RECONNAISSANCE OF GEOLOGY AND WATER RESOURCES ALONG THE NORTH FLANK OF THE SWEET GRASS HILLS, NORTH-CENTRAL MONTANA

By L.K. Tuck

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Multiply	By	To obtain
acre	4,047	square meter
acre-foot	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
barrel (for petroleum, 42 gallons)	0.159	cubic meter
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per foot (ft/ft)	1.0	meter per meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon	0.003785	cubic meter
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

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

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

Sea level: In this report, "sea level" refers to the 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 Sea Level Datum of 1929.

Abbreviated water-quality units used in this report:

µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 °C
mg/L	milligrams per liter

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ABSTRACT

Stratigraphic units of Mississippian through Holocene age crop out along the north flank of the Sweet Grass Hills in north-central Montana. Emplacement of Tertiary igneous rocks has caused uplift and structural deformation of consolidated rocks.

Two unconsolidated and two consolidated aquifers are sources of water in the area. Unconsolidated aquifers are Holocene alluvium and Quaternary interstratified sand and gravel in glacial deposits. Consolidated aquifers are the Upper Cretaceous Judith River Formation and the Upper Cretaceous Virgelle Sandstone Member of the Eagle Sandstone.

Water in the alluvium moves downstream, sub-parallel to stream channels. Recharge is through infiltration of precipitation, streamflow, irrigation-return flow, stored surface water, and subsurface inflow from glacial deposits. Discharge is through seepage to streams, withdrawals from wells, flow of springs and seeps, evapotranspiration, and subsurface outflow to underlying geologic units. One water sample had a dissolved-solids concentration of 439 milligrams per liter and was a calcium bicarbonate type water.

Water in the interstratified sand and gravel generally moves from south to north. Transmissivity was estimated to be 900 feet squared per day. Recharge is probably through infiltration of precipitation and stored surface water, and from subsurface inflow from overlying Quaternary deposits and underlying geologic units. Discharge is through withdrawals from wells (70 acre-feet per year), flow of springs and seeps, and possible subsurface outflow to other geologic units. The dissolved-solids concentration ranged from 154 to 1,600 milligrams per liter and the water ranged from a calcium bicarbonate to a sodium bicarbonate type. Water quality is marginal for domestic use but generally suitable for livestock watering. Irrigation is probably the least feasible use, because the water has large sodium concentrations.

Water in the Judith River Formation probably flows from the outcrop area, following the dip of the formation to the northeast and southeast. Recharge is through infiltration of precipitation on outcrops and in some subcrop areas, infiltration of streamflow across outcrops, and possible subsurface inflow from other geologic units. Discharge is through withdrawals from wells, flow of springs and seeps, evapotranspiration in recharge areas, and possible subsurface outflow to other geologic units. One water sample had a dissolved-solids concentration of 855 milligrams per liter and was a sodium bicarbonate type water.

Water in the Virgelle Sandstone Member generally flows from recharge areas downdip in northerly directions. Estimated transmissivity ranged from 200 to 3,700 feet squared per day. Recharge, estimated to be 3,280-5,790 acre-feet per year, is through infiltration of precipitation on outcrops and in some subcrop areas, infiltration of streamflow across outcrops, and possible subsurface inflow from other geologic units. Discharge, estimated to be about 157 acre-feet per year, is through withdrawals from wells, flow of springs and seeps, and subsurface outflow to other geologic units. Flow within the aquifer across the study-area boundary was about 4,490 acre-feet per year. The dissolved-solids concentration ranged from 213 to 1,360 milligrams per liter, and the water was generally a calcium bicarbonate type. Near the recharge area, water quality is mostly adequate for domestic and livestock watering and marginal for irrigation. Downgradient, the quality is marginal for

domestic and adequate for livestock-watering purposes. Irrigation might be precluded because of salinity and sodium hazards.

Increased development of water from the alluvium, the interstratified sand and gravel aquifer, and the Judith River Formation for irrigation purposes might be limited by local geologic and hydrologic characteristics and water quality. Water from the Virgelle Sandstone Member might be the only ground-water resource feasible for increased development. However, water quality could limit its development.

The principal surface-water resources are Miners Coulee, Breed Creek, and Bear Gulch and their tributaries. Low-flow measurements indicate that streamflow gains were due to seepage and irrigation-return flow from alluvium, and possibly from areas where the Virgelle Sandstone Member is saturated. Streamflow losses were due to evapotranspiration or recharge to the alluvium and the Virgelle. Chemical analyses of three samples from the creeks indicated a range in dissolved-solids concentration of 241 to 774 milligrams per liter, and a sodium bicarbonate to calcium bicarbonate type water.

INTRODUCTION

Several small tributaries of the Milk River originate in the Sweet Grass Hills in north-central Montana and flow northward into Canada (fig. 1). Increasing surface-water use, impoundment of these southern tributaries of the Milk River, and recent drought conditions have resulted in concern about streamflow apportionment by users in the United States and Canada, who depend on this intermittent water source for livestock and irrigation purposes.

The Boundary Waters Treaty of 1909 delimited requirements for the division of water in the Milk River basin. The International Joint Commission Order of 1921 further clarified water appropriations for the Milk River basin. The waters of the eastern and northern tributaries of the Milk River were divided equally between the two countries; however, waters of the southern tributaries of the Milk River were never apportioned.

In 1984, the International Joint Commission established a task force to investigate water-use concerns in the drainage area of the southern tributaries and to develop solutions to streamflow-supply problems. The proposed solution was to be an alternative to formal apportionment. One proposal of the task force was to increase development of ground-water supplies to alleviate the increasing water-supply shortages in the Sweet Grass Hills area. To effectively examine the potential of this proposal, an understanding of the geology and water resources of the Sweet Grass Hills area was needed. Consequently, the U.S. Geological Survey (USGS), in cooperation with the Montana Bureau of Mines and Geology, completed a reconnaissance study from 1988 to 1992 to obtain additional information to meet this need.

Purpose and Scope

This report describes the geology and water resources along the north flank of the Sweet Grass Hills. In terms of geology, the report describes the stratigraphy and structure of geologic units. In terms of water resources, the report describes the extent, hydraulic characteristics and interconnection, and water quality of four principal aquifers; the potential for increased ground-water development; and the availability, magnitude, and chemical quality of streamflow.

The geology and water resources of the Sweet Grass Hills area were assessed and characterized from existing data and from data collected during the study. Pertinent geologic information was revised after additional reconnaissance geologic and photogeologic mapping. Ground-water resources were assessed by an inventory of selected wells and springs, specific-capacity tests and pressure-recovery aquifer

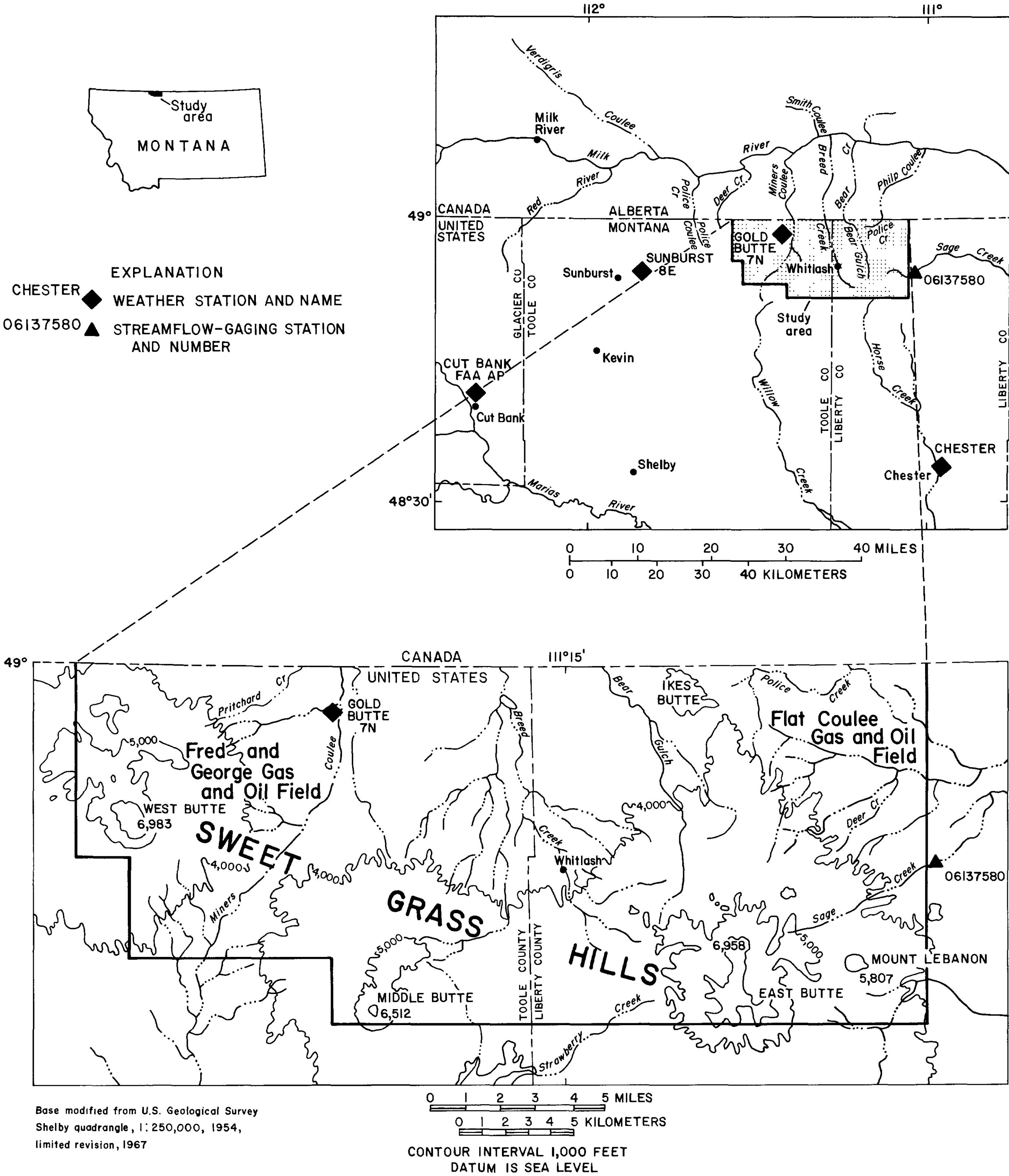

Figure 1.--Location and selected geographic features of the study area.

tests, and water-level monitoring. Streamflow resources were assessed by discharge measurements at various times including periods of low flow. In addition, water samples from selected wells and streamflow sites were analyzed for chemical quality.

Geography of the Area

The Sweet Grass Hills are three prominent buttes and smaller hills that form an arc near the United States-Canada border in northern Toole and Liberty Counties in north-central Montana (fig. 1). The study area encompasses about 230 mi^2 of the Milk River sub-basins of Miners Coulee, Breed Creek, and Bear Gulch. The northern edge of the study area is the international boundary between the State of Montana and the Province of Alberta, Canada.

Several communities are located in and near the study area. Whitlash (unincorporated) serves local residents with a community hall, church, one-room school, and post office. Shelby (population 2,763) and Chester (population 942), located about 30 mi southwest and southeast, respectively, are the largest towns serving as county seats and business hubs (population data from U.S. Bureau of the Census 1990 decennial census files).

Industry in this part of north-central Montana is largely agricultural, with about 90 percent of the land being used for this purpose (Water Resources Survey Board, 1969). Oil and gas production became an important industry in the 1920's, when these resources were discovered and developed. However, oil production in northern Montana generally has declined since the mid-1940's, except for slight increases in the 1960's (Montana Department of Natural Resources and Conservation, 1989, p. 5).

The Sweet Grass Hills area has a semiarid continental-polar climate typical of the northern Great Plains region. Winters are cold and dry with short periods of sub-zero temperatures. Winter storms bring some precipitation, which is stored in the highland areas and along protected coulees as dense snow drifts. These drifts generally provide a source of surface water throughout the spring and early to late summer. However, about 7 in. of the total precipitation received from November through April probably evaporates (National Oceanic and Atmospheric Administration, 1982). Summers are generally mild and dry, with periods of high temperatures. Occasional afternoon thunderstorms provide most of the precipitation received in the summer.

Weather records for the area are available from the Gold Butte 7N weather station. Mean monthly temperatures for 1961-90 ranged from about 20 to 65 °F (fig. 2). Mean annual temperature was 42.4 °F, with a mean minimum of 39.4 °F and a mean maximum of 46.1 °F. Mean monthly precipitation for 1961-90 ranged from about 0.25 to 2.7 in. Mean annual precipitation was 13.03 in., with about 37 percent of this quantity falling in May and June (National Oceanic and Atmospheric Administration, 1961-90).

Owing to orographic effects, the Sweet Grass Hills area has a climate that differs from that of the surrounding prairie flatlands (table 1). Temperature records indicate more moderate extremes near the hills than at nearby weather stations located at Cut Bank and Chester (fig. 1). Precipitation records indicate that the area near the hills receives about 1-2 in. more precipitation than at these stations. Furthermore, the quantity of precipitation increases with altitude, with the summits of the buttes receiving about 7 in. more precipitation than the Gold Butte 7N weather station (U.S. Soil Conservation Service, 1977).

Topography in the study area is largely affected by geology. The more resistant limestone and igneous rocks form rugged, steep-sided buttes. Altitudes are 6,983 ft at West Butte, 6,512 ft at Middle Butte, and 6,958 ft at East Butte (fig. 1). Less resistant sandstone and shale form subdued foothills that encircle the buttes. Igneous dikes and sills form irregular ridges and knobs. Below an altitude of about 5,000 ft (Lemke and others, 1965, p. 18), glacial deposits impart an undulating or hummocky surface, which is distinctive in most of the study area. The hummocky topography becomes more subdued away from the buttes and forms con-

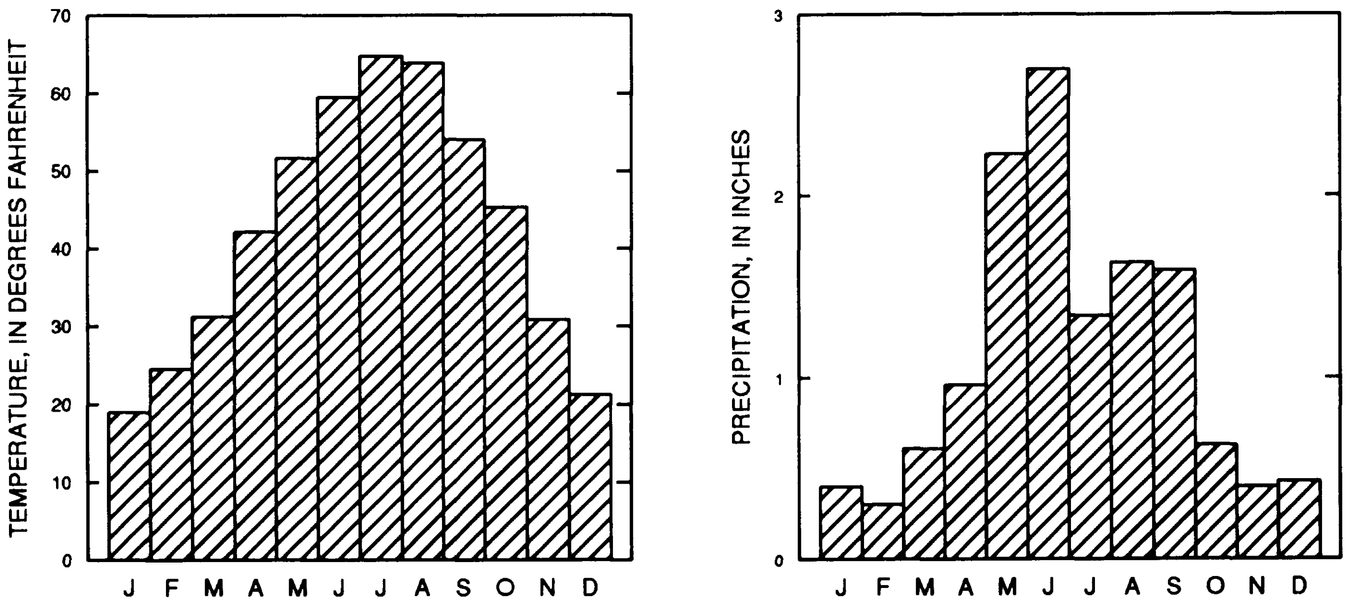

Figure 2.--Mean monthly temperature and mean monthly precipitation at the Gold Butte 7N weather station. Data from National Oceanic and Atmospheric Administration (1961-90).

Table 1.--Annual temperature and precipitation normals for the Sweet Grass Hills area and nearby stations, base period 1961-90[1]

[°F, degrees Fahrenheit]

Station name	Temperature (°F)			Precipitation (inches)
	Maxi-mum	Mini-mum	Mean	
Gold Butte 7N	55.3	29.6	42.4	13.03
Chester	56.9	27.0	41.9	10.51
Cutbank FAA AP	52.9	28.6	41.1	11.89

[1]Data from SNOTEL, Central Forecasting System, U.S. Department of Agriculture, Soil Conservation Service Snow Surveys, Bozeman, Montana.

tinuous gentle slopes that merge with the generally flat surface of the surrounding prairie.

Previous Studies

Kemp and Billingsley (1921) first described and mapped the geology in the study area. Many studies have focused on the geology of oil and gas occurrences in the Sweet Grass Hills and adjoining areas. Stebinger (1916) first summarized data concerning possible oil and gas resources in north-central Montana and reported that wells had been drilled north of West Butte near a natural oil seep. Perry (1928, 1937) and Collier (1929) briefly described the geologic conditions for oil and gas resources and exploration in and near the Sweet Grass Hills. Erdmann (1930, 1935, 1942) investigated the Sweet Grass Hills and adjacent areas to better define oil and gas resources and the geologic structure. Other investigators include Calhoun (1906) and Alden (1932), who briefly described the glacial geology and mapped surficial deposits. Ross (1947) assessed fluorspar deposits and mapped the igneous rocks without delimiting post-Mississippian rocks. Pierce and Hunt (1937) and Smith and others (1957) mapped the geology of selected areas of Liberty County. Truscott (1975) investigated the petrology and geochemistry of igneous rocks of East Butte. Feltis (1980) mapped the general configuration of the top of the Mississippian Madison Group.

The hydrology of the Sweet Grass Hills area has not been comprehensively studied. However, Levings (1982) mapped the generalized potentiometric surface of water in the Eagle Sandstone as part of the Northern Great Plains Regional Aquifer-System Analysis.

Numbering System for Wells, Springs, and Stream Sites

A local number is used to identify the location of wells, springs, and stream sites in this report. The local number, which is based on the rectangular system for the subdivision of public lands (fig. 3), consists of as many as 14 characters. The first three characters specify the township and its position north (N) of the Montana Base Line. The next three characters specify the range and its position east (E) of the Montana Principal Meridian. The next two characters are the section number. The next two to four characters designate the quarter section (160-acre tract), quarter-quarter section (40-acre tract), quarter-quarter-quarter section (10-acre tract), and quarter-quarter-quarter-quarter section (2.5-acre tract), respectively, in which the well, spring, or stream site is located. The subdivisions are designated A, B, C, and D in a counterclockwise direction, beginning in the northeast quadrant. The last two characters form a sequence number that indicates the order of inventory. For example, as shown in figure 3, well 37N03E12CBDD01 is the first well inventoried in the SE1/4 SE1/4 NW1/4 SW1/4 sec. 12, T. 37 N., R. 3 E.

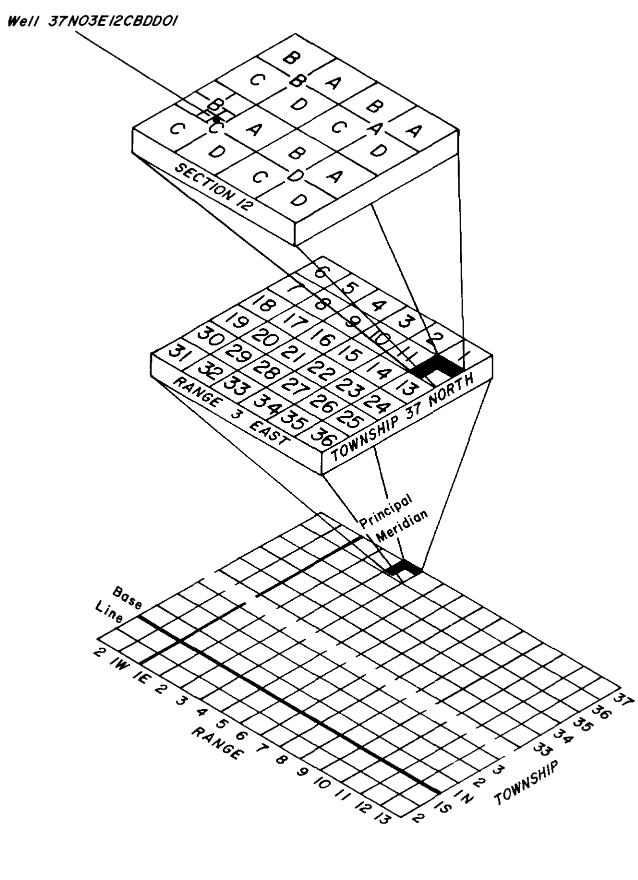

Figure 3.--System of specifying location of wells, springs, and stream sites.

In addition to the local number, a site number is used to identify stream sites where discharge and water-quality data are collected and evaluated. The site number consists of three or four characters that specify the drainage basin and its position, in downstream order, along the stream. For example, site BG-11 represents the 11th stream site along Bear Gulch.

Quality Assurance

Quality of water was determined from 29 analyses of water samples collected at selected sites and analyzed by the Analytical Division, Montana Bureau of Mines and Geology. Samples were collected to identify physical properties and common-constituent and trace-element concentrations that were present in ground water and streamflow at the time of sampling. Samples were processed and concentration values were rounded according to standard USGS procedures (U.S. Geological Survey, 1977; Knapton, 1985).

Quality-assurance practices for the collection and analysis of ground water and streamflow samples were those used by the Montana District of the USGS (Knapton, 1985; Knapton and Nimick, 1991). Eleven quality-assurance samples were collected: six replicates analyzed by the Montana Bureau of Mines and Geology, one replicate analyzed by the U.S. Geological Survey National Water Quality Laboratory in Denver, Colo., and four field blanks[1]. The results of these analyses are listed in tables 11, 12, 15, and 16 at the back of the report.

Water-Quality Standards

Under the Safe Drinking Water Act of 1986, the U.S. Environmental Protection Agency established two sets of regulations for finished (treated) drinking water: Primary Drinking-Water Regulations and Secondary Drinking-Water Regulations (table 2). National Primary Drinking-Water Regulations are established for contaminants, which, if present in public drinking-water supplies, might adversely affect human health. Either a Maximum Contaminant Level (MCL) or a treatment technique is specified for regulated contaminants. MCL's are health-based and enforceable (U.S. Environmental Protection Agency, 1991a). Secondary Drinking-Water Regulations are established for contaminants that can adversely affect the odor or appearance of water and result in discontinued use of the water. These regulations specify Secondary Maximum Contaminant Levels (SMCL'S), which are esthetically based and nonenforceable (U.S. Environmental Protection Agency, 1991b). Both sets of regulations may be used as water-quality guidelines for private domestic wells.

The Montana Department of Health and Environmental Sciences has established water-quality criteria for community water systems (table 2). State criteria are at least as stringent as U.S. Environmental Protection Agency Primary and Secondary Drinking-Water Regulations except for cadmium.

Guidelines of water quality for livestock watering and irrigation have also been established by the Montana Department of Health and Environmental Sciences (table 3). Dissolved-solids concentration is the principal indicator of water quality for livestock use. However, certain major ions may be more limiting than the dissolved-solids concentration. Livestock can tolerate the largest quantity of dissolved solids when the major ions are sodium and chloride, but are less tolerant to water having large sulfate content.

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[1] A field-blank sample is a solution free of analytes that is subjected to all aspects of sample collection, field processing, transportation, and laboratory handling as a water sample.

Table 2.--Drinking-water regulations for public water supply[1],[2]

[MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no regulation available or not applicable]

Water-quality characteristic	National Primary Drinking-Water Regulation[3] (MCL)	National Secondary Drinking-Water Regulation[4] (SMCL)	Montana drinking-water regulations[5]	Equivalent trace-element concentration[6] for MCL or SMCL (µg/L)
	Maximum concentration or value for indicated regulation			
	Physical property (standard units)			
pH	--	6.5-8.5	--	--
	Common constituents (mg/L)			
Dissolved solids	--	500	500	--
Chloride	--	250	250	--
Fluoride	4.0	2.0	4.0	--
Nitrate (as N)	10	--	--	--
Sulfate	--	250	250	--
	Trace elements (mg/L)			
Aluminum	--	0.05-0.2	--	50-200
Arsenic	0.05	--	0.05	50
Cadmium	.005	--	.01	5
Chromium	.1	--	.05	100
Copper[7]	--	1.0	--	1,000
Iron	--	.3	.3	300
Manganese	--	.05	.05	50
Selenium	.05	--	.01	50
Silver	--	.1	.05	100
Zinc	--	5.0	--	5,000

[1]Regulations in effect as of July 30, 1992.
[2]Listed only for properties, common constituents, and trace elements presented in this report.
[3]U.S. Environmental Protection Agency (1991a).
[4]U.S. Environmental Protection Agency (1991b).
[5]Roy Wells (Water Quality Bureau, Montana Department of Health and Environmental Sciences, oral commun., 1992).
[6]The U.S. Geological Survey reports trace-element concentrations in micrograms per liter.
[7]Copper is covered by an "action level" of 1.3 mg/L (U.S. Environmental Protection Agency, 1991c).

Table 3.--Livestock-watering and irrigation-water-quality guidelines[1]

[--, not applicable]

Water-quality characteristic	Livestock watering: Concentration (milligrams per liter)	Livestock watering: Concentration (micrograms per liter)	Irrigation: Concentration (milligrams per liter)	Irrigation: Concentration (micrograms per liter)	Irrigation: Guideline (dimensionless number)
Sodium-adsorption ratio (SAR)	--	--	--	--	5
Fluoride	2	--	15	--	--
Dissolved solids (calculated)	10,000	--	1,200	--	--
Arsenic	.20	200	.10	100	--
Boron	5	5,000	.75	750	--
Copper	.50	500	5	5,000	--
Selenium	.05	50	.02	20	--
Zinc	25	25,000	10	10,000	--

[1]Montana Department of Health and Environmental Sciences, 1986.

Quality of water for irrigation can be assessed by the relation between the total soluble-salt concentration and the relative proportion of sodium to calcium and magnesium. The total soluble-salt concentration, or salinity hazard, is based on the specific conductance of water, which is divided into four categories from low- to very high-salinity hazard. Water having a specific conductance less than about 750 µS/cm (low- to medium-salinity hazard) is generally satisfactory for irrigation, although salt-sensitive plants might be adversely affected (U.S. Salinity Laboratory Staff, 1954, p. 70-71). However, irrigation water with large concentrations of sodium relative to calcium and magnesium can cause sodium to accumulate in the soil and affect soil permeability and structure (Driscoll, 1987, p. 112-114). The relative proportion of sodium to calcium and magnesium (sodium hazard) is measured by the sodium-adsorption ratio (SAR), which is defined as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad (1)$$

where ion concentrations are expressed in milliequivalents per liter. The effect of the SAR (sodium hazard) is most pronounced when the specific conductance (salinity hazard) is large. The Montana Department of Health and Environmental Sciences (1986) has established an SAR guideline value for irrigation of 5.

Acknowledgments

The author acknowledges and thanks the Sweet Grass Hills residents who provided information about their wells and springs and who allowed access to their lands. This investigation could not have been conducted without their cooperation. Thanks are also extended to D.R. Nelson, Fulton Fuel Company, who provided information and access to water-supply wells, and Steven Sasaki, Oil and Gas Conservation Division, Montana Department of Natural Resources and Conservation, who provided personal observations of geology in the Sweet Grass Hills area.

GENERAL GEOLOGY

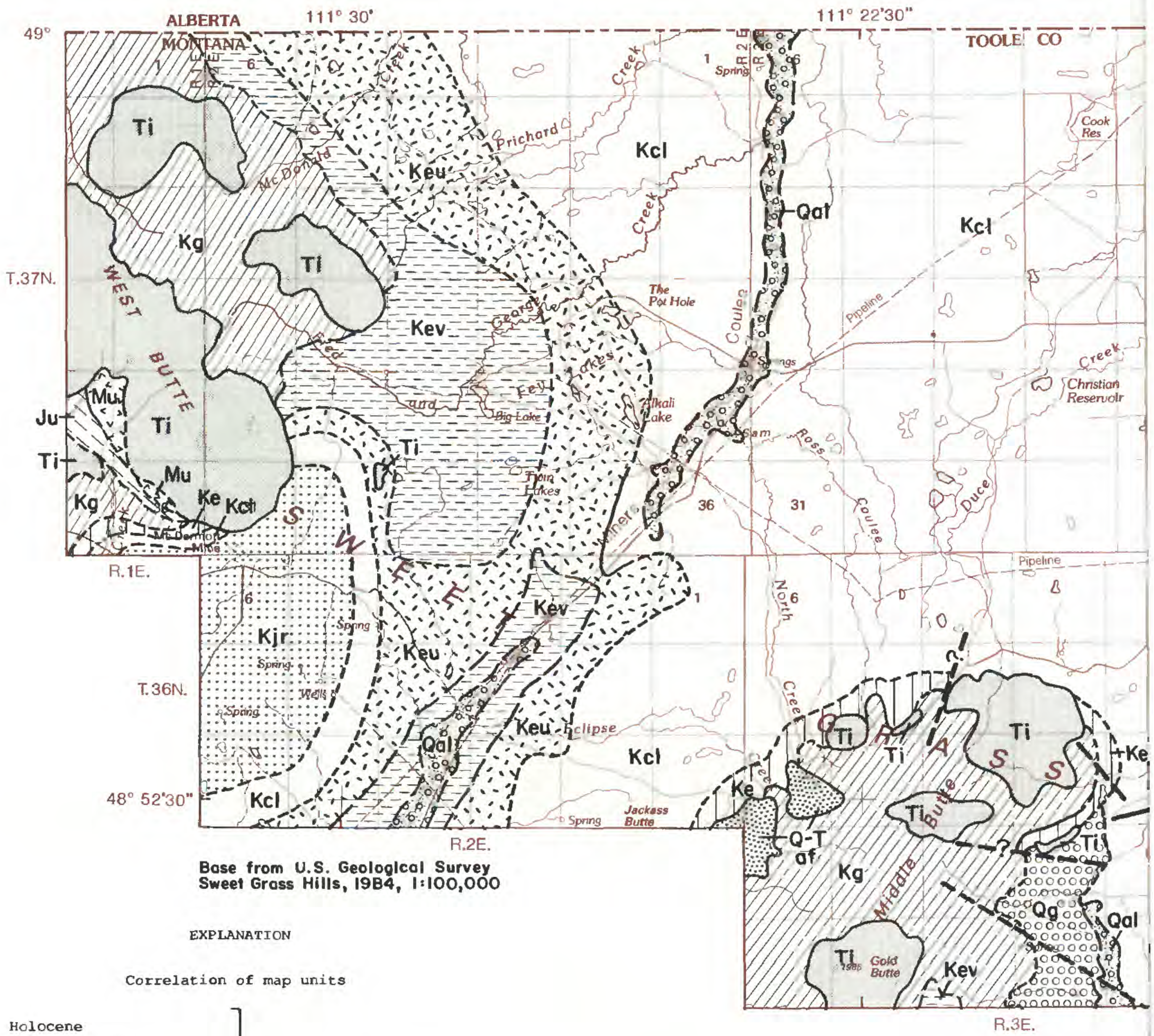
The stratigraphy and structure along the north flank of the Sweet Grass Hills partly control ground-water movement, recharge, and discharge. An overview of geologic units and their relation to structural deformation provide a framework for understanding ground water in the study area.

Stratigraphy

Stratigraphic units of Mississippian through Holocene age crop out along the north flank of the Sweet Grass Hills (fig. 4); units older than Mississippian occur at depth (table 4). The Madison Group of Mississippian age forms the oldest formations that crop out near the centers of West and East Buttes. The Lodgepole and Mission Canyon Limestones, which compose the Madison Group in the study area, consist of thin-bedded to massive limestone. Thickness of the Madison Group is about 1,000 ft, but may differ within the area owing to a regional unconformity and subsequent faulting, uplift, and erosion. Tertiary intrusives in contact with these rocks have extensively metamorphosed, replaced, and brecciated the limestone. Near Tootsie Creek, solution cavities are present in outcrops (Ross, 1947).

Similarly, the Ellis Group of Jurassic age crops out in small areas in the cores of West and East Buttes. The Sawtooth, Rierdon, and Swift Formations, which compose the Ellis Group, consist of about 300 ft of alternating marine shale, sandstone, mudstone, and limestone. The Madison and Ellis Groups have been target horizons for oil and gas exploration in the subsurface.

Sandstone and shale of Cretaceous age crop out around all three buttes; down-dip, they subcrop under glacial deposits. The Cretaceous stratigraphic sequence



Base from U.S. Geological Survey
Sweet Grass Hills, 1984, 1:100,000

EXPLANATION

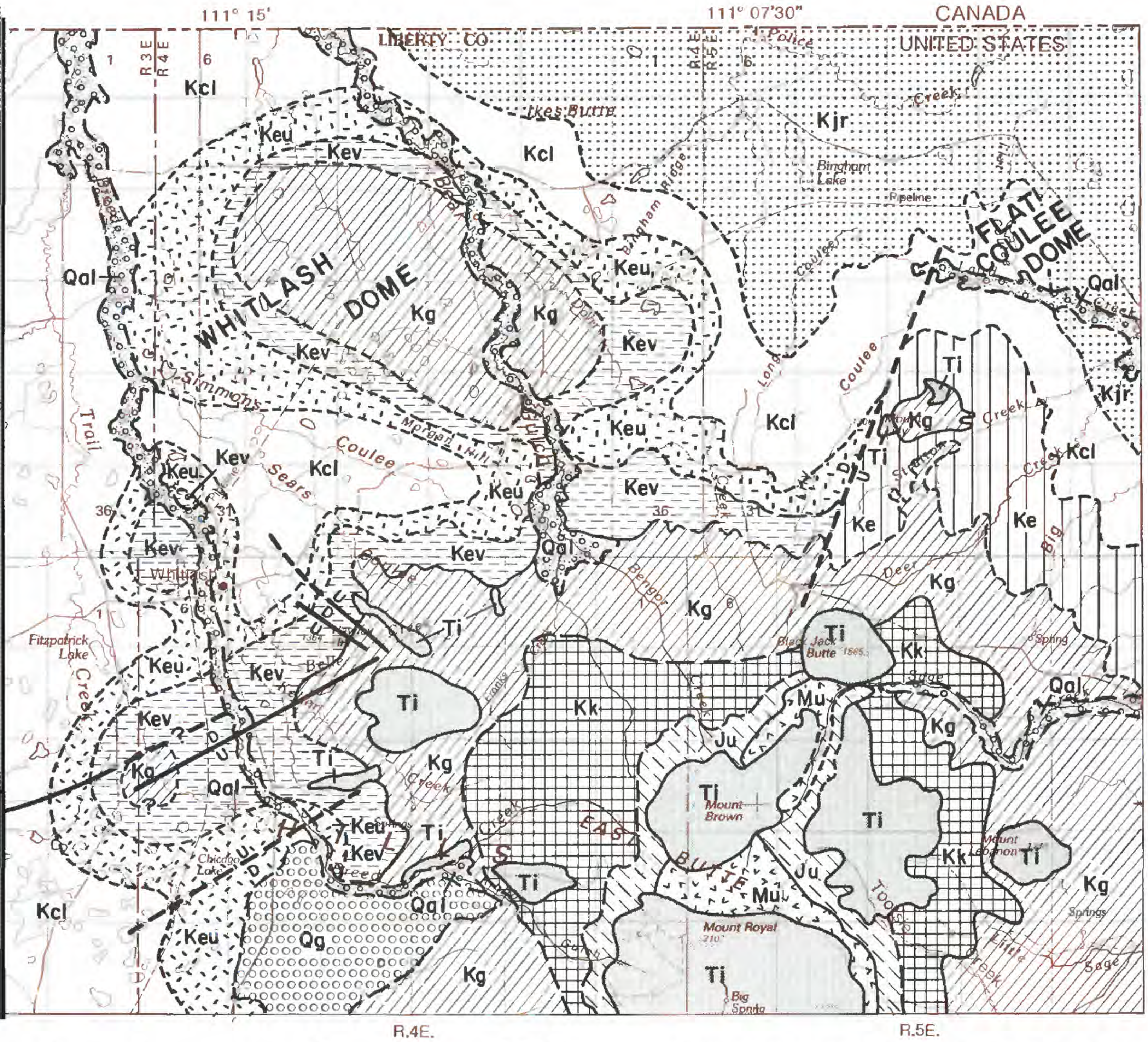
Correlation of map units

Qal	Holocene		Quaternary
	Unconformity(?)		
Qg	Pleistocene		
	Unconformity(?)		
Q-Taf	Pleistocene and Pliocene(?)		
	Unconformity(?)		
Ti	Eocene		Tertiary
	Unconformity		
Kjr, Kcl, Keu, Kev, Ke	Upper Cretaceous		Cretaceous
Kg, Kk	Lower Cretaceous		
	Unconformity		
Ju	Jurassic		Jurassic
	Unconformity		
Mu	Mississippian		Mississippian

Description of map units

- **Qal** ALLUVIUM--Unconsolidated gravel, sand, silt, and clay along present-day stream channels and terraces
- **Qg** GLACIAL DEPOSITS--Unconsolidated gravel, sand, silt, and clay; includes interstratified sand and gravel deposits
- **Q-Taf** ALLUVIAL-FAN DEPOSITS--Unconsolidated gravel, sand, silt, and clay
- **Ti** INTRUSIVE IGNEOUS ROCKS--Diorite and syenite porphyry. Only largest dikes and sills are identified
- **Kjr** JUDITH RIVER FORMATION--Interbedded sandstone, shale, and thin coal beds
- **Kcl** CLAGGETT SHALE--Shale with several bentonite beds in lower part

Figure 4.--Generalized geology.



Geology from Erdmann (1930, 1942), Ross (1947), and Intrasearch (1983); modified in part by reconnaissance geologic and photogeologic mapping by the author

Ke EAGLE SANDSTONE, UNDIFFERENTIATED--Shale with thin beds of sandstone, siltstone, and coal; massive sandstone and thin-bedded siltstone and shale

Keu EAGLE SANDSTONE, UPPER PART--Chiefly shale with thin beds of sandstone, siltstone, and coal

Kev VIRGELLE SANDSTONE MEMBER OF EAGLE SANDSTONE--Massive sandstone with thin-bedded siltstone and shale

Kg TELEGRAPH CREEK FORMATION AND COLORADO GROUP, UNDIFFERENTIATED--Colorado Group includes equivalents of the Niobrara Formation, Carlile Shale, Greenhorn Formation, Belle Fourche Shale, Muddy Sandstone, Skull Creek Shale, and First Cat Creek sandstone (of drillers' usage). Chiefly shale with sandy shale, siltstone, sandstone, bentonite, and limestone

Kk KOOTENAI FORMATION--Marine shale with a few thin beds and lenses of non-marine sandstone in upper part. Largely sandstone in lower part

Ju ELLIS GROUP--Includes the Swift, Rierdon, and Sawtooth Formations. Alternating beds of shale, sandstone, mudstone, and limestone

Mu MADISON GROUP--Includes the Mission Canyon and Lodgepole Limestones. Massive to thin-bedded limestone; metamorphosed near igneous rocks

——— - - -? GEOLOGIC CONTACT--Long dashed where approximately located; short dashed where uncertain; queried where probable

U/D ——— - - -? FAULT--Shows relative displacement. Dashed where approximately located; queried where probable. U, upthrown side; D, downthrown side

Bedrock below the altitude of about 5,000 feet (fig. 1) is covered by as much as 300 feet of glacial deposits, most of which are not shown on this map

Table 4.--Generalized geologic units and water-yielding properties[1] along the north flank of the Sweet Grass Hills

[ft, feet; gal/min, gallons per minute; symbols identify mapped units in figure 4; --, no data]

Erathem	System	Series	Group or formation	Approximate thickness or range (ft)	General character	Water-yielding properties
Cenozoic	Quaternary	Holocene	Alluvium (Qal)	0-25	Unconsolidated gravel, sand, silt, and clay along present-day stream channels and terraces.	Might be a source of water near perennial streams. Yields to two wells: 6 and 120 gal/min. Water quality suitable for most uses.
			Unconformity (?)			
Cenozoic	Quaternary	Pleistocene	Glacial deposits (Qg)	0-300	Unconsolidated gravel, sand, silt, and clay; occurs primarily as till. Includes the interstratified sand and gravel aquifer.	A limited source of water except in the interstratified sand and gravel aquifer. Yields range from 1 to 105 gal/min to wells. Water under flowing-artesian pressure in some places. Water quality might be unsuitable for some uses.
			Unconformity (?)			
Cenozoic	Quaternary / Tertiary	Pleistocene / Pliocene (?)	Alluvial-fan deposits (QTaf)	Unknown	Unconsolidated gravel, sand, silt, and clay. Deposits are isolated remnants on west flank of Middle Butte.	Unknown
			Unconformity (?)			
Cenozoic	Tertiary	Eocene	Intrusive igneous rocks (Ti)	Variable	Diorite to syenite porphyry and related rocks forming laccoliths, stocks, dikes, and sills. Water originates from fault zones and fractures.	Yields range from small seeps to more than 30 gal/min. Water suitable for most uses.
			Unconformity			
Mesozoic	Cretaceous	Upper Cretaceous	Montana Group: Judith River Formation (Kjr)	125[2] - 600[3]	Interbedded light-gray to buff, soft, fine-grained lenticular sandstone and shale. Thin coal beds in upper part.	A yield of 0.3 gal/min reported from one well. Water under flowing-artesian pressure in some places. Water quality might be unsuitable for some uses.
Mesozoic	Cretaceous	Upper Cretaceous	Montana Group: Claggett Shale (Kcl)	0-430[4]	Dark-gray marine shale. Sandy in the upper part. Contains several bentonite beds in lower part.	Yields little water. Not an aquifer. Shale is nearly impermeable.
Mesozoic	Cretaceous	Upper Cretaceous	Montana Group: Eagle Sandstone (Ke)	0-320	Upper part (Keu): Interbedded shale, siltstone, thin-bedded sandstone, and coal. Virgelle Sandstone Member (Kev): Gray to buff, massive sandstone, thinly-bedded siltstone, and gray shale.	Sandstone of Virgelle Sandstone Member yields from 1 to about 80 gal/min of water to wells. Water under flowing-artesian pressure in some places. Water quality might be unsuitable for some uses.

Table 4.--Generalized geologic units and water-yielding properties along the north flank of the Sweet Grass Hills--Continued

Erathem	System	Series	Group or formation		Approximate thickness or range (ft)	General character	Water-yielding properties
Mesozoic	Cretaceous	Upper Cretaceous	Montana Group	Telegraph Creek Formation (Kg)	100-170[3,4]	Largely gray silty an sandy shale siltstone in the lower part. Increasing sand and sandstone in the upper part. Transitional between the Colorado Group and the Eagle Sandstone[4].	Yields little water. Not an aquifer. Shale is nearly impermeable.
Mesozoic	Cretaceous	Upper Cretaceous / Lower Cretaceous	Colorado Group (Kg)	Equivalents of Niobrara Formation, Carlile Shale, Greenhorn Formation, Belle Fourche Shale, Muddy Sandstone, Skull Creek Shale, and First Cat Creek sandstone (drillers' usage)	1,480-1,845[2]	Upper part is chiefly dark marine shale and sandy shale with interbeds of siltstone, fine-grained sandstone, chert-pebble lenses, bentonite, and gray limestone. Lower part contains lenticular, nonmarine sandstone, siltstone, bentonite, and dark marine shale[4].	Yields little water. Shale is nearly impermeable. The sandstone yields oil and gas in Sweet Grass Hills. Produced water probably would be too mineralized for domestic or stock use.
Mesozoic	Cretaceous	Lower Cretaceous	Kootenai Formation (Kk)		350[4]-500[5]	Variegated argillaceous member: Marine shale, with a few thin beds and lenses of nonmarine sandstone. Lower unit: Largely sandstone.	Yields little water. Limestone and sandstone beds yield oil and gas. Produced water probably would be too mineralized for domestic or stock use (Erdmann, 1935, p. 273).
			Unconformity				
Mesozoic	Jurassic	Upper Jurassic	Ellis Group (Ju)	Swift Formation	307[6]	Alternating beds of marine shale, glauconitic sandstone, sandy mudstone, and impure limestone.	Yields little water. Limestone and sandstone beds yield oil and gas. Water quality is unknown. Produced water probably would be too mineralized for domestic or stock use.
Mesozoic	Jurassic	Middle Jurassic	Ellis Group (Ju)	Rierdon Formation			
Mesozoic	Jurassic	Middle Jurassic	Ellis Group (Ju)	Sawtooth Formation			
			Unconformity				
Paleozoic	Mississippian	Upper Mississippian / Lower Mississippian	Madison Group (Mu)	Mission Canyon Limestone	640	Mostly massive beds of gray limestone. Upper part contains solution cavities that range from small vugs to caverns. Metamorphosed and mineralized near Tertiary igneous rocks.	Yields some water. Group yields gas in the Sweet Grass Hills. Produced water probably would be too mineralized for domestic or stock use (Erdmann, 1935, p. 273).

Table 4.--Generalized geologic units and water-yielding properties along the north flank of the Sweet Grass Hills--Continued

Erathem	System	Series	Group or formation	Approximate thickness or range (ft)	General character	Water-yielding properties
Paleozoic	Mississippian	Lower Mississippian	Madison Group (Mu): Lodgepole Limestone Unconformity	380	Mostly thin-bedded, light- to dark-gray limestone; contains many small lenses of chert and thin partings of shale.	Yields some water. Group yields gas in the Sweet Grass Hills. Produced water probably would be too mineralized for domestic or stock use (Erdmann, 1935, p. 273).
	Devonian, Ordovician, and Cambrian		Devonian, Ordovician, and Cambrian rocks, undivided Unconformity	1,600	Mostly limestone and dolomite, but contains shale, siltstone, claystone, sandstone, and conglomerate.	Properties are unknown. Produced water probably would be too mineralized for domestic or stock use.
Precambrian			Pre-Belt Supergroup metamorphic and intrusive basement rocks	--	Mainly inclusions, as much as 2 ft in diameter, in Tertiary igneous rocks: hornblende and granite gneiss, granite, quartzite, and mica schist. These inclusions are presumed to be from the basal Precambrian rocks[7].	Properties are unknown. Probably has little or no fracture flow.

[1] Modified from Feltis (1983).
[2] Erdmann (1930).
[3] Pierce and Hunt (1937).
[4] Cobban (1955).
[5] Perry (1937).
[6] Sanderson (1931).
[7] Kemp and Billingsley (1921).

represents intertonguing wedges of marine shale, nonmarine sandstone, and continental coastal-plain sediments that formed as Cretaceous seas transgressed and regressed across what is now central Montana. Rocks of Cretaceous age, which comprise the Kootenai Formation and the Colorado and Montana Groups, have a composite thickness of almost 3,500 ft.

The Kootenai Formation crops out discontinuously around East Butte and ranges in thickness from about 350 to 500 ft in the Sweet Grass Hills. This formation is composed of marine shale with a few thin beds and lenses of non-marine sandstone in the upper part; the lower part is largely sandstone. A sandstone at the base of the Kootenai Formation is a target horizon for oil and gas exploration (Cobban, 1955, p. 107).

The Colorado Group, which ranges in thickness from 1,480 to 1,845 ft, crops out in thin broken ridges, subdued hills, and swales that mostly encircle each of the three buttes. The lower part of the Colorado Group contains lenticular, non-marine sandstone, siltstone, bentonite, and dark marine shale. Six or more of these sandstones (the Whitlash or Bow Island sands of drillers' usage) yield oil and gas (Erdmann, 1935). The upper part consists mostly of shale and sandy shale with interbeds of siltstone, fine-grained sandstone, chert-pebble lenses, bentonite, and limestone.

Along the north flank of the Sweet Grass Hills, the Montana Group consists of the Telegraph Creek Formation, Eagle Sandstone, Claggett Shale, and Judith River

Formation. The Telegraph Creek Formation is largely silty and sandy shale and siltstone in the lower part. Sand and sandstone increase in the upper part. Reported thickness of the Telegraph Creek Formation in areas near the Sweet Grass Hills ranges from 100 to 170 ft. This formation marks the transition between the deep-marine shale of the upper part of the Colorado Group and the shoreface-coastal plain deposits of the overlying Eagle Sandstone.

The Eagle Sandstone forms discontinuous outcrops around each butte in the foothills region. Its extent is dependent on both structural upwarping and subsequent erosion, which have removed or thinned this formation on four domes and along some flanks of buttes. The Eagle Sandstone, which has a maximum thickness of about 320 ft, is conformable with the underlying Telegraph Creek Formation and the overlying Claggett Shale and represents several depositional environments associated with an eastward prograding shoreline. The Virgelle Sandstone Member of the Eagle Sandstone is discussed in detail because it is the principal bedrock aquifer and is a potential source of water for supplemental use in the study area.

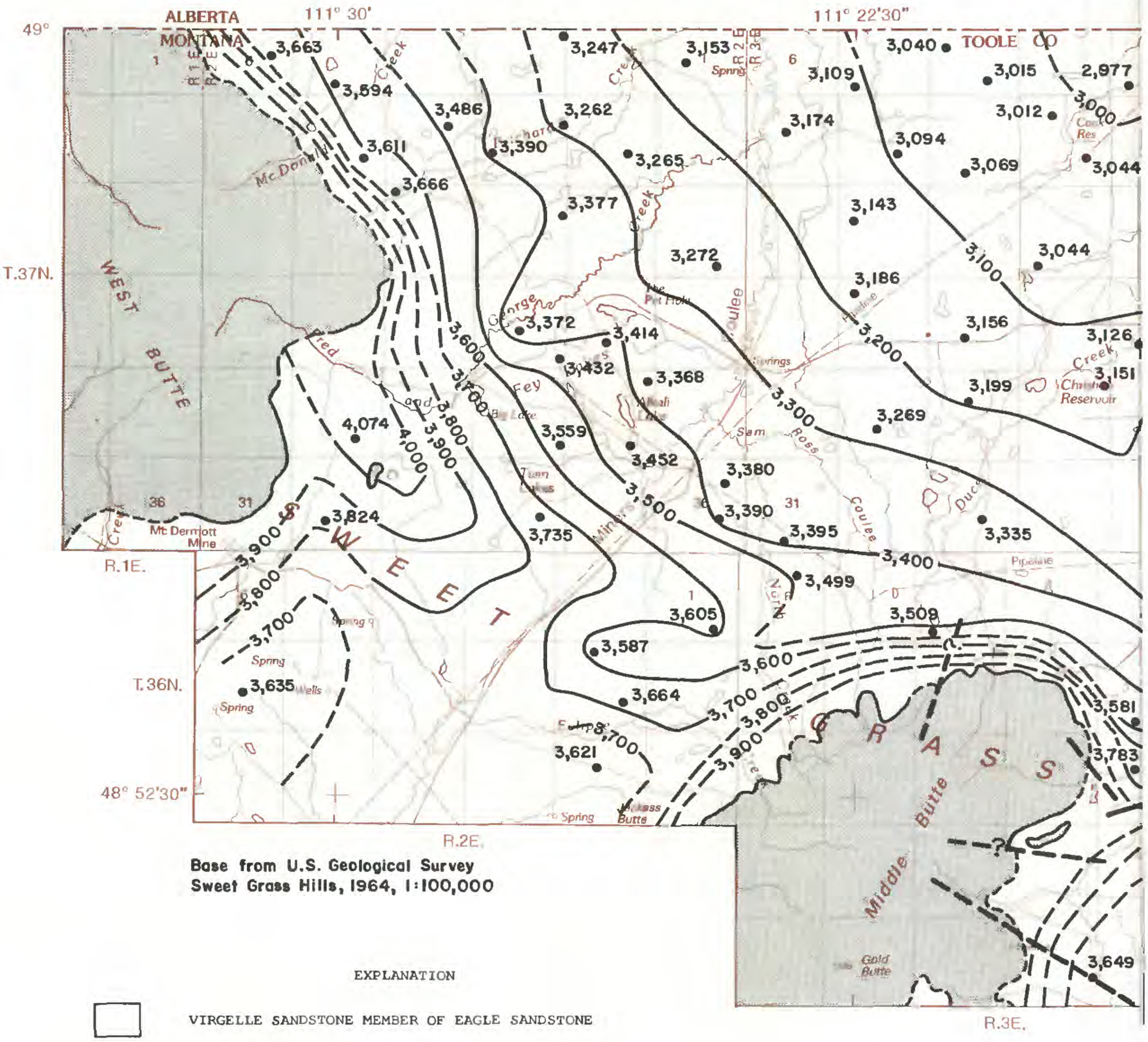
The Virgelle Sandstone Member is a massive, crossbedded, "salt and pepper" sandstone composed predominantly of very fine to medium-grained quartz, chert, feldspar, and mica. It is friable but commonly has well-indurated hematite-stained lenses that form resistant caprock in outcrop. Thin-bedded siltstone and shale occur at several different horizons within the sandstone. Meyboom (1960, p. 53) reported a porosity of 10 percent for the Milk River Sandstone (Virgelle equivalent in Alberta), whereas Rice (1980, p. 336) reported an average porosity of 26 percent.

The altitude and configuration of the base of the Virgelle Sandstone Member (fig. 5), were determined from data obtained from geophysical logs, principally resistivity logs, of oil and gas exploration holes. Resistivity logs record the electrical resistivity of rock material in a borehole. The electrical resistivity of a geologic unit is affected by the lithology and the dissolved-solids concentration of water in the interconnected pore spaces. Large resistivities were interpreted as sandstone containing water having a small dissolved-solids concentration. Conversely, small resistivities were interpreted as shale or a formation containing water having a large dissolved-solids concentration. The base, rather than the top, of the Virgelle was chosen for mapping because of the large number of resistivity logs available for study. In many exploration holes, surface casing obscures the upper contact from identification by resistivity logs. In addition, these logs were used to qualitatively describe unit thickness, apparent changes in lithology, and depth to top of the Virgelle.

As shown in figure 5, the base of the Virgelle progressively deepens off the flank of West, Middle, and East Buttes and the Whitlash and Flat Coulee Domes. The base ranges in altitude from about 4,200 ft at outcrops near East Butte to about 2,600 ft in the northeast corner of the study area. East of Whitlash Dome, the base of the Virgelle has a slope of about 800 ft/mi.

Thickness of the Virgelle Sandstone Member ranges from about 60 to 194 ft and averages about 130 ft. It is massive in all but two areas. In the southwest corner of the study area in secs. 5, 6, and 7, T. 36 N., R. 2 E., the sandstone thins to about 60 ft thick and is interbedded with shale. Along the international boundary in secs. 1-6, and continuing south into secs. 8-11, T. 37 N., R. 3 E., about 30-40 ft of interbedded shale separates the massive sandstone into two units. The interbedded shale is not recorded in resistivity logs south of these sections. In addition, the Virgelle thins to about 100 ft north of a line that trends southeast from approximately sec. 5, T. 37 N., R. 4 E., to sec. 22, T. 37 N., R. 5 E.; however, in this area the Virgelle retains its massive character.

Depth to the top of the Virgelle Sandstone Member ranges from 0 to about 900 ft. In the northeast corner of the study area, depth to the top increases from about 300 to 800 ft in a short distance as a result of the steep northeast dip off the Whitlash and Flat Coulee Domes. Along the international boundary from Ikes Butte to West Butte, depth to the top decreases from about 750 to 200 ft as the Virgelle rises along the west limb of a syncline on the northeast flank of West Butte.



Base from U.S. Geological Survey
Sweet Grass Hills, 1964, 1:100,000

EXPLANATION

VIRGELLE SANDSTONE MEMBER OF EAGLE SANDSTONE

AREA OF NO VIRGELLE SANDSTONE MEMBER

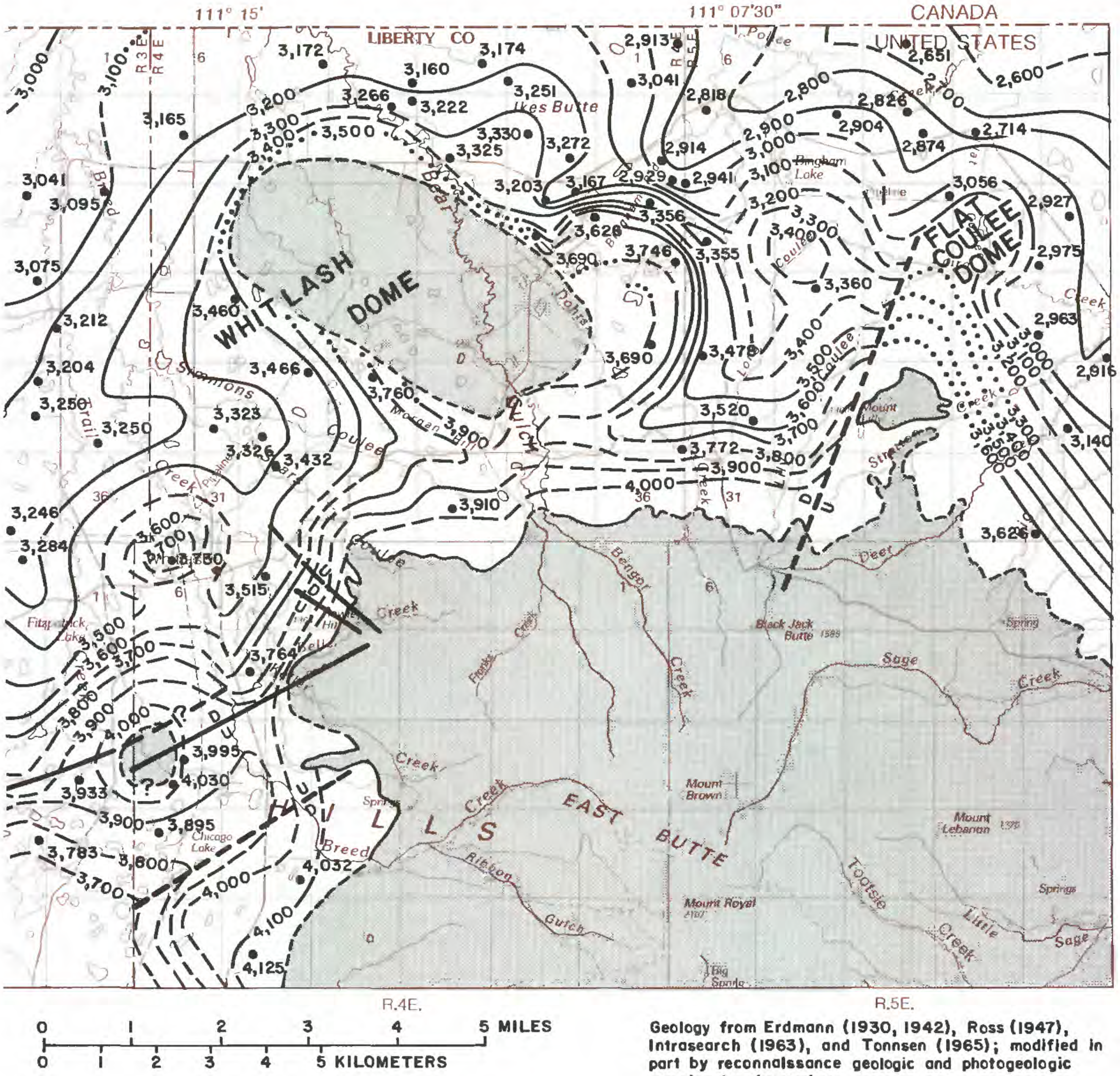
CONTACT--Shows general limit of Virgelle Sandstone Member. Long dashed where approximately located; short dashed where uncertain; queried where probable

U D FAULT--Shows relative displacement. Dashed where approximately located; queried where probable. U, upthrown side; D, downthrown side

3,800 STRUCTURE CONTOUR--Shows altitude and configuration of the base of the Virgelle Sandstone Member. Dashed where approximately located; dotted where data are insufficient to establish contour with certainty. Contour interval 100 feet. Datum is sea level

3,664 OIL OR GAS WELL OR TEST HOLE--Data from Oil and Gas Division, Montana Department of Natural Resources and Conservation, Billings, Mont. Number is altitude of base of the Virgelle Sandstone Member, in feet above sea level

Figure 5.--Altitude and configuration of the base of the Virgelle



Geology from Erdmann (1930, 1942), Ross (1947), Intrasearch (1963), and Tonnsen (1965); modified in part by reconnaissance geologic and photogeologic mapping by the author

Sandstone Member of Eagle Sandstone.

The upper part of the Eagle Sandstone consists of coastal-plain deposits of interbedded shale, siltstone, thin-bedded sandstone, and coal. Scattered chert-gravel lenses or a chert-pebble conglomerate, which can be as thick as 3 ft, marks the upper contact (Rice, 1980, p. 324). Thickness of the upper member ranges from about 100 to 160 ft and averages about 127 ft.

The Claggett Shale is a thick, nearly impermeable marine shale that also has been removed or thinned by erosion. The formation thickness, which is as much as 430 ft, is greatest in the north and east parts of the study area. The Claggett is mostly shale; however, bentonite interbeds from 2 in. to 3 ft thick occur in the lower part. The upper part is more sandy, as shale beds grade into the overlying Judith River Formation (Pierce and Hunt, 1937, p. 236-242).

The Judith River Formation crops out in the northeast part of the study area from Ikes Butte to the eastern boundary and in the southwest part near the southern flank of West Butte. This formation is composed of coastal-plain deposits of interbedded sandstone, shale, and coal. Individual sandstone beds are less than 50 ft thick, lenticular, and laterally discontinuous. The Judith River Formation in the study area ranges in thickness, but is probably less than 600 ft (Pierce and Hunt, 1937, p. 232-236).

The principal Tertiary intrusive igneous rocks that were formed as stocks and laccoliths crop out in the buttes. Small laccoliths, dikes, and sills also crop out in the buttes and radially from the main intrusive centers. These subordinate features are thought to have developed along weak zones as the overlying formations adjusted to periods of intrusive activity (Rhodes, 1955, p. 182). The stocks, laccoliths, dikes, and sills that compose the Sweet Grass Hills igneous complex range in composition from diorite to syenite porphyry. This area is part of the central-Montana alkalic geologic province, which includes several small, isolated mountains formed by igneous intrusions. The igneous rocks are rich in potassic and sodic feldspars and commonly have mafic to ultramafic mineral assemblages. Age dating of rocks in the Sweet Grass Hills indicates that the emplacement was 49.8 to 53.6 million years ago (Eocene Epoch) (Marvin and others, 1980). All consolidated geologic units younger than the Judith River Formation, excluding the Tertiary igneous rocks, have been eroded.

Small or remnant alluvial fans composed of unconsolidated gravel, sand, silt, and clay might be as old as late Tertiary. The alluvial fans on the west flank of Middle Butte are truncated by a series of Pleistocene recessional moraines and are devoid of clasts typical of Pleistocene deposits in the area.

During the Pleistocene Epoch, continental ice sheets moved southward from Canada, terminating far south of the Sweet Grass Hills and creating many depositional environments that resulted in complexly stratified deposits. At least two episodes of glacial advance with an interglacial period are recognized (Westgate, 1968). Calhoun (1906, p. 28) first recognized that glaciers left the tops of the Sweet Grass Hills as isolated peaks above the ice sheets.

Glacial deposits, which are generally below an altitude of 5,000 ft, are composed of clay- to boulder-sized material and occur as widespread moraines. Thickness of these deposits, which ranges greatly, has been reported from oil and gas exploration holes to be as much as 300 ft, but is probably less than 50 ft in most of the foothill areas.

Sand and gravel lenses are interstratified with the glacial deposits. The origin of the interstratified sand and gravel deposits is unknown, but may include the collapse of glaciofluvial outwash that formed on top of stagnant ice and subsequent deposition as the ice melted. The sand and gravel may also represent fluvial stream-channel deposits that formed during an interglacial period. Subsequent glacial advance buried the sand and gravel with 100 to 200 ft of glacial deposits. Thickness of interstratified sand and gravel deposits ranges greatly; thicknesses of 2-40 ft have been reported in oil and gas exploration and well-completion reports.

Glaciolacustrine deposits are reported from oil and gas exploration holes near the west flank of Ikes Butte. These deposits probably formed on the glacier surface in lakes that were common where the ice was stagnant, or near the front of the glacier such as those described by Westgate (1968, p. 28-35) north of the study area.

Holocene alluvium is restricted to present-day stream channels and terraces along creeks and coulees. Alluvium composed of unconsolidated gravel, sand, silt, and clay is formed primarily by stream erosion of Pleistocene glacial deposits and subsequent deposition. The alluvium is not laterally extensive and information from oil and gas exploration and well-completion reports indicates that alluvium ranges in thickness from 0 to about 25 ft.

Structure

Emplacement of the igneous rocks caused doming, folding, and faulting of the consolidated rocks. The study area has many domes (figs. 4, 5). The Whitlash Dome, the largest, encompasses about 18 mi^2 northeast of the community of Whitlash. In the dome core, the Eagle Sandstone has been eroded and the Colorado Group subcrops under glacial deposits. Erdmann (1935, p. 273) postulated that this dome might have an igneous core at depth. The Flat Coulee Dome, in the northeastern part of the study area, is associated with igneous activity near the Mount Lilly Laccolith (Perry, 1937, p. 73). Two smaller domes are present at Whitlash and about 2 mi south of Whitlash. The former dome has the Virgelle Sandstone Member exposed in its core, whereas the latter has rocks probably of the Colorado Group exposed in its core. Evidence that these two domes are associated with igneous activity is lacking; however, their shapes are similar to the Whitlash and Flat Coulee structures, which indicates a similar genesis. Reports from oil and gas exploration holes document that dikes and sills are found at depth throughout the study area.

Folding associated with the emplacement of igneous rocks has formed subsidiary synclines and anticlines. The folding is most complex near the buttes and decreases toward the international boundary. The Eagle Sandstone is downwarped in a broad syncline (fig. 5) in the central part of the study area and between the Whitlash and Flat Coulee Domes; a large anticline is located southeast of West Butte.

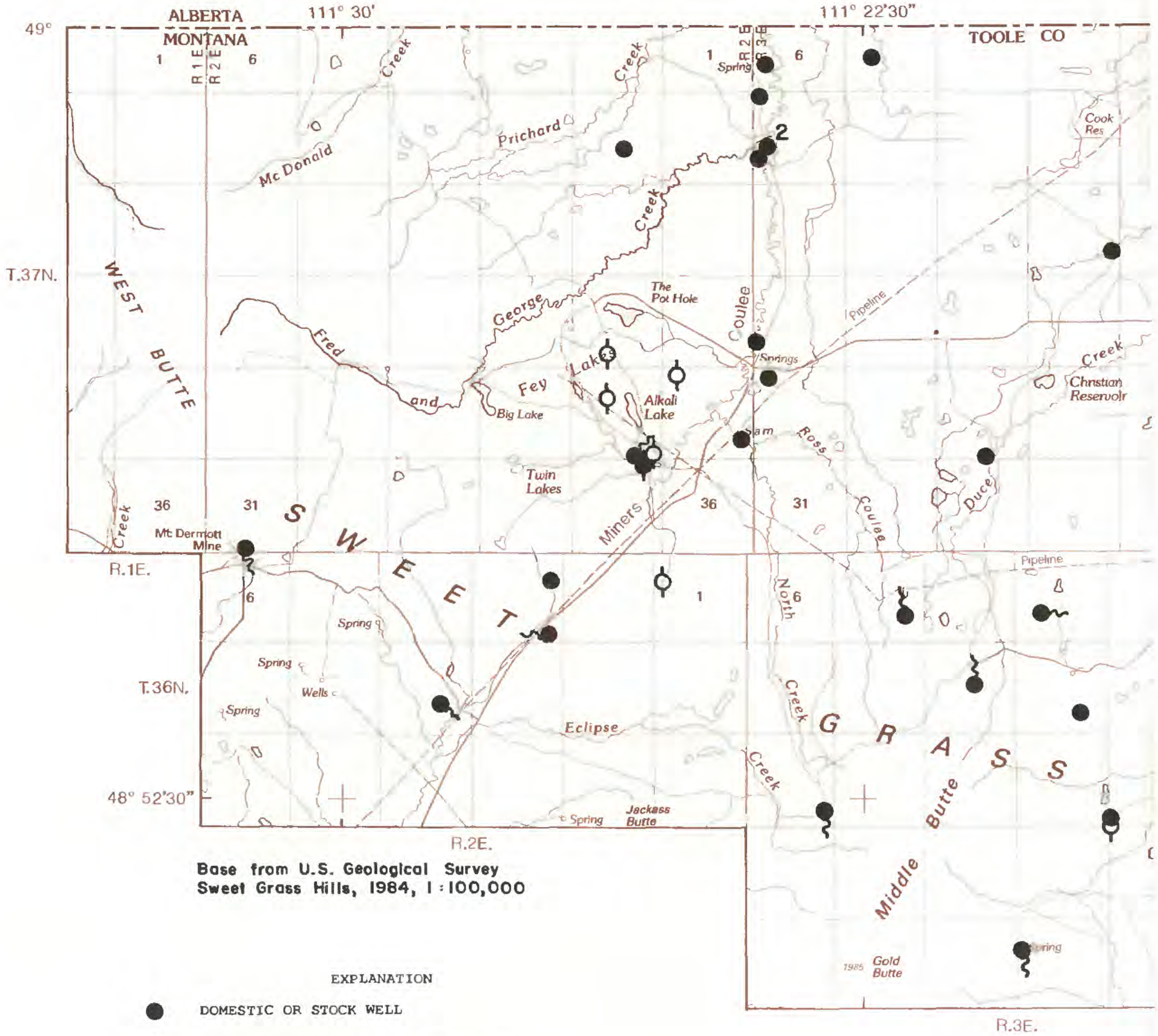
Radial faults and tension fractures are thought to be associated with emplacement of the igneous rocks. Dikes and sills occupy many of these structural features. Glacial deposits probably obscure many faults in the study area (Erdmann, 1930).

WATER RESOURCES

Water resources along the north flank of the Sweet Grass Hills include ground water from two unconsolidated and two consolidated aquifers, and surface water in streams, water stored in reservoirs, stock ponds, lakes, and potholes. Understanding these resources and their interaction is critical to determining the potential for increased development of ground water to alleviate increasing water-supply shortages.

Ground Water

Ground water is a source for domestic supply, livestock watering, secondary recovery of oil, and public supply. Of the 72 wells inventoried for this study (fig. 6, table 10 at the back of the report), 21 wells are used primarily for domestic supply, 21 are used primarily for livestock watering, 4 are used for secondary recovery of oil, 1 is used for public supply, and 25 are unused. Springs are numerous. Of the 10 springs inventoried, 8 are used for domestic supply and 2 are used for livestock watering.

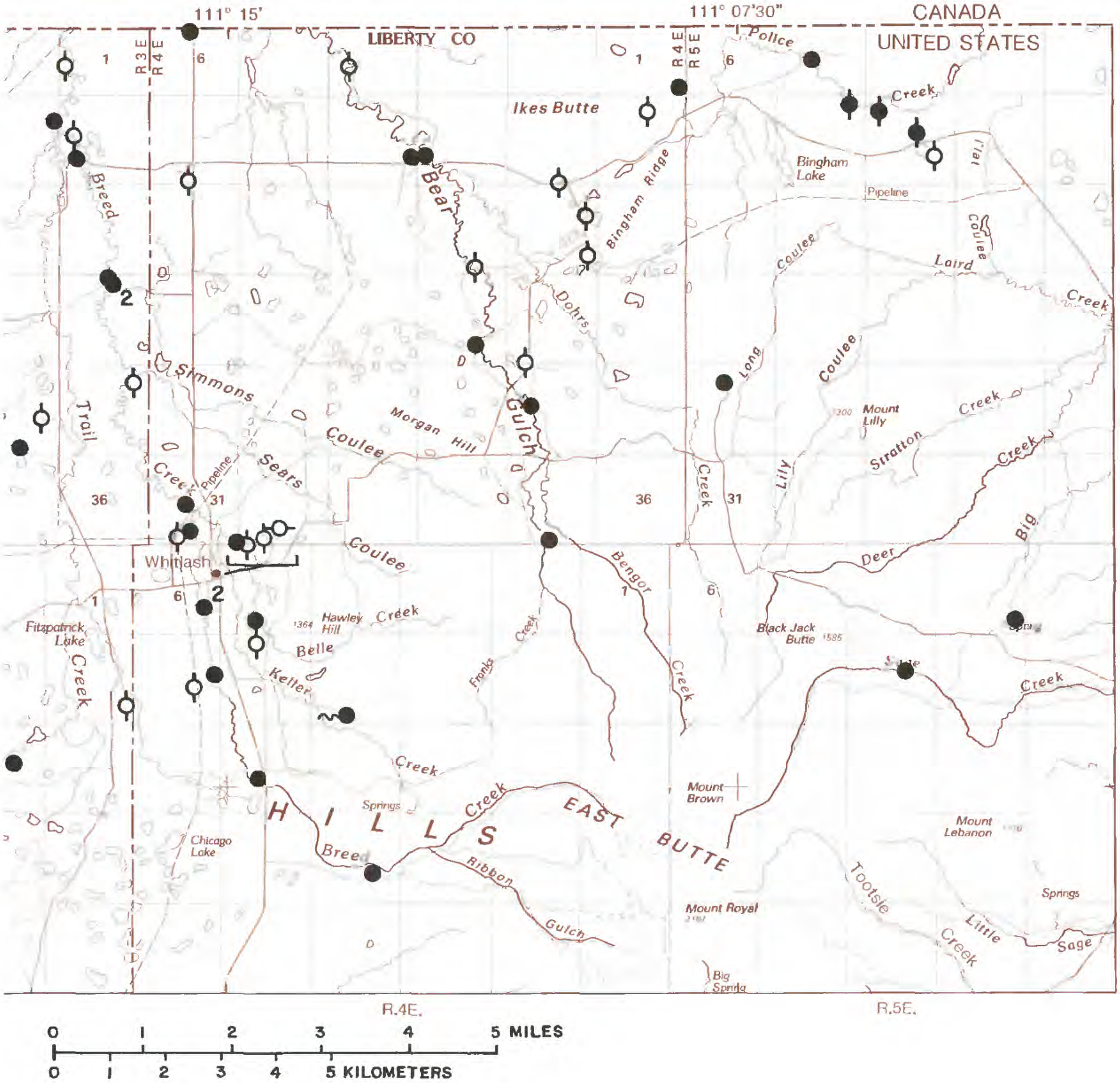


Base from U.S. Geological Survey
Sweet Grass Hills, 1984, 1:100,000

EXPLANATION

- DOMESTIC OR STOCK WELL
- SECONDARY-RECOVERY SOURCE WELL
- PUBLIC-SUPPLY WELL
- UNUSED WELL
- SPRING
- 2 NUMBER OF WELLS AT SAME GENERAL LOCATION

Figure 6.--Location of wells and springs.


111° 15'
111° 07'30"
CANADA
UNITED STATES
LIBERTY CO
R3E
R4E
R5E
Ikes Butte
Police
Creek
Bingham Lake
Pipeline
Bingham Ridge
Bear
Breed
Trail
Simmons
Coulee
Morgan Hill
Seers
Coulee
Gulch
Dohrs
Laird
Creek
Long
Coulee
Mount Lilly
Stratton
Creek
Lily
Big
Deer
Whitlash
Bengor
Creek
Fitzpatrick Lake
Creek
Hawley Hill
Creek
Belle
Keller
Franks
Black Jack Butte
Springs
H I L L S
EAST BUTTE
Mount Brown
Mount Lebanon
Chicago Lake
Breed
Ribbon
Gulch
Mount Royal
Tootsie
Little
Creek
Sage
Springs
Big Spring
R.4E.
R.5E.
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

Withdrawals of ground water for domestic supply and livestock watering are estimated to be about 20 acre-ft/yr, or 11 percent of ground-water use. Withdrawals for secondary recovery of oil are estimated to average (1989-90) 76 acre-ft/yr (table 5), or 43 percent of ground-water use. Many wells in the study area are allowed to flow freely. Withdrawals from these flowing wells are estimated to be about 83 acre-ft/yr, or 46 percent of ground-water use.

Table 5.--Summary of ground-water withdrawals for secondary recovery of oil in the study area

Oil field	Water-supply source	1989 production		1990 production	
		Barrels[1]	Acre-feet	Barrels[1]	Acre-feet
Fred and George Creek[2]	Virgelle Sandstone Member	57,741	7.4	56,206	7.3
Flat Coulee[3]	Virgelle Sandstone Member	561,536	72.4	505,716	65.5
Total		619,277	79.8	561,922	72.8

[1]One barrel equals 42 gallons.
[2]Data from files of the Oil and Gas Conservation Division, Montana Department of Natural Resources and Conservation.
[3]Data from Daniel Wilson (Breck Operating Company, oral commun., 1991).

Twenty-six samples of ground water were collected for chemical analysis--1 from alluvium, 12 from interstratified sand and gravel deposits, 1 from the Judith River Formation, and 12 from the Virgelle Sandstone Member. The physical properties and the common-constituent concentrations are given in table 11 and the trace-element concentrations are given in table 12.

Unconsolidated Aquifers

Two unconsolidated aquifers, Holocene alluvium and Quaternary interstratified sand and gravel in glacial deposits, are sources of ground water in the Sweet Grass Hills. The alluvium is not used extensively as an aquifer, whereas the interstratified sand and gravel deposits are used extensively.

Alluvium

Two inventoried wells (36N05E09ACDB01) and (37N04E35CDDD01) are completed in shallow alluvium--along Sage Creek and Bear Gulch, respectively. The aquifer is probably unconfined (water-table conditions) or leaky confined, laterally discontinuous, and affected by streamflow.

The general direction of flow in the alluvium is downstream, sub-parallel to the stream channels. Horizontal hydraulic gradients within the alluvium vary in response to recharge. Gradients are probably toward the stream when saturated alluvium contributes water to streamflow. Conversely, gradients are away from the stream when streamflow is lost to alluvium and evapotranspiration by phreatophytes along the channel.

A transmissivity of 2,000 ft^2/d and a hydraulic conductivity 156 ft/d were reported during an aquifer test of alluvium near well 36N05E09ACDB01; well discharge was 120 gal/min during the test (Osborne and Zaluski, 1985). For well 37N04E35CDDD01, the measured discharge was 6.0 gal/min and the specific capacity was 3.1 (gal/min)/ft of drawdown.

Recharge and discharge components for alluvium can be discussed only qualitatively, because data used to estimate a hydrologic budget are sparse or unknown. Recharge to the alluvium is through infiltration of precipitation, streamflow, irrigation-return flow, stored surface water (reservoirs and stock ponds), and subsurface inflow from glacial deposits. Discharge from the alluvium is through seepage to streams, withdrawals from wells, flow of springs and seeps, evapotranspiration, and subsurface outflow to underlying geologic units. Water in the alluvium also flows downgradient across the northern study-area boundary.

For the one water sample collected from alluvium for chemical analysis (well 37N04E35CDDD01), onsite determinations indicated a specific conductance of 670 µS/cm, a pH of 7.1, and a water temperature of 12.0 °C. Laboratory analysis indicated an SAR of 0.8 and a dissolved-solids concentration of 439 mg/L (table 11). This sample was a calcium bicarbonate type water, wherein calcium was the dominant cation and bicarbonate was the dominant anion.

No concentrations of analyzed constituents from the sample exceeded the MCL's for drinking water. However, concentrations of iron (920 µg/L) and manganese (690 µg/L) exceeded the respective SMCL's of 300 and 50 µg/L for drinking water. All constituent concentrations were less than State water-quality guidelines for livestock watering or irrigation.

A diagram for determining the salinity and sodium hazards of water used for irrigation is shown in figure 7. Water from the alluvium has a medium salinity hazard, and a low sodium hazard. Hence, on the basis of one sample, water from the alluvium probably is satisfactory for irrigation although salt-sensitive plants might be adversely affected (U.S. Salinity Laboratory Staff, 1954, p. 71).

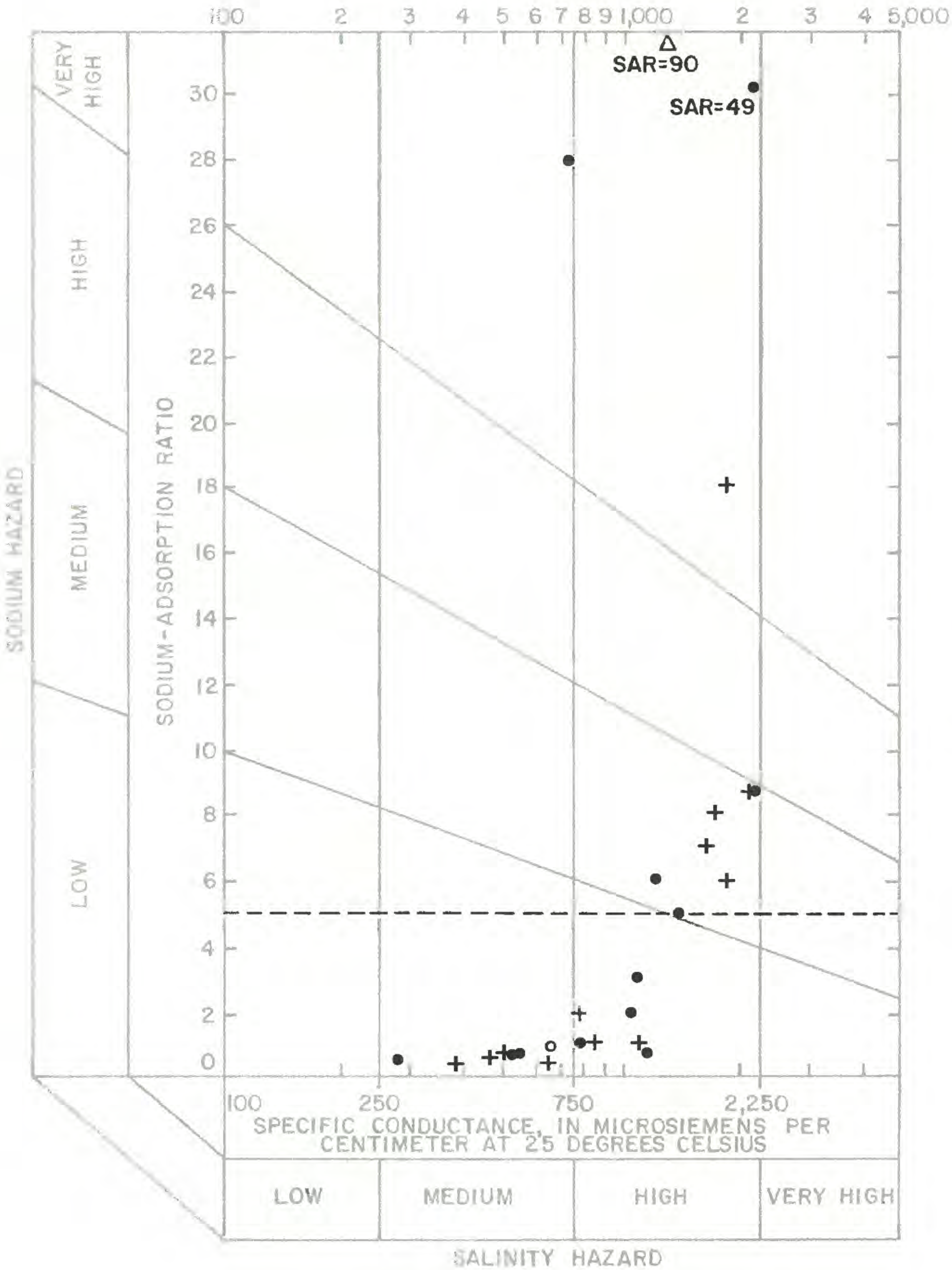
Interstratified Sand and Gravel in Glacial Deposits

The interstratified sand and gravel aquifer occurs both as laterally continuous deposits and as apparently discontinuous and poorly connected lenses below an altitude of about 5,000 ft (fig. 8). Analysis of wells near Breed Creek indicates that the interstratified sand and gravel are laterally continuous along the present-day channel and terraces. The extent beyond the Breed Creek area is unknown, but the unit probably pinches out or grades into the surrounding glacial deposits. Near Bear Gulch, interstratified sand and gravel also might be laterally continuous along the present-day stream channel and terraces. However, along Bear Gulch the deposits are less well documented because of the lack of wells in the area.

Water in the interstratified sand and gravel aquifer is leaky confined or confined (artesian or flowing artesian), wherein water levels are above the top of the aquifer. All measured water levels in wells completed in the aquifer indicate confined conditions; unconfined conditions were not found in this aquifer in the study area. Water-level data for this aquifer are given in table 13 at the back of the report.

The general direction of water movement in the interstratified sand and gravel can be determined from the potentiometric surface shown in figure 8. The direction of water flow is at right angles to these contours and downgradient, generally from south to north.

In the central part of the study area near Whitlash, water levels in wells completed in the interstratified sand and gravel aquifer (fig. 8) seem to have lower hydraulic heads than in wells completed in the Virgelle Sandstone Member (see fig. 12 in the section "Virgelle Sandstone Member"), thus indicating a slight upward gradient between the two aquifers in this area. For example, the water level in well 37N04E31CDCA01 (completed in the interstratified sand and gravel) is about 8 feet lower than nearby well 37N04E31CDAD01 (completed in the Virgelle). In addition, this well and two other wells near Whitlash (wells 36N04E07ADDD01 and



EXPLANATION

SOURCE OF WATER TO WELLS

o Holocene alluvium

● Quaternary interstratified sand and gravel within glacial deposits

△ Upper Cretaceous Judith River Formation

+ Upper Cretaceous Virgelle Sandstone Member of Eagle Sandstone

-- MAXIMUM SODIUM-ADSORPTION RATIO (SAR) GUIDELINE--Established by the Montana Department of Health and Environmental Sciences (1986)

Figure 7.--Diagram for determining salinity and sodium hazards of water used for irrigation (modified from U.S. Salinity Laboratory Staff, 1954, p. 80).

36N04E05CDAC01 completed in the Virgelle) flow, also indicating a probable upward gradient. North of this area in secs. 1, 11, and 12, T. 37 N., R. 3 E., water levels in wells completed in the interstratified sand and gravel aquifer seem to have a higher hydraulic head than in wells completed in the Virgelle, indicating a slight downward gradient between the two aquifers in this area. However, all wells in these sections flow. Hydraulic gradients between the interstratified sand and gravel aquifer and the Virgelle could not be established with data from this study.

Short-term changes in water levels in two wells (fig. 9, table 13) provide indirect evidence that the two aquifers could be hydraulically connected in the central part of the study area. Figure 9 illustrates the similarity of seasonal variation in water levels between the interstratified sand and gravel aquifer and the Virgelle. Water-level rises and declines are parallel after about mid-December 1989. Differences in water-level rises and declines before mid-December 1989 might be due to nearby well interference and possible well use prior to measurements.

In contrast, the interstratified sand and gravel aquifer in other areas apparently is discontinuous or occurs as poorly connected lenses. For example, figure 10 shows short-term changes in water levels that illustrate the dissimilarity of seasonal variation in water levels in three wells completed in this aquifer. These hydrographs do not have parallel water-level rises and declines, indicating that hydrologic conditions differ at each well.

Natural physical boundaries of flow in the interstratified sand and gravel include the overlying and underlying confining or leaky-confining glacial deposits, and the underlying Claggett Shale and unnamed upper member of the Eagle Sandstone. Apparent lateral boundaries include the surrounding glacial deposits.

Analysis of one single-well aquifer test resulted in an estimated transmissivity[2] of 900 ft^2/d. The reported or measured discharge from eight water wells ranged from 1.3 to 105 gal/min (table 10), and the measured specific capacity of three of these wells ranged from 0.1 to 4.8 (gal/min)/ft of drawdown (table 6).

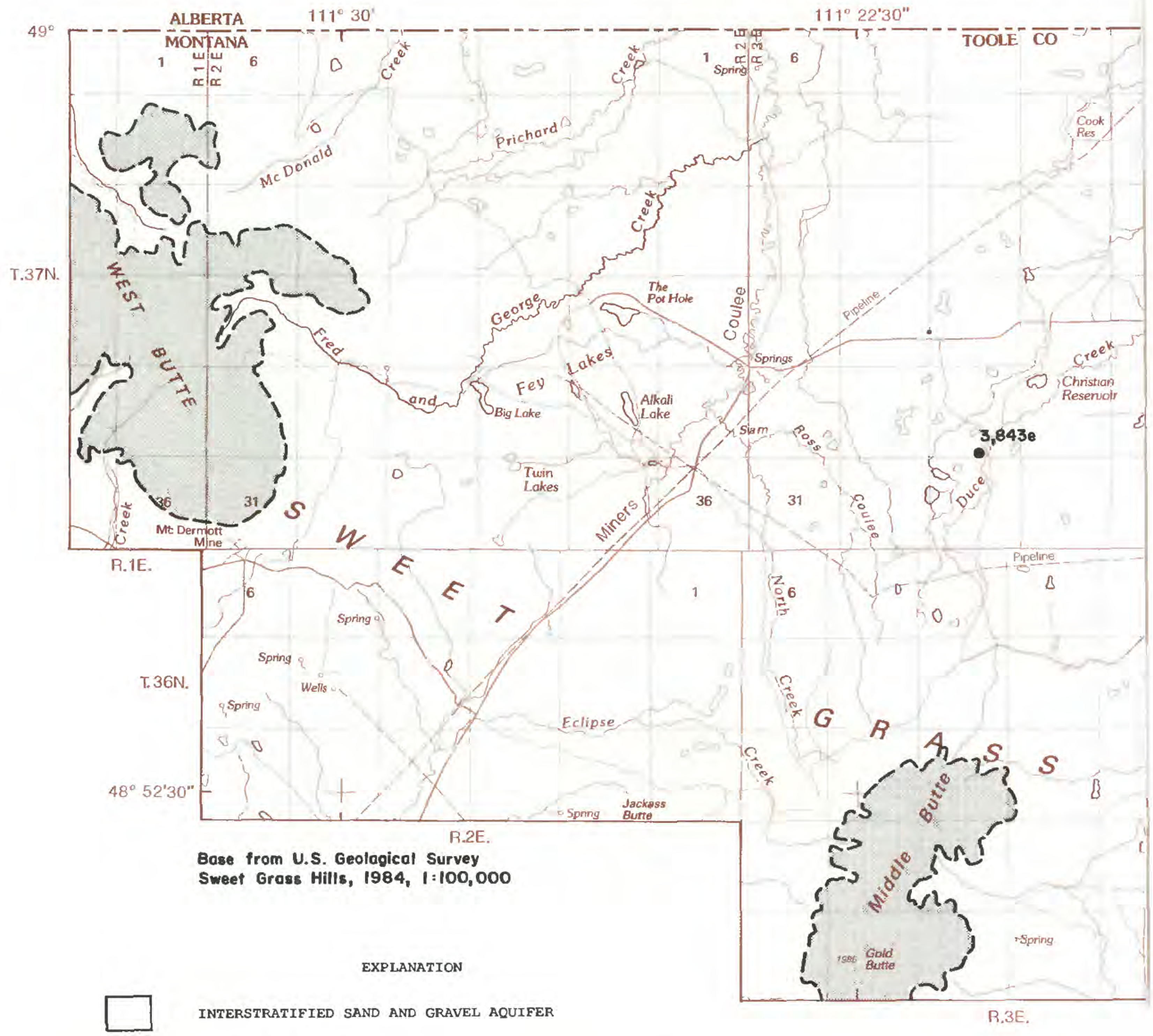
Table 6.--Hydraulic characteristics and specific-capacity data for the interstratified sand and gravel aquifer in the study area

[Data from U.S. Geological Survey. Discharge type: F, flowing; P, pumping. Water levels--in feet below or above (+) land surface. Abbreviations: ft^2/d, feet squared per day; gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot. --, no data]

Local number	Date	Discharge (gal/min)	Discharge type	Pumping period (hours)	Pumping water level (feet)	Static water level (feet)	Drawdown (feet)	Estimated transmissivity (ft^2/d)	Specific capacity [(gal/min)/ft]
36N03E14ACDC01	07-28-89	1.3	F	0.08	+2.17	+20.06	17.89	--	0.1
37N03E12CBDD01[1]	08-15-89	16.5	F	2.0	+3.55	+18.75	15.20	900	1.1
37N05E30BAD01	06-22-89	12.0	P	.5	38.88	36.37	2.51	--	4.8

[1] Well partly penetrates the aquifer.

[2] Recovery method for flowing wells (Lohman, 1979, p. 26-27). Although some boundary conditions were known for this aquifer test, the estimate is believed to represent aquifer transmissivity within an order of magnitude.



Base from U.S. Geological Survey
Sweet Grass Hills, 1984, 1:100,000

EXPLANATION

INTERSTRATIFIED SAND AND GRAVEL AQUIFER

AREA OF NO GLACIAL DEPOSITS

CONTACT--Shows general maximum altitude of glacial deposits, which include interstratified sand and gravel. Located at an altitude of about 5,000 feet

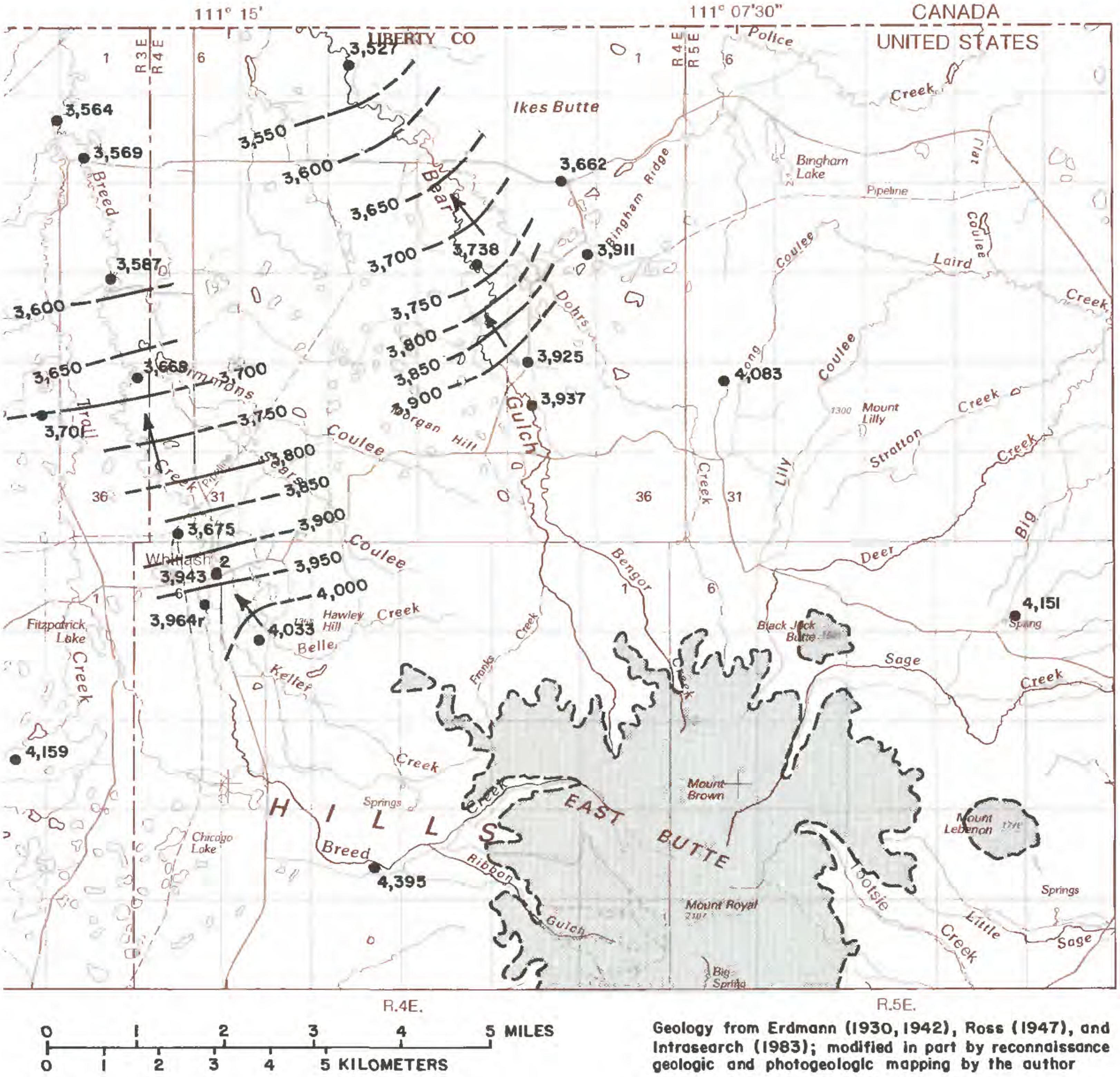
3,800 — POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells. Dashed where approximately located. Contour interval 50 feet. Datum is sea level

GENERALIZED DIRECTION OF GROUND-WATER FLOW

3,587 WELL--Number is altitude of water level, in feet above sea level. r, reported; e, estimated

2 NUMBER OF WELLS AT SAME GENERAL LOCATION

Figure 8.--Potentiometric surface and generalized direction of flow of



Geology from Erdmann (1930, 1942), Ross (1947), and Intrasearch (1983); modified in part by reconnaissance geologic and photogeologic mapping by the author

water in the interstratified sand and gravel aquifer, 1989-90.

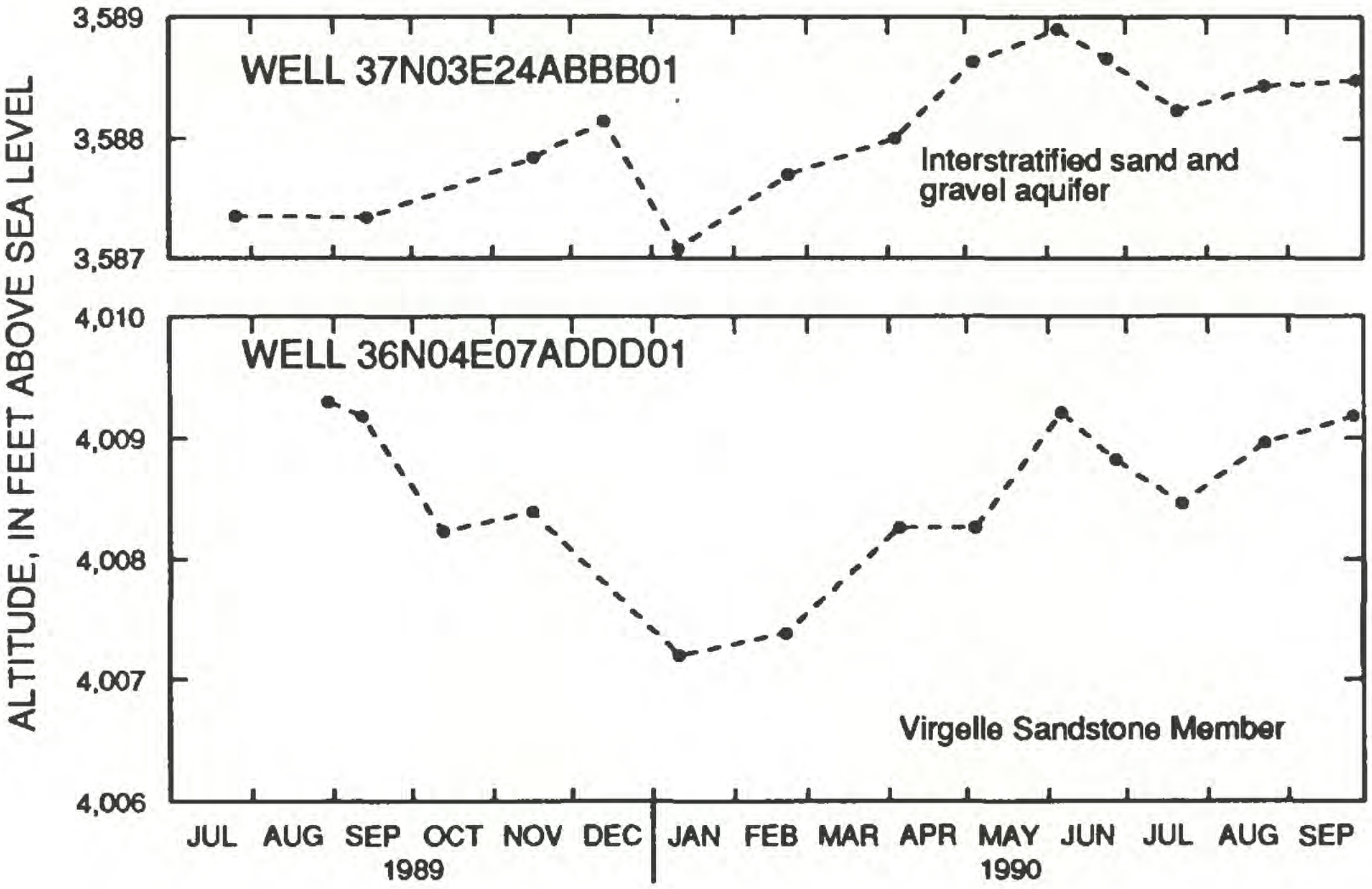


Figure 9.--Similarity of seasonal variation in water levels in selected wells completed in the interstratified sand and gravel aquifer and the Virgelle Sandstone Member of Eagle Sandstone, 1989-90.

Recharge and discharge components for the interstratified sand and gravel aquifer can be discussed only qualitatively, because data used to estimate a hydrologic budget are sparse or unknown. Recharge to the interstratified sand and gravel aquifer is probably through infiltration of precipitation and stored surface water and from subsurface inflow from overlying Quaternary deposits and underlying geologic units.

Discharge from the interstratified sand and gravel aquifer is through withdrawals from wells, flow of springs and seeps, and possible subsurface outflow to other geologic units. Water in the aquifer also flows downgradient across the northern study-area boundary. Discharge by withdrawal of water from wells is estimated to be about 70 acre-ft/yr, which includes estimated withdrawals for domestic and livestock purposes, and discharge from flowing wells. Domestic use was estimated using a statewide average withdrawal rate of 78 gal/d per person (Montana Department of Natural Resources and Conservation, 1986). Assuming that about 60 people use water from wells completed in the interstratified sand and gravel aquifer, withdrawals for domestic use were estimated to be about 5.2 acre-ft/yr. Withdrawals for livestock watering were estimated by assuming that each of eight stock wells (five inventoried as stock, one multiple use, and two existing but uninventoried) produced 1,000 gal/d for 6 months, which would total about 4.5 acre-ft/yr. This estimate might be excessive, because the period of withdrawal (6 months) could be less. Withdrawals from continuously flowing wells were calculated from measured or estimated flow to be about 60 acre-ft/yr. The quantity of discharge to springs and seeps, possible subsurface outflow, and flow across the study-area boundary is unknown.

For the 12 water samples that were collected from the interstratified sand and gravel aquifer (table 11), the specific conductance ranged from 270 to 2,100 µS/cm, with a median of 1,040 µS/cm. Values of pH ranged from 7.2 to 9.0, with a median of 7.3, indicating that the water is neutral to slightly alkaline. Nine of the measured values of pH were 7.5 or less. Water temperatures, which ranged from 7.5

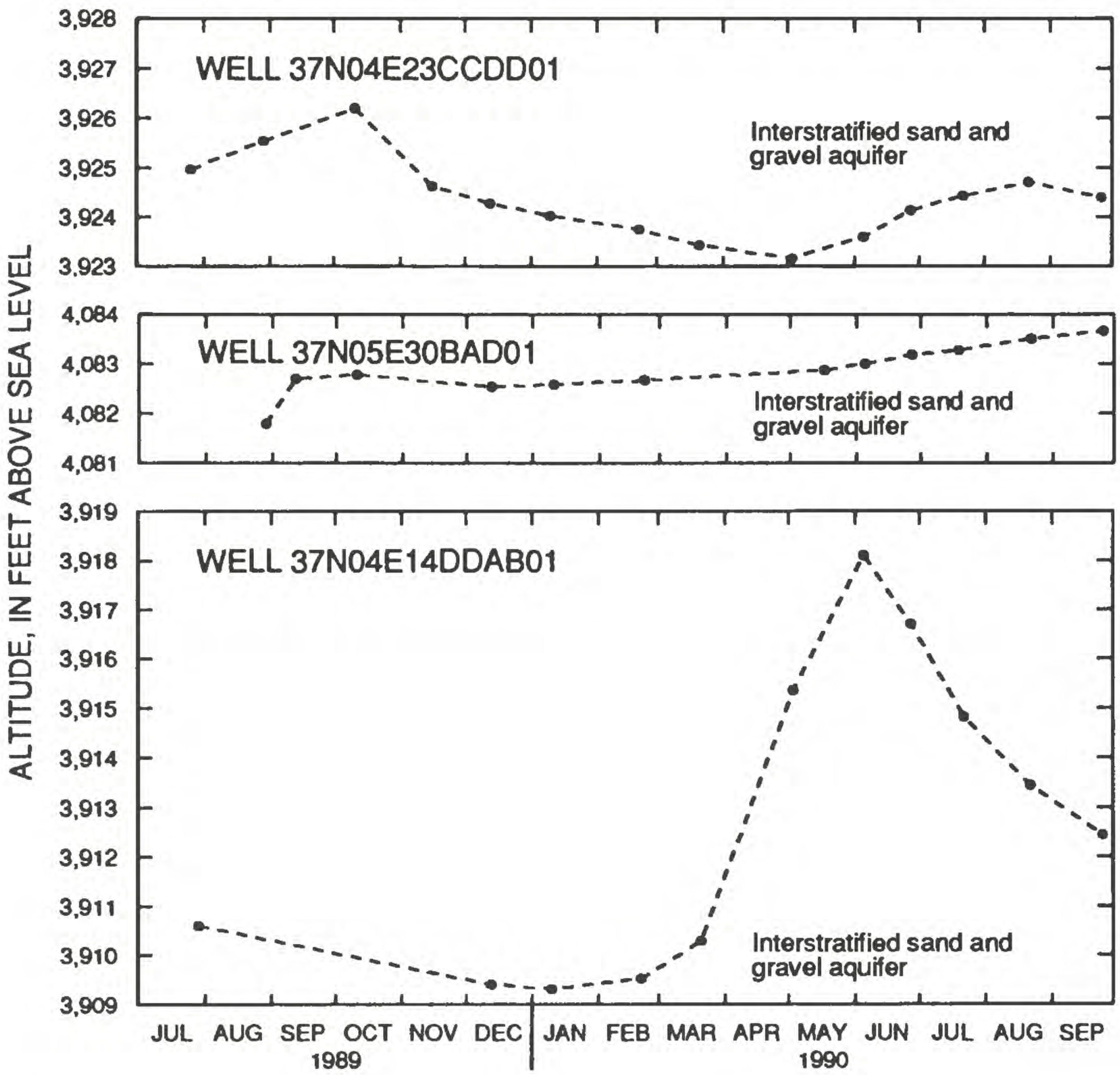
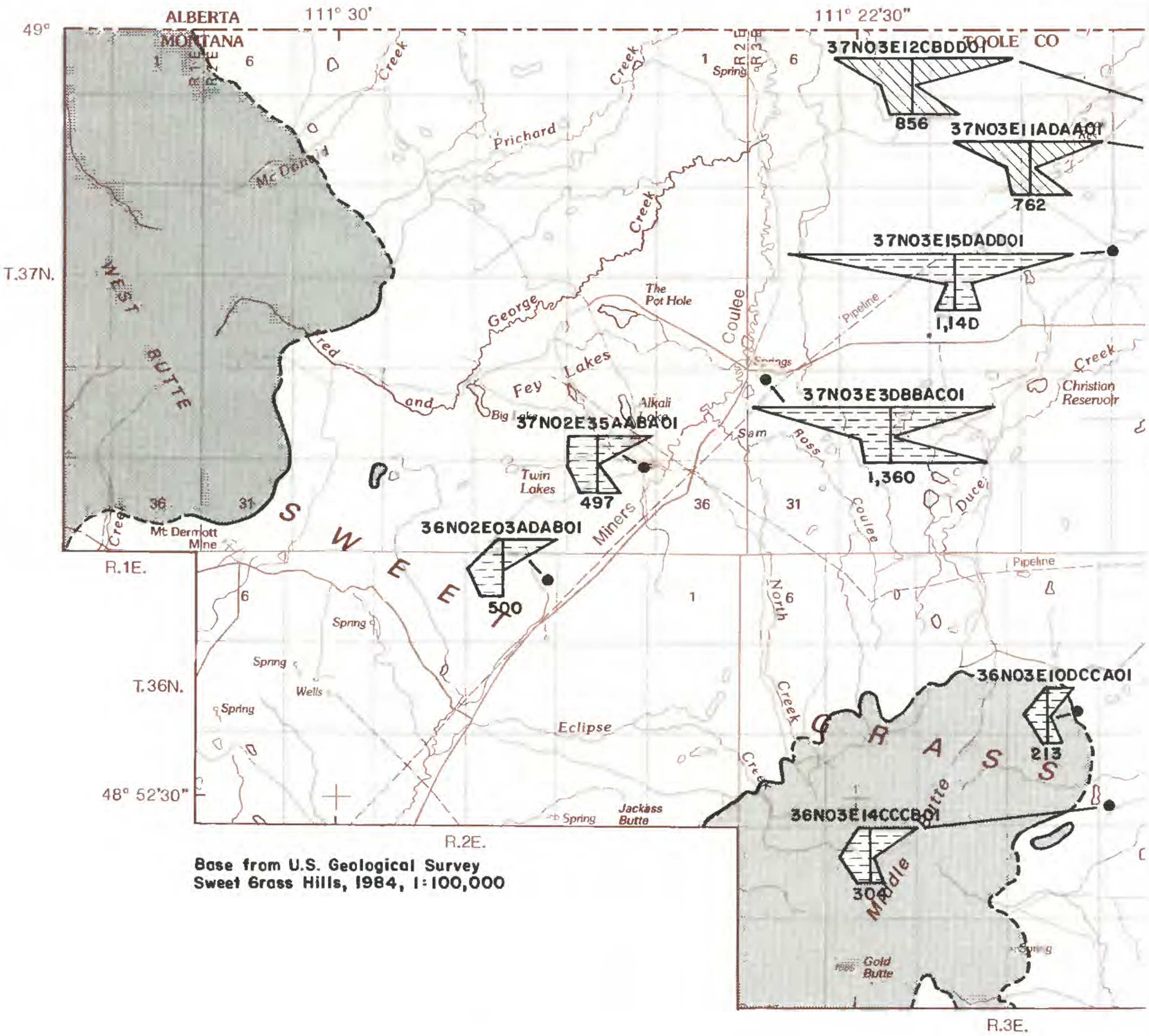


Figure 10.--Dissimilarity of seasonal variation in water levels in selected wells completed in the interstratified sand and gravel aquifer, 1989-90.

to 9.5 °C, varied little throughout the study area. The SAR ranged from 0.5 to 49, with a median of 2.5. The dissolved-solids concentration ranged from 154 to 1,600 mg/L, with a median of 647 mg/L. General chemical composition of these water samples ranged from a calcium bicarbonate to a sodium bicarbonate type (fig. 11).

No concentrations of analyzed constituents from the interstratified sand and gravel aquifer exceeded the MCL's for drinking water. The largest pH (9.0 in water from well 36N05E03DDAC01) exceeded the maximum SMCL of 8.5 for drinking water. Concentrations of sulfate in water from three wells, dissolved solids and manganese in water from eight wells, and iron in water from six wells also exceeded the SMCL's for drinking water. Concentrations of dissolved solids in water from two wells exceeded State water-quality guidelines for livestock watering.

Water used for irrigation from the interstratified sand and gravel aquifer has a medium- to high-salinity hazard and a low- to very high-sodium hazard. At some locations, water from this aquifer is not suitable for irrigation without management for salinity control or without possible adverse effects to soil permeability and structure. Water with a medium-salinity hazard (four samples, fig. 7) might adversely affect salt-sensitive plants, whereas water with a high salinity hazard (eight samples) will adversely affect soils with restricted drainage and requires



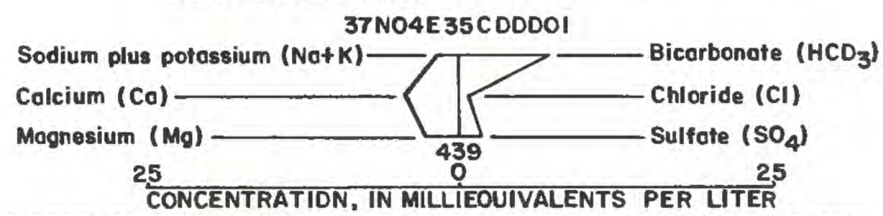
EXPLANATION

AREA OF NO VIRGELLE SANDSTONE MEMBER OF EAGLE SANDSTONE

CONTACT--Shows general limit of Virgelle Sandstone Member. Long dashed where approximately located; short dashed where uncertain; queried where probable

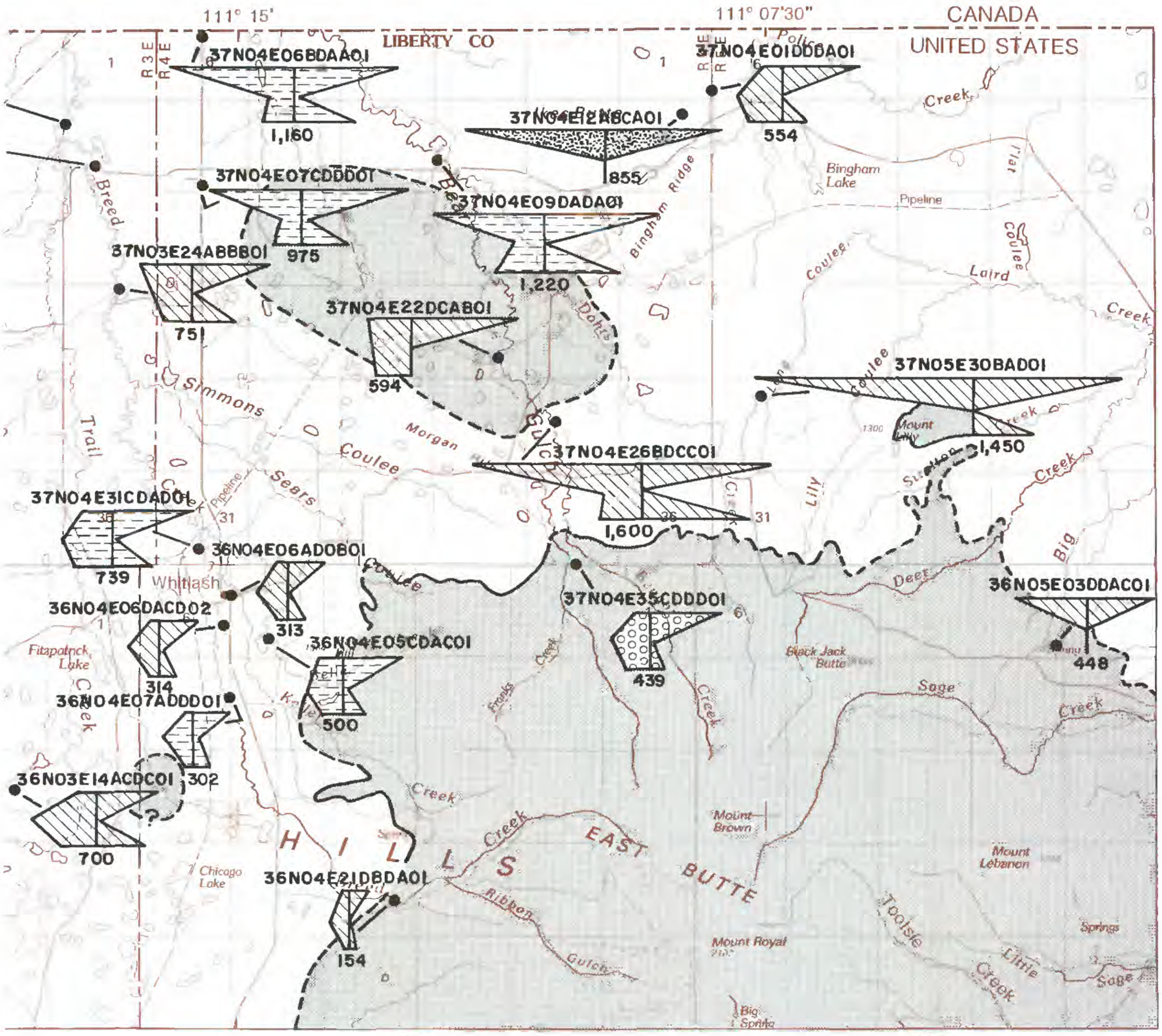
WELL

WATER-QUALITY DIAGRAM SHOWING CHEMICAL COMPOSITION OF WATER FROM WELLS



Concentrations of cations and anions are shown in milliequivalents per liter. Number above diagram is local well number. Number below diagram is calculated dissolved-solids concentration, in milligrams per liter. Pattern of diagram indicates source of water:

Figure 11.--Chemical composition



0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

Geology from Erdmann (1930, 1942), Ross (1947), and Intrasearch (1983); modified in part by reconnaissance geologic and photogeologic mapping by the author

Holocene alluvium

Interstratified sand and gravel aquifer in Quaternary glacial deposits

Upper Cretaceous Judith River Formation

Upper Cretaceous Virgelle Sandstone Member of Eagle Sandstone

of ground water.

management for salinity control (U.S. Salinity Laboratory Staff, 1954, p. 79-80). Water with a low-sodium hazard (seven samples) is satisfactory for irrigation. Water with a medium-sodium hazard (three samples) is suitable for use only on coarse-textured or organic-rich soils with good permeability, and irrigation water with a high- to very high-sodium hazard (two samples) might produce large concentrations of exchangeable sodium (U.S. Salinity Laboratory Staff, 1954, p. 81) that could affect soil permeability and structure (Driscoll, 1987, p. 112-114). The SAR in water from five wells equaled or exceeded the State guideline for irrigation.

The water-quality diagram (fig. 11) for water from well 37N04E26BDCC01, which is completed in the interstratified sand and gravel aquifer along Bear Gulch, is similar to many diagrams that represent water from wells completed in the Virgelle Sandstone Member (for example, wells 37N04E09DADA01 and 37N04E06BDAA01). For the site along Bear Gulch, the similarity is further evidence that the interstratified sand and gravel aquifer and the Virgelle might be hydraulically connected, and that the Virgelle recharges the overlying aquifer, thereby affecting the water quality of the interstratified sand and gravel.

Consolidated Aquifers

Two consolidated aquifers, the Upper Cretaceous Judith River Formation and the Virgelle Sandstone Member of the Eagle Sandstone, are sources of water in the Sweet Grass Hills. The Judith River Formation is not present in much of the study area and is not used extensively as an aquifer, whereas the Virgelle Sandstone Member is present in much of the study area and is used extensively.

Judith River Formation

Water in the Judith River Formation might be unconfined locally in outcrop areas. However, water in the two wells (37N04E12ABCA01 and 37N05E05CAAC01) inventoried in this study was confined (flowing artesian).

The potentiometric surface and general direction of water movement in the Judith River Formation are difficult to assess because of lack of data. Ground water probably flows downgradient northeasterly from the outcrop area near East Butte. Near West Butte, where structural downwarping and subsequent erosion have isolated the Judith River Formation, ground water probably flows downgradient southeasterly from the outcrop area (fig. 4). Information about aquifer hydraulic characteristics of the Judith River Formation is not available.

Recharge to the Judith River Formation is through infiltration of precipitation on outcrops and in some subcrop areas, infiltration of streamflow across outcrops, and possible subsurface inflow from other geologic units. Discharge from this formation is through withdrawals from wells, flow of springs and seeps, evapotranspiration in recharge areas, and possible subsurface outflow to other geologic units. Water in the formation also flows downgradient across the northeastern and western study-area boundaries. Limited data did not permit these flows to be quantified.

For the one sample collected for chemical analysis (well 37N04E12ABCA01), on-site determinations indicated a specific conductance of 1,320 µS/cm, a pH of 8.8, and a water temperature of 8.5 °C. The SAR was 90 and the dissolved-solids concentration was 855 mg/L. The sample was a sodium bicarbonate type water (fig. 11).

No concentrations of analyzed constituents for the Judith River Formation exceeded the MCL's for drinking water. The pH (8.8) and dissolved-solids concentration (855 mg/L) for the sample exceeded the SMCL's for drinking water. No constituent concentration exceeded State water-quality guidelines for livestock watering, although the fluoride concentration of 1.9 mg/L was near the guideline of 2 mg/L.

The SAR (90) of one sample from the Judith River Formation exceeded the State water-quality guideline for irrigation and had a high-salinity hazard and a very high-sodium hazard (fig. 7). The concentration of boron (900 µg/L) exceeded the State water-quality guideline for irrigation.

Virgelle Sandstone Member of Eagle Sandstone

Water in the Virgelle Sandstone Member is unconfined in and near the outcrop areas. Well 37N04E14ADAC01 exemplifies this condition. Water was confined (artesian or flowing artesian) in all other wells that were inventoried.

The potentiometric surface and the general direction of water movement in the Virgelle Sandstone Member are shown in figure 12. Water generally flows from recharge areas on the flank of the Sweet Grass Hills downdip in northerly directions to discharge areas; however, flow lines around the north flank of Middle Butte (S1/2 T. 37 N., R. 3 E.) indicate that ground water flows sub-parallel to the dip of the Virgelle. This flow anomaly might be due to pressure declines induced by several flowing wells along Miners Coulee in Montana and Alberta. In addition, a zone of small hydraulic conductivity associated with interbedded shale in the northern part of T. 37 N., R. 3 E., might divert downdip flow. Ground-water divides probably coincide with structural highs between West and Middle Buttes and Middle and East Buttes, resulting in southerly ground-water flows south of the structural highs. However, these divides are not well known because of lack of data.

Natural physical boundaries of flow in the Virgelle Sandstone Member include the underlying confining or leaky-confining unit of the Telegraph Creek Formation and the overlying confining or leaky-confining units of glacial deposits, the Claggett Shale, and the upper part of the Eagle Sandstone. North of the international boundary, the Virgelle becomes more shaley and eventually pinches out (Meyboom, 1960, p. 9-31).

Effects of structural deformation on movement, recharge, and discharge are difficult to assess. Igneous intrusion has caused faulting and fracturing that can increase permeability. Zimmerman (1967, p. 11) noted that fracturing from structural deformation greatly affected transmitting properties of the Virgelle Sandstone Member where it is present in the Cut Bank area. Fracturing adjacent to dikes and sills might create conduits for ground-water movement, recharge, or discharge. Some springs, such as spring 36N02E03DD01, appear to be affected by dikes that transect the Virgelle. Conversely, igneous dikes and sills might reduce flow. In secs. 8, 15, and 22, T. 36 N., R. 3 E., where sill outcrops overlie the Virgelle, infiltration of precipitation might be reduced.

The analysis of four single-well aquifer tests resulted in a range of estimated transmissivity[3] of 200 to 3,700 ft^2/d. Zimmerman (1967, p. 11, 12) reported that transmissivity for the Virgelle Sandstone Member in the Cut Bank area ranged from about 94 to 6,700 ft^2/d, whereas Meyboom (1960, p. 37-57) reported that transmissivity for the Milk River Sandstone (Virgelle equivalent in Alberta, Canada) ranged from about 1.3 to 480 ft^2/d and averaged about 75 ft^2/d. The smaller transmissivity values in Alberta probably reflect more shale as this formation pinches out. Meyboom (1960, p. 48-53) estimated the storage coefficient to range from 3.0×10^{-4} to 3.5×10^{-4}. The reported or measured discharge from 20 wells ranges from 1.6 to 83.2 gal/min. The specific capacity of 10 of these wells ranges from 0.3 to 9.5 (gal/min)/ft of drawdown (table 7).

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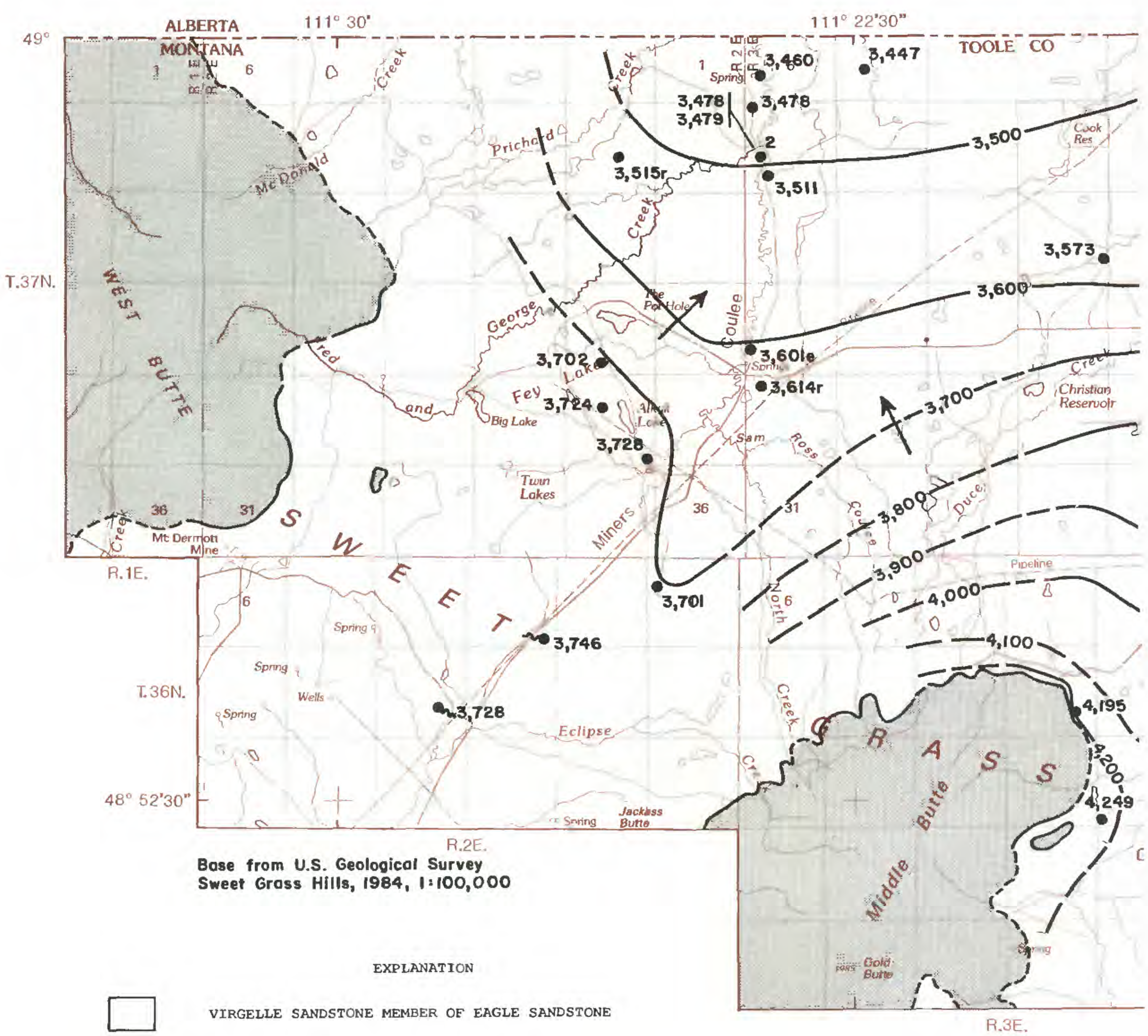
[3] Recovery method for flowing wells (Lohman, 1979, p. 26-27). Although some boundary conditions were known for all these aquifer tests, the estimates are believed to represent the aquifer transmissivity within an order of magnitude.



EXPLANATION

VIRGELLE SANDSTONE MEMBER OF EAGLE SANDSTONE

AREA OF NO VIRGELLE SANDSTONE MEMBER

—— – – – –? CONTACT--Shows general limit of Virgelle Sandstone Member. Long dashed where approximately located; short dashed where uncertain; queried where probable

——3,800—— POTENTIOMETRIC CONTOUR--Shows altitude at which water would have stood in tightly cased wells. Dashed where approximately located. Contour interval 100 feet. Datum is sea level

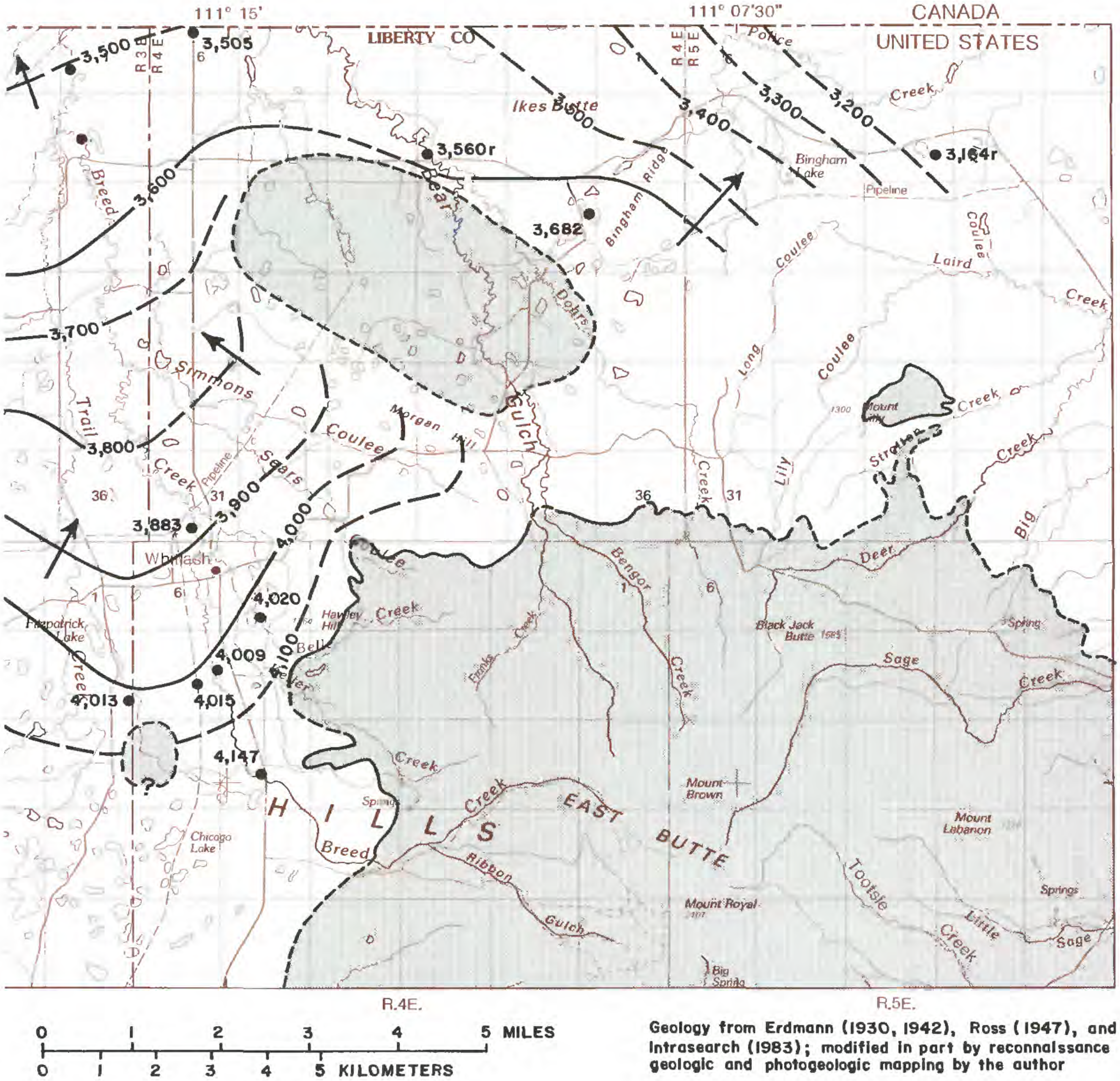
← GENERALIZED DIRECTION OF GROUND-WATER FLOW

3,601● WELL--Number is altitude of water level, in feet above sea level. r, reported; e, estimated

SPRING

2 NUMBER OF WELLS AT SAME GENERAL LOCATION

Figure 12.--Potentiometric surface and generalized direction of flow of water



in the Virgelle Sandstone Member of Eagle Sandstone, 1989-90.

Table 7.--Hydraulic characteristics and specific-capacity data for the Virgelle Sandstone Member of Eagle Sandstone, 1989-90, in the study area

[Discharge type: F, flowing; P, pumping. Water levels, in feet below or above (+) land surface. Data source--D, driller; S, U.S. Geological Survey. Abbreviations: ft^2/d, feet squared per day; gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot; --, no data]

Local number	Date	Discharge (gal/min)	Discharge type	Pumping period (hours)	Pumping water level (feet)	Static water level (feet)	Drawdown (feet)	Estimated transmissivity (ft^2/d)	Specific capacity [(gal/min)/ft]	Data source
36N04E05CDAC01	08-16-89	83.2	F	3.3	+10.74	+19.52	8.78	3,700	9.5	S
37N02E11DBBD01	05-10-69	45	P	24	325	180	145	--	.3	D
37N02E26BDAC01	06-12-73	60	P	24	250	90	160	--	.4	D
37N03E05CABC01	05-18-89	12.0	P	.8	103.96	82.60	21.36	--	.6	S
37N03E06CBD01[1]	06-08-89	1.6	F	2.0	+2.15	+4.03	1.88	500	.9	S
37N03E07BBBA01[1]	06-08-89	1.6	F	2.0	+1.81	+2.70	.89	300	1.8	S
37N03E07CBAC01	05-04-89	10.0	P	.4	20.49	12.44	8.05	--	1.2	S
37N03E07CBAC02	05-18-89	11.4	P	.5	32.76	26.03	6.73	--	1.7	S
37N03E15DADD01	09-13-89	15.0	P	1.1	54.90	29.70	25.20	--	.6	S
37N04E31CDAD01[1]	08-15-89	20.7	F	2.0	+29.43	+42.74	13.31	200	1.6	S

[1] Well partly penetrates the aquifer.

A steady-state mass balance or hydrologic budget for the Virgelle Sandstone Member can be summarized as:

$$\textit{Additions to the aquifer} = \textit{Subtractions from the aquifer} \quad (2)$$

Additions to the Virgelle include recharge, whereas subtractions from the Virgelle include discharge and flow across the study-area boundary.

Recharge to the Virgelle Sandstone Member is through infiltration of precipitation on outcrops and in some subcrop areas, infiltration of streamflow across outcrops, and possible subsurface inflow from other geologic units. Recharge to the Virgelle from infiltration of precipitation on outcrops is estimated to be about 1,610 acre-ft/yr. This component was determined on the basis of a storage coefficient of 0.05 (Ferris and others, 1962, p. 78; assuming unconfined conditions) and a measured increase in storage of about 6 ft (fig. 13, well 37N04E14ADAC01). Assuming a storage coefficient of 0.05, this seasonal increase in storage requires about 3.6 in. of precipitation infiltration on about 5,380 acres of outcrop.

Recharge to the Virgelle Sandstone Member from infiltration of precipitation in some subcrop areas was estimated to range from about 18 to 2,530 acre-ft/yr. Similarly, this component was determined on the basis of storage coefficients of 0.00035 (Meyboom, 1960, p. 48-53; assuming confined conditions), and 0.05 (assuming unconfined conditions), and a measured increase in storage of about 7 ft (fig. 13, well 36N04E17CAA01). This seasonal increase requires about 0.03 to 4.6 in. of precipitation infiltration on about 7,230 acres of subcrop. However, the aquifer in at least some of these subcrop areas is assumed to be under leaky-confined conditions; therefore, the actual quantity of recharge from precipitation infiltration in the subcrop area is probably between these two estimates.

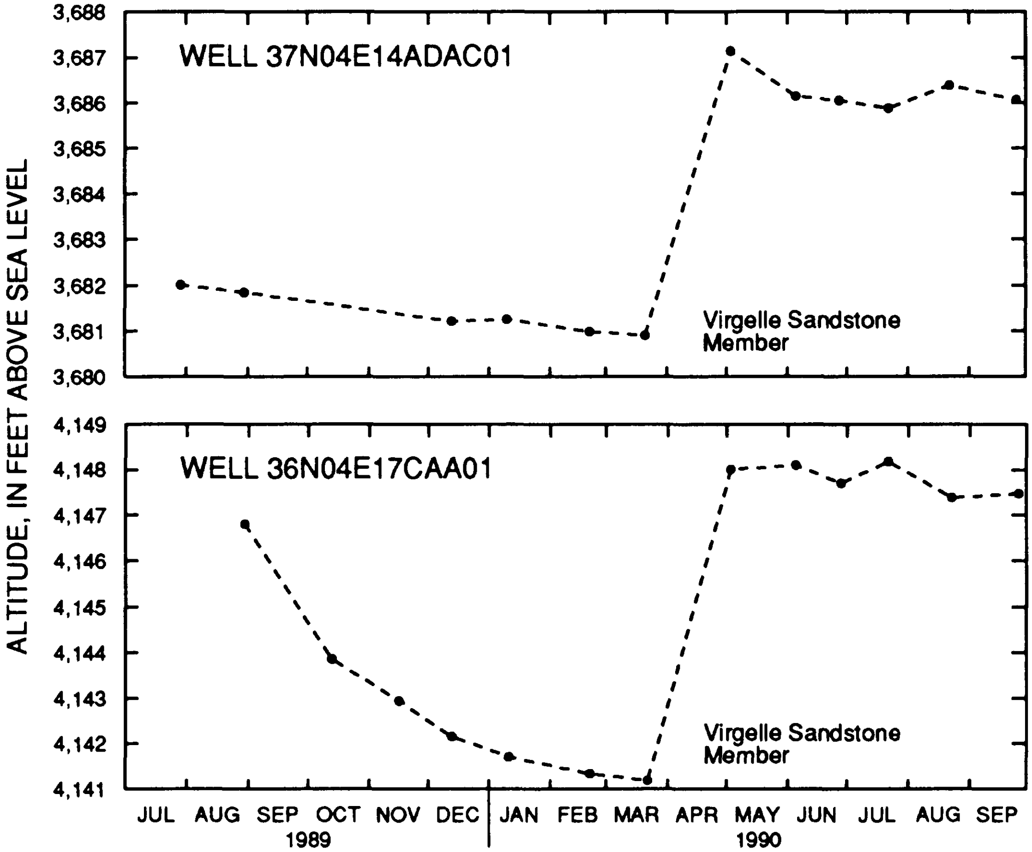


Figure 13.--Effect of infiltration of precipitation on water levels in wells completed in the Virgelle Sandstone Member of Eagle Sandstone, 1989-90.

Recharge to the Virgelle Sandstone Member from infiltration of streamflow across outcrops was estimated to be about 1,650 acre-ft/yr. This component was estimated on the basis of runoff, streamflow loss, and drainage area. Runoff for the study area was estimated by assuming similar streamflow conditions in Miners Coulee, Breed Creek, Bear Gulch, and Sage Creek. By using the 12-year average streamflow of 1,940 acre-ft/yr for Sage Creek and a drainage area of about 4,650 acres (Shields and others, 1990, p. 180), the average runoff of 5 in/yr was determined. The average loss of streamflow across the Virgelle outcrops was about 20 percent (as discussed in the section "Streamflow"), and the drainage area upgradient from the Virgelle outcrop is about 19,800 acres.

Recharge to the Virgelle Sandstone Member by possible subsurface inflow from other geologic units is difficult to assess owing to a lack of data, but contributions might be significant. Springs that issue from Tertiary igneous rocks supply water for domestic and stock use in the area. Water from these igneous rocks also might be a large source of recharge to the Virgelle in the subsurface.

Discharge from the Virgelle Sandstone Member is through withdrawals from wells, flow of springs and seeps, and subsurface outflow to other geologic units. Discharge from the Virgelle by withdrawals from wells is estimated to be about 109 acre-ft/yr, which includes withdrawals for secondary-recovery purposes, estimates for domestic and livestock purposes, and estimates for continuously flowing wells.

Discharge from the Virgelle from withdrawals for secondary recovery is about 76 acre-ft/yr (table 5). Domestic use was estimated using a statewide average withdrawal rate of 78 gal/d per person (Montana Department of Natural Resources and Conservation, 1986). Assuming about 30 people use water from wells completed in the Virgelle, withdrawals for domestic use were about 2.6 acre-ft/yr. Withdrawals for livestock watering were estimated by assuming that each of the 14 stock wells produced 1,000 gal/d for 6 months, for a total withdrawal of about 7.8 acre-ft/yr. This estimate could be excessive because the period of well use (6 months) might be less. Withdrawals from continuously flowing wells were determined from measured or estimated flow to be about 23 acre-ft/yr.

Discharge from the Virgelle Sandstone Member to springs and seeps is unknown, but might be large. For example, a discharge of 30 gal/min was estimated for spring 36N02E09DBDA01. Thus, the discharge from springs and seeps is at least 48 acre-ft/yr.

Discharge from the Virgelle Sandstone Member by subsurface outflow to other geologic units is also unknown. However, many wells completed in the Virgelle flow, indicating a probable upward gradient; therefore, overlying geologic units probably receive some water discharged from the Virgelle. In Alberta, Phillips and others (1986, p. 2006) used inferred and model-simulated hydraulic heads to determine that water discharges in the subsurface by upward and downward leakage.

Flow of water within the Virgelle Sandstone Member across the northern and eastern study-area boundaries was estimated to be about 4,490 acre-ft/yr. This flow was estimated on the basis of Darcy's Law using a hydraulic gradient of about 0.01 ft/ft, an estimated transmissivity of 400 ft^2/d (average of aquifer tests from wells 37N03E06CBD01 and 37N03E07BBBA01, table 7), and an effective lateral extent (corrected for perpendicular flow) of about 1.34×10^5 ft of the Virgelle along the study-area boundary.

Hydrologic-budget components are summarized in table 8. The difference between total additions and total subtractions primarily is a result of unknown values or estimation error, and probably not a result of change in aquifer storage. The difference between total additions and total subtractions from the Virgelle is largely a result of unquantified subsurface inflow to, and outflow from, other geologic units, and the assumption that aquifer hydraulic characteristics are constant throughout the study area. Even though most component estimates in the hydrologic budget are based on imprecise data, the budget is believed to approximate hydrologic conditions for the Virgelle Sandstone Member during this study.

For the 12 water samples that were collected from the Virgelle Sandstone Member (table 11), the specific conductance ranged from 392 to 2,070 µS/cm, with a median of 958 µS/cm. Values of pH ranged from 7.2 to 8.6, with a median of 7.4, which indicates that the water is neutral to slightly alkaline. For pH, 11 values were 7.6 or less. Water temperature varied considerably in the study area, ranging from 7.5 to 13.0 °C. The SAR ranged from 0.2 to 18, with a median of 1.5. The dissolved-solids concentration ranged from 213 to 1,360 mg/L, with a median of 620 mg/L.

General chemical composition of water from the Virgelle Sandstone Member was a calcium bicarbonate or sodium bicarbonate type; one sample (well 37N03E30BBAC01) contained principally sodium, bicarbonate, and sulfate (fig. 11). Generally, water was a calcium bicarbonate type near the recharge area. With distance from recharge areas, calcium was replaced by sodium and bicarbonate remained the dominant anion.

No concentrations of analyzed constituents from the Virgelle Sandstone Member exceeded MCL's for drinking water. One pH value (8.6 for water in well 37N03E15DADD01) exceeded the SMCL for drinking water. Concentrations of sulfate in water from four wells, dissolved solids in water from six wells, iron in water from seven wells, and manganese in water from five wells also exceeded the SMCL's for drinking water (tables 11 and 12). Concentrations of dissolved solids in two additional wells equaled the SMCL for drinking water. Water from well 37N03E15DADD01 had a fluoride concentration that exceeded the SMCL but not the State water-quality guideline for drinking water. Concentrations of fluoride in water from one well and dissolved solids in water from two wells exceeded State water-quality guidelines for livestock watering.

Table 8.--Estimated hydrologic budget for the Virgelle Sandstone Member of Eagle Sandstone, 1989-90, in the study area

[est., estimate]

Budget component	Acre-feet per year
Additions to the aquifer	
Recharge	
Infiltration of precipitation on outcrops (est.)	1,610
Infiltration of precipitation in subcrop areas (est.)	18-2,530
Infiltration of streamflow across outcrops (est.)	1,650
Subsurface inflow from other geologic units	(?)
Total additions (rounded)	3,280-5,790
Subtractions from the aquifer	
Discharge	
Withdrawals from wells:	
For the secondary recovery of oil	76
For domestic use (est.)	2.6
For livestock watering (est.)	7.8
From continuously flowing wells (est.)	23
Springs and seeps	48
Subsurface outflow to other geologic units	(?)
Flow across study-area boundary	4,490
Total subtractions (rounded)	4,650

Water used for irrigation from the Virgelle Sandstone Member has a medium- to high-salinity hazard and a low- to very high-sodium hazard (fig. 7). In much of the study area, use of water from this aquifer for irrigation probably would require management or treatment for salinity control to avoid possible adverse effects to soil permeability and structure. Water with a medium-salinity hazard (four samples, fig. 7) might adversely affect salt-sensitive plants, whereas water with a high-salinity hazard (eight samples) will adversely affect soils with restricted drainage and require management for salinity control (U.S. Salinity Laboratory Staff, 1954, p. 79-80). Water with a low-sodium hazard (seven samples) is satisfactory for irrigation. Water with a medium-sodium hazard (four samples) is suitable for use only on coarse-textured or organic-rich soils with good permeability, and irrigation water with a high- to very high-sodium hazard (one sample) might produce large concentrations of exchangeable sodium (U.S. Salinity Laboratory Staff, 1954, p. 81) possibly affecting soil permeability and structure (Driscoll, 1987, p. 112-114). The State SAR guideline for irrigation was exceeded in five samples.

Potential for Increased Ground-Water Development

The potential for increased ground-water development was based on the interpretation of existing and updated geologic information, geophysical and drillers' logs, geohydrologic and geochemical data obtained from wells and springs, and surface-water data obtained by direct methods. Potential for development is described for the four principal aquifers.

Increased development of water from the alluvium might be limited by local geologic and hydrologic characteristics. This aquifer is laterally discontinuous, and hydraulic characteristics probably differ from site to site. Along Sage Creek, which is perennial most years, aquifers might provide sufficient water for domestic, livestock, and limited irrigation purposes. For example, well 36N05E09ACDB01, which is completed in the alluvium of Sage Creek, provides water for about 60 households. The well was designed to yield 35-80 gal/min (Osborne and Zaluski, 1985, p. 1). Where streamflow is intermittent, the aquifer might provide water only during and shortly after periods of recharge; development would probably only induce infiltration of streamflow. During periods of no recharge, the aquifer might provide a limited quantity of water from storage--a process that could eventually dewater the alluvium. Analysis of only one water sample from the alluvium is insufficient to make even general statements about the suitability of the water for domestic, livestock-watering, and irrigation purposes.

Increased development of water from the interstratified sand and gravel aquifer for domestic, livestock-watering, and irrigation purposes might be limited by local geologic and hydrologic characteristics and water quality. The interstratified sand and gravel aquifer consists of either laterally continuous deposits within complexly stratified glacial deposits or apparently discontinuous, poorly connected lenses. Extent of the aquifer, and its geometry, recharge mechanisms, and hydraulic characteristics are largely unknown. In addition, possible hydraulic interconnection with the underlying Virgelle Sandstone Member is not well understood.

Analyses of water from the interstratified sand and gravel aquifer indicate that chemical quality is variable, and the quality at potential development sites might limit its use. Generally, the water quality is marginal for domestic use but generally suitable for livestock watering. Irrigation is probably the least feasible use, because at some locations the water cannot be used without management for salinity control and the water has generally large sodium concentrations (maximum of 560 mg/L) and SAR (maximum of 49).

Increased development of water from the Judith River Formation for domestic, livestock-watering, and irrigation purposes is probably limited by geologic and hydrologic characteristics and water quality. Irregular, discontinuous sandstones within the Judith River Formation that yield water are largely undefined and aquifer hydraulic characteristics are unknown; thus, this aquifer might be difficult to develop.

Analysis of only one water sample collected from the Judith River Formation is insufficient to make even general statements about the suitability of the water for the various uses. However, this analysis indicates that domestic use is probably limited by the large pH value and large dissolved-solids concentration. Livestock watering might be feasible in local areas, because no concentrations exceed State water-quality guidelines for livestock watering. Irrigation is probably limited or precluded by the high-salinity hazard, large SAR, and large boron concentration. Furthermore, large dissolved-solids concentrations (as much as 2,450 mg/L), accompanied by large sodium (860 mg/L) and sulfate (1,100 mg/L) concentrations and large SAR (59) in nearby downdip areas (Patton and others, 1989; unpublished data from the Montana Bureau of Mines and Geology), render water from the Judith River Formation unsuitable for most purposes.

Water from the Virgelle Sandstone Member might be the only ground-water resource feasible for increased development. However, water quality could limit its development for some purposes.

Analyses of water from the Virgelle Sandstone Member indicate that the quality is variable. Thus, the water quality at potential development sites could limit its use. Generally, the quality is adequate for domestic and livestock-watering purposes and marginal for irrigation purposes near the recharge area. Downgradient, the quality is marginal for domestic purposes and adequate for livestock watering. Irrigation might be precluded because of the high- to very high-salinity hazard and medium- to very high-sodium hazard.

Streamflow

The principal surface-water resources are Miners Coulee, Breed Creek, and Bear Gulch and their tributaries, and water stored in reservoirs, stock ponds, lakes, and potholes. The principal creeks, which are mostly intermittent, flow north to the Milk River, which is about 10 mi north of the international boundary. Surface water is used for livestock watering and sprinkler and flood irrigation of small parcels of cereal grain and hay crops of alfalfa and native grass. The total area of irrigated land is about 2,450 acres (C.E. Dalby, Montana Department of Natural Resources and Conservation, written commun., 1988).

Streamflow was periodically estimated at 22 miscellaneous-measurement sites during periods of runoff to provide information on its availability and magnitude (fig. 14, table 14 at back of report). Streamflow values are only estimates because of poor measuring conditions and variability associated with short-duration runoff.

Streamflow magnitude depends on the quantity of snowpack, timing of rainfall and warm temperatures, and level of mainstem reservoirs. Streamflow values in table 14 indicate that little surface water was available during the drought of 1988; thus, streamflow measurements ended in May. In 1989 and 1990, snowmelt and spring and early summer rains provided adequate water for streamflow through mid-July. Streamflow values in table 14 also indicate that from early March to mid-June, streamflow was small (generally less than 30 ft^3/s) and extremely variable. From late June to mid-July 1989 and 1990, streamflow was generally less than 5 ft^3/s and commonly zero.

Three low-flow investigations were conducted on Miners Coulee, Breed Creek, and Bear Gulch and their tributaries (fig. 14, table 9). These streams were measured to provide evidence of aquifer discharge (gains in streamflow) or aquifer recharge (losses in streamflow). Gains or losses of about 5 percent or less might be the result of measurement error rather than an actual gain or loss in streamflow.

For Miners Coulee and its main tributary Fred and George Creek, low-flow values in April indicate some gains due to unmeasured tributary inflow and seepage from alluvium. In June and July, small gains indicate that irrigation-return flow and seepage from alluvium were still contributing water for streamflow, nearly constant streamflow indicates that irrigation-return flow and seepage from alluvium were balanced by losses from evapotranspiration by phreatophytes along the channel, and losses indicate that evapotranspiration exceeded irrigation-return flow and seepage from alluvium. Low-flow values for Fred and George Creek between surface-water sites MC-6 and MC-8 show consistent losses that average about 20 percent for all three sets of investigations. Site MC-6 is located in the outcrop-subcrop area of the Virgelle Sandstone Member, whereas site MC-8 is located in the subcrop area of the upper part of the Eagle Sandstone. Across this reach of Fred and George Creek, streamflow was probably lost as recharge to the Virgelle.

Low-flow values for Breed Creek and its tributaries show gains and losses in April. Most gains were probably due to unmeasured tributary inflow and seepage from alluvium. Losses were probably due to increased storage in reservoirs and beaver ponds. In June and July, small gains indicate that some tributary inflow and alluvium contributed water for streamflow. Small losses indicate that evapotranspiration exceeded water discharged from the alluvium. In the upper reach of Breed Creek between surface-water sites BC-1 and BC-4 (fig. 14), consistent gains averaged about 40 percent for all three investigations. These gains are near an outcrop-subcrop area of the Virgelle Sandstone Member where the unit might be saturated and discharging to the stream. However, some water appears to discharge as springs and seeps near the contact between rocks of the Colorado Group and alluvium; thus, this water probably represents seepage from alluvium.

Low-flow values for Bear Gulch and its tributaries show gains in April due to unmeasured tributary inflow and contributions from alluvium. In June, gains indicate that some tributary inflow, irrigation-return flow and seepage from the alluvium contributed water for streamflow, whereas constant streamflow indicates that evapotranspiration losses were balanced by the contributions. Streamflow loss

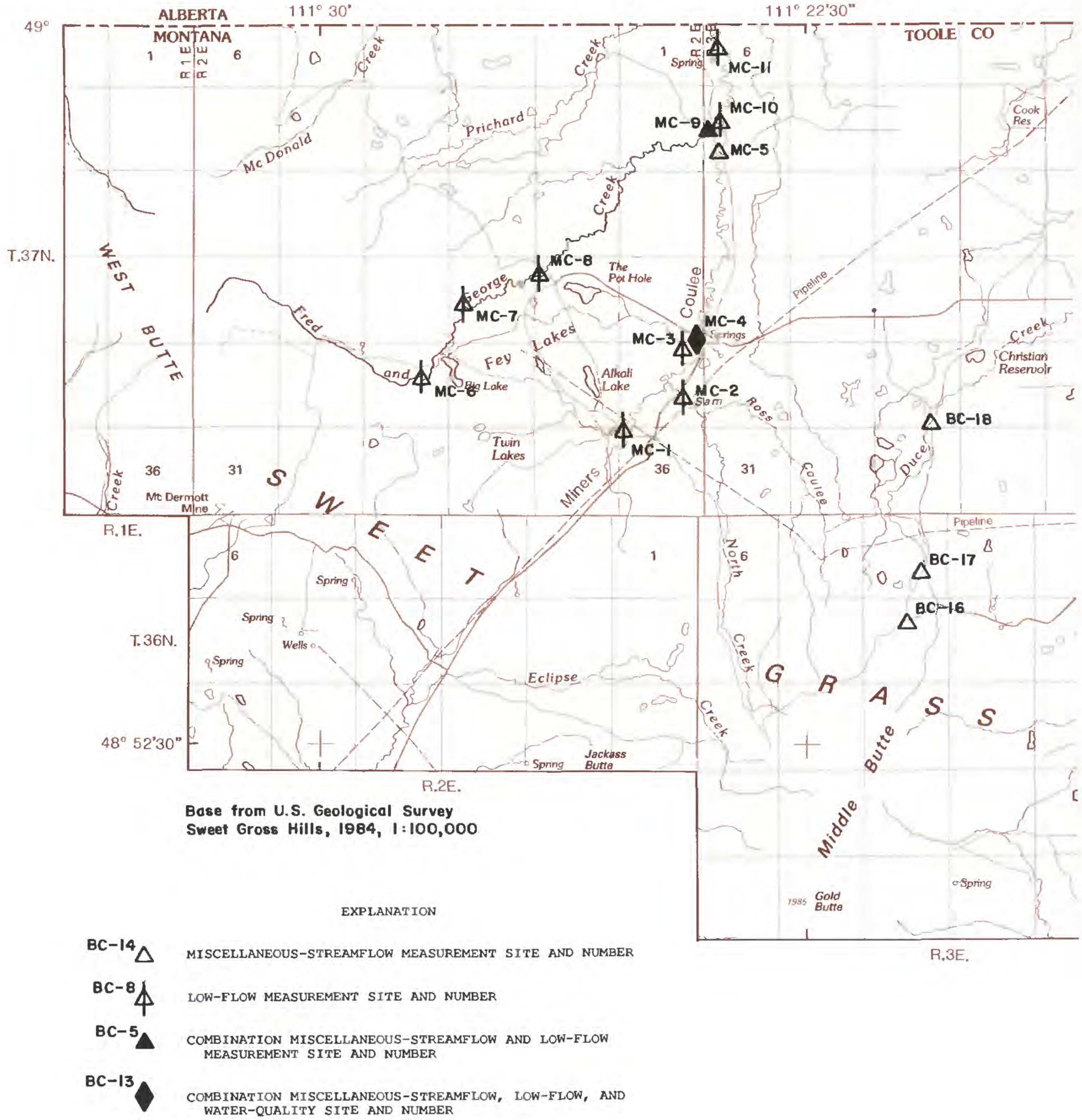


Figure 14.--Location of stream sites.

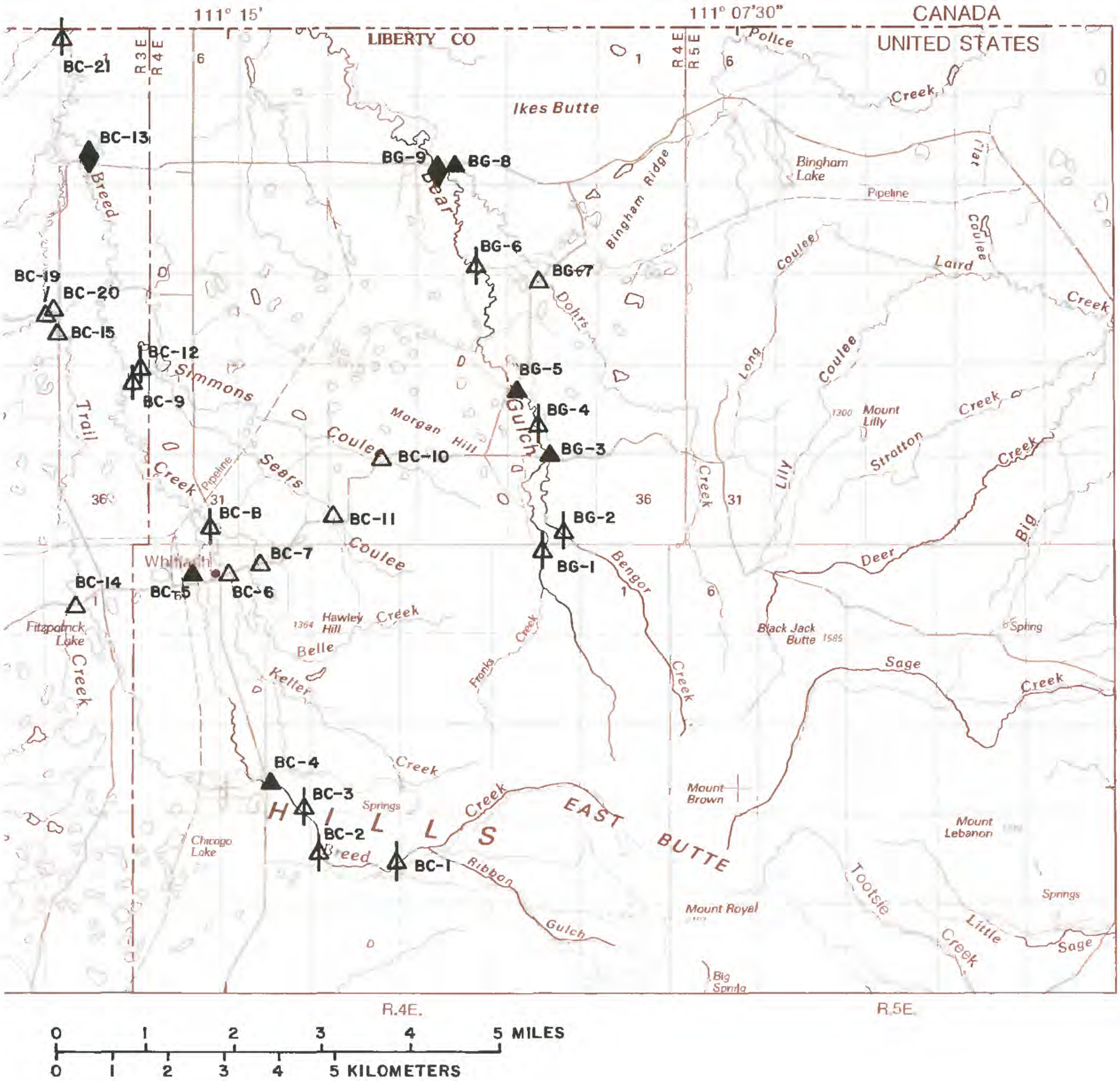

111° 15'
111° 07'30"
CANADA
UNITED STATES
LIBERTY CO
R3E
R4E
R5E
Ikes Butte
Bingham Ridge
Bingham Lake
Pipeline
BC-21
BC-13
BC-19
BC-20
BC-15
BC-12
BC-9
BC-10
BC-11
BC-8
BC-7
BC-6
BC-5
BC-14
BC-4
BC-3
BC-2
BC-1
BG-9
BG-8
BG-6
BG-7
BG-5
BG-4
BG-3
BG-2
BG-1
Breed
Trail
Simmons
Coulee
Creek
Sears
Morgan Hill
Bear
Gulch
Dohrs
Long Coulee
Laird
Mount Lilly
Stratton
Lily
Big
Deer
Bengor
Franks Creek
Hawley Hill
Belle
Keller
Black Jack Butte
Sage
Spring
Fitzpatrick Lake
Chicago Lake
Springs
EAST BUTTE
HILLS
Ribbon Gulch
Mount Brown
Mount Lebanon
Mount Royal
Tootsie
Little
Big Spring
R.4E.
R.5E.
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

Table 9.--Results of low-flow investigations, 1990, in the study area

[Site number: listed in downstream order for each tributary--MC, Miners Coulee; BC, Breed Creek; BG, Bear Gulch. Abbreviations: ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NF, no flow; --, no data; e, estimate]

Drainage basin	Site number	Local number	Discharge (ft^3/s)	Specific conductance (µS/cm)	Discharge (ft^3/s)	Specific conductance (µS/cm)	Discharge (ft^3/s)	Specific conductance (µS/cm)
			April 5		June 21		July 21	
Miners Coulee	MC-1	37N02E36BBBA01	0.41	461	0.19	477	--	--
	MC-2	37N02E25DACB01	1.4	723	.20	817	--	--
	MC-3	37N02E25AAB01	--	--	.35	623	--	--
	MC-4	37N02E24DDD01	2.5	714	.79	771	NF	--
	MC-6	37N02E28ACDA01	4.1	251	7.3	229	1.7	--
	MC-7	37N02E22CBA01	.13	555	.26	--	.06	--
	MC-8	37N02E23BBC01	3.5	354	5.6	287	1.4	--
	MC-9	37N03E07CBB01	5.1	449	5.6	343	.86	--
	MC-10	37N03E07BCD01	8.5	573	7.3	447	.81	--
	MC-11	37N03E06CBA01	8.8	584	6.5	495	--	--
			April 3		June 20		July 20	
Breed Creek	BC-1	36N04E21DAA01	12	223	8.7	192	.87	225
	BC-2	36N04E21BCC01	--	--	9.1	203	--	--
	BC-3	36N04E17DDD01	--	--	9.6	210	--	--
	BC-4	36N04E17DBCB01	16	252	11	216	1.4	300
	BC-5	36N04E06ACA01	16	288	12	243	.93	385
	BC-8	37N04E31DCA01	10	409	.73	653	.10(e)	--
	BC-9	37N03E25AAC01	29	388	13	309	.42	510
	BC-12	37N03E25AAAB01	.16	--	.03	--	--	--
	BC-13	37N03E12CACC01	21	485	12	343	.26	480
	BC-21	37N03E01BCCB01	20	498	--	--	--	--
			April 3		June 20		July 20	
Bear Gulch	BG-1	36N04E02ABB01	6.3	286	4.2	327	1.2	330
	BG-2	37N04E35DC01	1.9	295	--	--	.37	--
	BG-3	37N04E35BAAA01	11	421	6.5	433	1.9	412
	BG-4	37N04E26CAC01	--	--	5.5	427	.56	--
	BG-5	37N04E26BCB01	13	445	6.0	433	.29	530
	BG-6	37N04E15DCCA01	--	--	5.5	476	.08	--
	BG-8	37N04E10CDAB01	8.7	667	1.2	612	NF	--
	BG-9	37N04E10CCA01	24	567	5.9	505	.03(e)	--

from site BG-6 to site BG-9 was probably due to increased reservoir storage. In July, evapotranspiration losses exceeded any contributions from irrigation-return flow and alluvium. Low-flow values for Bear Gulch between sites BG-1 and BG-3 show consistent gains that average more than 30 percent for all three sets of measurements. Site BG-3 is located near an outcrop area of the Virgelle Sandstone Member, whereas sites BG-1 and BG-2 are located on a subcrop area of the Colorado Group. These gains also might indicate that the Virgelle is saturated and discharging to the stream; however, these gains are probably due to irrigation-return flow and seepage from alluvium.

Specific conductance was measured at most streamflow-measurement sites to indicate whether aquifers contribute water to streamflow. Specific-conductance values, in general, increased gradually downstream in all three creeks (table 9), with increases being attributed to tributary inflow, irrigation-return flow, or seepage from alluvium.

Three stream samples were collected for chemical analysis--one each from Miners Coulee, Breed Creek, and Bear Gulch (fig. 14). The physical properties and the common-constituent concentrations are given in table 15; trace-element concentrations are given in table 16. The specific conductance of these samples ranged from 340 to 1,170 µS/cm. Values of pH ranged from 7.7 to 8.5, which indicates that the water was slightly alkaline. Water temperature ranged from 15.0 to 17.5 °C. The dissolved-solids concentration ranged from 241 to 774 mg/L.

General chemical composition of these samples ranged from a sodium bicarbonate to a calcium bicarbonate type water. Sodium was the dominant cation in the sample from Miners Coulee, whereas calcium was the dominant cation in samples from Breed Creek and Bear Gulch. Miners Coulee water contained larger concentrations of sodium, bicarbonate, sulfate, and chloride, and was less alkaline than water from Breed Creek and Bear Gulch. Differences in water chemistry are probably due to larger volumes of irrigation-return flow in Miners Coulee compared to the other streams.

Water from Miners Coulee, Breed Creek, and Bear Gulch is not used for domestic purposes in the study area. No concentrations of analyzed constituents exceeded State guidelines for livestock watering or irrigation.

SUMMARY AND CONCLUSIONS

Stratigraphic units of Mississippian through Holocene age crop out along the north flank of the Sweet Grass Hills. The Madison Group of Mississippian age and Ellis Group of Jurassic age are exposed near the centers of West and East Buttes. Sandstone and shale of Cretaceous age, with a thickness of about 3,500 ft, crop out around all three buttes. Tertiary intrusive igneous rocks are exposed in the cores of the buttes, and small subordinate laccoliths, dikes, and sills are present throughout the study area. Emplacement of these igneous rocks caused uplift and structural deformation of consolidated rocks. Quaternary glacial deposits are composed of complexly stratified, clay- to boulder-sized material deposited as widespread moraines. Holocene alluvium, composed of unconsolidated gravel, sand, silt, and clay, is restricted to present-day stream channels and terraces along creeks and coulees.

Two unconsolidated and two consolidated aquifers are sources of water in the Sweet Grass Hills. Unconsolidated aquifers are Holocene alluvium and Quaternary interstratified sand and gravel. Consolidated aquifers are the Upper Cretaceous Judith River Formation and the Virgelle Sandstone Member of the Eagle Sandstone.

Water in the alluvium moves generally downstream, sub-parallel to the stream channels. Recharge to alluvium is through infiltration of precipitation, streamflow, irrigation-return flow, stored surface water, and subsurface inflow from glacial deposits. Discharge from alluvium is through seepage to streams, withdrawals from wells, flow of springs and seeps, evapotranspiration, and subsurface outflow to underlying geologic units. One water sample from alluvium had a dissolved-solids concentration of 439 mg/L and was a calcium bicarbonate type water. Increased development of water might be limited by local geologic and hydrologic characteristics. Where streamflow is perennial, alluvium might provide sufficient water for domestic, livestock, and limited irrigation purposes. Where streamflow is intermittent, the aquifer might provide water only during and shortly after periods of recharge; development would probably induce infiltration of streamflow. During periods of no recharge, the aquifer might provide a limited quantity of water from storage--a process that could eventually dewater the alluvium.

The interstratified sand and gravel aquifer is present in some places as laterally continuous deposits and in other areas is apparently discontinuous as poorly connected lenses. The general direction of water movement in this aquifer is from south to north. Transmissivity was estimated to be 900 ft^2/d. Recharge to the interstratified sand and gravel is probably through infiltration of precipitation and stored surface water and from subsurface inflow from overlying Quaternary deposits and underlying geologic units. Indirect evidence indicates that in some areas the Virgelle Sandstone Member provides recharge by upward leakage. Discharge from the interstratified sand and gravel aquifer is through withdrawals from wells (70 acre-ft/yr), flow of springs and seeps, and possible subsurface outflow to other geologic units. The dissolved-solids concentration ranged from 154 to 1,600 mg/L, with a median of 647 mg/L. The water ranged from a calcium bicarbonate type to a sodium bicarbonate type. Water quality is marginal for domestic use but generally suitable for livestock watering. Irrigation is probably the least feasible use, because at some locations the water is not suitable for use without management for salinity control and the water has generally large sodium concentrations. Increased development of water from the interstratified sand and gravel aquifer for domestic, livestock-watering, and irrigation purposes might be limited by local geologic and hydrologic characteristics and water quality. Extent of the aquifer, and its geometry, recharge mechanisms, and hydraulic characteristics are largely unknown. Water quality from this aquifer is variable and the quality at potential development sites might limit its use.

Water in the Judith River Formation probably flows from the outcrop area, following the dip of the formation to the northeast and southeast. Recharge to the Judith River Formation is through infiltration of precipitation on outcrops and in some subcrop areas, infiltration of streamflow across outcrops, and possible subsurface inflow from other geologic units. Discharge from the Judith River Formation is through withdrawals from wells, flow of springs and seeps, evapotranspiration in recharge areas, and possible subsurface outflow to other geologic units. One water sample collected from the Judith River Formation had a dissolved-solids concentration of 855 mg/L and was a sodium bicarbonate type water. The large dissolved-solids concentration, accompanied with large sodium and sulfate concentrations and large SAR (59) in water from nearby areas, indicate the water probably is unsuitable for most purposes. Increased development of water from the aquifer for domestic, livestock-watering and irrigation purposes is probably limited or precluded by geologic and hydrologic characteristics and water quality. Irregular, discontinuous sandstones that yield water are largely undefined, and thus might be difficult to develop. Owing to a lack of data, aquifer hydraulic characteristics are unknown.

Water in the Virgelle Sandstone Member generally flows from recharge areas downdip in northerly directions to discharge areas. Some flow sub-parallel to the dip might be due to pressure declines induced by flowing wells and a zone of small hydraulic conductivity. Effects of structural deformation on movement, recharge, and discharge are difficult to assess, but fracturing adjacent to dikes and sills might create conduits for ground water. Estimated transmissivity ranged from 200 to 3,700 ft^2/d. Recharge to the Virgelle, estimated to range from about 3,280 to about 5,790 acre-ft/yr, is through infiltration of precipitation on outcrops and in some subcrop areas, infiltration of streamflow across outcrops, and possible subsurface inflow from other geologic units. Discharge from the Virgelle, estimated to be about 157 acre-ft/yr, is through withdrawals from wells, flow of springs and seeps, and subsurface outflow to other geologic units. Flow within the Virgelle across the study-area boundary was estimated to be 4,490 acre-ft/yr. The dissolved-solids concentration ranged from 213 to 1,360 mg/L, with a median of 620 mg/L. The water was generally a calcium bicarbonate type. Water quality is mostly adequate for domestic and livestock-watering and marginal for irrigation purposes near the recharge area. Downgradient, the quality is marginal for domestic purposes and adequate for livesock-watering. Irrigation might be precluded because of the high- to very high-salinity hazard and the medium- to very high-sodium hazard. Water from the Virgelle might be the only ground-water resource feasible for increased development; however, the quality of the water is variable, which could limit its use at potential development sites.

The principal surface-water resources are Miners Coulee, Breed Creek, and Bear Gulch and their tributaries, and water stored in reservoirs, stock ponds, lakes, and potholes. Low-flow measurements indicate that streamflow gains were due to seepage and irrigation-return flow from alluvium, and possibly from areas where the Virgelle Sandstone Member is saturated. Streamflow losses were due to evapotranspiration or recharge to the alluvium and Virgelle. Three water samples were collected from the streams for chemical analysis. The dissolved-solids concentration ranged from 241 to 774 mg/L. The samples ranged from a sodium bicarbonate to a calcium bicarbonate type water.

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SUPPLEMENTAL INFORMATION

Table 10.--Records of inventoried wells and springs in the study area

[-- or -, no data or not applicable]

Local number--numbering system described in text.
Type of site--S, spring; W, well.
Aquifer--Qal, Holocene alluvium;
Qg, interstratified sand and gravel aquifer within Quaternary glacial deposits;
Ti, Tertiary intrusive igneous rocks;
Kjr, Upper Cretaceous Judith River Formation;
Kev, Upper Cretaceous Virgelle Sandstone Member of Eagle Sandstone;
Mu, Mississippian Madison Group.
Altitude of land surface--in feet above sea level.
Primary use of water--H, domestic; N, industrial; P, public supply; S, stock; U, unused.
Depth of well--in feet below land surface.
Well completion--O, open end; P, perforated; X, open hole.
Static water level--in feet below or above (+) land surface; F, flowing.
Water-level source--R, reported by owner or driller; S, U.S. Geological Survey.
Discharge--in gallons per minute.
Method of discharge measurement--M, totaling meter; R, reported; V, volumetric.
Onsite specific conductance--in microsiemens per centimeter at 25 degrees Celsius.
Onsite water temperature--in degrees Celsius.

Local number	Type of site	Aquifer	Altitude of land surface (feet)	Primary use of water	Depth of well (feet)	Well comple-tion	Static water level (feet)
36N02E01BCBA01	W	Kev	3,899	U	477	-	198.37
36N02E03ADAB01	W	Kev	3,780	S	150	-	--
36N02E03DD 01	S	Kev	3,746	S	--	-	--
36N02E09DBDA01	S	Kev	3,728	H	--	-	--
36N03E03CACB01	S	--	4,020	H	--	-	--
36N03E05DACA01	S	--	4,100	H	--	-	--
36N03E09ACC 01	S	Ti	4,290	H	--	-	--
36N03E10DCAA01	W	Kev	4,250	S	140	-	55.32
36N03E12DDAA01	W	Kev	4,059	U	150	O	45.78
36N03E14ACDC01	W	Qg	4,139	S	84	O	+20.06
36N03E14CCCB01	W	Kev	4,295	H	308	O	46.25
36N03E14CCCC01	W	Qg	4,295	U	185	-	--
36N03E18DDAA01	S	--	4,623	S	--	-	--
36N03E27BCB 01	S	Ti	4,595	H	--	-	--
36N04E05BCBC01	W	Qg	3,920	P	114	P	+48
36N04E05CDAC01	W	Kev	4,000	S	146	P	+19.52
36N04E06ADDA01	W	Qg	3,945	U	100	-	--
36N04E06ADDB01	W	Qg	3,943	H	134	O	+.25
36N04E06ADDB02	W	Qg	3,950	U	145	-	7.70
36N04E06DACD01	W	Qg	3,922	H	94	O	--
36N04E06DACD02	W	Qg	3,922	H	109	P	+62
36N04E07ADDD01	W	Kev	4,004	S	98	-	+5.30
36N04E07DBAD01	W	Kev	4,079	U	268	-	64.48
36N04E08BAAC01	W	Qg	4,045	U	170	P	12.22
36N04E09CDDB01	S	Ti	4,215	H	--	-	--
36N04E17CAA 01	W	Kev	4,160	H	165	-	13.20
36N04E21DBDA01	W	Qg	4,419	H	110	P	24.02
36N05E03DDAC01	W	Qg	4,134	S	110	O	+17.34
36N05E09ACDB01	W	Qal	4,325	H	20	P	--
37N02E11DBBD01	W	Kev	3,695	S	450	X	180
37N02E23CDAC01	W	Kev	3,801	U	440	O	98.94
37N02E25BBA 01	W	Mu	3,726	U	3,201	X	650
37N02E25DDAB01	W	--	3,680	S	--	-	--
37N02E26BDAC01	W	Kev	3,838	U	461	X	118.13
37N02E26DCDD01	S	--	3,719	H	--	-	--
37N02E26DDDB01	W	Kev	3,680	U	407	-	+47.34
37N02E31CDDD01	S	--	4,463	H	--	-	--
37N02E35AABA01	W	Kev	3,696	N	430	X	--
37N03E01CBCB01	W	Kev	3,507	U	530	O	F
37N03E05CABC01	W	Kev	3,530	S	330	O	82.60
37N03E06CBD 01	W	Kev	3,456	S	228	O	+4.03
37N03E07BBBA01	W	Kev	3,475	S	230	O	+2.70
37N03E07CBAC01	W	Kev	3,490	S	230	O	12.44
37N03E07CBAC02	W	Kev	3,505	S	220	-	26.03
37N03E07CBCD01	W	Kev	3,520	H	240	O	8

Water-level source	Date water level meas-ured	Dis-charge (gal/min)	Method of dis-charge meas-urement	Onsite spe-cific conduct-ance (µS/cm)	Onsite pH (stand-ard units)	Onsite water temper-ature (°C)	Date quality param-eter meas-ured	Local number
S	08-29-89	--	-	--	--	--	--	36N02E01BCBA01
-	--	12.0	V	570	7.5	8.5	05-03-89	36N02E03ADAB01
-	--	--	-	910	8.5	9.0	05-03-89	36N02E03DD 01
-	--	30.0	V	580	7.5	8.5	05-11-89	36N02E09DBDA01
-	--	--	-	470	7.7	7.5	05-11-89	36N03E03CACB01
-	--	4.6	V	670	7.1	7.5	09-26-90	36N03E05DACA01
-	--	--	-	480	7.4	7.0	05-10-89	36N03E09ACC 01
S	08-08-89	--	-	392	7.3	8.0	09-21-89	36N03E10DCAA01
S	05-24-89	--	-	--	--	--	--	36N03E12DDAA01
S	08-14-89	1.3	V	1,060	7.2	6.5	07-28-89	36N03E14ACDC01
S	07-28-89	7.1	V	515	7.4	8.5	07-28-89	36N03E14CCCB01
-	--	--	-	--	--	--	--	36N03E14CCCC01
-	--	--	-	240	7.4	5.0	05-12-89	36N03E18DDAA01
-	--	6.0	V	270	7.8	7.0	05-23-89	36N03E27BCB 01
R	09-19-85	--	-	550	7.6	8.0	05-10-89	36N04E05BCBC01
S	08-16-89	83.2	M	820	7.4	7.5	08-16-89	36N04E05CDAC01
-	--	--	-	530	7.6	7.5	06-29-89	36N04E06ADDA01
S	06-15-89	--	-	520	7.5	8.5	05-25-89	36N04E06ADDB01
S	06-15-89	--	-	--	--	--	--	36N04E06ADDB02
-	--	--	-	530	7.5	8.5	05-23-89	36N04E06DACD01
R	09-22-89	105	R	530	7.3	7.5	06-19-90	36N04E06DACD02
S	08-30-89	3.0	V	510	7.2	7.5	08-30-89	36N04E07ADDD01
S	08-30-89	--	-	--	--	--	--	36N04E07DBAD01
S	05-23-89	--	-	--	--	--	--	36N04E08BAAC01
-	--	--	-	385	7.4	8.5	06-14-89	36N04E09CDDB01
S	08-30-89	--	-	431	7.1	7.5	06-19-90	36N04E17CAA 01
S	05-25-89	3.0	V	250	7.1	7.0	05-25-89	36N04E21DBDA01
S	08-17-89	6.3	V	720	8.8	7.5	06-21-89	36N05E03DDAC01
-	--	120	R	300	7.3	8.0	06-21-89	36N05E09ACDB01
R	05-10-69	45	R	--	--	--	--	37N02E11DBBD01
S	08-29-89	--	-	--	--	--	--	37N02E23CDAC01
R	09-07-90	--	-	--	--	--	--	37N02E25BBA 01
-	--	--	-	--	--	--	--	37N02E25DDAB01
S	05-11-89	60	R	--	--	--	--	37N02E26BDAC01
-	--	--	-	--	--	--	--	37N02E26DCDD01
S	06-08-89	--	-	710	8.2	5.5	05-02-89	37N02E26DDDB01
-	--	30.0	V	123	7.9	3.5	05-17-89	37N02E31CDDD01
-	--	--	-	750	7.5	8.5	05-02-89	37N02E35AABA01
-	--	--	-	--	--	--	--	37N03E01CBCB01
S	05-18-89	12.0	V	1,640	9.1	9.5	05-18-89	37N03E05CABC01
S	06-08-89	1.6	V	720	8.0	9.0	05-04-89	37N03E06CBD 01
S	06-08-89	1.6	V	670	8.1	9.0	05-04-89	37N03E07BBBA01
S	05-04-89	10.0	V	690	8.2	--	05-04-89	37N03E07CBAC01
S	05-18-89	11.4	V	835	8.5	8.5	05-18-89	37N03E07CBAC02
R	05-04-89	4.3	V	830	8.3	6.0	05-04-89	37N03E07CCAB01

Local number	Type of site	Aquifer	Altitude of land surface (feet)	Primary use of water	Depth of well (feet)	Well comple- tion	Static water level (feet)
37N03E11ADAA01	W	Qg	3,535	H	143	O	+29.40
37N03E12BCDC01	W	Kev	3,530	U	530	X	F
37N03E12CBDD01	W	Qg	3,550	H	143	O	+18.75
37N03E15DADD01	W	Kev	3,610	S	523	O	31.27
37N03E19CBCC01	W	Kev	3,590	S	202	O	--
37N03E24ABBB01	W	Qg	3,622	H	131	O	34.65
37N03E24ABBD01	W	Qg	3,615	H	110	O	--
37N03E24ABBD02	W	Qg	3,605	S	110	-	--
37N03E25AACA01	W	Qg	3,675	U	118	-	7.28
37N03E26DABD01	W	Qg	3,718	U	145	-	17.29
37N03E26DCCA01	W	Qg	3,735	H	120	-	--
37N03E28DCCC01	W	Qg	3,840	S	150	-	+2.5
37N03E30BBAC01	W	Kev	3,607	S	220	O	+7
37N04E01DDDA01	W	Qg	3,780	H	85	O	--
37N04E04CBDA01	W	Qg	3,595	U	120	-	68.14
37N04E06BDAA01	W	Kev	3,581	H	600	O	76.33
37N04E07CDDD01	W	Kev	3,635	U	300	-	--
37N04E09DADA01	W	Kev	3,705	H	250	O	--
37N04E10CBCA01	W	Kev	3,700	H	250	O	140
37N04E11DCCD01	W	Qg	3,937	U	85	O	75.40
37N04E12ABCA01	W	Kjr	3,870	U	434	X	F
37N04E14ADAC01	W	Kev	3,911	U	327	-	228.99
37N04E14DDAB01	W	Qg	3,919	U	52	-	8.40
37N04E15DCDB01	W	Qg	3,820	U	139	O	81.96
37N04E22DCAB01	W	Qg	3,940	H	150	O	--
37N04E23CCDD01	W	Qg	3,994	U	150	P	69.02
37N04E26BDCC01	W	Qg	4,020	H	167	O	82.88
37N04E31CAAB01	W	Kev	3,805	S	240	O	6.59
37N04E31CDAD01	W	Kev	3,840	H	110	O	+42.74
37N04E31CDCA01	W	Qg	3,923	U	66	-	47.83
37N04E35CDDD01	W	Qal	4,180	H	14	-	6.22
37N05E05CAAC01	W	Kjr	3,652	S	300	-	F
37N05E08AABD01	W	Kev	3,614	N	847	P	--
37N05E09ACCA01	W	Kev	3,690	N	910	P	--
37N05E09BBDB01	W	Kev	3,590	N	851	-	--
37N05E09DACB01	W	Kev	3,689	U	893	P	525
37N05E30BAD 01	W	Qg	4,119	S	60	-	36.37

Table 10.--Records of inventoried wells and springs in the study area--Continued

Water-level source	Date water level measured	Discharge (gal/min)	Method of discharge measurement	Onsite specific conductance (µS/cm)	Onsite pH (standard units)	Onsite water temperature (°C)	Date quality parameter measured	Local number
S	07-26-89	--	-	1,210	7.4	8.0	05-17-89	37N03E11ADAA01
-	--	--	-	--	--	--	--	37N03E12BCDC01
S	08-15-89	16.5	V	1,210	7.4	8.0	05-17-89	37N03E12CBDD01
S	05-09-89	15.0	V	1,600	7.6	11.0	05-09-89	37N03E15DADD01
-	--	3.1	V	1,400	7.6	8.5	05-03-89	37N03E19CBCC01
S	07-26-89	--	-	1,060	8.0	9.0	09-14-89	37N03E24ABBB01
-	--	--	-	1,020	7.3	8.0	06-28-89	37N03E24ABBD01
-	--	--	-	1,160	7.3	8.0	06-28-89	37N03E24ABBD02
S	06-28-89	--	-	--	--	--	--	37N03E25AACA01
S	06-29-89	--	-	--	--	--	--	37N03E26DABD01
-	--	--	-	525	7.9	12.0	06-29-89	37N03E26DCCA01
S	09-12-90	--	-	--	--	--	--	37N03E28DCCC01
R	07-07-61	3.6	V	1,860	7.6	8.0	05-02-89	37N03E30BBAC01
-	--	6.0	V	790	7.2	9.5	09-22-89	37N04E01DDDA01
S	07-18-90	--	-	--	--	--	--	37N04E04CBDA01
S	09-27-90	6.7	V	1,580	7.5	11.5	05-09-89	37N04E06BDAA01
-	--	8.6	V	1,500	7.5	9.5	06-27-89	37N04E07CDDD01
-	--	--	-	2,000	7.2	8.5	06-22-89	37N04E09DADA01
R	07- -90	--	-	--	--	--	--	37N04E10CBCA01
S	08-15-89	--	-	--	--	--	--	37N04E11DCCD01
-	--	.3	V	1,100	9.1	9.0	08-30-89	37N04E12ABCA01
S	07-29-89	--	-	--	--	--	--	37N04E14ADAC01
S	07-29-89	--	-	--	--	--	--	37N04E14DDAB01
S	07-29-89	--	-	--	--	--	--	37N04E15DCDB01
-	--	--	-	1,040	7.5	9.0	06-16-89	37N04E22DCAB01
S	07-26-89	--	-	--	--	--	--	37N04E23CCDD01
S	11-06-90	9.6	V	2,400	7.1	8.0	05-09-89	37N04E26BDCC01
S	06-28-89	3.3	V	1,080	7.3	9.5	09-14-89	37N04E31CAAB01
S	08-15-89	20.7	M	1,190	7.3	8.0	05-23-89	37N04E31CDAD01
S	05-23-89	--	-	--	--	--	--	37N04E31CDCA01
S	07-17-90	6.0	V	1,630	7.0	8.0	07-17-90	37N04E35CDDD01
-	--	--	-	--	--	--	--	37N05E05CAAC01
-	--	--	-	--	--	--	--	37N05E08AABD01
-	--	--	-	--	--	--	--	37N05E09ACCA01
-	--	33	R	--	--	--	--	37N05E09BBDB01
R	06-19-90	--	-	--	--	--	--	37N05E09DACB01
S	06-22-89	12.0	V	2,400	8.3	7.0	06-22-89	37N05E30BAD 01

Table 11.--Physical properties and common-constituent concentrations in ground water in the study area

[Laboratory analyses by Montana Bureau of Mines and Geology except as indicated. Onsite measurements by U.S. Geological Survey except as indicated. Abbreviations: °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C. Symbols and acronyms: <, less than minimum reporting level; --, no data or not applicable. All common-constituent concentrations are reported as dissolved. Onsite bicarbonate and carbonate were determined by incremental titration. Onsite sulfide was determined using a colorimeter; concentrations are considered to be approximate]

Local number--numbering system described in text.
Aquifer--Qal, Holocene alluvium;
Qg, interstratified sand and gravel aquifer within Quaternary glacial deposits;
Kjr, Upper Cretaceous Judith River Formation;
Kev, Upper Cretaceous Virgelle Sandstone Member of Eagle Sandstone.
Remarks--NWQL, analysis by National Water Quality Laboratory of U.S. Geological Survey.

Local number	Aquifer	Date sampled	On-site specific conductance (µS/cm)	On-site pH (standard units)	On-site water temperature (°C)	On-site dissolved oxygen (mg/L)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Sodium-adsorption ratio (SAR)
36N02E03ADAB01	Kev	09-21-89	645	7.5	8.0	6.3	300	74	28	7.1	0.2
36N03E10DCAA01	Kev	09-21-89	392	7.3	8.0	2.8	180	54	11	6.7	.2
36N03E14ACDC01	Qg	09-21-89	1,120	7.2	8.0	.8	530	140	45	41	.7
36N03E14CCCB01	Kev	09-10-90	505	7.4	8.5	--	230	64	18	26	.7
36N04E05CDAC01	Kev	09-12-89	845	7.4	8.0	.2	310	75	29	60	1
36N04E06ADDB01[1]	Qg	09-18-89	505	7.4	7.5	--	230	66	16	21	.6
	--	09-18-89	[2]3.4	[2]5.5	--	--	<1	<.1	<.1	<.1	<.1
36N04E06DACD02	Qg	09-10-90	522	7.3	7.5	1.0	250	70	17	20	.6
36N04E07ADDD01	Kev	09-12-89	480	7.2	7.5	2.1	240	68	16	16	.4
	--	09-12-89	[2]525	[2]8.4	--	--	230	66	16	15	.4
36N04E21DBDA01	Qg	09-19-89	270	7.2	9.0	1.7	110	33	5.8	11	.5
36N05E03DDAC01	Qg	09-20-89	730	9.0	8.5	--	8	2.3	.5	180	28
37N02E35AABA01	Kev	09-19-89	770	7.6	9.0	--	270	63	28	76	2
37N03E11ADAA01	Qg	09-19-89	1,160	7.3	8.5	--	230	57	22	190	6
37N03E12CBDD01	Qg	09-13-89	1,300	7.3	9.5	--	310	77	30	210	5
37N03E15DADD01[1]	Kev	09-13-89	1,740	8.6	11.0	--	110	9.9	21	420	18
	--	09-13-89	[2]3.7	[2]5.3	--	--	<1	<.1	<.1	<.1	--
37N03E24ABBB01	Qg	09-14-89	1,060	8.0	9.0	--	370	83	39	130	3
37N03E30BBAC01	Kev	09-21-89	2,070	7.5	9.5	--	300	67	33	360	9
37N04E01DDDA01	Qg	09-22-89	790	7.2	9.5	--	420	93	46	50	1
37N04E06BDAA01	Kev	09-14-89	1,630	7.5	13.0	--	300	50	43	320	8
37N04E07CDDD01	Kev	09-11-90	1,540	7.4	9.5	--	280	46	41	260	7
	--	09-11-90	[2]1,500	[2]8.0	--	--	280	45	41	260	7
	--	09-11-90	[2]1,500	[2]8.0	--	--	280	45	41	260	7
	--	09-11-90	[2]1,520	[2]8.0	--	--	280	45	41	260	7
	--	09-11-90	[2]1,520	[2]7.8	--	--	280	45	41	270	7
37N04E09DADA01	Kev	09-19-89	1,770	7.3	10.5	.2	430	68	63	280	6
37N04E12ABCA01	Kjr	09-22-89	1,320	8.8	8.5	--	3	.9	.2	360	90
	--	09-22-89	[2]1,600	[2]8.9	--	--	3	.9	.2	350	84
37N04E22DCAB01	Qg	09-15-89	1,020	7.5	9.5	--	390	79	48	98	2
37N04E26BDCC01	Qg	09-15-89	2,090	7.2	8.5	--	430	79	56	430	9
37N04E31CDAD01	Kev	09-13-89	1,070	7.2	8.5	--	490	110	56	72	1
37N04E35CDDD01[1]	Qal	09-11-90	670	7.1	12.0	--	350	83	34	33	.8
	--	09-11-90	[2]2.9	[2]5.5	--	--	<1	<.1	<.1	<.1	<.1
37N05E30BAD 01	Qg	09-12-89	2,100	8.4	7.5	<1.0	25	6.3	2.3	560	49

[1]Field blank obtained at this site.
[2]Determined by Montana Bureau of Mines and Geology, Analytical Division Laboratory.
[3]Less than minimum reporting level, but detectable.

Table 11.--Physical properties and common-constituent concentrations in ground water in the study area--Continued

Potassium (mg/L as K)	On-site bicarbonate (mg/L as HCO_3)	On-site carbonate (mg/L as CO_3)	On-site alkalinity (mg/L as $CaCO_3$)	On-site sulfide (mg/L as S)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Silica (mg/L as SiO_2)	Dissolved solids, calculated (mg/L)	Nitrate (mg/L as N)	Remarks	Local number
2	370	0	310	--	14	2.9	0.3	13	500	0.14		36N02E03ADAB01
.6	190	0	160	--	37	1.1	.3	14	213	.23		36N03E10DCAA01
3	400	0	330	--	270	7.9	.3	15	700	.77		36N03E14ACDC01
2	300	0	240	[3]<.1	46	.9	.8	14	304	<.07		36N03E14CCCB01
3	380	0	310	--	130	4.8	.7	15	500	.07		36N04E05CDAC01
2	260	0	210	[3]<.1	61	2.0	.5	16	313	.07		36N04E06ADDB01
<.2	[2]2	[2]0	[2]1.2	--	<.1	<.02	<.02	<.1	--	.17	Field blank	
2	270	0	211	--	62	1.7	.3	14	314	.61		36N04E06DACD02
2	240	0	200	--	63	2.3	.4	19	302	1.5		36N04E07ADDD01
2	[2]230	[2]0	[2]190	--	62	2.3	.5	16	296	1.7	Replicate	
2	150	0	120	--	21	1.0	.3	13	154	.12		36N04E21DBDA01
.6	440	32	420	.7	10	2.1	.4	8.4	448	.01		36N05E03DDAC01
2	390	0	320	[3]<.1	130	2.1	.5	18	497	.12		37N02E35AABA01
3	523	0	430	[3]<.1	210	4.9	.6	15	762	.09		37N03E11ADAA01
4	670	0	550	[3]<.1	230	5.4	.3	16	856	.06		37N03E12CBDD01
2	840	13	710	1.6	140	65	2.1	13	1,140	.13		37N03E15DADD01
<.2	[2]1	[2]0	[2]1.1	--	<.1	<.02	<.02	<.1	.73	<.03	Field blank	
3	570	0	460	[3]<.1	210	5.1	.6	14	751	.04		37N03E24ABBB01
3	680	0	560	.1	550	5.2	1.1	20	1,360	.01		37N03E30BBAC01
4	520	0	420	.1	120	4.0	.4	13	554	.14		37N04E01DDDA01
4	730	0	600	.4	370	7.3	.4	16	1,160	.07		37N04E06BDAA01
3	680	0	550	.3	270	6.3	.7	16	975	.28		37N04E07CDDD01
3	[2]660	[2]0	[2]540	--	280	6.3	.7	16	982	.28	Replicate	
	[2]680	[2]0	[2]540	--	280	6.4	.8	16	988	.28	Replicate	
3	[2]660	[2]--	[2]550	--	280	6.3	.7	16	977	.28	Replicate	
3	--	0	520	--	330	9.7	.5	15	1,030	<.10	Replicate, NWQL	
3	760	0	620	--	400	22	.1	16	1,220	.16		37N04E09DADA01
.6	810	52	750	.2	3.6	2.5	1.9	7.7	855	.05		37N04E12ABCA01
.7	[2]870	[2]36	[2]770	--	5.3	2.1	2.2	7.1	837	.02	Replicate	
4	740	0	600	[3]<.1	2.5	4.2	.3	12	594	.16		37N04E22DCAB01
5	920	0	750	[3]<.1	580	9.7	.9	17	1,600	.07		37N04E26BDCC01
3	540	0	450	.1	230	4.2	.6	22	739	.24		37N04E31CDAD01
2	440	0	351	[3]<.1	66	2.1	.6	22	439	<.07		37N04E35CDDD01
<.2	[2]2	[2]0	[2]1.2	--	<.7	<.02	<.02	<.1	.72	<.07	Field blank	
.6	970	34	830	[3]<.1	340	4.0	.3	7.9	1,450	.05		37N05E30BAD 01

Table 12.--Trace-element concentrations in ground water in the study area

[Analyses by Montana Bureau of Mines and Geology except as indicated. Abbreviation: µg/L, micrograms per liter. Symbols: <, less than minimum reporting level; --, no data or not applicable. All trace-element concentrations are reported as dissolved]

Local number--numbering system described in text.
Aquifer--Qal, Holocene alluvium;
Qg, interstratified sand and gravel aquifer within Quaternary glacial deposits;
Kjr, Upper Cretaceous Judith River Formation;
Kev, Upper Cretaceous Virgelle Sandstone Member of Eagle Sandstone.
Remarks--NWQL, analysis by National Water Quality Laboratory of U.S. Geological Survey.

Local number	Aquifer	Date sampled	Aluminum (µg/L as Al)	Arsenic (µg/L as As)	Boron (µg/L as B)	Cadmium (µg/L as Cd)	Chromium (µg/L as Cr)	Copper (µg/L as Cu)	Iron (µg/L as Fe)	Lithium (µg/L as Li)
36N02E03ADAB01	Kev	09-21-89	<40	--	<40	<5	<5	<4	<4	13
36N03E10DCAA01	Kev	09-21-89	<40	0.4	140	<5	<5	<4	<4	18
36N03E14ACDC01	Qg	09-21-89	<40	--	220	<5	<5	<4	<2	55
36N03E14CCCB01	Kev	09-10-90	<40	--	140	<5	<5	6	730	58
36N04E05CDAC01	Kev	09-12-89	<40	--	140	<5	<4	<4	<4	55
36N04E06ADDB01[1]	Qg	09-18-89	<40	1.3	100	<5	<5	<4	370	8
	--	09-18-89	<40	<.1	<40	<5	<5	<4	<4	<2
36N04E06DACD02	Qg	09-10-90	<40	--	80	<5	<5	5	8	15
36N04E07ADDD01	Kev	09-12-89	<40	--	50	<5	<5	<4	<4	18
	--	09-12-89	<40	--	40	<5	<5	<4	<4	14
36N04E21DBDA01	Qg	09-19-89	<40	.3	90	<5	<5	<4	180	11
36N05E03DDAC01	Qg	09-20-89	<40	--	220	<5	<5	<4	10	200
37N02E35AABA01	Kev	09-19-89	<40	.7	150	<5	<5	<4	940	42
37N03E11ADAA01	Qg	09-13-89	<40	.5	180	<5	<5	<4	80	31
37N03E12CBDD01	Qg	09-19-89	<40	--	260	<5	<5	<4	750	43
37N03E15DADD01[1]	Kev	09-13-89	<40	--	520	<5	<5	<4	40	77
	--	09-13-89	<40	--	<40	<5	<5	<4	<4	<2
37N03E24ABBB01	Qg	09-14-89	<40	--	290	<5	<5	<4	19,000	45
37N03E30BBAC01	Kev	09-21-89	<40	3.2	420	<5	<5	<4	2,800	120
37N04E01DDDA01	Qg	09-22-89	<40	.8	130	<5	<5	5	1,400	49
37N04E06BDAA01	Kev	09-14-89	<40	.6	330	<5	<5	<4	1,800	96
37N04E07CDDD01	Kev	09-11-90	<40	--	240	<5	<5	<4	950	92
	--	09-11-89	<40	--	240	<5	<5	<4	910	90
	--	09-11-89	<40	--	210	<5	<5	<4	880	90
	--	09-11-89	<40	--	210	<5	<5	<4	850	90
	--	09-11-89	30	--	270	1	<5	<10	930	90
37N04E09DADA01	Kev	09-19-89	<40	.8	330	<5	<5	<4	1,400	140
37N04E12ABCA01	Kjr	09-22-89	<40	.4	900	<5	<5	<4	50	42
	--	09-22-89	<40	.8	1,160	<5	<5	<4	50	43
37N04E22DCAB01	Qg	09-15-89	<40	--	80	<5	<5	<4	3,400	49
37N04E26BDCC01	Qg	09-15-89	<40	--	170	<5	<5	<4	1,600	210
37N04E31CDAD01	Kev	09-13-89	<40	--	170	<5	<5	<4	1,900	43
37N04E35CDDD01[1]	Qal	09-11-90	<40	.7	100	<5	<5	<4	920	110
	--	09-11-90	<40	--	<40	<5	<5	<4	<4	<4
37N05E30BAD 01	Qg	09-12-89	<40	--	400	<5	<5	<4	50	110

[1]Field blank obtained at this site.

Manganese (µg/L as Mn)	Molybdenum (µg/L as Mo)	Nickel (µg/L as Ni)	Selenium (µg/L as Se)	Silver (µg/L as Ag)	Strontium (µg/L as Sr)	Titanium (µg/L as Ti)	Vanadium (µg/L as V)	Zinc (µg/L as Zn)	Remarks	Local number
2	<40	<20	--	<4	290	<4	<4	120	--	36N02E03ADAB01
<2	<40	<20	1.5	<4	350	<4	<4	59	--	36N03E10DCAA01
<2	<40	<20	--	<4	1,300	<4	12	24	--	36N03E14ACDC01
59	<40	<20	--	<4	1,200	5	<4	12	--	36N03E14CCCB01
480	<40	<20	--	<4	770	5	<4	14	--	36N04E05CDAC01
780	<40	<20	<.1	<4	540	<4	<4	8	--	36N04E06ADDB01
<2	<40	<20	<.1	<4	<2	<4	<4	<6	Field blank	
180	<40	<20	--	<4	680	9	<4	<6	--	36N04E06DACD02
<2	<40	<20	--	<4	750	10	5	<6	--	36N04E07ADDD01
<2	<40	<20	--	<4	740	6	<4	8	Replicate	
34	<40	<20	.5	<4	610	<4	<4	18	--	36N04E21DBDA01
<2	<40	<20	--	<4	81	<4	<4	<6	--	36N05E03DDAC01
22	<40	<20	.3	<4	680	<4	<4	<6	--	37N02E35AABA01
900	<40	<20	.4	<4	560	7	<4	12	--	37N03E11ADAA01
1,100	<40	<20	--	<4	870	8	5	<7	--	37N03E12CBDD01
2	<40	<20	--	<4	920	<4	<4	<6	--	37N03E15DADD01
<2	<40	<20	--	<4	<2	<4	<4	<6	Field blank	
770	<40	<20	--	<4	1,000	6	<4	75	--	37N03E24ABBB01
53	<40	<20	.5	<4	1,100	<4	<4	<6	--	37N03E30BBAC01
140	<40	<20	<.1	<4	1,500	--	<4	--	--	37N04E01DDDA01
110	<40	<20	.2	<4	860	6	<4	75	--	37N04E06BDAA01
40	<40	<20	--	<4	680	4	<4	16	--	37N04E07CDDD01
40	<40	<20	--	<4	680	<4	<4	19	Replicate	
39	<40	<20	--	<4	680	5	<4	13	Replicate	
39	<40	<20	--	<4	680	<4	<4	15	Replicate	
45	<10	<10	--	<1	710	--	<6	13	Replicate, NWQL	
10	<40	<20	.7	<4	1,400	5	<6	800	--	37N04E09DADA01
5	<40	<20	.4	<4	53	<4	<4	<6	--	37N04E12ABCA01
6	<40	<20	.2	<4	52	<4	<4	<7	Replicate	
170	<40	<20	--	<4	1,200	<4	<4	<6	--	37N04E22DCAB01
70	<40	<20	--	<4	1,400	<4	<4	10	--	37N04E26BDCC01
1,000	<40	<20	--	<4	1,100	9	<4	<6	--	37N04E31CDAD01
690	<40	<20	<.1	<4	880	5	<4	14	--	37N04E35CDDD01
<2	<40	<20	--	<4	<2	<4	<4	6	Field blank	
4	<40	<20	--	<4	300	<4	<4	<6	--	37N05E30BAD 01

Table 13.--Water-level data for selected wells in the study area

[Static water level--in feet below or above (+) land surface. Aquifer--Qg, interstratified sand and gravel aquifer within Quaternary glacial deposits; Kev, Upper Cretaceous Virgelle Sandstone Member of Eagle Sandstone]

Local number	Aquifer	Static water level	Date water level measured
36N02E01BCBA01	Kev	198.37	08-29-89
		198.23	10-13-89
		197.98	01-10-90
		198.22	02-22-90
		198.21	05-03-90
		197.71	06-04-90
		197.68	06-26-90
		197.56	07-22-90
		197.24	08-21-90
		197.20	09-26-90
36N03E10DCAA01	Kev	55.32	08-08-89
		55.68	10-31-89
		55.94	11-15-89
		56.33	01-10-90
		56.61	02-21-90
		51.45	04-04-90
		52.90	05-04-90
		52.90	06-04-90
		52.97	06-26-90
		52.78	07-20-90
		54.50	08-21-90
		55.05	09-26-90
36N03E12DDAA01	Kev	45.78	05-24-89
		47.01	11-16-89
		47.11	12-13-89
		46.97	01-10-90
		47.16	02-21-90
		47.38	03-22-90
		46.51	05-04-90
		46.03	06-04-90
		46.27	06-28-90
		46.62	07-21-90
		46.17	08-22-90
		45.97	09-25-90
36N04E07ADDD01	Kev	+5.30	08-30-89
		+5.18	09-12-89
		+4.23	10-13-89
		+4.39	11-16-89
		+3.21	01-11-90
		+3.38	02-21-90
		+4.26	04-05-90
		+4.83	05-04-90
		+5.21	06-06-90
		+4.82	06-27-90
		+4.46	07-22-90
		+4.96	08-23-90
		+5.18	09-26-90
36N04E07DBAD01	Kev	64.48	08-30-89
		65.55	10-13-89
		65.82	11-10-89
		65.63	11-16-89
		65.99	01-11-90
		65.69	02-21-90
		65.23	04-05-90
		64.72	05-04-90
		64.34	06-06-90
		64.56	06-27-90
		64.90	07-22-90
		64.45	08-23-90
		64.32	09-26-90
36N04E17CAA01	Kev	13.20	08-30-89
		16.14	10-13-89
		17.06	11-16-89
		17.84	12-13-89
		18.29	01-11-90
		18.66	02-21-90
		18.81	03-22-90
		11.99	05-03-90
		11.90	06-05-90
		12.30	06-28-90
		11.82	07-22-90
		12.62	08-23-90
		12.53	09-26-90

Table 13.--Water-level data for selected wells in the study area--Continued

Local number	Aquifer	Static water level	Date water level measured
37N02E23CDAC01	Kev	98.94	08-29-89
		98.72	10-13-89
		98.72	11-15-89
		97.95	01-10-90
		97.07	02-21-90
		97.18	04-04-90
		97.01	05-03-90
		95.05	06-04-90
		94.76	06-26-90
		94.65	07-21-90
		94.91	08-21-90
		95.83	09-26-90
37N02E26BDAC01	Kev	118.13	05-11-89
		114.08	08-29-89
		113.82	10-13-89
		113.76	11-15-89
		112.93	01-10-90
		112.03	02-21-90
		112.91	04-04-90
		112.17	05-03-90
		110.21	06-04-90
		110.10	06-26-90
		109.93	07-21-90
		110.14	08-21-90
		111.09	09-26-90
37N03E12CBDD01	Qg	+18.75	08-15-89
		+18.71	09-13-89
		+20.91	11-17-89
		+19.58	01-11-90
		+19.23	02-21-90
		+24.16	04-05-90
		+25.21	05-03-90
		+22.45	06-07-90
		+22.57	06-26-90
		+22.29	07-21-90
		+21.07	08-22-90
		+24.82	09-25-90
37N03E15DADD01	Kev	31.27	05-09-89
		29.70	09-13-89
		30.85	01-10-90
		31.22	05-04-90
		30.63	06-05-90
		30.62	06-26-90
		30.74	07-22-90
		30.58	08-22-90
		30.63	09-26-90
37N03E24ABBB01	Qg	34.65	07-26-89
		34.66	09-14-89
		34.12	11-17-89
		33.86	12-14-89
		33.92	01-11-90
		34.30	02-22-90
		34.00	04-04-90
		33.37	05-04-90
		33.10	06-05-90
		33.34	06-24-90
		33.77	07-21-90
		33.57	08-23-90
		33.52	09-27-90
37N03E25AACA01	Qg	7.28	06-28-89
		7.39	11-01-89
		7.16	01-11-90
		7.14	02-22-90
		7.25	04-03-90
		7.02	06-05-90
		7.19	06-27-90
		7.28	08-23-90
		7.24	09-25-90
37N03E26DABD01	Qg	17.29	06-29-89
		17.35	08-08-89
		17.31	11-17-89
		17.32	12-14-89
		17.27	01-11-90
		17.22	02-22-90
		17.11	04-04-90
		17.06	05-04-90
		16.98	06-05-90
		16.96	06-24-90
		16.99	07-22-90
		17.04	08-22-90
		17.10	09-26-90

Table 13.--Water-level data for selected wells in the study area--Continued

Local number	Aquifer	Static water level	Date water level measured
37N04E11DCCD01	Qg	75.40	08-15-89
		75.45	12-13-89
		75.55	01-10-90
		75.51	02-21-90
		75.62	05-03-90
		75.51	06-05-90
		75.59	06-27-90
		75.61	07-22-90
		75.58	08-22-90
		75.48	09-25-90
37N04E14ADAC01	Kev	228.99	07-29-89
		229.15	08-30-89
		229.78	12-13-89
		229.74	01-10-90
		230.01	02-21-90
		230.09	03-21-90
		223.86	05-03-90
		224.59	06-05-90
		224.95	06-27-90
		225.12	07-22-90
		224.62	08-22-90
		224.93	09-25-90
37N04E14DDAB01	Qg	8.40	07-29-89
		9.60	12-13-89
		9.69	01-10-90
		9.48	02-21-90
		8.71	03-21-90
		3.65	05-03-90
		.90	06-05-90
		2.30	06-27-90
		4.18	07-22-90
		5.55	08-22-90
		6.53	09-27-90
37N04E15DCDB01	Qg	81.96	07-29-89
		81.56	12-13-89
		80.80	01-10-90
		81.02	02-21-90
		79.31	04-05-90
		80.12	05-04-90
		81.16	06-05-90
		79.85	06-27-90
		79.54	07-19-90
		79.40	08-21-90
		80.31	09-26-90
37N04E23CCDD01	Qg	69.02	07-26-89
		68.46	08-29-89
		67.80	10-11-89
		69.37	11-16-89
		69.72	12-13-89
		69.97	01-10-90
		70.25	02-21-90
		70.57	03-21-90
		70.84	05-03-90
		70.40	06-05-90
		69.86	06-27-90
		69.57	07-22-90
		60.29	08-22-90
		69.60	09-25-90
37N05E30BAD01	Qg	36.37	06-22-89
		37.20	08-29-89
		36.30	09-12-89
		36.22	10-11-89
		36.46	12-13-89
		36.42	01-11-90
		36.32	02-22-90
		36.00	05-05-90
		36.11	05-17-90
		35.82	06-27-90
		35.73	07-18-90
		35.43	08-22-90
		35.34	09-25-90

Table 14.--Estimated instantaneous streamflow at miscellaneous measurement sites in the study area

[Site number: listed in downstream order for each basin--MC, Miners Coulee; BC, Breed Creek; BG, Bear Gulch. Abbreviations: ft³/s, cubic feet per second; NF, no flow; tr, trickle. Symbol: <, less than]

Site number	Local number	Date	Discharge (ft³/s)	Date	Discharge (ft³/s)
		Miners Coulee			
MC-4	37N02E24DDD01	03-02-88	NF	04-05-89	0.25
		03-22-88	[1]<0.01	04-12-89	1.2
		03-29-88	[1].04	04-25-89	.30
		04-12-88	[1]NF	05-09-89	.18
		04-26-88	[1].04	05-17-89	.01
		05-10-88	[1]<.01	06-06-89	.67
		05-31-88	.04	06-13-89	1.0
				06-20-89	.01
		03-28-89	[1]4.7	06-29-89	.01
		03-30-89	[1]3.1	07-20-89	.08
		04-01-89	[1]1.8		
MC-5	37N03E07CCA01	03-02-88	NF	03-30-89	[1]7.6
		03-22-88	[1]NF	04-01-89	[1].78
		03-29-88	[1]NF	04-12-89	.30
		04-12-88	[1]NF	04-25-89	.64
		04-26-88	[1]NF	05-09-89	NF
		05-10-88	[1]NF	05-17-89	NF
		05-31-88	NF	06-06-89	.19
				06-13-89	2.4
		03-28-89	[1]21		
MC-9	37N03E07CBB01	03-02-88	.10	03-30-89	[1].07
		03-22-88	[1].42	04-01-89	[1]NF
		03-29-88	[1].07	04-05-89	NF
		04-12-88	[1].35	04-12-89	.18
		04-26-88	[1].21	04-25-89	.23
		05-10-88	[1]<.01	05-09-89	.18
		05-31-88	NF	05-17-89	NF
				06-06-89	3.6
		03-28-89	[1].04	06-13-89	2.5
		Breed Creek			
BC-4	36N04E17DBCB01	03-02-88	[1].40	05-09-89	11
		03-22-88	[1].39	05-17-89	4.8
		03-29-88	[1].25	05-30-89	14
		04-12-88	[1].39	06-06-89	14
		04-26-88	[1]1.4	06-13-89	31
		05-10-88	[1]1.0	06-29-89	3.9
		05-31-88	1.2	07-18-89	1.5
		03-28-89	[1]3.1	03-21-90	3.2
		03-30-89	[1]1.3	04-18-90	4.5
		04-01-89	[1]1.5	05-02-90	9.1
		04-05-89	1.2	05-17-90	8.1
		04-13-89	2.5	05-31-90	22
		04-26-89	5.7	06-06-90	11
BC-5	36N04E06ACA01	03-02-88	.50	04-13-89	2.8
		03-22-88	[1]1.9	04-26-89	6.1
		03-29-88	[1].95	05-09-89	13
		04-12-88	[1].85	05-17-89	5.6
		04-26-88	[1]2.0	05-30-89	16
		05-10-88	[1].05	06-06-89	15
		05-31-88	.06	06-13-89	33
				06-29-89	3.9
		03-28-89	[1]3.7	07-18-89	1.5
		03-30-89	[1]3.2		
		04-01-89	[1]2.9	04-18-90	5.0
		04-05-89	1.7		
BC-6	36N04E05BCB01	03-02-88	<.01	04-25-89	.10
		03-22-88	[1].07	05-09-89	.30
		03-29-88	[1].04	05-17-89	.10
		04-12-88	[1].04	06-06-89	.11
		04-26-88	[1].04		
		05-10-88	[1]<.01	03-21-90	1.5
		05-31-88	tr	04-18-90	.94
				05-02-90	2.0
		03-30-89	[1].42	05-17-90	.44
		04-01-89	[1].39	05-31-90	1.5
		04-05-89	.15	06-06-90	1.3
		04-12-89	.20		

Table 14.--Estimated instantaneous streamflow at miscellaneous measurement sites in the study area--Continued

Site number	Local number	Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)
		Breed Creek--Continued			
BC-7	36N04E05BADC01	03-02-88	[1]NF	04-25-89	NF
		03-22-88	[1]NF	05-09-89	NF
		03-29-88	[1]NF	05-17-89	NF
		04-12-88	[1]NF	06-06-89	.02
		04-26-88	[1]NF		
		05-10-88	[1]NF	03-21-90	2.4
		05-31-88	NF	04-18-90	.79
				05-02-90	.85
		03-30-89	[1].70	05-17-90	.11
		04-01-89	[1].04	05-31-90	.46
		04-05-89	NF	06-06-90	.19
		04-12-89	.20		
BC-10	37N04E33ABB01	03-22-88	[1]NF	04-25-89	NF
		03-29-88	[1]NF	05-09-89	NF
		04-12-88	[1]NF	05-17-89	NF
		04-26-88	[1]NF	06-06-89	NF
		05-10-88	[1]NF		
		05-31-88	NF	03-21-90	.01
				04-18-90	.01
		03-30-89	[1]NF	05-02-90	.05
		04-01-89	[1]NF	05-17-90	<.01
		04-05-89	NF	05-31-90	.10
		04-12-89	NF	06-06-90	NF
BC-11	37N04E33CBC01	03-22-88	[1]NF	04-25-89	.03
		03-29-88	[1]NF	05-09-89	NF
		04-12-88	[1]NF	05-17-89	NF
		04-26-88	[1]NF	06-06-89	NF
		05-10-88	[1]NF		
		05-30-88	NF	03-21-90	.57
				04-18-90	.05
		03-30-89	[1].70	05-02-90	.64
		04-01-89	[1].70	05-17-90	.04
		04-05-89	.01	05-31-90	.10
		04-12-89	.06	06-06-90	.03
BC-13	37N03E12CACC01	03-02-88	[1].15	05-09-89	9.7
		03-22-88	[1]3.2	05-17-89	4.1
		03-29-88	[1].57	05-30-89	14
		04-12-88	[1].32	06-06-89	14
		04-26-88	[1].57	06-21-89	3.6
		05-10-88	[1].10	06-29-89	2.3
		05-31-88	.10	07-18-89	.99
		03-28-89	[1].18	03-21-90	9.4
		03-30-89	[1].18	04-18-90	5.4
		04-01-89	[1].14	05-02-90	13
		04-05-89	.80	05-17-90	9.6
		04-12-89	1.6	06-06-90	13
		04-25-89	6.4		
BC-14	36N03E01CAC01	03-22-88	[1]NF	04-25-89	NF
		03-29-88	[1]NF	05-09-89	NF
		04-12-88	[1]NF	05-17-89	NF
		04-26-88	[1]NF	06-06-89	NF
		05-10-88	[1]NF		
		05-31-88	NF	03-21-90	<.01
				04-18-90	.06
		03-28-89	[1].35	05-02-90	NF
		03-30-89	[1]1.0	05-17-90	NF
		04-01-89	[1].25	05-31-90	.29
		04-05-89	NF	06-06-90	<.01
		04-12-89	.06		
BC-15	37N03E23DADA01	03-02-88	NF	04-12-89	NF
		03-22-88	[1]NF	04-25-89	NF
		03-29-88	[1]NF	05-09-89	NF
		04-12-88	[1]NF	06-06-89	NF
		04-26-88	[1]NF		
		05-10-88	[1]NF	03-21-90	1.9
		05-31-88	NF	04-18-90	.05
				05-02-90	.57
		03-28-89	[1].53	05-17-90	NF
		03-30-89	[1].07	05-31-90	1.0
		04-01-89	[1]NF	06-06-90	NF
		04-05-89	NF		

Table 14.--Estimated instantaneous streamflow at miscellaneous measurement sites in the study area--Continued

Site number	Local number	Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)
		Breed Creek--Continued			
BC-16	36N03E09ACBB01	03-22-88	[1] NF	04-25-89	NF
		03-29-88	[1] NF	05-09-89	.01
		04-12-88	[1] NF	05-17-89	.01
		04-26-88	[1] .04	06-06-89	.01
		05-10-88	[1] NF		
		05-31-88	NF	03-21-90	NF
				04-18-90	.37
		03-30-89	[1] .35	05-02-90	.12
		04-01-89	[1] .04	05-17-90	.06
		04-05-89	NF	05-31-90	.12
		04-12-89	tr	06-06-90	.14
BC-17	36N03E04DBDA01	03-02-88	NF	04-25-89	.03
		03-22-88	[1] .07	05-09-89	.02
		03-29-88	[1] .04	05-17-89	tr
		04-12-88	[1] NF	06-06-89	.05
		04-26-88	[1] NF		
		05-31-88	NF	03-21-90	.01
				04-18-90	.51
		03-30-89	[1] .07	05-02-90	.43
		04-01-89	[1] .04	05-17-90	.20
		04-05-89	.01	05-31-90	.22
		04-12-89	.07	06-06-90	.36
BC-18	37N03E28DCDC01	03-22-88	[1] NF	05-09-89	NF
		03-29-88	[1] NF	05-17-89	NF
		04-12-88	[1] NF	06-06-89	NF
		04-26-88	[1] NF		
		05-10-88	[1] NF	03-21-90	1.0
		05-31-88	NF	04-18-90	.32
				05-02-90	.45
		04-01-89	[1] NF	05-17-90	.23
		04-05-89	NF	05-31-90	.26
		04-12-89	NF	06-06-90	.29
		04-25-89	NF		
BC-19	37N03E23ADDB01	03-02-88	NF	04-12-89	NF
		03-22-88	[1] NF	04-25-89	NF
		03-29-88	[1] NF	05-09-89	NF
		04-12-88	[1] NF	06-06-89	NF
		04-26-88	[1] NF		
		05-10-88	[1] NF	03-21-90	6.0
		05-31-88	NF	04-18-90	.46
				05-02-90	1.1
		03-28-89	[1] .71	05-17-90	.26
		03-30-89	[1] .14	05-31-90	3.3
		04-01-89	[1] NF	06-06-90	.19
		04-05-89	NF		
BC-20	37N03E23ADCD01	03-22-88	[1] NF	04-25-89	.01
		03-29-88	[1] NF	05-09-89	NF
		04-12-88	[1] NF	06-06-89	.01
		04-26-88	[1] NF		
		05-31-88	NF	03-21-90	1.9
				04-18-90	.46
		03-28-89	[1] .35	05-02-90	.84
		03-30-89	[1] .07	05-17-90	.09
		04-01-89	[1] NF	05-31-90	.96
		04-05-89	NF	06-06-90	.22
		04-12-89	NF		
		Bear Gulch			
BG-3	37N04E35BAAA01	03-02-88	.20	05-09-89	2.5
		03-22-88	[1] .64	05-17-89	.90
		03-29-88	[1] .11	06-06-89	11
		04-12-88	[1] .18	06-14-89	22
		04-26-88	[1] .25	06-29-89	4.2
		05-10-88	[1] .05	07-18-89	2.1
		05-31-88	.60		
				03-21-90	8.0
		03-30-89	[1] .88	04-18-90	6.3
		04-01-89	[1] .49	05-02-90	18
		04-05-89	.71	05-17-90	11
		04-12-89	1.9	05-31-90	25
		04-25-89	1.3	06-06-90	18

Table 14.--Estimated instantaneous streamflow at miscellaneous measurement sites in the study area--Continued

Site number	Local number	Date	Discharge (ft^3/s)	Date	Discharge (ft^3/s)
		Bear Gulch--Continued			
BG-5	37N04E26BCB01	03-02-88	1.0	04-25-89	.20
		03-22-88	[1].42	05-09-89	1.4
		03-29-88	[1].28	05-17-89	.20
		04-12-88	[1].35	06-06-89	2.2
		04-26-88	[1].21		
		05-10-88	[1].05	03-21-90	5.9
		05-31-88	.07	04-18-90	4.5
				05-02-90	13
		03-30-89	[1].25	05-17-90	6.8
		04-01-89	[1].14	05-31-90	16
		04-05-89	.05	06-06-90	7.3
		04-12-89	.09		
BG-7	37N04E23BAB01	03-02-88	NF	05-09-89	1.6
		03-22-88	[1]NF	05-17-89	[1].12
		03-29-88	[1]NF	06-06-89	6.6
		04-12-88	[1]NF	06-14-89	3.7
		04-26-88	[1].07	07-18-89	.17
		05-10-88	[1].01		
		05-31-88	tr	03-21-90	4.8
				04-18-90	1.7
		03-30-89	[1].42	05-02-90	9.5
		04-01-89	[1].18	05-17-90	1.3
		04-05-89	.07	05-31-90	3.5
		04-12-89	.63	06-06-90	2.4
		04-25-89	1.6	07-19-90	NF
BG-8	37N04E10CDAB01	03-22-88	[1]NF	05-09-89	1.0
		03-29-88	[1]NF	05-17-89	.05
		04-12-88	[1]NF	06-06-89	3.6
		04-26-88	[1]NF		
		05-31-88	NF	03-21-90	11
				04-18-90	1.8
		03-30-89	[1].60	05-02-90	11
		04-01-89	[1].14	05-17-90	2.0
		04-05-89	.05	05-31-90	7.6
		04-12-89	.22	06-06-90	2.3
		04-25-89	1.0		
BG-9	37N04E10CCA01	03-02-88	1.0	05-17-89	.60
		03-22-88	[1].88	05-30-89	8.0
		03-29-88	[1].42	06-06-89	8.0
		04-12-88	[1].53	06-14-89	16
		04-26-88	[1].18	06-21-89	7.2
		05-10-88	[1].01	06-29-89	5.2
		05-31-88	<.01	07-18-89	2.4
		03-28-89	[1]4.7	03-21-90	12
		03-30-89	[1]1.1	04-18-90	6.2
		04-01-89	[1].04	05-02-90	27
		04-05-89	.03	05-17-90	8.0
		04-12-89	.22	05-31-90	21
		04-25-89	2.1	06-06-90	9.7
		05-09-89	1.6		

[1] Source of data is Environment Canada, Conservation and Protection, Inland Waters Directorate, Water Resource Branch; conversion from cubic meters per second.

Table 15.--Physical properties and common-constituent concentrations in streamflow in the study area

[Analyses by Montana Bureau of Mines and Geology. Onsite measurements by U.S. Geological Survey except as indicated. Abbreviations: ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C. Symbols and acronyms: <, less than minimum reporting level; --, no data or not applicable. All common-constituent concentrations are reported as dissolved. Onsite bicarbonate and carbonate were determined by incremental titration]

Site number	Local number	Date sampled	Discharge (ft^3/s)	Onsite specific conductance (µS/cm)	Onsite pH (standard units)	Onsite water temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Sodium-adsorption ratio (SAR)
				Miners Coulee							
MC-4	37N02E24DDD 01	06-20-89	0.01	1,170	7.7	16.5	420	91	47	120	3
				Breed Creek							
BC-13	37N03E12CACC01[1]	06-21-89	3.6	340	8.2	15.0	190	51	14	11	.4
		06-21-89	3.6	340	8.2	15.0	190	52	14	11	.4
		06-21-89	--	[2]1.7	[2]5.4	--	0	<.1	<.1	.1	<.1
				Bear Gulch							
BG-9	37N04E10CCA 01	06-20-89	7.2	540	8.5	17.5	270	68	24	14	.4

Potassium (mg/L as K)	Onsite bicarbonate (mg/L as HCO_3)	Onsite carbonate (mg/L as CO_3)	Onsite alkalinity (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Silica (mg/L as SiO_2)	Dissolved solids, calculated (mg/L)	Nitrate (mg/L as N)	Remarks
					Miners Coulee					
4	530	0	440	220	11	0.7	18	774	0.10	--
					Breed Creek					
4	210	0	180	51	1.6	.3	11	241	.13	--
4	210	0	180	50	1.7	.3	11	241	.13	Replicate
<.1	[2]2	0	1	<.1	.3	<.1	<.1	1.3	.06	Field blank
					Bear Gulch					
4	250	24	240	75	1.7	.6	13	336	.11	--

[1]Field blank obtained at this site.
[2]Determined by Montana Bureau of Mines and Geology, Analytical Division Laboratory.

Table 16.--Trace-element concentrations in streamflow in the study area

[Analyses by Montana Bureau of Mines and Geology. Abbreviation: µg/L, micrograms per liter. Symbols: <, less than minimum reporting level; --, not applicable. All trace-element concentrations are reported as dissolved]

Site number	Local number	Date sampled	Aluminum (µg/L as Al)	Boron (µg/L as B)	Cadmium (µg/L as Cd)	Chromium (µg/L as Cr)	Copper (µg/L as Cu)	Iron (µg/L as Fe)	Lithium (µg/L as Li)	Manganese (µg/L as Mn)
					Miners Coulee					
MC-4	37N02E24DDD 01	06-20-89	<30	120	<2	<2	<2	80	30	860
					Breed Creek					
BC-13	37N03F12CACC01[1]	06-21-89	<30	24	<2	<2	<2	40	20	90
		06-21-89	<30	24	<2	<2	<2	40	10	90
		06-21-89	<30	<20	<2	<2	<2	<2	<2	<2
					Bear Gulch					
BG-9	37N04E10CCA 01	06-20-89	<30	<20	<2	<2	<2	10	20	22

Molybdenum (µg/L as Mo)	Nickel (µg/L as Ni)	Silver (µg/L as Ag)	Strontium (µg/L as Sr)	Titanium (µg/L as Ti)	Vanadium (µg/L as V)	Zinc (µg/L as Zn)	Remarks
				Miners Coulee			
<20	<10	<2	770	12	<1	<3	--
				Breed Creek			
<20	<10	<2	500	11	<1	<3	--
<20	<10	<2	500	8	<1	<3	Replicate
<20	<10	<2	<1	3	<1	<3	Field blank
				Bear Gulch			
<20	<10	<2	560	9	<1	<3	--

[1]Field blank obtained at this site.

*U.S. GOVERNMENT PRINTING OFFICE:1993-774-207/60061