WATER RESOURCES OF THE FORT UNION COAL REGION, EAST-CENTRAL MONTANA

by Steven E. Slagle

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CONVERSION FACTORS

The following factors can be used to convert inch-pound units in this report to the International System of Units (SI).

Multiply inch-pound unit	By	To obtain SI unit
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometers per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	0.003785	cubic meter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
micromho per centimeter at 25° Celsius (μmho/cm)	100	microsiemens per meter at 25° Celsius
square mile (mi^2)	2.590	square kilometer
ton, short	0.9072	megagram

Temperature can be converted to degrees Celsius (°C) and degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\ (°F - 32)$$
$$°F = 9/5°C + 32$$

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

The shallow ground-water system in the Fort Union coal area of east-central Montana is contained in the Upper Cretaceous Fox Hills Sandstone and Hell Creek Formation, the Paleocene Fort Union Formation, and Pleistocene and Holocene glacial deposits, terrace deposits, and alluvium. All these units overlie the Upper Cretaceous Bearpaw Shale, which forms the base of the shallow aquifer system.

Recharge to the shallow ground-water system is from infiltration of rainfall and snowmelt on the outcrops (estimated to be 50,000 acre-feet per year), infiltration of surface runoff in streams, seepage from Fort Peck Lake, and deep percolation of applied irrigation water. Discharge from the system is to perennial streams (about 5,000 acre-feet per year to the Redwater River) and withdrawal from wells for livestock use (about 2,000 acre-feet per year) and domestic use (about 2,500 acre-feet per year). Evapotranspiration rate in the area is estimated to be between 34 and 45 inches per year.

Ground-water quality varies significantly as a function of depth and aquifer. Water-quality patterns indicate two general flow patterns for aquifers above the Hell Creek Formation; a shallow flow pattern that is controlled by the local topography occurs in aquifers less than about 200 feet deep, and a more regional pattern is present in deeper aquifers. The distinct chemical character of water in the Fox Hills-lower Hell Creek aquifer may indicate a separate flow path. Primary constituents in water from aquifers above the Hell Creek Formation are sodium, bicarbonate, and sulfate. Average dissolved-solids concentrations are about 1,800 milligrams per liter. Water below a depth of about 200 feet contains a larger percentage of sodium and bicarbonate than water at depths less than 200 feet. Water from the Fox Hills-lower Hell Creek aquifer, the deepest aquifer in the shallow ground-water system, is dominated by sodium and bicarbonate, with an average dissolved-solids concentration of 1,180 milligrams per liter.

The study area is drained principally by the Missouri and Yellowstone Rivers, which are perennial, and their major tributaries, which are mostly ephemeral or intermittent. Flows in most streams have large seasonal variations, with most flow occurring in the spring as a result of rainfall and snowmelt.

Water quality in streams within the area is dependent on flow conditions. Dissolved-solids concentrations generally are largest during intervals of low flow, when streamflow is sustained by ground-water inflow, and smallest during intervals of high flow. Dissolved-solids concentra-

tions of water from small streams within the area ranged from 160 to 6,960 milligrams per liter. Quality of the water in the Missouri and Yellowstone Rivers is more uniform, and dissolved-solids concentrations generally range from 400 to 600 milligrams per liter.

INTRODUCTION

Large supplies of near-surface, low-sulfur coal make the Fort Union coal region of east-central Montana attractive as a major source of supply for future energy needs. The coal occurs as numerous and widespread lignite deposits contained principally within the Fort Union Formation. Coal presently is being extracted by surface-mining methods at one mine near Savage, Mont., and several of the proposals for future coal mining are for the Fort Union coal region. The prospect of increased coal development including coal conversion and synfuels plants has fostered concern about the effects on the water resources.

The coal beds and lenticular sandstone contained in the Fort Union Formation are important aquifers in the area, supplying water to numerous stock and domestic wells and springs. Surface mining of certain coal beds not only would remove part of the aquifer, but would cause temporary dewatering of parts of the coal and overlying beds. Changes in the chemistry of the ground water in the vicinity of the mine site may also occur.

In anticipation of widespread development of the coal resources in the Fort Union coal region, the U.S. Geological Survey, in cooperation with the Montana Bureau of Mines and Geology and the U.S. Bureau of Land Management, began a series of investigations describing the water resources in the coal areas of eastern Montana in 1974. This study, which was begun in 1979, constitutes a continuation of those investigations.

Purpose and scope

The purpose of this report is to describe the existing hydrologic and water-quality conditions of the shallow ground-water system above the Bearpaw Shale and to describe the surface-water resources in the Fort Union coal region of east-central Montana. The objective of the study was to provide premining data that would be useful for water-resources planning. To meet this objective, about 500 wells were inventoried, 17 observation wells were drilled and cased, and about 250 water samples were collected for chemical analysis. Previously collected information also was compiled for about 1,700 wells in the area. These data include well depth, water levels, well discharge, drawdown, and water use (Slagle, 1981). Information on surface-water quantity and quality was compiled from existing records and previously published reports.

Location and extent of area

The area of study for this report includes about 7,300 mi^2 in east-central Montana (fig. 1). The study area is bounded on the north by the Missouri River, on the east by the Montana-North Dakota boundary, on the southeast by the Yellowstone River, and on the west by the Dry Arm of Fort Peck Lake, the Timber Creek-Little Dry Creek divide, and the Cherry Creek-Custer Creek divide.

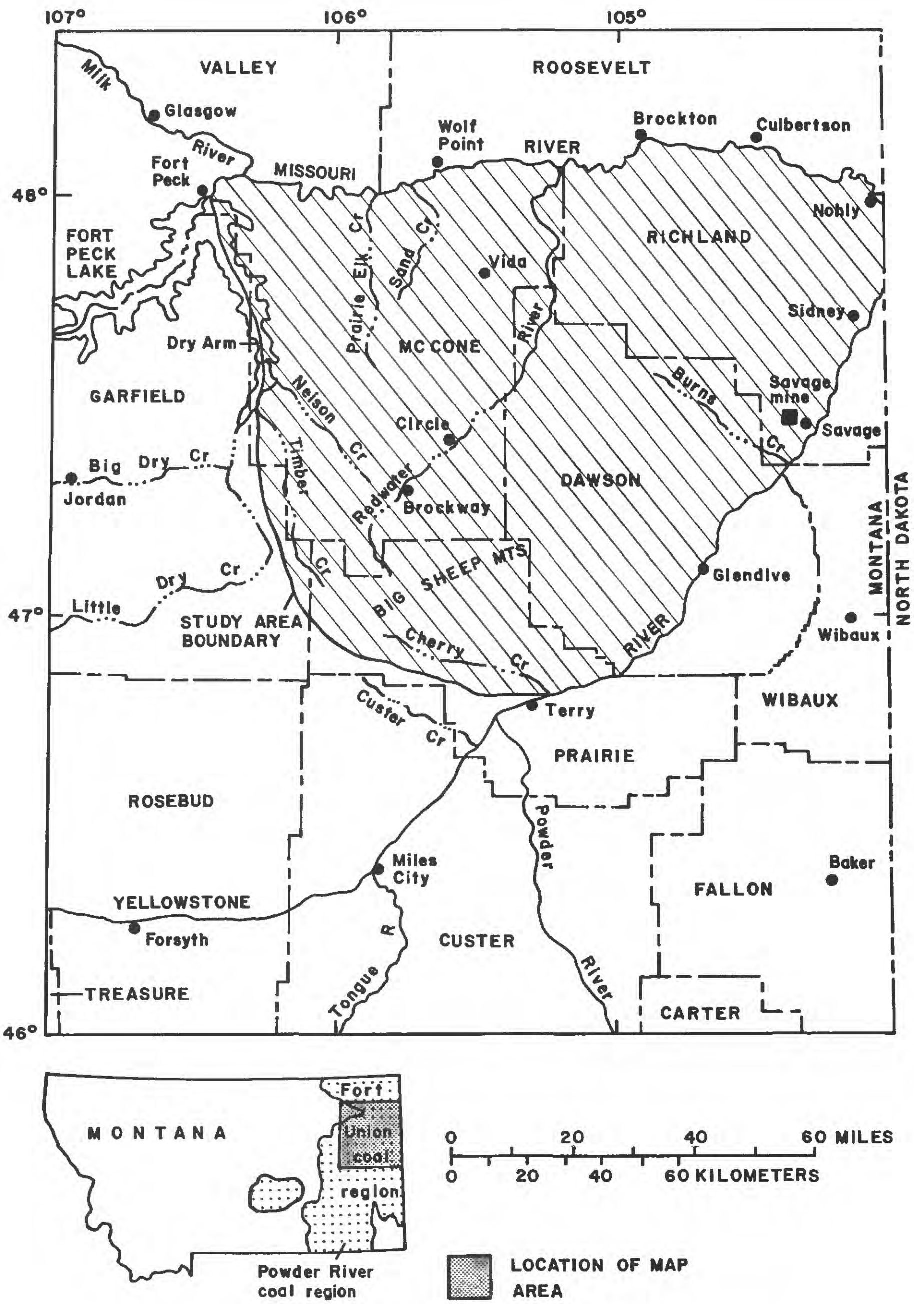


Figure 1.--Location of study area. Coal-region boundaries from Trumbull (1960).

Physiography

The land surface consists predominantly of gently rolling hills slightly eroded by intermittent streams. Grass-covered rangeland is interspersed by nonirrigated farmland in the uplands and, where soil and water permit, by irrigated farmland in the valleys. Locally, badlands have developed in easily eroded shales and siltstones. Badlands are common in the northern part of the area near the Missouri River where the upper part of the Hell Creek Formation is exposed. Badlands in this area are often referred to as the "Missouri River breaks." Major streams in the study area flow on alluvial flood plains that commonly are bordered by remnants of alluvial terraces. Altitudes range from about 1,850 ft above sea level where the Missouri River flows from Montana in the northeast corner of the study area to about 3,600 ft in the Big Sheep Mountains in the southwest part of the area.

Climate

The climate is semiarid continental and is characterized by cold dry winters, cool moist springs, and hot dry summers. January normally is the coldest month. Average January temperatures range from 8.6°F at Culbertson to 14.9°F at Glendive. Minimum temperatures of about -30°F may occur during the winter months. Winter cold is frequently interrupted by intervals of warm weather. Summers are dominated by hot sunny days and cool nights. July generally is the warmest month. Average temperatures in July range from 69.5°F at Circle and Culbertson to 74.0°F at Glendive. Maximum temperatures in excess of 100°F are not uncommon. Average annual temperatures range from 40.8°F at Culbertson to 45.6°F at Glendive.

National Weather Service records indicate that most precipitation occurs in the late spring and early summer. June generally is the wettest month. Average June precipitation ranges from 2.83 in. at Fort Peck to 3.34 in. at Culbertson. Average annual precipitation ranges from 11.52 in. at Fort Peck to 16.34 in. at Vida.

Industry

Farming, ranching, and related services constitute the primary industry in east-central Montana. Oil and gas production has been a major industry in the area for many years. Recent price decontrols have spurred a renewed interest in oil and gas exploration and production.

The only mine in the area currently (1982) producing commercial quantities of coal is the Savage Mine near Savage. Annual production from this mine was about 300,000 tons during the mid- and late 1970's and during 1980, but decreased to about 200,000 tons during 1981, according to the Montana Department of Revenue (1974-81).

Previous investigations

Early studies in the area dealt primarily with the geology of individual coal fields (Leonard, 1907; Calvert, 1912; Hance, 1912; Herald, 1912; Stebinger, 1912; and Rogers, 1913). Areal investigations of geology of northeastern Montana and adjacent areas were conducted by Collier and Thom (1918), Collier (1919), Dobbin and Reeside (1930), and Alden (1932). The 1950's and 1960's brought a continuation of areal geologic studies (Brown, 1952; Dobbin and Erdmann, 1955; Howard, 1960; and Jensen and Varnes, 1964) as well as studies concerned primarily with water resources of the alluvium along the major streams (Torrey and Swenson, 1951; Torrey and Kohout, 1956; Moulder and Kohout, 1958; and Hopkins and Tilstra, 1966). The 1970's and early 1980's were marked by a resurgence of coal-resource evaluation studies (Matson, 1970; Spencer, 1976; Wincentsen, 1978, 1979; and Spencer, 1980) and geologic investigation of aquifer units (Stoner and Lewis, 1980). The surface-water resources of the area were described by McKinley (1979), Moore and Shields (1980), Knapton and Jacobson (1980), and Shields and White (1981). Results of an investigation of surface water-ground water interaction are contained in a report by Dodge and Levings (1980). Additionally, data on surface-water quantity and quality are published in U.S. Geological Survey Water-Supply Papers and in an annual series, Water Resources Data for Montana.

Acknowledgments

Appreciation is expressed to the many residents of the area who permitted access to their property and provided information about their wells. Special appreciation is extended to those who permitted use of their land for installation of observation wells.

GEOLOGY

Stratigraphy

The shallow aquifer system in east-central Montana is composed of sedimentary units ranging in age from Late Cretaceous to Holocene (table 1). The geologic units consist of marine deposits of the Upper Cretaceous Fox Hills Sandstone and continental deposits of the Upper Cretaceous Hell Creek Formation, the Paleocene Fort Union Formation, and Pleistocene and/or Holocene glacial drift, terrace deposits, and alluvium. Generalized outcrops of the most extensive of these geologic units are shown in figure 2. The shallow aquifer system is underlain by the Bearpaw Shale (and equivalent upper part of the Pierre Shale) of Late Cretaceous age.

The Bearpaw Shale consists primarily of massive gray to black marine shale and shaly claystone. Thin beds of siltstone, silty sandstone, and bentonite occur locally. The Bearpaw Shale crops out along the Missouri River in the northwestern and north-central parts of the study area. An outcrop of about 2 mi^2 of the Pierre Shale is present in the southeast part of the area along the Yellowstone River near Glendive.

The Fox Hills Sandstone crops out in the northwestern, north-central, and southeastern parts of the study area. Two members of the formation are recognized. The unnamed lower member consists of alternating thin beds of gray to brownish-gray fine-grained sandstone, soft sandy shale, and siltstone. The upper Colgate Member is composed primarily of light-gray massive fine- to medium-grained sandstone. Some small-scale crossbedding is present and the occurrence of crossbedding increases toward the top. Large ellipsoidal to cylindrical concretions are common.

The lower part of the Hell Creek Formation consists of fairly well sorted medium-grained sandstone, which commonly has large-scale crossbedding. Hard ellipsoidal to cylindrical concretions cemented with calcium carbonate occur in some locations. Locally, a poorly sorted conglomerate occurs at the base. The upper part of the formation is composed of gray to yellowish-gray clayey sandy carbonaceous and bentonitic shale and siltstone. Locally, a yellowish-gray to tan fine- to medium-grained silty sandstone containing thin coal beds predominates. A few bentonitic beds occur locally. The Hell Creek Formation crops out in the northwestern, north-central, and southeastern parts of the study area.

The Fort Union Formation is composed of the Tullock, Lebo Shale, and Tongue River Members, in ascending order. In the Tullock Member, interbedded medium-gray to light-gray shale, light-gray fine-grained sandstone, siltstone, and thin but

Table 1.--*Generalized description and water-yielding characteristics of sedimentary units in east-central Montana*

Erathem	System	Series	Geologic unit	Thickness (feet)	General description	Water-yielding characteristics
Cenozoic	Quaternary	Pleistocene and Holocene	Alluvium	0-130	Mostly unconsolidated sand, silt, and clay with local lenses of gravel.	Coarse gravels along major streams are reported to yield as much as 1,000 gallons per minute to large-diameter wells. Along smaller streams with less saturated thickness yields of 50 gallons per minute have been reported. Yields commonly are 30 gallons per minute or less to stock and domestic wells.
			Terrace deposits	0-100	Mostly gravel and sand with some silt and clay. Includes the Crane Creek and Cartwright Gravels (Howard, 1960).	Terraces generally are topographically high isolated units having limited saturation. Yields to domestic and stock wells may be as much as 20 gallons per minute from larger deposits at lower altitudes along major streams.
			Glacial drift	0-70	Massive clay-enriched deposits containing silt, sand, pebbles and cobbles, and boulders. Generally dark gray. Consists of ground moraine and outwash deposits.	Serves as a source of water in the northern part of the study area, generally within the area traversed by continental glaciation. Measured yields to wells ranged from 2 to 18 gallons per minute. Larger yields may be available from more extensive gravel lenses.
			Flaxville Formation	0-100	Yellow to gray fluvial gravel, sand, and clay with local marl and beds of volcanic ash. Wells reported to be completed in the Flaxville Formation may be completed in the slightly older Miocene (?) or Oligocene (?) Rimroad Gravel.	A possible source of water in areas of occurrence in the Redwater River-Yellowstone River divide area. Because of the topographically high location, the Flaxville is not always saturated. Where saturated, yields to wells commonly are about 10 gallons per minute.
	Tertiary	Paleocene	Fort Union Formation: Tongue River Member	0-1,200	Light-gray to brownish-gray fine- to medium-grained thick-bedded to massive lenticular sandstone and siltstone. Contains lenses of shaly siltstone and shale and thick extensive coal beds. Burning of coal along outcrops has baked overlying sandstone and shale to form red to lavender clinker.	Sandstone and coal beds compose the major water-yielding units. Siltstone and shale do not yield appreciable quantities of water. Yields to wells of as much as 50 gallons per minute have been reported; however, yields to most stock and domestic wells are less than 20 gallons per minute. Where saturated, fractured clinker may yield as much as 50 gallons per minute to wells.
			Fort Union Formation: Lebo Shale Member	0-300	Predominantly dark shale interbedded with light-gray and brown to black carbonaceous shale, siltstone, and locally thin coal beds.	A limited source of water in the study area. Relatively impermeable shale in this unit retards vertical movement of water. Yields to wells of as much as 40 gallons per minute have been reported; however, yields of this magnitude are rare. The probable source of these yields is the lenticular sandstones that occur locally within the unit.
			Fort Union Formation: Tullock Member	0-200	Interbedded medium-gray to light gray shale, light-gray sandstone and siltstone, and thin coal beds.	Fine-grained sandstone and coal beds supply small quantities of water for stock and domestic use. Yields to inventoried wells range from 2 to 42 gallons per minute and average 9.4 gallons per minute.
Mesozoic	Cretaceous	Upper Cretaceous	Hell Creek Formation	0-400	Gray to yellowish-gray shale, siltstone, and thin coal beds compose the upper part of the unit. Sandstone, commonly crossbedded, occurs near the base of the unit.	Upper part of Hell Creek -- limited as a water supply in the study area. Well yields of as much as 38 gallons per minute have been measured, but generally average about 5 gallons per minute.
			Fox Hills Sandstone	0-400	Two members of the unit are recognized: Colgate Member--very light gray fine- to medium-grained massive sandstone; unnamed lower member--gray to brownish-gray fine-grained thin-bedded sandstone, with interbedded sandy shale and siltstone.	Lower part of Hell Creek and Fox Hills Sandstone -- considered to be one aquifer in the study area. A significant source of water for artesian wells in the study area. Natural flows of as much as 70 gallons per minute have been measured and maximum yields of 400 gallons per minute have been reported from large-capacity wells.
			Bearpaw (Pierre) Shale	600-1,200	Gray to black marine shale and shaly claystone.	Relatively impermeable. Generally does not yield water to wells in the study area.

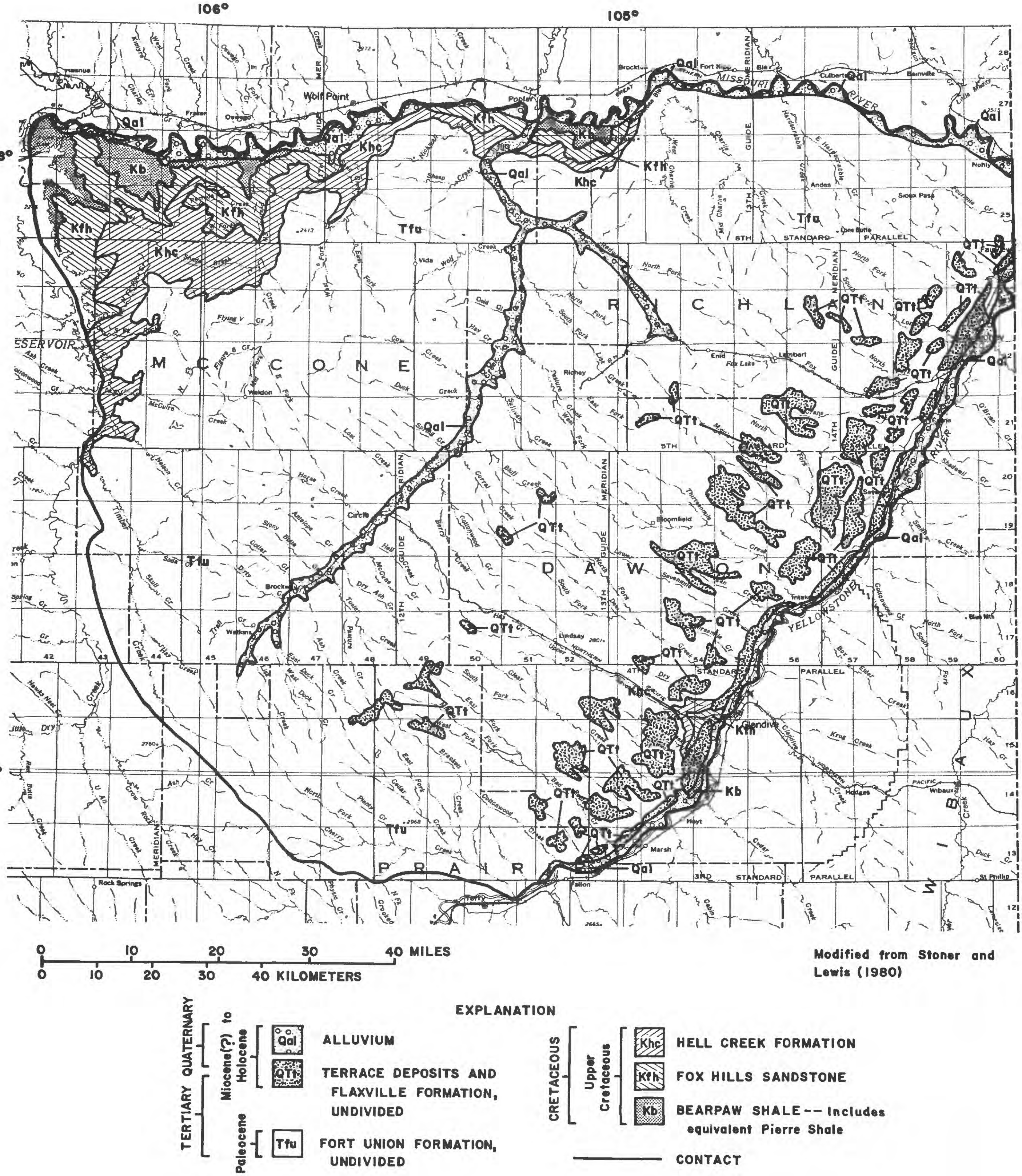


Figure 2.--Generalized geology. Localized or thin units not shown.

persistent coal beds grade upward into silty or sandy shale and local sandstone. A resistant sandstone commonly forms a rimrock at the top of the unit. Locally, sandstones and siltstones weather yellow to brown. The Lebo Shale Member consists of predominantly dark shale with interbedded light-gray and brown to black carbonaceous shale, siltstone, and locally thin coal beds. Shales contain altered and devitrified volcanic ash and reddish-brown ferruginous concretions. White to light-gray argillaceous crossbedded and lenticular sandstones occur locally. The Tongue River Member occurs as light-gray to brownish-gray fine- to medium-grained thick-bedded to massive and locally crossbedded lenticular calcareous sandstone and siltstone. The sandstone commonly weathers light yellow to buff. The Tongue River Member also contains lenses of light-buff to dark-gray shaley siltstone and shale, brown to black carbonaceous shale, and numerous thick and extensive coal beds. The Fort Union Formation is at the surface in most of the study area.

Clinker zones occur along burned coal horizons throughout the Tertiary stratigraphic section. Clinker is composed of the residue from burned coal beds, and baked and fused overlying layers.

The Flaxville Formation is composed principally of fluvial and locally crossbedded gravel, sand, and clay. Gravels consist of well-rounded chert, agate, and igneous-rock pebbles averaging about 1 in. in diameter but boulders as much as 12 in. in diameter are included. Beds of marl and volcanic ash occur locally. Locally, the sand and gravel are cemented with calcite to form sandstone and conglomerate. In the study area, the Flaxville caps many of the ridges in the Redwater River-Yellowstone River divide area.

Glacial drift of Wisconsin age mantles the northern part of the study area. The ground moraine generally consists of a compact mixture of clay, silt, sand, scattered pebbles and cobbles, and relatively few boulders. Locally, it is more silty with a greater boulder content and contains local lenses of gravel. The drift is generally dark gray but contains many local variations in color. The clay, silt, sand, and some cobbles and boulders appear to be of local origin. The boulders and some pebbles and cobbles, consisting of limestone, dolomite, granitoid rocks, metamorphic rocks, and minor quantities of plutonic rocks other than granite were transported from Canada by glaciers (Jensen and Varnes, 1964, p. F32). Outwash deposited by melt water from the receding glacial ice is present in channels eroded in the ground moraine. Outwash deposits consist primarily of sand and gravel interbedded with lenses of silt and clay and contain numerous glacial erratics.

Terrace deposits are located primarily along benches of the Yellowstone River. These deposits consist principally of gravel and sand with some silt and clay. Well rounded 1- to 12-in. diameter cobbles and boulders and sand-size particles of quartzite, chert, and igneous rock are common. Some localized terraces in the northern part of the study area may be of glacial origin (Jensen and Varnes, 1964, p. F32).

The valleys of major streams and some tributaries are underlain by Holocene alluvium, which consists of lenticular deposits of sand, silt, and clay with local lenses of gravel. Coarse well-rounded gravel interbedded with finer material is common in the basal alluvial deposits along the Missouri and Yellowstone Rivers. Along the smaller streams, the alluvium consists primarily of fragments of clinker and sandstone. Glacial-deposited igneous pebbles are present in the alluvium of streams in the northern part of the study area. Thickness of the unit is as much as 130 ft along the Missouri River, 50 ft along the Yellowstone River, and 40 ft along smaller streams.

Structure

East-central Montana is located on the southwestern flank of the Williston basin (fig. 3). Lesser structures superimposed on the Williston basin and wholly

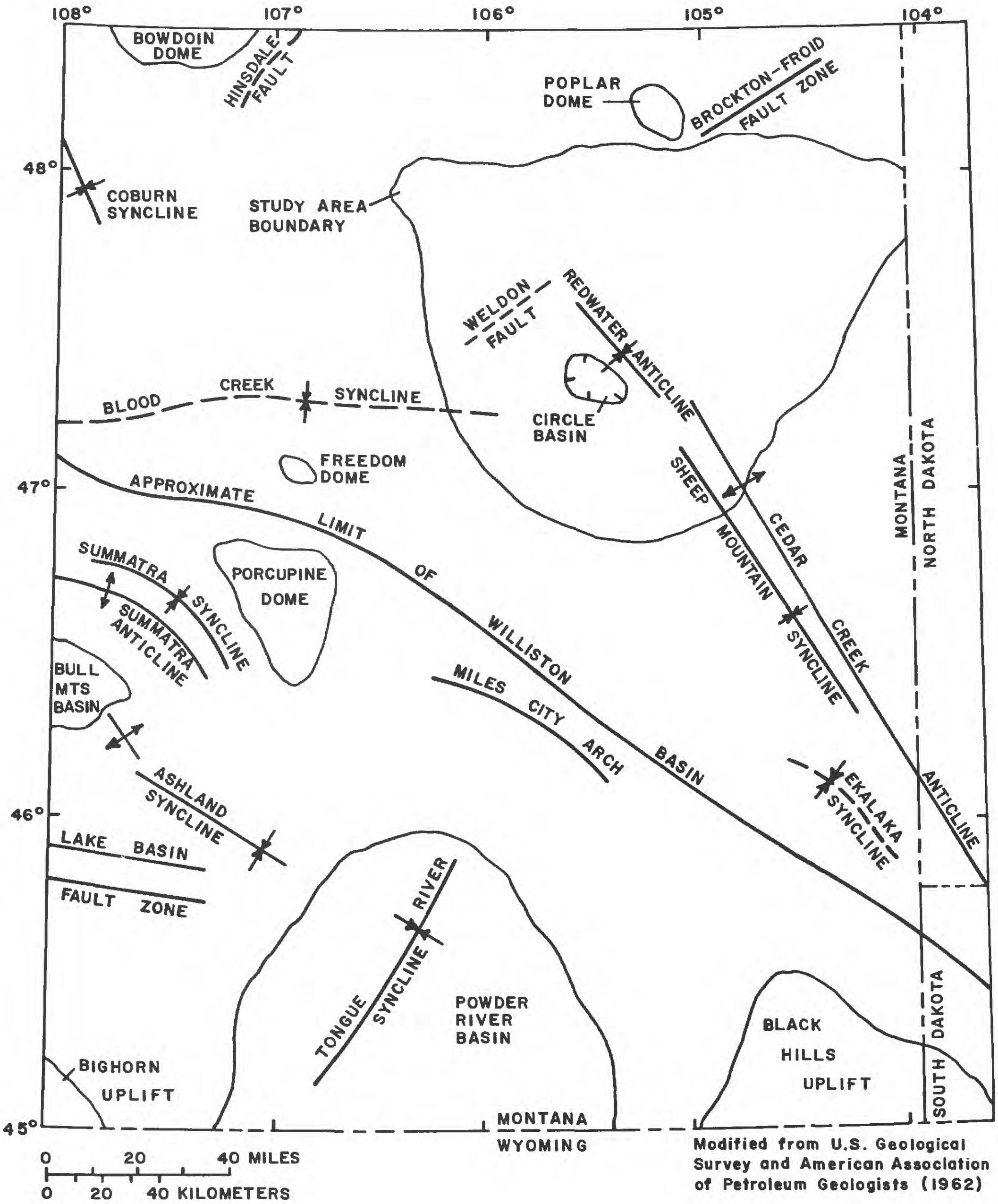


Figure 3.--Structural features of eastern Montana.

within the study area are the Redwater anticline, the Circle basin, and the Weldon fault. The eastern end of the Blood Creek syncline extends into the western part of the study area, and the northwestern ends of the Cedar Creek anticline and the Sheep Mountain syncline are located in the southeastern part of the study area. Structural features located outside, but near, the study area include the Poplar dome and the Brockton-Froid fault zone.

HYDROLOGY

This study involved determination of the occurrence and movement of water contained in shallow aquifers--those aquifers above the Bearpaw Shale--in east-central Montana. Maximum depth to the Bearpaw, about 2,300 ft, occurs in the Big Sheep Mountains in the southwest part of the study area. Other than in this topographically high area, maximum depths to the Bearpaw are about 1,800 ft in the area of the Circle basin and in the northeast corner of the study area near Nohly. In general, the greatest thickness of the shallow aquifer system is in a southwest-trending band located slightly southeast of the centerline of the study area. The depths to the top of the Bearpaw Shale can be determined by the difference in altitude between the top of the Bearpaw (fig. 4) and the land surface.

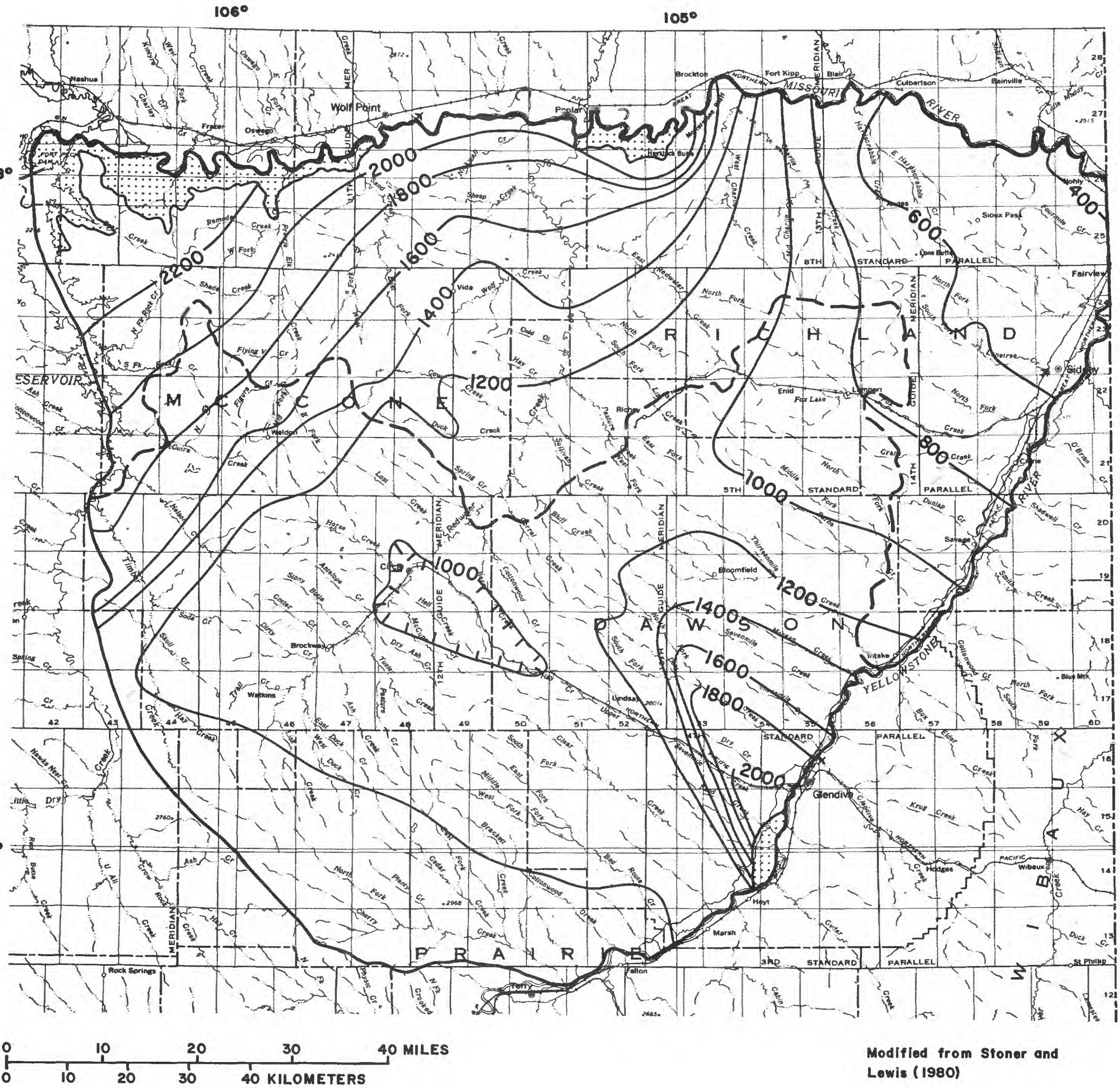
Water-yielding characteristics of the shallow aquifer system

Bearpaw confining layer

This thick shale sequence is a barrier to the vertical movement of water and is considered to be the lower boundary of the shallow aquifer system in east-central Montana. The Bearpaw contains a few thin sandstone beds that, where saturated, yield small quantities of water to wells. Wells generally are completed in these sandstone beds only in areas where the beds constitute the first available water below land surface. Yields of as much as 5 gal/min have been measured from wells completed in the areas of Bearpaw outcrop.

Fox Hills-lower Hell Creek aquifer

The Fox Hills Sandstone and the overlying lower part of the Hell Creek Formation represent a single aquifer in the study area because of direct hydraulic connection and similar lithology. This aquifer provides the most promising prospect for large quantities of water that is suitable for use by industry in the area. Although the water from this unit generally contains fewer dissolved solids than water from other units in the area, its use is restricted by the fact that the aquifer commonly lies at depths of about 1,000 to 1,500 ft; shallower aquifers generally provide more economical sources of supply for domestic and stock purposes. Yields by natural flow from wells completed in the Fox Hills-lower Hell Creek aquifer in the area range from about 1 to 70 gal/min. Yields of as much as 400 gal/min are produced by pumping. Yields generally range from about 30 to 60 gal/min, and average about 50 gal/min.



EXPLANATION

2000 — STRUCTURE CONTOUR--Shows altitude of top of Bearpaw Shale. Contour interval 200 feet. Datum is sea level

BEARPAW SHALE--Area where Bearpaw crops out or directly underlies alluvium, terrace deposits, or glacial drift

CONTACT

APPROXIMATE MAXIMUM EXTENT OF GLACIAL ADVANCE--Area north of line is mantled by glacial drift

Figure 4.--Altitude and configuration of the top of the Bearpaw Shale and the extent of glacial advance.

Upper Hell Creek confining layer

Because of the large percentage of shale, siltstone, and claystone and the availability of large quantities of water in the underlying Fox Hills-lower Hell Creek aquifer, the upper part of the Hell Creek Formation generally is not regarded as a source of supply of water to wells. Some wells in the study area are completed in the silty sandstone beds present in this part of the formation. Yields from these wells commonly range from about 1 to 12 gal/min and average about 5 gal/min.

Tullock aquifer

The sandstone and coal contained in the Tullock Member of the Fort Union Formation are a reliable source of water for stock and domestic supplies. The aquifer is not extensively used, however, because it commonly occurs at depths of 500 to 1,000 ft in most of the study area and because of the general availability of adequate water supplies at shallower depths. Yields from inventoried wells completed in the Tullock range from 2 to 42 gal/min and average 9.4 gal/min.

Lebo confining layer

Owing to the predominance of shale in the Lebo Shale Member of the Fort Union Formation and the usual availability of water at shallower depths, it is not commonly explored for water supplies. Wells producing from the Lebo are primarily completed in sandstone in or near the areas of outcrop and generally withdraw water from the first available water supply below land surface. One inventoried well was reported to yield 40 gal/min. Yields of other wells ranged from 1 to 15 gal/min and commonly were about 9 gal/min.

In the eastern part of the study area where the Lebo and Tullock become indistinct, the two units have been combined and described as the lower Fort Union aquifer by Stoner and Lewis (1980). The correlation between geologic and hydrogeologic units is shown in figure 5.

Tongue River aquifer

The Tongue River Member of the Fort Union Formation directly underlies the surface in most of east-central Montana and commonly is the shallowest and most easily accessible source of ground water. Most ground-water supplies in the area are obtained from the sandstone and fractured coal beds contained in this aquifer. The Tongue River Member is a reliable source of water for stock and domestic supplies, although the depth of drilling required and the probable yield are difficult to predict because of the random distribution of sandstone lenses and fractured coal. Measured yields of inventoried wells range from 0.4 to 30 gal/min. One well was reported to yield 50 gal/min. Yields from wells completed in the Tongue River Member generally range from 5 to 10 gal/min but yields of 2 to 5 gal/min are not uncommon.

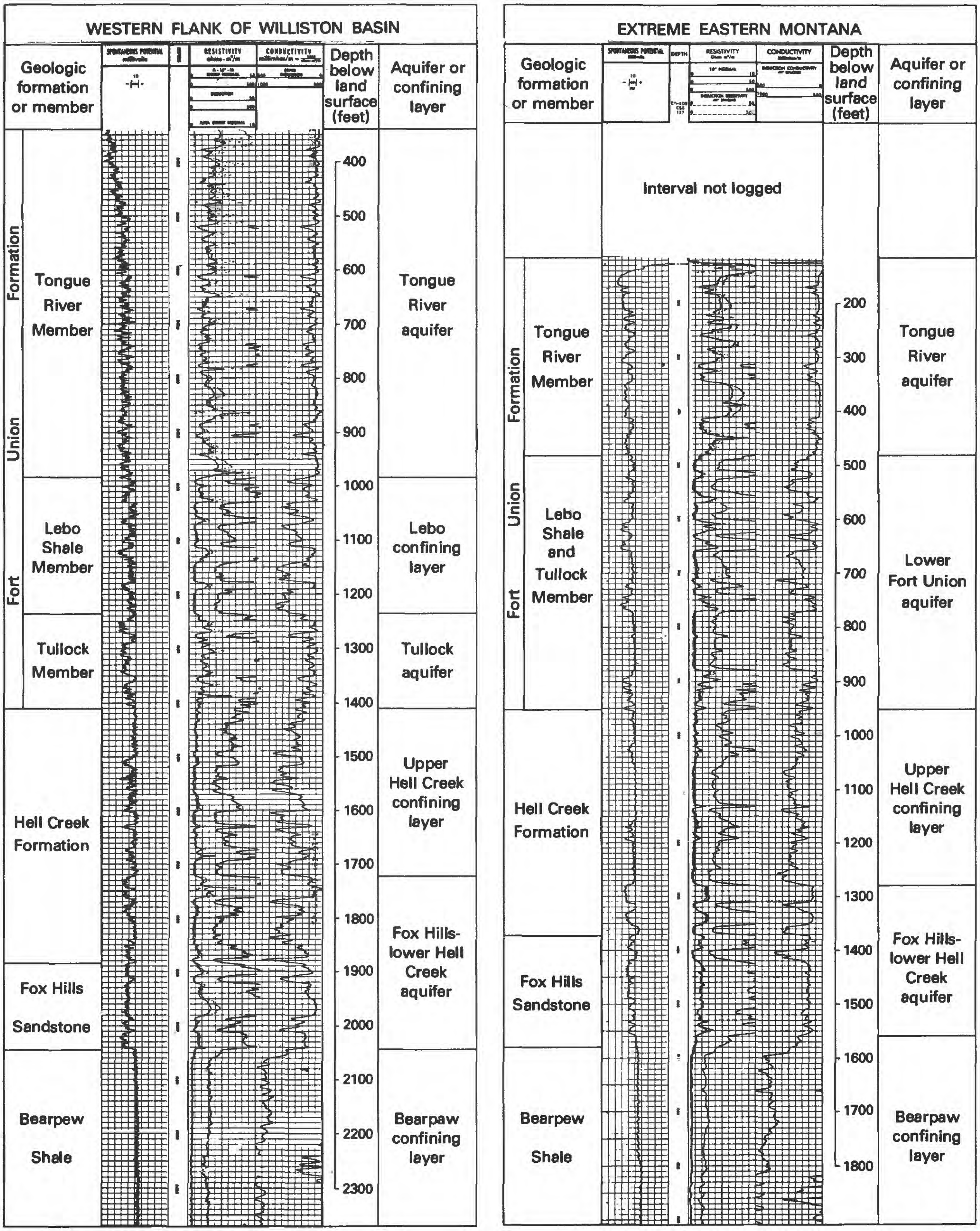


Figure 5.--Representative electric logs showing correlation between selected geologic and hydrogeologic units. Modified from Stoner and Lewis (1980).

Flaxville aquifer

The rounded and coarse sand and gravel comprising the Flaxville Formation provide a potentially favorable medium for the production of water in the Redwater River-Yellowstone River divide area. But, because of its topographically high location, the unit generally is not saturated. Where saturated, yields to wells are about 10 gal/min.

Glacial-drift aquifer

Glacial drift constitutes a source of water in the northern part of the study area. The large clay content of the ground moraine composing most of this unit is not favorable for the production of water. However, glaciofluvial sand and gravel lenses and channel-fill deposits provide adequate quantities of water for stock and domestic use. Yields from wells completed in the glacial drift range from 2 to 18 gal/min and average about 8 gal/min.

Terrace deposits and alluvium

Because of the shallow depth of occurrence, terrace deposits and alluvium provide an economical and easily obtainable source of water. Alluvium along streams generally is saturated but terrace deposits commonly are above the saturated zone. Terrace deposits at low altitudes along major streams may yield as much as 20 gal/min to domestic and stock wells. Yields from wells completed in alluvium along smaller streams generally range from 5 to 10 gal/min but may be as much as 50 gal/min. Alluvium composed of coarse gravel may yield several hundred gallons per minute to properly constructed wells along the larger streams. Yields of as much as 1,000 gal/min have been reported from wells completed in the alluvium of the Missouri River near Brockton.

Ground-water movement

Alternating aquifers and confining layers, coupled with complex intertonguing and interfingering within most units, results in complicated patterns of ground-water flow. Diversity of water quality with depth indicates that two distinct flow patterns are present in the aquifers above the Hell Creek Formation. A separate flow path in the Fox Hills-lower Hell Creek aquifer may be indicated by the distinct chemical character of the water contained in that aquifer.

The uppermost flow pattern generally occurs in aquifers at depths of less than about 200 ft below land surface and consists of localized flow that is controlled by topography. Water-level data from wells indicate that ground-water flow from topographic divides to the adjacent drainages and the flow patterns reflect the surface topography.

The approximate altitude of the water surface in wells less than 200 ft deep is depicted on plate 1. The map was constructed from water levels in wells completed in various sandstone lenses and coal beds having many different potentiometric surfaces. The map approximates a single potentiometric surface that represents composite hydraulic heads and indicates the general direction of ground-water movement.

Water enters the shallow ground-water system by surface infiltration, flows downgradient, and discharges to the streams and rivers and to deeper aquifers. In recharge areas, which generally coincide with topographically high areas, the altitude of the potentiometric surface decreases with depth, signifying a downward component of ground-water flow. Locally, water moving downward is retarded or intercepted by relatively impermeable material, causing water to move laterally and discharge as contact springs at the land surface.

Discharge areas are characterized by an upward component of flow, wherein the altitude of the potentiometric surface increases with depth. Water moves upward through the aquifers and confining layers to land surface, where it discharges as base flow to streams, evaporates, or is transpired by plants. Discharge areas for aquifers at depths of less than about 200 ft primarily coincide with the valleys of perennial and intermittent streams.

Flow patterns in aquifers above the Bearpaw Shale become more regional with depth. Most water in the deeper aquifers in the study area flows toward and discharges to the Yellowstone, Missouri, and Redwater Rivers.

Ground-water recharge

The primary source of recharge to the shallow aquifers is direct infiltration of precipitation and associated surface runoff in streams. Minor quantities of recharge are contributed by seepage from Fort Peck Lake and by deep percolation of applied irrigation water.

Precipitation

Water that falls on the land surface as rain or snow either runs off, evaporates, is transpired by plants, is retained to supply deficiencies in soil moisture, or percolates to the saturated zone and becomes recharge to the shallow ground-water system. Miller (1979) estimates that recharge from surface infiltration of rainfall and snowmelt in the Powder River basin in southeastern Montana (see fig. 3), an area with similar geology and climate, is about 1 percent of the average annual precipitation. Recharge in areas with gravel at the surface probably is somewhat greater because of the large hydraulic conductivity and consequent rapid infiltration through the gravel. Thus, recharge from infiltration of rainfall and snowmelt to the 7,300-mi^2 study area, with an average annual precipitation of about 14 in., is about 50,000 acre-ft/yr.

Streams and lakes

Recharge occurs from seepage of flowing and ponded water in ephemeral and intermittent streams during times of runoff. Most recharge from this source results from runoff of spring snowmelt and late spring and early summer rain. Some recharge results from runoff from summer rainstorms but is limited by the usual intensity and short duration of these storms.

Recharge to the shallow aquifers also occurs along perennial streams during intervals of high streamflow. Because most reaches of perennial streams are hydraulically connected to the aquifer, water recharged during times of high flow merely raises the water table in the alluvium and is returned to the stream as base flow during subsequent intervals of low flow. Recharge occurs locally along reaches of perennial streams that are above the water table.

The filling of Fort Peck Lake has created an artificially high hydraulic head that may be a source of recharge near the northwestern corner of the study area. The lake is in contact with the Hell Creek Formation and the Fox Hills Sandstone along approximately the southern two-thirds of Dry Arm. The hydraulic head in most wells near the lake is above the conservation pool altitude. However, the water level in one inventoried well in the NE1/4 sec. 3, T. 22 N., R. 43 E., was 9 ft below the conservation pool altitude and 11 ft below the maximum pool altitude in 1979. Thus, in some areas, the ground-water level is below the lake level, providing the opportunity for some water to seep from the lake and recharge the ground-water system. In most areas, however, the lake has had the effect of decreasing natural discharge from the aquifers.

Irrigation

Recharge from irrigation results from deep percolation of ditch losses and applied water that is not lost to evaporation or transpiration. As most irrigated land is in alluvial valleys, this recharge is confined primarily to the alluvium and probably is retained only temporarily. Water that reaches the saturated zone raises the water table above normal levels, which induces increased lateral flow and results in increased ground-water discharge to the stream, virtually recycling the water to the stream from which it was obtained.

Ground-water discharge

Streams

The principal means of discharge from the shallow aquifers in east-central Montana is to streams. Several streams in the area are perennial or nearly perennial and function as drains for the aquifers. The two major streams, the Yellowstone and Missouri Rivers, bound two sides of the study area. Other streams in the area, which either are perennial or flow most of the year, include the Redwater River, Burns Creek, and Prairie Elk Creek. Ground-water flow to drainages is indicated by the upstream deflection of contours on plate 1.

An indication of the quantity of ground-water discharge to the Redwater River can be obtained from low-flow data reported by Dodge and Levings (1980). Base flow in the river increased from 0.52 ft^3/s near Brockway to 7.38 ft^3/s near the mouth. Flow steadily increased to 9.39 ft^3/s in the part of the river that flows over the Fort Union Formation but decreased as the stream traversed the lower part of the Hell Creek Formation and the Fox Hills Sandstone. If the ground-water contribution was constant throughout the year, the annual discharge of ground-water to the Redwater River would amount to about 5,000 acre-ft/yr.

Detailed low-flow measurements are not available for other streams in the study area. Analysis of several years of gaging-station records for the Missouri and Yellowstone Rivers and gaged tributaries failed to produce any discernible trend. The results indicated that unknown withdrawals for irrigation and inflow from ungaged tributaries were of greater magnitude than the surface water-ground water interaction.

Evapotranspiration

Water is discharged from the ground-water reservoir by evapotranspiration along the valleys of perennial and near-perennial streams where the water table is near the land surface. The rate of evapotranspiration is dependent on many factors including depth to water, type and density of vegetation, temperature, and solar radiation. The greatest rate of evapotranspiration occurs during the summer months when plant growth is active.

A method developed by Blaney and Criddle (1950) was used to calculate potential evapotranspiration in the study area. This method infers that, where sufficient moisture is available, consumptive use (evapotranspiration) is expressed by the equation:

$$U = K \sum_{1}^{n} \frac{T \times P}{100} \tag{1}$$

where

U = consumptive use, in inches;
K = emperical consumptive-use coefficient, which is dependent on type and location of the crop;
n = number of months;
T = mean monthly temperature, in degrees Fahrenheit; and
P = monthly percentage of total daytime hours in the year.

Using K values from Cruff and Thompson (1967), T from National Weather Service records, and P from a table in Blaney and Criddle (1950), the potential annual evapotranspiration was calculated to be 34 in. at Culbertson and Circle, 35 in. at Fort Peck, and 37 in. at Glendive.

According to Farnsworth and Thompson (1982, p. 1), the free-water-surface evaporation from a shallow-water surface is considered to be a good index to potential evapotranspiration. Maps by the U.S. Environmental Data Service (1968) show that the mean annual lake (free-water-surface) evaporation in the study area is about 38 in. Maps by Farnsworth and Thompson (1982) show that the annual free-water-surface evaporation is between 35 and 45 in. Both maps show values that are similar to potential annual evapotranspiration calculated for selected locations in the study area by the method of Blaney and Criddle (1950).

Withdrawal by wells

Although many wells are present within the study area, the ground-water system is relatively undeveloped, because of the small density of wells and small quantity of water withdrawn relative to the quantity of ground water discharged by natural processes. Of the approximately 2,200 wells that have been inventoried within the study area, about 60 percent are stock wells and 40 percent are used for domestic water supply. Irrigation and public-supply wells constitute a small percentage of the total number of wells. The discharge of wells commonly is controlled by the capacity of the pumping unit and not by the hydraulic properties of the aquifer. Discharges from inventoried wells generally are between 5 and 8 gal/min.

Annual water use by livestock can be estimated by considering the number and types of livestock, as well as the consumption per head. Most livestock in the study area are watered from ground-water sources, as surface-water supplies are sparse. Livestock inventories by the Montana Crop and Livestock Reporting Service (1982, p. 76-80) indicate that there were about 138,000 cattle and 39,000 sheep in the study area on January 1, 1981, and about 9,000 swine on December 1, 1980. The herd size fluctuates seasonally and is smallest during the winter. Ranchers commonly deplete their herds about 40 percent in the fall by marketing calves and culls. Therefore, the average herd size for the entire year is about 120 percent of the winter herd. The size of sheep bands fluctuates similarly. Swine population is relatively constant throughout the year. The Federal Water Pollution Control Administration (1968, p. 130) lists the daily per-head consumption of water as 7 to 12 gal for cattle, 1 to 4 gal for sheep, and 3 to 5 gal for swine. Using average water consumption for each animal and average annual numbers of livestock, the consumption of water by livestock in the study area is about 2,000 acre-ft/yr.

Annual pumpage for domestic use can be estimated using per capita consumption and the number of persons served. The National Water Well Association (1977) states that daily per capita consumption may be as much as 150 gal, when outdoor water use is considered. Census figures for 1980 place the population of Dawson, McCone, Prairie, and Richland Counties at 28,586. Excluding the towns of Glendive (5,978) and Sidney (5,726), which obtain their water supplies from the Yellowstone River, and considering the parts of the counties outside the study area, about 14,500 people rely on ground water for water supply. The estimated withdrawal from wells, based on the above figures, is about 2,500 acre-ft/yr.

The withdrawal from wells for stock and domestic purposes is estimated to be about 4,500 acre-ft/yr. This quantity of water distributed evenly over the 7,300-mi^2 study area would amount to about 0.01 in. or about 7 percent of the annual recharge to the aquifers from direct infiltration of precipitation.

Surface water

The Fort Union coal region lies within the Missouri River drainage basin and is drained principally by the Missouri and Yellowstone Rivers. The Yellowstone River is the major tributary to the Missouri within the study area. Lesser tributaries include the Redwater River, Prairie Elk Creek, and Sand Creek. Tributaries to the Yellowstone River within the area include Burns and Cherry Creeks.

Most streams within the study area are ephemeral or intermittent and the volume of streamflow varies greatly. The Missouri and Yellowstone Rivers and the downstream reaches of the Redwater River are the only perennial streams in the study area. Other streams, such as the downstream reaches of Prairie Elk and Burns Creeks, are nearly perennial; these streams generally flow most of the year and, in some years, flow year round.

Records of streamflow (table 2) at selected locations (fig. 6) in the study area show that flows in unregulated streams have large seasonal variations, with

Table 2.--*Average discharge at selected streamflow-gaging stations*

Station No.	Station name	Period of record used for computation	Average annual discharge: Acre-feet per year	Average annual discharge: Cubic feet per second	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
					Discharge, in cubic feet per second for month indicated											
06131200	Nelson Creek near Van Norman, Mont.	1976-81	1,800	2.48	.14	.03	.04	.10	.69	8.37	7.17	2.97	2.33	3.32	1.79	2.71
06132000	Missouri River below Fort Peck Dam, Mont.	1943-81	7,235,000	9,986	13,180	9,575	8,909	9,385	9,314	7,645	7,466	8,341	8,450	10,570	13,410	13,480
06175540	Prairie Elk Creek near Oswego, Mont.	1976-81	14,270	19.7	5.04	2.10	1.08	1.90	12.0	108	34.0	10.1	30.1	14.5	4.34	12.8
06177000	Missouri River near Wolf Point, Mont.	1943-81	7,723,000	10,660	13,350	9,792	8,792	9,318	9,557	9,020	10,650	9,654	9,395	11,030	13,600	13,700
06177500	Redwater River at at Circle, Mont.	1929-72; 1975-81	9,850	13.6	.23	.26	.40	.25	16.0	83.0	25.0	4.40	15.0	15.0	2.80	.44
06177825	Redwater River near Vida, Mont.	1976-81	34,700	47.9	5.25	5.86	4.16	2.06	29.0	146	198	39.4	58.2	67.4	12.8	7.57
06185500	Missouri River near Culbertson, Mont.	1943-51; 1958-81	7,941,000	10,960	12,350	10,120	9,147	9,746	10,590	10,920	11,870	10,260	9,957	11,090	12,660	12,760
06327500	Yellowstone River at Glendive, Mont.	1897-1910; 1931-34	9,737,000	13,440	6,666	5,570	4,479	4,612	4,633	8,844	8,488	19,550	46,310	30,280	12,260	7,982
06329200	Burns Creek near Savage, Mont.	1958-67; 1976-81	4,780	6.60	.96	.99	.77	.52	4.90	42.0	14.0	4.00	5.50	4.20	.49	.64
06329500	Yellowstone River near Sidney, Mont.	1910-31; 1933-81	9,469,000	13,070	8,386	7,329	5,831	5,522	6,709	11,470	10,830	18,770	41,310	24,310	9,046	7,244

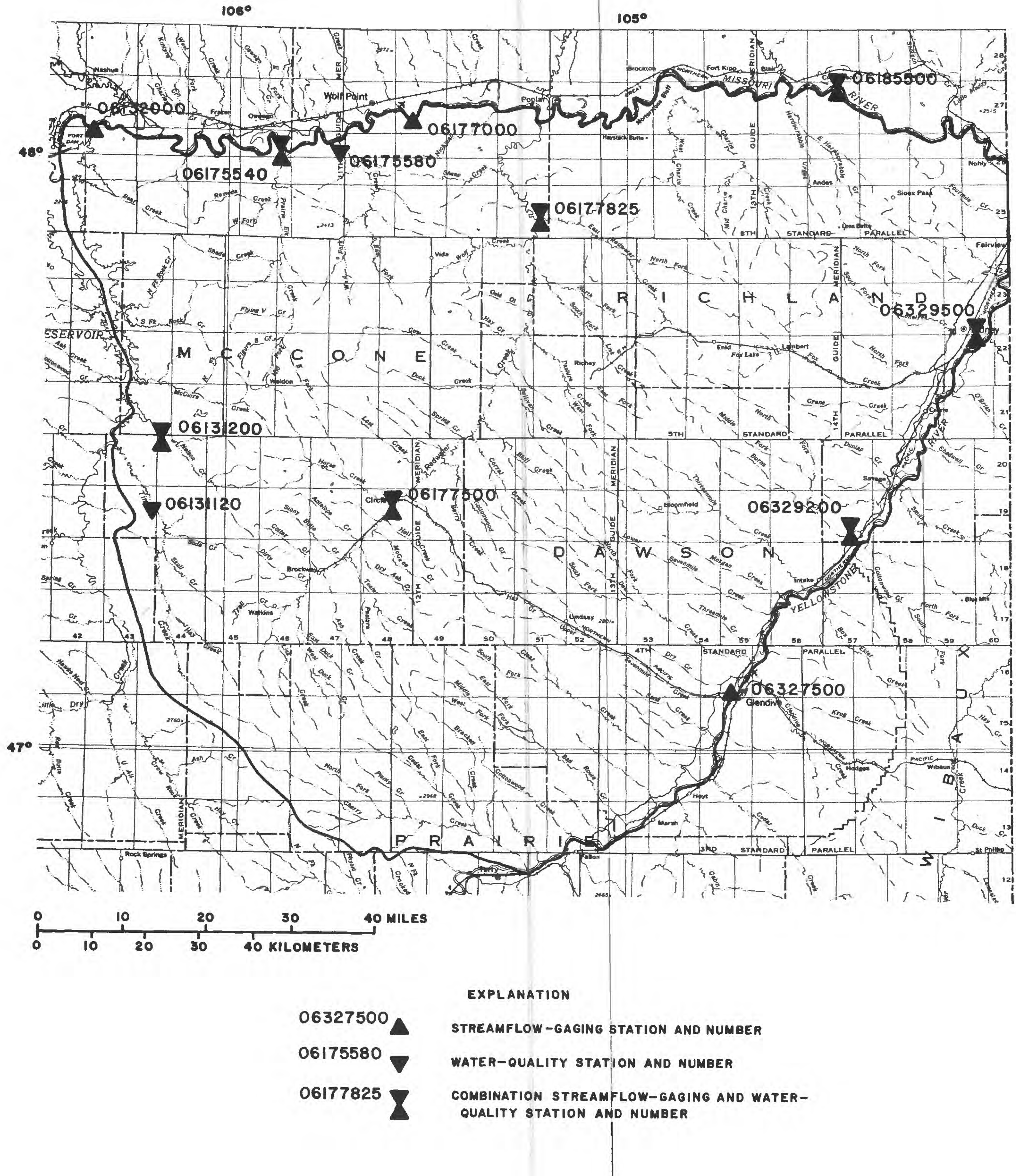


Figure 6.--Location of selected streamflow-gaging and water-quality stations.

the largest flows occurring in the spring as a result of snowmelt and rainfall. Zero or near-zero flow has been recorded on all streams except the Missouri and Yellowstone Rivers. The annual flow cycle of the Missouri River is modified by regulation of Fort Peck Lake and other upstream reservoirs.

Snowmelt commonly results in increased flows in the smaller streams during March and April (fig. 7) and in the larger streams during May through July. Summer thunderstorms result in short intervals of increased streamflow in the smaller streams during June through September but have little effect on the streamflow in the larger streams.

Peak flows may result from either snowmelt or rainfall. Peak flows in the Missouri and Yellowstone Rivers typically result from snowmelt or snowmelt mixed with rain. Annual peak flows in the smaller streams commonly result from snowmelt but the larger peak flows generally result from rainfall--commonly localized, intense thunderstorms.

Minimum flows generally occur in midwinter, commonly in December in the larger streams and in January in the smaller streams. Flow in the downstream reaches of the Redwater River and in some years in other creeks is sustained by base flow from ground-water inflow. Ground-water inflow also contributes to the flow of the Missouri and Yellowstone Rivers.

Chemical quality of water

Water-use standards

Domestic supply and livestock watering constitute the most common uses of ground water in the Fort Union coal region of east-central Montana. Some ground water is used for irrigation.

Primary and secondary drinking-water standards (see table 3) established by the U.S. Environmental Protection Agency (1977, 1979) may be used as guides to the suitability of water for domestic use. Primary standards pertain to public water supplies and include substances known to be toxic to humans in small quantities. An excess concentration of any of the constituents constitutes a basis for rejection of the supply. Secondary standards are to be complied with for public water supplies unless no better supply is available.

Livestock raising is a major industry throughout the area and stock consumption is an important water use. McKee and Wolf (1971, p. 112) list the maximum limits of dissolved-solids concentration for various types of livestock as follows:

Livestock	*Dissolved-solids concentration, in milligrams per liter*	*Livestock*	*Dissolved-solids concentration, in milligrams per liter*
Poultry	2,860	Cattle (dairy)	7,150
Swine	4,290	Cattle (beef)	10,000
Horses	6,435	Sheep (adult)	12,900

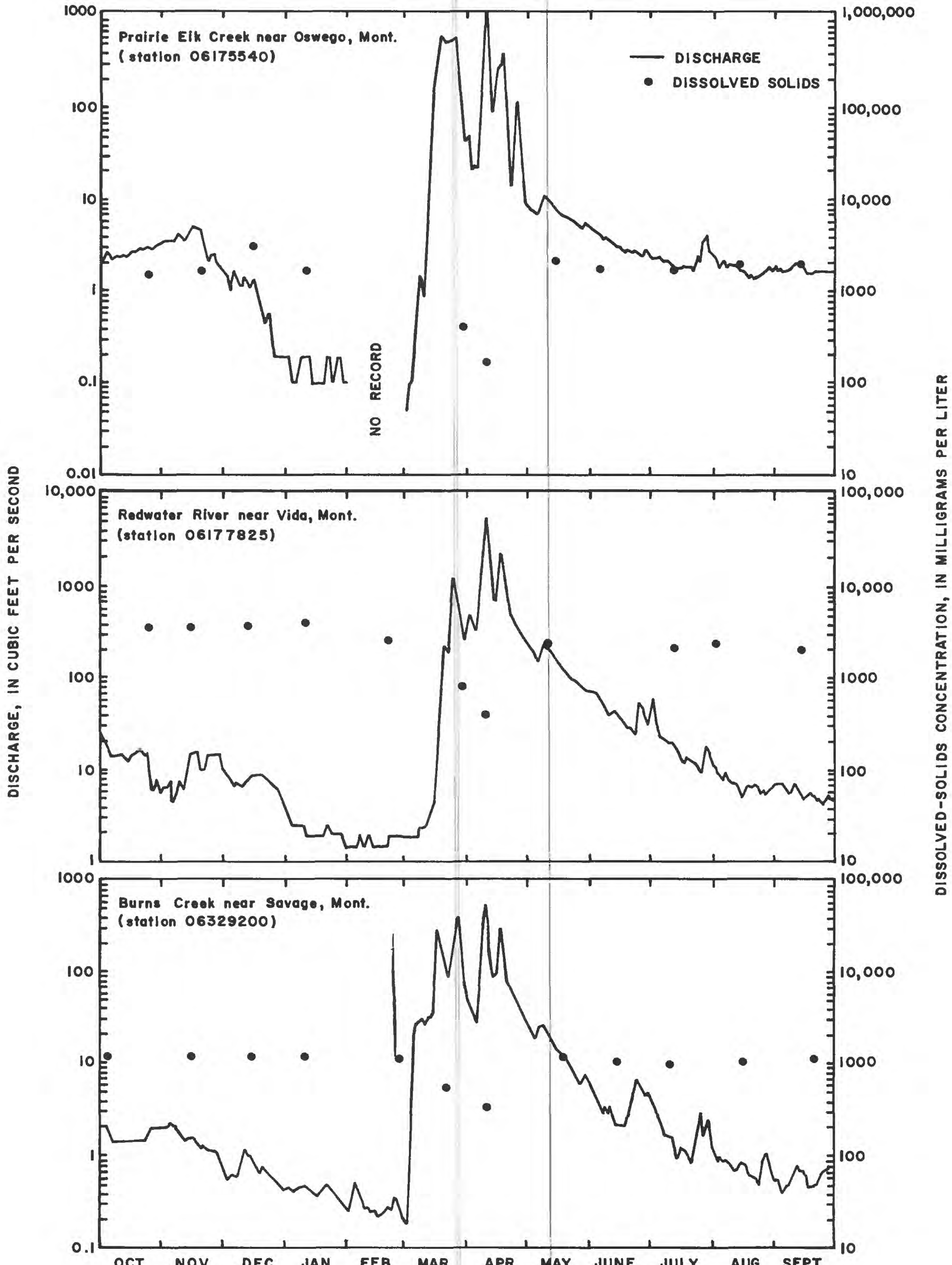


Figure 7.--Average daily discharge and dissolved-solids concentrations at three stations on small streams, 1979 water year.

Table 3.--*Drinking-water standards*

	Maximum contaminant level		
	Primary standard[1], in milligrams per liter	Secondary standard[2], in milligrams per liter	Equivalent trace-constituent concentration[3], in micrograms per liter
Arsenic	0.05	--	50
Barium	1	--	1,000
Cadmium	.010	--	10
Chloride	--	250	--
Chromium	.05	--	50
Copper	--	1	1,000
Dissolved solids	--	500	--
Fluoride	[4]2.2	--	--
Iron	--	.3	300
Lead	.05	--	50
Manganese	--	.05	50
Mercury	.002	--	2
Nitrate (as N)	10	--	--
Selenium	.01	--	10
Silver	.05	--	50
Sulfate	--	250	--
Zinc	--	5	5,000

[1] U.S. Environmental Protection Agency (1977).
[2] U.S. Environmental Protection Agency (1979).
[3] The U.S. Geological Survey reports trace-constituent concentrations in micrograms per liter.
[4] Based on the range in annual average of maximum daily air temperatures of 53.8° to 58.3°F.

Some investigators (see McKee and Wolf, 1971, p. 113) indicate that these values are much too large for optimum growth and development of livestock. Also, certain major ions may be more limiting than the sum of all constituents. For example, livestock can tolerate the greatest dissolved solids when the primary constituents in the water are sodium and chloride. Water containing a large concentration of sulfate is much less desirable.

The suitability of ground water for livestock watering in southeastern Montana can be assessed by reference to classifications developed by the South Dakota Agriculture Experiment Station and by the Montana State College, Agriculture Experiment Station (McKee and Wolf, 1971, p. 113):

<table>
<tr><th rowspan="2">Classification</th><th colspan="2">Dissolved-solids concentration, in milligrams per liter</th></tr>
<tr><th>Montana</th><th>South Dakota</th></tr>
<tr><td>Excellent</td><td rowspan="2">0-2,500</td><td>0-1,000</td></tr>
<tr><td>Good</td><td>1,000-4,000</td></tr>
<tr><td>Fair</td><td>2,500-3,500</td><td rowspan="2">4,000-7,000</td></tr>
<tr><td>Poor</td><td>3,500-4,500</td></tr>
<tr><td>Unfit</td><td>More than 4,500</td><td>More than 7,000</td></tr>
</table>

The suitability of water for irrigation use is dependent on the concentrations of dissolved solids and specific ions as well as factors such as soil type, soil drainage, and crop type. Sustained application of water containing large dissolved-solids concentrations can result in increased salt concentrations in the root zone. The part of the applied irrigation water that remains in the soil, the soil solution, tends to become more concentrated as relatively pure water is used by plants or lost upward through capillary action and evaporation. If the root zone is not leached, the salt concentration of the soil solution will increase until it reaches the limit of solubility of the salt.

According to McKee and Wolf (1971, p. 107) the maximum concentration of dissolved solids considered suitable for best crop growths of all types of plants, including salt-susceptible plants, is about 1,000 mg/L (milligrams per liter). A dissolved-solids concentration of about 3,150 mg/L generally is the maximum for the safe watering of any plant, provided that drainage is excellent and each watering is of sufficient volume to leach the root zone. Large concentrations of sodium and sulfate are primary contributors to salinity problems in eastern Montana.

Large concentrations of sodium in irrigation water can cause accumulations of sodium ions and a breakdown of granular soil structure. The result is deflocculation of the soil, which results in a sealing of soil pores and a decrease in soil permeability. Additional increases in sodium percentage cause continued deterioration of the soil and an increase in pH, producing alkali soil.

A measure of the probability of damage to soil structure from applied irrigation water, termed sodium-adsorption ratio (SAR), was developed by the U.S. Salinity

Laboratory Staff (1954). SAR indicates the tendency of water to enter into ion-exchange reactions in the soil and is defined as:

$$SAR = \frac{(Na^{+})}{\sqrt{\frac{(Ca^{+2}) + (Mg^{+2})}{2}}} \qquad (2)$$

where ion concentrations (Na = sodium, Ca = calcium, and Mg = magnesium) are expressed in milliequivalents per liter. Because divalent cations generally are preferentially held in exchange positions on clay minerals, the displacement of Ca^{+2} and Mg^{+2} by Na^{+} is unlikely unless the sodium percentage is considerably larger than 50 or the total concentration of solutes is very large (Hem, 1970, p. 229). The Federal Water Pollution Control Administration (1968, p. 155) reports that SAR values of 4 to 8 may injure sodium-sensitive plants. Waters with an SAR value greater than 10 will present an appreciable sodium hazard in fine-textured soil having a large cation-exchange capacity (McKee and Wolf, 1971, p. 110).

The solubilities of sodium sulfate and magnesium sulfate are greater than the tolerance limit of many plants. Therefore, toxic soil-solution concentrations may result from sustained application of water containing large sulfate concentrations. Critical concentrations of sulfate in irrigation water are dependent on soil drainage, quantity of water applied, and concentration of dissolved constituents, especially chloride. Chloride concentrations in water in the study area are commonly small; thus, sulfate is the determining ion. Considering the average chloride concentrations of 18 mg/L for ground water from 394 sampled wells and springs in the study area, critical sulfate concentrations range from about 150 to 700 mg/L, depending on soil conditions.

Ground-water quality

Ground-water quality in the study area varies widely as a function of both depth and aquifer. Water in aquifers above the Hell Creek Formation and at depths of less than 200 ft contains an average dissolved-solids concentration of 1,740 mg/L (table 4). Sodium, bicarbonate, and sulfate are the dominant ions. Average concentrations of major cations are 380 mg/L for sodium and 100 mg/L for calcium. Average anion concentrations are 690 mg/L for bicarbonate and 780 mg/L for sulfate. Water from wells less than 200 ft deep in recharge areas commonly contains a smaller percentage of sodium and sulfate, a larger percentage of calcium and bicarbonate and smaller dissolved-solids concentration than water from wells less than 200 ft deep in non-recharge areas. Dissolved-solids concentrations as small as 159 mg/L were present. In many instances, calcium is the dominant cation. As water moves from recharge areas to discharge areas, dissolution of minerals and cation exchange results in increased percentages of sodium and sulfate. In discharge areas, water from shallow wells generally is dominated by sodium and sulfate and may contain dissolved-solids concentrations as large as about 6,450 mg/L.

Water quality in aquifers above the Hell Creek Formation and at depths greater than about 200 ft is more uniform in quality and contains slightly larger dissolved-solids concentrations than water in shallower aquifers. Sodium concentrations are noticeably larger and calcium concentrations commonly are smaller. Average

Table 4.--*Summary of physical-property values and chemical-constituent concentrations in water from selected wells*

[Consituents are dissolved and concentrations are reported in milligrams per liter except where indicated as micrograms per liter (μg/L). Abbreviations: μmho/cm, micromhos per centimeter at 25° Celsius; <, less than]

Property or constituent	Aquifers above upper Hell Creek confining layer: Number of samples	Maximum	Minimum	Median	Average	Number of samples used for average	Fox Hills-lower Hell Creek aquifer: Number of samples	Maximum	Minimum	Median	Average	Number of samples used for average
Specific conductance (μmho/cm)	344	9,700	450	2,290	2,420	344	52	5,500	760	1,740	1,850	52
pH, onsite	213	10.5	6.3	7.8	--	--	31	9.2	7.6	8.6	--	--
Hardness as $CaCO_3$	340	3,000	3	380	510	340	57	99	0	6	13	57
Noncarbonate hardness as $CaCO_3$	340	2,600	0	0	200	340	57	0	0	0	0	57
Calcium (Ca)												
Wells less than 200 feet deep	266	440	1.2	82	100	266	12	17	1.5	3.0	5.8	12
Wells more than 200 feet deep	74	330	1.4	7.6	39	74	45	18	.0	1.8	2.5	45
Magnesium (Mg)	340	490	.1	46	70	340	57	15	.0	.3	1.2	56
Sodium (Na)												
Wells less than 200 feet deep	266	1,400	3.1	290	380	266	12	740	140	460	460	12
Wells more than 200 feet deep	74	1,500	34	620	600	74	37	1,300	300	420	470	37
Sodium-adsorption ratio (SAR)	340	171	.1	9	21	340	52	98	6	70	68	52
Potassium (K)	339	19	.6	5	5	339	49	5	.7	1	1	49
Bicarbonate (HCO_3)												
Wells less than 200 feet deep	266	2,090	60	620	690	266	12	1,550	370	920	920	12
Wells more than 200 feet deep	72	1,740	230	940	980	72	39	1,960	360	770	860	39
Carbonate (CO_3)	125	230	0	0	15	125	33	160	0	40	42	33
Alkalinity as $CaCO_3$	338	1,710	116	570	620	338	55	1,610	303	670	770	55
Sulfide (S)	4	1.6	0	.6	.7	4	--	--	--	--	--	--
Sulfate (SO_4)												
Wells less than 200 feet deep	265	4,200*	.3	640*	780*	265	12	660*	5.3	160	220	12
Wells more than 200 feet deep	72	2,400*	.2	740*	680*	72	45	1,300*	1.8	61	140	45
Chloride (Cl)	337	130	.6	9.4	14	337	57	210	3.1	26	40	57
Fluoride (F)	335	5.7*	< .1	.4	.9	324	57	5.3*	.1	2.2	2.2	57
Silica (SiO_2)	340	50	.9	9.6	11	340	48	21	8.3	11	12	48
Dissolved solids (sum of constituents)												
Wells less than 200 feet deep	265	6,450*	159	1,540*	1,740*	265	12	2,040*	461	1,170*	1,180*	12
Wells more than 200 feet deep	69	4,220*	681*	1,810*	1,910*	69	36	3,620*	746*	1,070*	1,190*	36
Nitrate as N	157	33*	.02	1.2	2.8	157	11	1.0	.00	.00	.18	11
Phosphorous (P)	--	--	--	--	--	--	3	.70	.26	.69	.55	3
Aluminum (Al) (μg/L)	76	370	<30	30	111	37	9	100	<30	<30	70	2
Arsenic (As) (μg/L)	72	24	0	0	3	51	9	3	0	0	1	7
Barium (Ba) (μg/L)	83	1,100*	<10	50	150	50	11	200	<50	50	98	4
Boron (B) (μg/L)	97	2,700	<20	310	440	96	15	1,600	90	1,000	950	15
Cadmium (Cd) (μg/L)	73	16*	<2	2	5	33	8	6	<2	<2	--	--
Chromium (Cr) (μg/L)	76	30	<2	3	9	39	8	3	<2	<2	--	--
Copper (Cu) (μg/L)	78	58	<2	12	21	57	9	10	<2	<2	9	2
Iron (Fe) (μg/L)	248	26,000*	<2	100	960*	225	56	2,100*	0	55	120	55
Lead (Pb) (μg/L)	81	150*	0	40	62*	24	9	50	0	40	--	--
Lithium (Li) (μg/L)	137	240	<2	50	64	135	21	200	30	60	80	21
Manganese (Mn) (μg/L)	335	4,200*	<1	30	200*	225	47	210*	<3	10	24	21
Mercury (Hg) (μg/L)	7	< .5	< .5	< .5	--	--	1	< .5	< .5	< .5	--	--
Molybdenum (Mo) (μg/L)	81	90	<5	20	40	42	9	60	<5	20	42	3
Nickel (Ni) (μg/L)	76	120	<10	20	43	43	9	40	<4	10	28	3
Selenium (Se) (μg/L)	79	80*	0	0	6	43	12	5	0	0	1	7
Silver (Ag) (μg/L)	76	43	<2	2	12	29	8	6	<2	<2	6	2
Strontium (Sr) (μg/L)	90	12,000	70	1,200	1,930	90	12	590	30	110	160	12
Vanadium (V) (μg/L)	76	57	<1.0	6.5	16	43	9	11	<1.0	<1.0	6.4	3
Zinc (Zn) (μg/L)	76	28,000*	<4	60	710	68	9	250	0	20	80	7

*Exceeds standard established by U.S. Environmental Protection Agency, 1977, 1979.

sodium concentration of water tested was 600 mg/L and average calcium concentration was 39 mg/L. Bicarbonate concentrations commonly are larger than sulfate concentrations, whereas the reverse generally is true in the shallower aquifers. Average bicarbonate concentration was 980 mg/L and average sulfate concentration was 680 mg/L. Dockins and others (1980) reported that the decrease in sulfate concentration in southeastern Montana is a result of the action of sulfate-reducing bacteria. Although not documented, the same process probably occurs in the Fort Union coal area of east-central Montana.

Water from wells completed in the Fox Hills-lower Hell Creek aquifer is notably different in chemical character from water contained in overlying aquifers. The water in the Fox Hills-lower Hell Creek aquifer is dominated by sodium and bicarbonate and contains smaller concentrations of calcium and sulfate than water from overlying aquifers. Average concentrations for constituents in water from the Fox Hills-lower Hell Creek aquifer less than 200 ft deep are: calcium, 5.8 mg/L; sodium, 460 mg/L; bicarbonate, 920 mg/L; and sulfate, 220 mg/L. Average concentrations for water at depths greater than 200 ft in the Fox Hills-lower Hell Creek aquifer are: calcium, 2.5 mg/L; sodium, 470 mg/L; bicarbonate, 860 mg/L; and sulfate, 140 mg/L. Average dissolved-solids concentration is about 60 to 70 percent of the average concentration in water in overlying aquifers and the range is smaller. Water in the Fox Hills-lower Hell Creek generally is soft with an average hardness (as calcium carbonate) of 13 mg/L, whereas water in overlying aquifers generally is very hard with an average hardness of 510 mg/L. Composition of chemical constituents in the Fox Hills-lower Hell Creek aquifer does not vary significantly with depth.

Analyses of water samples collected from wells in the study area indicate that most water contains constituent concentrations that are in excess of standards (table 3) for drinking water established by the U.S. Environmental Protection Agency (1977, 1979). Maximum values for sulfate, fluoride, and dissolved solids for all aquifers sampled exceeded the standards. The maximum value for nitrate (as N) in aquifers above the Hell Creek Formation exceeded the standards. Average and median values of sulfate for aquifers above the Hell Creek and the average and median values of dissolved solids for all aquifers exceeded the standards.

Variation in concentration of most trace constituents is not large from aquifer to aquifer (table 4). Where significant variation exists, concentrations generally are larger in aquifers above the Hell Creek Formation. Median values for boron, iron, manganese, nickel, and zinc show an approximate one- to three-fold variation. The variation in copper and strontium is most pronounced. Median values show more than a 6-fold variation in copper and a 10-fold variation in strontium.

Commonly, concentrations of trace constituents are less than standards for drinking water (U.S. Environmental Protection Agency, 1977, 1979). Some samples, however, contained concentrations in excess of the standards. Maximum values obtained for barium, cadmium, iron, lead, manganese, selenium, and zinc in water from aquifers above the Hell Creek Formation exceeded the standards. Maximum values for iron and manganese in water from the Fox Hills-lower Hell Creek aquifer were in excess of the standards. Median values for all trace constituents were less than the standards. The extremely large maximum values for iron, manganese, and zinc may be the result of contamination by the well casing and lack of sufficient pumping before the sample was collected.

Average dissolved-solids concentrations of 1,180 to 1,910 mg/L (table 4) for individual aquifers indicate that most of the ground water in the study area can be classified as good to excellent for livestock watering. Water containing dissolved-solids concentrations near the observed maximum of 6,450 mg/L, however, may be shunned by livestock that are accustomed to less mineralized water.

The commonly large dissolved-solids concentrations, average sulfate concentrations of 140 to 780 mg/L, and average SAR values of 21 to 68 (table 4) result in high to very high salinity and sodium hazards. Consequently, most ground water in the study area is not suitable for irrigation use.

Surface-water quality

The water quality of streams is monitored at selected locations (fig. 6) in the study area. Streamflow water quality is variable and is dependent primarily on flow conditions. Dissolved-solids concentration generally is largest during intervals of low flow, when streamflow is sustained by ground-water inflow. Dissolved-solids concentration is smallest during intervals of high flow resulting from snowmelt or rainfall runoff (fig. 7). Minimum dissolved-solids concentrations result from runoff over frozen ground.

Records from water-quality monitoring stations on small streams within the study area (McKinley, 1979; J. H. Lambing, U.S. Geological Survey, Helena, Mont., written commun., 1982) give ranges of dissolved solids for the period of record at these sites as: Timber Creek near Van Norman (station 06131120), 468 to 5,530 mg/L; Nelson Creek near Van Norman (station 06131200), 181 to 6,960 mg/L; Prairie Elk Creek near Oswego (station 06175540), 160 to 2,380 mg/L; Sand Creek near Wolf Point (station 06175580), 212 to 2,480 mg/L; Redwater River at Circle (station 06177500), 216 to 4,270 mg/L; Redwater River near Vida (station 06177825), 270 to 3,490 mg/L; and Burns Creek near Savage (station 06329200), 222 to 1,620 mg/L. Most streamflow during intervals of low flow is of the sodium sulfate type (fig. 8), which is a reflection of the ground-water quality and geology in the area. Water in the downstream reaches of Prairie Elk and Sand Creeks is of the sodium bicarbonate type, probably a result of ground-water inflow from the Fox Hills Sandstone and the lower part of the Hell Creek Formation. During times of high flow, the percentages of sodium and sulfate ions decrease and calcium, magnesium, and bicarbonate ions generally increase owing to the effects of the surface-runoff component.

Dissolved-solids and sulfate concentrations in most small streams exceed U.S. Environmental Protection Agency (1977, 1979) maximum recommended limits for drinking water (table 3), but generally are less than the maximum limits recommended for livestock watering. Dissolved-solids concentrations in small streams commonly exceed the 3,150 mg/L considered to be the maximum for the safe watering of any plant, and the water in most streams is considered to have a high to very high salinity hazard. Also, average SAR values range from 4.1 to 16 (McKinley, 1979), which produces a medium to very high sodium hazard. As a result, water from these small streams generally is not suitable for irrigation use on most soils. However, during intervals of high streamflow, dilution of base flow by overland runoff from spring snowmelt and summer rains (fig. 7) may provide water that is suitable for irrigation.

Quality of water in the Missouri and Yellowstone Rivers differs significantly from that in the smaller streams in the study area, because these streams primarily

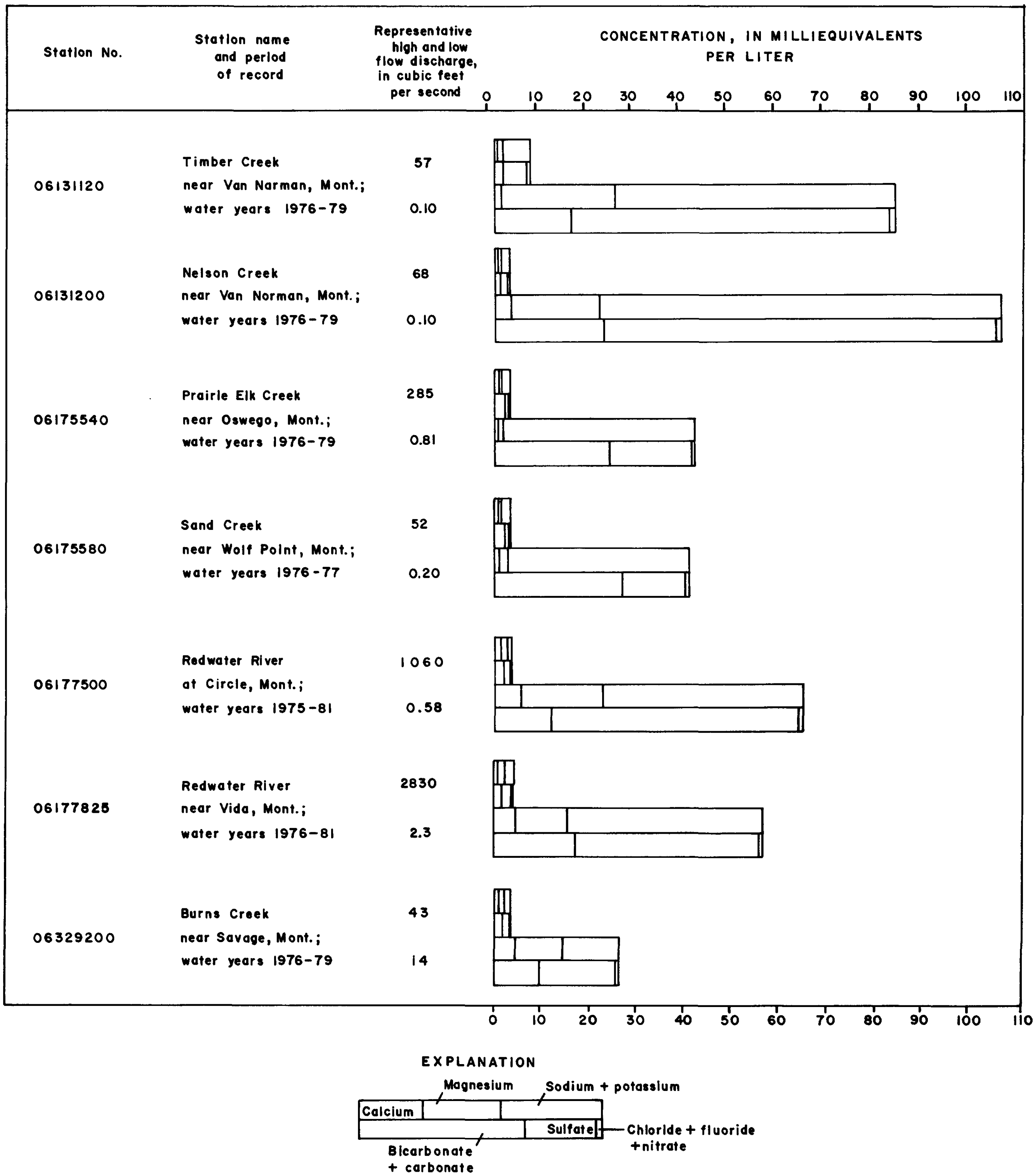


Figure 8.--Relationship of discharge to water type and dissolved-solids concentration at selected stations on small streams.

transport water that, in large part, originated upstream from snowmelt in the Rocky Mountains. A very small percentage of the flow in these rivers originates in the study area.

Dissolved-solids concentrations in both the Missouri and Yellowstone Rivers are commonly much less variable than in small streams within the area and generally range from 400 to 600 mg/L. The smaller dissolved-solids values usually coincide with higher flows. Calcium and sodium are the primary cations and occur in about equal concentrations. Average sulfate concentrations of 173 mg/L for the Missouri River near Culbertson (station 06185500, fig. 6) and 211 mg/L for the Yellowstone River near Sidney (station 06329500) are much less than the concentrations in the smaller streams. At times the sulfate concentrations slightly exceed the U.S. Environmental Protection Agency recommended limit for drinking water. Average dissolved-solids concentrations of 427 and 476 mg/L and SAR values of 1.5 and 1.9 at the same stations indicate that the water is suitable for irrigation supplies.

SUMMARY

The shallow aquifers are sedimentary geologic units ranging in age from Late Cretaceous to Holocene. Geologic units that compose the shallow ground-water system consist of, in ascending order, the Fox Hills Sandstone, Hell Creek Formation, Fort Union Formation, glacial deposits, terrace deposits, and alluvium. Maximum thickness of the section is about 2,300 ft. Prominent structural features in and near the study area are the Redwater anticline, Cedar Creek anticline, Circle basin, Blood Creek syncline, Sheep Mountain syncline, Poplar dome, Weldon fault, Brockton-Froid fault zone, and Williston basin.

The thick sequence of the Bearpaw Shale is a barrier to vertical movement of water and is considered to form the lower boundary of the shallow aquifer system. Average yields of wells completed in consolidated geologic units above the Bearpaw are: Fox Hills-lower Hell Creek aquifer, 50 gal/min; Upper Hell Creek confining layer, 5 gal/min; Tullock aquifer, 5 gal/min; Lebo confining layer, 9 gal/min from sandstone lenses; and Tongue River aquifer, 5 to 10 gal/min. Well yields from unconsolidated units are 10 gal/min from the Flaxville where it is saturated; 8 gal/min from the glacial drift aquifer; 20 gal/min from terrace deposits at low altitudes along major streams; and 5 to 10 gal/min from alluvium along smaller streams and several hundred gallons per minute along larger streams.

Alternating aquifers and confining layers coupled with complex intertonguing and interfingering within most units results in complicated patterns of ground-water flow. Difference in water quality indicates that two general flow patterns are present in aquifers above the Hell Creek Formation. A flow pattern that is controlled by the local topography occurs in aquifers less than about 200 ft below land surface and a more regional flow pattern occurs in aquifers at depths greater than about 200 ft. The distinct chemical character of water contained in the Fox Hills-lower Hell Creek aquifer may indicate a separate flow path.

Recharge to the shallow ground-water system in the study area is from infiltration of rainfall and snowmelt on the outcrops and from infiltration of associated surface runoff in streams. Recharge from direct infiltration of rainfall and snowmelt is estimated to be 50,000 acre-ft/yr. Minor quantities of recharge are contributed by seepage from Fort Peck Lake and by deep percolation of applied irrigation water.

Discharge from the shallow ground-water system primarily is to perennial streams. Lesser quantities of water are discharged by evapotranspiration and wells. Discharge to the Redwater River is estimated to be about 5,000 acre-ft/yr. About 2,000 acre-ft/yr is withdrawn by wells for livestock watering and about 2,500 acre-ft/yr is withdrawn for domestic use. The annual evapotranspiration rate in the area is estimated to be between 34 and 45 in.

Ground-water quality in the area varies significantly as a function of depth and aquifer. Water from aquifers at depths less than about 200 ft contains an average dissolved-solids concentration of 1,740 mg/L, with sodium, bicarbonate, and sulfate being the primary ions. Water in aquifers greater than about 200 ft deep and above the Hell Creek Formation contains slightly larger dissolved-solids concentrations and noticeably larger sodium concentrations than water from aquifers less than 200 ft deep. Water from the Fox Hills-lower Hell Creek aquifer is dominated by sodium and bicarbonate, with an average dissolved-solids concentration of 1,180 mg/L. Water from the Fox Hills-lower Hell Creek aquifer generally is soft, whereas water from overlying aquifers generally is very hard. Most ground water in the area does not meet standards for public drinking water established by the U.S. Environmental Protection Agency. Most ground water in the area can be classified as good to excellent for livestock watering. Because of large dissolved-solids and sulfate concentrations, most ground water in the area is not suitable for irrigation.

The Fort Union coal region is principally drained by the Missouri and Yellowstone Rivers. Tributaries to these rivers include the Redwater River and Prairie Elk, Sand, Burns, and Cherry Creeks. Most streams within the area are ephemeral or intermittent and the volume of streamflow varies greatly. Average monthly flows range from 7,466 to 13,700 ft^3/s in the Missouri River and 4,479 to 46,310 in the Yellowstone River. Average monthly flows in smaller gaged streams range from near zero to about 200 ft^3/s. Minimum flows generally occur in midwinter, whereas the largest flows occur in the spring as a result of snowmelt and rainfall.

Water quality in streams within the study area is dependent primarily on flow conditions. Dissolved-solids concentrations generally are largest during low-flow intervals when streamflow is sustained by ground-water inflow. During times of high flow from runoff, dissolved-solids concentrations and the percentages of sodium and sulfate decrease, and the percentages of calcium, magnesium, and bicarbonate increase. Dissolved-solids concentrations of water samples collected from small streams within the area ranged from 160 to 6,960 mg/L. Quality of the water in the Missouri and Yellowstone Rivers differs significantly from water in the smaller streams, because only a small percentage of the streamflow originates in the study area. Dissolved-solids concentrations in these streams generally range from 400 to 600 mg/L. Water from the Missouri and Yellowstone Rivers is suitable for irrigation, whereas water from streams within the study area generally is suitable only during times of high streamflow.

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