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

BULLETIN 19

PRELIMINARY REPORT ON THE

GEOLOGY AND GROUND-WATER RESOURCES OF NORTHERN BLAINE COUNTY, 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, 1960

CONTENTS

ILLUSTRATIONS

TABLES

PRELIMINARY REPORT ON THE GEOLOGY AND GROUND WATER OF NORTHEASTERN BLAINE COUNTY, MONTANA

By

Everett A. Zimmerman

ABSTRACT

The geology and ground-water resources of northeastern Blaine County were investigated under a cooperative program between the U. S. Geological Survey and the Montana Bureau of Mines and Geology. The area includes rocks ranging in age from Late Cretaceous to Recent.

Limited supplies of ground water can be obtained from the Judith River, Fox Hills, and Hell Creek formations of Cretaceous age and deposits of Pleistocene and Recent age. Large supplies of water of good quality are available from the Flaxville formation, which underlies the Big Flat. The only source of recharge to the aquifer is precipitation falling on the plateau which it underlies. It is estimated that 5,000 acre-feet of recharge is available for use from the Flaxville formation. Approximately 300,000 acre-feet of ground water is in storage and depletion of the aquifer is not imminent under present patterns of water use.

INTRODUCTION

Increasing water requirements for irrigation, industry, and domestic use in Montana have necessitated an evaluation of its water resources. The total water resources available for use by man are: (1) surface water, the water that is visible in streams, lakes, and reservoirs; (2) ground water, the water in the zone of saturation beneath the land surface; and (3) rain and snow which are the ultimate source of both surface water and ground water. This report, as a part of a program for the development, conservation, and use of the water resources of Montana, summarizes the results to date of an investigation of the ground-water resources of northeastern Blaine County. It is based on studies made between June 1957 and November 1959. Pending publication of a final report, progressively more detailed information will become available at the offices of the Montana State Bureau of Mines at Butte and the U. S. Geological Survey in Billings.

The investigation was made by the Geological Survey in cooperation with the Montana Bureau of Mines and Geology. It is one of a series of investigations begun since the 1955 Montana State Legislature first appropriated funds to the Montana Bureau of Mines and Geology for cooperation with the Geological Survey to investigate the availability and quality of the ground water of the State. (See fig. 1.) The Federal Government and the State of Montana share equally the cost of these cooperative investigations.

The general purpose of this investigation is to appraise the ground-water resources of northeastern Blaine County. The objectives were to determine (1) the character and extent of the water-bearing rocks; (2) the mode of occurrence, direction of movement, and the availability of ground water; (3) the annual, seasonal, and long-term fluctuations in the amount of water in storage underground; (4) the chemical quality of the water; and (5) the areas from which substantial supplies of ground water of good quality can be obtained.

The wells cited in this report are numbered according to their location within the U. S. Bureau of Land Management's survey of the area. (See fig. 2) As all wells lie within the northeast quadrant of the Montana Principal Meridian and Base Line system, the prefix letter A is omitted for convenience. 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. Lowercase letters after the section number indicate the location of the well within the quarter section and the quarter-quarter section, respectively. The lowercase letters are assigned in a counterclockwise direction, beginning in the northeast quadrant. If two or more wells are located within the same quarter-quarter section, suffix serial numbers assigned in the order that the wells were inventoried are added to the well numbers. Springs and surface-water sampling points are numbered in the same manner.

Appreciation is expressed to the residents of northeastern Blaine County and to the organizations and agencies that contributed to this investigation. Special thanks are given to residents who freely supplied information and permitted access to their wells and land.

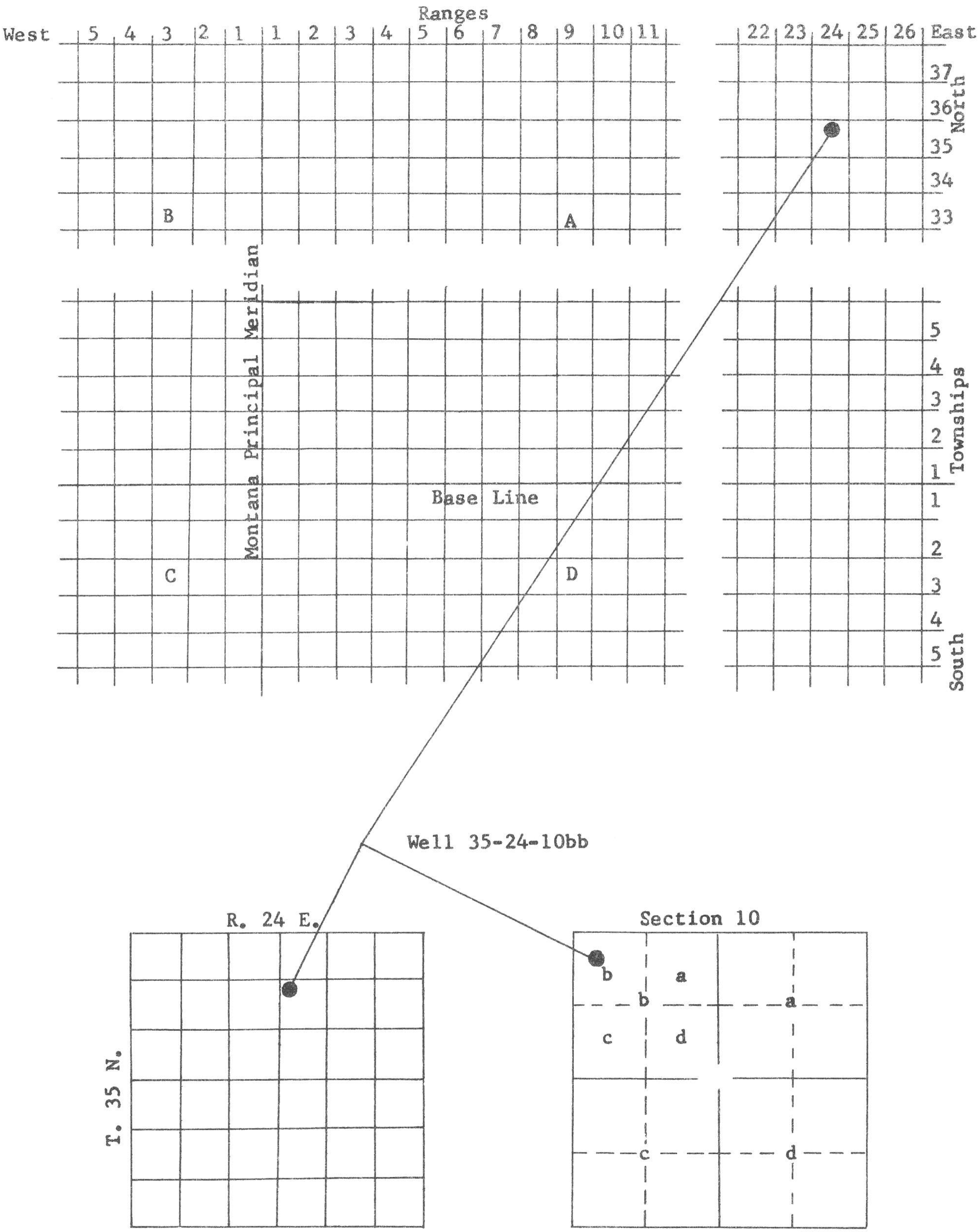

Figure 2.--Sketch showing well-numbering system

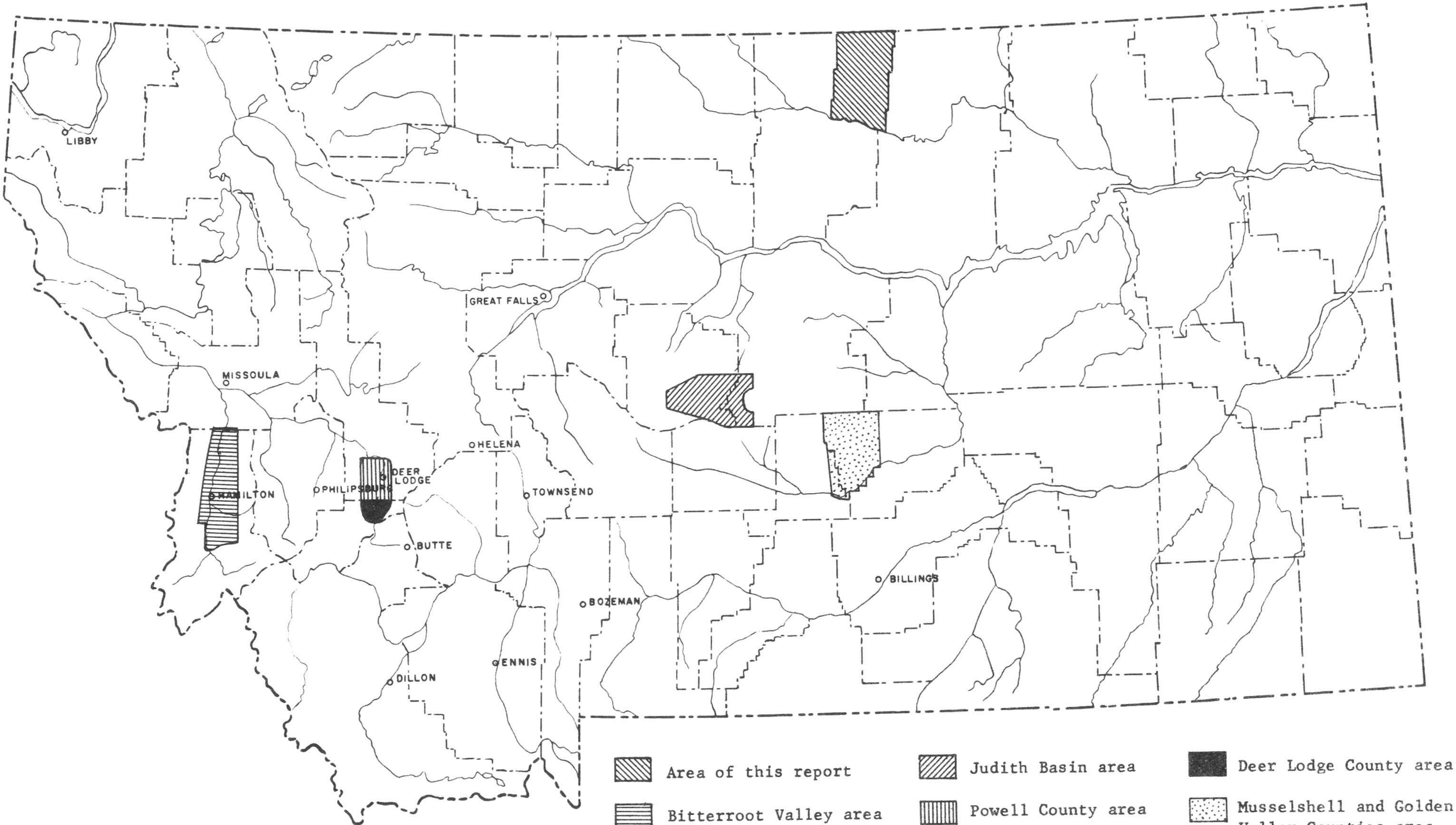

Figure 1.--Map of Montana showing the location of cooperative ground-water investigations, 1955-60.

PREVIOUS INVESTIGATIONS

The geology of part of northeastern Blaine County was first described by L. J. Pepperberg (1908) in his report on the Milk River coal field. A. J. Collier and W. J. Thom, Jr. prepared a report (1917) entitled "The Flaxville gravel and its relation to other terrace gravels of the northern Great Plains" in which this as well as several other areas were discussed. Northeastern Blaine County is included in several studies of larger areas such as F. H. Calhoun's "The Montana lobe of the Keewatin ice sheet" (1906) and W. C. Alden's "Physiography and glacial geology of eastern Montana and adjacent areas" (1932). In addition to these published papers the writer was permitted the use of an unpublished map by Roger Colton based on photogeologic reconnaissance of the glacial geology of eastern Montana.

GEOGRAPHY

The 830 square miles of northeastern Blaine County, covered in this report, lie in the glaciated part of the Great Plains. Boundaries for this study are the township line between Ts. 22 and 23 E. on the west, the Milk River on the south, the Blaine-Phillips County line on the east, and the U. S. - Canadian boundary on the north. (See fig. 1 and pl. 1.)

The population of Blaine County was 8,516 in 1950. Within the study area are the towns of Harlem with a population of 1,107, Turner with 175, and Hogeland with 125.

The climate of northeastern Blaine County is characterized by cold winters, hot summers, moderate wind, and light precipitation. Large daily and seasonal temperature fluctuations are common.

CLIMATIC DATA FOR HARLEM

Average annual temperature	42° F.
Highest recorded temperature (Aug. 12, 1940)	107° F.
Lowest recorded temperature (Feb. 15, 1936)	-50° F.
Average length of growing season	124 days
Average date of last killing frost	May 19
Average date of first killing frost	Sept. 20
Average annual precipitation	12.68 in.

The heaviest precipitation, about 26% of total, normally falls in May and June.

The Milk River drains the area studied. Approximately the southern third is drained by five small ephemeral streams flowing southeastward to the Milk River. The remainder is drained to the north and east and thence to the Milk River. Drainage has been only partly restored since glaciation; parts of the area are characterized by undrained shallow depressions.

Agriculture is the principal industry in northeastern Blaine County. Irrigation farming is confined to the Milk River valley except for the small acreage presently irrigated by ground water. The principal crops grown with irrigation are forage crops, sugar beets, potatoes, and grains. The raising of livestock is important in the economy of the irrigated portions of the area. The non-irrigated land is used for livestock pasture and small-grain farming.

Northeastern Blaine County may be divided into four physiographic sectors: (a) the Milk River valley; (b) a gently rolling glaciated plain to the north of the Milk River valley; (c) an elevated plateau; and (d) an irregular glaciated plain. (See fig. 3.) The Milk River valley is a broad nearly level flood plain along the Milk River. North of the valley a rolling glaciated plain rises toward the north. This plain is incised by a number of tributary streams occupying trench-like valleys and by channels once occupied by streams of glacial meltwater but now dry except for ephemeral lakes and small ephemeral streams.

A broad, gently rolling plateau bounds the glaciated plain on the north. Glacial deposits also cover the surface of this plateau but their topographic expression is subdued. Some early workers called this plateau The Boundary Plateau but local usage terms it the "Big Flat." Local usage is followed in this paper.

The Big Flat is bounded on the north by Woody Island coulee which is a broad incised valley eroded by glacial meltwater and now occupied by one small intermittent creek. North of Woody Island coulee are glacial deposits left by stagnant, melting ice. The topographic expression of these deposits is a patternless assemblage of hillocks with small wet-weather ponds occupying low places among them. These hillocks extend northward into Canada.

GROUND WATER

Occurrence

Because water beneath the earth's surface is hidden, it is often regarded as shrouded in mystery. Many varied and fanciful explanations as to its source and occurrence have been advanced. However, scientific study shows that ground water is an important part of the hydrologic cycle (see fig. 4) and obeys certain physical laws and principles. These laws and principles are, in general, simple and easily understood, although they may be complex in detail.

The rocks and unconsolidated overburden that form the outer crust of the earth generally contain many voids or interstices.

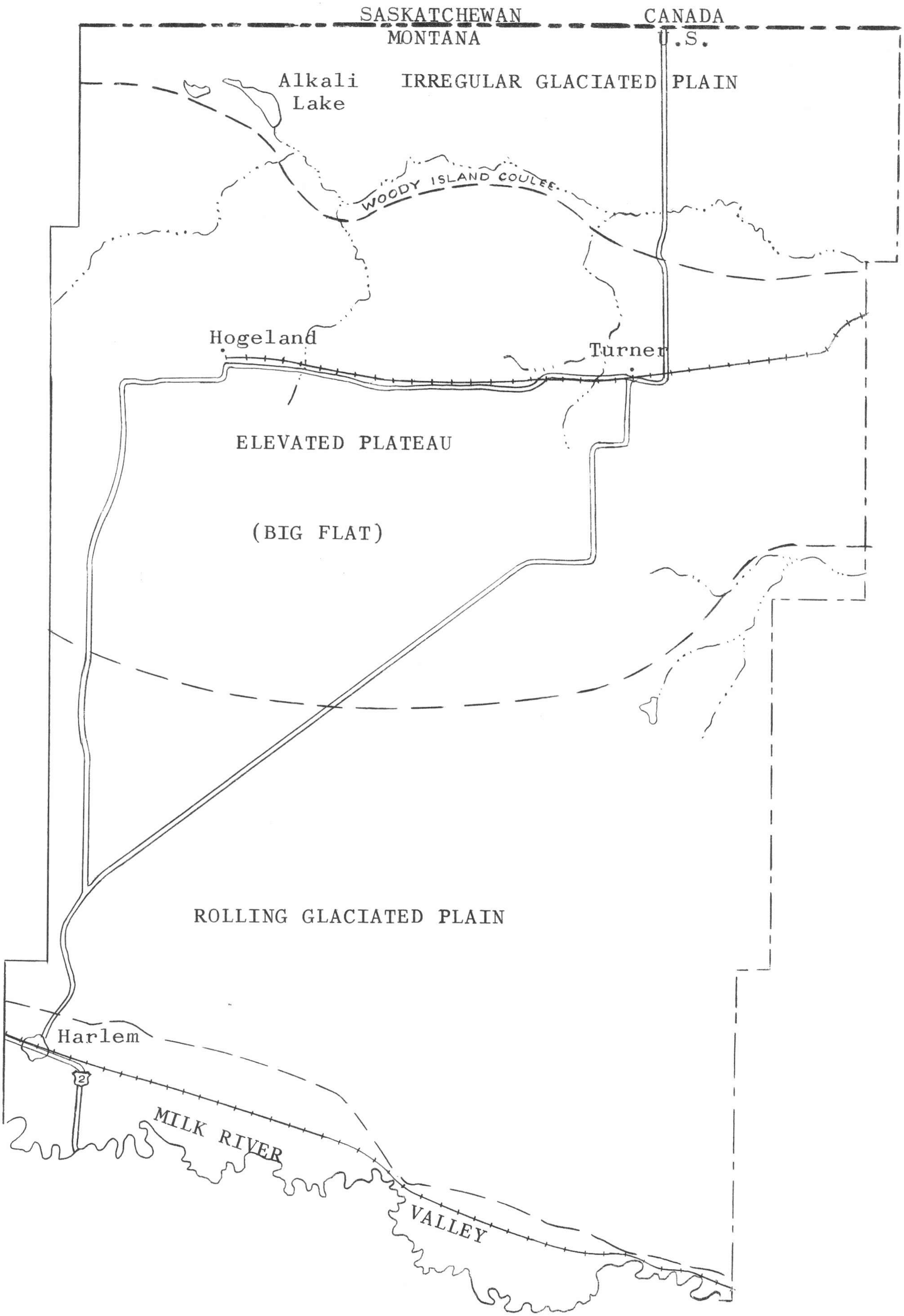

Figure 3.--Sketch map showing physiographic sectors of area studied.

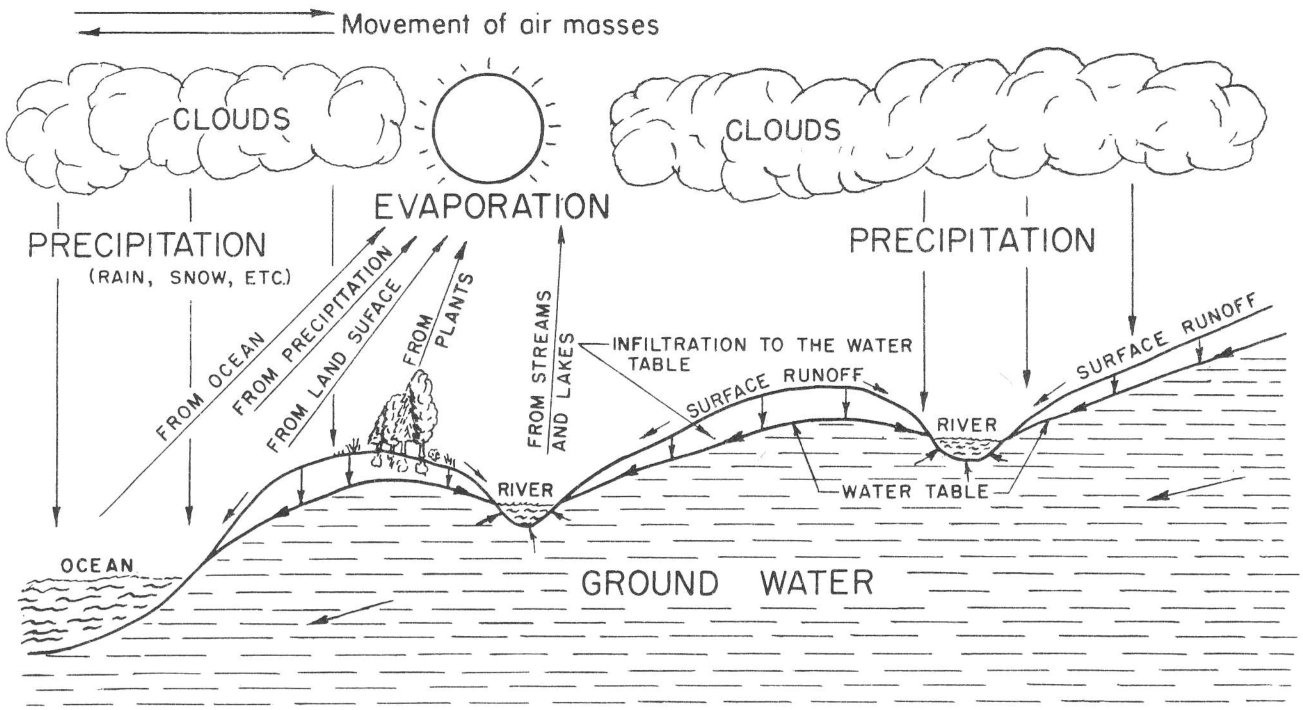

Figure 4.--Hydrologic cycle.

Below a certain level these voids are filled with water and form vast underground reservoirs for the storage and conduits for the transmission of water. This reservoir is replenished by downward percolation of water from precipitation and by seepage from irrigation water, streams, and canals. It is depleted by discharge to the earth's surface through springs, wells, and effluent streams, or to the atmosphere by evaporation and transpiration.

The water in an underground reservoir may be under either artesian or water-table conditions. A formation, group of formations, or part of a formation that may yield ground water in useful quantities is called an aquifer. Ground water that rises in a well above the point at which it is first encountered in an aquifer is called artesian water. If the hydrostatic pressure in the aquifer is sufficient to cause the water to flow at the ground surface the well is called a flowing artesian well. If ground water does not rise in wells above the level at which it is encountered in drilling it is said to be under water-table conditions. Both artesian and water-table conditions occur in northeastern Blaine County.

Hydrologic Properties of Aquifers

The hydrologic properties of an aquifer are governed by the size, shape, and degree of interconnection of the voids, and by the confinement or lack of confinement of the aquifer. These properties control the movement of ground water through the encompassing rock material from its point or area of intake to its point or area of discharge and the ability of the aquifer to take water into and release it from storage. In general, coarse size, roundness, and uniformity in size favor the ability of a formation to absorb and transmit water if the formation is composed of clastic material. In addition to these factors are secondary voids such as cracks, fissures, and solution cavities that make any kind of rock more permeable. The principal aquifers in northeastern Blaine County are clastic sandstone, sand, and gravel beds.

Recharge and Movement

The water table does not remain stationary but rises and falls as does the water level of a surface reservoir. A rising water table indicates that the recharge, the addition of water to the underground reservoir, is greater than the discharge in that area; conversely, a falling water table indicates that discharge is greater than recharge. The water table fluctuates more by the addition or discharge of a certain 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.

Ground water generally is moving, continuously but slowly, from places of recharge to places of discharge. Ground water moves down a so-called 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 low elevation or low pressure head. Ground water in northeastern Blaine County moves downstream and generally toward the stream in the stream alluvium and principally toward the northeast in the Flaxville formation. The rate of movement of ground water is slow in comparison to the rate of movement of water on the land surface. Under a gradient of 10 feet to the mile, the rate of movement may range from less than 1 foot per year in clay to about 4 miles per year in clean, coarse gravel. In contrast, a surface stream under the same gradient may move several miles per hour.

Storage and Discharge

Changes in water levels reflect changes in the amount of ground water in storage. Fluctuations of the water table in the area were determined by periodic measurements of 21 wells. The records of these measurements are on file at the U. S. Geological Survey office in Billings.

Ground water may be discharged from the zone of saturation by evaporation, transpiration, or by hydraulic discharge through streams, drains, springs, seeps, or wells. Discharge by evaporation and transpiration is relatively great along stream courses and in poorly drained areas, such as those in the Milk River valley. At some places, as along Woody Island coulee where water-bearing rocks have been exposed by erosion, water drains out in the form of numerous seeps and springs. Much of this water is lost to evaporation and transpiration by water-loving plants during the warm growing season between May and September. In the fall and winter when frost and cool weather have killed off plants and reduced evaporation, there is an increase in the discharge of the springs. At present, the amount of water discharged by natural means greatly exceeds that withdrawn by wells. In any ground-water system the amount of water discharged must, over a long period, balance the amount imbibed by the aquifer. If discharge by one means is increased without a corresponding increase in recharge, the amount discharged by the other means will be reduced.

GEOLOGY AND ITS RELATIONSHIP TO GROUND WATER

Sedimentary rocks ranging in age from Cambrian to Recent underlie northeastern Blaine County. Of these, only those of Late Cretaceous age and younger crop out in the study area. These are: the Montana group consisting of the Judith River formation, the Bearpaw shale, and the Fox Hills sandstone, and the Hell Creek formation of Late Cretaceous age; the Flaxville formation of Miocene or Pliocene age; the glacial and glacio-fluvial deposits of Pleistocene age; and the alluvium of Recent age. The stratigraphic relations, lithology, and water-bearing properties of these formations are shown in table 1. Their relation to the topography is illustrated in figure 5.

Rocks Older Than Late Cretaceous Age

Deeper unexposed formations underlying northeastern Blaine County have not yet been developed as important sources of ground water. It is, however, probable that in the future these formations may be considered as water sources. One of these unexposed formations that has in many places displayed ability to produce large quantities of moderately mineralized water is the Mission Canyon limestone of the Madison group. This white massive limestone of Mississippian age has yielded copious flows of water to numerous oil tests in eastern Montana. On several occasions the flow proved difficult to control. The limestone itself is nearly impermeable but the upper part is jointed and cavernous. These joints and caverns can transmit water at a high rate. Thus, if a hole happens to penetrate one of the joints or caverns a large amount of water may be obtained; if no joint or cavern is penetrated, however, little or no water will be found. No method by which the location of these voids may be determined before drilling is now known. The formation is buried at a depth of from about 3,900 to 4,800 feet below the study area. Thus, development of ground water from the Mission Canyon limestone is an expensive and risky undertaking.

Upper Cretaceous Rocks

The Judith River formation of Late Cretaceous age, the oldest formation exposed in northeastern Blaine County, consists of about 400 feet of lenticular beds of sandstone, shale, clay, and coal. These beds are predominantly light in color but contain many brown ferruginous concretions and some beds are cemented with

Table 1.--Stratigraphic units and their water-bearing properties, Northeastern Blaine County, Montana

System	Series	Formation	Approx. max. thickness (feet)	Lithologic character	Water supply
Quaternary	Recent	Alluvium, lake, and pond deposits	200	Unconsolidated gravel, sand, silt, and clay. Alluvium underlies stream valleys. Paludal sediments floor numerous undrained depressions.	Alluvium in Milk River valley locally yields moderate supplies of highly mineralized water. Alluvium in tributary valleys is variable in its water-bearing characteristics but locally provides moderate supplies of water of fair quality. Paludal deposits are too thin and fine-grained to be a source of ground water.
	Pleistocene	Glacial deposits (Kames, eskers, ice-contact deposits, and outwash deposits)	100	Unsorted clay, silt, sand, gravel, and boulders (glacial till) and stratified deposits of sand and gravel.	Wells in glacial till yield little water. Saturated stratified deposits may yield moderate supplies.
Tertiary	Miocene or Pliocene	Flaxville formation	75	Well-rounded, moderately well sorted, generally unconsolidated beds of sand and quartzite and argillite pebbles and cobbles.	Yields moderate to large amounts of water of good quality.
Cretaceous	Upper Cretaceous	Hell Creek formation	200	Interbedded tan and gray sandstone and shale with a few thin lignite beds. Numerous brown concretions in places.	Yields small to moderate amounts of water of fair quality.
		Montana group: Fox Hills sandstone	100	Fine-grained, friable, gray sandstone containing a few marine fossils.	Untested as an aquifer in the study area but probably may yield small quantities of water.
		Montana group: Bearpaw shale	1,000	Dark bluish-gray to brown, marine shale containing numerous concretions and thin beds of white or gray bentonite.	Essentially non-water-bearing.
		Montana group: Judith River formation	400	Light-colored continental and brackish-water deposits of lenticular sandstone, shale, and clay, with some lignite.	Yields small to moderate amounts of water. Water rather highly mineralized but may be used for stock and domestic purposes.

brown ferruginous material. Approximately the upper 200 feet of the formation is exposed in the southeastern part of the area. The Judith River formation supplies water to only a few wells in northeastern Blaine County and these wells provide only enough water for stock and domestic use.

The Judith River formation is overlain by approximately 1,000 feet of blue-black shale containing numerous ironstone concretions and bentonite beds which constitute the Bearpaw shale of Late Cretaceous age. This formation, which underlies most of northeastern Blaine County, is not a favorable source of ground water.

The Fox Hills sandstone of Late Cretaceous age overlies the Bearpaw shale. The formation has a thickness of about 100 feet but is exposed only in a few places along Woody Island coulee. The formation consists largely of gray fine-grained friable marine sandstone with a few fossils. The formation has not been tapped as a source of ground water in northeastern Blaine County largely because it is overlain by aquifers capable of producing relatively abundant supplies of water. The general lithology of the formation suggests that it may yield enough water for domestic and stock use.

Overlying the Fox Hills sandstone is the Hell Creek formation, also of Late Cretaceous age. This formation, like the Fox Hills sandstone, crops out discontinuously in only a few places in the western part of the Big Flat. White, light-brown, and gray sandstone, clay, shale, and a few thin coal beds constitute the formation. It may be distinguished from the underlying marine Fox Hills by the brown color of some of its beds, the presence of coal beds, and land plant remnants that form the nucleus of small brown concretions. The formation provides water to a few wells in the western part of the Big Flat. The water is adequate both in quantity and quality for limited domestic use.

Tertiary Flaxville Formation

Overlying the eroded surface of the Hell Creek formation, the Fox Hills sandstone, and the Bearpaw shale is a layer of sand and gravel, as much as 75 feet thick, called the Flaxville formation. (Colton, R. B., in press, Geology of the Otter Creek quadrangle, Montana, U. S. Geol. Survey Geologic Quadrangle Series.) The sand and gravel composing this formation is generally unconsolidated and consists of well-rounded quartzite and argillite pebbles and cobbles in a matrix of medium-grained sand. The proportion of sand to gravel differs from place-to-place within the formation. In some places, the formation is partially cemented by calcite.

The gravel constituting the Flaxville is believed to have been derived by the reworking of the Cypress Hills beds of Oligocene age, which in turn were derived from the erosion of the Rocky Mountains. The Flaxville formation has been dated as Miocene or Pliocene on the basis of a few widely scattered vertebrate fossils.

The Flaxville formation is the most productive aquifer in northeastern Blaine County. It provides water for domestic and stock use for many farms on the Big Flat. Since 1957 a number of irrigation wells with yields up to 1,200 gpm (gallons per minute) have been drilled to tap the Flaxville. Because the Flaxville underlies an elevated plateau, recharge to the formation is entirely derived from precipitation on the plateau surface. This precipitation is light and consequently recharge to the formation is small. These facts have led to alarm among some residents about the possible depletion of the aquifer by heavy pumping for irrigation. This problem has been considered, although danger of this happening does not appear imminent.

The Flaxville formation underlies about 100,000 acres on the Big Flat. The average annual precipitation is about 12 inches and probably about 5 percent of this infiltrates to the aquifer. Thus it is estimated that about 5,000 acre-feet (an acre foot will cover 1 acre to a depth of 1 foot) a year now recharges the aquifer under the Big Flat. This water is discharged by springs, wells, and transpiration by plants, where the water is within reach of the roots. If the discharge by any one of these is increased, it must be at the expense of the others, or water must be withdrawn from storage.

Water has been accumulating for many years in the groundwater reservoir underlying the Big Flat. Before the advent of man a state of equilibrium had been reached and the amount of recharge was balanced by the amount of discharge. Water use by man, to date, has done little to disturb this equilibrium because water use, until the advent of the irrigation wells in 1957, amounted only to a few acre-feet a year at most.

If an average saturated thickness of 15 feet of gravel underlies the Big Flat and has a porosity of 20 percent, then about 300,000 acre-feet of water is in storage in the Flaxville formation under the Big Flat. Water is constantly spilling from this storage to supply the numerous seeps and springs along Woody Island coulee. After periods of above-normal precipitation and the accompanying increase in recharge, the discharge from the ground-water reservoir through the seeps and springs also increases, according to local reports.

The growing season on the Big Flat is short and this places a limit on the crops it is possible to raise. Raising of small grains by dry-land methods has been successful in the area, farms are large and investments in farming equipment which would not be suitable for irrigated crops are great. These factors make it unlikely that any large increase in acreages irrigated by wells will take place in the near future on the Big Flat.

With the 5,000 acre-feet of recharge each year it should be possible to apply light irrigation for at least 7,000 acres of land. Part of the water pumped from the irrigation wells may be expected to percolate back into the ground-water reservoir. With the 300,000 acre-feet of water in storage in the gravel aquifer it would be possible to pump somewhat more water than the average annual recharge for a long period before serious depletion of the aquifer would take place.

The fact that the Flaxville formation is nowhere more than 75 feet thick will serve to limit the amount of water that can be withdrawn by irrigation wells. Large-capacity wells develop broad cones of depression in this aquifer when pumped continuously for the irrigation season. Because of the local lenticularity of the Flaxville formation, large capacity wells should be located at least 1 mile apart to avoid major mutual interference.

Post-Flaxville Formation and Pre-Pleistocene Interval

A period of erosion followed the deposition of the Flaxville formation. The land surface was dissected to leave the Flaxville, which was deposited as a broad flood plain, capping a plateau. At some time during this interval the Missouri River established a course that is now, except for minor deviations, followed by the Milk River. During the course of erosion one or more minor gravel terraces were formed below the surface of the Flaxville formation and above the present river flood plain. Subsequent erosion has nearly destroyed all traces of these minor terraces.

During the period that the Missouri River flowed through the valley now occupied by the Milk River, it deposited gravel, sand, and silt which have since been covered by flood-plain deposits of the Milk River. (See fig. 5.) Several wells and test holes drilled in the valley have penetrated these deposits and some wells obtain water from these buried Missouri River alluvial deposits. Locally the chemical quality of the water makes it unsuitable for domestic, stock, and irrigation use.

Pleistocene Deposits

During several stages of the Pleistocene epoch, glaciers moved south and southeastward from Canada across northeastern Blaine County. As the glaciers occupied the valley of the ancient Missouri River, the river was forced to make a new channel south of the ice front. Intermixed with the ice of the glacier was a great amount of rock material picked up and incorporated in the glacier as it moved. When the ice melted this material was left as a heterogeneous deposit up to 100 feet thick. This material, called glacial till, is shown on plate 1 as ground moraine, except in a few places where it forms recessional moraines. Because the material was not uniformly distributed in the glacial ice and because the ice did not melt evenly the surface of the moraine was very irregular. This irregularity is characteristic of the ground moraine today.

The glacial till is generally unfavorable as a source of ground water, although a few wells obtain small amounts of water from it.

During the melting of the glaciers, water drained over the ice, through tunnels under the ice, and through channels melted through the ice. The melt-water streams were heavily loaded with rock material which had been suspended in the ice. As it flowed, the water dropped the coarser fractions in the channels and carried the finer particles away. Thus, moderately-sorted sand and gravel deposits were left to mark the water courses. These deposits are shown on plate 1 as ice-contact, outwash terrace, and outwash deposits. The ice-contact deposits also include esker deposits, if the deposits were laid down in channels on or under the ice, or kames, if the deposits were formed by water flowing along or over the edge of the ice. The outwash or outwash terrace deposits were laid down in channels leading away from the ice. Variations in the rate of melting and consequent variations in the carrying capacity of the melt-water streams are believed to account for the alternate downcutting and deposition that resulted in the formation of a series of outwash terraces above the present bottoms of some outwash channels. Melt-water deposits are generally favorable sources of ground water where they are topographically low enough to extend below the water table. They are not now developed as ground-water sources in this area.

Recent Deposits

Following the melting of the last glacier the Milk River occupied the pre-glacial channel of the Missouri River and established a tributary system to drain the area. (See fig. 5.) Some of the tributary streams occupied glacial melt-water channels and others have eroded their own channels. The stream valleys are now floored with stream deposits of gravel, sand, clay, and silt which are mapped as alluvium. The alluvium in the tributary valleys generally contains a higher proportion of sand and gravel than that in the Milk River valley which has been laid down as a flood-plain deposit. Alluvium in the tributary valleys yields enough water for stock and domestic purposes whereas that in the Milk River valley does not.

Because of the irregularity of the surface of the glacial till, drainage has been established slowly and is yet uncoordinated. Much of the water draining off the till flows into small usually ephemeral ponds and lakes. Clay and silt have been eroded from the till into these ponds and deposited there. The deposits are ordinarily too thin and too small in area to map. However a few such deposits are large enough and thick enough to map. These are shown on plate 1 as Paludal deposits. They are too impermeable to yield water to wells hence are of no value as aquifers.

Erosion on hillsides results in the accumulation of unconsolidated material of a very heterogeneous material called colluvium at the foot of hill slopes. This material is nearly ubiquitous but has only been mapped on plate 1 where it is widespread and thick enough to obscure the underlying rocks. Because of its heterogeneity it is generally of low permeability hence is not a likely source of water.

CHEMICAL QUALITY OF THE WATER

The extent to which water resources can be utilized depends on the quality as well as the quantity of the available water. As part of the ground-water investigation, a study was made to determine the chemical quality of the water and to evaluate the suitability of the water for agricultural, domestic, and industrial uses. The results of the analyses of 13 ground-water and 2 surface-water samples collected in October 1959 and of 3 analyses of ground water provided by residents of the area are shown in table 2. The location of sampling points is shown on plate 1. The data pertain only to the dissolved mineral substances in the water and not to the sanitary condition of the water.

Ground water in the report area is moderately to highly mineralized. The content of dissovled solids ranges from 293 ppm (parts per million) to 4,440 ppm in ground water and 5,930 ppm in water from Alkali Lake, an aptly-named lake in the northwest part of the area. The highest concentrations of dissolved solids in ground water are in the samples collected from wells tapping the combined Missouri and Milk River alluviums. The lowest concentrations were found in the samples collected from wells in the Flaxville formation. Water from outwash gravel is similar to that from the Flaxville. Water from two wells in the Judith River formation had dissolved solids of 1,560 and 2,760 ppm. Water from two wells in the Hell Creek formation is moderately mineralized having 891 and 975 ppm of dissolved solids.

Table 2.--Chemical analyses of ground and surface waters in northeastern Blaine County, Montana

(Analyses in parts per million, except as indicated)

Number	Depth of well or other source.	Water-bearing formation 1/.	Date of collection.	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids Residue at 180°C	Hardness as $CaCO_3$	Percent sodium	Specific conductance (micro-mhos at 25°C)	pH	Sodium-adsorption-ratio.
31-24-1da	145	Qal	10/59	47	18	5.9	60	26	898	5.3	1030	978	287	1.0	7.0	1.6	2880	258	88	4120	7.6	24
31-25-13ac	167	Kjr	10/59	47	10	2.2	15	7.4	930	4.5	919	1030	221	3.2	.7	2.5	2760	68	96	3960	7.6	49
*31-25-21ad	100	Qal	2/47	-	31	.4	76	26	1298		732	2190	160	-	-	-	3970	297	-	-	-	-
32-23-26bc	70	Qal	10/59	47	20	9.4	185	133	1050	7.5	964	2320	115	.7	3.1	1.9	4440	1010	69	5470	7.3	14
32-23-26cc	130	Qal	10/59	50	8.4	3.3	19	5.5	1070	7.5	999	1390	134	1.0	7.5	2.5	3180	70	97	4420	7.8	56
32-23-31ab	70	Qal	10/59	50	19	6.9	69	34	685	6.6	710	1160	51	1.6	3.0	2.3	2410	312	82	3300	7.7	17
*32-23-36ac	120	Qal	5/48	-	144	5.0	68	32	897		915	1314	88	-	-	-	3040	301	-	-	-	-
32-24-33dc	240	Qal	10/59	47	7.5	1.8	19	6	1250	4.9	582	2200	69	.6	7.6	1.6	3920	72	97	5220	7.7	64
*34-23-1ab	240	Khc?	4/47	-	15	.8	20	8	325		406	318	51	-	-	-	975	83	-	-	-	-
34-24-13cd	1210	Kjr	10/59	51	10	.5	2.4	1.9	609	2.4	953	279	166	4.5	3.9	3.6	1560	14	99	2420	8.0	71
35-24-10bb	49	Tf	10/59	46	17	.02	27	30	37	3.4	253	52	7.4	.6	2.3	.09	293	190	29	505	7.6	29
35-25-27dd	22	Tf	10/59	48	21	.14	87	46	69	5.4	318	229	24	.4	41	.13	700	406	27	1000	7.3	1.5
36-23-25ad	49	Tf	10/59	49	16	.4	75	88	266	5.2	310	737	85	.6	21	.28	1540	549	51	2080	7.5	4.9
36-23-30ac	225	Khc	10/59	45	12	3.2	58	48	200	5.7	684	210	11	.3	1.3	.43	891	341	56	1360	7.6	4.7
36-26-33da	39	Tf	10/59	46	20	.12	46	39	89	5.2	316	161	31	.8	7.5	.13	557	274	41	883	7.5	2.3
37-23-12cb	Spring	Qow	10/59	47	13	.08	39	30	99	6.2	252	205	16	.4	8.9	.17	556	221	48	852	7.1	2.9
37-23-13db	Alkali Lake		10/59	47	4.2	.01	5.0	38	1850	171	650	2340	1060	.3	.3	6.4	5930	168	91	8310	8.7	61
37-25-35bd	Woody Island Coulee Stream		10/59	40	13	.02	39	40	169	6.4	465	239	20	.6	.5	.3	769	264	58	1180	8.0	4.5

*Analysis furnished by owner.

1/Water-bearing formations: Kjr., Judith River; Khc., Hell Creek; Tf., Flaxville gravel; Qow., Outwash; Qal., Alluvium.

The water sampled in the report area was generally of the sodium sulfate bicarbonate type. The predominance of sodium in the water is probably due to direct solution of sodium salts in the rocks and, in part, to cation-exchange reactions, whereby calcium and magnesium in the water are exchanged for sodium from the rocks. In general, water from the Judith River, Hell Creek, and Flaxville formations is highest in bicarbonate content and that from alluvium is highest in sulfate content.

Ground water from the Flaxville is well suited for irrigation. Ground water from all other formations is poorly suited for irrigation because of its high mineralization; sodium is the predominant cation, and boron is present in excess of optimum amounts in many samples.

The U. S. Public Health Service has established standards of quality for drinking water used on interstate carriers. Water for domestic supplies in the area commonly is obtained from the Flaxville, Hell Creek, and Judith River formations. Of the waters sampled, only that from the Flaxville meets Public Health Service standards. Although some of the water used for domestic purposes is more mineralized than Public Health Service standards recommend for drinking water, residents in the area have become accustomed to the water and have suffered no apparent harm. Water from the Judith River formation, however, contains fluoride in high enough concentrations to cause mottling of the teeth of children. The presence of relatively high concentrations of nitrate in water from wells 35-25-27dd and 36-23-25ad suggests possible pollution.

Water to be used by stock is subject to limitations of quality of the same type as those relating to quality of drinking water for human consumption. However, most animals are able to use water of much higher mineralization than would be considered satisfactory for humans. In general, an arbitrary limit of 5,000 ppm of dissolved solids has been set for water to be used for livestock. All samples collected, except that from Alkali Lake, have concentrations lower than this. However, because of the predominance of sodium, magnesium, and sulfate, water from the alluvium is considered a rather poor water for livestock.

SELECTED REFERENCES

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U. S. Geol. Survey Prof. Paper 174, 133 p., 19 figs., 51 pls.

Calhoun, F. H., 1906, The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, 59 p., 7 pls.

Collier, A. J., and Thom, W. T., Jr., 1917, The Flaxville gravel and its relation to other terrace gravels of the northern Great Plains: U. S. Geol. Survey Prof. Paper 108-J, p. 179-184, pls. 62-65.

Colton, R. B., 1956, Glacial geology of northeastern Montana: unpublished map.

Davis, N. B., 1918, Clay resources of southern Saskatchewan: Canada Dept. Mines, Mines Branch Rept., p. 11.

McGuinness, C. L., 1951, The water situation in the United States with special reference to ground water: U. S. Geol. Survey Circ. 114, 138 p., 20 figs. with appendix.

Pepperberg, L. J., 1908, The Milk River coal field, Montana: U. S. Geol. Survey Bull. 381-A, p. 82-107, pl. 6.