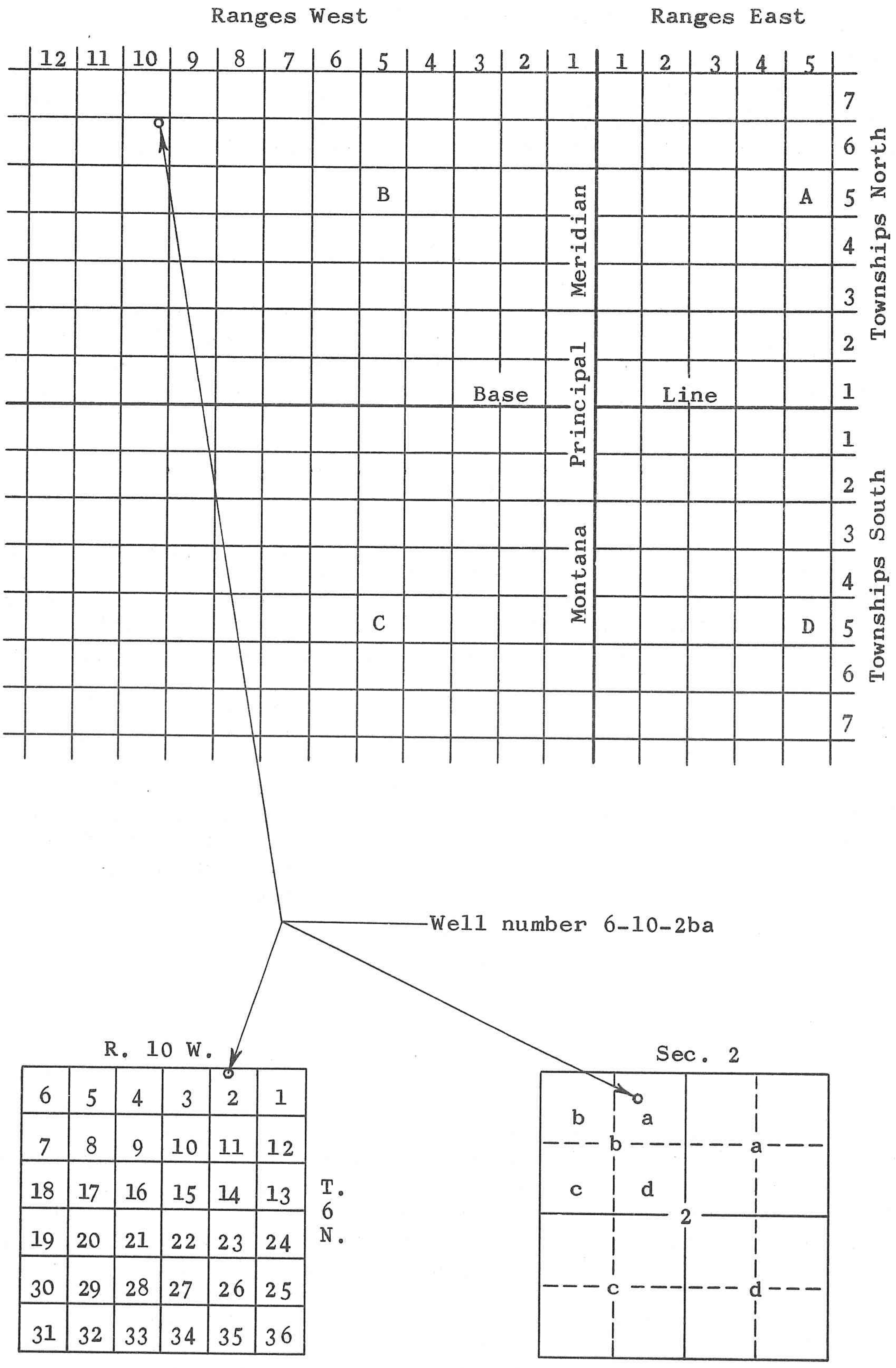

Figure 3.--Sketch showing system of numbering wells.

The valley topography is dominated by great terraces,* here as "high" terraces that slope gently downward from the mountains and end in abrupt scarps above "low" fringing terraces, which, in turn, border the broad flood plain of the Clark Fork. (See fig. 4.) In the southwestern part of the study area these several topographic features have been largely obliterated by dissection of the terraces and subsequent emplacement of great coalescent fans that spread valleyward below the canyons of the principal tributary streams.

The main stream (Clark Fork) enters the south end of the valley through a narrow gorge and flows northward through the study area at an average gradient of about 20 feet per mile. It is joined within the study area by several perennial tributaries from the west and numerous intermittent tributaries from both sides of the valley. Its mean annual flow at the city of Deer Lodge (9 miles north of the study area) has been estimated at about 250 ± 75 cfs (Frank Stermitz, U.S. Geological Survey, personal communication, 1960).

Upon leaving the mountains, the Clark Fork and all its tributaries flow from consolidated (relatively impermeable) basement rock onto unconsolidated (relatively permeable) valley fill, where large amounts of water seep into the earth and become ground water. During the spring and summer, most of the water in the perennial and intermittent tributary streams is diverted for irrigation. Therefore, only a small part of this water enters the Clark Fork as surface drainage.

As much as 60,000,000 gallons of water per day is taken from the Warm Springs Creek drainage and from drainage outside the valley for use at the Washoe Smelter in Anaconda. Most of this, and all the Clark Fork flow above Gregson, eventually flows into settling basins near the town of Opportunity. Most of it passes through the study area as surface drainage, but some of it probably infiltrates to the water table.

CLIMATE

The climate of the valley is characterized by long cold winters, relatively cool summers, light precipitation, and moderate winds. Wide daily and seasonal variations in temperature are common. The average length of the frost-free growing season at East Anaconda is 117 days. May 27 is the average date of the last killing frost and September 21 of the first killing frost. The highest temperature recorded at East Anaconda for the years 1931-1960 was 100°F., the lowest was 35°F. below zero; the mean

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*So designated because they are developed mostly on unconsolidated valley fill, although some on the southeast side of the valley transect relatively small inliers of basement rock. Lahee, F.H., p. 271, 1916: "In this book the term bench will be used to denote forms in <u>solid</u> rock; and terrace, forms in <u>unconsolidated</u> materials." (Underlining mine.)

annual temperature is 42.9°F. The average yearly precipitation at East Anaconda is 13.11 inches, approximately two-thirds of which occurs during April through September. (See fig. 5.) This precipitation pattern is characteristic of the Great Plains.

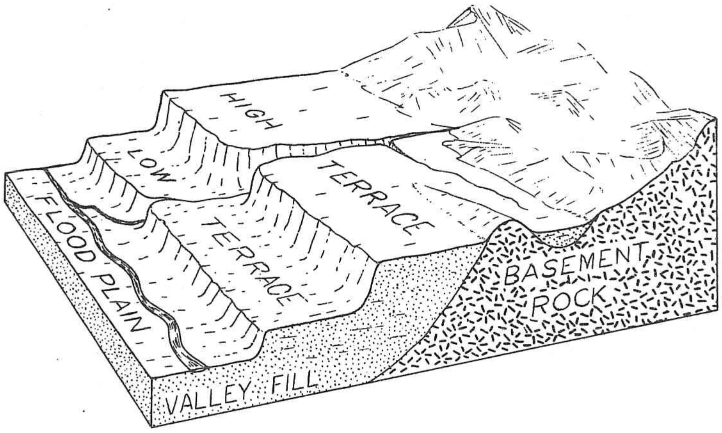


Figure 4.--Diagrammatic section across east side of Deer Lodge Valley showing terraces developed on unconsolidated valley fill and an inlier of basement rock.

CULTURE

The economy of the study area is supported mostly by the metallurgical industry, agriculture, and various State agencies. Anaconda, (population 12,054 as of 1960 census) is the county seat and only city. The Washoe Smelter at Anaconda treats copper and other ores from the Butte mines and employs a large part of the regional labor force. Land in the study area is primarily devoted to grazing of livestock and to cultivation of hay, small grains, and potatoes. The State Tuberculosis Sanitarium at Galen and the State Mental Hospital at Warm Springs also employ a considerable labor force.

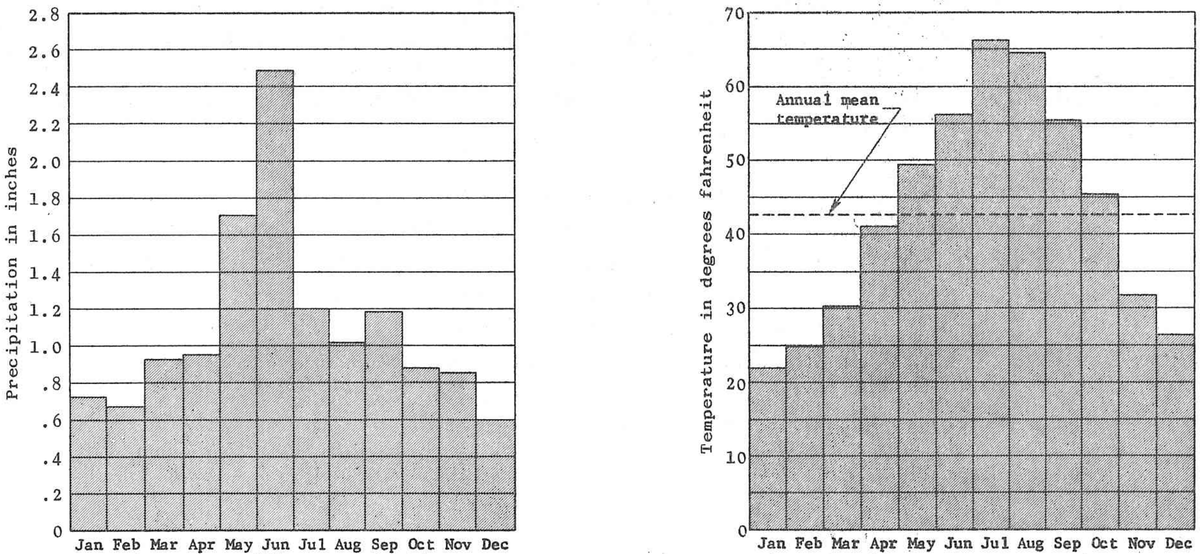
GEOLOGY

STRATIGRAPHY

Basement Rocks

The Flint Creek Range is formed of more than 35,000 feet of sedimentary rocks ranging in age from Precambrian to early Tertiary and a great core of Laramide granitic rocks. The sedimentary rocks are exposed on the flanks of the range; the granitic rocks in the central part of the range. The sedimentary rocks consist of more than 10,000 feet of fine-grained clastic rocks of the Belt Series; 6,000 feet of Paleozoic limestone and dolomitic rocks; and 16,000 feet of Mesozoic clastic rocks (Mutch, 1961).

The mountains east and south of the study area are formed mostly of Laramide granitic rocks and Cretaceous and early Tertiary extrusive rocks. The lower foothills southwest of the valley, in the vicinity of Anaconda, are formed mostly of early Tertiary pyroclastic rocks and interbedded sedimentary rocks. Consolidated basement rocks of these various types presumably occur everywhere



Average monthly precipitation

Monthly average temperature

Figure 5.--Graphs showing climatological data for East Anaconda, Montana, 1931-1960.

beneath the valley fill. The basement rocks are relatively impermeable and do not seem to be major potential aquifers.

Tertiary Sediments

The oldest exposed valley fill in the study area is probably of Oligocene age. It consists of more than 250 feet of well- to semiconsolidated siltstone, sandstone, and conglomerate that crops out near the base of the mountain slopes west of the valley. These deposits include much volcanic debris, but some beds are composed almost entirely of erosional waste from Precambrian sedimentary and/or Laramide granitic rocks. These Oligocene strata are overlain in most places by sedimentary rocks,but in places by pyroclastic rocks. Their subsurface distribution may be extensive but is difficult to determine because of their extreme variability in texture and composition. They may have a moderate ground-water potential.

More than 160 feet of semiconsolidated Miocene sediments overlie early Tertiary pyroclastic rocks near the base of the mountain slopes between Warm Springs Creek and Lost Creek. These well-bedded deposits include beds of clay, silt, and conglomerate and occasional boulders greater than 3 feet in diameter. Although the basal section contains much volcanic debris, the overlying beds are composed mostly of erosional waste from rocks of the Belt Series and/or granitic rocks. From an intercalated lignitic lense, Bela Csjetey (personal communication 1961) collected a flora of probable early Miocene age.

More than 260 feet of lime-cemented sandstone and conglomerate of probable Miocene age overlie early Tertiary pyroclastic rocks at the base of the mountain slopes between Antelope Gulch and Modesty Creek. A small Miocene outlier of lime-cemented conglomerate overlies Tertiary volcanic rocks on the east side of the valley near the head of Johnson's Gulch. The subsurface distribution of the Miocene strata, and consequently their ground-water potential, is unknown.

More than 250 feet of unconsolidated Pliocene sediments are exposed on the terraces and presumably underlie most of the Quaternary alluvium. Fossil vertebrates of middle Pliocene age have been obtained from exposures (Konizeski, 1957, p. 131-150). The sediments consist mostly of three depositional types: (a) finely bedded flood-plain silt; (b) cross-bedded channel sand and gravel; and (c) heterogenous accumulations of colluvium. Considerable percentages of volcanic ash are usually included in the flood-plain silt, and lenses of ash are intercalated in the flood-plain deposits in places.

The Pliocene channel deposits are generally well sorted, coarse grained, and occur in areas of maximum recharge, that is, along the central parts of the valley with local extensions towards the mouths of the major tributary canyons. Because of these facts, the channel deposits constitute a major aquifer, which is tapped by most of the high-yield deeper wells. The Pliocene flood-plain silt is uniformly fine grained, and the colluvium is poorly sorted and has a restricted distribution. Therefore, these sediments are relatively minor aquifers.

Quaternary Sediments

Part of the great Racetrack Creek terminal moraine extends southward over about 2 square miles of the study area. Because of its restricted extent and generally poor sorting, it is not considered as a potential aquifer.

Quaternary alluvium mantles about three-fourths of the area to an average thickness of about 25 feet. It is composed mostly of glacio-fluvial debris and slope wash deposited in a wide variety of environments. Its greatest single segment, covering about 45 square miles, consists of four great coalescent fans that extend valleyward from the canyon mouths of Warm Springs Creek, Lost Creek, Mill Creek and the Clark Fork. Superimposed on the fans are about 10 square miles of modern accumulations of silt and sludge from the settling basins of the Washoe Smelter.

Although the Quaternary alluvium constitutes a very small percentage of the total volume of Cenozoic fill, it usually occurs in areas of maximum recharge. Because of this and its relatively large grain size and sorting, it is the chief shallow aquifer. With local exceptions, around the margins of the valley and on the high terraces, ground water is generally available in the alluvium in amounts adequate for domestic and stock use and for irrigation of some small areas.

STRUCTURE

Preliminary analysis of a gravimetric survey, made in 1961 by E.A. Cramer in conjunction with this study, indicates that the Deer Lodge Valley is a down-dropped block or "graben." The basement rocks west and south of the study area are strongly contorted, folded, and faulted. On the lower slopes of the Flint Creek Range they commonly dip to the east beneath the valley. Several northward-trending faults cut early Tertiary volcanic rocks near the south side of Warm Springs Canyon. Similarly oriented faults cut the bordering valley fill. On the west side of the valley, between Antelope Gulch and Modesty Creek, large blocks of fill have been faulted and tilted sharply to the west. The vertical displacement of these blocks at the fault line is not known, but is at least several hundred feet.

Most of the Oligocene and Miocene strata have been greatly deformed by postdepositional movement. They are variously oriented, but north of Antelope Gulch they generally have a westerly component of dip. The Pliocene strata are mostly undeformed and retain their original dips of a few degrees valleyward and to the north. However, some of them in the Spring Gulch-Modesty Creek area dip westward into the mountains at angles as much as 40 degrees.

SUMMARY OF GEOLOGIC (CENOZOIC) HISTORY

Local evidence from the northern part of the Deer Lodge Valley suggested that it was formed in Late Cretaceous and Paleocene time (Konizeski, R.L., and others, 1961, p. 11). However, additional evidence from the southern part of the valley indicates an Eocene or perhaps early Oligocene origin. The history of the valley, as interpreted from all available data is as follows:

1. Eocene and Oligocene: Tectonic origin of valley, probably accomplished mostly by block faulting accompanied and followed by local emplacement of extrusive rocks and interbedded conglomerate, sand, silt, and clay; maximum cross-valley relief.

2. Miocene: Gradual reduction of regional relief; ponding of ancestral Clark Fork and accumulation of fine-grained lacustrine deposits and coarser grained stream and colluvial deposits; subsequent re-emphasis of tectonic activity.

3. Pliocene: Increased cross-valley relief accomplished by block faulting accompanied by drainage of Miocene lake and deposition of fluvial deposits; continued movement along western margin of valley.

4. Pleistocene and Recent: Intrenchment of drainage system within valley fill preceded, accompanied, and followed by multiple glaciation of Flint Creek Range; deposition of glacial debris and other Quaternary alluvium and development of modern topography.

GROUND WATER

OCCURRENCE*

Hydrologic principles are little understood, as reflected by the many mysteries and controversies about water beneath the surface of the earth. Scientific studies have shown (1) that most usable ground water is an important component of the hydrologic cycle (fig. 6); (2) it obeys natural laws; and (3) its occurrence is intimately associated with the geologic history of the area.

All ground water occurs in the open spaces within the rock materials of the outer crust of the earth. These open spaces may be voids, interstices, pore spaces, joints, fractures, or solution channels. They range in size from minute pores in clay to large solution channels in limestone. Thus, their size, shape, distribution, and degree of interconnection determine to a great extent the occurrence of ground water. In the southern part of the Deer Lodge Valley most of the ground water occurs in the pore spaces between the grains of the Quaternary and Tertiary sediments; some occurs in the joints and fractures of the volcanic rocks.

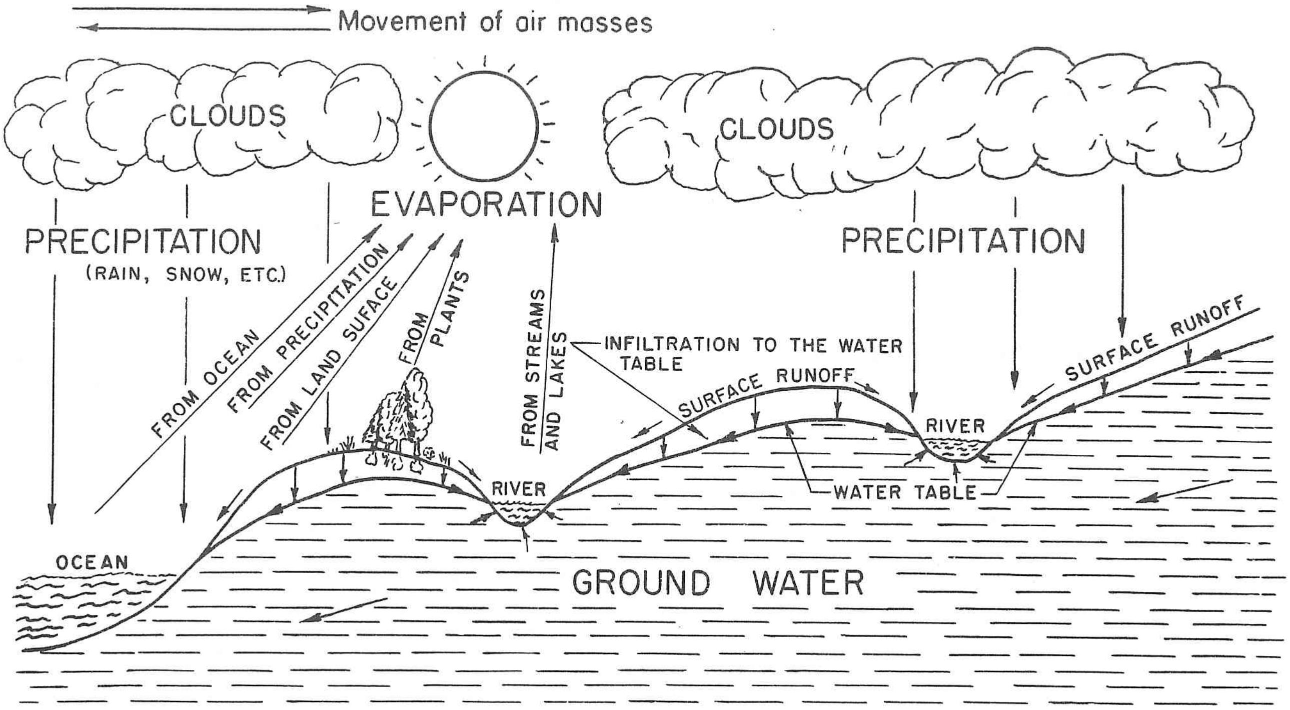


Figure 6.--Hydrologic cycle.

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*For a more complete discussion, see Meinzer (1923).

Part of the water falling on or flowing over the ground seeps into the soil zone and percolates downward until it reaches the zone of saturation.* In the zone of saturation the interconnected open spaces act as conduits through which ground water constantly moves toward lower levels under the pull of gravity. The rate of movement of ground water through the pore spaces is much slower than that of surface water. The velocity of surface water is measured in feet per second; the velocity of ground water is measured in feet per day or feet per year. It is the slow rate of movement and relatively steady discharge of ground water that makes possible the flow of streams during drought.

Water is discharged from the zone of saturation to the earth's surface through springs, wells, and effluent streams, or to the atmosphere by evaporation and by transpiration by vegetation. Under natural conditions the discharge from the zone of saturation is equal to the recharge. In many areas man-made installations have disturbed natural conditions, and adjustments have been or are being made in the patter of ground-water recharge, movement, and discharge. In the southern part of the Deer Lodge Valley, industrial development and irrigation of agricultural land changed the natural conditions. However, the change was far enough in the past that a new balance between recharge and discharge has been fairly well established.

Water in the zone of saturation may occur either under unconfined (water table) or confined (artesian) conditions. (See fig. 7.) Most of the ground water in the area of study is under water-table conditions.

HYDROLOGIC PROPERTIES OF AQUIFERS

The amount of water that can be stored in a given aquifer depends on its porosity. The porosity varies with the arrangement, shape, and degree of sorting of the particles making up the aquifer. The size of particle is not a determining factor. Fine-grained material such as clay or silt may be just as porous as coarse sand or gravel. The coefficient of storage of an aquifer is a measure of its capacity to take water into or release it from storage. The permeability of a material, which is measured by the coefficient of permeability, is not indicated by its porosity. A fine sand may have a porosity of more than 30 percent, but, because of the small size of its pores, the transmission of water through it is much more difficult than transmission through coarse sand or gravel having the same porosity. A clay stratum may be more porous than a sand or gravel stratum, but because of the minute size of its pores, it may be nearly impermeable. The difference then is that in the fine-grained materials most of the water is held by molecular attraction, whereas in the coarser grained materials the pore spaces are sufficiently large and interconnected that water can more readily move through them under the force of gravity. The rate at which water can be transmitted through an

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*Definitions of underlined words may be found in Glossary (page 22).

aquifer is indicated by the coefficient of transmissibility.

A well in saturated strata may yield very little water. therefore, if the pore spaces of the strata are very small or unconnected. A well driller does not actually look for water, but looks for a formation that will yield sufficient water.

QUANTITATIVE OBSERVATIONS

The approximate hydrologic properties of aquifers may be determined either by laboratory or field methods. Because of the difficulties of obtaining "undisturbed" samples from aquifers in the Deer Lodge Valley, field methods rather than laboratory methods were used.

The field method used was the aquifer test, often called a "pumping test." As water is pumped from a well a depression is developed in the water table in the shape of an inverted cone whose apex is at the water level in the well during pumping. The depth of the cone (drawdown in the well) is proportional to the pumping rate, and, other factors being equal, inversely proportional to the permeability of the aquifer. Formulas developed by C.V. Theis (1935, p. 519-524) and by C.E. Jacob (1946, p. 526-534) were used to relate the drawdown in the vicinity of a discharging well to the discharge of the well and to the coefficients of transmissibility and storage. An aquifer test using only the pumped well is termed a "single-well test;" a test using the pumped well and one or more observation wells is termed a "multiple-well test." Three single-well and two multiple-well tests were

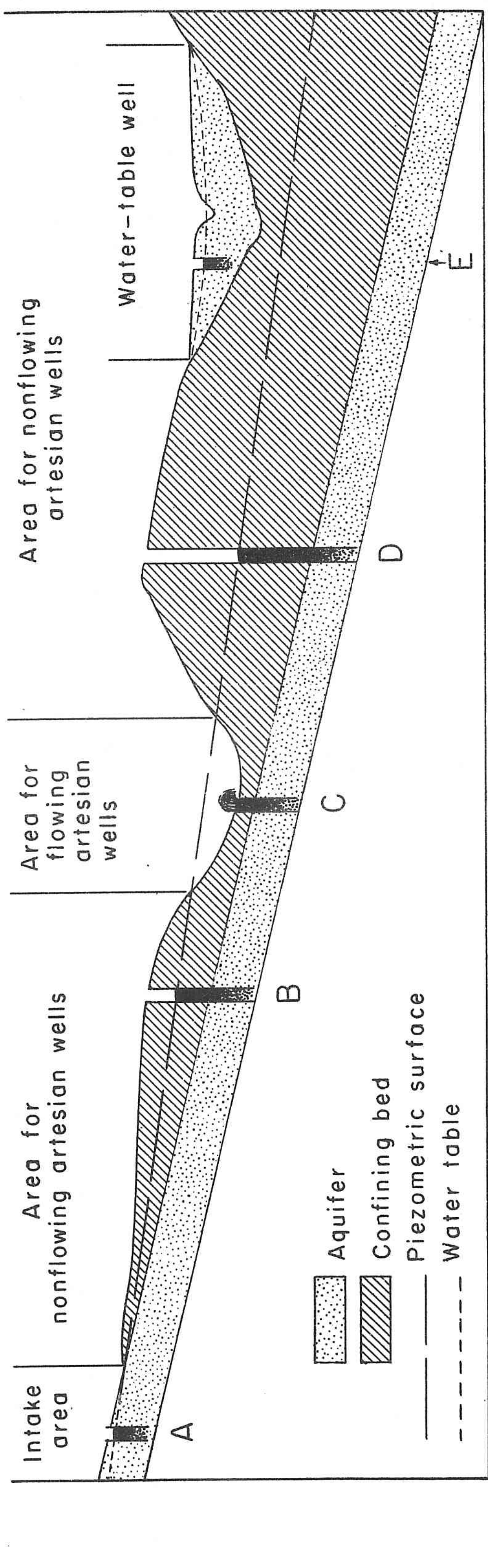

Figure 7.--Hypothetical section showing geologic environment necessary for unconfined (water table) and confined (artesian) aquifers. A and E are water-table wells; B and D are nonflowing artesian wells; and C is a flowing artesian well.

made in the area of study. The coefficient of transmissibility was determined at five places in the area. None of the tests continued long enough to obtain a coefficient of storage. Aquifer-test data are given in table 1. At a given pumping rate, the drawdown is inversely proportional to the coefficient of transmissibility and/or coefficient of storage. Therefore, the *specific capacity* of a well is an indication of the hydrologic properties of the aquifer tapped. It should be realized, however, that the specific capacity also is dependent on well construction and development, and on the thickness of the aquifer penetrated by the well. The principal aquifers in the southern part of the Deer Lodge Valley are the Quaternary and the Tertiary sedimentary deposits.

TABLE 1.--Aquifer-test data.
(Geologic source: A, Quaternary alluvium; T, Tertiary sediments)

Well	Geologic source	Depth of well (feet)	Pumping rate (gpm)	Drawdown in pumped well (feet)	Length of test (min)	Specific capacity (gpm/ feet)	Coefficient of transmissibility (gpd/feet)	Remarks
4-10-5ab	A, T	160.0	61	---	30	---	95,000	Too wet to measure water level while pumping.
4-10-15aa	A	23.1	11	10.6	470	1	20,000	Shallow well, open end casing. Probably large entrance loss.
5-10-17dc	A(?)	69.1	270	29.5	1800	9.2	77,000	Obs. well at 550 feet.
5-10-23cb	T, A	150	580	38.2	450	15.2	20,000	Well casing perforated.
5-10-24aa	T	200	975	102.3	220	9.5	15,000	Gravel-packed well.

The Quaternary deposits on the flood plain of the Clark Fork consist chiefly of medium- to well-sorted unconsolidated gravel; those on the west side of the valley consist mostly of heterogeneous mixtures of unconsolidated glaciofluvial debris; and those in the southeastern part of the area consist mostly of detrital material either residual or transported only a short distance. The flood-plain alluvium is relatively thin and not extensive laterally. Yields to wells in this aquifer are limited to a few hundred gallons per minute even in areas of higher transmissibilities and specific capacities. The Quaternary alluvium in the northwest part of the area is fairly thin. Most of the wells penetrate the alluvial mantle and obtain water from the underlying Tertiary sediments. However, a few shallow dug wells in the alluvium yield adequate water for stock and domestic use. The Quaternary alluvium in the southwest part of the area is much thicker. Adequate water for domestic and stock needs can easily be obtained from these sediments. Two drilled wells, 4-10-8 and 5-10-33, on the Mill Creek-Warm Springs Creek alluvial fan reportedly yielded 1,200 and 800 gpm, respectively, but the water was probably obtained from both the Quaternary alluvium and the underlying Tertiary sediments. An aquifer test at the site of a well in the same vicinity (4-10-5) drawing water from both the Quaternary and Tertiary sediments indicated a coefficient of transmissibility of 95,000 gpd per ft (gallons per day per foot). In the relatively small area obscured by slope wash in the southeastern part of the valley no wells were located from which information could be obtained. As recharge to this area is small, wells of large yield probably could not be obtained. Adequate water probably could be obtained locally for stock or domestic use.

Tertiary sediments consist mostly of semiconsolidated fluvial silt, interfingering (and intercalated) beds of unconsolidated sand and gravel. They are generally less permeable than the Quaternary deposits but are much thicker. Most wells finished entirely in Tertiary sediments have specific capacities of less than 10 gpm per foot of drawdown. Locally, yields of more than 1,000 gpm can be obtained from properly constructed and developed wells. Sufficient water for domestic and stock use generally can be obtained from wells in these sediments.

THE WATER TABLE AND MOVEMENT OF GROUND WATER

The water table is an irregular sloping surface that conforms roughly to the topography. It rises and falls as does the water level of a surface reservoir. It has many irregularities, caused by local differences in the permeability of the aquifer material and local and seasonal differences in withdrawals from or additions to the reservoir. Other factors being equal, where the aquifer material is coarse and permeable, the slope of the water table is gentle; where the material is fine-grained and less permeable, the water-table slope is steeper. The direction and rate of movement of ground water are governed by the slope and shape of the water table.

The water levels and altitudes of 88 wells were determined by instrumental leveling. The data were used in the preparation of a water-table contour map that shows the general shape and slope of the water table in part of the area and also the location of observation wells. (See pl. 2.) With observation wells 2 miles or more apart, many of the details of the shape and slope could not be shown in the area contoured, and some of the area could not be contoured. Ground water moves downslope at right angles to the contours. The water-table contour map shows that in the northwestern part of the area ground water moves generally eastward toward the Clark Fork. In the southwestern part of the area, ground water moves generally northeastward toward the Clark Fork, but has components toward the effluent creeks (Warm Springs, Dutchman, Mill, or Willow) in that part of the area. Insufficient data were obtained to contour the water table on the east side of the river. However, the topography and the orientation of the Tertiary beds indicate that ground water in that part of the area moves generally northwestward toward the Clark Fork.

The rate of movement of ground water in the southern part of the Deer Lodge Valley is relatively slow. The water-table gradient across the Warm Springs Creek and Mill Creek alluvial fans is about 50 feet per mile. Using the coefficient of transmissibility obtained at well 4-10-5ab (95,000 gpd per foot), a porosity of 40 percent and an aquifer thickness of 100 feet, the rate of movement is roughly 3 feet per day. Lower values of transmissibility more than offset steeper gradients in other parts of the area so the rate of movement is probably much less than 3 feet per day in those parts.

CHANGES OF WATER LEVELS IN WELLS

A record of the fluctuations of the water table in an area furnishes valuable information about ground-water conditions. The amount and rate of fluctuations depend on the net rate of gain or loss of storage in the ground-water reservoir. If the discharge from the reservoir exceeds the recharge to it, the water table will decline; if recharge exceeds discharge, the water table will rise.

The ground-water reservoir in the southern part of the Deer Lodge Valley is recharged by water from irrigation, influent streams, precipitation, and snowmelt that percolates down to the water table. The major streams tributary to the Clark Fork in the area of study are perennial in their upper reaches, but during the summer most of the flow is diverted for irrigation or sinks into the valley fill. These streams are effective sources of considerable recharge to the underlying and adjacent sediments. Much of the water diverted for irrigating 12,000 acres of land in the area percolates into the ground-water reservoir.

Water is discharged from the underground reservoir by evaporation, transpiration, pumping from wells, and seepage into effluent streams and drains. During most of the year the Clark Fork is effluent through its course in the study area. Some of the tributary streams (notably Lost, Dutchman, Warm Springs, and Willow Creeks) are effluent in their lower reaches. Parts of an 8-mile tile drainage system in the vicinity of Opportunity discharge several cubic feet per second of water from the ground into Willow Creek. Six open drainage ditches in the study area have a total length of 2½ miles. They discharge an estimated 8 cubic feet per second of water into the Clark Fork River through tributary stream channels (Bill Smett, U.S. Soil Conservation Service, written communication, 1961). Ground water is evaporated and transpired over large areas where the water table is within a few feet of the land surface during much of the year. In addition, much water is evaporated from large areas of open water in the settling basins prepared for the tailings from the Washoe Smelter in Anaconda. More water probably is discharged by evapotranspiration from these areas during late June, July, August and early September than leaves the area as streamflow during the same period. Discharge of water from wells is relatively small in comparison to discharge by evapotranspiration and effluent streams.

Changes in the level of the water table can be observed readily in observation wells. Water-level measurements were made monthly from August 1960 to September 1961 in about 40 wells. The period of measurement was not long enough to determine long-term trends or even to be sure that the seasonal or short-term trends are typical. However, hydrographs for the wells indicate that location, depth to water, and geological setting have a noticeable effect on the seasonal fluctuations. The hydrograph for well 5-9-6dc (fig. 8a) shows the water level rising from September through April and declining from May through September. This is fairly typical of several shallow observation wells in areas of high water table and indicates a large evapotranspiration effect. The presence of alkali in the vicinity of this well also indicates considerable evaporation from the area. The hydrograph of well 4-10-15aa (fig. 8b) also shows the effect of evapotranspiration. In addition, it shows that recharge to the aquifer during May was sufficient to offset discharge by evapotranspiration and other means. Well 4-11-1bb is near the mouth of the canyon of Warm Springs Creek, and recharge from mountain snowmelt causes a rapid rise in the water level in May and a continued rise during June. Storage and utilization of almost the entire flow of Warm Springs Creek caused a rapid decline in water level in the well in July and August. Recharge was about equal to discharge from November through April. Wells 5-10-16ac and 6-10-27cc (fig. 8d, e) are both in Tertiary sediments on the west side of the area. The difference in the time of peak water level in these wells, with respect to each other and to wells 4-10-15aa and 4-11-1bb (fig. 8b, c), results partly from the time required for recharge to reach the aquifer because of differences in depth to the water table. Other contributing factors are (1) the size, sorting, and bedding of the material between the source of recharge and the water table; and (2) the amount of local irrigation. Well 4-9-31bd (fig. 8f) is artesian and reflects the fluctuation of the water level in the indurated volcanic-rich sediments. The fairly constant rate of decline of water level from October through May is unusual.

UTILIZATION

About 6,000 acre-feet of ground water is presently being pumped annually from three municipal wells, three State institution wells, and several hundred domestic and stock wells.

About 60 percent of the 6,000 acre-feet is pumped from the three municipal wells at Anaconda. These wells obtain water from the alluvium along Warm Springs Creek, just west of town. A total of several hundred acre-feet of water per year are pumped from three wells at the State hospitals at Warm Springs and Galen. Most of this water is obtained from the Tertiary sediments. Probably less than 200 acre-feet of water per year are withdrawn from stock and domestic wells in the area. This water is obtained from the Quaternary sediments by some of the wells and from the Tertiary by others.

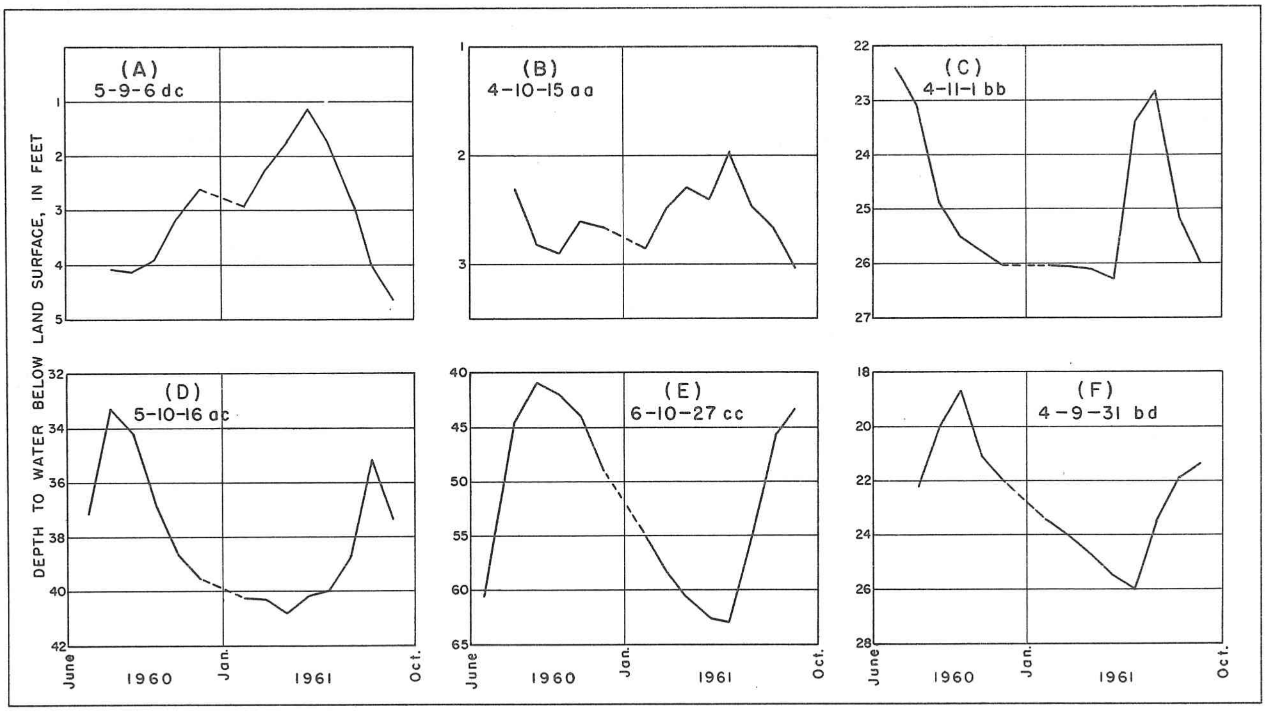

Figure 8.--Hydrographs of water level fluctuations in six observation wells showing variations in seasonal fluctuations.

SUMMARY AND CONCLUSIONS

The principal aquifers in the southern part of the Deer Lodge Valley are in the upper few hundred feet of valley fill, which includes sediments of both Quaternary and Tertiary age. The Quaternary deposits are relatively thin; but domestic and stock wells can obtain sufficient water from them, except in the northwest part of the area. Locally, water for irrigation of small areas can be obtained from the Quaternary sediments. The Tertiary sediments are fairly thick. The permeability of the Tertiary sediments is variable and is generally fairly low. Most wells in the Tertiary sediments yield less than 10 gpm per foot of drawdown even when properly constructed and developed. However, the thickness of these sediments is great enough so that yields of 1,000 gpm or more can be obtained locally.

Depth to water in the flood-plain area is generally less than 10 feet, but on the fans and terraces it ranges from 10 to 150 feet. In the northern part of the area, the general direction of movement of ground water is toward the flood plain from the east and west. In the southern part west of the Clark Fork, movement of ground water is generally northeastward with components of flow toward the tributary streams.

TABLE 2.--Table of selected wells.

Well number: See explanation of well-numbering system in text.
Type of well: Dn, driven; Dr, drilled; Du, dug.
Depth of well: Reported depths are shown in whole feet below land surface; measured depths are shown in feet and tenths below land surfaces.
Type of casing: C, concrete; P, pipe; R, rock; W, wood.
Type of pump: C, centrifugal; Cy, cylinder; J, jet; N, none; P, pitcher; T, turbine.

Type of power: E, electric; H, hand; N, none.
Use of water: D, domestic; F, firefighting; I, irrigation; O, observation; S, stock; U, used; PS, public supply; In, industrial.
Measuring point: Tca, top of casing; Tco, top of cover.
Altitudes determined by spirit level.
Remarks: Log.

Well number	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Type of pump	Type of power	Use of water	Measuring point			Depth to water level below measuring point (feet)	Date of measurement	Remarks
										Description	Distance above or below (-) land surface (feet)	Altitude			
3-10-1aa	John Green		Du	23.1	24	C	J	E	U	Tco	-5.0	5142.1	9.76	8-3-60	
3-10-1cd	William Peterson		Dr	26.4	6	P	J	E	D	Tca	-3.9	5113.7	4.94	--do--	
3-10-2ba	Ray Spangler		Dr	23.1	4	P	C	E	D	Tca	-6.3	5127.6	3.63	--do--	Log
4-9-31bd	-----do-----		Dr	70.2	6	P	N	N	O	Tca	2.7	5110.7	24.95	--do--	
4-10-8dc	Dave Williams		Du	45.3	48x48	W	Cy	H	U	Tco	.3	5130.1	28.50	7-28-60	
4-10-9ab	Jospeh Blevins		Du	6.2	30	R	N	N	U	Tca	0.0	5004.8	3.86	9-7-60	
4-10-9bd	Mt. Haggin Land and Livestock Co.		Du	29.3	48x48	C	N	N	D	Tco	1.0	5037.3	18.46	7-6-60	
4-10-9da	Anaconda Country Club		Du	12.7	---	C	Cy	E	U	Tco	1.3	5003.1	10.70	7-27-60	
4-10-10ad	Olga Hansen		Du	5.4	18	C	P	H	D	Tco	1.1	4941.1	4.58	--do--	
4-10-10cc	Opportunity Fire Dept.		Dr	22.6	6	P	N	N	F	Tca	1.9	5003.9	5.52	7-26-60	
4-10-10db	Darcy Delong		Du	6.1	30-24	C	N	N	U	Tca	1.5	4963.3	6.30	7-27-60	
4-10-10dc1	Opportunity Fire Dept.		Dr	17.1	6	P	N	N	F	Tca	2.1	4973.0	5.68	7-26-60	
4-10-10dc2	-----do-----		Dn	20.0	4	P	N	N	F	Tca	1.3	4978.8	5.35	--do--	
4-10-11dd	U.S. Geol. Survey	1960	Dn	8.2	3/4	P	N	N	O	Tca	3.0	4925.7	8.75	8-16-60	
4-10-15aa	James Rouse	1958	Dr	23.1	6	P	N	N	O	Tca	.5	4947.9	2.80	7-27-60	Log
4-10-15ac	Opportunity Fire Dept.		Dn	18.4	6	P	N	N	F	Tca	1.6	4974.4	5.77	7-26-60	
4-10-15ba	-----do-----		Dn	20.8	6	P	N	N	F	Tca	2.4	4994.6	5.90	--do--	
4-10-15cb	Mt. Haggin Land and Livestock Co.		Du	9.2	36x36	W	C	E	S	Tco	0.0	5012.9	2.44	7-27-60	
4-10-15da	Opportunity Fire Dept.		Dn	18.6	6	P	N	N	F	Tca	1.4	4965.2	3.34	7-26-60	
4-10-16cd	Mt. Haggin Land and Livestock Co.		Dr	70.6	4	P	J	E	D,S	Tca	-2.0	5061.6	4.00	7-28-60	
4-10-17bb	Raymond Patterson		Du	51.2	---	-	J	E	D	Tco	.5	5178.1	17.60	--do--	
4-10-17bd	Bonneville Power	1953	Dr	125.0	10-5	P	T	E	O	Tca	-7.3	5162.1	40.93	8-2-60	Log
4-10-18ac	Edward Noll		Du	20.0	24	C	N	N	U	Tca	-5.70	5207.5	5.81	7-28-60	Log
4-10-18db	Bill Latray	1960	Dr	68.4	6	P	J	E	D	Tca	1.0	5231.0	25.74	--do--	Log
4-10-22bb	U.S. Geol. Survey	1960	Dn	6.8	3/4	P	N	N	O	Tca	3.7	5017.3	6.94	8-16-60	
4-10-22dc1	Leonard Roffler	1957	Dr	37.8	6	P	N	N	F	Tca	3.0	5008.1	7.56	8-2-60	Log
4-10-23cc	W.F. Ritschel		Du	7.3	30	R	N	N	S	Tco	0.0	4987.2	4.28	8-3-60	Log
4-10-25bc	Montana Power Co.	1931	Dr	78.8	6	P	N	N	O	Tca	3.0	4996.1	43.69	9-12-60	Log
4-10-26cb	Ben Poston	1957	Du	15.8	24	C	J	E	D	Tca	.4	5014.6	13.83	8-2-60	
4-10-26dd	L.S. Johnson	1955	Dr	57.9	6-4	P	J	E	D	Tca	.3	5035.1	43.68	8-3-60	Log
4-10-27ac	Mt. Haggin Land and Livestock Co.		Du	8.7	48x60	W	Cy	H	S	Tco	1.0	5009.9	4.44	8-2-60	
4-10-36ab1	Lewis Wertz		Dr	73.0	6	P	N	N	O	Tca	2.0	5054.5	50.97	8-3-60	
4-11-1bb	Anaconda Copper Mining Co.	1957	Dr	82.7	2	P	N	N	O	Tca	.5	5192.9	23.63	7-26-60	Log
5-9-5ba	Paul Noack		Du	31.3	30	R	Cy	H	U	Tca	0.0	4769.5	26.64	8-9-60	
5-9-5cd	-----do-----		Du	17.0	48	R	J	E	D	Tca	0.0	4765.5	12.33	--do--	

5-9-6dc	U.S. Geol. Survey	1960	Dn	9.5	3/4	P	N	N	O	Tca	1.0	4758.1	5.04	8-8-60	
5-9-7cb	-----do-----	1960	Dn	9.6	3/4	P	N	N	O	Tca	1.0	4780.7	7.50	8-17-60	
5-9-17bc	Montana Power Co.	1931	Dr	131.0	6	P	J	E	D,O	Tca	0.0	4827.4	42.95	8-9-60	Log
5-9-18ab	U.S. Geol. Survey	1960	Dn	8.1	3/4	P	N	N	O	Tca	2.4	4783.6	7.46	8-10-60	
5-9-29bc	Anaconda Copper Mining Co.		Du	20.0	20	P	J	E	D	Tca	-3.5	4843.5	5.23	9-12-60	
5-10-2aa1	Mt. Haggin Land and Livestock Co.		Du	34.5	48	R	J	E	D,S	Tco	1.0	4870.5	25.80	6-20-60	
5-10-3aa	-----do-----		Dr	105.4	6	P	N	N	U	Tca	0.0	4926.0	64.90	8-1-60	
5-10-3cb	-----do-----		Dr	152.0	6	P	Cy	N	U	Tca	2.0	5029.9	88.37	9-13-60	Log
5-10-3dd	-----do-----		Dr	80.0	6	P	N	N	O	Tca	2.6	4924.3	55.05	6-22-60	Log
5-10-4aa	C.P. Shonnard	1958	Dr	245.5	8	P	N	N	O	Tca	3.5	5084.6	149.46	--do--	Log
5-10-10cb	Mt. Haggin Land and Livestock Co.		Dr	74.8	6	P	N	N	U	Tca	1.0	4963.8	61.91	9-7-60	Log
5-10-13bc	U.S. Geol. Survey	1960	Dn	9.8	3/4	P	N	N	O	Tca	1.0	4831.9	8.65	8-16-60	
5-10-13da	-----do-----	1960	Dn	9.0	3/4	P	N	N	O	Tca	1.7	4808.7	7.98	--do--	
5-10-14dc	Mont. State Hospital	1939	Dr	8.2	6	P	N	N	U	Tca	1.2	4857.6	8.05	9-22-60	
5-10-15ba1	Mt. Haggin L. & L. Co.		Dr	56.2	5	P	N	N	O	Tco	0.0	4888.7	13.71	6-22-60	
5-10-16ac	-----do-----		Dr	98.3	6	P	N	N	O	Tca	.5	4966.0	37.40	7-4-60	Log
5-10-16dc	-----do-----		Du	14.8	24	C	Cy	H	U	Tco	0.0	4933.0	11.26	--do--	
5-10-17ca1	Steve Tribovitch		Dr	59.1	6	P	N	N	O	Tca	.8	5035.9	43.04	7-5-60	
5-10-17cb	-----do-----		Dr	89.5	12-8	P	T	N	U	Tca	1.0	5059.9	66.63	--do--	
5-10-20cd	Mt. Haggin L. & L. Co.		Dr	59.4	6	P	Cy	H	D	Tca	.6	5031.4	37.40	--do--	
5-10-22dd	Mont. State Hospital	1949	Dr	141.5	12	P	N	N	U	Tca	.5	4903.7	3.40	8-9-60	
5-10-23dc	Simplex Homes	1959	Dr	48.0	6	P	C	E	U	Tca	.7	4881.7	5.37	7-5-60	Log
5-10-23dd	Harold Slye	1957	Dr	51.2	6	P	J	E	D	Tca	0.0	4874.0	11.40	--do--	Log
5-10-24cb	U.S. Soil Cons. Ser.	1954	--	8.4	3	P	N	N	O	Tca	.8	4858.5	6.74	8-16-60	
5-10-24da	U.S. Geol. Survey	1960	Dn	9.2	3/4	P	N	N	O	Tca	1.2	4841.0	7.67	--do--	
5-10-25da	-----do-----	1960	Dn	4.1	3/4	P	N	N	O	Tca	1.3	4856.5	1.90	8-23-60	
5-10-33ab	-----do-----	1960	Dn	8.3	3/4	P	N	N	O	Tca	2.2	5009.1	7.11	8-16-60	
5-10-33da	Anaconda Copper Mining	1937	Dr	52.2	16	P	N	N	U	Tca	0.0	4996.0	2.73	9-21-60	Log
5-11-33ca1	-----do-----	1937	Dr	46.0	16	P	T	E	In,PS	---	---	---	flows	---	Log
5-11-33ca2	-----do-----	1937	Dr	47.0	16	P	T	E	In,PS	---	---	---	5.00	---	Log
5-11-33ca3	-----do-----	1937	Dr	52.0	16	P	T	E	In,PS	---	---	---	4.00	---	Log
6-9-19ac2	U.S. Geol. Survey	1960	Dn	8.1	3/4	P	N	N	O	Tca	2.0	4728.8	7.35	8-16-60	
6-9-19db	Fred Jacobson		Du	21.5	48	C	N	N	U	Tca	-5.5	4737.2	3.19	8-10-60	
6-9-20bd	Lewis Pinocci		Dr	25.5	6	P	J	E	D	Tca	-2.0	4689.7	1.32	8-8-60	
6-9-21cd1	Wallace Beck		Dr	150.0	6	P	S	E	D,S	Tca	.5	4785.5	91.25	9-12-60	
6-9-21cd2	Quintin Rickter		Dr	160.0	6	P	J	E	D,I	Tca	0.0	4809.6	115.37	9-7-60	Log
6-9-29ac	Robert Johnson		Dr	15.6	6	P	N	N	U	Tca	0.0	4703.9	2.66	8-8-60	
6-9-29bb	U.S. Geol. Survey	1960	Dn	8.2	3/4	P	N	N	O	Tca	2.3	4708.2	3.45	8-22-60	
6-9-30ab2	-----do-----	1960	Dn	6.1	3/4	P	N	N	O	Tca	1.5	4727.7	.64	9-6-60	
6-9-30cd	Donald Beck		Du	10.0	---	---	C	E	D	Tco	1.6	4754.5	6.46	8-10-60	
6-9-31bb	Mont. T.B. Sanitarium	1956	Dr	208.0	30-12	P	T	E	PS	---	---	---	25.00	---	Log
6-9-31cd	Mt. Haggin L. & L. Co.		Du	157.0	6	P	J	E	D	Tco	-8.5	4772.3	.73	9-7-60	
6-9-31dd	U.S. Geol. Survey	1960	Dn	8.2	3/4	P	N	N	O	Tca	2.5	4745.0	5.39	8-10-60	
6-9-32aa1	Robert Johnson		Du	18.8	48	R	N	N	O	Tca	0.0	4732.2	12.95	8-8-60	
6-10-22dd	Art Job		Du	5.0	---	W	N	N	U	Tco	0.0	4929.3	1.35	6-20-60	
6-10-23bb	Andy Nicholes		Dr	175.0	4	P	Cy	H	O	Tca	1.0	4926.6	21.94	6-21-60	
6-10-23bc	-----do-----		Du	37.4	12	P	J	E	S	Tco	-6.0	4925.6	11.38	--do--	
6-10-23da	Catherine Vanisko		Dr	96.7	6	P	J	E	S	Tca	-6.2	4890.2	62.32	--do--	
6-10-23dc	-----do-----		Dr	113.0	8	P	T	N	I	Tca	1.0	4906.7	16.12	9-7-60	
6-10-26ab	Alfred Joseph		Du	19.9	12	P	C	E	I	Tco	0.0	4893.9	7.78	6-20-60	
6-10-26dc	Frank Jones		Du	6.2	36	C	Cy	N	O	Tco	1.1	4880.7	3.08	--do--	
6-10-27aa	Amelia Donich		Du	12.4	24x36	W	N	N	O	Tca	1.0	4929.1	1.48	6-22-60	
6-10-27cc	Mt. Haggin L. & L. Co.		Dr	88.7	6	P	N	N	O	Tca	.5	5005.7	60.88	6-21-60	Log
6-10-28bb	Dell Jennings		Du	71.5	48	C	J	E	D	Tca	2.8	5114.7	55.78	--do--	
6-10-34ad	Mt. Haggin L. & L. Co.		Du	27.2	60	R	N	N	U	Tco	1.0	4914.8	12.81	6-22-60	
6-10-34dd	-----do-----		Dr	84.9	6	P	N	N	O	Tca	.5	4924.7	24.58	6-21-60	Log
6-10-35ab	Donald Beck		Du	3.3	18	C	N	N	D	Tca	.2	4868.6	.71	6-20-60	

GLOSSARY

Aquifer, a formation, group of formations, or part of a formation that will yield ground water in useful quantities.

Artesian water, ground water that rises in a well above the point at which it is confined in an aquifer; water confined under artesian pressure.

Confining bed, a bed overlying an aquifer which because of its impermeability, or low permeability relative to the aquifer, prevents or impedes upward movement of water and pressure until penetrated by a well; a similar bed beneath an aquifer.

Drawdown, the lowering of water level in a well as a result of discharge from it or another well.

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

Flowing well, an artesian well through which water is forced above the land surface by hydrostatic pressure in the aquifer.

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

Permeability, a measure of the capacity of an aquifer to transmit water.

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

Piezometric surface, an imaginary surface that everwhere coincides with the static level of water in an aquifer.

Porosity, the percentage of the total volume of a rock that is occupied by interstices and other openings.

Specific capacity, a measure of the productivity of a well; the amount of water, in gallons per minute, that is yielded per foot of drawdown.

Storage, coefficient of, a measure of an aquifer's capacity to store and release water; 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.

Transmissibility, coefficient of, the rate of flow of water, in gallons per day under prevailing conditions, that is transmitted across each mile strip extending the saturated thickness of the aquifer, under a hydraulic gradient of 1 foot per mile. It is equal to the field coefficient of permeability multiplied by the saturated thickness of the aquifer, in feet.

Water table, the upper surface of a zone of saturation; the water at the water table is under atmospheric pressure.

Zone of saturation, the zone in which the interstices (pore spaces, joints, fractures, etc.) are saturated with water under hydrostatic pressure.

SELECTED REFERENCES

Alden, W.C., 1953, Physiography and glacial geology of western Montana and adjacent areas: U.S. Geol. Survey P.P. 231, 200 p.

Billingsley, Paul, 1915, The Boulder batholith of Montana: Am. Inst. Min. Eng. Trans., v. 51, p. 31-56.

Douglass, Earl, 1902, Fossil Mammalia of the White River beds of Montana: Am. Philo. Soc. Trans., new ser., v. 20, p. 237-279.

Jacob, C.E., 1946, Drawdown test to determine effective radius of artesian well: Proc. A.S.C.E., v. 72, no. 5, p. 629-646.

Konizeski, R.L., 1957, Paleoecology of the middle Pliocene Deer Lodge local fauna, western Montana: Geol. Soc. America Bull., v. 68, p. 131-150.

Konizeski, R.L., McMurtrey, R.G., Brietkrietz, Alex, 1961, Preliminary report on the geology and ground-water resources of the northern part of the Deer Lodge Valley, Montana: Mont. Bur. Mines and Geol. Bull. 21, 24 p.

Lahee, Frederic H., 1916, Field geology: McGraw-Hill Inc., p. 1-528.

Meinzer, O.E., 1923, The occurrence of ground water in the United States, with a discussion of principles: U.S. Geol. Survey Water Supply Paper 489, 314 p.

Mutch, T.A., 1961, Geologic map of the northeast flank of the Flint Creek Range, western Montana: Mont. Bur. Mines and Geol., Spec. Pub. 22 (Geol. Map 5), with text.

Pardee, J.T., 1913, Coal in the Tertiary lake beds of southwestern Montana: U.S. Geol. Survey Bull. 531-G, p. 229-244.

Perry, E.S., 1933, Possibilities of ground-water supply for certain towns and cities of Montana: Mont. Bur. Mines and Geol. Misc. Contr. no. 2, p. 13-14.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., 16th Ann. Mtg., pt. 2, p. 519-524.