STATE OF MONTANA
Tim Babcock, *Governor*

BUREAU OF MINES AND GEOLOGY
E. G. Koch, *Director*

BULLETIN 32
November, 1962

PRELIMINARY REPORT ON THE GEOLOGY AND GROUND-WATER RESOURCES OF SOUTHERN JUDITH BASIN, MONTANA

By

E. A. Zimmerman

This bulletin has been prepared by the United States Geological Survey, Water Resources Division, under a cooperative agreement with the Montana Bureau of Mines and Geology

MONTANA BUREAU
of
MINES AND GEOLOGY
Butte, Montana

STATE OF MONTANA
BUREAU OF MINES AND GEOLOGY
E. G. Koch, Director

BULLETIN 32

PRELIMINARY REPORT ON THE GEOLOGY AND GROUND-WATER RESOURCES OF THE SOUTHERN JUDITH BASIN, MONTANA

By

Everett A. Zimmerman

This bulletin has been prepared by the United States Geological Survey, Water Resources Division, under a cooperative agreement with the Montana Bureau of Mines and Geology

MONTANA SCHOOL OF MINES
Butte, Montana
November 1962

Free from

Montana Bureau of Mines and Geology

Room 203-B, Main Hall

Montana School of Mines

Butte, Montana

CONTENTS

I L L U S T R A T I O N S

T A B L E S

PRELIMINARY REPORT ON THE GEOLOGY AND GROUND-WATER RESOURCES OF THE SOUTHERN JUDITH BASIN, MONTANA

By

Everett A. Zimmerman

ABSTRACT

The Judith Basin, a structural and topographic basin in central Montana, is nearly surrounded by isolated mountain ranges. The Little Belt and Big Snowy Ranges bound Judith Basin on the south and east, respectively. Agriculture is the principal occupation in the study area. The climate is semiarid; thus, a shortage of water for stock and irrigation use is common.

Ground-water recharge is derived mainly from precipitation, infiltration from streams, and return irrigation water. Wells, springs, and evapotranspiration are means of ground-water discharge. Ground water in the area moves generally toward the north in the unconsolidated Quaternary deposits and from the mountains toward scattered discharge points in the artesian bedrock aquifers.

Rocks ranging in age from Mississippian to Quaternary were studied in this area. Ground water in usable quantities can be obtained from: the Madison Limestone of Mississippian age, the Kibbey Sandstone of Mississippian age, part of the Amsden Formation of Mississippian and Pennsylvanian age, the Swift Sandstone of the Jurassic Ellis Group, the Early Cretaceous Kootenai Formation, the Late Cretaceous Eagle Sandstone and Judith River Formation, Quaternary terrace gravel deposits and alluvium.

INTRODUCTION

In 1955 the U.S. Geological Survey, in cooperation with the Montana Bureau of Mines and Geology, began a series of investigations of the occurrence of ground water in different parts of Montana. (See fig. 1.) The investigation of the southern part of the Judith Basin was begun in 1959 as part of this series.

PURPOSE AND SCOPE

This study was undertaken to determine (1) the character, thickness, and extent of water-bearing materials; (2) the source, occurrence, and direction of movement of the ground water; and (3) the quantity and availability of the ground water.

LOCATION AND EXTENT

The part of the Judith Basin studied in this investigation is bounded on the north by U.S. Highway 87, on the northwest by the Judith River, on the southwest by the outcrop zone of the Madison Limestone on the flanks of the Little Belt Mountains, on the south by the Wheatland County line, and on the east by the east side of Range 16 E. Thus, it includes about 450 square miles in portions of Judith Basin and Fergus Counties, Mont. The location of the study area is shown on figure 1.

PREVIOUS INVESTIGATIONS

The first comprehensive description of the geology and economic resources of a part of this area appeared in the Little Belt Mountains and Fort Benton folios of the Geological Survey (Weed, 1899a and 1899b) and in a description of the geology of the Little Belt Mountains (Weed, 1900). Calvert (1909) investigated the geology and coal resources of the Lewistown coal field. Reeves (1930) mapped the Big Snowy Mountains. Alden (1932) discussed the general physiographic history of this area. Perry (1932) investigated the ground-water resources of the Judith Basin. Vine and Hail (1950) prepared a preliminary map of the Stanford-Hobson area and Vine (1956) enlarged upon it as a bulletin of the Geological Survey. The latter two publications were especially helpful in this investigation.

METHODS OF INVESTIGATION

Recent mapping (Vine and Hail, 1950) was available for most of the study area, and this mapping was adopted for this report after field checking. The mapping was extended to the southwest and east, and a small area on the south edge omitted on Vine's map was mapped by the writer. Geologic mapping was done

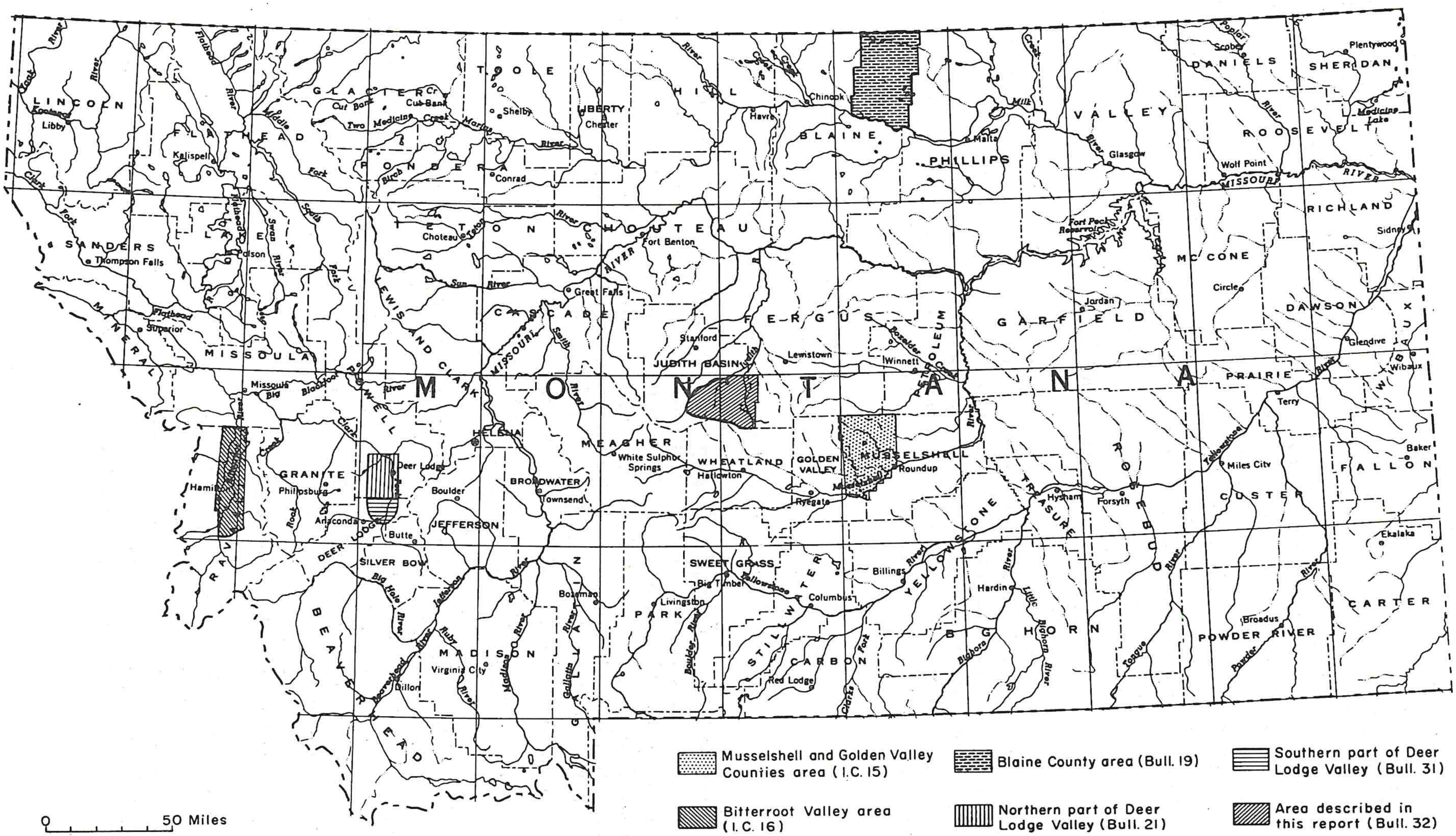

Figure 1.--Map of Montana showing locations of cooperative ground-water investigations, 1955-1962.

of water from precipitation and by seepage from irrigation water, streams, and canals. Ground water is discharged to the earth's surface by springs, wells, and effluent streams or to the atmosphere by evapotranspiration (combined evaporation and plant transpiration).

Ground water in southern Judith Basin is obtainable from openings in consolidated rocks of Mississippian, Pennsylvanian, Jurassic, and Cretaceous age and from unconsolidated rocks of Quaternary age. Any formation or other rock unit that can yield water in useful quantities is called an aquifer. The openings in an aquifer may be intergranular spaces between grains of silt, sand, or gravel; joints; bedding planes; or solution cavities. Solution cavities are especially common sources of ground water in limestone, dolomite, and gypsum strata. Many cavities are enlarged by chemical action from joints and openings along bedding planes. Clastic sediments such as sand and gravel contain intergranular openings. Consolidated clastic sediments such as sandstone and siltstone commonly contain fracture openings in addition to intergranular openings. Fracture openings and solution cavities are especially abundant near the mountains or other places, where the rocks have undergone intense deformation.

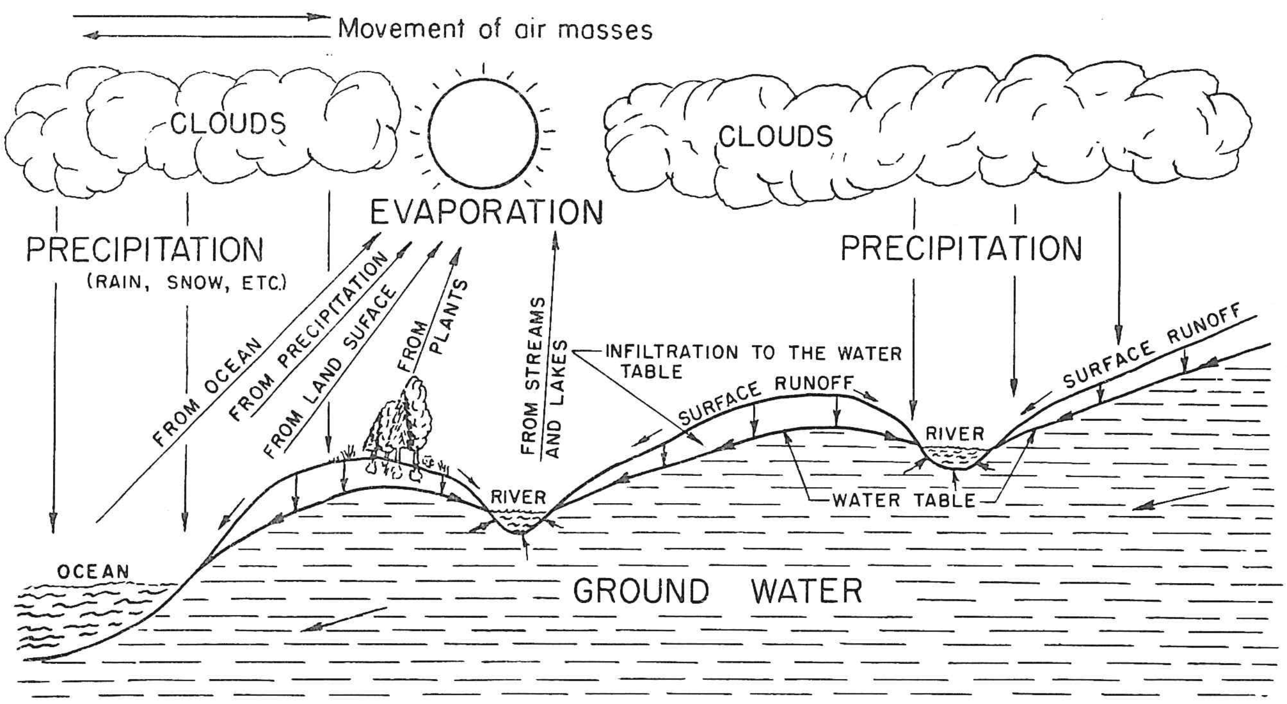

Figure 2.--Hydrologic cycle.

HYDROLOGIC PROPERTIES OF AQUIFERS

The proportion of the volume of the pore spaces to the volume of the rock is called the porosity of the rock. The pore spaces must be interconnected to transmit water to a well or other point of discharge. Generally, the larger the connected openings the greater the rate at which water can be transmitted. The capacity of a material to transmit water is called its permeability.

Water in an aquifer is said to be under water-table conditions if the water is under atmospheric pressure only and the water table is the upper surface of the saturated zone. If an aquifer is confined by less permeable beds so that it rises in the borehole when a well taps the aquifer, it is said to be under artesian conditions. The hypothetical surface to which artesian water would rise under its full head is called the piezometric surface. Ground water is commonly under water-table conditions in one part of an aquifer and under artesian conditions in another part. (See fig. 3.)

RECHARGE AND MOVEMENT

Most ground-water recharge comes from precipitation, either directly by infiltration from the land surface or indirectly by influent seepage from streams or seepage from applied irrigation water. All the aquifers discussed in this report are exposed in the Judith Basin or on the flanks of the adjacent mountains, where precipitation is greater than it is in the center of the basin. Part of the rain and snow that falls on these rocks filters downward and recharges the ground-water reservoir.

Ground water generally moves continuously but slowly through aquifers from places of recharge to places of discharge. The direction of movement is that of the hydraulic gradient--that is from an elevated point in a water-table aquifer or a point of high pressure head in an artesian aquifer to a point of lower elevation or lower pressure head. Ground-water movement in the unconsolidated Quaternary deposits in the southern Judith Basin generally parallels the direction of surface drainage. Movement in artesian aquifers is toward points of discharge that are comparatively few and widely scattered. The rate of movement of ground water is slow in comparison to that of surface water. Under a gradient of 10 feet per mile, the rate of movement of ground water may range from less than 1 foot per year in clay to about 4 miles per year in clean coarse gravel. In contrast, surface water under the same gradient may move several miles per hour.

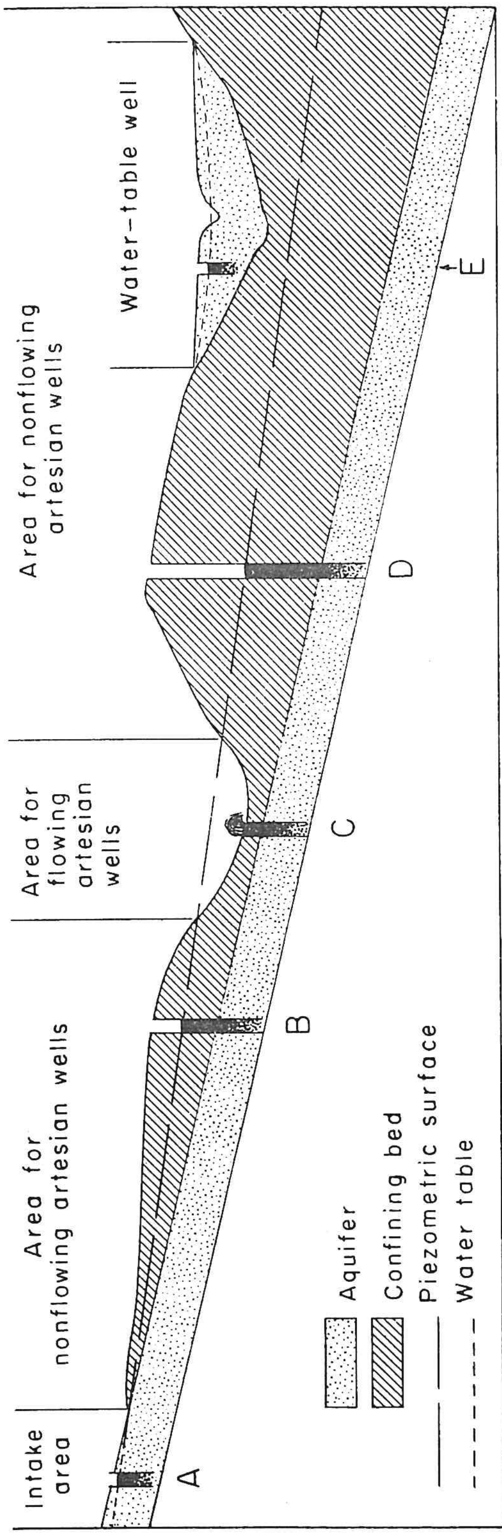

Figure 3.--Hypothetical section showing geologic environment necessary for unconfined (water table) and confined (artesian) aquifers. A and E are water-table wells; B and D are nonflowing artesian wells; and C is a flowing artesian well.

STORAGE AND DISCHARGE

The water table or piezometric surface does not remain stationary but rises and falls as does the water level of a surface reservoir. A rising water table indicates that recharge, the addition of water to the ground-water reservoir, is greater than discharge in that area; a falling water table indicates that discharge exceeds recharge. The water table fluctuates more by the addition or discharge of a given quantity of water than does the level of a surface reservoir because ground water occupies only part of the volume of a ground-water reservoir. Thus, changes in water levels reflect changes in ground-water storage. Records of fluctuations of the water table, determined by periodic measurements in 50 wells in the southern Judith Basin, are on file at the office of the Ground Water Branch of the Geological Survey in Billings.

Ground water may be discharged from the zone of saturation by evapotranspiration, by discharge into streams or artificial drains, or by springs, seeps, and wells. Discharge by evapotranspiration is relatively great where the water table is close to the surface, as along streams and in poorly drained places. Plants that grow in water, called hydrophytes, and plants whose roots extend down to the water table, called phreatophytes, grow thickly in swampy areas or where the water table is close to the surface and transpire large quantities of ground water. Along the edge of the Judith River valley near Hobson and at other places where water-bearing rocks have been exposed by erosion, ground water is discharged by seeps and springs. Much ground water is evaporated and transpired during the warm growing season between May and September. In the fall and winter when frost and cool weather kill plants and evaporation is less intense, spring discharge increases. The amount of water discharged by natural means in the southern Judith Basin exceeds that withdrawn by wells. In any ground-water reservoir under natural conditions, the amount of water discharged will, over a long period, be balanced by recharge. If discharge from the reservoir is increased, as by withdrawals from wells, without a corresponding increase in recharge, either the natural discharge from the reservoir will decrease or water will be withdrawn from storage with resultant lowering of the water table.

THE STRATA AND THEIR WATER-BEARING PROPERTIES

Sedimentary strata, ranging in age from Mississippian to Recent, are exposed in the study area. (See table 1.) Older formations, including 850 to 1,300 feet of Cambrain rocks and 130 to 165 feet of Devonian rocks, were described by Weed (1899a) and Reeves (1930) in the Big Snowy and Little Belt Mountains. These rocks have not been considered in this study because they underlie the study area at great depths, and their hydraulic properties have not been tested by wells.

MADISON LIMESTONE

Outcrops of the Madison Limestone of Mississippian age along the flanks of the Little Belt and Big Snowy Mountains form a part of the boundary of the study area. According to Weed (1899b, p. 2) the Madison Limestone is about 1,000 feet thick in the Little Belt Mountains. It is a prominently outcropping formation and forms conspicuous hogbacks on the mountain flanks. Only the uppermost beds were studied in this investigation. The upper beds of the Madison consist of gray dense limestone, which is greatly fractured and brecciated with numerous openings ranging in size from pinpoint vugs to caves.

The form of the openings in the beds of the Madison gives rise to a high but erratically distributed porosity and permeability. No water wells have been drilled into the Madison in the study area. Many oil-test holes in central Montana have been drilled into the Madison and some yielded water in such copious quantities that it proved difficult to control. Crawford (1942, p. 1367) reported that the flow of an oil-test hole drilled in the SW$\frac{1}{4}$ sec. 30, T. 14 N., R. 15 E., no trace of which was found during this study, was estimated to be 4,000 barrels per day, about 115 gpm (gallons per minute), of potable water.

The flow of many streams heading both in the Big Snowy and the Little Belt Mountains decreases markedly where they cross

Table 1.--Stratigraphic units and their water-bearing characteristics in the study area.

System	Series	Formation		Maximum thickness (feet)	Lithologic character	Water supply
Quaternary	Recent	Alluvium		30(?)	Unconsolidated gravel, sand, silt and clay..	A good source of water locally where materials are coarse, well sorted, and adequately recharged.
	--?-- Pleistocene(?)	Terrace deposits		100	Unconsolidated sand and gravel. Very widespread.	Most used source of ground water in study area. Yields enough water for stock and domestic needs.
Tertiary(?)		Igneous rocks		20	Dark-colored quartz-free rock, forming sill in Heath Shale.	Not an aquifer.
Cretaceous	Upper Cretaceous	Montana Group	Judith River Formation	400(?)	Gray to brown sandstone, sandy shale, clay, and some coal.	Yields water to some wells in the small outcrop area.
		Montana Group	Claggett Shale	500	Gray and brown shale. Poorly exposed.	Poor aquifer.
		Montana Group	Eagle Sandstone	300	Massive tan and white sandstone; contains some sandy shale beds.	A fair aquifer but present in only the southeastern part of the study area.
		Montana Group	Telegraph Creek Formation	160	Sandy shale beds; transitional between the Colorado Shale and the Eagle Sandstone. Mapped with the Colorado Shale.	Not a good aquifer.
	Upper Cretaceous / Lower Cretaceous	Colorado Shale		1,500	Fissile gray or black marine shale with thin local sandstone beds, numerous concretionary zones, and bentonite beds.	Generally not water-bearing. A few sandy beds, particularly the First Cat Creek sand of drillers at the base, may yield moderate amounts of water.
	Lower Cretaceous	Kootenai Formation		500	Red shale and brown to gray sandstone. A few thin nodular fresh-water limestone beds.	Sandstone beds, particularly the basal bed, constitute a widely used aquifer. Flows obtainable in structurally favorable places.
Jurassic	Upper Jurassic	Morrison Formation		300	Variegated shale and siltstone; thin, nodular limestone; white and brown sandstone; black shale; and a bed of coal or carbonaceous shale near the top.	Not generally favorable as a source of ground water.
	Upper Jurassic	Ellis Group	Swift Formation	165	Glauconitic sandstone and shale.	Can yield moderate amounts of water. Flows obtainable from this formation in lowermost parts of the basin.
	Upper Jurassic	Ellis Group	Rierdon Formation	200	Gray calcareous shale. Missing in outcrops through most of the area.	Not an aquifer in the study area.
	Middle Jurassic	Ellis Group	Piper Formation	200	Red to varicolored shale and siltstone with thin limestone and shale beds. Absent in most outcrops in the study area.	Not an aquifer.
Pennsylvanian	?	Amsden Formation		920	Lower unit of red shale; siltstone; and red, brown, or white sandstone and conglomerate. Upper unit of gray limestone with red and gray shale partings.	Lower unit may be a good aquifer but is untested.
Mississippian	Upper Mississippian	Big Snowy Group	Heath Shale	500	Fissile carbonaceous shale; dense black and gray limestone; sandstone in upper part.	Unfavorable as a source of water except for sandstone in upper part.
	Upper Mississippian	Big Snowy Group	Otter Formation	500	White to gray limestone and gray to green shale.	Not an aquifer.
	Upper Mississippian	Big Snowy Group	Kibbey Sandstone	300	Red, white, or yellow sandstone, siltstone, limestone, and gypsum.	Offers promise of good yields out in the basin, but the water table has not been found in the outcrop zone. Probably hydraulically interconnected with underlying Madison Limestone.
	Upper and Lower Mississippian	Madison Limestone		1,000	Massive gray dense limestone, greatly fractured and brecciated in the upper part. Numerous solution openings.	Potentially a copious aquifer, but water is largely confined in discreet solution channels whose location cannot be determined on the ground surface. Water level seems to be very deep in the outcrop zone.
Pre-Mississippian		Older formations		--?--	Not studied but consist largely of limestone and shale beds over crystalline Precambrian rock.	Not economically important as aquifers in the study area.

outcrops of the Madison Limestone. The loss of water is due largely to infiltration into the cavernous limestone. No water table has as yet been found in the outcrop zone of the Madison. Several holes drilled in the outcrop to test rock conditions for construction have penetrated caves, but water was not found. According to a local report, a road crew uncovered a cave below the level of the streambed in the canyon of the south fork of the Judith River. No water was found in the cave, but the sound of cascading water could be heard.

Thus, it seems that the Madison Limestone is a potential aquifer in the Judith Basin; however, the unpredictable distribution of the cavernous porosity and the great depth to the formation make drilling to the Madison expensive and risky.

BIG SNOWY GROUP

The eroded upper surface of the Madison Limestone is overlain by three formations which compose the Big Snowy Group in this area. These formations of Late Mississippian age are, in ascending order, the Kibbey Sandstone, the Otter Formation, and the Heath Shale.

Kibbey Sandstone

Red sandstone, siltstone, and shale constitute the lowermost 50 to 100 feet of the Kibbey Sandstone. The formation ranges in thickness from 150 to nearly 300 feet, according to Vine (1956, p. 421). The upper part consists of white or yellow fine- to medium-grained porous commonly friable clean sandstone overlain by interbedded siltstone, limestone, and gypsum. The upper part is rarely exposed.

The friable porous sandstone beds in the upper part of the Kibbey should form a good aquifer, but water has not yet been found in these rocks in the study area. One dry hole was drilled into the Kibbey near the outcrop zone in sec. 3, T. 13 N., R. 12 E. This disappointing result may be compared with a yield of about 2,200 gpm from the Kibbey Sandstone in an oil-test hole near Hanover (Perry, 1932, p. 26) about 15 miles northeast of the study area. This comparison suggests that, although the formation can transmit water readily, the water table is at considerable (as yet unknown) depth. Thus, it may prove impossible to find water in the Kibbey near its outcrop area. However, the Kibbey, with the underlying Madison Limestone, is a promising potential aquifer at depth in the Judith Basin.

The presence of the porous permeable sandstone beds of the Kibbey over the irregular eroded surface of the cavernous upper part of the Madison indicates that the two formations probably are interconnected. Consequently, the water tables or piezometric surfaces of the formations may nearly coincide, and one may be recharged by the other through interformational leakage.

Otter Formation

The Otter Formation overlies the Kibbey Sandstone and consists of 400 to nearly 500 feet of limestone and green, gray, and purple shale (Vine, 1956, p. 422). Where it is exposed, the Otter may be easily recognized by the characteristic green shale which comprises much of the upper 200 to 300 feet.

Because the rocks of the Otter Formation are easily eroded, it is generally soil covered and exposures are few. The Otter and the similarly nonresistant beds of the overlying Heath Shale commonly underlie valleys and gentle slopes.

The Otter Formation offers almost no potential as an aquifer in the southern Judith Basin. No wells or springs are known to yield water from it.

Heath Shale

The Heath Shale is composed of fissile carbonaceous shale (petroliferous in some places) and includes some dense black and gray thin-bedded limestone and sandstone in the upper part. The shale weathers readily into soil, mantling most outcrops. The shale forms slopes that become slippery when wet, thus facilitating landslides of the overlying Amsden Formation. These landslides further obscure outcrops of the shale. However, aragonite fragments on the weathered soil provide a clue to the Heath Shale.

The Heath Shale is discontinuous in outcrop. Vine and Hail (1950) attributed this either to nondeposition or to lateral gradation of the black shale into green shale of the Otter Formation or red shale of the Amsden Formation. Walton (1946, p. 1,304) thought the discontinuity was owing to erosion subsequent to deposition. Where exposed, the formation attains a maximum thickness of almost 500 feet. The Heath Shale is unfavorable as a source of ground water except for local 10- to 20-foot sandstone beds near the top of the formation.

AMSDEN FORMATION

The Amsden Formation of Mississippian and Pennsylvanian age is as much as 920 feet thick near the Big Snowy Mountains but thins and disappears out in the basin owing to post-depositional erosion (Vine, 1956, p. 430). The formation can be divided into several lithologic units. Two units are recognizable in most exposures--a lower clastic unit of red shale and siltstone with red, brown, or white massive sandstone and conglomerate and an upper unit of gray limestone in thick beds with red and gray shale partings. In addition to the above-mentioned units, a shale bed overlies the upper unit near Wait Creek, and a marine limestone bed 30 feet thick underlies the lower clastic unit near Antelope Creek.

The sandstone beds of the Amsden are commonly friable and, although fine grained, may be a fair source of ground water. No wells and few springs in the area are known to yield water from the formation.

ELLIS GROUP

The Piper, Rierdon, and Swift Formations (in ascending order) constitute the Ellis Group of Middle and Late Jurassic age. These sedimentary rocks were deposited in a sea spread over an irregular land surface on the Amsden Formation and older rocks. The Piper and Rierdon Formations were deposited only in the lowest parts of this surface in the northern part of the area. Only the Swift Formation covered the higher parts of the erosional surface near the present Little Belt and Big Snowy Mountains. The Ellis Group differs greatly in thickness along the front of the Little Belt Mountains and is locally missing. Where penetrated by oil-test holes, this group is as much as 500 feet thick when all three formations are present. The Ellis Group seems to become thicker to the north at about the same rate as the underlying Amsden Formation and Big Snowy Group become thinner, so that the combined thickness of these formations probably remains about 1,400 feet (Vine and Hail, 1950). The Ellis Group is shown as a unit on the geologic map (pl. 1, in pocket), but the formations composing the group are discussed separately in the section that follows.

Piper Formation

The Piper Formation of Middle Jurassic age consists of red to varicolored shale and siltstone with thin limestone and gypsum beds. The formation is as much as 200 feet thick. Gypsum is mined from the Piper Formation at Heath and Hanover in the eastern Judith Basin. The Piper is not a source of good water in the study area.

Rierdon Formation

The Rierdon Formation of Late Jurassic age consists principally of gray calcareous shale. The formation is commonly missing in outcrops in the study area but is as thick as 200 feet in outcrops around the South Moccasin Mountain (Miller, 1959, p. 16). The Rierdon is not a source of ground water in the study area.

Swift Formation

The Swift Formation of Late Jurassic age, ranging in thickness from a few to 165 feet, overlies the Rierdon unconformably. The Swift consists principally of brown to orange medium- to coarse-grained glauconitic calcareous, ferruginous sandstone. Interbedded shale and sandstone compose a transitional zone at the base of the formation but are not present in all outcrops. Fossils, particularly oyster shells, are numerous at some exposures.

The Swift Formation is the source of water for several springs and flowing wells in the southwestern part of the area but, because of its depth, it is poorly tested in the center of the basin. Owing to a greater amount of interstitial cementing and thus a lower permeability, wells tapping the Swift probably will yield less water per unit of head than the more friable sandstone beds in the study area.

MORRISON FORMATION

The Morrison Formation of Late Jurassic age is composed of 50 to 300 feet of extremely lenticular continental beds that consist of variegated shale and siltstone; thin nodular limestone; white and brown sandstone; black shale; and a bed of coal or carbonaceous shale near the top. Dinosaur bones, gastroliths, and fresh-water clam shells are common in the Morrison, but the softness of the beds makes exposure rare. A coal bed near the top of the Morrison is useful as a marker bed; but, owing to an erosional unconformity between the Morrison and overlying Kootenai Formation, the coal bed has been removed locally.

The lenticularity of the beds composing the Morrison Formation makes it impractical to predict the sequence of beds that will be penetrated by a drill hole or if the hole will produce water. In general, the formation is not a good aquifer.

KOOTENAI FORMATION

The Kootenai Formation of Early Cretaceous age averages 400 to 500 feet in thickness and is characterized by red shale and brown to gray sandstone. A few thin nodular fresh-water limestone beds also are present. A massive crossbedded gray to brown basal sandstone bed about 100 feet thick is one of the most prominently outcropping beds in the study area. The bed is known by drillers as the Third Cat Creek sand in the Cat Creek oil field of Petroleum County, Mont., and as the Cutbank sand in the Kevin-Sunburst field in Toole County, Mont.

The characteristic red shale of the Kootenai Formation is a good marker bed for drillers in the southern Judith Basin, contrasting sharply with the drab gray shale of the overlying Colorado Shale. The formation is one of the best aquifers in central Montana. The basal sandstone is the best water-bearing bed, but several other sandstone beds stratigraphically higher commonly contribute some water to wells. Springs are fairly numerous in the outcrop zone of the Kootenai Formation. The few water wells drilled through the Kootenai in the study area generally have been successful. A well at Eddy's Corner (NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 18, T. 14 N., R. 16 E.) was drilled to a depth of 1,375 feet and flowed 60 gpm. This well had a static pressure of 110 pounds per square inch or about 254 feet of head. The water is of good quality and supplies a cafe, bar, motel, service station, and trailer court.

A well drilled for the town of Moore to supplement their water supply penetrated the Kootenai Formation. The town, 3 miles east of Eddy's Corner, is about 180 feet higher. The well flowed about 5 gpm under about 5 feet of head. Because the quantity was insufficient and the pressure too low to force the water into their storage tank, the city is seeking (1962) to have the well deepened to the Swift Sandstone where, they hope, higher pressure and yield can be obtained.

A successful well was drilled into the Kootenai Formation for the Utica Women's Club in sec. 16, T. 14 N., R. 13 E., just outside the study area. The well, near the outcrop zone of the Kootenai Formation, flowed 15 gpm with a pressure of 60 pounds per square inch.

Several other wells have been drilled into the Kootenai Formation in the southern Judith Basin and, with few exceptions, they have been successful for the intended use as stock or domestic supplies. However, none have produced sufficient water to irrigate any but small tracts of land.

COLORADO SHALE AND TELEGRAPH CREEK FORMATION

The Colorado Shale and Telegraph Creek Formation are poorly exposed in the southern Judith Basin, and thus are shown as a unit on the geologic map. (See pl. 1, in pocket.) However, the character and water-bearing properties of the formation are well enough known that they are discussed separately in the sections that follow.

Colorado Shale

The Colorado Shale of Early and Late Cretaceous age is composed of approximately 1,500 feet of fissile gray or black marine shale with thin local sandstone beds, numerous concretionary zones, and bentonite beds. The beds are very poorly exposed owing to deep weathering of the nonresistant shale and extensive mantling with alluvial deposits of Quaternary age.

With the exception of a few thin sandstone beds, the Colorado Shale is not an aquifer. A few shallow dug wells in weathered shale yield small quantities of water for stock and domestic use, but these generally are undependable. Several wells in the Colorado Shale have had small flows; however, except for the interbedded sandstone and shale beds at the base, the Colorado Shale is not a good source of water. The basal sand and shale unit can yield small to moderate quantities of water to wells but is less productive than the sandstone beds of the underlying Kootenai Formation.

Telegraph Creek Formation

The Telegraph Creek Formation of Late Cretaceous age is composed of 160 feet of yellow weathering dark-gray to dark-brown shale and sandy shale beds. The formation is transitional between the underlying Colorado Shale and the overlying Eagle Sandstone. Like the Colorado Shale, the Telegraph Creek is poorly exposed in the southern Judith Basin and has, therefore, been mapped with the Colorado Shale, although faunal studies indicate that it is more nearly associated with the overlying Eagle Sandstone.

The Telegraph Creek Formation is a poor aquifer. No wells or springs are known to tap this formation in the study area.

EAGLE SANDSTONE

The Eagle Sandstone of Late Cretaceous age comprises about 250 feet of massive friable brown and white sandstone beds and interbedded gray shale and thin coal beds. The sandstone beds form cliffs at some places and, where so exposed, are commonly weathered into grotesque forms. Generally, however, the Eagle Sandstone is poorly exposed in the study area. The formation crops out in only a small area in the southeastern part of the Judith Basin.

The Eagle Sandstone is a good aquifer in the small part of the southern Judith Basin underlain by it. A well in sec. 20, T. 11 N., R. 16 E. penetrated 225 feet of the Eagle, and yielded 70 gpm of water with 28 feet of drawdown. The town of Judith Gap obtains its municipal water supply from the Eagle.

CLAGGETT SHALE

The Claggett Shale of Late Cretaceous age, about 500 feet thick, is present only in the southeastern part of the study area. (See pl. 1, in pocket.) It consists principally of gray and brown shale, which is easily eroded. Hence, broad valleys are commonly developed in the Claggett outcrop zone. Because the shale weathers deeply, exposures are poor. In the vicinity of Harlowton, about 15 miles south of the study area, the Claggett contains some lenticular beds of sandstone that yield water. Because of poor exposures it was not possible to determine if the sandstone is present in the Claggett within the study area. Except for the possible presence of these sandstone lenses, the Claggett Shale is not favorable as a source of water.

JUDITH RIVER FORMATION

Only the lower part of the Judith River Formation of Late Cretaceous age is present in the study area. It is poorly exposed, and its thickness could not be determined. The formation consists of lenticular soft, friable gray sandstone beds; gray shale or claystone; and some thin coal beds. Sandstone beds of the Judith River Formation yield enough water for domestic and stock needs. Few wells were found that obtain water from the Judith River Formation because of the small areal extent of the outcrop zone in the study area.

IGNEOUS ROCKS

A sill of dark-colored quartz-free medium-grained intrusive rock was found emplaced in the Heath Shale near the Judith River in secs. 9, 17, and 20, T. 13 N., R. 12 E. The rock is deeply weathered, and no positive identification of its mineral constituents was made. Available data do not permit determination of the time of emplacement, but it was probably contemporaneous with the post-Cretaceous emplacement of many other intrusive bodies in central Montana. Other sills have been noted in various strata penetrated by oil-test holes.

The observed sill in the Heath Shale has little apparent significance to the local occurrence of ground water. The rock itself is not very permeable, and, emplaced as it is in impermeable shale, it does not serve as an aquiclude.

TERRACE GRAVEL

Gravel deposits, probably Pleistocene or younger in age, mantle approximately half of the southern Judith Basin. The gravel consists chiefly of fragments of limestone with lesser amounts of sandstone and, locally, igneous rocks. The gravel is generally coarser near the source of the rocks, in the mountains, than out in the basin. Most of the gravel is less than 6 inches in diameter, though boulders up to 2 feet in diameter can be found near the mountains. The degree of rounding increases away from the mountains.

The gravel deposits underlie a series of terrace levels, which are designated by numbers on the basis of their relative altitude. The highest and presumably the oldest known terrace is designated number 1, Qt, on map (pl. 1, in pocket), and progressively lower terraces are designated by larger numbers. Local variations of a terrace surface, some of which merge with the main surface, are designated by a plus (+) or minus (-) sign following the terrace number, according to whether they are higher or lower than the main surface.

The gravel deposits range in thickness from zero to as much as 100 feet but generally are no thicker than 50 feet. A thin gravelly, loam soil is developed on most terraces. The soil is usually thicker on lower, younger surfaces; and this fact suggests that it is weathered from flood-plain deposits of sand and silt that covered the gravel deposits, rather than being weathered from the gravel itself. The finer material has been partly eroded away from the older terraces, leaving a stony soil at many places.

The similarity of the terrace gravel deposits to modern alluvial gravel deposits suggests that the conditions of deposition were similar. It is not clear, however, whether the terraces are dissected remnants of much broader surfaces that once covered almost the entire basin or represent former lowlands in valleys between bedrock hills that have since been eroded away (inverted topography). The mechanism causing the alternate deposition and erosion that formed the steplike terraces is also somewhat obscure. Pluvial conditions during glacial advances probably produced the torrential streams necessary to erode and transport the gravel; and periodic changes in erosional base level, due to disruptions of the course of the Missouri River by glacial ice, caused the alternating deposition by streams in this area. Alden (1932, p. 13) correlated the highest terrace (number 1) with the Tertiary (Miocene or Pliocene) Flaxville Formation of northeastern Montana. However, as this correlation is based only on physiographic relations and because no evidence of age was found for this or any other terrace, all terraces in the study area have been designated as Quaternary in age.

The terrace gravel deposits are of much economic importance in the southern Judith Basin. The soils developed on the terraces are among the best suited for agriculture in the area. The surfaces are smooth enough to facilitate the use of heavy equipment and to make irrigation feasible, although only a small area northeast of Ackley Lake is now irrigated (1962). The gravel underlying the terraces is permeable enough to provide good drainage of the overlying soil. The terrace gravel is partly saturated with water, thus forming the most widely used aquifer in the study area. The saturated thickness is not great, but most farms and ranches obtain enough water for domestic and stock use from wells or springs in the gravel. No very large well yields have been observed. The town of Moore obtains its municipal water supply from a tunnel at the base of the gravel underlying the number 2 terrace. The yield from this source is approximately 50 gpm. Several excavations made to the base of the gravel for construction have required pumping about 20 gpm to keep the gravels dewatered.

Numerous springs of the contact type issue from the base of the terrace gravel. Springs are especially common along the edge of terrace number 2 (Qt_2) bordering the south side of the Judith River valley. Several businesses in Hobson obtain their water supply from a hillside spring flowing from gravel underlying terrace number 2. Excavation and street grading have been hampered in Hobson by springs uncovered during construction. On terrace number 3 west of Highway 19 are many marshy areas, resulting from ground water being discharged at the surface because of thinning of the gravel.

The gravel deposits underlying the lower and most extensive terraces are favorable as a source of ground water. The best results in prospecting for water in the terrace deposits can be expected in the middle of the terraces. Along the edges of terraces the drawdown of the water table caused by discharge of springs is appreciable, and the gravel may be nearly dewatered. Even in the middle of the terraces no very large yields to wells can be expected, but quantities adequate for ordinary stock and domestic needs can be obtained.

ALLUVIUM

The streams of the southern Judith Basin flow through valleys partly filled by Recent alluvium. The alluvium consists of unconsolidated sand, gravel, silt, and clay. The relative proportions of the constituents and the degree to which they are sorted vary considerably. However, the alluvium of the Judith River and Antelope Creek contains a relatively high proportion of gravel compared with that of the Ross Fork of the Judith River, which contains considerable clay. The clay material in the alluvium of Ross Fork is probably derived from tributaries draining lands where the Colorado Shale is exposed.

Like the terrace gravel, the alluvium is a fairly reliable aquifer in the southern Judith Basin. It underlies a relatively small part of the area, but many shallow wells dug or (rarely) drilled into it produce adequate stock and domestic water supplies.

Information is lacking as to the thickness of the alluvium. Shallow wells suffice for the present demand for domestic and stock water, thus no well logs record the thickness of the alluvium. Located as it is along stream courses, the alluvium is in a better position to receive recharge than the terrace gravel deposits.

Alluvium in the Judith River valley is almost all irrigated with surface water. The water table is within a few feet of the surface in most places; and, in some places, the soil is moist during most of the year. Wet soil makes the use of machinery problematical at times, but the land is suitable for pasturing of livestock. The good quality of the ground water in alluvium in the Judith River valley and the permeability of the alluvium effectively prevent the accumulation of soil-damaging "alkali." A substantial part of the valley is occupied by wild phreatophytes--cottonwoods, willows, wild roses, chokecherries, and others.

The alluvium underlying the Ross Fork Valley contains a greater proportion of clay than that in the valley of the Judith River. This additional clay was probably derived from the Colorado Shale; and, during the weathering and erosion of the shale, various salts were leached from the shale and flushed into the alluvium. The dissolved salts are not concentrated in the ground water to an extent sufficient to make it unsuitable for domestic and stock use. However, in some places the mineralized ground water rises to the land surface through tiny openings in the soil, which function as capillary tubes. The water evaporates and the salts are left as a residue called "alkali." The "alkali patches" are local and small in extent, but the salinity causes the soil underlain by them to be almost sterile.

The clayey sediments form a confining layer in some places, and the ground water in underlying sand and gravel beds may be under artesian pressure. A well in sec. 11, T. 12 N., R. 14 E. penetrated water-bearing gravel confined by clayey sediments in the alluvium of Buffalo Creek. The water rose about 3 feet above the land surface and flowed about 15 gpm.

The alluvium along the Ross Fork supports a much less extensive growth of phreatophytes than the alluvium along the Judith River, probably because of the greater salinity of much of the soil and, commonly, to the greater depth to water. Little irrigation is done in the Ross Fork Valley; thus, very little recharge reaches the ground-water reservoir from this source, and the water table is lower.

Some potential for development of fairly large amounts of ground water from alluvium in the Judith River valley seems to exist, but little inducement exists to develop the water at the present time (1962). Domestic and stock needs are met by small-capacity wells, and irrigation water is economically supplied by diversions of surface water. The ground-water potential in alluvium along the Ross Fork does not seem to be great.

WELL-NUMBERING SYSTEM

The wells or springs cited in this report (table 2) are numbered according to their location within the system of land subdivision used by the U.S. Bureau of Land Management. The first numeral of the well number denotes the township, the second the range, and the third the section in which the well is located. The lowercase letters a, b, c, and d after the section number show the location of the well within the section; the first letter indicates the quarter section and the second the quarter-quarter section. The lowercase letters are assigned in a counterclockwise direction, beginning in the northeast quarter. If two or more wells are located within the same quarter-quarter section, consecutive numbers follow the lowercase letters. (See fig. 4.)

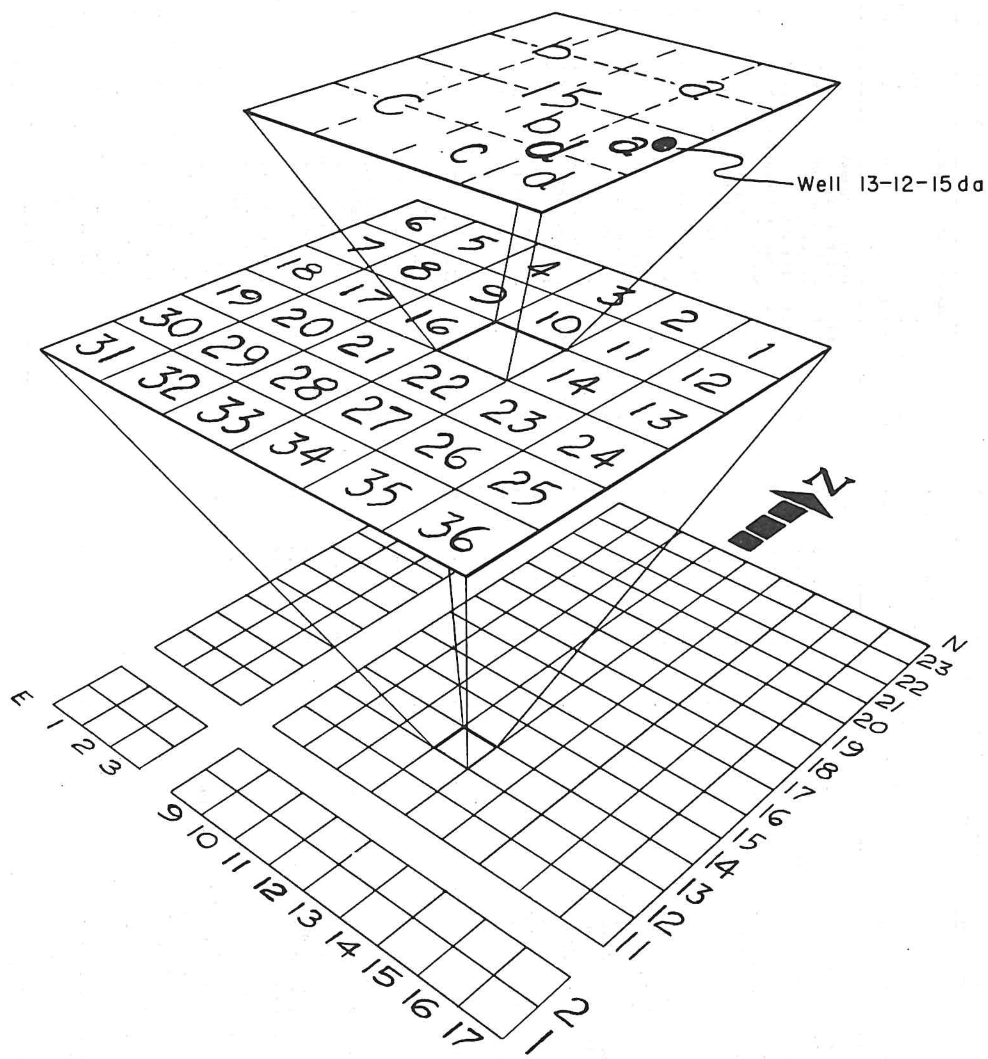

Figure 4.--Sketch showing system of numbering wells.

Table 2.--Table of selected wells and springs.

Well number: See explanation of well-numbering system in text.
Topographic location: C, creek bank; H, hillside; L, level or nearly so; S, gentle slope; U, undulating topography.
Type of well: DD, dug and drilled well; Dr, drilled well; Du, dug well; Sp, spring.
Depth of well: Reported depths below the land surface are given in feet; measured depths are given in feet and tenths below measuring points.
Type of casing: C, concrete (brick tile or pipe); P, iron or steel pipe; T, clay tile; W, wood; R, rock; B, brick; N, none.
Character of material: Cl, clay, and sandy clay; G, gravel; S, sand; Sh, shale; Ls, limestone; Ss, sandstone.

Method of lift: C, horizontal centrifugal; Cy, cylinder; F, natural flow; N, none; P, pitcher pump; J, jet.
Type of power: E, electric; G, gas engine; H, hand operated; W, windmill.
Use of water: D, domestic; I, irrigation; N, not being used; O, observation; S, stock.
Measuring point: Tca, top of casing; Tco, top of cover; Hca, hole in casing.
Depth to water level below measuring point: Measured depths to water level are given in feet, tenths and hundredths; reported depths to water level are given in feet.

								Principal water-bearing bed				Measuring point				
Well number	Owner or tenant	Year drilled	Topographic location	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Character of material	Geologic source	Method of lift	Use of water	Description	Distance above or below (-) land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
11-14-1ad1	Ben Peterson	----	H	Sp	----	---	---	G	Terrace deposit	----	S	---	---	----	-----	
11-15-14dd	Leo Mauws	1917	U	Du	17.2	36	W	S,Cl	Colorado Shale	Cy,W	N	Tco	0.2	5.52	8/19/59	
24dd	Emil Olson	1952	L	Dr	100.0	6	P	Ss,Sh	Eagle Sandstone	Cy,H	N	Tca	0.5	23.75	6/25/59	
11-16-6aa	Garneill School Dist.	----	U	Du	25.7	?	W	S,G	Alluvium	Cy,H	D	Tco	0.0	12.93	7/2/59	
6bb	Wm. D. Gaugler	----	L	Dr	17.0	6	P	S,G,Cl	Alluvium	Cy,H	S	Tca	1.1	3.25	7/8/59	
15cb	Phil Bradley	----	L	Du	13.1	48	R	S,G,Cl	Claggett Formation	N	N	Tco	0.0	3.97	7/1/59	
12-12-15cd	Flanagan Ranch	----	C,H	Sp	----	---	---	Ls,Ss	Morrison Formation	----	S	---	---	----	-----	Yield 10 gpm
12-13-1dc	J. J. Steel	----	H	Du	14.5	48	C	G,S	Terrace deposit	J,E	D,S	Tco	0.2	9.05	7/29/60	
18da	Wertheimer Ranch	----	C,H	Sp	----	---	---	Ss	Kootenai Formation	----	S	---	---	----	-----	Yield 25 gpm
12-14-9bc	J. J. Steel	1961	H	Dr	675.0	2½	P	Ss	Kootenai Formation	F	S	---	---	----	-----	Yield 10 gpm
11aa	Vern Watson	----	L	Du	16.8	36	C	S,G	Alluvium	J,E	D	Tco	0.0	7.30	8/10/59	
24da2	Frank Cromer	1912	L	Du	24.3	24	T	S,Cl	Colorado Shale	Cy,H	S	Tco	1.8	17.94	8/11/59	
12-15-1bc1	Joan Renthrow	----	S	Du	12.4	24	W	S,G	Alluvium	Cy,W	S	Tco	0.0	5.42	7/17/59	
4cd	Ted Wilhelm	1955	L	Du	16.0	42	C	S,G	Alluvium	Cy,H	S	Tco	0.6	7.92	8/19/59	
6dc1	Fred Mathews	----	L	Du	17.3	24	C	G	Terrace deposit	N	N	Tco	0.1	5.60	7/21/59	
10aa3	W. J. Griffith	----	L	Dr	750.0	5	P	Sh,Ss	Colorado Shale	N	N	Tca	-0.2	16.08	7/17/59	
10bb2	----- Heiman	----	L	Du	14.7	48	W	G	Alluvium	N	N	Tco	0.2	9.79	7/16/59	
13bb	Acie McDonald	----	L	Du	36.4	36	W	G	Terrace deposit	J,E	D,S	Tca	1.3	10.61	7/14/59	
20bc	Ben Peterson	----	L	Dr	52.5	4	P	G,S	Terrace deposit	Cy,H	N	Tca	0.6	16.64	8/11/59	
12-16-16dc	Wm. Belden	1945	L	Dr	35.5	6	P	S,Cl	Colorado. Shale	Cy,E	S	Tca	1.0	7.80	7/10/59	
18aa1	Clarence Biehl	1920	L	Du	17.6	60	C	G,S	Terrace deposit	Cy,W	S	Tco	0.5	7.41	7/10/59	
30ab	Clifford Barkhoff	----	S	Du	11.9	48	C	S,G	Alluvium	Cy,E	S,O	Tco	1.3	3.71	7/9/59	
30bb3	John F. Huffman	1959	L	Dr	236.0	6	P	Sh	Colorado Shale	N	O	Tca	0.1	4.94	7/9/59	
31ac	A. Songer	1949	L	DD	20.0	44	C	G	Alluvium	N	O	Tca	0.8	4.08	7/6/59	
36ad	Raymond Luther	1900	S	Du	39.7	4½	R	G	Alluvium	Cy,H	O	Tco	0.0	36.00	7/6/59	
13-12-19bd	Arnott Ranch	1900	L	Du	18.0	36	C	G	Alluvium	Cy,W	S	Tco	1.0	14.54	8/23/61	
13-13-3aa1	Anton Roseman	----	U	Du	40.5	48	C	Ss	Kootenai Formation	N	O	Tco	0.6	29.83	7/15/60	
12cc4	Tom Watson	----	L	Du	4.5	48	B	G	Alluvium	P,H	O	Tco	0.2	2.67	8/16/60	
36cc	Ernest Olson	----	H	Dr	75.5	8	P	G	Terrace deposit	Cy,W	S	Tca	0.2	43.80	6/24/59	
13-14-4cb	Louis Rehfus	----	L	Du	31.5	48	N	G	Terrace deposit	N	N	Tco	0.3	29.57	7/24/59	
20aa	Vern Watson	----	C	Sp	----	---	---	G	Terrace deposit	----	---	---	---	----	-----	Yield 15 gpm
25bc	Newell Nish	----	L	Dr	55.2	4	P	G	Terrace deposit	N	N	Tca	0.4	54.84	8/21/59	
35da	M. A. Mathews	----	L	Du	34.5	42	N	G	Terrace deposit	Cy,W	O	Tco	0.7	29.40	7/22/59	
34dd2	Joe Barta	----	L	DD	65.0	48 to 4	W,P	G	Terrace deposit	Cy,W	I	Tco	0.0	7.78	7/22/59	
13-15-12dc	Vera Gorman	----	U	Dr	55.2	6	P	G	Terrace deposit	N	N	Tca	0.5	44.72	8/2/61	
17aa	O. A. Nesing	----	U	Dr	1,975.0	2	P	Ss	Kootenai Formation	F	S	---	---	----	-----	Yield 5 gpm
23db	Wm. S. Gaugler	----	L	Dr	14.2	6	N	G	Terrace deposit	N	N	Tco	0.7	12.96	7/29/59	
26cd2	Ida and Mabel Huether	----	L	Du	26.0	48	N	G,S	Alluvium	Cy,H	N	Tco	0.1	18.04	7/23/59	
36bb1	Gottlieb Huether	----	S	Du	19.6	36	C	S,Cl	Colorado Shale	Cy,G	I,O	Tco	2.0	11.68	7/15/59	
13-16-1ba	Mary Nessan	----	L	Dr	127.7	5	P	G	Terrace deposit	Cy,H	N	Tca	0.0	69.99	7/20/59	
8aa	Hickey Hereford Ranch	----	H	Du	24.0	36	R	S,G	Terrace deposit	N	O	Tco	1.1	20.43	7/31/59	
15aa	Trout Creek School	----	S	Du	55.7	24	?	G	Terrace deposit	Cy,H	O	Tco	0.3	51.98	7/13/59	
20bb	Louis Serucek	1915	L	Du	26.5	48	N	G	Terrace deposit	Cy,G	O	Tco	0.2	20.68	7/30/59	
23cc	Herbert E. Hart	1949	C	Du	24.8	96	R	Ss	Kootenai Formation?	C,E	D	Tco	0.0	15.18	8/6/59	
13-17-18bb	Manfred Hannah	1900	H	Dr	52.9	3	P	Ss,Cl	Kootenai Formation	N	N	Tca	1.0	29.53	8/20/59	
14-13-16cc1	Utica Women's Club	1959	L	Dr	515.0	2	P	Ss	Kootenai Formation	F	D	---	---	----	-----	Flows 15 gpm
21aa	Lear Flanagan	----	L	Dr	6.4?	8	T	S,G	Alluvium	Cy,H	N	Tca	0.1	2.50	8/8/60	
33da	Anton Roseman	----	L	Dr	46.3	6	P	Ss	Kootenai Formation	Cy,J	D,S	Hca	-7.0	20.42	8/8/60	
14-14-1dd1	Henry A. Nygren	----	H	Dr	42.0	4	P	G	Terrace deposit	C,E	D	Tca	-7.0	11.93	7/5/60	
17ab	Mrs. R. W. Brading	----	L	Du	14.5	24	W	G	Alluvium	Cy,J	D	Tca	-5.0	5.20	7/14/60	
24ab1	Joseph Hoven	1926	L	Du	9.4	24	C	G	Terrace deposit	C,E	D	Tca	1.2	5.28	6/28/60	
26cd	Robert Sayers	----	S	Du	4.6	16	P	G,Cl	Colorado Shale	N	N	Tca	1.7	3.92	9/20/60	
28bb	Mike Patte	----	L	Du	33.5	36	C	G	Terrace deposit	Cy,H	N	Tco	0.2	26.17	7/24/59	
36ac	P. J. Hoven	1958	H	Dr	1,335.0	2	P	Ss	Kootenai Formation	F	---	---	---	----	-----	Flows 6 gpm
14-15-6ca2	Town of Hobson	----	L	Du	11.0	60	R	G	Terrace deposit	C,G	I	Tco	0.5	6.91	7/15/60	
13cd1	Walter O'Brien	----	L	Dr	23.3	5	P	G	Terrace deposit	Cy,H	S	Tca	0.4	5.91	7/2/59	
18aa	Virgil McDonnell	----	H	Du	18.7	40	C	G	Terrace deposit	Cy,H	N	Tco	0.8	14.89	6/29/60	
26dd	Keith Royston	----	S	Du	8.6	48	C	G	Terrace deposit	P,H	N	Tco	-4.0	2.43	8/6/59	
28ba	Keester Miller	----	S	Dr	380.0	3	P	Ss,Sh	Colorado Shale	P,F	D,S	---	---	----	-----	Flows 2 gpm
14-16-11dd	Leo Coulter	----	L	Du	32.7	48	C	G	Terrace deposit	Cy,G	S	Tco	0.5	24.54	8/5/59	
13dd	Wm. Serucek	1949	L	Du	16.1	36	P	G	Alluvium	Cy,H	S	Tco	1.1	11.10	8/4/59	
15bb	J. J. Pospisil	----	S	Du	38.5	48	C	G,S	Terrace deposit	Cy,W	D	Tco	0.0	34.95	10/31/50	
18ab	Eddy's Corner	1958	S	Dr	1,375.0	2	P	Ss	Kootenai Formation	F	D	---	---	----	-----	Pressure 110 psi Flows 55-60 gpm
14-16-22ba	William Petri	----	L	Du	46.0	30	---	G	Terrace deposit	Cy,H	N	Tco	0.0	38.87	8/4/59	
25dc	H. A. Borcherding	----	L	Du	96.7	60	?	G	Terrace deposit	Cy,H	N	Tco	0.8	85.24	7/31/59	
28da	E. Mellicahar	----	L	Du	53.2	36	?	G	Terrace deposit	Cy,N	N	Tco	0.7	49.86	7/31/59	
32cd	----- McClelland	----	S	DD	67.8	24	C	G	Terrace deposit	Cy,W	N	Tco	0.1	65.38	7/15/59	

S E L E C T E D   R E F E R E N C E S

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

Calvert, W.R., 1909, Geology of the Lewistown coal field, Montana: U.S. Geol. Survey Bull. 390.

Crawford, J.G., 1942, Oil-field waters of Montana Plains: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 8, p. 1317-1374.

Gardner, L.S., 1959, Geology of the Lewistown area, Fergus County, Mont: U.S. Geol. Survey Oil and Gas Inv. Map OM-199.

Imlay, R.W., Gardner, L.S., Rogers, C.P., Jr., and Hadley, H.D., 1948, Marine Jurassic Formations of Montana: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 32.

Miller, R.N., 1959, Geology of the South Moccasin Mountains, Fergus County, Mont: Montana Bur. Mines and Geology Mem. 37.

Perry, E.S., 1932, Ground-water resources of Judith Basin, Montana: Montana Bur. Mines and Geology Mem. 7.

Perry, E.S., and Sloss, L.L., 1943, Big Snowy Group: Lithology and correlation in the northern Great Plains: Am. Assoc. Petroleum Geologists Bull., v. 27, p. 1287-1304.

Reeves, Frank, 1930, Geology of the Big Snowy Mountains, Montana: U.S. Geol. Survey Prof. Paper 165-D, p. 135-149.

Vine, J.D., 1956, Geology of the Stanford-Hobson area, central Montana: U.S. Geol. Survey Bull. 1027-J.

Vine, J.D., and Hail, W.J., Jr., 1950, Geologic map of the Hobson area, central Montana: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 108.

Walton, P.T., 1946, Ellis, Amsden, and Big Snowy Group, Judith Basin, Montana: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 8, p. 1294-1304.

Weed, W.H., 1899a, Fort Benton, Montana: U.S. Geol. Survey Atlas Folio 55.

____________ 1899b, Little Belt Mountains, Montana: U.S. Geol. Survey Geol. Atlas Folio 56.

____________ 1900, Geology of the Little Belt Mountains, Montana: U.S. Geol. Survey Ann. Rept. 20, pt. 3, p. 257-461.

THE MONTANA BUREAU OF MINES AND GEOLOGY IS A PUBLIC SERVICE AGENCY FOR THE STATE OF MONTANA. ITS PURPOSE IS TO ASSIST IN DEVELOPING THE STATE'S MINERAL RESOURCES. IT CONDUCTS FIELD STUDIES OF MONTANA GEOLOGY AND MINERAL DEPOSITS, INCLUDING METALS, OIL AND GAS, COAL, OTHER NON-METALLIC MINERALS, AND GROUND-WATER. IT ALSO CARRIES OUT RESEARCH IN MINERAL BENEFICIATION, EXTRACTIVE METALLURGY, AND ECONOMIC PROBLEMS CONNECTED WITH THE MINERAL INDUSTRY IN MONTANA. THE RESULTS OF THESE STUDIES ARE PUBLISHED IN REPORTS SUCH AS THIS.

FOR FURTHER INFORMATION, ADDRESS THE DIRECTOR, MONTANA BUREAU OF MINES AND GEOLOGY, MONTANA SCHOOL OF MINES, BUTTE.

MONTANA BUREAU OF MINES AND GEOLOGY * 1919 *