VOLUME I

# OCCURRENCE AND CHARACTERISTICS OF GROUND WATER IN THE GREAT PLAINS REGION, MONTANA

by

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Report to

U. S. ENVIRONMENTAL PROTECTION AGENCY
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Project Officer
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# PREFACE

This report, "Aquifer Characterization of Montana", is a two-volume study; Volume I has been compiled for the Great Plains physiographic province and Volume II for the Rocky Mountains physiographic province of Montana. The division into two volumes was necessary in order to facilitate descriptions of the various aquifers that occur in these two distinct topographic and structural provinces. This report contains descriptions of thickness, potentiometric surface, structural configuration and water-quality data for the major aquifers within each province.

These two volumes contain a compilation of existing hydrogeologic information for the State. Because state-wide hydrogeologic investigations have only recently begun in Montana, there are many data gaps especially for the deeper aquifers, and consequently some information is still conjectural. Demands on Montana's ground water are expanding because of increasing energy development and agricultural requirements (especially irrigation). For new developments, ground water is the only alternative left, as most of Montana's surface waters are already over-appropriated.

Montana is currently quantifying its water use and consumption through a water-right adjudication program. This program is being implemented by the Department of Natural Resources and Conservation through Senate Bill No. 76. The completion date for the adjudication program is April 30, 1982; therefore, quantitative statistics for Montana's ground-water use will not be available until after this date. The ground-water use section is thus based on estimates of current trends.

This study, "Aquifer Characterization of Montana", was funded by the U. S. Environmental Protection Agency through Contract No. GO-082-908-10, for the Underground Injection Control Program. The U. S. Congress enacted the Safe

Drinking Water Act (Public Law 93-523) for the purpose of protecting underground sources of water from contamination caused by well injection. This act mandated the U. S. Environmental Protection Agency to establish the Underground Injection Control Program for the purpose of preventing underground injections that endanger ground-water resources. The Montana Bureau of Mines and Geology's role in the Underground Injection Control Program is to identify and characterize the aquifers in the State of Montana.

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Legend

TF - Thickness of Formation
AT - Altitude of Formation
DS - Dissolved Solids
PS - Potentiometric Surface
211.11 - Formation Code
E - Eastern Half of Montana's 1:500,000 scale map
W - Western Half of Montana's 1:500,000 scale map

# GENERAL STATEMENT

## A. Purpose and Scope

This report was prepared by the Montana Bureau of Mines and Geology in order for the State of Montana to comply with federal requirements relating to the Underground Injection Control Program. Existing hydrogeologic data were used for the aquifer characterization maps and the descriptive narrative. The aquifer characterization maps depict: (1) the areal and subareal extent; (2) surface configuration; (3) thickness; (4) potentiometric surface; and (5) water chemistry is expressed as dissolved solids for the major aquifers in Montana. The narrative describes the lithology, general hydrogeologic parameters and potential well yields for individual aquifers. The inventory of injection wells was compiled from information obtained from the Montana Oil and Gas Commission. The inventory provides a listing of injection wells with locations, owners, affected aquifers and injection rates. The report also contains a section delineating well use by county. While broad in scope, this report is designed to meet the needs of federal regulatory agencies responsible for writing and implementing regulations for underground injection.

## B. Description of Montana

Montana, the third largest state of the forty-eight contiguous United States, is vast and diverse. It has an area of 147,138 square miles and a population of 786,690 (U.S. Dept. of Commerce, 1980); the average population density is 5.4 people per square mile. Most Montanans live in the major cities that are geographically dispersed throughout the state. These cities are supported by the surrounding rural communities. Although Montana is sparsely populated, it is rich in natural resources and is a prime producer of agricultural staples for the nation. Montana's abundant natural resources include fossil fuels, minerals, timber and water. These resources, however, are either fully appropriated or are being exploited rapidly.

In 1980, Montana's low-sulfur coal reserves were estimated to be in excess of 120 billion tons (U.S. Bureau of Mines, 1980). These coal deposits of the Fort Union Formation are easily accessible through strip-mining procedures and supply a substantial part of needed energy for the nation. Total coal production for 1980 was 29,905,627 tons (Cole and others, 1981), of which 90 percent was exported to other states. Montana also has projected oil reserves of 248 trillion barrels, an undetermined reserve of natural gas and unknown potential for uranium resources (Montana Dept. of Natural Resources and Conservation, 1980).

Montana's mineral resources are of great economic importance to the state. Montana ranks among the top five states in the production of antimony, silver, copper, talc, vermiculite and bentonite (U.S. Dept. of Interior, 1979). In addition to these commodities, Montana has significant deposits of lead, zinc, tungsten, chromium, manganese, nickel, titanium, vanadium, platinum-group metals, molybdenum, arsenic, iron, antimony, thorium and other rare earths. Metallic and non-metallic exploration activity in the state is increasing every year.

Most of western Montana is heavily forested and most of these forests lie within designated state and national forests or parks. Timber harvesting occurs on selected tracts within these forests and on privately-owned land. The volume of timber harvested in Montana from 1976 to present (1982) has decreased because high mortgage rates have substantially reduced the number of new buildings being constructed.

Montana's water, both from ground-water reserves and surface-water flow, is one of the state's most valuable resources because it is vital to agriculture, mining and power production. More than forty-three million acre-feet of water flow from the state each year; 65 percent of it originates in Montana (Montana

Department of Natural Resources and Conservation, 1976). Three major river basins, the Columbia, Upper Missouri and Yellowstone, account for 97 percent of this flow. Statistics concerning the drainage areas of the major river basins are presented in Table I-1 with the major drainage basins displayed in Figure I-1.

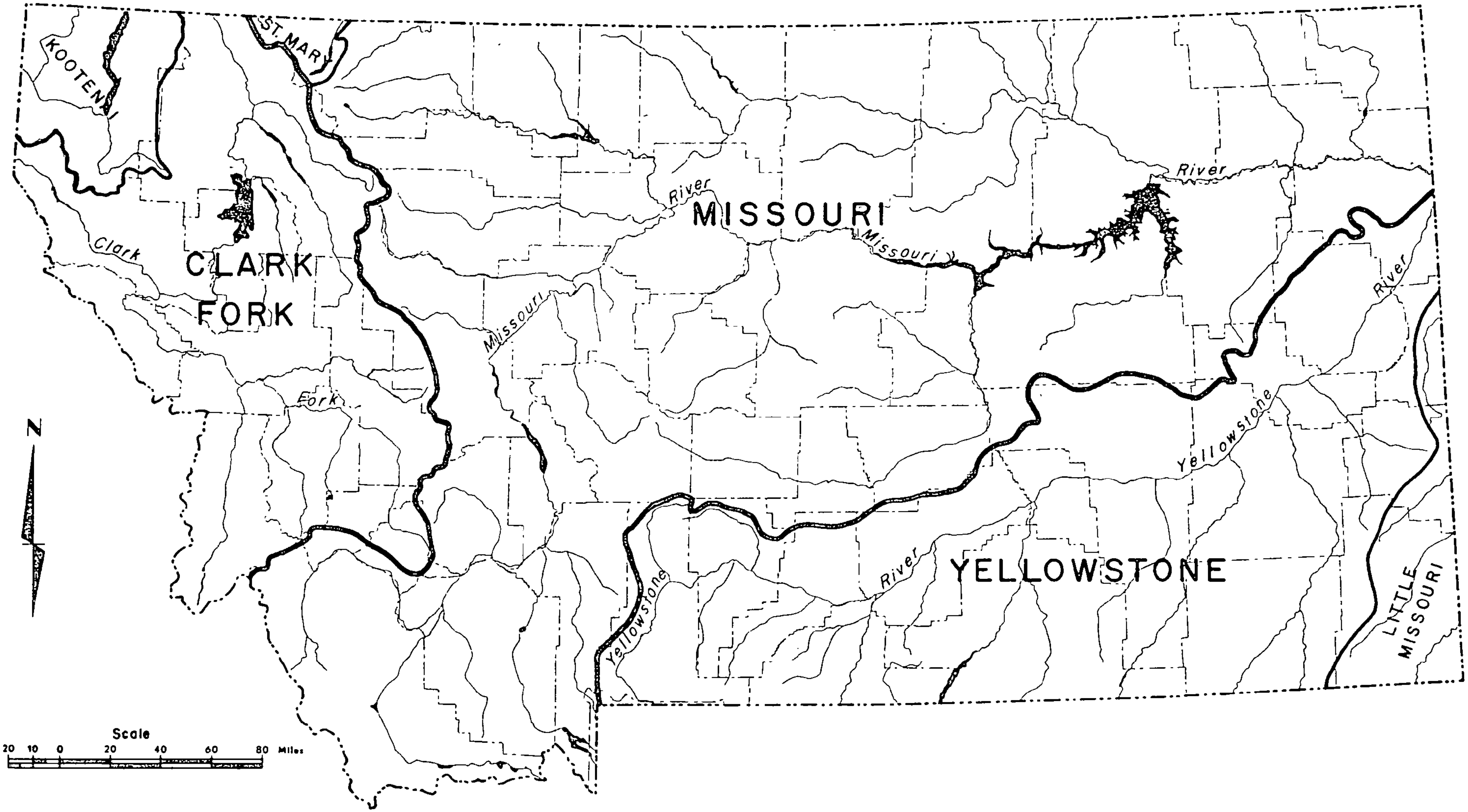
TABLE I-1

DRAINAGE AREA IN MONTANA

| River Basin | Area (sq. mi.) | Percentage of Montana's Area | Percentage of Montana's Water |
|---|---|---|---|
| Columbia | 25,152 | 17% | 59% |
| Upper Missouri | 82,352 | 56% | 17% |
| Yellowstone | 35,890 | 24% | 21% |
| Little Missouri | 3,428 | 2% | 1% |
| St. Mary | 648 | 1% | 2% |
| | 147,470 | 100% | 100% |

Of the fifteen million acres of cropland in production in the state, 12.5 million acres are dryland and the remainder are irrigated. Montana's major water use is the irrigation of these 2.5 million acres of cropland from both surface-water and ground-water diversions. Agricultural demands, hydro-electric generating facilities and instream-flow reservations have already claimed most of the surface water. This surface-water demand has resulted in over-appropriation of these waters, placing additional demands on ground-water resources. Sources of potable ground water in certain areas are now limited.

For the purpose of this report, the state has been divided into the Rocky Mountains region and the Great Plains region. Because geology, climate and aquifer characteristics of the Great Plains region are significantly different from those of the Rocky Mountains region, this natural physiographic division was used to facilitate the aquifer descriptions in this report. The line separating the two divisions is not precisely the same as that used by geographers




MAJOR DRAINAGE BASINS

FIGURE I-1

because it follows the eastern edge of rocks that were severely disturbed by the Laramide Orogeny rather than the actual mountain front except where the two coincide. The following is a compilation of data for each of the major aquifers of the Great Plains region.

C. Previous Investigations and Sources of Information

The collection of data for this report was made possible by the cooperation of the U. S. Geological Survey, especially Richard D. Feltis and William R. Hotchkiss, who furnished essential information on particular aquifer units. Other data were compiled from oil well logs of the Montana Oil and Gas Commission, various Montana Bureau of Mines and Geology and U. S. Geological Survey publications, numerous theses and dissertations and unpublished information generated from water-well logs and records.

Water quality data in this report were obtained from Montana Bureau of Mines and Geology files. Additional analyses were collected from the U. S. Geological Survey.

# I. INTRODUCTION TO THE GREAT PLAINS REGION

The Great Plains region of Montana extends from the eastern base of the Rocky Mountains between $45^{\circ}$ and $49^{\circ}$ north latitude to Montana's eastern border. Nearly two-thirds of the state's 147,138 square miles lie within this region. Along the western edge of the Great Plains is a zone, as much as 25 miles wide, that was tectonically disturbed during the formation of the Rocky Mountains. Although mountains did not develop in this zone, the structure is generally so complex that meaningful structural contour, isopach or potentiometric surface maps could not be produced. For this reason the Disturbed Belt has been included with the Rocky Mountains region in Volume II of this report and the western edge of the Great Plains region thus begins at the eastern edge of the Disturbed Belt for this discussion.

Agricultural trade, based on livestock and grain production, is the main economy of the region. Industry and retail marketing, however, are expanding in importance. Oil well drilling and coal mining operations have grown rapidly since 1974 when the need to develop additional domestic energy resources was recognized. These operations are adding significant strength to the economic base for the region, but are placing additional demands on the ground-water resources of the region.

## A. Physiography

### 1. Topography

The Great Plains region comprises almost two-thirds of Montana (roughly 92,400 square miles) east of the Disturbed Belt. This region is underlain by flat to gently-dipping sedimentary rocks. The rocks that form the surface are generally quite soft and have been eroded into open, rolling plains. Near some of the major rivers and in areas of recent drainage changes, however, the plains have been sharply dissected into badlands and isolated, flat-topped buttes. Near the western edge of the plains, especially in central Montana, igneous intrusions and extrusions have formed minor mountain ranges such as the Sweetgrass Hills, the Bearpaw Mountains, the Little Rocky Mountains, the Big Snowy Mountains, the Bighorn Mountains and the Pryor Mountains. Although many of these folded mountains are high and rugged, they generally are not severely disturbed by faulting as are rocks in the Disturbed Belt. Because useful structural contour, isopach and potentiometric surface maps can be made up to the bases of these mountains, they are included in the Great Plains region. Altitudes within the area designated as the Great Plains region range from 1,864 feet above sea level at the Montana-North Dakota border where the Missouri River flows out of the state to 11,214 feet above sea level at the summit of Crazy Peak in the Crazy Mountains.

2. Surface Drainage

The Upper Missouri River, the Yellowstone River and the Little Missouri River comprise the major drainage systems of Montana's Great Plains region. The Upper Missouri River basin is the largest river basin in the state. It contains approximately 56 percent of the land area, yet it discharges only 17 percent of the water that annually leaves the state. Within the Upper Missouri basin there are 38 reservoirs that have storage capacities of 5,000 acre-feet or more. Fort Peck Reservoir on the main stem of the Missouri River is the largest of these, having a storage capacity of 19,410,000 acre-feet. The net reservoir storage for the basin is greater than 25,000,000 acre-feet.

The Yellowstone River basin in Montana includes 24 percent of the state's area and annually discharges 21 percent of Montana's surface water. Yellowtail Reservoir (1,375,000 acre-feet) is the largest of seven reservoirs that have a storage capacity of 5,000 acre-feet or more.

River basin inflow and outflow figures for drainages in the Great Plains region of Montana are presented in Table I-2. The mean annual runoff of the major streams for this region is represented schematically in Figure I-2.

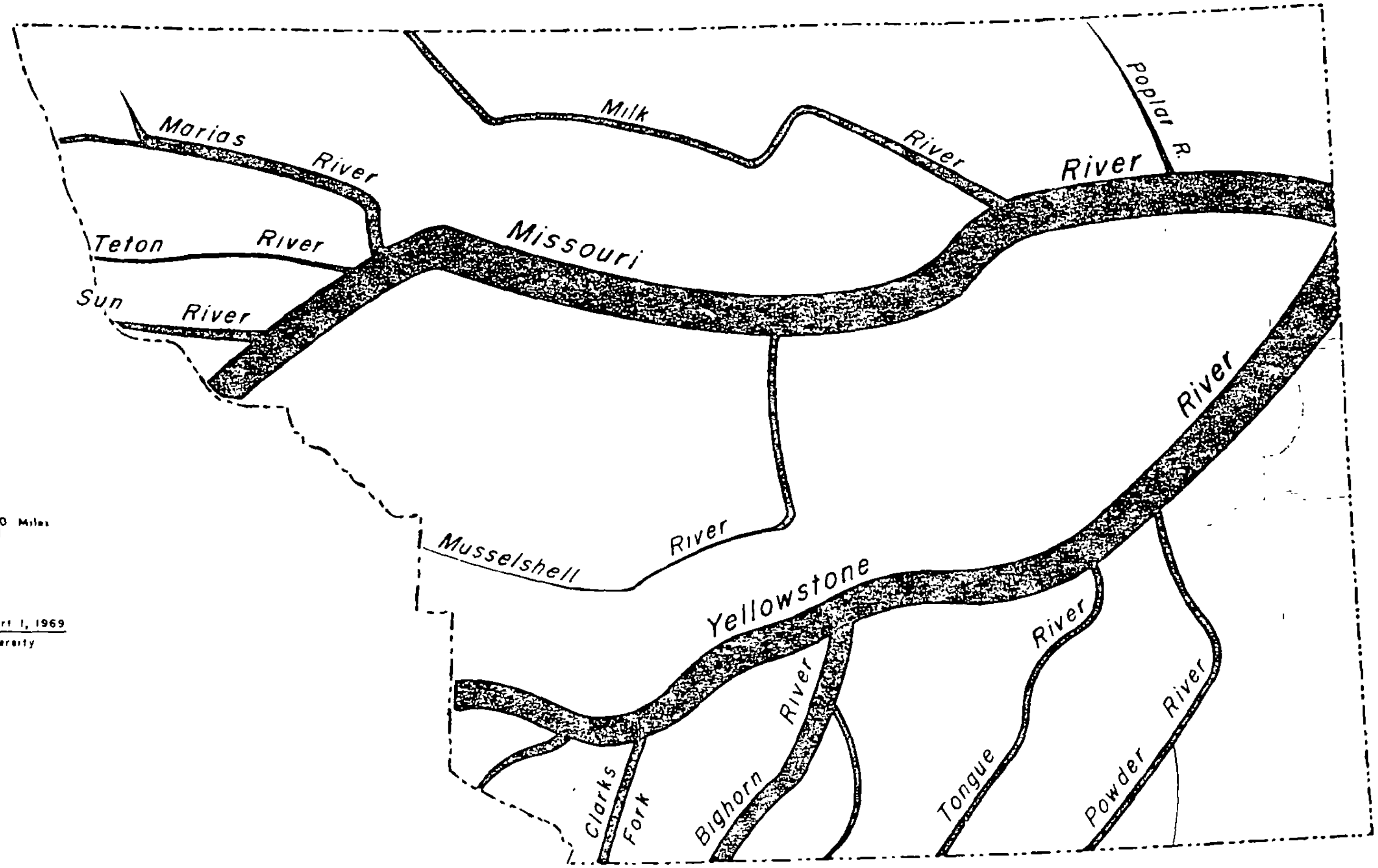
TABLE I-2

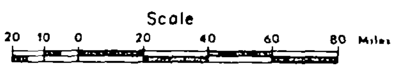
RIVER BASIN INFLOW AND OUTFLOW (IN ACRE-FEET)

| Drainage | Inflow | Originating in the State | Leaving the State | Percentage Originating in the State |
|---|---|---|---|---|
| Upper Missouri | 893,600 | 6,431,400 | 7,325,000 | 88 |
| Yellowstone | 6,227,000 | 3,126,000 | 9,353,000 | 33 |
| Little Missouri | 55,930 | 132,500 | 188,430 | 70 |

3. Climate

Warm-to-hot summers, cold winters and scant precipitation characterize the Great Plains region of Montana. In the Köppen system, the climate of the area is classed as "steppe" (BSk). In the Thornwaite system, the plains are classed as "semiarid, microthermal, precipitation deficiency in all seasons", (DC'd). Because Thornwaite's map is more detailed than most regional climate maps, additional climate zones are shown within the region. The mountains (based on the data available at the time of compilation) are shown as "subhumid, microthermal, precipitation deficiency in all seasons", (CC'd). Had the data been available, an additional class would have been added for the eastern outliers of the Rocky Mountains and classified as "subhumid, microthermal, adequate precipitation in all seasons", (CC'r). Also on the summit of the Crazy Mountains additional classes of "humid, microthermal, precipitation adequate in all seasons", (BC'r) and "taiga", (D') would be shown. In the Bighorn Basin, Thornwaite shows a small area where the climate is "arid, microthermal, precipitation deficiency in all seasons", (EC'd).


SOURCE
U.S.G.S. Water Resources Data For Montana Part 1, 1969
Earth Sciences Department, Montana State University

## MEAN ANNUAL RUNOFF OF MAJOR STREAMS

Width of stream line corresponds to top width of channel. Mean annual discharge, in thousands of cubic feet per second, is represented by channel cross section.

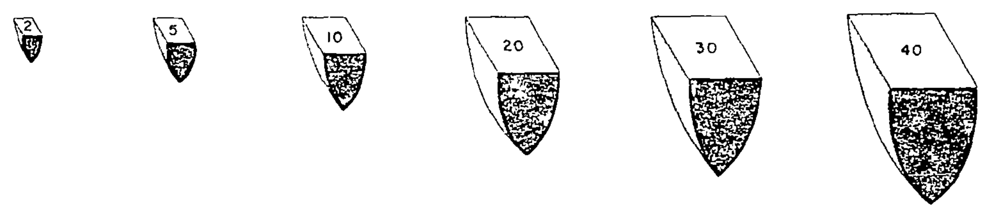



FIGURE 1–2

The warmest average July temperatures occur along the Yellowstone and Powder Rivers where July maximum temperatures exceed $90^{O}F$. The coldest average January temperatures occur in extreme northeastern Montana where average January minimums are approximately $0^{O}F$. The difference in temperature between the average monthly maximum and the average monthly minimum is about $80^{O}F$. Average temperatures moderate toward the western edge of the great Plains. The summers are cooler because of the altitude, and the winters are warmer because of the proximity of Pacific air masses and because of the occurrence of chinook (foehn) winds.

Although precipitation averages about 14 inches per year throughout the plains region, amounts as low as eight inches per year occur in some of the low-lying valleys and in the rainshadows of mountains and amounts as much as 18 inches per year (enough to support the growth of coniferous trees) occur on some of the higher hills and pleateaus. Most of the isolated mountain ranges receive more than 20 inches of precipitation per year, thereby supporting abundant conifers. Precipitation amounts of as much as 40 inches per year occur on the summits of the Big Snowy, Little Belt and Bighorn Mountains and 60 inches per year fall on the summit of the Crazy Mountains. Spring is the main season of ground-water recharge because this is usually the only time when there is a surplus of precipitation, cool weather and little evapotranspiration.

Snowfall is scant over most of the Montana plains; the average is about 40 inches per year. The average annual snowfall increases from east to west. At the eastern border of the state the average is about 30 inches per year, but at the western edge of the plains the average annual snowfall is about 50 inches per year. The summits of the isolated mountain ranges of the plains receive much more snowfall than the lower-lying plains: 100-200 inches per year on the Little Rocky, Judith and Moccasin Mountains, 200-300 inches per year on the

Bearpaw, Highwood and Bighorn Mountains and 300-500 inches per year on the Big Snowy and Little Belt Mountains and Crazy Mountains. The moisture content of a deep snowpack on these mountains helps assure abundant surface water during warm, dry summers.

B. Cultural Geography

1. Population

Most of the Great Plains region is sparsely populated. The 1980 census showed 393,063 persons living in this region. The average population density of the region is 4.25 persons per square mile. Approximately 40 percent of these people reside in five cities of over 7,000 population: Billings, Great Falls, Miles City, Havre and Lewistown. The population distribution is summarized in Table I-3, with the county census subdivisions represented in Figure I-3.

The largest city of the Montana plains region is Billings with a population of 66,798 in 1980. Nearby subdivisions and towns raise the population of the Billings marketing area to nearly double that figure. Billings is a home-base for most of the coal and oil exploration activity in the Powder River and Williston Basins, and is also a hub for livestock processing for south-central and southeastern Montana.

Great Falls, in north-central Montana, closely follows Billings with a population of 56,725 and is supported by surrounding subdivisions doubling its population. Great Falls is primarily a marketing outlet for grain and livestock production. The city also is the site for operations of Malmstrom Air Force Base which contributes to the economy of the area.

Although the population of the Great Plains region of Montana has increased by only 3.7 percent from 1970 to 1980, the population of Richland and Rosebud Counties has increased 24.5 and 64.1 percent, respectively. The population

TABLE I-3

POPULATION OF COUNTIES AND COUNTY SUBDIVISIONS
OF THE GREAT PLAINS REGION, MONTANA

| County/County Subdivision | 1980 | 1970 | % Change |
|---|---|---|---|
| Big Horn County | 11,096 | 10,057 | 10.3 |
| Crow Reservation Division | 5,645 | --- | --- |
| Hardin Division | 4,249 | --- | --- |
| Northern Cheyenne Division | 1,013 | --- | --- |
| Tongue River Division | 189 | --- | --- |
| Blaine County | 6,999 | 6,727 | 4.0 |
| Chinook Division | 3,172 | 3,263 | - 2.8 |
| Fort Belknap Division | 1,854 | 1,312 | 41.3 |
| Harlem Division | 1.973 | --- | --- |
| Carbon County | 8,099 | 7,080 | 14.4 |
| Carbon East Division | 658 | --- | --- |
| Fromberg-Bridger Division | 1,753 | 1,613 | 8.7 |
| Joliet Division | 1,782 | 1,384 | 28.8 |
| Red Lodge Division | 3,082 | --- | --- |
| Roberts Division | 824 | 753 | 9.4 |
| Carter County | 1,799 | 1,956 | - 8.0 |
| Ekalaka Division | 1,100 | 1,135 | - 3.1 |
| Little Missouri Division | 699 | 821 | -14.9 |
| Cascade County | 80,696 | 81,804 | - 1.4 |
| Belt Division | 1,626 | 1,406 | 15.6 |
| Cascade Division | 1,559 | 1,354 | 15.1 |
| Eden-Stockett Division | 862 | 866 | - 0.5 |
| Great Falls Division | 70,600 | --- | --- |
| Great Falls North Division | 2,514 | --- | --- |
| Monarch-Neihart Division | 277 | 260 | 6.5 |
| Choteau County | 6,092 | 6,473 | - 5.9 |
| Big Sandy Division | 9.998 | 2,127 | - 6.1 |
| Fort Benton Division | 2,866 | 3,066 | - 6.5 |
| Geraldine Division | 1,228 | --- | --- |
| Custer County | 13,109 | 12,174 | 7.7 |
| Miles City Division | 11,846 | --- | --- |
| Mizpah-Pumpkin Division | 511 | --- | --- |
| North Custer Division | 383 | --- | --- |
| Shirley-Ismay Division | 369 | --- | --- |

TABLE I-3
(CONTINUED)

| County/County Subdivision | 1980 | 1970 | % Change |
|---|---|---|---|
| Daniels County | 2,835 | 3,083 | - 8.0 |
| Daniels North Division | 2,709 | --- | --- |
| Fort Peck Division | 126 | --- | --- |
| Dawson County | 11,805 | 11,269 | 4.8 |
| Dawson North Division | 1,552 | --- | --- |
| Glendive Division | 10,253 | --- | --- |
| Fallon County | 3,763 | 4,050 | - 7.1 |
| Baker Division | 3,235 | 3,471 | - 6.8 |
| Plevna Division | 528 | 579 | - 8.8 |
| Fergus County | 13,076 | 12,611 | 3.7 |
| Denton Division | 820 | 977 | -16.1 |
| Grass Range Division | 617 | 721 | -14.4 |
| Hanover Division | 765 | 899 | -14.9 |
| Lewistown Division | 10,046 | --- | --- |
| Roy Division | 405 | 437 | - 7.3 |
| Winifred Division | 423 | 492 | -14.0 |
| Garfield County | 1,656 | 1,796 | - 7.8 |
| North Garfield Division | 1,204 | 1,309 | - 8.0 |
| South Garfield Division | 452 | 487 | - 7.2 |
| Glacier County | 10,628 | 10,783 | - 1.4 |
| Cut Bank Division | 4,540 | --- | --- |
| Golden Valley County | 1,026 | 931 | 10.2 |
| Lavina Division | 438 | --- | --- |
| Ryegate Division | 588 | --- | --- |
| Hill County | 17,985 | 17,358 | 3.6 |
| Gildford Division | 910 | --- | --- |
| Havre Division | 13,738 | --- | --- |
| Rocky Boy Division | 1,778 | --- | --- |
| Rudyard Division | 998 | --- | --- |
| Wild Horse Lake Division | 561 | --- | --- |
| Judith Basin County | 2,646 | 2,667 | - 0.8 |
| Geyser Division | 542 | 644 | -15.8 |
| Hobson Division | 920 | 960 | - 4.2 |
| Stanford Division | 1,184 | 1,063 | 11.4 |
| Liberty County | 2,329 | 2,359 | - 1.3 |
| Chester Division | 1,839 | 1,851 | - 0.6 |
| Joplin Division | 490 | 508 | - 3.5 |

TABLE I-3
(CONTINUED)

| County/County Subdivision | 1980 | 1970 | % Change |
|---|---|---|---|
| McCone County | 2,702 | 2,875 | - 6.0 |
| Circle Division | 1,766 | --- | --- |
| North McCone Division | 936 | --- | --- |
| Musselshell County | 4,428 | 3,734 | 18.6 |
| Klein Division | 988 | 411 | 140.4 |
| Melstone Division | 656 | 623 | 5.3 |
| Roundup Division | 2,784 | --- | --- |
| Petroleum County | 655 | 675 | - 3.0 |
| Winnett North Division | 189 | 457 | -58.6 |
| Winnett South Division | 466 | 218 | 113.8 |
| Phillips County | 5,367 | 5,386 | - 0.4 |
| Belknap Division | 206 | --- | --- |
| Malta Division | 4,242 | --- | --- |
| Phillips South Division | 390 | --- | --- |
| Whitewater Division | 529 | --- | --- |
| Pondera County | 6,731 | 6,611 | 1.8 |
| Blackfeet East Division | 148 | --- | --- |
| Conrad Division | 4,522 | --- | --- |
| Valier-Dupuyer Division | 1,588 | 2,080 | -23.7 |
| Powder River County | 2,520 | 2,862 | -11.9 |
| Broadus Division | 1,321 | 1,442 | - 8.4 |
| East Powder River Division | 725 | 928 | -21.9 |
| Otter Division | 474 | --- | --- |
| Prairie County | 1,836 | 1,752 | 4.8 |
| Terry North Division | 270 | 259 | 4.2 |
| Terry South Division | 1,566 | 1,493 | 4.9 |
| Richland County | 12,243 | 9,837 | 24.5 |
| Fairview Division | 2,267 | --- | --- |
| Lambert Division | 753 | --- | --- |
| Savage-Crane Division | 1,341 | --- | --- |
| Sidney Division | 7,882 | --- | --- |
| Roosevelt County | 10,467 | 10,365 | 1.0 |
| East Roosevelt Division | 2,134 | --- | --- |
| Fort Peck Division | 8,333 | --- | --- |
| Rosebud County | 9,899 | 6,032 | 64.1 |
| Ashland Division | 564 | --- | --- |
| Forsyth Division | 3,516 | --- | --- |
| Northern Cheyenne Division | 2,651 | --- | --- |
| Rosebud Division | 3,168 | --- | --- |

TABLE I-3
(CONTINUED)

| County/County Subdivision | 1980 | 1970 | % Change |
|---|---|---|---|
| Sheridan County | 5,414 | 5,779 | - 6.3 |
| Fort Peck Division | 179 | --- | --- |
| Medicine Lake Division | 1,040 | --- | --- |
| Plentywood Division | 3,562 | --- | --- |
| Westby Division | 633 | 721 | -12.2 |
| Stillwater County | 5,598 | 4,632 | 20.9 |
| Columbus Division | 2,387 | --- | --- |
| Park City Division | 1,223 | 822 | 48.8 |
| Stillwater North Division | 581 | --- | --- |
| Sweet Grass County | 3,216 | 2,980 | 7.9 |
| North of Yellowstone Division | 675 | 678 | - 0.4 |
| South of Yellowstone Division | 2,541 | 2,302 | 10.4 |
| Teton County | 6,491 | 6,116 | 6.1 |
| Choteau Division | 3,481 | --- | --- |
| Dutton-Power Division | 1,198 | 1,298 | - 7.7 |
| Fairfield Division | 1,812 | 1,719 | 5.4 |
| Treasure County | 981 | 1,049 | - 8.2 |
| North Treasure Division | 288 | 427 | -32.6 |
| South Treasure Division | 693 | 642 | 7.9 |
| Valley County | 10,250 | 11,471 | -10.6 |
| Fort Peck Reservation Division | 1,283 | --- | --- |
| Glasgow Division | 6,636 | --- | --- |
| Wheatland County | 2,359 | 2,529 | - 6.7 |
| Harlowton Division | 1,821 | --- | --- |
| Judith Gap-Shawmut Division | 538 | --- | --- |
| Wibaux County | 1,476 | 1,465 | 0.8 |
| Pine Hills-St. Phillips Division | 347 | 459 | -24.4 |
| Wibaux Division | 1,129 | 1,006 | 12.2 |
| Yellowstone County | 108,035 | 87,367 | 23.7 |
| Billings Division | 86,493 | --- | --- |
| Buffalo Creek Division | 191 | 156 | 22.4 |
| Huntley Project Division | 2,905 | 2,179 | 33.3 |
| Laurel Division | 10,086 | --- | --- |
| Northwest Yellowstone Division | 1,669 | --- | --- |
| Shepherd Division | 2,550 | 1,226 | 108.0 |
| South Yellowstone Division | 4,141 | 1,320 | 213.7 |
| Yellowstone National Park Division | 275 | 64 | 329.7 |

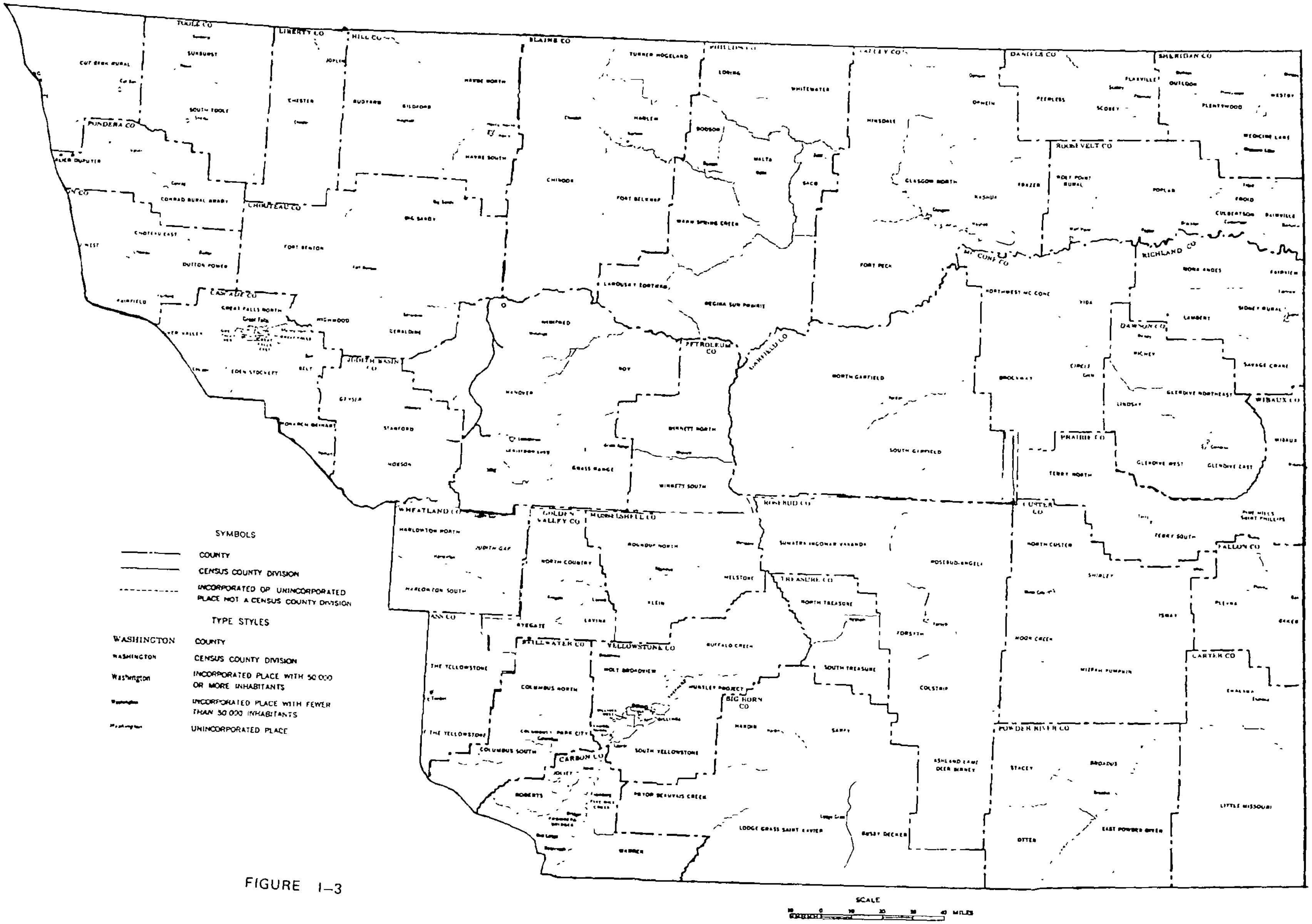



FIGURE 1–3

COUNTY CENSUS SUBDIVISIONS

growth in these counties can be attributed dominantly to oil exploration in Richland County and coal strip-mining in Rosebud County. This rapid growth usually produces a "boom" for the area and increases construction activity.

2. Land Use and Ownership

Roughly 60 percent of Montana's Great Plains region is used as pasture and range for livestock grazing (this includes the open woodland areas used as summer pasture as well as for timber operation). Twenty-five percent of the pasture and less than one percent of the range are irrigated. The Great Plains region has 13,138,066 acres that are classified as cropland, accounting for 22 percent of the land use in the region. According to the 1974 Census of Agriculture, 54 percent of those 13,138,066 acres are classified as harvested and five percent are used as pasture (not included in the above class). Other activities such as mining and petroleum operations, human habitations and recreational areas account for the small remainder of land use.

About 60 percent of the Great Plains region of Montana are privately owned, but state and federal agencies administer large portions of certain counties. The federally administered lands include game ranges, national forests, Indian Reservations and lands that were either never homesteaded or were withdrawn from homesteading at a later time. The state-owned lands include two sections (school sections) out of nearly every township and school sections that were traded out of Indian Reservations, national forests, etc. The state land is administered by the Department of State Lands, whereas federal land dominantly falls under the jurisdiction of either the Bureau of Land Management or the U. S. Forest Service.

## C. Geology

### 1. Stratigraphy

Sedimentary rocks of all geologic ages, from Precambrian to Quaternary, underlie parts of the Great Plains region of Montana. The seas that repeatedly covered Montana in the geologic past were comparatively shallow, but gradual subsidence of the region allowed a great thickness of sediments to accumulate. The thickness of sedimentary rock over Precambrian crystalline basement ranges from 4,000 feet along the Sweetgrass Arch in west-central Montana to 15,000 feet in the Montana portion of the Williston Basin.

The Precambrian sedimentary rocks are predominantly quartzite and argillite, belonging to the Belt Group. The Paleozoic sedimentary rocks are mainly limestone and dolomite, but shale is abundant also. Many of the Paleozoic units, especially the Madison Group, are the targets of oil exploration in the Great Plains region or Big Horn, Powder River and Sweetgrass Arch. The Madison Group is also one of the most productive deep aquifers in eastern Montana. Mesozoic sedimentary rocks are dominantly shale but there are also several sandstone units of great areal extent which are generally good aquifers. The Fort Union Formation and Wasatch Formation are Cenozoic sedimentary units that contain abundant coal. Other important Cenozoic sedimentary formations are the Flaxville gravel, glacial deposits and alluvium. Almost all of the Cenozoic formations are used for water supplies because they are at or near the surface. Glacial deposits sometimes yield as little as two gallons per minute, whereas alluvium may yield more than 1,000 gpm. The various stratigraphic units and their time relationship are shown in Figure I-4.

### 2. Structure

Most of the Great Plains region of Montana is underlain by sedimentary

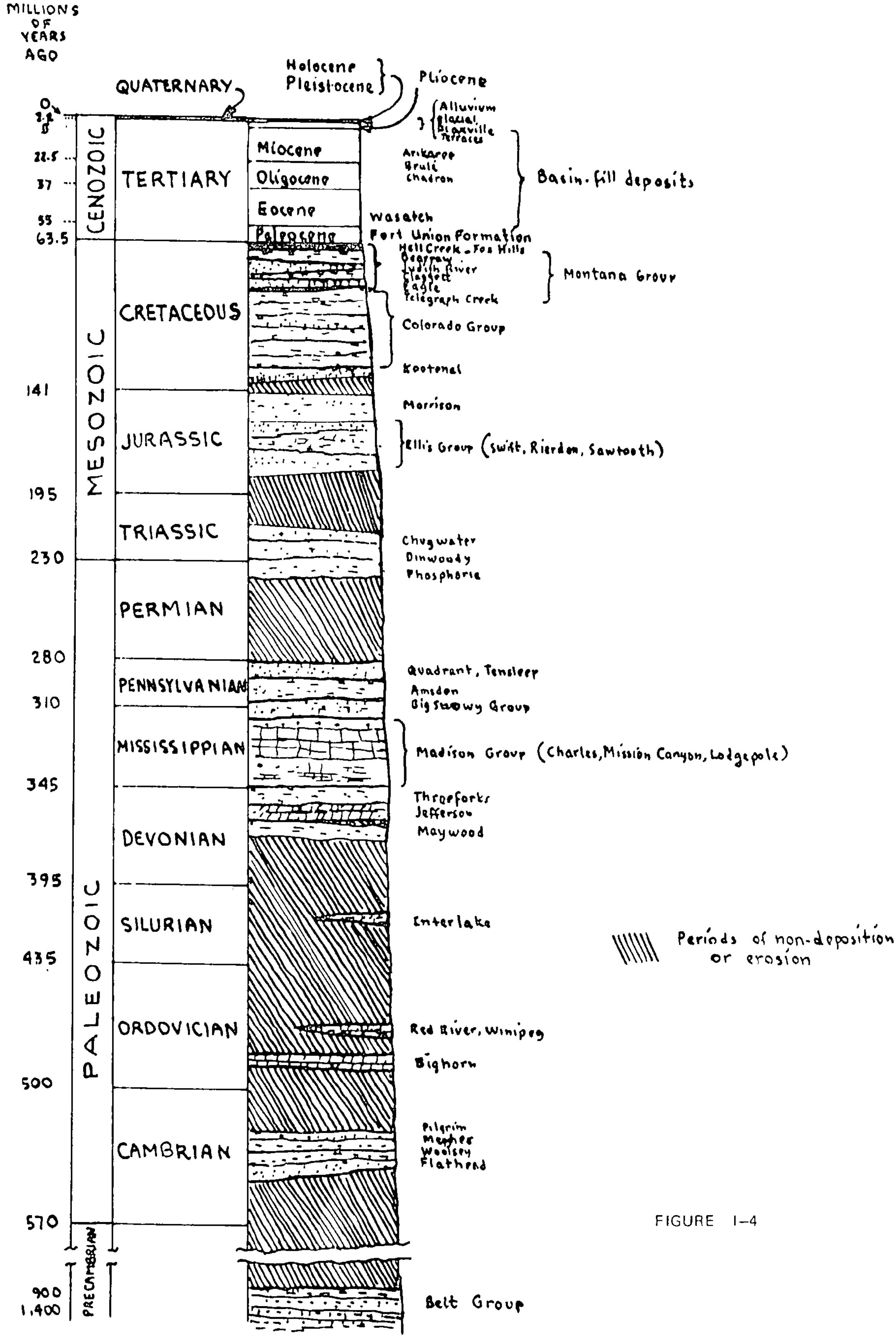
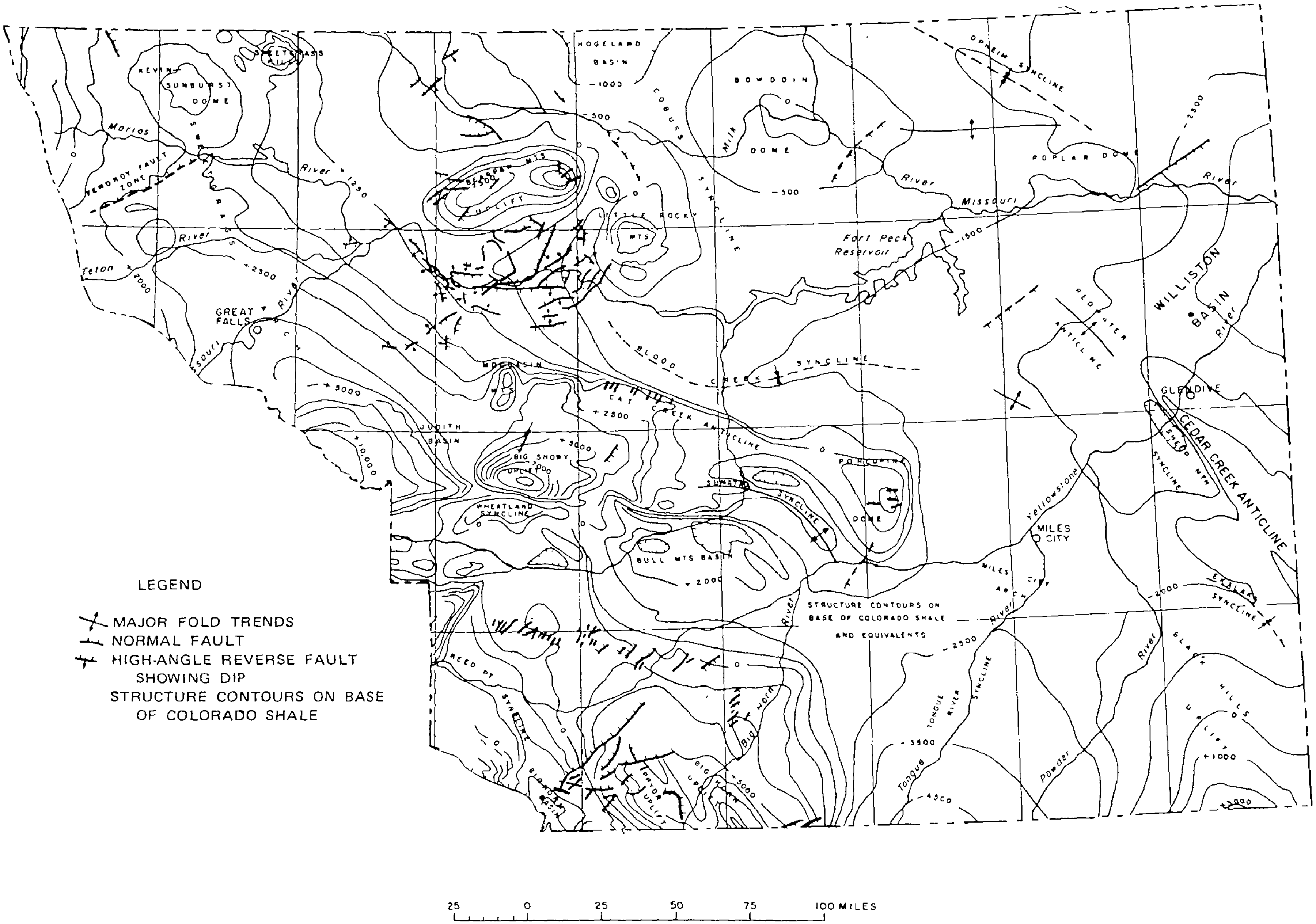

MILLIONS OF YEARS AGO
QUATERNARY
Holocene
Pleistocene
Pliocene
Alluvium
Glacial
Terraces
CENOZOIC
TERTIARY
Miocene
Oligocene
Eocene
Paleocene
Arikaree
Brulé
Chadron
Basin-fill deposits
Wasatch
Fort Union Formation
Hell Creek - Fox Hills
Bearpaw
Judith River
Claggett
Eagle
Telegraph Creek
Montana Group
MESOZOIC
CRETACEOUS
Colorado Group
Kootenai
Morrison
JURASSIC
Ellis Group (Swift, Rierdon, Sawtooth)
TRIASSIC
Chugwater
Dinwoody
Phosphoria
PALEOZOIC
PERMIAN
PENNSYLVANIAN
Quadrant, Tensleep
Amsden
Big Snowy Group
MISSISSIPPIAN
Madison Group (Charles, Mission Canyon, Lodgepole)
DEVONIAN
Threeforks
Jefferson
Maywood
SILURIAN
Interlake
ORDOVICIAN
Red River, Winipeg
Bighorn
CAMBRIAN
Pilgrim
Meagher
Woolsey
Flathead
PRECAMBRIAN
Belt Group
Periods of non-deposition or erosion
0
22.5
37
55
63.5
141
195
230
280
310
345
395
435
500
570
900
1,400

FIGURE I-4

rocks that have eastward dips usually less than $5^{o}$. Reversals of this dip occurs only in open anticlines, synclines and domes. Near the mountains and adjacent to the Porcupine Dome and the western flank of the Cedar Creek Anticline, dips exceed $30^{o}$ for a few miles. The major structural features of the Montana plains are shown in Figure I-5.

The plains region has not undergone appreciable deformation since the end of the Laramide in Eocene times. Small-scale, open folds occur in Oligocene and Miocene formations of southeastern Montana. This deformation may be evidence of small-scale compression or tectonism since these sediments were deposited. Epeirogenic uplift of 1,500 feet has occurred in extreme eastern Montana and 4,000 feet of uplift has occurred near the Rocky Mountains. This uplift is thought to have occurred since mid- or late-Pliocene, and may have been accompanied by regional tectonic deformation.

There have been few recorded seismic events in eastern Montana since the days of organized records in 1805. The absence of seismic events, however, does not necessarily imply tectonic quiescence. A fault-zone extending from Froid, in northeastern Montana, through Brockton, on the Missouri River, to south of Weldon in McCone County (a distance of more than 100 miles) seems to have had displacement of several tens of feet since the Wisconsin glaciation. The recency of this faulting is suggested by the glacial deposits preserved in the central graben of the fault but eroded from its flanks.




# TECTONIC MAP OF THE GREAT PLAINS REGION

FIGURE I–5

## II. HYDROGEOLOGY BY AQUIFERS

### A. Unconsolidated Deposits

Above the Mesozoic and early Tertiary formations are several types of unconsolidated deposits from which ground water may be derived. These unconsolidated aquifers include: alluvium, colluvium, terrace deposits, eolian deposits, glacial deposits, high-level gravels and the deeply weathered surface of some sandstone formations.

Alluvium and terrace deposits are sinuous, river-lain sands, silts, gravels and clays within or adjacent to present-day drainage systems. Alluvium and terrace deposits are generally less than 30 feet thick along most drainages, but may be as much as 200 feet thick along some of the major rivers. Colluvium exists nearly everywhere, but it is rarely thicker than 15 feet except near the base of slopes undergoing active erosion. Eolian deposits are quite thin also (usually less than 10 feet thick) and sometimes are hard to distinguish from colluvium unless good exposures are available. Eolian deposits are commonly found on the lee side of sandy hills and on the top of high river terraces. Extensive areas of eolian deposits occur in glaciated northern Montana, but the material does not resemble typical loess. Glacial deposits are found primarily north of the Missouri River. The deposits left behind by the ice that advanced as much as 50 miles south of the Missouri River have been largely removed by post-glacial erosion. Glacial deposits are usually less than 50 feet thick but thicknesses greater than 100 feet occur in the Havre-Great Falls-Shelby area, in the extreme northeastern corner of Montana and where extensive terminal or recessional moraines developed. High-level gravels are unconsolidated to semi-consolidated, Miocene and younger fluvial deposits. High-level gravels adjacent to the isolated mountains of central Montana and those extending from the Beartooth and Bighorn Mountains may have developed either as a result of recent uplift of these mountains or from climatic change. The high-level gravels 700 to 1,400 feet above the Missouri and Yellowstone Rivers were deposited by river systems ancestral to these two rivers. Differential uplift, glacial diversion and stream piracy have left many of these deposits as much as 75 miles from the present-day rivers. High-level gravels are generally less than 50 feet thick, but may be as much as 100 feet thick.

Although well yields of 1,000 gallons per minute or more have been obtained from high-level gravels, terrace deposits, reworked glacial deposits and some bedrock aquifers, alluvium typically yields more water to a well than any other aquifer. The certainty of obtaining water from alluvium and the shallowness of a well necessary to reach this water make alluvium the most used aquifer in the Great Plains region of Montana. This high usage of alluvium for wells occurs because alluvial valleys contain the best farmland and have the greatest population density.

Terrace deposits within major river valleys adjacent to alluvium generally yield more water than terrace deposits outside the main valley or where isolated from alluvium. This difference in yield is largely a result of less ground-water recharge to the higher or more isolated deposits.

Colluvium and eolain deposits are generally thin and rarely yield more than 10 gpm to a well. These aquifers were used mainly during the "Homestead Days" when dug wells were common. Despite the low yield of water from these deposits, the water was often satisfactory in quantity and quality to provide domestic and stockwater to the homesteader.

Well yields from glacial deposits are highly variable. Where the glacial deposits are mainly heterogeneous silt, clay and sand (till), water is rarely obtained, but where glacial deposits have been reworked by running water (glacio-fluvial deposits, ice-marginal stream deposits, etc.) yields of more than 1,000 gpm have been obtained. Generally, however, a yield of 5 to 10 gpm may be expected from glacial deposits.

The quality of water from unconsolidated deposits is as variable as the nature of the deposits themselves. Water from alluvium normally ranges from 300 mg/L to 2,500 mg/L. The dissolved solids content increases where alluvial deposits are in contact with Cretaceous shale or is influenced by salt migration from irrigated areas.

Water from colluvium or weathered bedrock contains few dissolved solids if the parent material is a sandstone, but contains a large amount of dissolved solids if the parent material is a siltstone or contains much shale.

Water from terrace deposits generally contains more dissolved solids than does water from alluvium. These higher concentrations of dissolved solids probably occur because there is less flushing of the terrace deposits by ground-water movement. Terrace deposits that have been cultivated for many years or overlie shale also seem to contain water with higher concentrations of dissolved solids.

High-level gravels often yield water with a low dissolved solids content. Because areas underlain by these gravels are often quite flat and cultivated, water from these gravels is in demand for irrigation.

Glacial deposits usually contain water with higher than average concentration of dissolved solids. This condition probably results from the admixture of Cretaceous shale into much of the glacial till. Glaciofluvial deposits, on the other hand, often contain water with few dissolved solids.

Few chemical analyses are available for water from eolian aquifers and, considering the size and distribution of these deposits, the water quality is probably variable.

Unconsolidated deposits are widely used as aquifers throughout the Great Plains region of Montana. The first well in the state was probably an alluvium well because the water table in alluvium is usually close to the ground surface and the probability of obtaining water is very good--a strong consideration when a well was made with the pickax and shovel. More water is probably withdrawn from unconsolidated deposits (especially alluvium) than any of the other aquifers. These shallow ground-water systems are highly susceptible to contamination and over-use.

B. Lower Tertiary Formations

Only a few small patches of the Eocene Wasatch Formation are present in Montana, and the Cretaceous-Paleocene Willow Creek Formation of the northwestern Great Plains region has been little studied. For these reasons, the main formation addressed is the Fort Union Formation.

Continuous outcropping and maximum areal extent of the Fort Union Formation occur primarily in the eastern third of Montana. A large area of Fort Union Formation that is separated from the main body lies in the Bighorn Basin-Reedpoint Syncline area of south-central Montana. Small isolated patches, often less than one square mile in extent, occur adjacent to the Bearpaw Mountains in north-central Montana.

Erosion has removed the lower Tertiary deposits from much of Montana east of the Disturbed Belt and has beveled much, if not all, of these formations even where they are preserved. The lower Tertiary formations were not deposited as a uniform, continuous blanket as were most of the previously deposited formations. Tectonic activity of the Laramide Orogeny was already producing major folds in the nearly horizontal strata of the Great Plains region and these lower Tertiary deposits are accordingly thick or thin depending upon the tectonic pattern that was then current in their area of deposition. Over much of the Great Plains of Montana, restored thickness of lower Tertiary deposits indicates an accumulation of less than 1,500 feet. In the Bighorn and Powder River Basins, however, lower Tertiary formations are more than 8,000 feet thick.

The lower Tertiary formations in Montana were deposited entirely by fluvial systems. Channel sandstones are common in the Tullock and Tongue River Members of the Fort Union formation, and overbank siltstones and shales occur. Back-water swamps in which lush, subtropical vegetation grew were plentiful and of long duration in southern Montana--especially during Tongue River time. Thick, extensive coal beds attest to the presence of these swamps. Because lower Tertiary sediments were deposited by fluvial systems, lithologic changes often occur rapidly in short distances.

Ground water from lower Tertiary formations is obtained mainly from the sandstone units and from the coal beds, but some water is obtained from clinker. The water from the lower Tertiary formations is usually a calcium or magnesium bicarbonate type and dissolved solids concentrations range from about 500 mg/L to more than 5,000 mg/L. The water quality and chemistry often reflect the lithologic changes that are the result of fluvial deposition. Yields of water from wells completed in lower Tertiary formations are typically less than 15 gallons per minute, but wells yielding as much as 50 gpm have been reported. The Fort Union Formation is the most widely used aquifer in eastern Montana. This usage is because of the great areal extent of the formation and because water is often available from it within 250 feet of the ground surface.

C. Fox Hills-Hell Creek Formations

These uppermost Cretaceous formations once extended from western Montana into the eastern Dakotas. Although erosion has removed much of the formations, they still are present in eastern Montana. These formations also occur just east of the Disturbed Belt where they are referred to as the Horsethief Sandstone and St. Mary's River Formation. Throughout most of its extent, the Fox Hills Sandstone is usually about 300 feet thick. In parts of east-central Montana, however, it was eroded and often completely removed during Hell Creek time. The Hell Creek Formation ranges in thickness from 500 to 1,100 feet. The Fox Hills Sandstone was the last marine formation to have developed in Montana. It was deposited as forest beds in a wide-spread delta that formed as the Bearpaw Sea withdrew. Sandstone is its most abundant component, but siltstone and shale units are also present. The Hell Creek Formation is the uppermost Cretaceous formation to be deposited in Montana. It is a fluvial deposit that contains lenticular sandstone bodies and overbank silt and clay. Carbonaceous shale lenses provide evidence that swampy conditions existed during the deposition of the Hell Creek Formation. Although the structural configuration of the surface of these formations was formed by the end of the Laramide orogeny, their present altitude was attained only during early Pleistocene as the result of epeirogenic uplift.

In eastern Montana these uppermost Cretaceous formations are sought as a preferred source of water. Wells often penetrate several other water-bearing zones that are close to the surface, but that water is cased off in order to obtain the softer water contained in the Fox Hills and Hell Creek formations. Total dissolved solids in these aquifers typically range from 500 mg/L to 1,100 mg/L. Yields of water from wells completed in these aquifers are also somewhat higher than those from aquifers nearer the surface. In many places, especially in southeastern Montana, wells penetrating Fox Hills-Hell Creek Formations will have static water levels above that of the ground surface. Because many people like to have flowing artesian wells as their water sources, these aquifers are often preferred over shallower aquifers.

D. Judith River Formation

The Judith River Formation is a wedge of sandstone, siltstone and silty shale overlying the Claggett Shale and underlying the Bearpaw Shale; all these units are Cretaceous in age. Near the western margin of the Great Plains, the Judith River Formation grades into the Two Medicine Formation and is more than 700 feet thick. Near the eastern border of Montana the Judith River Formation has thinned to usually less than 50 feet, and is dominantly a silty shale. In much of north-central Montana, the lower part of the Judith River Formation is a fluvial, continental deposit, and includes coal seams as much as five feet thick. In south-central Montana, the lower part of the Judith River Formation is a marine sandstone and is often designated as the Parkman Sandstone or Parkman Member of the Judith River Formation. Although the Judith River Formation thins eastward, east-west zones occur where the formation is considerably thicker than it is either to the north or south. These east-west zones probably mark the location of fluvial distributary channels or major near-shore submarine channels that were later filled with sand transported by longshore currents. The present structural configuration of the Judith River Formation was essentially attained at the close of the Laramide orogeny. At that time, however, the top surface of the formation was generally well below sea level except along the major uplifts. The Judith River Formation was raised to its present altitude during the early Pleistocene as a result of regional epeirogenic uplift.

Well yields from the Judith River Formation range up to approximately 100 gallons per minute. There is usually a good correlation between yield and total sandstone thickness for wells that fully penetrate an aquifer. Unfortunately, most wells completed in the Judith River Formation do not fully penetrate it, but stop when enough water for household or stock use has been obtained. Thus, the yields from this aquifer usually reflect water needs rather than true capacity of the aquifer. High drilling costs and low well yields have combined to prevent development of this aquifer where it is substantially beyond 500 feet below ground surface. Consequently, little is known about its water-yielding capabilities or potentiometric surface of few tens of miles east of its outcrop areas.

Water from the Judith River Formation is under sufficient pressure to cause it to rise in the well considerably above the level at which it enters the well. Flowing wells occur along the Missouri River between Little Rocky Mountans and Larb Creek and along the Musselshell River (and its preglacial course) from about Mosby to Beaver Creek.

The quality of water from the Judith River Formation can range up to 5,000 mg/L dissolved solids. The water with the fewest dissolved solids is found close to recharge areas and the more saline water is found in the eastern part of the state where the formation contains more shale. Ground water that stays in contact with salt-containing formations leaches the salts by solution. In structurally low areas this water rarely moves laterally and the dissolved solids concentration of the water increases greatly. Wide ranges in water quality occur even near the outcrops. These quality variations may reflect lithologic differences.

E. Eagle Formation

The Eagle Formation is one of the main aquifers in the northwestern part of the Great Plains region of Montana. It is also commonly used in southern Montana west of $108^{\circ}$ west longitude. The areas in which this aquifer is highly used correspond to the area of its outcrop and where the formation is less than 300 feet below the ground surface. The Eagle Formation is rarely more than 400 feet thick; its thickest section is near the western limit of the Great Plains region where the formation is predominantly sandstone. Siltstone and shale become dominant in the Eagle Formation with distance eastward from the disturbed Belt. East of $107^{\circ}$ west longitude, the Eagle Formation contains so much shale that it is often called the Gammon Formation or Gammon Shale and includes the equally shaley Telegraph Creek Formation. The Gammon Shale is exposed in the Black Hills uplift of southeastern Montana, but contains so much shale that only about five wells are known to obtain water from it. The yields from these wells average less than 3 gpm and the water can be used only for stock watering. The Eagle Formation receives little use as an aquifer in northeastern Montana because of its great depth below surface and scant yield of water. In northwestern Montana and near the Bowdoin Dome, water from the Eagle Formation may contain natural gas. Cattle will drink this water after some of the gas has escaped, but humans who try to use this water complain of a sulfur taste.

In the areas where the Eagle Formation is highly used as a source of water, the quality of its water is generally good. Dissolved solids content of the water is usually less than 1,500 mg/L and often less than 1,000 mg/L. Yields of 500 gpm have been reported from the Cut Bank area, but yields generally average less than 50 gpm.

F. Kootenai Formation

In latest Jurassic time, mountain uplift began in extreme western Montana and eastern Idaho with the primary intrusion of the Idaho Batholith. The intensive mountain building of the Laramide Orogeny was millions of years in the future, but the steepened gradients formed by these newly emergent hills produced streams that flowed eastward across swampy deposits that were to become the Morrison Formation. At first the streams cut into the eroded Morrison deposits but, as uplift ceased or was reduced in the west, the streams began to deposit sand along their channels. In time, the channels coalesced and migrated laterally. Eventually, sand blanketed most of eastern Montana to a depth of as much as 100 feet. This sand now forms the basal unit of the Kootenai Formation and is referred to as: the Sunburst Sandstone, Cutbank Sandstone, the Third Cat Creek Sandstone, the Pryor Conglomerate or the Lakota Sandstone. Following the deposition of this basal unit, crustal subsidence of the continental interior allowed the Cretaceous sea to enter eastern Montana. In this sea, the upper part of the Kootenai Formation was deposited. It consists of maroon or red and green shale with local bodies of sandstone. Locally, fresh-water limestone was deposited.

The basal sandstone unit of the Kootenai Formation is the main aquifer but, in many places the upper sandstone units and the limestone unit produce enough water for stock or domestic use. Throughout most of the central and western Montana plains, where the Kootenai Formation is within 500 feet of the surface, the Kootenai Formation is sought for its ground water. Although yields as low as ten gallons per minute are sometimes obtained from the upper part of this formation, yields of 300 gpm have been obtained from the basal sandstone. In many places a well tapping the basal sandstone will produce flowing water.

Chemical analyses of water from the Kootenai Formation show dissolved solids ranging from less than 500 mg/L near outcrop areas in the Little Belt Mountains to more than 14,000 mg/L in the Sweetgrass Arch near Cutbank.

G. Swift Formation

The only Jurassic formation known to have sufficient water-bearing potential to be considered an aquifer is the Swift Formation. This formation is present throughout the Great Plains region of Montana except in the central areas of the plains mountains from where it has been eroded. The Swift Formation generally thickens from west to east. It is about 100 feet thick along the east edge of the Disturbed Belt and 400 to 600 feet thick along Montana's eastern border. This greater thickness is caused by shale units which are more abundant in the east than in the west. Throughout most of central and western Montana the Swift Formation contains a total sandstone thickness of 40 to 150 feet. In eastern Montana, however, the total sandstone thickness is commonly less than 50 feet and in many places is less than 25 feet.

Because the Swift Formation is at a considerable depth below land surface, few wells have been drilled into it solely to obtain water, thus, most information on its water-bearing characteristics comes from oil wells. This information indicates that where total sandstone thickness is more than 100 feet (western and central Great Plains region), wells will generally yield 50 gallons of water per minute. In eastern Montana, where the Swift Formation is much deeper below land surface and where the total thickness of sandstone is less, data are insufficient to evaluate its aquifer characteristics.

Almost all chemical analyses of water from the Swift Formation are from western and north-central Montana. These analyses show that water from the Swift Formation commonly contains less than 500 mg/L dissolved solids within ten miles of the outcrop, but dissolved solids increase rapidly with increasing distance from the outcrop. Water with a dissolved solids content of more than 4,000 mg/L is found in many places along the axis of the Sweetgrass Arch.

II. Madison Group

The Madison Group aquifer extends across the entire Great Plains region. It is absent only in a few small areas at the center of mountain uplifts where it has been removed by emplacement of igneous rocks or by erosion. The Madison Group is dominantly limestone, but its uppermost unit, the Charles Formation, becomes increasingly an anhydrite with proximity to the center of the Williston Basin. In some places the limestone has been largely dolomitized. Throughout most of eastern Montana, the Madison Group is more than 600 feet thick. A maximum thickness of more than 1,000 feet occurs along a trough that extends from the Big Snowy Mountains to the center of the Williston Basin. Because of its great potential as an aquifer, the Madison Group has been the object of an extensive drilling and investigation program throughout the northern Great Plains. Data are currently becoming available to make a reasonably detailed evaluation of this aquifer.

The test wells drilled through the Madison Group showed a great degree of variability in yield of water from this aquifer. The yield was highly dependent on fracture porosity, initial porosity and degree of dolomitization. Well yields ranged from 20 gpm to more than 1,000 gpm. Data from oil well drill-stem tests are currently being compiled to determine the spatial variation in water yield. Because the Madison Group is recharged with ground water in the central areas of mountain uplifts, water in this aquifer is commonly under enough pressure to flow at the surface from any well that penetrates the aquifer. In some places the pressure is great enough to produce a static water level several hundred feet above the land surface.

The quality of water in the Madison Group is highly dependent on the composition of the Madison Group and the distance the water has traveled from area of recharge or, more specifically, the amount of time it has spent within the aquifer. Adjacent to the mountains, where the aquifer is recharged and where the Madison Group is dominantly limestone, dissolved solids content of the water within the Madison Group is commonly less than 500 mg/L. Dissolved solids content of the water increases within a few miles of the 500 mg/L isoline to more than 1,000 mg/L and then increases more slowly. Near the periphery of the Williston Basin, where the Charles Formation is largely an anhydrite, dissolved solids again rapidly increase from 4,000-5,000 mg/L to more than 15,000 mg/L within about ten miles. The dissolved solids content of water from the Madison Group near the center of the Williston Basin is greater than 300,000 mg/L or about ten times that of seawater.

Water-bearing formations occur below the base of the Madison Group. Some of these formations have great potential as aquifers. The well depth required to obtain water from these formations exceeds 6,000 feet throughout most of eastern Montana. Well depths of 16,000 feet are necessary to reach the base of these formations in the Williston Basin. Because of these extreme drilling depths and the sparse data on aquifer characteristics, these pre-Madison Group formations are not included as aquifers in this report.

## III. GROUND-WATER USE

Information on water use in Montana prior to 1980 is extremely limited because of a lack of accurate withdrawal rate data. While communities have the best opportunity to record water use, in most instances only new delivery systems are equipped to measure discharge. Similarly, rural, agricultural and industrial water users often have no means of measurement and only estimates can be made for these values. However, Montana is presently quantifying its water use and consumption through a water-right adjudication program. This program is being implemented through the Department of Natural Resources and Conservation under Senate Bill No. 76. All water-use applications are to be filed by April 30, 1982 and then will be reviewed and summarized. Better estimates of precise ground-water and surface-water use will become available after that date.

Major uses of ground water in the Great Plains region are for irrigation, municipalities, industry, rural domestic use, and livestock. Table I-4 is a summary by county of the various well uses in this region. Most of these wells are completed in the Quaternary alluvium or Tertiary and Cretaceous aquifers, although deeper aquifers are exploited locally. The cumulative total of ground water withdrawn from the Great Plains region is approximately 114.41 million gallons per day (mgd) or 56.68 acre-feet per day. This value for ground water represents about two percent of the total amount of water diverted within the Great Plains region, a value much lower than for most other Western states. Even though two percent is a small percentage, ground water is the only viable source of potable water that can and will be further developed now that surface-water supplies are over-appropriated in this region.

# TABLE I – 4

## WELL USE BY COUNTY IN THE GREAT PLAINS REGION

| COUNTY | COM | DOM | D+S | IRR | IND | PUB | STK | MU | OTH | NOT RPT | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bighorn | 3 | 199 | 180 | 7 | 18 | 10 | 377 | 39 | 41 | 13 | 887 |
| Blaine | 1 | 109 | 233 | 23 | 6 | 8 | 374 | 14 | 10 | 8 | 786 |
| Carbon | 1 | 611 | 269 | 13 | 2 | 13 | 202 | 55 | 63 | 8 | 1237 |
| Carter | 0 | 65 | 120 | 0 | 0 | 2 | 648 | 13 | 6 | 0 | 854 |
| Cascade | 22 | 904 | 417 | 14 | 5 | 11 | 233 | 62 | 53 | 1 | 1722 |
| Choteau | 0 | 96 | 395 | 6 | 0 | 28 | 338 | 82 | 34 | 5 | 984 |
| Custer | 12 | 225 | 218 | 19 | 3 | 9 | 685 | 92 | 22 | 8 | 1293 |
| Daniels | 1 | 135 | 126 | 2 | 2 | 6 | 191 | 74 | 11 | 6 | 554 |
| Dawson | 13 | 362 | 338 | 17 | 17 | 14 | 693 | 89 | 30 | 4 | 1577 |
| Fallon | 0 | 62 | 235 | 3 | 8 | 7 | 568 | 28 | 8 | 6 | 925 |
| Fergus | 1 | 301 | 424 | 10 | 13 | 7 | 449 | 110 | 52 | 3 | 1370 |
| Garfield | 0 | 65 | 153 | 4 | 2 | 2 | 685 | 25 | 15 | 0 | 951 |
| Golden Valley | 0 | 50 | 115 | 3 | 0 | 0 | 276 | 17 | 3 | 0 | 464 |
| Hill | 0 | 345 | 319 | 12 | 9 | 21 | 226 | 70 | 25 | 4 | 1031 |
| Judith Basin | 2 | 175 | 150 | 15 | 3 | 8 | 308 | 60 | 15 | 1 | 737 |
| Liberty | 0 | 66 | 102 | 2 | 0 | 3 | 116 | 33 | 7 | 1 | 330 |
| McCone | 2 | 133 | 167 | 10 | 0 | 7 | 486 | 25 | 12 | 9 | 851 |
| Musselshell | 0 | 235 | 311 | 6 | 2 | 9 | 823 | 33 | 14 | 21 | 1454 |
| Petroleum | 1 | 15 | 56 | 4 | 47 | 1 | 189 | 22 | 7 | 1 | 343 |
| Phillips | 2 | 162 | 435 | 20 | 8 | 7 | 476 | 29 | 21 | 4 | 1164 |
| Pondera | 0 | 36 | 148 | 2 | 0 | 13 | 83 | 21 | 6 | 1 | 310 |
| Powder River | 1 | 226 | 216 | 28 | 3 | 9 | 1577 | 11 | 15 | 1 | 2087 |
| Prairie | 4 | 109 | 102 | 10 | 9 | 5 | 580 | 14 | 10 | 1 | 844 |
| Richland | 1 | 354 | 281 | 17 | 23 | 20 | 817 | 48 | 17 | 8 | 1586 |
| Roosevelt | 1 | 193 | 212 | 41 | 13 | 10 | 331 | 48 | 10 | 9 | 868 |
| Rosebud | 0 | 164 | 152 | 9 | 17 | 21 | 663 | 21 | 32 | 9 | 1088 |
| Sheridan | 0 | 112 | 224 | 5 | 6 | 12 | 185 | 26 | 19 | 4 | 593 |
| Stillwater | 3 | 453 | 215 | 7 | 5 | 6 | 394 | 40 | 30 | 1 | 1154 |
| Sweetgrass | 0 | 185 | 156 | 5 | 2 | 2 | 175 | 22 | 11 | 1 | 559 |
| Teton | 5 | 368 | 390 | 43 | 2 | 10 | 257 | 79 | 14 | 4 | 1172 |
| Toole | 0 | 23 | 88 | 4 | 1 | 11 | 123 | 47 | 14 | 2 | 313 |
| Treasure | 0 | 27 | 44 | 2 | 0 | 2 | 221 | 9 | 0 | 1 | 306 |
| Valley | 0 | 273 | 435 | 21 | 6 | 24 | 553 | 99 | 29 | 21 | 1461 |
| Wheatland | 1 | 64 | 57 | 8 | 2 | 2 | 288 | 26 | 10 | 0 | 458 |
| Wibaux | 0 | 51 | 188 | 5 | 2 | 7 | 405 | 23 | 12 | 1 | 694 |
| Yellowstone | 4 | 1711 | 544 | 152 | 17 | 18 | 737 | 219 | 54 | 8 | 3464 |
| Total | 81 | 8664 | 8215 | 549 | 253 | 345 | 15732 | 1725 | 732 | 175 | 36471 |

COM- Community; DOM-Domestic, D+S-Domestic and Stockwater; IRR-Irrigation; IND-Industrial; PUB-Public, STK-Stockwater only, MU-Multiuse; OTH-Other, NOT RPT- Not Reported.

A. Municipal and Domestic

A computer listing produced by the Montana Department of Health and Environmental Sciences (1980) shows that there are 89 communities in the Great Plains region of Montana that have a municipal water-supply system. The total number of public supply systems exceeds 250, if including trailer courts, nursing homes and other institutions. Of the 89 communities, 13 rely exclusively on surface water, another 8 use both surface and ground water and the remaining 68 communities depend solely on wells or springs for their water supply. Of the 393,063 people who reside within the Great Plains region of Montana, approximately 264,300 live in municipalities. Of these, 91,400 (35%) depend exclusively upon ground water for their drinking and household needs; they withdraw a total of about 19.06 million gallons of ground water per day. Only a small percentage of this total is used to satisfy industrial or commercial needs.

Although several different aquifers are used throughout the Montana plains for municipal water, no study or examination has been made to determine which aquifers are used. A cursory examination of the relationship of towns in the plains to geology indicates that, perhaps, as many as 90% of these water supplies derive their water from alluvium or other unconsolidated deposits. At least two towns (Broadus and Ekalaka) obtain water from either the Foxhills or Hell Creek Formations, several may obtain water from the Eagle and Kootenai Formations and Lewistown obtains its water supply from a spring that emerges from a limestone formation of the Madison Group.

The quality of water used by many of the communities in the Montana plains region often exceeds the EPA's maximum recommended limits for dissolved solids. Several systems distribute water that contains more than 1500 mg/L and the well supplying the town of Jordan has dissolved solids of about 1800 mg/L. Although these values greatly exceed the 500 mg/L recommended maximum, most communities have no other source.

Iron is a problem for many community water systems. Most systems distribute water that contains less than the recommended maximum of 0.3 mg/L for iron, but others greatly exceed it. Four community systems that distribute water exceeding 4.0 mg/L in 1980 were North Harlem Colony, Wibaux, Wolf Point and Wyola. Nitrates in water are a problem in some farming communities both from application of fertilizers and from degradation of water supplies caused by saline seeps. The following community systems in 1980 delivered water with exceptionally high nitrate values: North Turner Colony (35 mg/L), Flaxville (28 mg/L), Conrad (21 mg/L), Coffee Creek (14 mg/L) and Denton (13 mg/L). In addition, the water from several trailer courts was analyzed to contain more than 7 mg/L. These latter high nitrate values may result from septic system effluent or related pollution. Fluoride values are generally well below the EPA recommended maximum. Community systems that distributed water high in fluorides in 1980 were: Sidney (5.1 mg/L), Circle (4.7 mg/L), Richey (4.2 mg/L) and Lambert (4.0 mg/L). Several trailer courts also distributed water in 1980 that exceeded 2.0 mg/L. Trace metals in water from public supply systems were all usually within the recommended maximum. One exception was Wyola with 0.805 mg/L of lead.

Domestic water is that which is used by all persons not served by a municipal or community water system. For the most part, domestic wells primarily belong to rural residents, although some subdivisions have individual wells. There are approximately 17,000 domestic and stockwater wells in the Great Plains region. Ground water from these wells provides 95% of the rural population with a potable supply. Rural inhabitants withdraw

25.85 million gallons per day, most of which is consumed.

Domestic wells are commonly drilled until sufficient amounts of relatively good quality water are reached, and for this reason, well yields are generally small. For most rural inhabitants of the Great Plains region, ground water is essential for their well being and livelihood.

B. Agriculture

Agriculture is the largest ground-water user in the Great Plains region. The principal use of ground water is for cropland irrigation with a secondary use for livestock consumption.

1. Irrigation

There are about 1,347,740 acres of irrigated land in the Great Plains region. However, the percentage of this acreage that is irrigated in any given year is uncertain. Roughly 5.62 billion gallons per day (bgd) are applied to this acreage of which 1% is withdrawn from ground-water sources. Almost all of these irrigation wells are completed in the unconsolidated alluvial aquifer. The Madison aquifer is also receiving renewed interest as a deeper source of good quality water.

Requirements for diversion are more than double consumptive use, resulting in a return flow of 53% of the total diversion (DNRC, 1975). Consumptive use varies with irrigation efficiency, rates of application and other factors such as the crop, soil, precipitation, growing season and temperature. Nearly all irrigation is used to raise crops and feed to support the livestock industry.

2. Livestock

Stock consumptive use of ground water in the Great Plains is estimated to be 19.71 million gallons per day of which 50% is withdrawn from ground-water sources. Cattle and sheep account for the majority of the water being consumed, with average daily consumption values of 15 and 3 gallons per head per day, respectively. Pigs, horses and other livestock make up the remainder of stock water consumed.

Stock water wells comprise the largest single category of permitted wells in this region; roughly 43 percent of the wells in the Great Plains region are used solely for stock watering purposes. These wells tap all the aquifers within the region and are usually completed when a sufficient yield is obtained. In many cases these wells are the only viable source of water in the area for livestock ranchers.

C. Industry

Ground-water withdrawals by industry are separated into two distinct constituents: (1) the petroleum industry which uses the largest quantity; and (2) self-supplied industry which withdraws only a minor amount.

Ground-water withdrawals by the petroleum industry fall into two major categories--fresh water, which is developed solely for use in the secondary recovery of crude oil; and produced water, which is withdrawn as a byproduct of primary and secondary oil recovery. Estimates of the total petroleum ground water withdrawn are highly variable and for this reason an accurate value could not be predicted. However, records show that there are 659 injection wells reinjecting water for secondary recovery in the Great Plains region. According to Montana's Oil and Gas Conservation Division (1980), these wells have an average daily injection rate of 15.06 million gallons per day.

Major aquifers used to produce water for secondary oil recovery include the Fox Hills, Judith River, Eagle and Kootenai Formations and the Madison

Group. The Madison aquifer has been the principle source of secondary recovery water for most oil fields in this region.

Future projections of oil production within the Big Horn Basin cannot be made reliably. Much oil remains to be produced by secondary and tertiary recovery methods, but economics will play a major role in whether or not this oil is produced. It seems likely that with rising prices oil production in the basin, especially the percentage produced by secondary recovery methods, will continue to grow, as will petroleum industry water consumption.

The Montana Department of Natural Resources and Conservation defines self-supplied industrial water as that which is obtained from a source of supply by industry as opposed to that provided by a municipality. An industry is also considered to be self-supplied if any of the water it uses is obtained from its privately owned water supply facilities. The primary industrial use of water is for condenser cooling, while smaller amounts are used for processing, washing, conveying, air conditioning, boiler feeding and sanitation. Ground water accounts for about 10.5 percent of the total water used by industry in the Great Plains region. Approximately 3.47 million gallons of ground water are used daily as self-supplied industrial water. A large percentage of this water is consumed by industry. Examples of consumptive use are water, canned or bottled in foods or beverages, and water absorbed or chemically combined into a manufactured product.

# IV. WATER QUALITY

## A. DATA SOURCES

More than 3,600 water quality analyses contained in the computer files at the Montana Bureau of Mines and Geology (MBMG) were reviewed for the Underground Injection Control project, with approximately 3,100 of these analyses from the Great Plains region. Additional analyses were located and reviewed from MBMG and U. S. Geological Survey (USGS) publications including: bulletins, memoirs, open-file reports, professional papers, hydrologic atlas maps, and unpublished reports. USGS Open-File Report 76-40 by William Hopkins provided much data relating to deeper aquifers in eastern Montana.

The MBMG water-quality file contains water-quality analyses generated by the MBMG Analytical Division. Primary customers of this Division are the MBMG Hydrology Division, the USGS Water Resources Division and the U. S. Forest Service (USFS). The USGS Water Resources Division and the MBMG Hydrology Division furnish water samples taken from ground-water sources within the state of Montana to the MBMG laboratory for analysis, and the results of these analyses become part of an integrated data bank. Approximately 2,000 ground-water analyses were completed and entered into computer's storage during the USGS's Northern Great Plains project of recent years. Additionally, the computer files contain data extracted from selected USGS and MBMG publications which existed prior to the creation of the data bank. Documents such as USGS Water Supply Papers 599 and 600, covering ground-water resources for Rosebud, Treasure, and Yellowstone Counties, have been coded and included in the file. Many similar publications are yet to be included.

Appendix V. contains a tabulation of those analyses in the ground-water quality system selected for this project. These analyses have been sorted by aquifer and according to township, range, and section within the aquifer. Many of these have been plotted on the Dissolved Solids Map series included with this report. Occasionally, points will appear on the listings that have not been plotted on the maps and, conversely, points will appear on the maps which are not contained in the tabulation. This has occurred because much of the previously published data are not computerized and because the listings may include data created since the compilation of the maps.

B. General Water Quality

Ground-water quality data for eight aquifers or aquifer groups in the Great Plains region were compiled. These aquifers included the:

1. Quaternary and late Tertiary (Flaxville Formation) unconsolidated materials
2. Fort Union and Wasatch Formations
3. Foxhills and Hell Creek Formations
4. Judith River (Parkman) Formation
5. Eagle (Virgelle) Formation
6. Kootenai Formation and equivalents
7. Jurassic Age Formations
8. Madison Group and other formations of Mississippian age

The next sections will discuss the water quality of these eight groups in terms of their dissolved solids (DS) expressed as milligrams per liter (mg/L) and dominant cation and anion.

1. Quaternary and Late Tertiary Unconsolidated Rocks

(Add description of unconsolidated materials when available)

The late Tertiary unconsolidated rocks of the Great Plains regions consist principally of the Flaxville Formation and its equivalents. Only four analyses for waters from these materials are in the data bank.. Dissolved solids for these analyses range from 250 to 900 mg/L. Of these, three analyses reported magnesium as being the dominant cation and all four reported bicarbonate as the dominant anion. The fourth analysis had calcium as the dominant cation. Zimmerman (1960) reports four additional analyses from northern Blaine County, Montana. These analyses ranged in dissolved solids from 300 to 1,430 mg/L. Two of these waters were sodium bicarbonate while the others were sodium sulfate and magnesium bicarbonate waters.

The Flaxville Formation gravels underlie approximately 37 townships in northeastern and eastern Montana. The formation generally occurs in isolated patches except on the Big Flat north of Harlem and in the Plentywood-Scobey area of northeastern Montana. In these latter areas the Flaxville Formation is an important water source often providing the best quality water available in the area, but elsewhere it finds relatively minor use as an aquifer.

2. Early Tertiary Fort Union and Wasatch Formations

(Add early Tertiary when available)

3. Foxhills and Hell Creek Aquifers

The regional Foxhills and Hell Creek aquifers in eastern Montana are represented by 276 water-quality analyses in the MBMG's water quality files. Ground water from these formations is generally soft and is of good quality ranging in dissolved solids from 107 to 4,400 mg/L. The lowest dissolved solids value reported is from an 80-foot-deep well in Sweetgrass County which is completed in the Hell Creek Formation. The water is used for domestic purposes and is a sodium bicarbonate type. The highest dissolved solids value of 4,421 mg/L was measured in water from a 350 foot deep stock well in Musselshell County and the water is a sodium sulfate type.

Figure I-8 is a histogram of the number of analyses of waters versus dissolved solids for the Foxhills and Hell Creek aquifers. This histogram shows that 223 of the 276 samples (81%) were for waters with less than 2,000 mg/L dissolved solids. There are no reports of waters containing more than 10,000 mg/L of dissolved solids in these aquifers. The frequency of higher dissolved solids in waters tails off rapidly as values for dissolved solids increase. The chart also shows that ground water with less than 1,000 mg/L of dissolved solids from the Foxhills and Hell Creek Formations is more often a sodium bicarbonate type with sodium sulfate becoming predominant as values above 1,000 mg/L occur.

4. Judith River Aquifer

MBMG's data file contains 220 analyses of Judith River Formation waters. Measurements range from a low dissolved solids value of 161 mg/L for water from a 203 foot deep well in Wheatland County, to a high value of 27,500 mg/L for ground water from a 200 foot deep well in Liberty County. The low value represents a calcium bicarbonate type that is used for stock water. The high dissolved solids value is a sodium sulfate type that is unused.

Figure I-9 is a histogram showing the number of analyses and dominant water type plotted against values for dissolved solids. The three most common water types in descending order are: sodium sulfate, sodium bicarbonate and sodium chloride. Other water types reported include: magnesium sulfate (8 occurrences), magnesium bicarbonate (2 occurrences), and calcium bicarbonate (5 occurrences). The histogram shows that analyses with dissolved solids of

FREQUENCY OF OCCURRENCE COMPARED TO DISSOLVED SOLIDS IN WATER FROM THE FOX HILLS AND HELL CREEK AQUIFERS

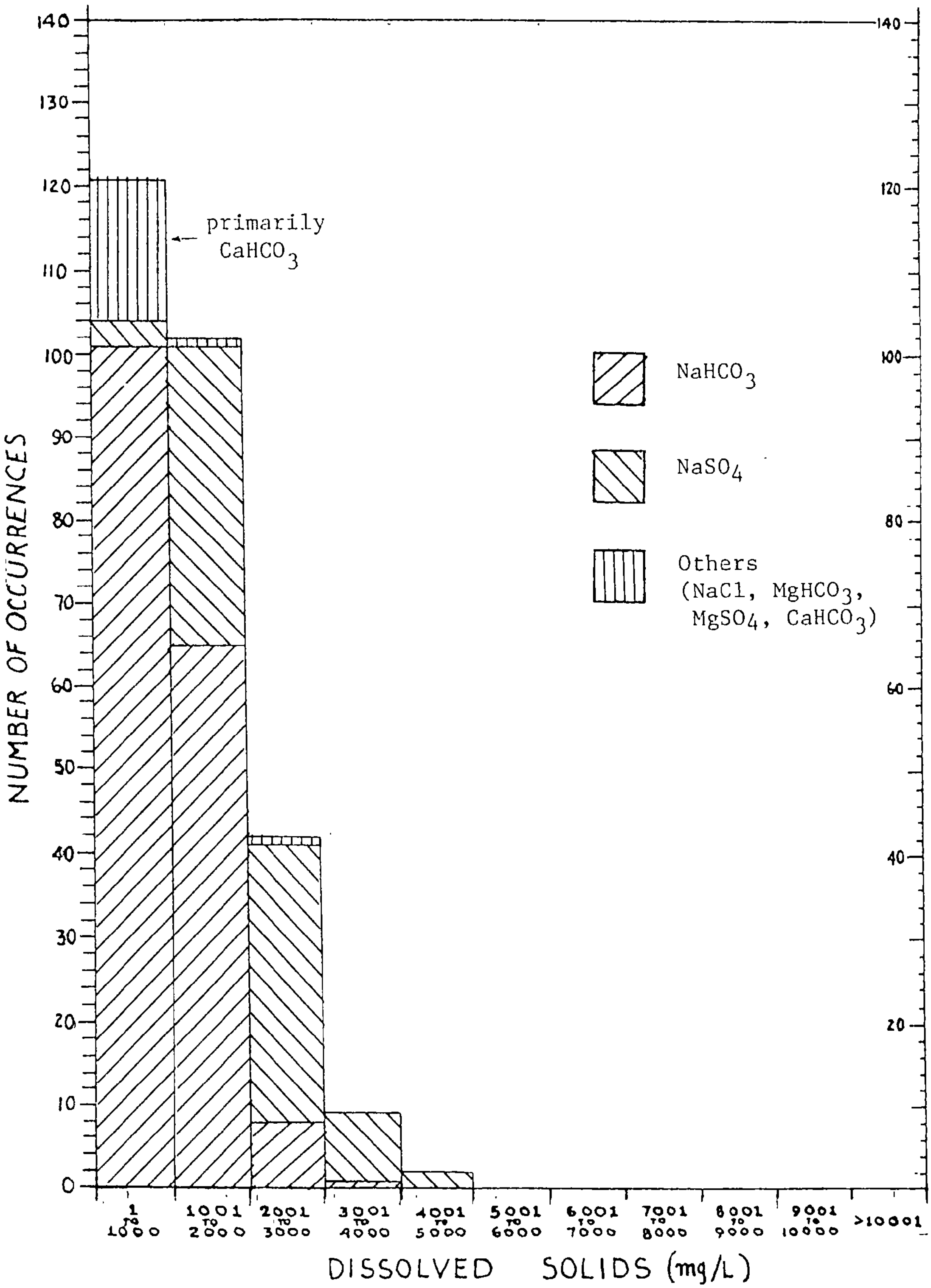



FIGURE I–8

FREQUENCY OF OCCURRENCE COMPARED TO DISSOLVED SOLIDS IN WATER FROM THE

JUDITH RIVER FORMATION

(TWO MEDICINE FORMATION AND PARKMAN SANDSTONE INCLUDED)

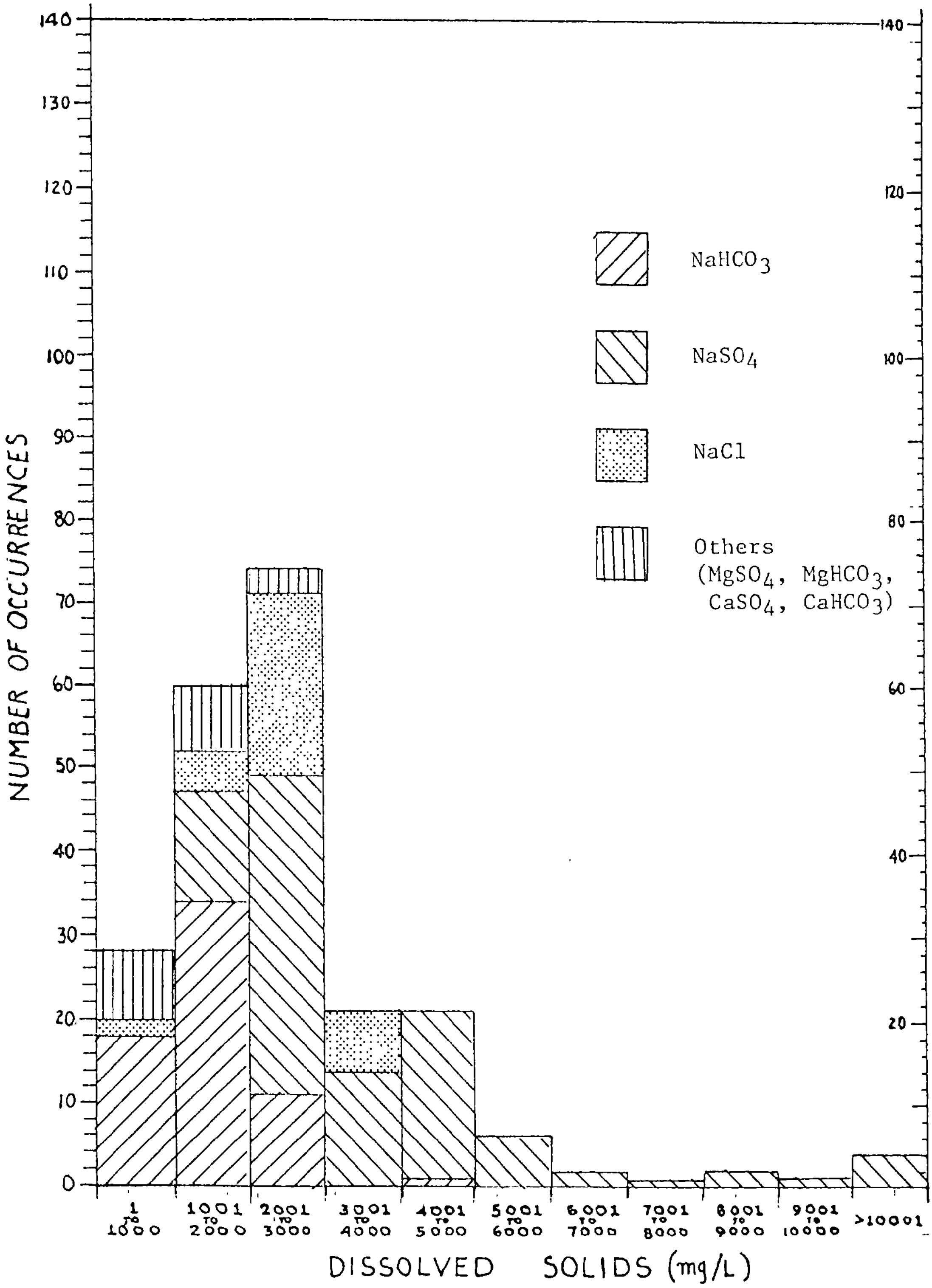



FIGURE I–9

less than 2,000 mg/L are dominantly sodium bicarbonate waters with sodium sulfate becoming more common as dissolved solids increase. Variability in water types appears to decrease as values of dissolved solids increase. Of the 220 analyses, 162 or 74% contained less than 3,000 mg/L of dissolved solids and four analyses were for waters in excess of 10,000 mg/L. All waters having dissolved solids values of more than 5,000 mg/L were sodium sulfate waters.

5. Eagle (Virgelle) Formation

The Eagle Formation of north-central Montana has 93 analyses on file in the water-quality data bank. Waters range from a low dissolved solids value of 285 mg/L in a 91-foot-deep well in southern Blaine County on the northwest flanks of the Little Rocky Mountains, to a high value of approximately 16,000 mg/L of a sodium sulfate water from a 91-foot-deep flowing well in Toole County. A dissolved solids value of 13,000 mg/L of a sodium chloride water recovered during a drill-stem test of the Shannon Sandstone in Bighorn County was also reported. Both occurrences of dissolved solids in excess of 10,000 mg/L are apparently related to oil and gas exploration work. The Shannon test was from ground water between 2,300 and 2,350 feet below land surface.

Copious data points appear on the Eagle Formation DS map from the Cut Bank area; an area of primary use for this aquifer. Data for this region is contained in MBMG Bulletin 60 by E. A. Zimmerman. Analyses in this report are from water samples taken between T. 32 N. to T. 37 N. and between R. 3 W. to R. 6 W. in Toole and Glacier Counties. Values of dissolved solids in this area ranged from 384 mg/L in a 160-foot-deep well in T. 34 N., R. 5 W., Section 35DC to 5,210 mg/L in a 575-foot-deep well in T. 36 N., R. 6 W., 21CB. According to Zimmerman (1960) the quality of the water in the Eagle Formation varies locally in this area, but sodium is normally the

FREQUENCY OF OCCURRENCE COMPARED TO DISSOLVED SOLIDS IN WATER FROM THE

EAGLE AND VIRGELLE FORMATION

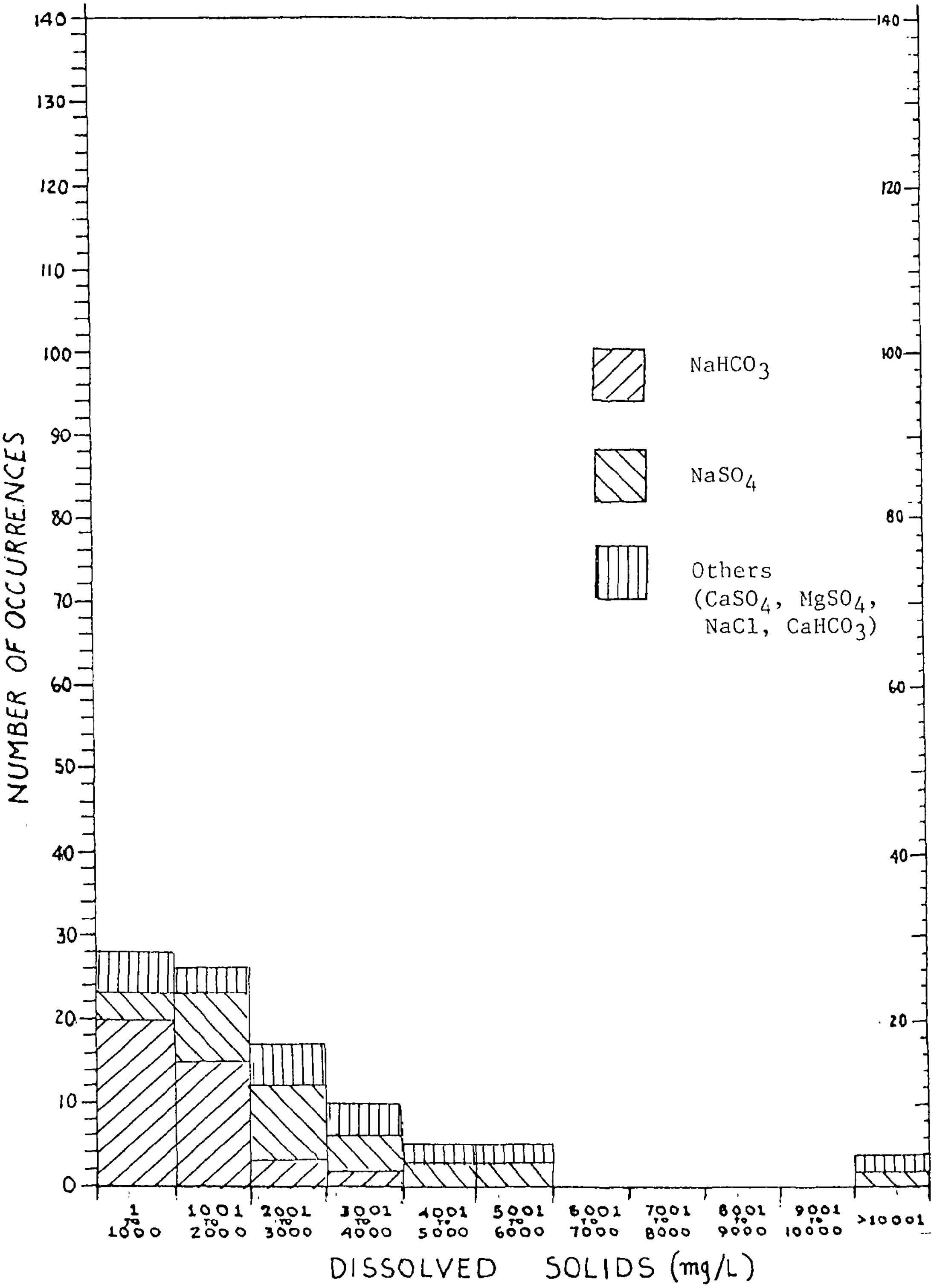



FIGURE I–10

predominant cation and bicarbonate or sulfate the predominate anions.

Figure I-10 is a histogram showing the number of analyses versus dissolved solids values for the Eagle aquifer. Of the samples in MBMG's data files, 45 (58%) had dissolved solids values of less than 2,000 mg/L. Most of these were sodium bicarbonate waters with the second most prevalent type being sodium sulfate waters. Other ground water types represented were calcium sulfate (2 occurrences), calcium bicarbonate (5 occurrences), magnesium sulfate (2 occurrences), calcium bicarbonate (5 occurrences) and magnesium sulfate (1 occurrence). Above the 2,000 mg/L level, sodium bicarbonate waters become less common and sodium sulfate waters more prevalent. Sodium chloride waters also become more common above this level.

6. Kootenai Formation

The water-quality data bank contains 130 analyses of Kootenai Formation and Kootenai equivalent waters. Equivalent formations included are: the Cloverly; the Fuson; the Lakota and the Second and Third Cat Creek Sandstones. In addition to those analyses in MBMG's files, 20 analyses presented by Hopkins in 1976 were reviewed. Of the 130 samples, 108 are from wells or springs in an area bounded by T. 11 N. on the south side and T. 18 N. on the north side and R. 9 E. and R. 35 E. on the west and east sides respectively, in Judith Basin and Fergus Counties. Therefore, only a limited area extent of these aquifers is represented, although this is their primary-use area. A low dissolved solids value of 204 mg/L was reported in water from a 690-foot-deep well in Judith Basin County; this water is a calcium bicarbonate type. A high dissolved solids value of 10,500 mg/L representing a sodium chloride water was reported in drill-stem test water from an oil well completed in the Third Cat Creek Formation in Stillwater County.

The histogram of Figure I-11 shows that 121 (81%) of the 150 analyses have dissolved solids values of less than 1,000 mg/L. These waters are primarily sodium bicarbonate (32%), calcium bicarbonate (37%), and calcium sulfate (18%). So few samples exist in the higher values ranging between 1,000 and 5,000 mg/L that water-type breakdowns are not valid, however, it does appear that sodium chloride type waters become more common. In the Cut Bank area, the lower Kootenai equivalent sands are oil and gas producers and contain water ranging from 4,000 to 13,000 mg/L of dissolved solids.

7. Jurassic Formations

Of the 35 (34 MBMG and 1 Hopkins) analyses reviewed for aquifers in Jurassic-age rocks, one contained 36,100 mg/L of dissolved solids. This water was a sodium chloride type from the Piper Formation and was obtained during a drill-stem test at a well in eastern Valley County. In MBMG's data bank, the highest value noted for dissolved solids was 4,245 mg/L from a 4,702-foot-deep livestock well in northern Rosebud County; this is a sodium sulfate type water. The lowest dissolved solids value was for a calcium bicarbonate type water from a 249-foot-deep well finished in the Morrison Formation in Judith Basin County.

Figure I-12 is a histogram of water analyses plotted against values of dissolved solids. There are too few analyses represented to distinguish definite trends in water type. It does appear, however, that calcium bicarbonate group waters predominate when dissolved solids values are less than 1,000 mg/L.

8. Mississippian (Madison and equivalent)

MBMG's computer file contains 44 analyses from 37 different wells or

FREQUENCY OF OCCURRENCE COMPARED TO DISSOLVED SOLIDS IN WATER FROM THE KOOTENAI FORMATION

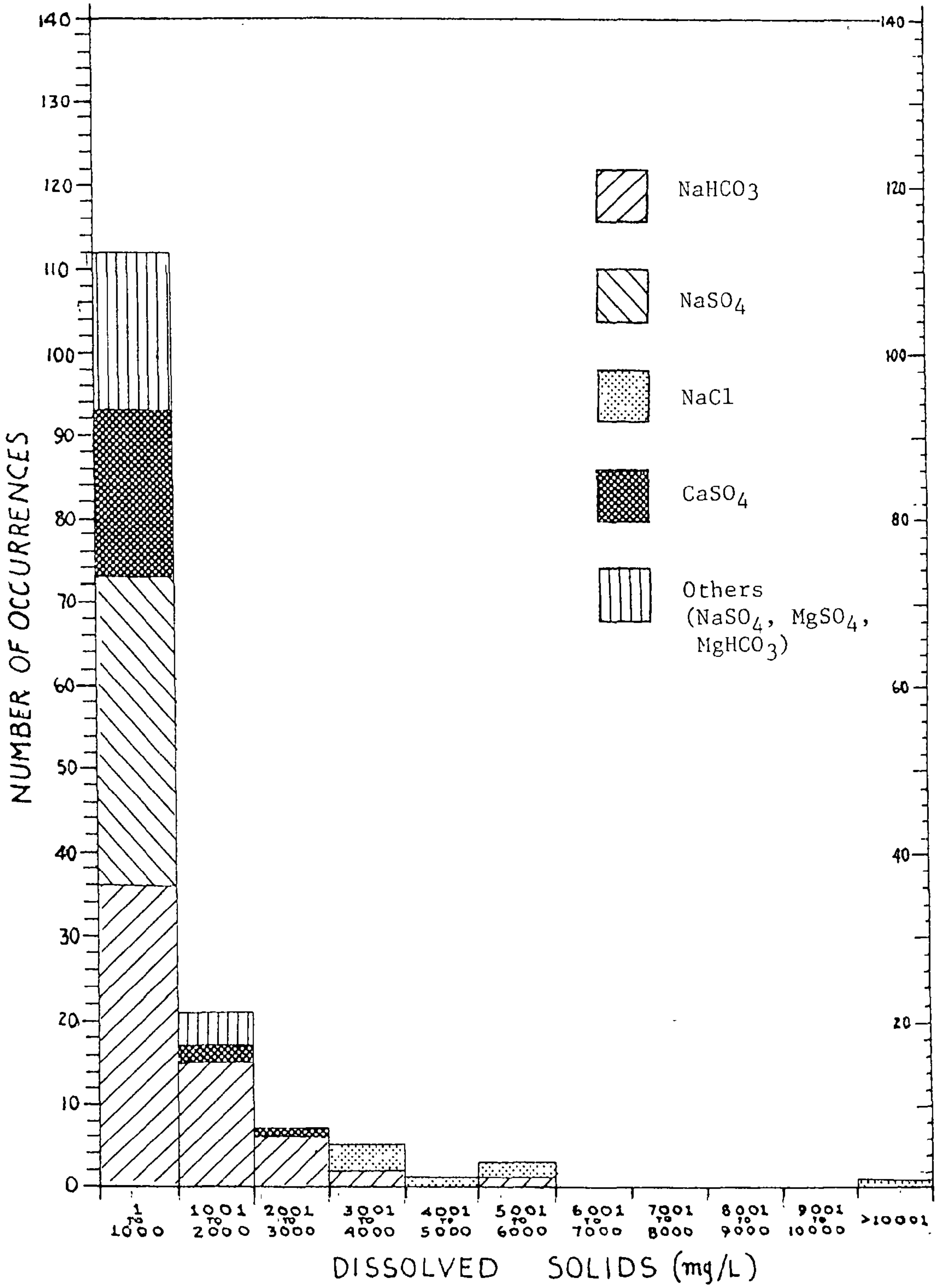



FIGURE I–11

FREQUENCY OF OCCURRENCE COMPARED TO DISSOLVED SOLIDS IN WATER FROM THE JURASSIC FORMATION

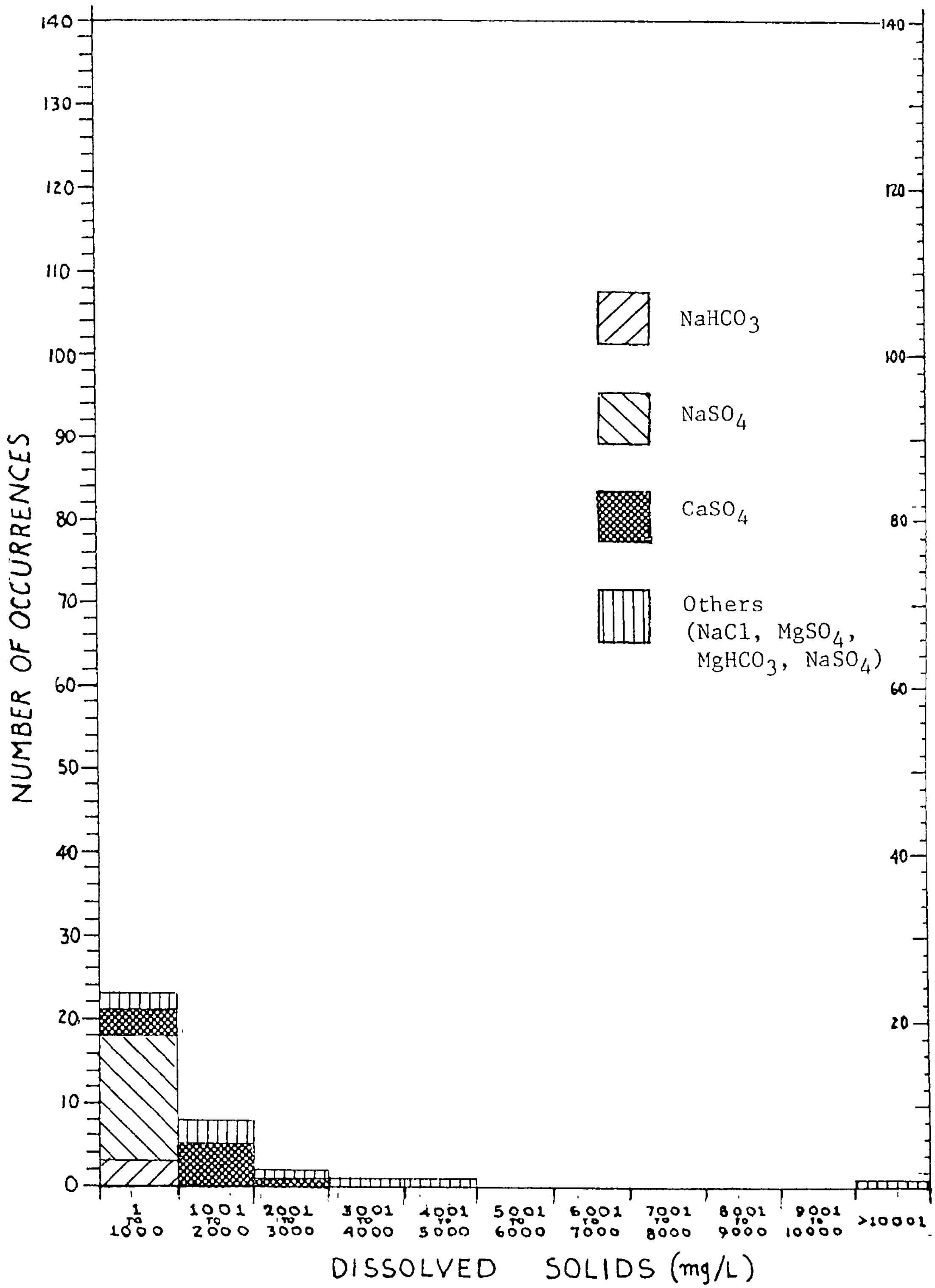



FIGURE I–12

springs producing water from Mississippian age rocks. These analyses represent water sources in the western and central portions of the Great Plains region. The water samples were obtained during research on warm water wells and springs. Figure I-13 is a comparison of dissolved solids values to the number of analyses from waters from Mississippian age rocks. Hopkins (1976) evaluated and classified an additional 75 waters from Mississippian age rocks. Feltis (1980) mapped DS values, ratios of sulfate to total anions and ratios of sodium plus potassium plus chloride to dissolved solids values from Madison Group rocks in the Great Plains region. These references plus others represent a wealth of information and data that has been gathered for the Madison Group because of the high interest in the water-yielding and water-quality characteristics of these rocks relative to their potential for industrial water development.

The highest dissolved solids values reported occur in the extreme northeastern corner of Montana underlying portions of Sheridan, Richland and eastern Roosevelt Counties. In this area, dissolved solids values of 100,000 mg/L are common and values approaching 300,000 mg/L are reported. These waters are sodium chloride brines associated with evaporite deposits within the Charles and Mission Canyon Formations of this portion of the Williston Basin. The highest dissolved solids value in MBMG's files is for water from the Angela Hot Springs well in northeastern Rosebud County. This well produces a sodium calcium chloride sulfate water from well perforations placed between 8,152 and 8,183 feet below land surface.

Waters obtained from sources near the outcrops of Mississippian age rocks represent the other extreme and are very much lower in dissolved solids. The lowest dissolved solids value noted was from rocks of the Big Snowy

FREQUENCY OF OCCURRENCE COMPARED TO DISSOLVED SOLIDS IN WATER FROM THE MISSISSIPPIAN FORMATIONS

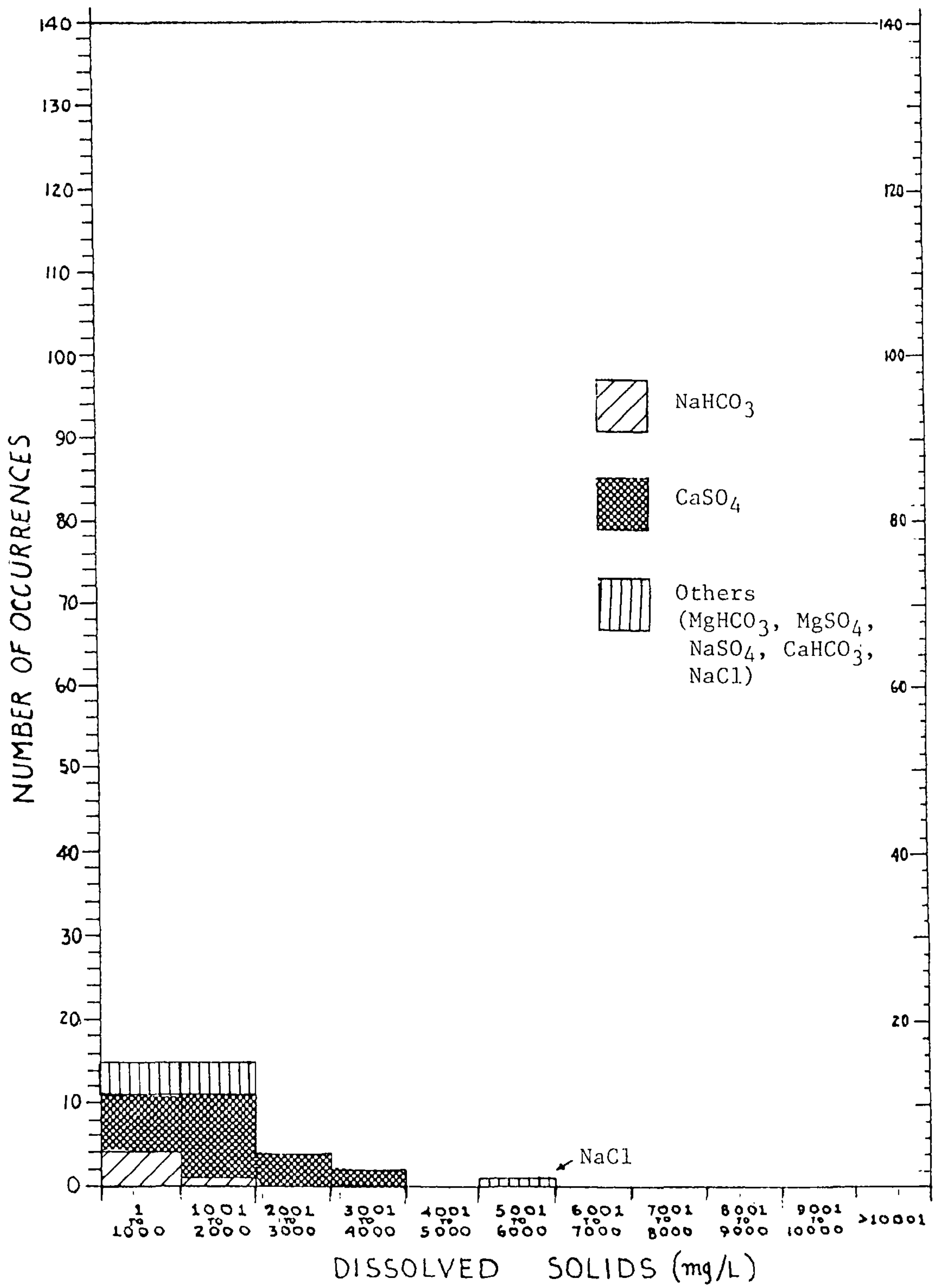



FIGURE I–13

Group in Fergus County. A 225-foot-deep well completed in these rocks produced a magnesium bicarbonate water of approximately 256 mg/L. This water is used for domestic purposes. Figure I-13 shows that 30 of the 37 analyses in this small group had dissolved solids values of less than 2,000 mg/L and calcium sulfate being the predominant water type. Most of these analyses represent waters in or relatively near the outcrop areas for Mississippian age rocks.

According to Feltis (1980), anion trends closely follow increases in dissolved solids values. Waters with low sulfate concentrations are generally found near outcrops, but sulfate concentrations increase rapidly even a short distance from the outcrop. Over most of the Great Plains region, sulfate concentration is greater than 50% of the total anion content of the water. In both the Williston Basin and Sweetgrass Arch areas, chloride becomes the dominant anion. In these areas, Mississippian age rocks produce oil and gas and have sodium plus potassium plus chloride ratios to dissolved solids values of greater than 50 percent.

## V. SUMMARY AND CONCLUSIONS

(In Progress)

## VI. REFERENCES

Appendix A: System of Geographical Locations

Appendix B: Glossary

Appendix C: Montana Water Law

Appendix D: Printout of Injection Wells

Appendix E: Printout of Water Quality Analyses

(In Progress)