VOLUME II

OCCURRENCE AND CHARACTERISTICS OF GROUND WATER IN THE ROCKY MOUNTAINS REGION, MONTANA

by

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Report to

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PREFACE

This report, "Aquifer Characterization of Montana", is a two-volume study; volume one has been compiled for the Great Plains physiographic province and volume two for the Rocky Mountains physiographic province of Montana. Because of the complex structural geology of Montana, this division is necessary in order to describe the various aquifers that occur in each of the physiographic provinces. This report contains descriptions of thickness, yield, structural configuration and water quality data for the major aquifers within each province.

These two volumes contain a comprehensive compilation of existing hydrogeologic information for the State. Because statewide hydrogeologic investigations have only recently begun in Montana, there are many data gaps, especially for the deeper aquifers. 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 study, "Aquifer Characterization of Montana", was funded by the U. S. Environmental Protection Agency through Contract No. G0-082-908-10, for the Underground Injection Control Program. The Safe Drinking Water Act (Public Law 93-523) was enacted by Congress for the purpose of protecting underground sources of water from contamination by well injection. This act mandated the U. S. Environmental Protection Agency to establish the Underground Injection Control Program to prevent underground injections which endanger ground-water resources. The Montana Bureau of Mines and Geology's participation in the Underground Injection Control Program involves the identification and characterization of aquifers for the State of Montana.

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Legend

TF - Thickness of Formation
DS - Dissolved Solids
211.11 - Formation Code
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, 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 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 II-1.

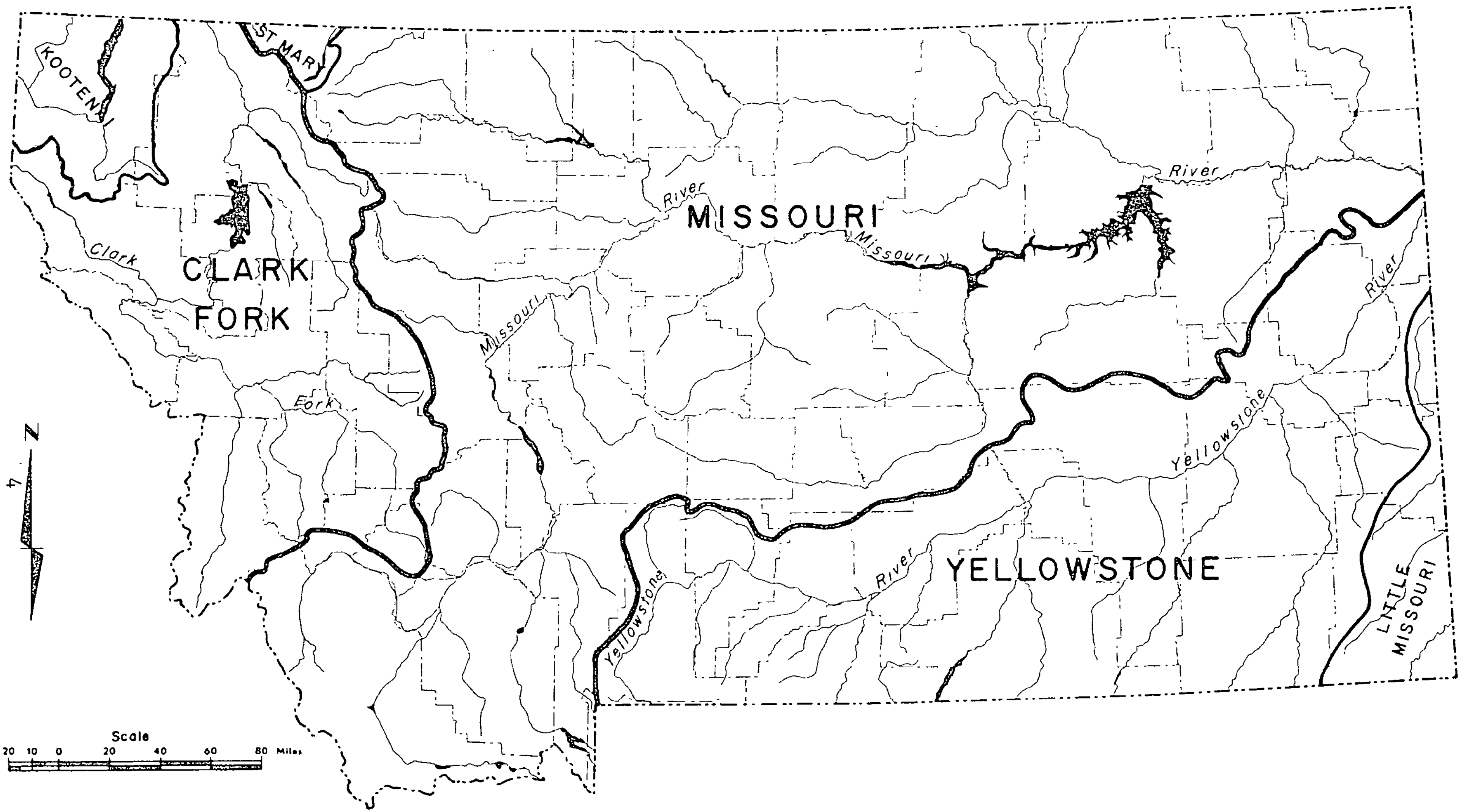
TABLE II-1

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 II - 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 and 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 ROCKY MOUNTAINS REGION

The Rocky Mountains region of Montana is predominantly an area of rugged mountain ranges and intervening valleys constituting the western one-third of the state. This region extends from the eastern front of the Disturbed Belt (a northwest-trending zone 25 miles wide where mountain-building forces deformed the rocks, but did not result in a mountainous terrain) west to the Montana-Idaho border. Latitude 49° north establishes the northern border, and the state borders of Idaho and Wyoming with Montana delineate the region's southern extent. Linear mountain ranges form the Continental Divide separating this region into two major drainage basins. The headwaters of the Columbia River drain the northwestern portion of this region, whereas the tributaries of the Missouri River drain the southeastern portion. Most of the state's large-scale hydroelectric generating sites are located along these major rivers or their tributaries. Although the rugged mountains are especially scenic features within this region, the intermontane valleys or basins are important areas for habitation, agriculture and ground-water usage.

The economy of the Rocky Mountains region is based on forest products, mining, smelting, agriculture, governmental and educational activities and light industry. Glacier and Yellowstone National Parks and numerous designated wilderness areas account for a substantial amount of the seasonal tourism. Oil and gas exploration is increasing rapidly, with the current interest generated along Montana's Overthrust Belt.

These economic operations have already placed a significant demand on the region's water resources. As the population continues to grow, additional sources of potable water will be needed. Because of the geologic nature of this region, there exist only limited areas suitable for ground-water development. Volume II of this report is an examination of the occurrence and characteristics of ground water in Montana's Rocky Mountains.

PHYSIOGRAPHY

Topography

The Rocky Mountains region of Montana covers approximately 54,750 square miles of the Northern Rocky Mountains physiographic province or roughly the western one-third of Montana. The region consists of contrasting steep mountain slopes and flat river valleys which often contain some well-defined terraces, but relatively few foothills or prairie expanses. About three-fourths of the region is occupied by a series of 40 or more individual mountain ranges that are 25 to 75 miles long. In general, the mountain fronts rise abruptly from the valley floors to peaks which vary in altitude from 10,448 feet above sea level at Mount Cleveland in northern Glacier National Park to 12,799 feet above sea level at the summit of Granite Peak in the Beartooth Mountains, northeast of Yellowstone National Park. Floors of the intermontane valleys which separate the mountain ranges lie at elevations ranging from 2,800 to 6,700 feet above sea level (the Mission and Centennial valleys, respectively). These valleys, generally containing a river, may be from a few to as much as 20 miles wide and 10 to 50 miles long. Elevations in the Rocky Mountains region range from 1,825 feet above sea level, where the Kootenai River flows out of the state, to 12,799 feet above sea level at Granite Peak. The locations and names of many of the mountain ranges and intermontane valleys are shown in Figure II-2. Terraces or pediments often adjoin the mountain fronts.

With some exceptions, the mountains of western Montana are dominantly composed of metasedimentary rocks of Precambrian age; marine sandstones, shales and carbonate rocks of Paleozoic and Mesozoic age; marine strata of Jurassic and Cretaceous age; and andesitic volcanic rocks of late Cretaceous and early Tertiary ages. The Boulder Batholith and its associated satelites in the center of the region are principally composed of quartz monzonite of Cretaceous age. The intermontane basins have been filled with Tertiary and Quaternary

Map of western Montana and adjacent areas, showing relations of the mountain ranges and intermontane valleys (stippled): 1, Purcell Trench, 2, Flathead Valley, 3, Kalispell Valley; 4, Little Bittrroot Valley; 5, Camas Prairie Basin, 6, Mission Valley; 7, Jocko Valley; 8, Blackfoot Valley; 9, Missoula Valley; 10, Camas Prairie, 11, Nevada Valley; 12, Bitterroot Valley; 13, Flint Creek Valley; 14, Avon Valley; 15, Prickly Pear Valley; 16, Phillipsburg Valley; 17, Deer Lodge Valley; 18, Townsend Valley; 19, Smith River Valley; 20, Silver Bow Valley; 21, Big Hole Basin, 22, Vipond Park, 23, Jefferson Valley; 24, Gallatin Valley; 25, Beaverhead Valley, 26, Madison Valley, 27, Centennial Valley

MOUNTAIN RANGES AND INTERMONTANE VALLEYS OF THE ROCKY MOUNTAINS REGION

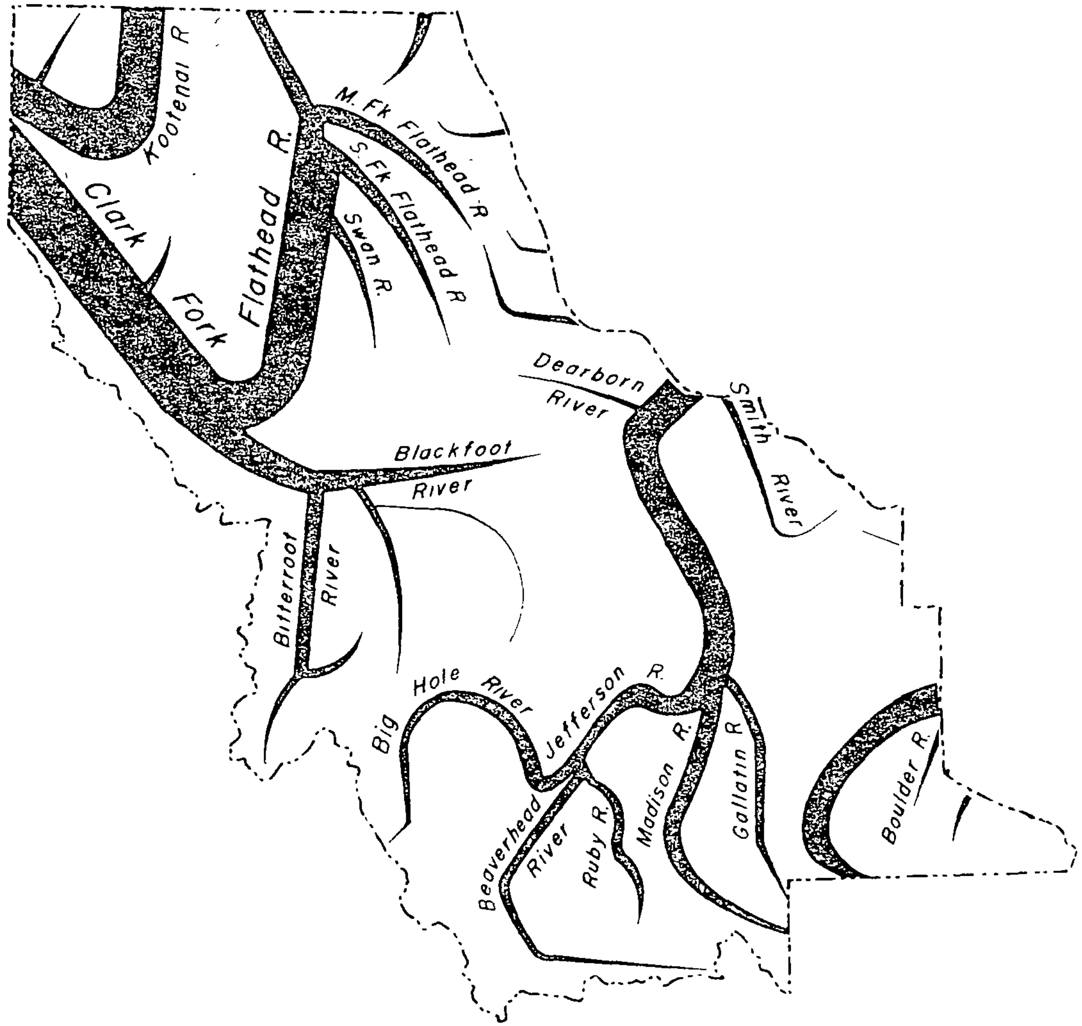
FIGURE II–2

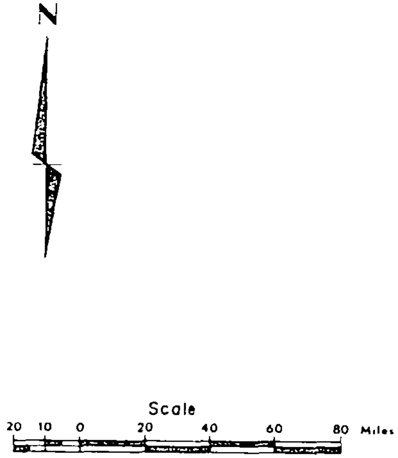
sediments derived from the surrounding mountains.

Mountain glaciers extended over most of the region, leaving either some various glacial deposits or erosional features. These glaciers were responsible for such erosional features as the jagged peaks and U-shaped valleys in Glacier National Park and the Beartooth Mountains. They also produced the hummocky kame and kettle topography around Ovando and the low hills (which are moraines) in the Kalispell area. Many of the mountain lakes which dot mountain slopes and valley plains mark the occurrence of glacial activity. Because of the geologic diversity, topographic variability and structural complexity of this region, isopach, potentiometric surface and structural configuration maps could be produced only for specific aquifer units.

Surface Drainage

Three major river systems in North America have their origins along the Continental Divide in the Rocky Mountains region of Montana. These three river systems are the Columbia, Missouri and Saskatchewan Rivers. The common point of juncture for these rivers is located at Triple Divide Peak in Glacier National Park. Because of the westward deflection of the Continental Divide, most of the drainage area for the Columbia River occupies the northwest portion of the region, while the watershed of the Missouri River lies within the southeastern portion of the region. Tributaries of the Saskatchewan River drain only a small percentage of the region located in Glacier National Park. The mean annual runoff of the major streams for the Rocky Mountains region is presented schematically in Figure II-3, with a breakdown of drainage basin inflow and outflow values shown in Table II-2.





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.

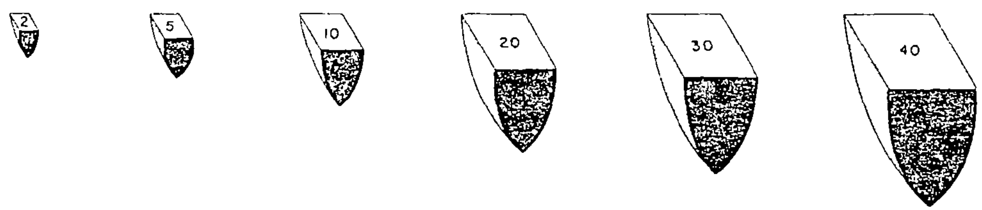


FIGURE II-3

TABLE II-2

RIVER BASIN INFLOW AND OUTFLOW (IN ACRE-FEET)

Drainage	Inflow	Originating in the region	Leaving the region	Percentage Originating in the region
Clark Fork	694,800	15,515,200	16,210,000	96
Kootenai	6,600,000	2,510,000	10,110,000	25
Missouri	0	4,913,000	4,913,000	100
Hudson Bay	0	510,000	510,000	100
Yellowstone	2,259,000	475,000	2,734,000	17

The Columbia River Basin comprises all land in Montana west of the Continental Divide. This area has a substantial volume of surface water compared with its total land area. While containing only 17 percent of the land mass of Montana, this basin is the source of 59 percent of the state's total surface water outflow. The Clark Fork River and the Kootenai River are the two major tributaries of the basin. The Clark River heads in Silver Bow basin south of Butte, originating as Silver Bow Creek. The Clark Fork River joins other major tributaries, the Bitterroot, Blackfoot and Flathead Rivers at their confluences to become the Pend d'Oreille River in Idaho. A small area in the northwestern corner of the region adds to the watershed of the Kootenai River. The Clark Fork has an average annual flow of 16,210,000 acre-feet per year near Cabinet, Idaho, at the Montana-Idaho border as compared to the Kootenai's average outflow of 10,110,000 acre-feet per year at Leonia, Idaho. Major tributaries of the Kootenai River are the Yaak and Fischeries Rivers.

The Columbia River Basin has almost 12 million acre-feet of storage. Lake Koocanusa is the largest reservoir with a storage capacity of 5,850,000 acre-feet. Hungry Horse Reservoir and Flathead Lake are the other major storage sites, with capacities of 3,468,000 and 1,791,000 acre-feet of total storage, respectively.

The Missouri River Basin drains the eastern slopes of the Continental Divide. At the eastern border of the Rocky Mountains region, the Missouri River has a drainage area slightly smaller than the Columbia River, yet has about 1/3 of the Columbia River's average discharge. The Missouri River proper begins at the confluence of the Jefferson, Madison and Gallatin Rivers below Three Forks. Canyon Ferry, with a total storage capacity of 2,051,000 acre-feet on the main-stream of the Missouri River, is the largest reservoir in this portion of the region.

The Hudson Bay drainage in Rocky Mountains region consists primarily of the St. Mary River and its tributaries draining the northeast corner of Glacier National Park. The river flows northward to join the Saskatchewan River in Canada.

A portion of the Yellowstone River's watershed arises also in the south-eastern corner of the Rocky Mountains region. Only a few hundred cubic feet per second are produced from its small watershed.

Climate

Because western Montana has a great amount of topographic variation, it also has a great variety of climate. This climate diversity is such that most small-scale climate maps show western Montana as having merely a "highland" climate. More detailed climate maps using the Köppen classification system would show that the intermontane valleys have a "steppe" climate (BSk), that the mountains would have various microthermal or "snow forest" climates such as Dbf, Dbs, Dcf and Dcs and that the summits of the higher mountains would have "tundra" climates (ET). The Thornwaite climate classification shows the climate of the intermontane valleys and some of the mountains in southwestern Montana to be, "subhumid, microthermal, precipitation deficiency in all seasons," (cc'd). The mountains of northwestern Montana and those in the southeastern part of the Rocky Mountains region are shown to have the following climates: subhumid, microthermal, precipitation adequate in all seasons, (cc'r); humid, microthermal, precipitation adequate in all seasons (Bc'r) and taiga (d'). Not shown on the Thornwaite map, but present on many of the higher peaks, would be "tundra" (E'). That a map has yet to be prepared for Montana accurately showing the extent of these climatic provinces is not surprising, considering that many other factors besides topography are important in determining mountain climates. Some of these other factors are: rainshadow effect, direction and strength of the prevailing wind, slope angle, air drainage, latitude, longitude, valley width and valley orientation. Long-term temperature and precipitation records are generally available only for major cities, most of which are located in intermontane valleys. Supplemental climate data from snow survey sites on the mountains are now adding greatly to the understanding and quantification of the climate of western Montana.

Climate records show that the valleys of extreme west-central Montana have the warmest July temperatures. July average maximum temperatures of 88^{o}F occur at Thompson Falls along the Clark Fork River. Warm July temperatures in this part of the state result from long, clear days, lower altitudes and reflective heating from the north valley slopes (south-facing slopes). The July average maximum in Butte is 80^{o}F and at West Yellowstone, 75^{o}F. Maximum shade temperatures on mountain summits in July often average 65^{o}F or less. Average minimum temperatures in July are as low as 40^{o}F in northwestern Montana and the high valleys of southwestern Montana. Because of the low humidity, radiative cooling begins as soon as the sun sets. January average minimum temperatures are generally as much as 15^{o}F warmer than those in northwestern Montana and generally keep the temperature more moderate compared to the Great Plains region where Arctic air masses are dominant in winter. Extreme low temperatures occur in western Montana when Arctic air masses spill across the mountain barriers.

Average annual precipitation amounts in western Montana range from less than ten inches in the intermontane basins of southwestern Montana to more than

100 inches in Glacier National Park. Precipitation amounts generally increase with altitude except where severe rainshadow conditions exist on the lee side of the mountains. Monthly weather records show that two precipitation maxima occur in western Montana, one in mid-winter and the other in late May to early June. Average annual snowfall amounts range from 25 inches in the area near Townsend (along Canyon Ferry Reservoir) to more than 1,000 inches on the summits in Glacier National Park. The average snowfall in most of the major cities is between 40 and 90 inches. The snowpack on the mountains of western Montana acts like a great storage reservoir for the many streams that have their headwaters in this area. Melting snows release water slowly to these streams, keeping them flowing long after the late spring rains have ceased.

CULTURAL GEOGRAPHY

Population

The Rocky Mountains region encompasses roughly one-third of Montana's land area, yet one-half of the state population inhabits the region. According to 1980 census figures, 393,625 persons are living in the region, yielding a population density of 7.12 persons per square mile. Because the region is predominantly rugged mountain ranges, approximately 90 percent of the people live in the intervening valleys. Major cities exceeding 10,000 people account for 37 percent of the region's population. The 1980 census defined a city as an incorporated place and according to this classification the major cities in order of their size are: Butte, Missoula, Helena, Bozeman, Anaconda and Kalispell. The population distribution for the Rocky Mountains region is summarized in Table II-3 with the county census subdivisions represented in Figure II-4.

Butte is the largest incorporated place within the region attributing its size to a prosperous copper mining industry of the past. Butte typifies a boom

TABLE II-3

POPULATION OF COUNTIES AND COUNTY SUBDIVISIONS
OF THE ROCKY MOUNTAINS REGION, MONTANA

County/County Subdivision	1980	1970	% Change
Beaverhead County	8,186	8,187	---
Big Hole Basin Division	740	---	---
Clark Canyon-Horse Prairie Division	426	---	---
Dillon Division	6,567	---	---
Lima-Centennial Valley Division	453	---	---
Broadwater County	3,267	2,526	29.3
Townsend East Division	2,522	2,016	25.1
Townsend West Division	745	510	46.1
Cascade County	80,696	81,804	- 1.4
Sun River Valley Division	3,258	2,558	27.4
Deer Lodge County	12,518	15,652	-20.0
Anaconda Division	10,403	---	---
Deer Lodge Valley Division	2,115	---	---
Flathead County	51,966	39,460	31.7
Bad Rock-Columbia Heights Division	2,793	---	---
Columbia Falls Division	6,574	---	---
Creston-Bigfork Division	4,114	2,315	77.7
Glacier Division	105	153	-31.4
Kalispell Division	22,860	---	---
Kalispell Northwest Division	1,939	---	---
Kalispell Southwest Division	2,700	---	---
Lower Valley-Somers Division	1,183	---	---
South Fork Division	2,000	---	---
Whitefish Division	7,698	---	---
Gallatin County	42,865	32,505	31.9
Belgrade Division	5,884	---	---
Bozeman Division	28,604	---	---
Gallatin Gateway Division	1,949	---	---
Manhattan Division	3,057	2,448	24.9
Three Forks Division	1,997	1,839	8.6
West Yellowstone Division	1,374	1,099	25.0
Glacier County	10,628	10,783	- 1.4
Blackfeet Division	6,039	---	---
Glacier National Park Division	49	---	---
Granite County	2,700	2,737	- 1.4
Drummond Division	1,092	1,141	- 4.3
Philipsburg Division	1,608	1,596	0.8
Jefferson County	7,029	5,238	34.2
Boulder Division	4,518	3,350	34.9
Whitehall Division	2,511	1,888	33.0

TABLE II-3 (Continued)

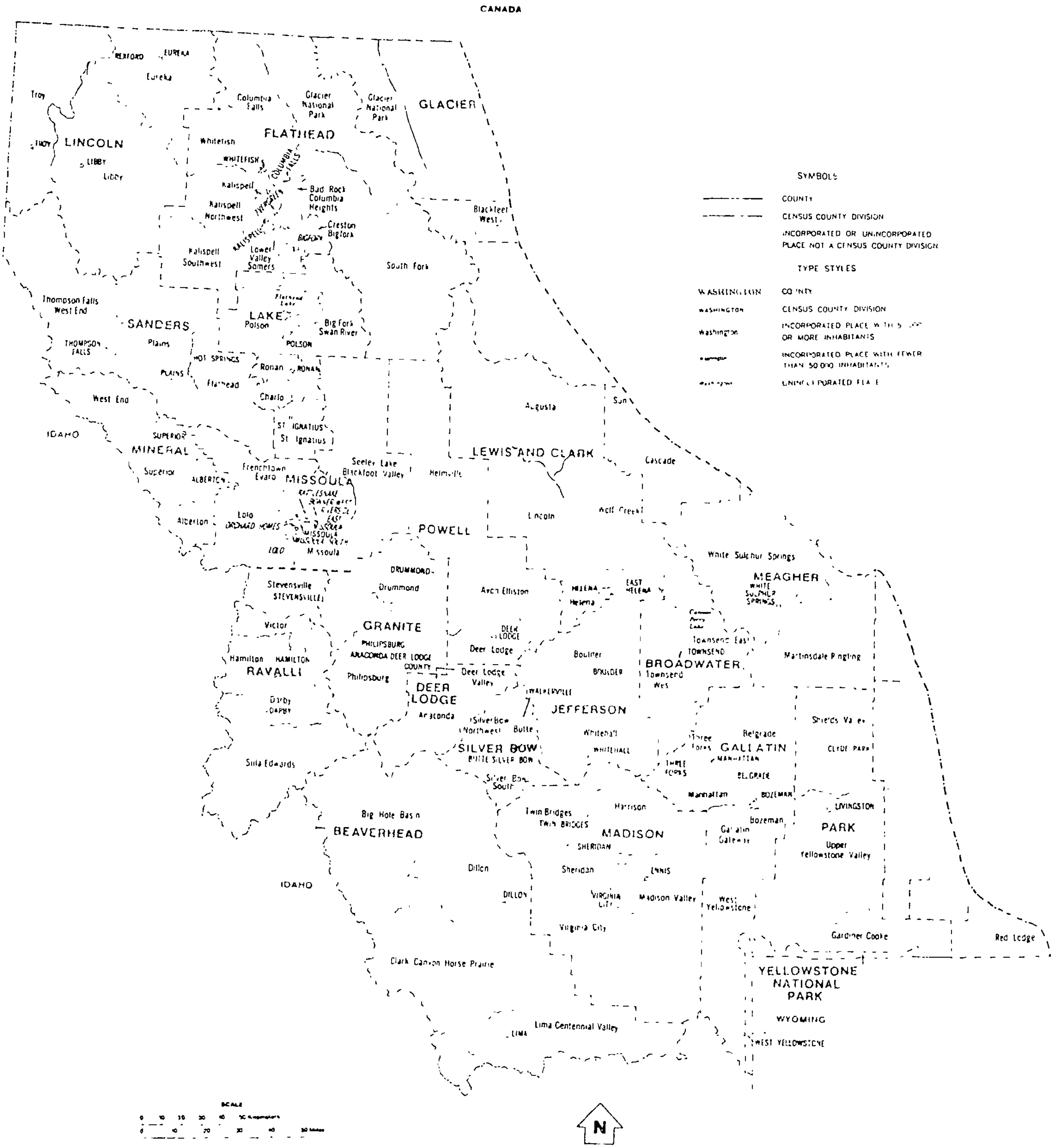
POPULATION OF COUNTIES AND COUNTY SUBDIVISIONS
OF THE ROCKY MOUNTAINS REGION, MONTANA

County/County Subdivision	1980	1970	% Change
Lake County	19,056	14,445	31.9
Big Fork-Swan Division	1,998	---	---
Charlo Division	1,242	1,111	11.8
Polson Division	7,492	---	---
Ronan Division	4,875	---	---
St. Ignatius Division	3,449	2,797	23.3
Lewis and Clark County	43,039	33,281	29.3
Augusta Division	847	854	- 0.8
Helena Division	38,853	---	---
Lincoln Division	2,234	---	---
Wolf Creek Division	1,105	---	---
Lincoln County	17,752	18,063	- 1.7
Eureka Division	3,727	3,558	4.7
Libby Division	10,960	12,045	- 9.0
Troy Division	3,065	2,460	24.6
Madison County	5,448	5,014	8.7
Harrison Division	762	800	- 4.8
Madison Valley Division	1,466	1,179	24.3
Sheridan Division	1,525	1,337	14.1
Twin Bridges Division	1,387	1,437	- 3.5
Virginia City Division	308	261	18.0
Meagher County	2,154	2,122	1.5
Martinsdale-Ringling Division	377	---	---
White Sulphur Springs Division	1,777	---	---
Mineral County	3,675	2,958	24.2
Alberton Division	587	600	- 2.2
Superior Division	2,126	1,580	34.6
West End Division	962	778	23.7
Missoula County	76,016	58,263	30.5
Frenchtown-Enaro Division	3,665	1,547	136.9
Lolo Division	4,871	1,747	178.8
Missoula Division	65,476	---	---
Seeley Lake-Blackfoot Valley Division	2,004	1,201	66.9
Park County	12,660	11,197	13.1
Gardiner-Cooke Division	860	845	1.8
Shields Valley Division	1,471	---	---
Upper Yellowstone Valley Division	10,329	---	---

TABLE II-3 (Continued)

POPULATION OF COUNTIES AND COUNTY SUBDIVISIONS
OF THE ROCKY MOUNTAINS REGION, MONTANA

County/County Subdivision	1980	1970	% Change
Pondera County	6,731	6,611	1.8
Blackfeet West Division	473	---	---
Powell County	6,958	6,660	4.5
Avon-Elliston Division	1,002	1,018	- 1.6
Deer Lodge Division	5,473	---	---
Helmville Division	483	---	---
Ravalli County	22,493	14,409	56.1
Darby Division	1,718	---	---
Hamilton Division	11,467	---	---
Stevensville Division	6,516	---	---
Sula-Edwards Division	950	---	---
Victor Division	1,842	---	---
Sanders County	8,675	7,093	22.3
Flathead Division	1,887	1,907	- 1.0
Plains Division	2,553	1,938	31.7
Thompson Falls-West End Division	4,235	3,248	30.4
Silver Bow County	38,092	41,981	- 9.3
Butte Division	36,817	---	---
Silver Bow Northwest Division	491	---	---
Silver Bow South Division	784	---	---
Toole County	5,559	5,839	- 4.8
South Toole Division	3,932	---	---
Sunburst Division	1,627	1,904	-14.5
Yellowstone County	108,035	87,367	23.7
Yellowstone National Park Division	275	64	329.7



COUNTY CENSUS SUBDIVISIONS

FIGURE II–4

town which had a population of over 100,000 around the turn of the century and has now receded to 35 percent of that early-day size. This trend in population decline roughly parallels the decline in employment for copper production. According to Rand-McNally's 1977 Atlas, Butte has a basic trading area of 91,300 people.

Missoula and Helena are respectively the second and third largest incorporated places of the region, however, Missoula's metropolitan area now exceeds 80,000. Missoula initially owed its growth to the timber industry; once being the home of five major lumber mills for the area. The population of this city, however, has increased 13.2 percent since 1970 as small industry and the University of Montana expand. Serving in excess of 118,000 residents, Missoula has the largest basic trading area in the Rocky Mountains. Helena is the capital of Montana and is dominantly supported by governmental employees. Its population, though, continues on an upward trend.

The overall population of the Rocky Mountains has increased 16.6 percent since the 1970 census, yet particular counties deviate greatly from this trend. An example of this is the 56.1 percent increase of Ravalli County which is due to an influx of people throughout the Bitterroot Valley. The other extreme is the 9.3 percent decline of Silver Bow County due to a depressed copper mining industry.

Land Use and Ownership

The primary land use in the Rocky Mountains region is forest. Roughly one-half of this region is considered forest land of which 60 percent is classified as commercial forest. However, timber harvesting has been reduced due to the associated decline in construction. Most of the forest land in the region is under federal control and managed by the U. S. Forest Service of Bureau of

Land Management. The remainder is either under state jurisdiction or private ownership.

The next largest land use is rangeland for livestock grazing. Rangeland consists of grazeable forest land, tame pasture and native rangeland. These lands are vital not only for cattle and sheep production, but are grazed also by big game and other wildlife. Approximately 35 percent of total land area of the Rocky Mountains region is used for rangeland and is owned dominantly by private individuals or corporations.

Agricultural cropland accounts for approximately eight percent of land use of the region. This land use includes irrigated and non-irrigated cropland and irrigated and non-irrigated pasture land. With agriculture being ranch oriented, hay production is the major use of cropland acreage. Most of this acreage occurs along the flat and gentle slopes of the river bottom land and terraces and along the foothills of the mountains. Nearly all cropland is privately owned.

The remainder of land use for the Rocky Mountains region spans from recreation and wildlife refuges to community facilities. Indian lands, national parks and wilderness areas comprise the majority of land acreage, while municialities and subdivisions are increasing rapidly. For the most part, the former areas are federally owned and the latter are under private ownership.

GEOLOGY

Stratigraphy

A composite stratigraphic section ranging in age from Precambrian to Holocene is present in the Rocky Mountains region of Montana. These formations constitute many of the rugged mountains of western Montana.

The oldest rocks are the gneisses and schists of the early Precambrian

Era (1.7 billion years old) of southwestern Montana. The majority of the bedrock formations exposed are the Precambrian metasediments of the Belt Series which dominantly cover the northern half of the region. These formations were mainly shelf and marginal shelf sediments deposited in a geosyncline. They were then altered by burial metamorphism to argillites and quartzites of their present configuration. Often they exist as assemblages tens of thousands of feet thick.

Seas again spread over the area during the Paleozoic Era depositing the shales and limestones of the Cambrian period. A temporary hiatus occurred during the Ordovician until mid-Devonian leaving a stratigraphic gap. Widespread shallow seas then deposited carbonates from late Devonian through Mississippian time. Fractures in the Madison limestone of this period serve for both recharge and sources of ground water in bedrock aquifers. Tectonic activity accompanied the invasion of Pennsylvanian and Permian seas, producing the clastic sediments of those periods. During the Jurassic and Cretaceous times, seas again moved into the region leaving alternating transgressive and regressive sedimentary sequences. These Paleozoic and Mesozoic formations exist in large bedrock assemblages of shales, carbonates and sandstones, with the carbonates and sandstones being the primary sources of ground water.

Tertiary and Quaternary deposits of the Cenozoic Era mainly occur in the intermontane valleys. For the most part, they are fluvial sediments derived from the surrounding mountains. These unconsolidated sediments serve as a primary ground-water source for most municipalities throughout the region. Mountain valley glaciers covered much of western Montana during the Pleistocene Epoch. These glaciers produced till and outwash deposits which now form a veneer over some valleys and mountain fronts and are sources of nominal amounts of ground water. Figure II-5 portrays the generalized stratigraphic sections for the Rocky Mountains region.

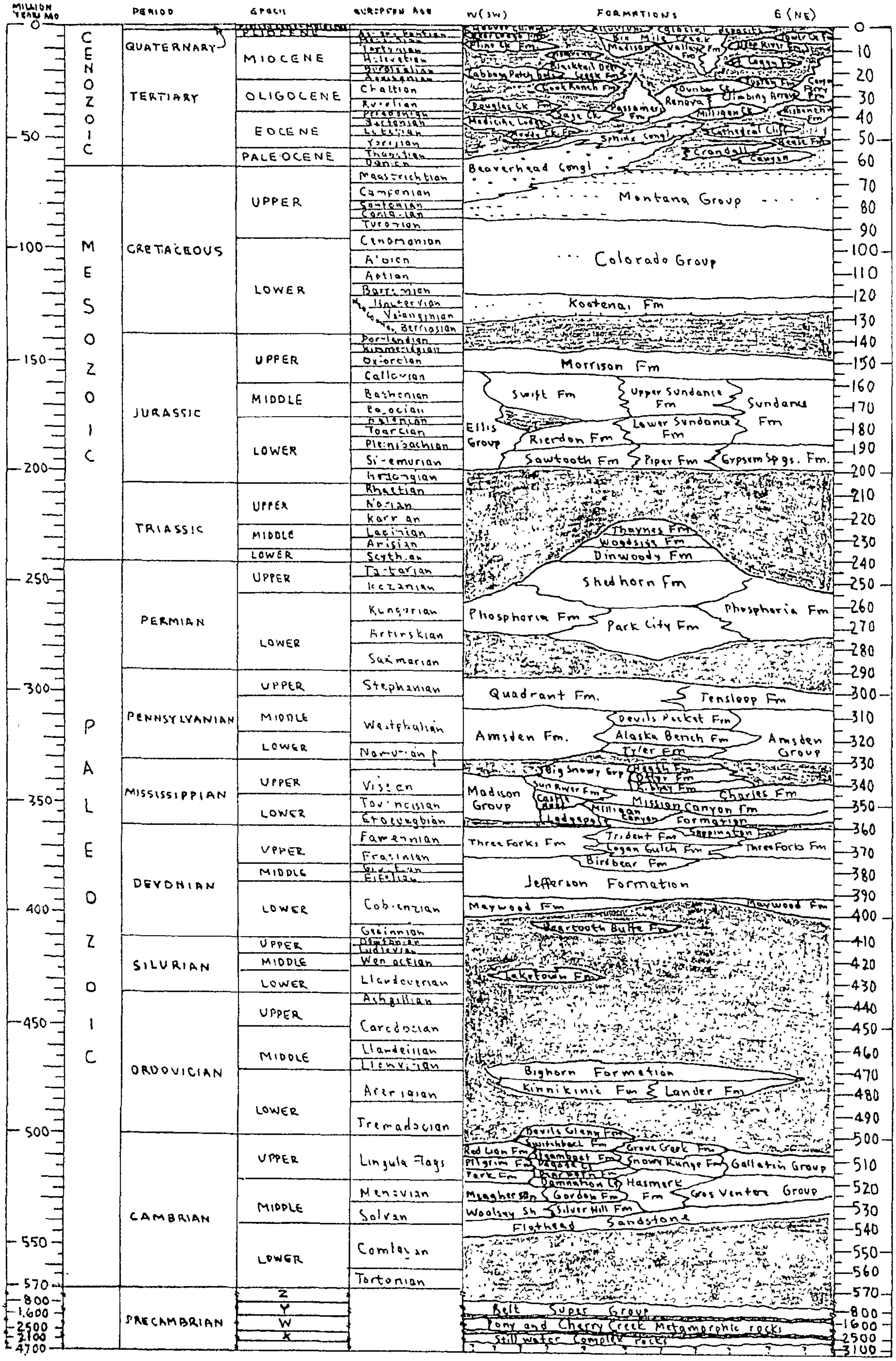
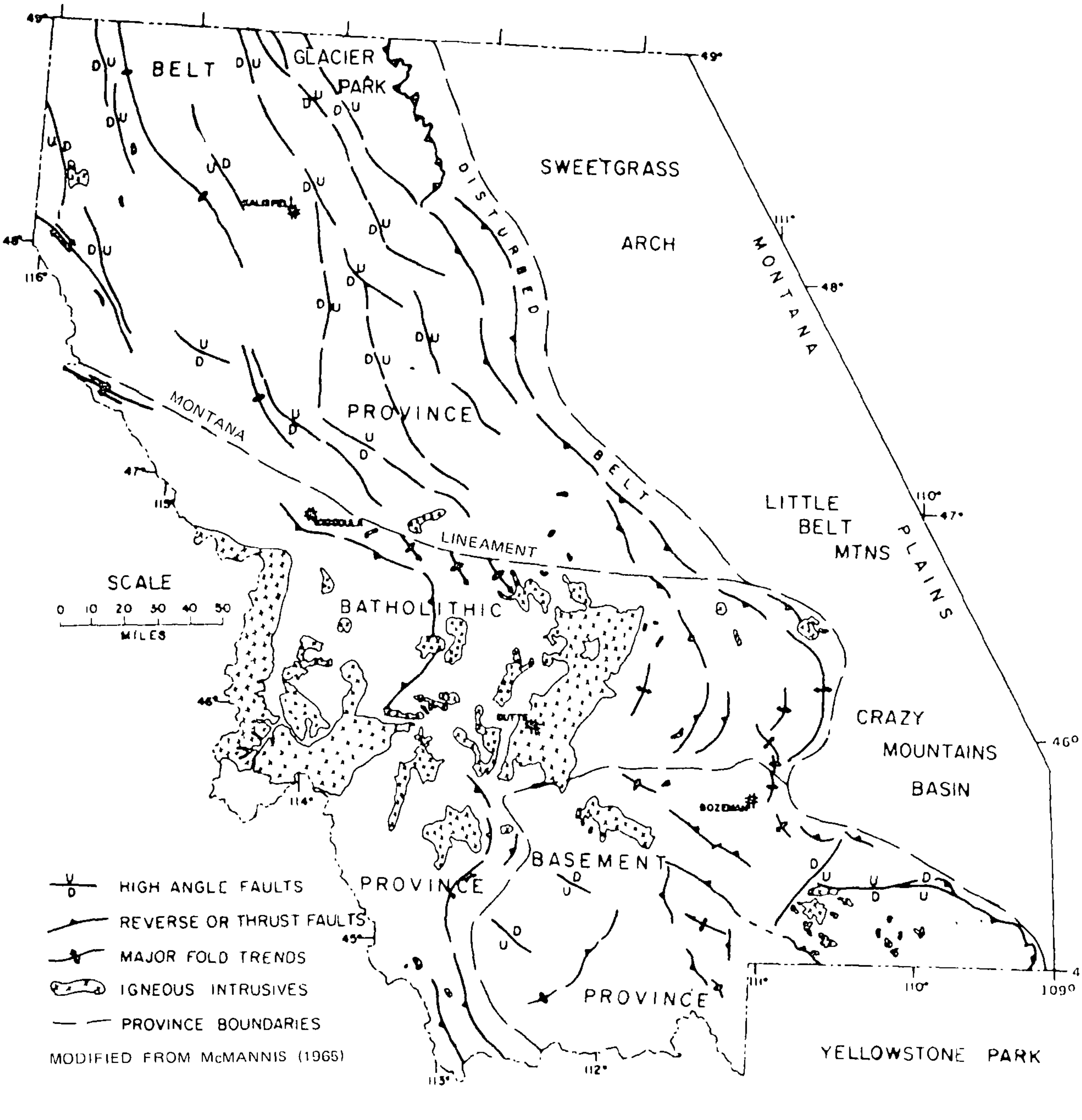

MILLION YEARS AGO
PERIOD
EPOCH
EUROPEAN AGE
W (SW)
FORMATIONS
E (NE)
CENOZOIC
MESOZOIC
PALEOZOIC
QUATERNARY
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PRECAMBRIAN
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
UPPER
MIDDLE
LOWER
Chattian
Maastrichtian
Campanian
Turonian
Cenomanian
Albian
Aptian
Oxfordian
Callovian
Bathonian
Toarcian
Pleinsbachian
Rhaetian
Norian
Karnian
Ladinian
Anisian
Scythian
Tatarian
Kazanian
Kungurian
Artinskian
Sakmarian
Stephanian
Westphalian
Namurian
Visean
Tournaisian
Famennian
Frasnian
Coblenzian
Gedinnian
Wenlockian
Llandoverian
Ashgillian
Caradocian
Llandeilian
Llanvirnian
Arenigian
Tremadocian
Lingula Flags
Menevian
Solvan
Comleyan
Tortonian
Z
Y
W
X
Beaverhead Congl
Montana Group
Colorado Group
Kootenai Fm
Morrison Fm
Swift Fm
Upper Sundance Fm
Sundance Fm
Lower Sundance Fm
Ellis Group
Rierdon Fm
Sawtooth Fm
Piper Fm
Gypsum Spgs. Fm.
Thaynes Fm
Woodside Fm
Dinwoody Fm
Shedhorn Fm
Phosphoria Fm
Park City Fm
Quadrant Fm.
Tensleep Fm
Devils Pocket Fm
Alaska Bench Fm
Amsden Fm.
Amsden Group
Tyler Fm
Big Snowy Grp
Heath Fm
Madison Group
Charles Fm
Mission Canyon Fm
Lodgepole Formation
Three Forks Fm
Trident Fm
Logan Gulch Fm
Birdbear Fm
Jefferson Formation
Maywood Fm
Beartooth Butte Fm
Bighorn Formation
Kinnikinic Fm
Lander Fm
Devils Glen Fm
Grove Creek Fm
Red Lion Fm
Pilgrim Fm
Park Fm
Hasmark Fm
Gallatin Group
Gros Ventre Group
Meagher Ls
Gordon Fm
Woolsey Sh
Silver Hill Fm
Flathead Sandstone
Belt Super Group
Pony and Cherry Creek Metamorphic rocks
Stillwater Complex rocks

FIGURE II-5

Structure

The structural geology of the Rocky Mountains region is extremely complex and variable throughout the area. Deformation occurred in several phases beginning in Late Cretaceous and extending to the end of the Paleocene. This deformation through folding, faulting and igneous activity has produced the mountain ranges and valleys of western Montana. Particular ranges are oriented so that they can be categorized into distinct geologic provinces.

Through a combination of geographic, structural and lithologic characteristics, the region can be divided into three separate provinces. The northernmost is the Belt province which lies north of the Montana Lineament and extends to the eastward margin of the Disturbed Belt. The area is characterized by northwest-southeast trending mountain ranges and accompanying high-angle normal faults. Precambrian Belt sediments outcrop across most of the area, while imbricate thrusts of Paleozoic and Mesozoic age comprise the Disturbed Belt. Northwest-southeast trending intermontane valleys filled with Cenozoic sediments are also characteristic of the region. Lying south of the Montana Lineament and north of the Basement Province is the Batholithic Province. This area contains numerous late Cretaceous and Tertiary igneous plutons, the best of which is the Boulder Batholith. Extrusive igneous rocks and irregularly shaped basins are also abundant in this province. The Basement Province is the third province of the region and is typified by its pre-Belt metamorphic assemblages. Northeast-striking, high-angle faults in this area demonstrate the regional stress orientation active during the Laramide Orogeny. The generalized tectonic map showing these provinces for the Rocky Mountains region is represented in Figure II-6. Because the Rocky Mountains region is so structurally complex and active, it has been placed in seismic risk zones of 2 and 3, moderate and major damage, respectively. Fault lines usually serve as good water conduits and are occasionally tapped by wells.



Generalized tectonic map of the Rocky Mountains region

Figure II–6

Since deformation of individual formations beyond meaningful aquifer units has occurred, four separate hydrologic units were identified for the Rocky Mountains region. The four units defined for the presentation are: consolidated sedimentary rocks--of all geologic ages; Tertiary basin-fill deposits; and Quaternary unconsolidated sediments. Also, because of the structural complexity of the region, no attempt was made to construct isopach or structure contour maps with the exception of Cenozoic basin-fill. Thicknesses of Cenozoic basins were determined largely by interpretation of gravity data because of the paucity of drill holes penetrating bedrock.

II. HYDROGEOLOGY BY AQUIFERS

QUATERNARY UNCONSOLIDATED SEDIMENTS

Alluvium and glacial deposits comprise most of the Quaternary unconsolidated aquifers, while other aquifers consist of colluvium and terrace gravel deposits. All of these sediments are composed of unconsolidated gravels, sands, silts and clays. Water availability from these deposits is widely variable and is dependent upon the characteristics of the deposits.

Alluvial aquifers border present-day streams. These aquifers consist of a variety of sedimentary sequences such as pointbars of cross-bedded sands, gravel lag deposits and finer-grained materials that form natural levees. The stream is hydraulically connected to the alluvial aquifer and there exists a definite surface-water--ground-water interaction between them. For the most part, the alluvium is a water-table aquifer and ground-water movement normally follows the topography in a downstream direction. An alluvial aquifer may also be a confined or semi-confined system when clays form impervious boundaries. Because these aquifers adjoin a stream, they tend to have an elongated surface expression. The increase in thickness and areal extent of an alluvial aquifer is usually directly proportional to the stream's average annual discharge except where the stream is constricted by resistant geologic formations.

The transmissivity and storativity of alluvial aquifers may vary considerably from one location to the next, reflecting depositional variations in the sediments themselves. However, an alluvial aquifer imparts a stronger horizontal than vertical conductivity. Transmissivity and storativity values for an alluvial aquifer are generally large and these aquifers will produce yields of up to 1,500 gallons per minute (gpm). Recharge to alluvial aquifers in western Montana is primarily from rainfall and snow-melt water, while additional amounts result from irrigation return flows and influent streams. Wells, effluent streams, evapotranspiration and leakage to underlying aquifers are the primary means of discharge. The ground water in alluvial aquifers has a generally dissolved solids content of around 350 mg/L and is highly sought for domestic and municipal use. Alluvial aquifers are one of the most important sources of ground water in the Rocky Mountains region.

Glacial aquifers are the other primary source of ground water among unconsolidated sediments. These Pleistocene-age deposits occur as till and glaciofluvial or lacustrine sediments that mantle bedrock and Tertiary sediments. They range from a few to hundreds of feet thick, depending upon their location and mode of deposition.

Because glacial till is a heterogeneous mixture of boulders, gravel and sand within a matrix of silt and clay, it has a relatively low hydraulic conductivity. Well yields from till are usually small and discharges range from 5 to 20 gpm. Near rock outcrops, the till contains an abundance of boulders and gravels and progressively becomes more clay-rich farther from the outcrops. When running water reworks the till, it sorts the glacial materials, removing the finer-grained deposits. The remaining deposits often resemble alluvium, but because of their mode of formation, are termed glaciofluvial deposits. These deposits are paleodrainages that were once Pleistocene river channels. This type of deposit covers a substantial area near Kalispell. Although glaciofluvial deposits may often be masked by a blanket of till deposited by an advance of glacial ice, their linear form often is surficially expressed on aerial photographs. Well yields increase measurably in glaciofluvial deposits because fluvial action has removed most of the silt and clay increasing porosity and permeability to produce a highly conductive aquifer. Wells and ground-water pits that have been completed in glaciofluvial deposits have yielded as much as 1,500 gpm with only a few feet of drawdown throughout the irrigation season.

In areas where glacial drift is thick and stratified, a number of aquifers can be found. Some areas have a deep artesian aquifer, a shallow artesian aquifer and a perched aquifer. Wells developed in the deep artesian aquifer have been found to be capable of yielding 3,500 gpm with almost no drawdown. Yields for the shallow and perched aquifers are primarily used for domestic wells, but yields of 500 gpm in some areas are possible.

The glacio-lacustrine sediments are a less common aquifer and are composed primarily of silt- and clay-sized materials that were deposited as glacial lake sediments. Well yields from these aquifers are exceedingly small. They are usually passed over for a better source due to their aquitard characteristics.

Depending on location throughout the Rocky Mountains region, there may exist only a single aquifer or a combination of these aquifers contingent upon the extent of glaciation. Recharge to the deep aquifers is dominantly from precipitation infiltrating along the mountain fronts, whereas the shallow systems receive direct infiltration. Minor sources of recharge are irrigation return flow, aquifer leakage and stream and lake seepage. Wells and springs account for most of the discharge with the remainder from evapotranspiration and effluent streams.

Water quality of glacial aquifers is generally very good, having an average dissolved solids concentration of 450 mg/L. This figure often varies though as a factor of depth and locality. The glacial deposits are the most important source of ground water in the northern half of the Rocky Mountains region because of their quality and quantity.

A number of wells are drilled in colluvium and terrace gravel deposits which are geomorphically expressed as fans and benches, respectively. Both colluvial fans and terrace benches are juxtaposed next to mountain fronts and are usually incised by ephemeral streams. Coarser-grained materials, such as cobbles and gravels, lie nearer to the mountain front, while finer-grained materials such as sand, silt and clay increase toward the center of the valley. These sediments interfinger laterally and show a marked decrease in hydraulic conductivity with distance from the mountain front until the valley stream is reached. Well yields of up to 200 gpm have been recorded, but values of 20 to 50 gpm are more representative of average well yields. Water from these wells is of good quality and primarily used for domestic and stock water purposes. Recharge is dominantly from precipitation, whereas springs and wells are the major medium of discharge. Colluvium and terrace gravels serve as a reliable source for small capacity wells.

TERTIARY VALLEY-FILL SEDIMENTS

Tertiary-age sediments comprise most of the basin-fill deposits found in western Montana's intermontane valleys. Originally, these terrestrial deposits were referred collectively to as the Bozeman Group (Robinson, 1963). Recent investigations by Kuenzi, Fields, Richard, Petkowich and others have divided the Bozeman Group into various formations dependent upon lithologic and paleontologic relationships. The Tertiary deposits in the basins of southwestern Montana are composed of a distinct upper and a lower sequence of sediments.

Although two separate formations are recognized, it appears detritus from the surrounding mountains infilled the basins under similar climatic conditions, but different drainage systems account for the varied lithologies. Volcanic ash seems ubiquitous to both formations and, according to Kuenzi (1966), the composition of the volcanic glass and clay mineral suite cannot be used to distinguish rock units or geologic age. Correlating the different formations from one basin to the next is a recognized problem that has yet to be unraveled.

Unconformably underlying the Quaternary unconsolidated sediments is the Six Mile Creek Formation and its equivalents of middle Miocene to Pliocene age. The formation is topographically expressed as pedimented slopes which dip toward the center of the valley. This formation is lithologically characterized by coarse-grained sediments of higher energy environments such as perennial and ephemeral streams. Typical lithologies include interbedded sandstones, channel conglomerates, tuffs and siltstones. Because of the coarse-grained nature of this formation, it represents a viable source for ground water. Wells penetrating this upper formation usually have yields of 5 to 35 gpm depending upon locations. Values for transmissivity and storativity for these sediments are generally unknown because only a few wells have been aquifer tested. Wells completed in Tertiary sediments are drilled to varying depths, but usually extend from 100 to 300 feet below the ground surface. The water quality of the Six Mile Creek Formation is fair to good and is suitable for domestic and stock-watering purposes. Values for dissolved solids range from 83 mg/L in the Bitterroot Valley to 1,268 mg/L in the Deer Lodge Valley, with an average of about 500 mg/L.

The lower sedimentary sequence, the Renova Formation, unconformably underlies the Six Mile Creek Formation. The Renova ranges from late Eocene to early Miocene age. This formation is dominantly comprised of finer-grained sediments indicative of restricted depositional environments such as ponds, lakes and floodplains. Common lithologies found in the Renova Formation include alternating layers of thin-bedded claystones, siltstones, poorly-sorted mudstones and tuffaceous deposits. Although these sediments probably contain a large amount of ground water in storage, the nature of the clays prevent it from being withdrawn. Because this formation generally occurs at substantial depths in the basins and does not readily produce ground water, it is seldom used as an aquifer.

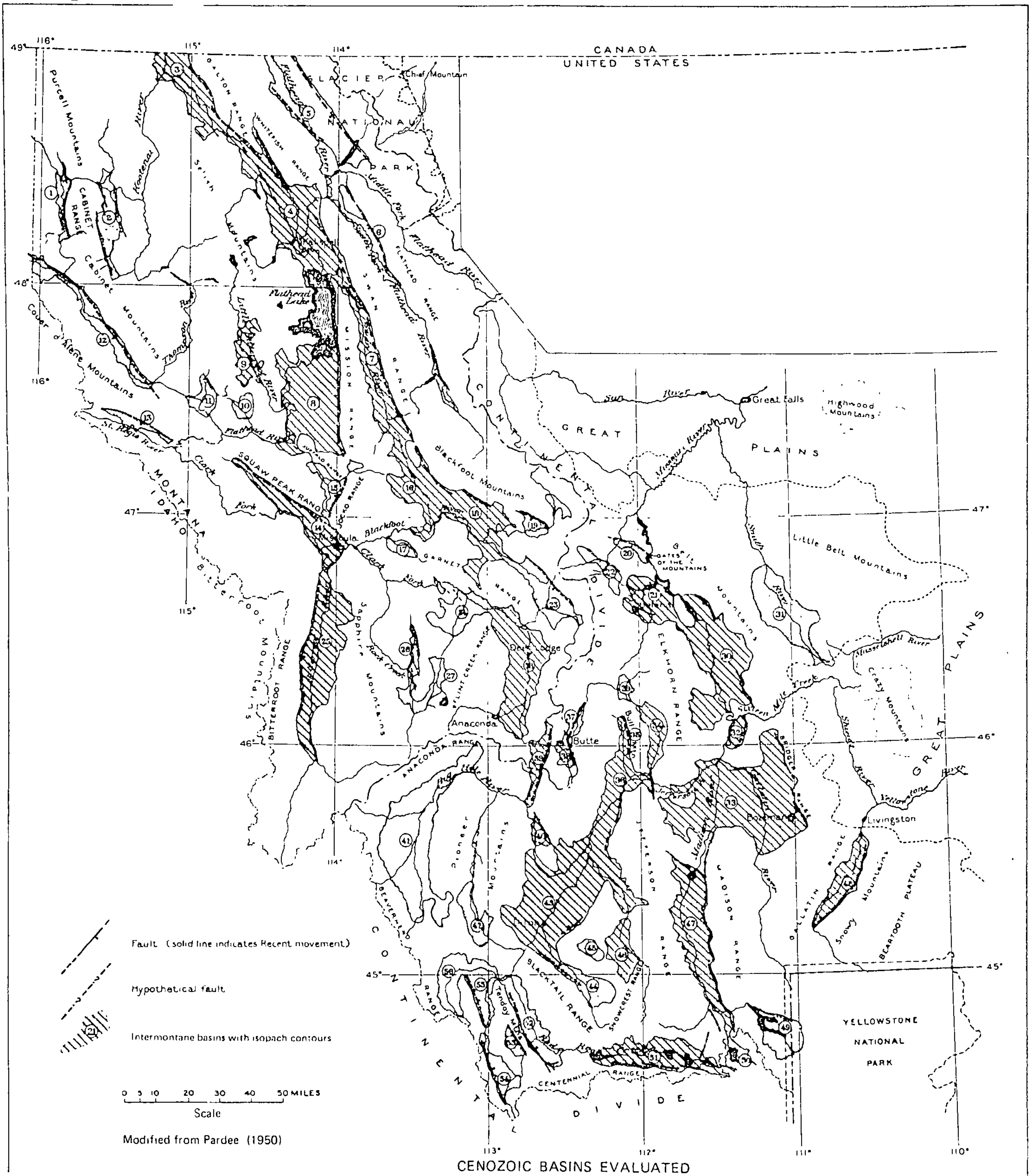
Recharge to Tertiary valley-fill sediments is derived from inter-aquifer seepage from the overlying stream alluvium and alluvial fans, infiltration from precipitation and irrigation return flows. Wells, springs, seeps and evapotranspiration account for most of the discharge from these sediments.

The thickness of the Tertiary sediments and the configuration of the basement bedrock of Montana's intermontane valleys have been largely unknown variables. In order to compile an aquifer thickness map for the UIC project, the valleys were computer-modeled where sufficient gravity surveys have been completed. The modeling program integrates Bouguer gravity values versus depth using a predetermined value for the difference between bedrock density and valley-fill density. Because very little is actually known about the degree of compaction or alteration of deeper sediments, a single density contrast value is used for the total depth of the sediments.

Inasmuch as this is a two-dimensional program, numerous gravity profiles across the valley were needed to construct isopach contours. The result is an interpretation of the total thickness of the Cenozoic sediments within the intermontane basin. Seismic investigations and scant drill-hole data were utilized to add credence to the predicted bedrock depths.

Many hours were spent obtaining the extensive information necessary to evaluate the basins. Additional computer time was also logged to generate supplementary data. Nevertheless, inaccuracies exist and revisions will be made as new information becomes available. It should be noted that many of the previous estimates of Cenozoic valley-fill thickness appear to be on the conservative side compared with projections in this report.

The following is a basin-by-basin analysis of the Cenozoic valley-fill thickness of selected intermontane valleys in western Montana and a summary of the ground-water occurrence in these valleys. Figure II-7 is a schematic diagram showing the locations of the intermontane valleys of western Montana and those which were evaluated.



CENOZOIC BASINS EVALUATED

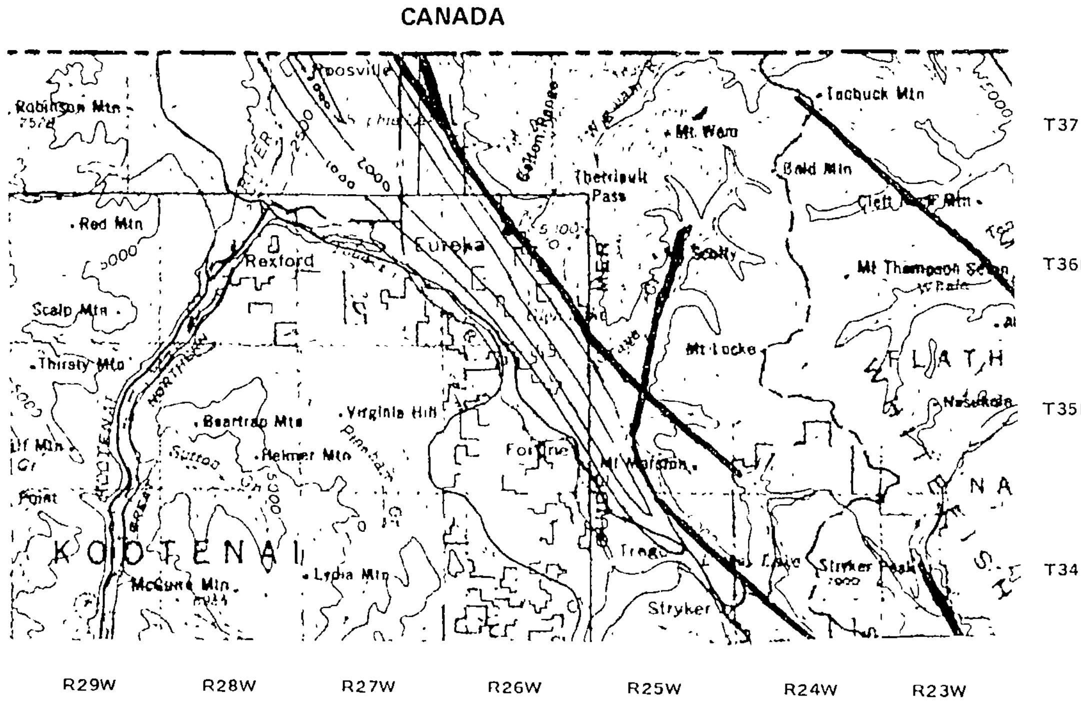
Figure II–7

The Tobacco Plains

The Tobacco Plains valley is located in the extreme northwest corner of the state. The valley lies within the Rocky Mountain Trench and is bordered by major longitudinal gravity faults (Coffin and others, 1971). The Whitefish Mountain Range forms the eastern wall of the valley, whereas the Salish and Purcell Mountains delineate its western border. The northern limit of the basin is the international border, although the valley extends into Canada.

Rocks outcropping along the valley margin, for the most part, belong to Precambrian Siyeh Formation with others being lower Piegan and Ravalli Group rocks. These rocks are inferred to underlie the Cenozoic fill in the valley. The types of sediments deposited in the valley during the Tertiary Period are unknown because they are not exposed and deep-test-hole logs are not available. Along the international border, gravity data indicate that the valley fill is slightly more than 3,000 feet thick at the center of the valley (See Figure II-8). Glacial deposits of unknown thickness overlie the Tertiary sediments. Three distinct periods of glaciation occurred in the valley, with the last glacial advance and retreat largely obscuring or eradicating earlier deposits (Coffin and others, 1971). This last glacial epoch is responsible for the formation of the major aquifers in the valley.

The hydrogeology of the Tobacco Plains is rather complex because of its glacial origin. The oldest aquifer of the area is the Precambrian metasedimentary rocks. Fractures in these rocks yield from 1 to 10 gpm of water to wells and springs. The ground-water availability of Tertiary sediments is unknown because of their undetermined presence. Glaciofluvial deposits are the most important source of ground water in the basin. These deposits are composed of moderately-to-well-sorted clays, sands and gravels. The thickness of these glaciofluvial deposits varies from one locale to the next and they are generally capable of 10 to 50 gpm sustained yields. Alluvium bordering the Kootenai River is the other primary source of ground water. Wells tapping the alluvium have



Isopach Interval: 1000 ft.

Map Scale· 1·500,000

Refer to basin no 3

Isopach of Cenozoic fill in the Tobacco Plains

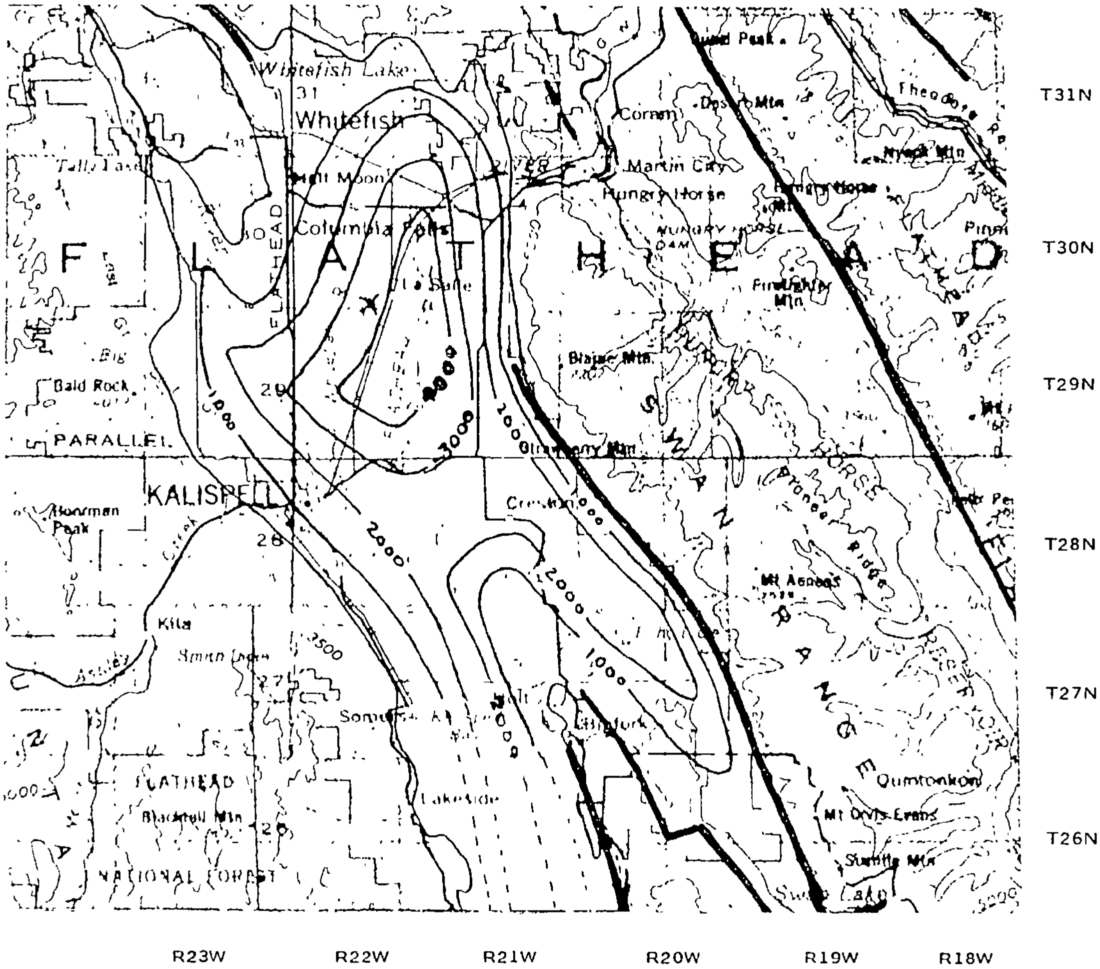
Figure II-8

yields ranging from 5 to 25 gpm, sufficient for domestic and stockwater use.

Overall, the ground water of the basin is of good chemical quality. Though the water is somewhat hard, it is suitable for domestic, stockwater and irrigation uses. Dissolved solids have an average value of around 300 mg/L and the major constituents are calcium, magnesium, sodium and bicarbonate. Precipitation accounts for most of the recharge to the aquifer system, with a minor amount contributed by irrigation runoff. Discharge occurs dominantly from wells, springs and evapotranspiration. Ground water also maintains a base flow for most of the streams in the drainage basin. The Tobacco Plains basin is sparsely populated, and to date has not placed substantial demands on the ground-water system.

Kalispell Valley

The Kalispell Valley lies in the southern portion of the Rocky Mountain Trench. The valley is bounded on the west by the Kalispell Fault which is located along the east base of the Salish Mountains. The Swan-Whitefish Fault forms its eastern border. The north shore of Flathead Lake is considered the southern limit of the valley, while the northern end progressively pinches out at Whitefish Lake. The structural framework of the valley is apparently controlled by a series of north-northwest-trending subparallel faults and two associated cross faults (see Figure II-9). The area north of the Creston Fault is a graben. These structural features contribute to spatially render the valley an elliptical bowl. Isopach contours show that the Cenozoic fill has a maximum thickness of 4,000 feet near LaSalle, Montana. South of the Creston Fault, gravity data indicate that the area around Big Fork is an upthrown block which is bounded by two smaller grabens. Both of these smaller valleys contain approximately 2,000 feet of valley fill (see Figure II-9). According to Konzeski, 1968, unconsolidated to semiconsolidated Tertiary rocks occur in many northern Rocky Mountain intermontane basins of comparable size, but none



Isopach Interval: 1000 ft.

Map Scale. 1:500,000

Refer to basin no. 4

Isopach of Cenozoic fill in the Kalispell Valley

Figure II-9

are exposed in the Kalispell Valley. It is assumed that Tertiary fill overlies the same Precambrian bedrock which crops out along the valley margins. The fill is probably comprised of Miocene and Oligocene age gravels, sands, silts and clays. An unknown thickness of Pleistocene glacial deposits of Wisconsin age then overlie the Tertiary sediments. The north-central and western parts of the valley are mostly morainal deposits composed of till, whereas the south end of the valley contains well-bedded clays and silts of glaciolacustrine origin. In some locales, dune sand or glaciofluvial deposits cover the area. Holocene alluvium overlies the glacial sediments along valley bottoms and borders the major streams. Point bars and floodplain deposits characterize alluvial deposits and generally are only a few feet thick. The hydrogeology of the Kalispell Valley is exceeding complex because of the heterogeneity of the glacial sediments. The discontinuity and interfingering of these deposits make it virtually impossible to predict aquifer parameters. Konizeski and others (1968) have delineated three distinct aquifer systems for this area: (1) the Holocene floodplain aquifer; (2) the Pleistocene systems comprised of a perched aquifer, a shallow artesian aquifer and a deep artesian aquifer; and (3) the Precambrian bedrock aquifer. Values for hydraulic conductivity contrast sharply depending on the nature of the sediments. Glaciofluvial deposits have high values for conductivity and are capable or producing yields exceeding 3,000 gpm, as is the case of a 400-foot well drilled in SE¼NW¼ sec. 27, T. 29 N., R. 22 W. Wells completed in till that has poor hydraulic conductivity, however, usually yield less than 5 gpm.

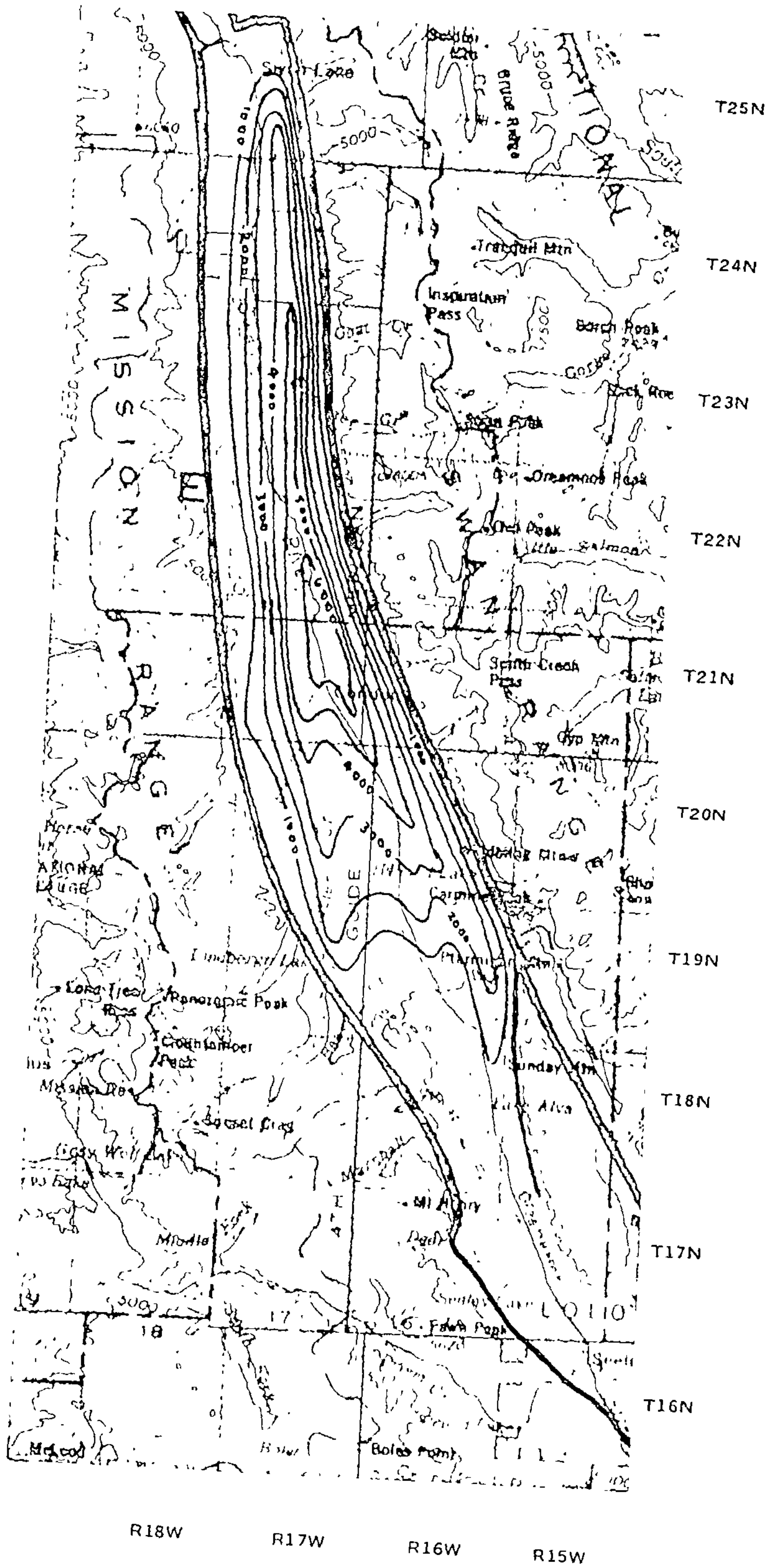
The availability of potable ground water in the Kalispell Valley is very good. Wells capable of yielding large amounts of water for irrigation or municipal supplies can generally be found in the deeper artesian aquifer. Domestic and stockwater wells producing from 10 to 20 gpm are common throughout the valley at shallow depths.

Values for dissolved solids average approximately 400 mg/L. The general water quality of glacial deposits is a dominantly calcium bicarbonate type which results in hard water. Recharge to the hydrogeologic system is primarily from rainfall and snowmelt water infiltrating along the mountain fronts with a minor amount from irrigation return flow and leakage from overlying aquifers. Most discharge is from evapotranspiration and wells, with the remainder occurring as springs and effluent streams.

Currently, the area along Highway 93 between the cities of Kalispell and Whitefish is rapidly developing, thus placing increased demands on the ground-water resources. The potential problem of lowering the potentiometric surface in the area is becoming more and more relevant. A comprehensive study of this area should be undertaken to determine the effects development is creating and to evaluate the ground-water resources for future development.

Swan Valley

The Swan Valley is located along the eastern branch of the Rocky Mountain Trench at its southern end. The Precambrian Belt strata of the Mission Range on the west and Swan Range of the east dip gently eastward forming the valley margins. The valley manifests an asymmetry about its north-south axis which is a surface expression of the controlling Swan Fault. Gravity data, however, demonstrates unequivocally that major faulting occurs at the valley's boundary with the Mission Mountains, although maximum depth to bedrock is nearer the Swan Range (Crosby, 1968). The valley fill attains a maximum thickness of 6,500 feet approximately five miles north-northwest of Condon (See Figure II-10). The valley began initially filling with material derived from the adjacent mountains during early Tertiary time. Tertiary or early Pleistocene sediments along the Swan River (T. 25 N.) are described by Alden as being rusty, clayey sand and buff sandy-clay with some gravel in which some of the pebbles are badly decomposed. They are overlain by lighter colored, grayish glacial drift containing striated pebbles. Elsewhere, Tertiary sediments are not exposed because



Isopach Interval 1000 ft.

Map Scale 1:500,000

Refer to basin no. 7

Isopach of Cenozoic fill in the Swan Valley

Figure II-10

they have been eroded, reworked or buried by glacial deposits. Retreating glaciers of Wisconsinan age have mantled the floor of the Swan Valley with a substantial thickness of glacial drift. These glaciofluvial and till deposits may be several hundreds of feet thick.

The hydrogeology of the Swan Valley is rather complex as a result of glaciation. Pleistocene and Recent alluvial sediments form the principal aquifers of the valley. A review of well logs within the valley determined that most wells were completed in till. Well yields are generally small, ranging from 1/2 to 50 gpm; an exception is the Forest Service's 330 gpm well at Condon. The average well yield is approximately 12 gpm. Ground water from the till is of good chemical quality and used dominantly for domestic purposes. The glacial till has low permeability in the center of the valley where most of the wells are drilled, but because sorting of deposits by proglacial streams occurred along the eastern margin, well yields would likely be higher there. The alluvium bordering the Swan River serves as the other reliable source of ground water. Well depths are shallow and sufficient quantities for domestic and stockwater use are easily obtained, making the alluvium a desirable source. North of Summit Lake, shallow ground water moves northward toward Swan Lake; south of the lake the flow is in a southerly direction.

Because of the paucity of information on the Tertiary deposits and scarcity of deep lithologic well logs, very little is known on the composition, water-bearing potential and general nature of these sediments.

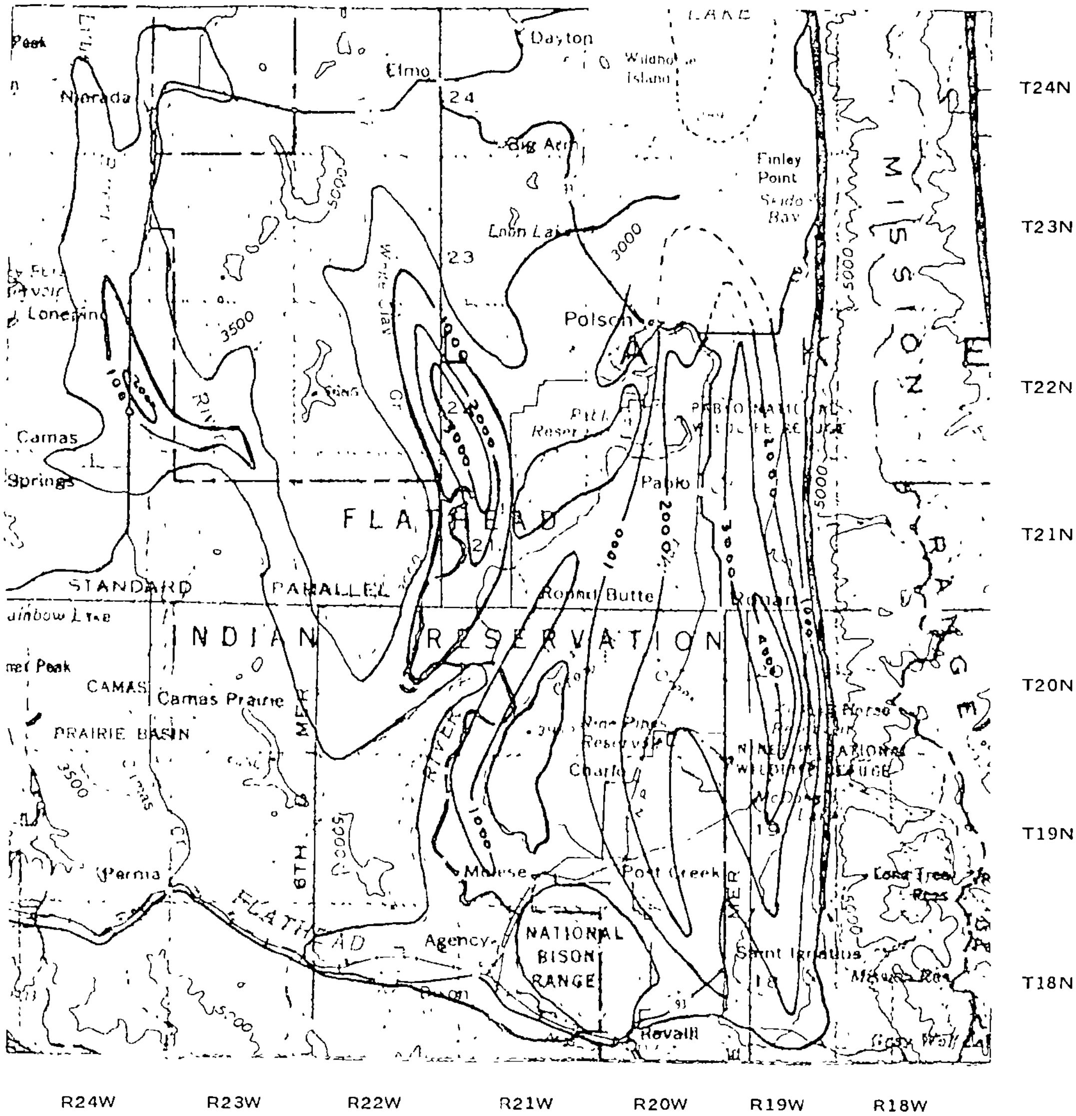
Recharge to the aquifer system is from precipitation and snowmelt infiltration along the mountain fronts. Discharge occurs through springs and wells, and ground water maintains a base flow for the Swan River during periods of low flow.

Mission Valley

The Mission Valley lies in the southernmost extension of the Rocky Mountain Trench. The eastern side of the valley is extremely linear which is indicative of the Mission Fault. This fault is a high-angle, normal fault with an apparent stratigraphic throw of about 15,000 feet down to the west. The southern border of the valley also has a linear expression which represents the St. Mary's Fault zone. Because of the Mission Fault, the valley has a distinct north-south alignment. Cenozoic fill is deepest near the east-central margin of the valley (approximately 4,000 feet to the Precambrian basement) and progressively thins to the west. Isopach contours have an elongated pattern, and this trend probably continues under the southern shoreline of Flathead Lake (see Figure II-11). Gravity data west of the large Mission Valley manifests a smaller valley, structurally independent of the main basin. This valley is also elongated along a north-south axis and attains a maximum depth of 3,000 feet. Preliminary geologic mapping by Harrison and others (1974) revealed that an anticlinorium coincides with the axis of this fault-bounded valley.

The oldest rocks in the valley are of Precambrian age. They are probably overlain by Tertiary sediments; however, no reference has been found of Tertiary outcroppings or presence on well logs. Overlying the Tertiary strata are Quaternary glacial and lake bed deposits and Holocene alluvium. The Precambrian rocks, for the most part, are argillites with some quartzites and limestones present. Wells or springs which tap these sediments along fractures usually yield less than 10 gpm. The potential for ground water in Tertiary sediments is unknown because of its uncertain presence.

Glacial deposits are the most important source of ground water in the Mission Valley, but well yields are unpredictable because of the heterogeneity of the aquifer material. Wells drilled in morainal material generally yield small amounts of water, but there are large capacity wells of more than 300 gpm tapping glacial deposits near Ronan and Polson (Boettcher, 1980). In some areas a confining layer overlies glacial or alluvial deposits creating flowing artesian conditions. Flowing wells yield as much as 600 gpm near Ronan (Boettcher, 1980). Dissolved solids have an average value of around 350 to 400 mg/L and the chemical



Isopach Interval. 1000 ft.

Map Scale. 1 500,000

Refer to basins no. 8 and 9

Isopach of Cenozoic fill in the Mission and Little Bitterroot Valleys

Figure II-11

quality of ground water derived from glacial deposits is generally good.

Well yields range from 10 to 400 gpm for the alluvial aquifer. These yields are largely dependent on location and well completion with the average yield approximately 40 to 50 gpm. The alluvial aquifer serves as a potable source for numerous domestic and stockwater wells. Overall water quality of the alluvium is good, but the water is somewhat hard. Recharge to the aquifer system is from precipitation, snowmelt runoff, influent streams and irrigation return flows. Discharge occurs from well pumping, springs and evapotranspiration. Ground water is a valuable resource for the inhabitants of the Mission Valley. Whereas all the towns in the valley depend partly or entirely on ground water for their supply, the rural residents are totally dependent on wells and springs for their livelihood.

Little Bitterroot Valley

The Little Bitterroot Valley is a structural depression, probably bounded by high angle normal or listric normal faults of Tertiary age (Donovan and Sonderegger, 1981). Geological mapping by Harrison and others (1974) shows a series of north-northwest trending normal faults transecting the valley. Encompassing the valley are various Precambrian-age formations. A geothermal test well near Campaqua encountered what was thought to be Precambrian Ravalli Group rock at 264 feet below land surface. Gravity data demonstrates a bedrock high at this well site and also suggests that the Cenozoic fill rapidly deepens approximately three miles due west. The fill attains a maximum thickness of more than 2,000 feet in the south-central part of the valley based on gravity data calculations (see Figure II-11).

Although Tertiary sediments were absent in the geothermal test well, there are Tertiary outcroppings of volcanoclastic sandstones and conglomerates, ash layers and fluvial sediments along the northern margins of the valley. It is likely that similar Tertiary deposits overlie the Precambrian bedrock floor in the deeper segment of the valley, but may have been removed by Pleistocene glacial erosion in localized shallow areas. Glaciofluvial and glaciolacustrine deposits unconformably overlie Tertiary and Precambrian rocks and can be continuously correlated over the entire basin. Donovan and Sonderegger and others (1981) describe a permeable Pleistocene gravel bed of an estimated 20 to 60 feet thickness occurring extensively throughout the valley. The top of the gravel bed appears to be nearly planar and is overlain by 200 to 300 feet of homogenous silty clays of glacial Lake Missoula. These silts are surficially present over most of the valley. The Little Bitterroot River has deposited an alluvial veneer along the eastern margin of the valley.

The hydrogeology of the Little Bitterroot Valley is extremely complex because of the interrelationship of the separate aquifers. Deep fractures in the Precambrian rocks provide conduits for the circulation of hydrothermal waters. Localized hot and warm springs issue from these fractures. Wells reaching this aquifer have yields of up to 800 gpm and water temperatures of approximately 45°C. Although the water is somewhat mineralized by sulfate, manganese and iron, it is generally softer because of the higher sodium concentration. Average values for dissolved solids are approximately 400 mg/L. The potential availability of ground water in Tertiary sediments is presently unknown, though Boettcher (1980) believes water from these deposits has high iron concentrations.

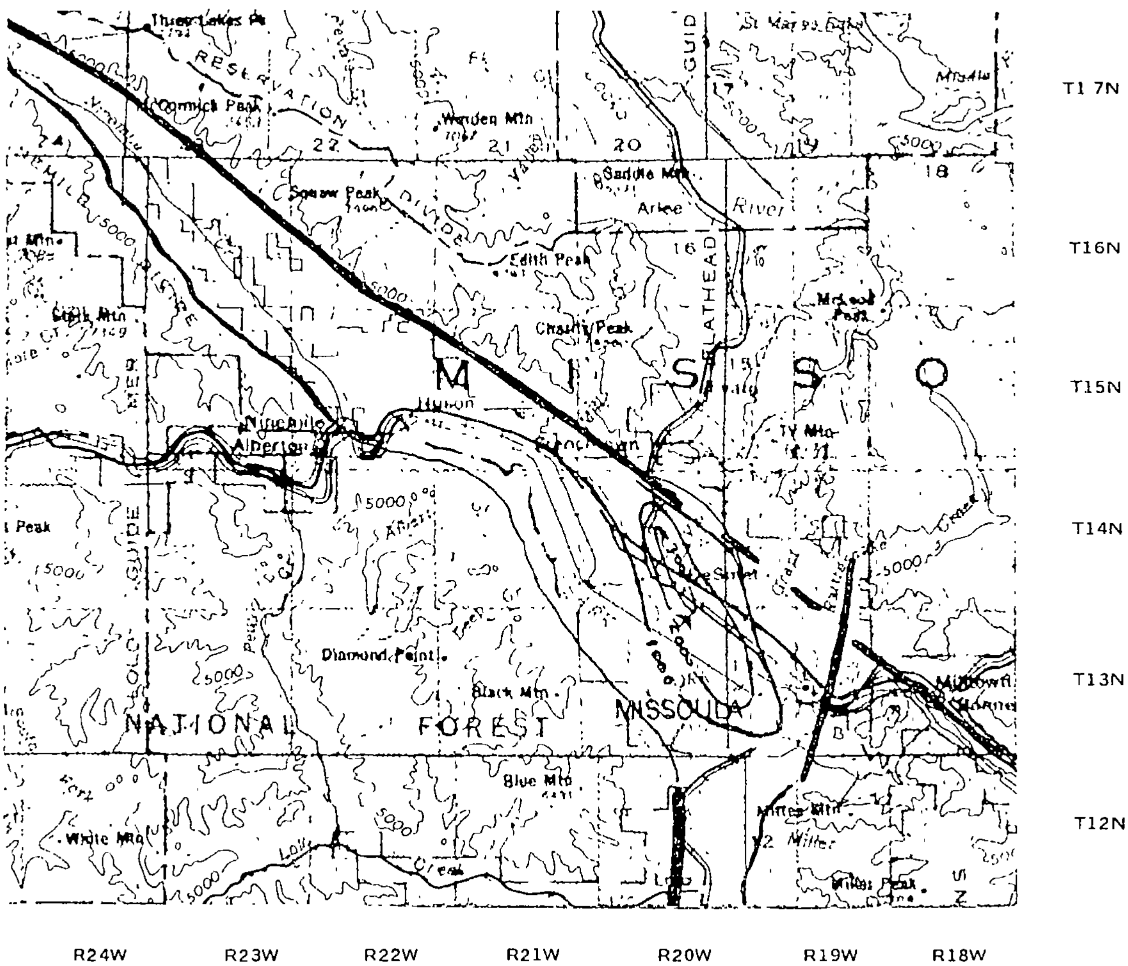
Locally, the aforementioned Pleistocene gravel aquifer appears to be hydraulically interconnected with the Precambrian system and probably recharged through vertical leakage and infiltration. This aquifer produces flowing artesian wells and is ubiquitously used for irrigation in the valley. Water levels in wells penetrating this aquifer decline during the irrigation season and rise the rest of the year. Long-term records (8 years) show a net water-level decline in the area, probably owing to the large number of flowing irrigation wells (Boettcher, 1980). It appears this gravel aquifer has reached its appropriation limit and further exploitation may result in lowering of water pressures to the point that wells will no longer flow. The overall water quality is generally good. Ground water from the alluvium of the Little Bitterroot River is moderately used. Wells tapping the alluvial aquifer are producing substantial yields, but it is dominantly used for domestic and stockwater purposes.

Recharge to the ground-water system is from precipitation, snowmelt runoff and irrigation return flow. Discharge is primarily the result of irrigation wells, springs and evapotranspiration.

Missoula-Ninemile Valley

The Missoula and Ninemile Valleys form an elongated northwest-trending trough approximately 42 miles long that is commonly referred to as the Missoula Basin. Geomorphically represented as a linear succession of truncated spurs along the southern margin of the Reservation Divide Mountains, the Ninemile Fault delineates the northeastern edge of the valley. The southwest side of the valley is formed by the Bitterroot Range and the Ninemile Divide Mountains. The basin was formed by extensional faulting which downdropped the bedrock floor during early Tertiary time. Contemporaneous with downfaulting, the basin began filling with detritus eroded from the surrounding mountains into which were interbedded layers of volcanic ash. The resultant deposits of interbedded shale, ash and conglomerate were subsequently mantled by a few hundred feet of well-sorted channel gravel and sand of Pliocene age (McMurtrey and others, 1964). The Clark Fork River has dissected the valley deposits and has mantled the glacial sediments with an alluvial veneer along its course. The sediments have a cummulative thickness of more than 3,000 feet near the airport (see Figure II-12).

There are three basic aquifer units within the Missoula Basin: Holocene to Pliocene-age unconsolidated deposits forming the floodplain of the Clark Fork River and the remainder of the valley floor; Tertiary sediments of the Oligocene age which underlie the alluvium or border it as terrace deposits; and a Precambrian bedrock aquifer. The alluvium is composed of discontinuous layers of



Isopach Interval: 1000 ft.

Map Scale: 1.500,000

Refer to basin no. 14

Isopach of Cenozoic fill in the Missoula-Ninemile Valley

Figure II-12

gravels, sand and clay that range in thickness from a few feet to 250 feet; the maximum thickness is near the mouth of Grant Creek (Geldon and Curry, 1978). Well yields vary depending upon use; some large irrigation and municipal wells have yields in excess of 4,000 gpm. The chemical quality of water from the alluvium is generally excellent; the average dissolved solids concentration is 175 mg/L. Alluvial ground waters are generally a calcium bicarbonate type, and therefore, moderately hard. Recharge to this system is from precipitation, irrigation return-flow and losing streams. Aquifer discharge is from well pumpage, evapotranspiration, seepage to underlying units and losses to maintain stream baseflow.

The Oligocene sediments are characterized as semiconsolidated bedded deposits of sand, silt, clay, ash and gravel; these rocks underlie Holocene to Pliocene-age sediments, but are best exposed as sloping sediments. Well yields from these deposits are generally small, ranging from 1 to 20 gpm, because of the fine-grained nature of the sediments. Tertiary rocks account for the majority of the valley fill and may be up to 3,000 feet thick. Dissolved solids content of ground water from Tertiary sediments averages 300 mg/L, which is quite low. Because well yields are small, the ground water is generally used for domestic and stockwater purposes. Recharge is from precipitation and infiltration from the overlying alluvium. Discharge occurs as springs and well pumpage.

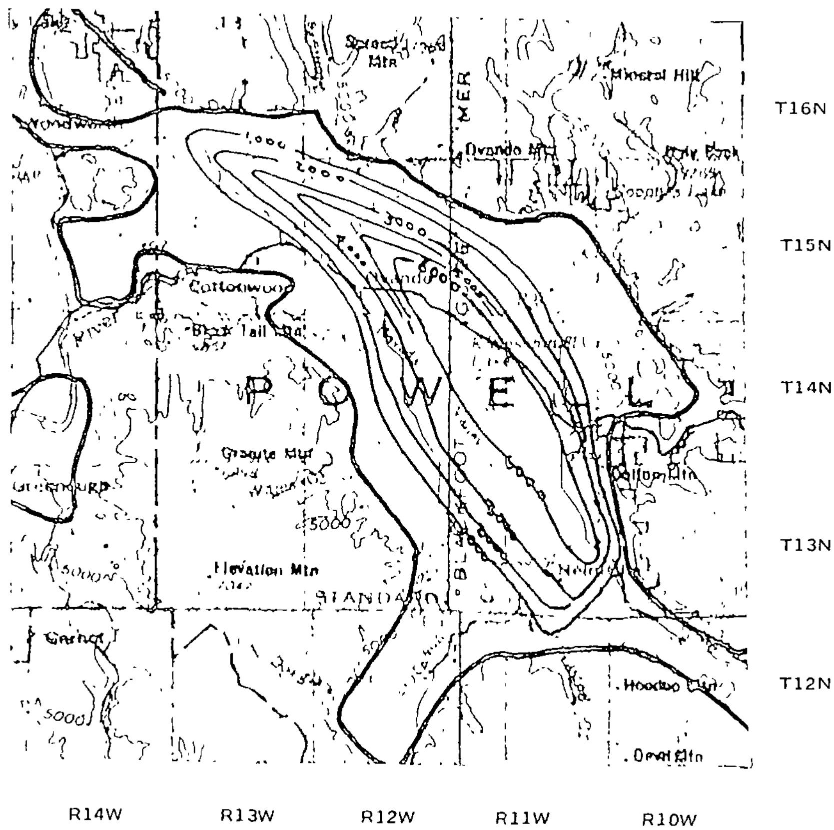
The Precambrian bedrock aquifer is of only minor importance because it is relatively impermeable. Fracture systems within the bedrock yield small quantities (1-5 gpm) of water. Little is known of the water quality of this aquifer, but the water appears to be potable.

Blackfoot Valley

Although gravity data suggest that the Blackfoot and Nevada Valleys are separate basins, they are topographically continuous. For this reason they are jointly referred to as the Blackfoot Valley in this report. This intermontane valley, located in the northern part of Powell County, has a general northwest trend. The Blackfoot Mountains, composed of Belt Supergroup rocks, form the northeastern border of the valley. At the base of this range is an unnamed valley-margin fault. It is a high angle normal fault dipping to the southwest (Witkind, 1975). The northwestern part of the Garnet Range forms the southwestern border of the valley. These mountains are also composed of Precambrian Belt Supergroup rocks. Small bodies of quartz monzonite occur locally in the strata and extensive Tertiary basalts and andesites outcrop near Helmville.

Block faulting and tilting occurred intermittently during deposition and continued in late Oligocene and (or) early Miocene time, after which the region was deeply eroded (Cantwell, 1980). Again, during late Miocene and Pliocene time, block faulting recurred and detritus eroded from the surrounding mountains, infilling the basin. During Pleistocene time, glaciers advanced and retreated across the valley. Deposits of glacial outwash and till cover most of the Tertiary valley-fill deposits north of Helmville. The low rolling hills which dominate the present valley floor were formed by the glaciers (Cantwell, 1980). Quaternary stream and fan alluvium mantle the glacial deposits in some locales. Gravity data indicate that the Tertiary and Quaternary deposits attain a maximum thickness of more than 6,000 feet near the center of the valley (see Figure II-13). It is assumed that similar Belt Supergroup rocks underlie Cenozoic sediments.

Ground water in the Blackfoot Valley is derived mainly from the Quaternary alluvial and glaciofluvial deposits. These deposits are composed of unconsolidated gravels, sands, silts and clays that are moderately well-sorted. The average thickness of the alluvium along the Blackfoot River is probably 80 to 100 feet. Wells completed in alluvial and glaciofluvial sediments generally produce good-quality water that has concentrations of dissolved solids ranging between 150 and 250 mg/L. Well yields for the alluvial aquifer are usually about 20 to 25 gpm. Glacial till covers much of the Blackfoot Valley. The till consists of a heterogeneous mixture of unsorted and unconsolidated gravels and boulders in a



Isopach Interval. 1000 ft.

Map Scale· 1·500,000

Refer to basin no. 18

Isopach of Cenozoic fill in the Blackfoot Valley

Figure II-13

silty to clayey matrix. The till can be up to 150 feet thick but has low well yields ranging from 5 to 15 gpm. Underlying the glacial and alluvial deposits is Tertiary valley-fill. The Tertiary sedimentary rocks in this area are a semiconsolidated light-gray, sandy clay containing interbedded lime marl and conglomerate. These sediments have a high percentage of fine-grained materials and are therefore not very permeable. Well yields are small from Tertiary sediments, averaging about 5 gpm.

Precambrian meta-sediments and Tertiary volcanic rocks serve as another source of ground water. Generally, wells completed in these rocks yield only small quantities of water from fractures. However, there are two large capacity wells in T. 12 N., R. 12 W., section 23 and section 28 that produce 3,000 and 350 gpm, respectively. It is believed the wells are completed along a fracture network in Tertiary basalts.

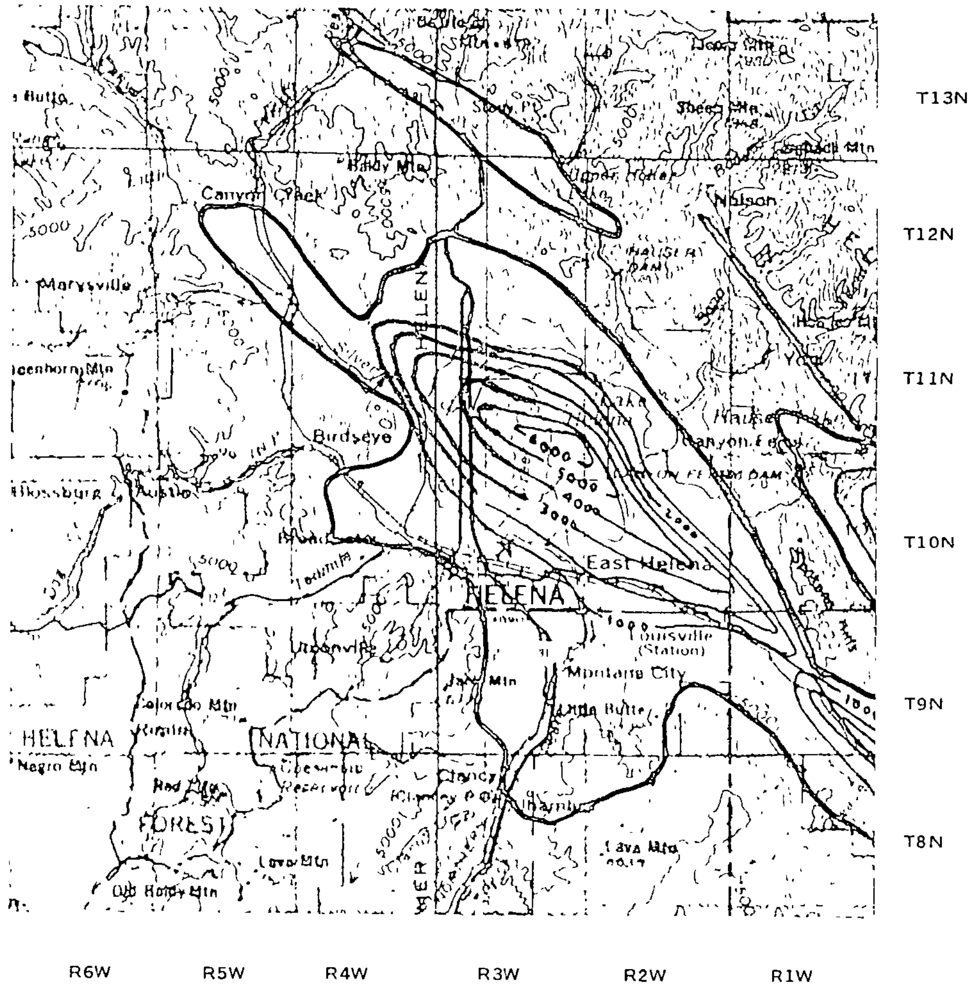
All the geohydrologic units in the Blackfoot Valley are recharged directly or indirectly by precipitation. Rain, snowmelt-runoff and influent streams account for most of the recharge. Ground water is discharged to springs, effluent streams and to the atmosphere by evapotranspiration. Discharge by wells is minimal even though most residents use water supplied by wells.

Prickly Pear Basin (Helena Valley)

The Prickly Pear basin, or Helena valley, is roughly a nearly-circular basin surrounded by mountains: the Big Belt Mountains on the north; Scratchgravel Hill on the west; Elkhorn Mountains on the south; and Spokane Hills on the east. Drainages between each of these mountain ranges lead to other Cenozoic basins. Most of the bedrock exposed in the mountains east, north and west of the Helena valley belong to the Belt Supergroup. Paleozoic and Mesozoic rocks outcrop along the southern valley margin. Granodiorite and related rocks of the late Cretaceous Boulder batholith intruded and metamorphosed sedimentary rocks along the south and west margins of the Helena valley. At the southern edge of the valley, the Elkhorn Mountain Volcanics overlie sedimentary and intrusive rocks in the northern Elkhorn Mountains.

The Helena valley is a northwest-trending structural and topographic basin which began to form in early or middle Tertiary time by block faulting, possibly along pre-existing zones of basement weakness. Two major northwest-trending fault zones bound the valley. The Prickly Pear fault zone (northeast side down) roughly parallels the southwest valley margin. A 9.5 mile segment, half the total trace length of the Prickly Pear fault zone, lies buried beneath young alluvial deposits in the western part of the valley. A part of the Lewis and Clark line, the Helena valley fault zone (southwest side down) consists of five segments which form the northeast valley margin. The western segments are remarkably linear and appear to offset middle Pleistocene deposits. Along the southwest side of this fault zone, basin-fill deposits reach a maximum thickness of 6,000 feet and average over 3,000 feet thick along most of the fault's length (see Figure II-14). The sediments gradually thin in the western and southern parts of the valley. Numerous small faults near the southern Scratchgravel Hills and along the northwest valley margin offset deposits as young as late Pleistocene, but do not appear to define an extensive fault zone.

The oldest recognized Tertiary clastic deposits include well-bedded olive-gray to yellowish clay, tan siltstone, light gray, poorly sorted arkosic sand, rounded to subangular pebble gravel and thin lignite beds of probable Oligocene age. Rocks of similar age outcrop along the southern valley margin and include white to gray well-indurated volcaniclastic rocks containing pumice fragments and rhyolite pebbles. The Tertiary deposits covering 80 percent of the eastern Helena valley consist of tan, micacious siltstone with interbedded sandy pebble and cobble gravel. Probably middle Miocene to Pliocene in age, this siltstone is generally coarser-grained than the Oligocene deposits. Early Pleistocene and possibly latest Tertiary alluvial deposits, cap ridge tops along the southern valley margin and form eroded and faulted hills along the northeast portion of



Isopach Interval: 1000 ft.

Map Scale: 1:500,000

Refer to basin no. 21

Isopach of Cenozoic fill in the Prickly Pear Basin

Figure II-14

the Helena valley. A veneer of poorly-sorted, silty gravel covers extensive pediment surfaces developed along the northwest and southwest perimeter of the valley. Late Pleistocene to Holocene alluvial plain deposits which overlie the western Helena valley probably do not exceed 150 feet in thickness. Other unconsolidated deposits outcropping over relatively small areas include channel and terrace alluvium, loess, strath terrace remnants along the Missouri River and fine sand, silt, clay and minor gravel deposits of Glacial Lake Great Falls (Stickney and Bingler, 1981).

Ground water in the Helena valley is derived from three separate aquifer units, distinction of these units is based on their relative geologic ages and lithologic characteristics. The units are: 1) a bedrock aquifer; 2) Tertiary age sediments; and 3) various deposits of Pleistocene and Holocene times.

The bedrock aquifer consists of a variety of sedimentary rocks ranging from Precambrian to Cretaceous age and late Cretaceous and early Tertiary age igneous rocks. The oldest rocks of the valley are the Precambrian meta-sediments belonging to the Belt Supergroup. They are composed of red, green and brown argillites and red and white quartzites, which outcrop along the east, west and north margins of the valley. Paleozoic and Mesozoic rocks made up of brown to white quartzite and sandstone, black to brown shale, and bluish-gray to tan limestone and dolomite are exposed along the southern valley border (Stickney, 1981). In some locales, the eastern extension of the Boulder Batholith has intruded and metamorphosed the pre-existing sedimentary rocks of the southwestern margin. Andesites and tuffs of the Elkhorn Mountain Volcanics have also interdivided and overlie sedimentary rocks in the southern portion of the valley. For the most part, these rocks are well indurated and contain no interstitial water. Wells drilled along the periphery of the Helena valley are completed in this bedrock aquifer and attempt to intersect bedrock fractures of joints to obtain sufficient yields. Well yields usually average 5 to 10 gpm and are of good chemical water quality for domestic and stock use.

Tertiary-age sediments comprise another aquifer unit in the valley, but also have limited use. These sediments, which overlie bedrock and underlie Quaternary deposits, account for the major portion of basin-fill deposits. Tertiary sediments outcrop in the southern part of the valley and cover a large area in the eastern part of the valley. In general, the basin-fill deposits are composed of detrital materials eroded from the surrounding mountains. The oldest recognized Tertiary deposits include well-bedded, olive-gray to yellowish clay, tan siltstone, light gray, poorly-sorted arkosic sand, rounded to subangular pebble gravel and thin lignite beds of probably Oligocene age (Stickney, 1981). Interbedded volcanic ash and flows of similar age are exposed along the southern border of the valley. Overlying the Oligocene deposits are Miocene and Pliocene age sediments. These coarser-grained sediments are composed of gravels and sands in a silty-clay matrix and are laterally discontinuous. Exposed Tertiary sediments are generally unconsolidated and tend to become semi-consolidated with depth of burial.

The fine-grained nature of these sediments limits the permeability of this aquifer unit. Most wells obtaining ground water from Tertiary sediments have yields of 15 to 30 gpm, but some of the deeper wells have yields in excess of 200 gpm. In some cases, wells have tapped confined water-bearing zones which yielded water under artesian conditions. These wells are in the lower part of the valley and include wells at the Masonic Home in T. 11 N., R. 3 E., section 2 and at the Montana State Vocational School in T. 11 N., R. 3 W., section 34 (Lorenz and Swenson, 1951). The overall ground-water availability from this aquifer unit is highly variable and dependent upon location and the composition of the deposits. This ground water is somewhat hard, but it is suitable for domestic, stockwatering and irrigation purposes. Some wells produce water with iron and manganese concentrations higher than recommended limits for potable supplies. Although these concentrations are not detrimental to health, they give the water an undesirable taste and stain fixtures reddish-brown. A possible source of these chemicals is the solution of iron and manganese oxides that have formed coatings on the gravel and boulders in the basin-fill deposits (Wilke and Coffin, 1973).

Pleistocene and Holocene-age deposits serve as the most prolific and readily available source for ground water in the Helena valley. Late Pleistocene to Holocene-age unconsolidated alluvial plain deposits mantle the floor of the Helena valley. These deposits are composed of a heterogeneous mixture of gravels, sands, silts and clays, and are usually moderately-sorted from fluvial processes. A large portion of the finer-grained material is carried off downstream. This loss of fine-grained material enhances the permeability of these sediments. The sand and gravel layers of this aquifer yield water freely to wells, but often interfinger with impermeable clay beds and, for this reason, are laterally discontinuous. Because of the heterogeneous nature of the sediments, the layers of sand and gravel form a complex, but generally interconnected, system of aquifer zones that are considered as one multiple-aquifer system. Several large-capacity wells (pumping in excess of 500 gpm) have been constructed, and most irrigation wells derive their supply from these sediments. A transmissivity of about 10,000 gallons per day represents a reasonable estimate for the alluvial aquifer penetrated by most shallow wells in the southern part of the valley (Moreland and Leonard, 1980).

A thin veneer of poorly-sorted gravel covers extensive pediment surfaces of middle Pleistocene age. These surfaces are extensively developed along the northwest and southwest sides of the Helena valley. Most of the city of Helena is built on such deposits. These deposits have a moderate degree of permeability and supply ample water for domestic and stockwater uses. Other unconsolidated deposits that outcrop over relatively small areas throughout the basin include loess deposits, strath terrace remnants along the Missouri River and lacustrine silts and clays of Glacial Lake Great Falls. They are only of nominal importance because their well yields are very small.

With few exceptions, ground water from this aquifer is of good-to-excellent quality. Chemical analyses show the water is dominantly a calcium bicarbonate type, however, a well's proximity can influence the type. Although there is variation in some instances, the concentration of dissolved solids in water from most wells sampled in the valley is less than 400 mg/L.

Infiltration from rainfall, snowmelt-runoff and irrigation return flows account for most of the recharge to the aquifer system. Other sources of recharge are influent stream losses and inter-aquifer leakage. Ground-water discharge in the valley occurs from evapotranspiration, wells, springs, seeps and losses to effluent streams.

Bitterroot Valley

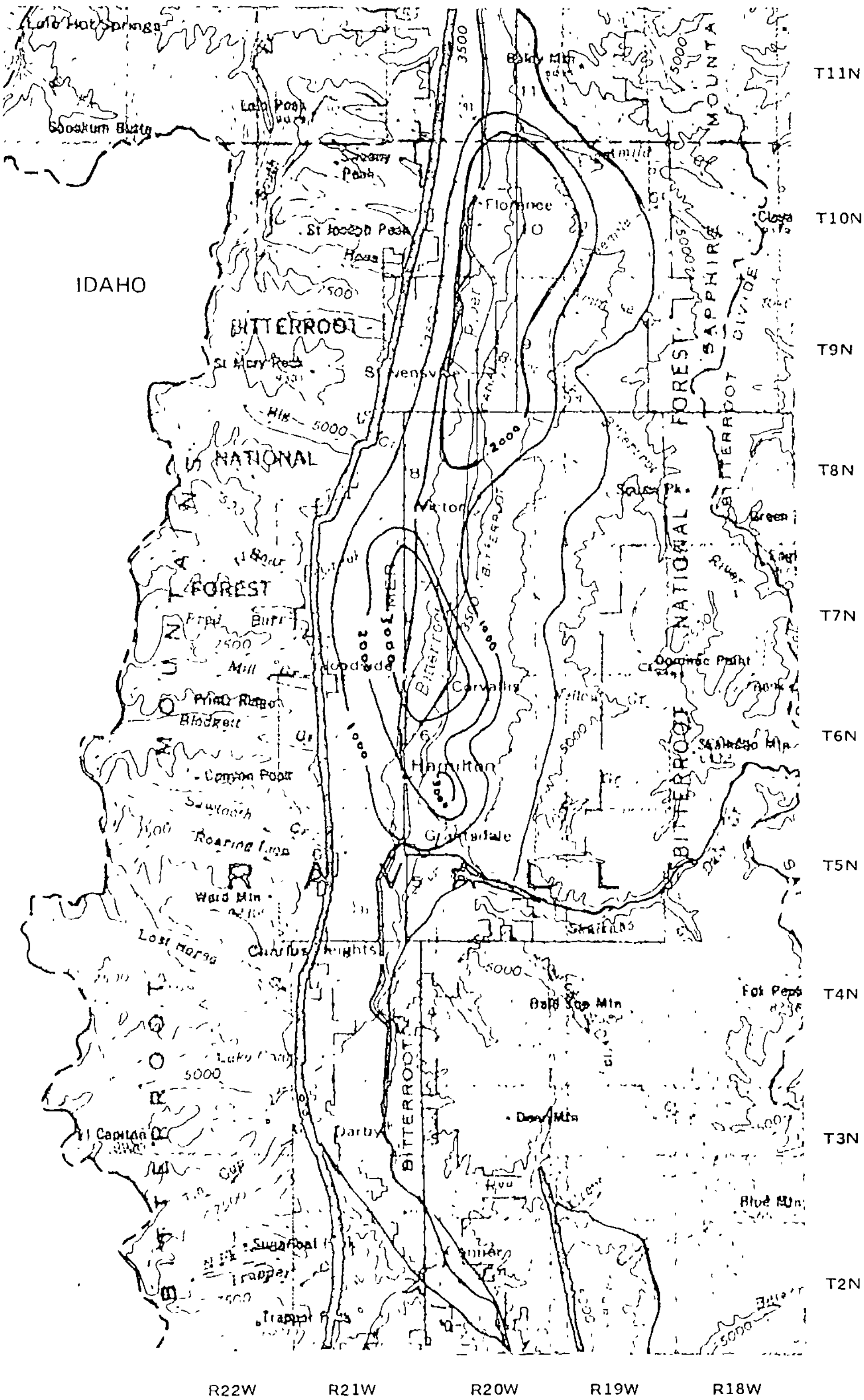
The Bitterroot Valley is topographically expressed as a wedge-shaped intermontane basin in west-central Montana. The valley's asymmetry about its north-south axis is a surface expression of the controlling Bitterroot Fault along the western margin of the valley. This high angle normal fault dips steeply to the east and forms the triangular facets on the eastern face of the Bitterroot Range. Activity along the fault may have been as recent as historic time (Witkind, 1975). The Bitterroot Range is a high-grade metamorphic complex derived from lower Beltian sedimentary rocks which border the Idaho batholith (Wehrenberg, 1968). The Sapphire Mountains form the eastern border of the valley. The northern portion of the Sapphire Range is composed of Precambrian Belt sediments, whereas the southern portion is Cretaceous to early Tertiary-age granitic rocks.

The surface of the Bitterroot valley is largely an alluvial floodplain, but also has low-to-moderately high gravel-veneered Tertiary terraces along the eastern margin. Except for an area of Tertiary volcanic rocks south of Hamilton, the west side of the valley appears to be underlain by later (Quaternary) alluvium including glacial moraines and outwash from the Bitterroot Range (Pardee, 1950). The alluvium, glacial deposits and Tertiary tuffs and sediments together compose the valley-fill. Gravity data suggest that these Cenozoic sediments attain a thickness of more than 3,000 feet between the towns of Woodside and Corvallis (Figure II-15). The isocontours also show the valley-fill thins in the vicinity of the town of Victor. This apparent bedrock high is probably related to a thinner section of valley-fill rather than a bedrock density change. It should be noted the contour pattern along the east margin of the valley is very irregular, indicating that the eastern wall of the Bitterroot valley has a different structural origin than the western margin (Lankston, 1975).

Although the Bitterroot valley has been besieged by residential development, there still exists only sparse data concerning ground water deeper than 100 feet. This is because the alluvial sediments of the Bitterroot River are widespread and capable of sufficient yields of good-quality water for domestic and stock use. The alluvium is composed of unconsolidated gravels, sands, silts and clays. These sediments dominantly have a high percent of coarse-grained materials because the finer fraction is carried downstream. This results in a higher degree of permeability. The alluvial aquifer of the Bitterroot River is thickest in the center of the valley and progressively thins towards the valley margins. Wells in the alluvium generally yield between 15 and 25 gpm, but the potential for larger capacities is readily available. Concentrations of dissolved solids in the alluvium range from 40 to 705 mg/L for springs and wells.

Glaciolacustrine and morainal deposits along the western and southern borders of the valley are grouped as another aquifer. These deposits have a large percentage of fine-grained materials and, therefore, have low permeabilities. The thickness of the glacial sediments varies considerable depending upon location, however, well yields are consistently small--usually averaging 5 gpm.

Underlying and bordering the Quaternary-age deposits are unconsolidated to semiconsolidated Tertiary sediments. These sediments consist of arkosic channel-sand containing thin lenses of gravel eroded from the surrounding



Isopach Interval: 1000 ft.

Map Scale 1 500,000

Refer to basin no. 25

Isopach of Cenozoic fill in the Bitterroot Valley

Figure II-15

mountains, occasional lacustrine silts and clays and some beds of volcanic ash. Within short distances, materials of different textures interfinger and intergrade both laterally and vertically in accordance with changes in the original environments of deposition, and with the degree of volcanic activity in the region (McMurtrey and others, 1959). Tertiary deposits contain a large percentage of fine-grained materials which greatly inhibit the permeability of the sediments. A preliminary evaluation of numerous deep aquifer zones was recently completed. Transmissivities ranged from low values of 25 and 122 gpd/ft. to higher values of 1,650 and 3,750 gpd/ft. Calculated values for storage coefficients varied from 0.00005 to 0.35 (Norbeck, 1980). Wells completed in Tertiary sediments usually have yields of 8 to 12 gpm, but there are some large-capacity municipal wells in the valley. The city of Stevensville has a well drilled to 460 feet; this well produces 400 gpm. Tertiary ground waters are generally of good chemical quality, but often have moderate concentrations of iron. A geothermal study has also been completed on numerous deep Tertiary test wells in the valley. The study determined there is no evidence for hydrothermal discharge (Leonard and Wood, 1980).

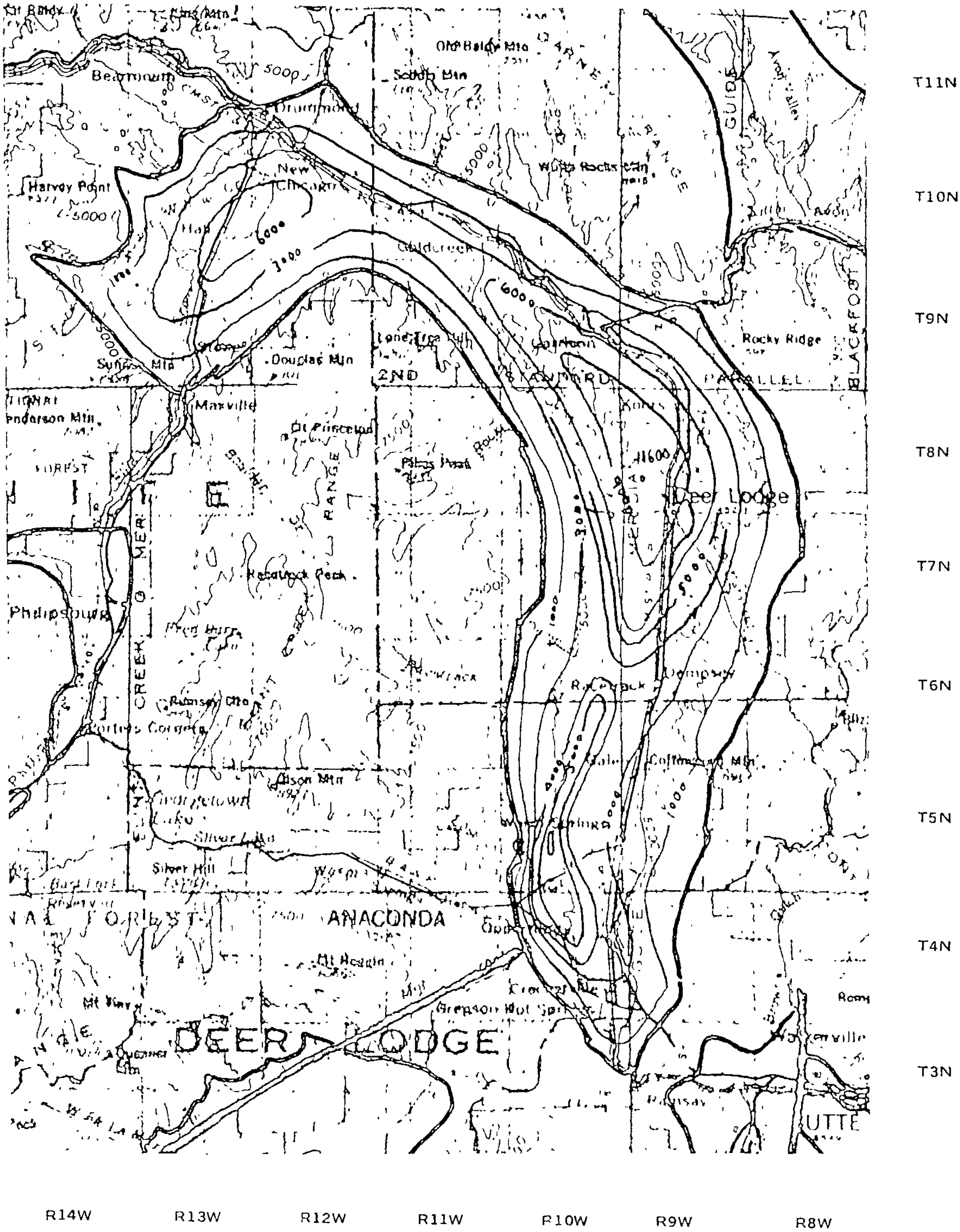
Annual precipitation for this area is approximately 16 inches per year, which contributes to recharging the ground-water system. Other forms of recharge are irrigation return flows, influent streams and inter-aquifer leakage. Ground water in the valley is discharged by evapotranspiration, effluent streams, springs, seeps and wells.

Deer Lodge Valley

The Deer Lodge valley is located west of the Continental Divide (locally known as the Deer Lodge Mountains) and east of the Flint Creek Range. To the north is the Garnet Range, and to the south, the Anaconda Range. In general, Precambrian through Mesozoic sediments outcrop on the west and north sides of the valley, and Tertiary volcanics and Cretaceous intrusions outcrop to the south, east and north. The Anaconda and Flint Creek Ranges contain Precambrian through Cretaceous sedimentary rocks with numerous Cretaceous intrusions. To the east, the Boulder Batholith quartz monzonite and Lowland Creek Volcanics make up the mountains of the Continental Divide (Sonderegger and others, 1980). Extensive andesite flows are found on the east side and at both ends of the valley (Cremer, 1966).

The Deer Lodge valley probably began forming as a shallow topographic low in response to batholithic intrusion and doming of country rocks. Later, block faulting increased the topographic relief. Fault scarps of the Powell fault zone are evident along the western margin of the valley (Cremer, 1966). At the base of the Continental Divide mountains, gravity data indicate another major fault along the eastern edge of the valley (Sonderegger and others, 1980).

The basin began filling with sediments during the Oligocene Epoch. Some uncertainty exists concerning the actual thickness of basin-fill deposits in the Deer Lodge valley. Gravity profiling of the valley indicates a maximum thickness of 6,000 feet near the center of T. 5 N., R. 10 W., but in the center of the valley south of Deer Lodge an exploratory oil well recently penetrated 10,300 feet of Cenozoic sediments (Montana Oil Journal, 12/31/81). Original gravity profiles for the same region indicate a maximum depth of 3,000 feet to bedrock. Figure II-16 shows the Deer Lodge basin-fill thickness contoured from available gravity data. The location of the exploratory well and the basin-fill thickness are included to give an idea of the uncertainty of the gravity information. A reason gravity data does not coincide with drill-hole data is the large amount of Tertiary volcanics interbedded with basin-fill deposits throughout the valley. These volcanics increase the density of the Deer Lodge basin-fill as a whole and influence gravity measurements in the field. Unless the increased density is taken into account during computer modelling of the gravity data, the resulting basin depths are also influenced. As a part of the same problem, gravity profiles show a bedrock high in the center of the valley. This



Isopach Interval: 1000 ft.

Map Scale. 1.500,000

Refer to basin no. 28

Isopach of Cenozoic fill in the Deer Lodge Valley

Figure II-16

high is a reflection of lava flows concentrated in the center of the valley (Konizeski and others, 1968). Before contouring the basin-fill isopach, the gravity profiles were 'smoothed' to eliminate the false high.

The basin is filled with unconsolidated to consolidated sediments and interbedded volcanics ranging in age from Oligocene to Holocene. Oligocene bentonitic conglomerate and arkose of Oligocene age are overlain by Miocene age unconsolidated to well consolidated fluvial clays, silts, sands and pebble conglomerates. Pliocene deposits include cemented colluvium and fan deposits near the valley margins. The deposits grade into floodplain and channel deposits toward the center of the valley. These Pliocene alluvial deposits consist of interbedded limestone, shale, sandstone and gravel with minor pebble and cobble conglomerates and varying amounts of bentonitic clay. Three-fifths of the Deer Lodge valley is mantled by Quaternary floodplain and fan deposits. Other Quaternary deposits include glacial moraines, travertine (near Warm Springs) and boulder fields near Warm Springs Canyon (Konizeski and others, 1968).

Ground water in the Deer Lodge valley is derived mainly from the alluvium of the Clark Fork River. Wells completed in this aquifer are generally shallow, ranging from 10 to 150 feet deep. Water in these Quaternary sediments is generally unconfined and the water table fluctuates seasonally. Overall water quality is good and the water is suitable for household and stock uses. Well yields can vary from 5 to 150 gpm with the average being about 25 gpm.

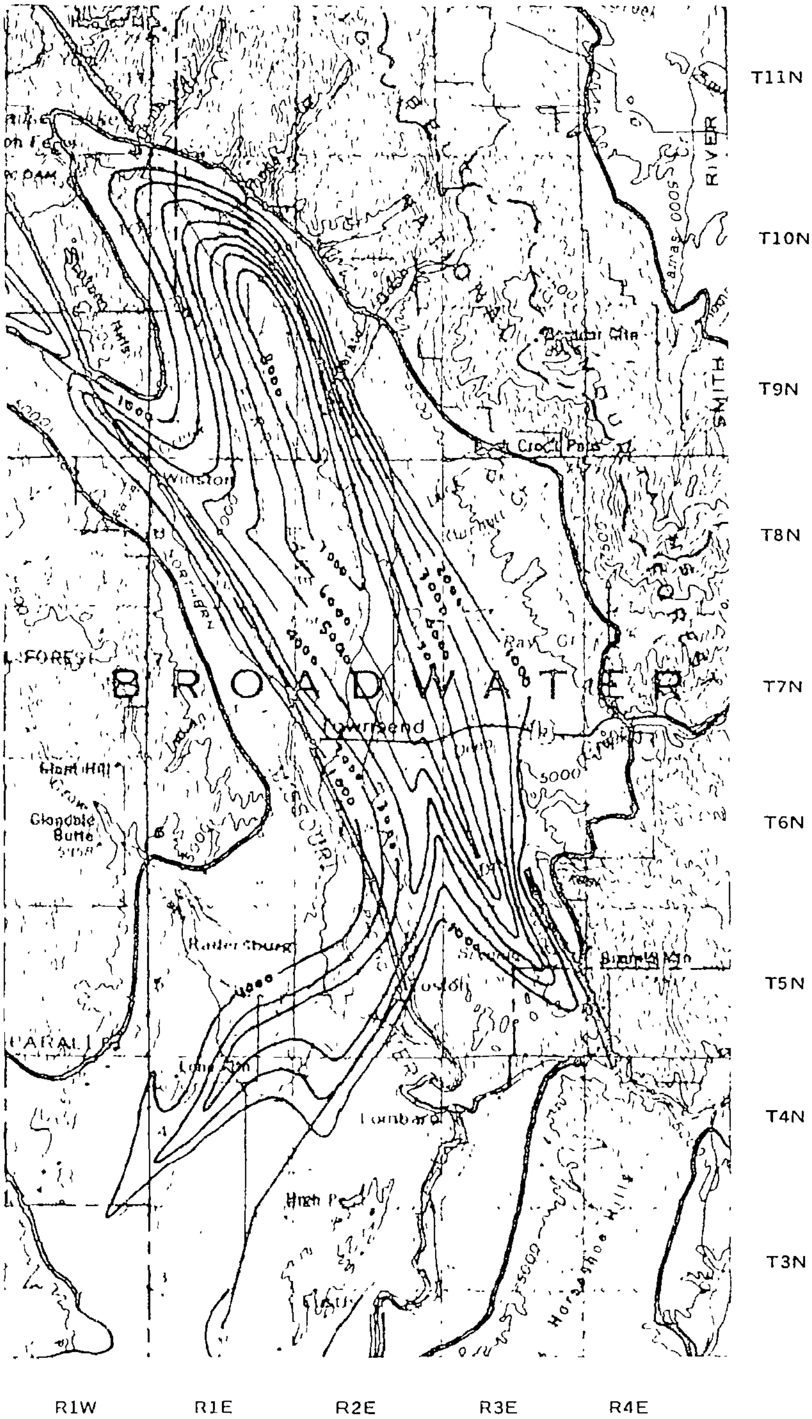
Tertiary sediments are the other primary source of ground water in the valley. These rocks either underlie the Quaternary alluvial deposits or flank the alluvium as deeply incised pediments. Tertiary rocks are composed of finer-grained sediments which become more consolidated with depth. The water in wells completed in the Tertiary sediments is generally confined resulting in artesian conditions. Because of the low permeability of the Tertiary sediments well yields on the average are generally small (15-20 gpm), however, there are exceptions. A well drilled to 436 feet in T. 6 N., R. 9 W., section 7 is recorded to produce 2,400 gpm. The city of Deer Lodge is also reported to have completed a 900 gpm test well. These large capacity wells are used for irrigation and municipal water systems, respectively.

The ground-water system is recharged partially from precipitation, irrigation return-flow and from influent streams. Discharge occurs from springs, wells, evapotranspiration and effluent streams.

Townsend Valley

Located along the southern end of the Lewis and Clark line, the Townsend valley trends roughly northwest between the Elkhorn Mountains (west) and the Big Belt Mountains (east). Precambrian through Mesozoic sedimentary rocks are found on all sides of the valley. On the west and south sides, Cretaceous and Tertiary volcanics and intrusive rocks outcrop.

The Townsend valley is a graben formed by crustal extension. Faults are evident along the mountain fronts to the east and west (Reynolds, 1979). In the north, the graben splits into two parts around the Spokane Hills horst (Kinoshita and others, 1964). To the east of the horst, the graben comes to an abrupt end against faults of the Lewis and Clark line. On the west side of the Spokane Hills, the Townsend valley extends into the Helena valley. These basins developed together in early Tertiary time; later, the drainage between them became blocked by a broad bedrock ridge (Davis and others, 1963). Tertiary deposits located between the two valleys are less than 1,000 feet thick, but thicken quickly toward the center of either basin. The Townsend valley-fill is more than 8,000 feet thick in the northeast and gradually thins to the west and south (see Figure II-17). A major fault (east side down) extends southeast down the center of the valley from the Spokane Hills. At the valley's southern margin, basin-fill deposits form an irregular contact with bedrock. This contact may be a depositional feature or may have been formed from a complex of small fault blocks (Kinoshita and others, 1964).



Isopach Interval: 1000 ft.

Map Scale: 1:500,000

Refer to basin no 30

Isopach of Cenozoic fill in the Townsend Valley

Figure II-17

The graben floor originally dropped with little or no tilting (Davis and others, 1963). Block faulting, with the major amount of movement along the Lewis and Clark line and with tilting of the graben floor to the east, continued intermittently from late Oligocene through Miocene. Throughout the valley, Tertiary strata have been displaced by small northwest-trending faults and show varying degrees of dip to the east.

The Tertiary deposits in the Townsend valley include the early Oligocene Climbing Arrow Formation, middle Oligocene Dunbar Creek Formation, and Miocene-age Sixmile Creek Formation (Kinoshita and others, 1964). The Climbing Arrow Formation consists of light-colored, fine-grained tuffaceous sediments with small amounts of interbedded sand and gravel. Locally, it contains thin beds of coal or diatomaceous earth. Above the Climbing Arrow beds, the Dunbar Creek Formation contains coarse sediments mixed with a large amount of tuffaceous material. Unconformably overlying the Dunbar Creek Formation, the Sixmile Creek Formation is a light to buff colored sandy clay with some sand and gravel beds, locally overlain by conglomerate. The thin layer of Quaternary alluvium in the valley consists of fan and floodplain deposits and a gravel mantle on the benchlands (Lorenz and McMurtrey, 1956).

The Townsend valley has the most copious ground-water resources of western Montana's intermontane basins. Numerous large-capacity wells and significant spring-flows issue from the valley sediments. Whereas most intermontane basins are underlain with Precambrian metasediments or crystaline igneous rocks, this valley is partially underlain with a stratigraphic sequence of Paleozoic sediments. It is believed that a direct relationship exists between ground-water availability and the Paleozoic strata.

Ground water in the Townsend valley is derived from three distinct aquifers: (1) unconsolidated Pleistocene and Holocene-age deposits; (2) unconsolidated to semi-consolidated Tertiary sediments; and (3) bedrock.

The Pleistocene and Holocene age deposits are primarily composed of alluvium of the Missouri River and its tributaries and alluvial fans along the valley margins. Alluvial deposits are composed of a heterogeneous mixture of cobbles, gravel, sand, silt and clay. They have been moderately sorted by streamflow which carried the finer-grained materials downstream. Although sand and gravel beds interfinger with clays and silts making them discontinuous, the aquifer is hydraulically interconnected. Alluvial deposits of variable thickness extensively cover the bottom lands from Townsend to Toston and veneer pediment slopes in the Radersburg area. Most wells completed in the alluvial aquifer are of a small diameter for domestic and stockwater purposes. These wells generally range from 25 to 50 feet deep and have sustained yields of 15 to 30 gpm. The city of Townsend has three wells completed in the alluvial aquifer which are 50, 60 and 93 feet deep; they produce 600, 650 and 440 gpm, respectively. Ground water from the alluvium is usually of good to excellent quality. Generally the water from the alluvium is a calcium bicarbonate type. Though the water is somewhat hard, it is highly suitable for irrigation and potable uses.

Unconsolidated to semi-consolidated Tertiary sediments underlie the alluvium and mantle the remainder of the valley floor. The deposits are geomorphologically expressed as a series of terraces that slope toward the center of the valley. At the north end of the valley near Canyon Ferry Dam, these sediments are comprised of gravels and cobbles in a sandy-clay matrix representative of broad channel deposits. In other locales, Tertiary sediments are considerably finer-grained and contain interbedded tuffaceous layers. These fine-grained beds are relatively impermeable and act as confining layers which produce artesian conditions. Artesian pressures occur in Tertiary beds that underlie the southern end of the valley and the area along the west flank of the Dry Creek anticline east of Townsend (Lorenze and McMurtrey, 1956).

Many large-capacity irrigation wells have been completed in this Tertiary aquifer. Well depths generally range between 200 and 400 feet. The areas east and southeast of Canyon Ferry Reservoir have numerous wells with yields in excess of 1,000 gpm. Wells penetrating Tertiary sediments west of the reservoir, however, have yields of 20 to 50 gpm. The ground water is of good chemical quality and is suitable for domestic, irrigation and stockwater purposes.

Numerous springs with substantial flows also issue from alluvial and Tertiary sediments. The waters are dominantly a calcium sulfate type, representative of the Madison Group. It is supposed that fractures in the Tertiary sediments act as conducts for water discharging from the Mission Canyon Limestone, a member of the Madison Group. Spring flows range from seeps to roughly 20,000 gpm.

The bedrock aquifer consists of Paleozoic and Precambrian age sediments and Cretaceous age igneous rocks outcropping along the periphery of the valley. These contain little interstitial water, and ground water is derived from secondary permeabilities such as fractures, solution voids and joints. Well yields are generally less than 10 gpm.

Recharge to the ground-water system of the Townsend valley occurs through a variety of means. The major source of recharge are canal losses and irrigation return flow. A large portion of the valley is inundated by Canyon Ferry Reservoir and seepage from it and influent streams likely contribute to the system. Inter-aquifer leakage, precipitation and spring seepage account for the remainder of the recharge.

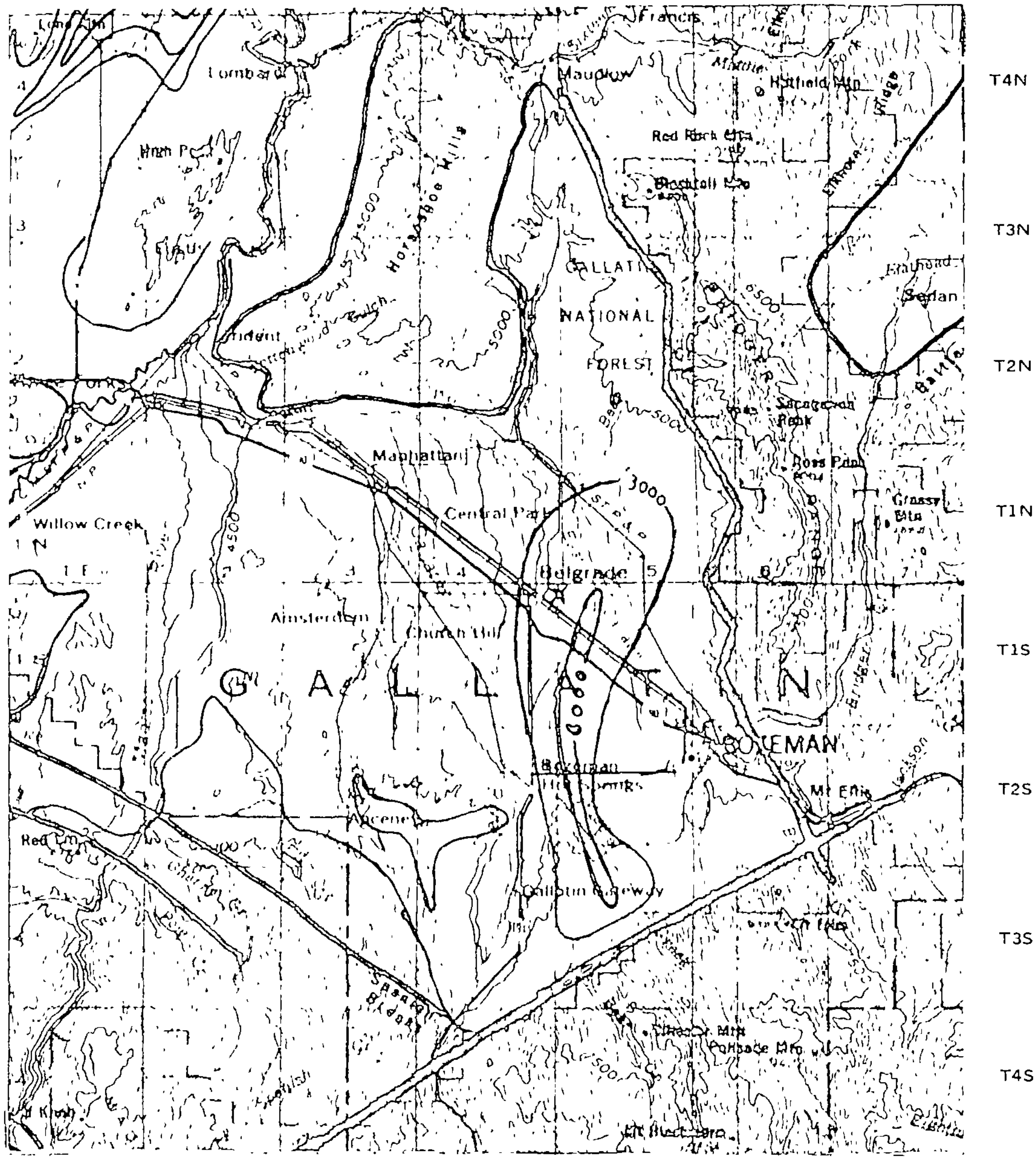
Large-capacity irrigation wells and evapotranspiration are the primary means of discharge. Minor amounts occur through effluent streams, seeps and domestic and stockwater wells.

Three Forks Basin

The Three Forks basin is the largest of the Tertiary basins in Montana. Most intermountain basins in Montana trend north-south, but the Three Forks basin is elongated east-west because of the Willow Creek fault which runs west-northwest along the northern part of the valley. Concealed by basin-fill deposits, the fault's presence has been inferred from gravity data and from the marked change in bedrock lithology and regional structure across the fault zone (Davis and others, 1965a). Precambrian through Mesozoic sedimentary rocks crop out in the low hills to the north of the Willow Creek fault, whereas Precambrian metamorphics are the most common rocks in the mountain ranges to the east, west and south of the basin. Elkhorn Mountain Volcanics and Tertiary intrusives also crop out to the west of the basin, and the Cretaceous-Tertiary Livingston Formation is found to the northeast.

Erosion and tectonism probably played interrelated parts in the origin of the basin (Robinson, 1963). On the western side, sinuous basin-fill bedrock contacts indicate a depositional origin, but on the eastern side, movement along the Bridger Creek fault played a major role in the basin's formation (Mifflin, 1963). The Bridger Creek fault (basin side down) zig-zags along the west front of the Bridger Range and is unlike most mountain front faults which run fairly straight. The valley fill is over more than 6,000 feet thick east of Bozeman along this fault zone (see Figure II-18). On the southeast side of the Three Forks basin, a high-angle normal fault (northwest side down) forms the Gallatin Range front. Another fault (southeast side down) runs roughly parallel to and two miles northwest of the Gallatin Range fault, forming a narrow trough about 3,000 feet deep (Davis and others, 1965b). Mifflin (1963) mapped a series of block faults along the Madison Range front to the southwest of the basin. Farther to the west, gravity and magnetic data suggest a fault trending west-northwest along the edge of the valley north of Harrison (Davis and others, 1965a). Gravity data also shows the Jefferson Canyon thrust and Lombard thrust connected beneath the basin-fill. These thrust faults are exposed in bedrock on the west and north sides of the Three Forks basin.

In general, the bedrock beneath the basin is an eastward-tilted slab with a series of troughs and broad, low ridges roughly trending east-west (Davis and others, 1965b). Lower Tertiary rocks dominate the western portion of the



Isopach Interval. 1000 ft

Map Scale: 1.500,000

Refer to basin no. 33

Isopach of Cenozoic fill in the Three Forks Basin

Figure II-18

basin and have been deformed into broad, gentle folds, and upper Tertiary beds dominate the eastern half of the valley (Robinson, 1961). In the north, the Tertiary beds have a southeasterly dip (Wantland, 1953).

The basin fill in the Gallatin valley ranges from late Eocene to Holocene in age (Robinson, 1961). The lower portion of the Tertiary beds consists of a limestone conglomerate overlain by light-colored, fine-grained, tuffaceous strata including limestone, siltstone, mudstone and bentonitic clay with interbedded channel sandstones and conglomerates. Robinson (1963) divided these beds into four formations: Sphinx Conglomerate; Milligan Creek; Climbing Arrow; and Dunbar Creek. Separated from the Dunbar Creek formation by a Miocene unconformity, the upper Bozeman Group beds are a similar sequence of light-colored, fine-grained tuffaceous deposits with some interbedded conglomerates and sandstones. Above the Tertiary deposits, a thin layer of Quaternary terrace and floodplain gravels, cemented fanglomerates and wind-blown silt has been laid down (Hackett, 1960).

The Quaternary alluvial veneer covering the floor of the Three Forks valley serves as the principal aquifer within the area. This aquifer is composed of unconsolidated deposits of gravel, sand, silt and clay. Although it is a prolific aquifer, agricultural and subdivision development is rapidly approaching the appropriation limit. The aquifer is characterized by generally high values of transmissivity--100,000 to 300,000 gallons per day per foot--and, in many places yields ample water for irrigation (Hackett and others, 1960). Well depths vary from 10 to 120 feet and well yields range from 10 to 2,000 gpm from the aquifer. Chemically, water in the alluvium is a calcium-magnesium-bicarbonate type, and is suitable for domestic, stock and irrigation uses. Values of dissolved solids average around 250 to 300 mg/L.

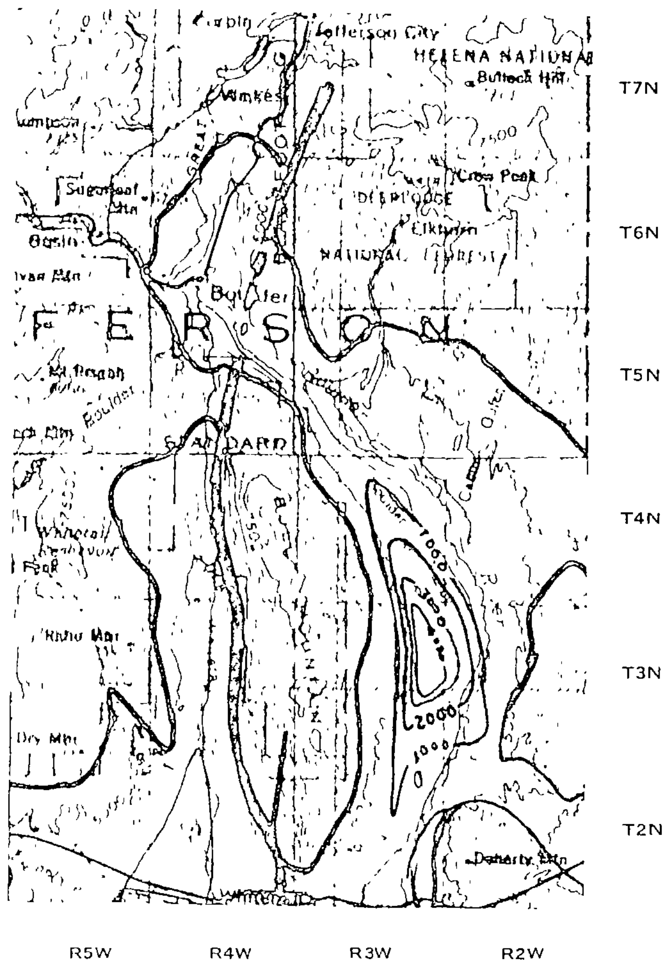
Underlying the alluvial veneer are semi-consolidated Tertiary sediments. Characteristically, these sediments have a low permeability as a result of their lithologic nature. The Tertiary strata have low values of transmissivity (generally less than 6,000 gallons per day per foot) and yield sufficient water for only stock and domestic use (Hackett and others, 1960). Domestic and stock well yields usually average about 15 gpm. However, recent deep wells completed in the Tertiary are now producing yields in excess of 1,500 gpm. The water quality of Tertiary sediments varies from one locale to the next as well as being a function of depth. Sodium appears to be a common constituent of ground water from Tertiary deposits and there are generally higher concentrations of other minerals.

Recharge to the ground-water system of the Three Forks valley is dominantly from irrigation return flow and seepage from losing streams. Rainfall and snow-melt runoff account for only a small portion of the recharge. Ground-water discharge occurs mainly as evapotranspiration, springs and well pumpage. During seasonal periods of low stream flow the alluvial aquifer maintains a baseflow of the rivers.

Cold Spring Valley (North Boulder)

The North Boulder valley is located southwest of the Elkhorn Mountains and east of Bull Mountain. At the southwest end of the valley, the North Boulder River joins the Jefferson River. At the southeastern end, Tertiary deposits in Nigger Hollow extend into the Three Forks basin. Pre-basin rocks surrounding the valley include the Precambrian LaHood Formation, Paleozoic and Mesozoic sedimentary rocks and early Tertiary intrusives. Burfeind (1967) found the valley fill to be a maximum of 4,500 feet thick. At the northwest end of Nigger Hollow, the Tertiary sediments may be as thick as 1,000 feet (Parker, 1961), but at the east end, they thin to about 300 feet (Wilson, 1962).

The Red Lane fault bounds the North Boulder valley on its western side (see Figure II-19). The fault extends from the Jefferson River along the east side of Red Hill and through T. 4 N. Alexander (1955) mapped this fault as a reverse fault with the basin side (east) upthrown. Burfeind's (1967) gravity data suggests the fault may be normal with basin side downthrown. Another



Isopach Interval: 1000 ft.

Map Scale: 1:500,000

Refer to basin no. 34

Isopach of Cenozoic fill in the Cold Spring Valley

Figure II-19

possible fault (east side down) runs along the North Boulder River across the northwest border of Nigger Hollow.

Oligocene and late Miocene strata of the Bozeman Group fill the basin. In this area the Bozeman Group consists of soft, light-colored, silty, sandy and conglomeratic vitric tuffs (Alexander, 1955). Large amounts of volcanic glass are present in various stages of devitrification. Sorting is generally poor, though a few beds are made up entirely of silt or sand. An unconformity of early Miocene age separates the Oligocene and late Miocene strata.

The Cold Springs valley is so named because of the cold springs (approximately 12^{o}C) which issue from the alluvium, probably discharging from the Madison near the center of the valley. Presently the springs are nonconsumptively utilized to support an aquaculture project.

Ground water in the Cold Spring valley is principally derived from the alluvial aquifer which borders the North Boulder River. This aquifer is laterally quite extensive because of the coalescing floodplain deposits created by the river's meandering. The aquifer is composed of gravel, sand and some silt and may be as much as 80 to 100 feet thick. The variability of the sedimentary deposits directly relates to variations of aquifer transmissivities. Shallow wells tapping the alluvium are capable of yields ranging from 10 to 50 gpm and are used for domestic and agricultural purposes. There are very few irrigation wells within the valley, but the aquifer appears to be capable of large yields. A well drilled to 95 feet below the land surface in T. 4 N., R. 3 W., section 1 is recorded to have a sustained yield in excess of 1,000 gpm. Ground water of the alluvium is generally hard, potable and of good chemical quality. Based on water levels in wells along the valley and on the hydrogeological setting, it appears that the direction of ground-water flow is from north to south.

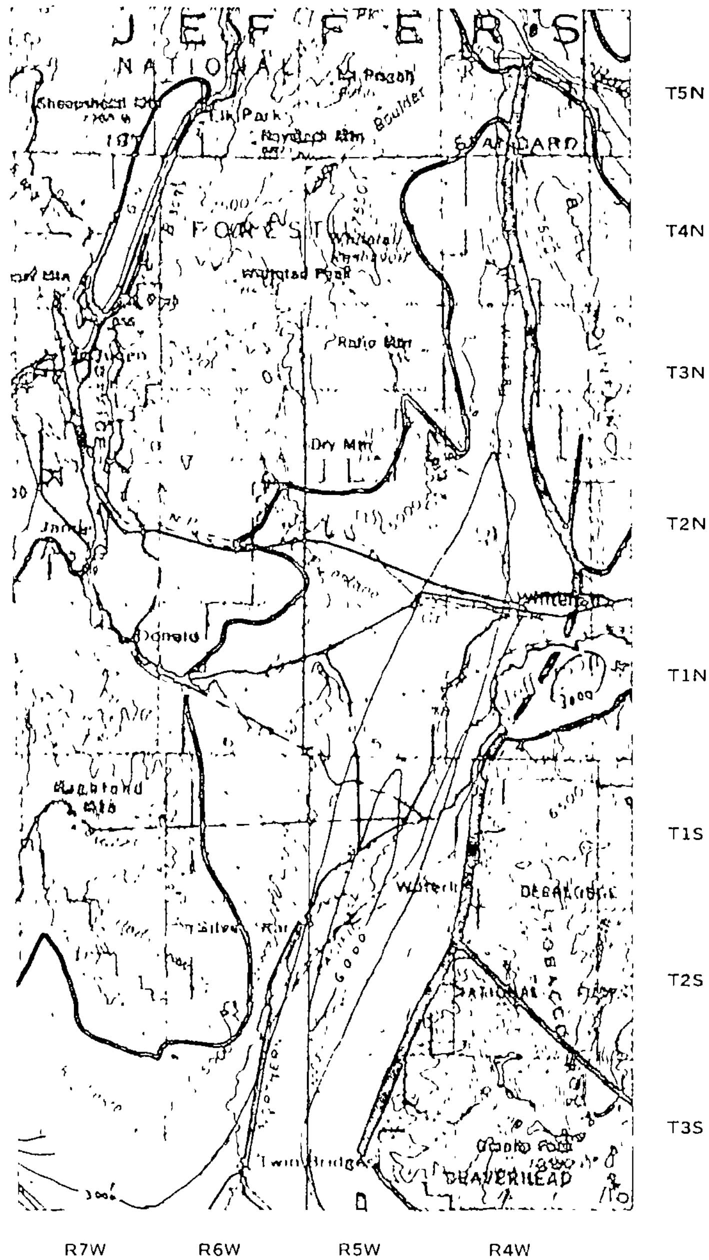
Underlying and flanking the alluvial aquifer are Tertiary age sediments. These deposits are generally composed of poorly-sorted, fine-grained sediments and characteristically have little storage capacity. Ground-water yields from these Tertiary sediments are small and only used for domestic and stockwater purposes. Recharge to the aquifers of the Cold Springs valley is from precipitation and snowmelt, whereas discharge occurs from wells and springs and as influent streams.

Little Whitetail and Jefferson Valleys

The Little Whitetail Creek and Jefferson River valleys cover about 250 square miles in Madison, Jefferson and Silver Bow Counties. These Tertiary basins are bounded by the Tobacco Root Mountains and Bull Mountain to the east, the Highland Mountains or Boulder batholith on the west and Bull Mountain to the north. At its southern limit, the Jefferson valley borders the Beaverhead valley.

Faults form the eastern boundaries of the basins (see Figure II-20). The Tobacco Root fault (basin side down) extends along the west front of the Tobacco Root Mountains. Gravity data (Wilson, 1962) suggests faulting in the subsurface one mile west of and roughly parallel to the mountain front fault. Kuenzi (1966) extended the Tobacco Root fault across Tertiary deposits near Whitehall to intersect the Bull Mountain fault on the east edge of Little Whitetail valley. East of the Tobacco Root fault, the Mayflower Gulch fault (west side down) forms the east and southeast boundary of a small basin in the Parrot Bench region. Gravity data from Parker (1961) suggest another fault along the east edge of the shallow depression at the eastern end of the Jefferson River valley near Cardwell.

Cenozoic movement along this series of faults (each upthrown on the east) plus erosion and doming of the Boulder batholith to the west, produced the Jefferson-Little Whitetail valley, Parrot Bench depression, and the small valley at Cardwell. In early Tertiary time, an irregular erosion surface formed across the Belt rocks, Paleozoic and Mesozoic sediments, Elkhorn Mountain Volcanics and Boulder batholith granites of these valleys. Starting in early Oligocene, Tertiary sediments filled the basins to varying depths (see Figure II-20). The



Isopach Interval: 1000 ft.

Map Scale: 1:500,000

Refer to basins no. 35 and 36

Isopach of Cenozoic fill in the Little Whitetail and Jefferson Valleys

Figure II-20

maximum thickness of Tertiary sediments in the Jefferson-Little Whitetail basin is 7,000 feet (Burfeind, 1967; Petkewich, 1972). Burfeind (1967) gives a maximum depth of 3,700 feet for the Parrot Bench depression, but the reconstructed thickness of Tertiary deposits there by Kuenzi and Fields (1971) indicates a maximum depth of 4,500 feet. Unknown structural complications in the subsurface may account for the differences. To the east, the small valley at Cardwell is only about 850 feet deep.

The basins are filled with about 6,000 feet of Tertiary deposits that make up the Bozeman Group. The lower formation of the group, the Renova, consists of light-colored, fine-grained strata unconformably overlying pre-basin rocks. Ranging from 0 to more than 3,500 feet thick, the formation contains alternating limestones, mudstones, siltstones, sandstones and gravels with a few conglomerates. More than 70 percent of these sediments are composed of very fine sand or finer-grain size fraction. Deposition of the Renova Formation ended in middle Oligocene (or later). A period of erosion followed this deposition and removed a large volume of Renova strata. Currently, the youngest sediments to be identified as Renova are middle Oligocene in age.

Deposition of the upper part of the Bozeman Group, the Sixmile Creek Formation began in late Miocene and ended in middle to late Pliocene. Generally darker than the Renova Formation, the Sixmile Creek Formation consists of from 0 to more than 2,400 feet of coarse-grained sediments. Kuenzi (1966) describes the lithology of the 900-foot type section of the formation as: sandy, gritty, medium-to-coarse sand (30%), very fine-to-medium sandstone (21%), sandy siltstone (11%), mudstone (3%) and marl (7%). Since the late Pliocene, an unknown amount of Sixmile Creek strata has been removed and locally veneered by Quaternary deposits.

Most of the wells drilled in these valleys are completed in the alluvium of the Jefferson or Little Whitetail Rivers. These alluvial aquifers serve as a reliable ground-water source that can continually produce yields of 50 to 100 gpm. Higher yields necessary for irrigation do not appear to be possible around the town of Whitehall; however, there does exist a 1,000 gpm irrigation well in the southern part of the Jefferson valley. The water quality of the alluvium is generally good, with the exception of high iron concentrations in some areas. It also tends to be slightly hard from the calcium carbonate concentration. Recharge to the system during the summer and fall months results from influent streams, whereas during the rest of the year recharge is from precipitation. Beneath and adjacent to the alluvium are Tertiary sediments which form gently-sloping terraces. As previously mentioned, more than 70 percent of these sediments are composed of very fine sand or finer grain-size fraction which results in a lack of void spaces. A review of well-appropriation data showed only a few wells completed in Tertiary sediments, and their average yield was 10 to 15 gpm. Although there is not any water quality data on these Tertiary wells, the water is generally considered suitable for domestic and stockwater use. The terraces are recharged primarily from precipitation and discharge occurs through wells, springs, seeps and evapotranspiration.

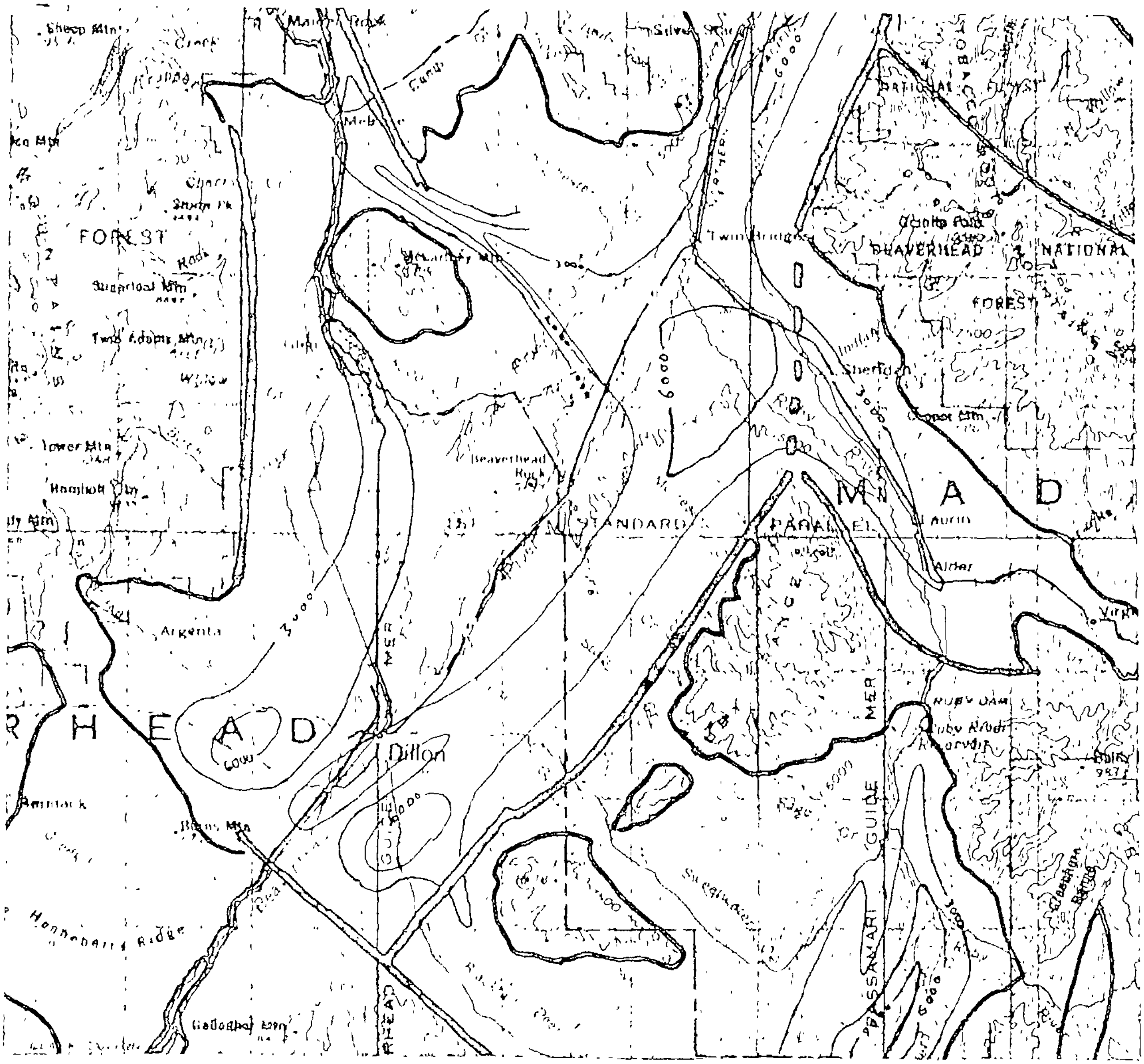
Melrose and Beaverhead Valleys

The Beaverhead valley is an irregularly shaped basin with one arm extending southeast between the Tobacco Root and Ruby Ranges, and another arm, the Melrose valley, extending northwest between the Highlands and McCartney Mountain. A third extension runs along the south side of McCartney Mountain. To the south, the Beaverhead valley is bounded by the Blacktail Range, and to the west, by the Pioneer Mountains. The Jefferson valley on the north and the Blacktail valley on the southeast adjoin the Beaverhead valley.

Tertiary basins in this region formed by block faulting with some basins bounded on both sides by faults (Chandler, 1973). In the Beaverhead valley, the east side has been tectonically active, whereas little evidence of activity is seen to the west (Hoffman, 1972). Tertiary beds in the valley have a gentle eastward dip and the thickness of basin-fill deposits is greater on the east side than the west.

A high-angle normal fault (west side down) on the west flank of the Ruby Range forms the eastern boundary of the Beaverhead valley (see Figure II-21). To the north beyond the Alder valley, another northeast-trending fault runs along the west flank of the Tobacco Root Mountains. Six miles west of Sheridan, the basin's depth is over 8,000 feet (Petkewich, 1972). The Blacktail fault (north side down) forms the southern boundary of the Beaverhead basin. This high-angle normal fault cuts Miocene beds, but has not moved since the beginning of the Pliocene. Tertiary deposits thicken to 8,500 feet near the junction of this fault and the Ruby Range fault. A high-angle normal fault (south side down) is inferred to be on the northeast border of the Melrose valley (Chandler, 1973; Witkind, 1975). The Melrose valley is over 2,000 feet thick near its northeastern boundary. On the south side of McCartney Mountain, the valley fill is over 3,000 feet thick. Along the sides of the Alder valley, Petkewich (1972) mapped three faults trending northwest-southeast. The graben has two faults parallel to the south border of the Tobacco Root Mountains, each with south side downthrown, and another fault (north side down) along the northeast border of the Ruby Range. The Alder valley fill is over 4,000 feet thick near Alder.

Bedrock that outcrops along the basin's borders consists of Precambrian metamorphics, Paleozoic and Mesozoic sediments, Createceous-Tertiary intrusives and early Tertiary volcanics. It is presumed that unconsolidated Tertiary deposits of the Bozeman Group are underlain by rocks similar to those outcropping along the mountain fronts. The lower portion of the Bozeman Group (the Renova Formation) contains alternating limestones, mudstones, siltstones, sandstones, gravels and a few conglomerates. Over 70 percent of the Renova Formation is very fine or finer sediments. Deposition of the formation ended in middle Oligocene; an episode of erosion that removed a large volume of Renova beds followed. Deposition of the upper part of the Bozeman Group, the



Isopach Interval. 1000 ft.

Map Scale 1 500,000

Refer to basins no. 40 and 43

Isopach of Cenozoic fill in the Melrose and Beaverhead Valleys

Figure II-21

Sixmile Creek Formation, began in late Miocene and ended in middle-to-late Pliocene. Generally darker and coarser than the Renova Formation, the Sixmile Creek Formation consists of 60 percent medium sand and coarser sediments, 20 percent fine-to-medium sand and 20 percent silt and finer sediments. Since the late Pliocene, an unknown amount of Sixmile Creek strata has been eroded and locally a veneer of Quaternary deposits laid down.

Within the Melrose and Beaverhead valleys are three distinct aquifer units: Cretaceous to Precambrian bedrock; semi-consolidated Tertiary sediments; and Quaternary alluvium. Fracture networks in the bedrock of the surrounding mountains create a bedrock aquifer. This aquifer has only minor importance because it is only capable of small yields and has limited access in the mountains. Overlying the bedrock are Tertiary deposits primarily composed of fine-grained materials of silt, clay and some volcanic ash. This Tertiary aquifer probably has a large volume of ground water in storage, but because the aquifer contains so much fine-grained material, this water is not able to be released from storage. Therefore, wells penetrating the Tertiary aquifer have low yields ranging between 5 and 10 gpm. The ground water from this aquifer is usually hard and values for dissolved solids average about 400 mg/L. The Tertiary sediments receive recharge principally from streams and irrigation water; probably very little direct recharge to Tertiary deposits occurs from rainfall and snowmelt (Botz, 1967).

The alluvium bordering the Beaverhead River and its tributaries serves as the most valuable aquifer in these valleys. It is composed of interlayered gravels, sands, silts and clays and has a maximum total thickness of 200 feet along the Beaverhead River (Botz, 1967). Yields of more than 900 gpm have been obtained from this aquifer. The water is dominantly a calcium-magnesium bicarbonate type, and because of this is quite hard.

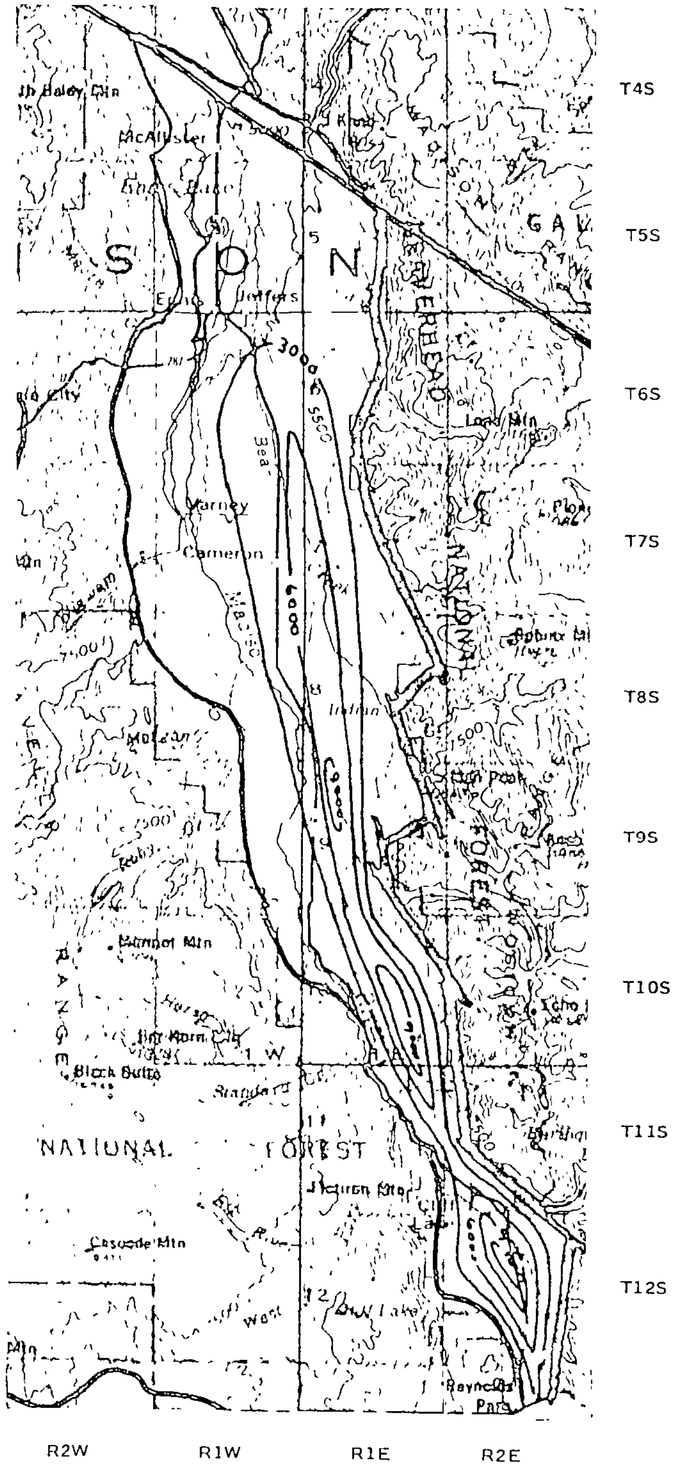
Recharge to the aquifer is from snowmelt-runoff, rainfall and leakage from the Tertiary sediments. Discharge occurs from evapotranspiration, wells and springs and as baseflow for the Beaverhead River during periods of low flow.

Madison Valley

The Madison valley is located west of the Madison Range, east of the Gravelly Range and southeast of the Tobacco Root Mountains. Bedrock around the valley includes Precambrian gneisses to the west and north and Precambrian dolomite and schist to the southeast (Gary, 1980). Paleozoic and Mesozoic sedimentary rocks outcrop northeast of the valley, and a Tertiary granitic intrusion is found to the northwest in the Tobacco Root Mountains. To the southwest and south of the Madison valley, Pliocene basalt and tuffs and Pleistocene tuff cover a large area.

On the east side of the valley, the Madison fault (west side down) extends for 55 miles along the west flank of the Madison Range. Movement occurred along this irregular north-trending fault in 1959. The fault block beneath the Madison valley is tilted 5 to 10 degrees eastward into the Madison fault (Pardee, 1950); and maximum thickness of basin-fill strata is 9,000 feet along the east side of the valley (see Figure II-22). Along the north side of the valley, another fault (south side down) trends west-northwest and intersects the Madison fault. In the upper Madison River valley, gravity data indicate a trough filled with low-density material, such as basin-fill sediments, beneath the Tertiary volcanics (Schofield, 1980). This trough is about 3,000 feet deep and extends from the Madison valley to the Centennial valley. Detailed mapping in the area has shown block faults (northwest side down) breaking the Tertiary volcanic rocks along the southeast side of the trough (Gary, 1980).

Basin-fill in the Madison valley consists mainly of unconsolidated conglomerate with rounded boulders and cobbles in a sandy, silty matrix and is late Tertiary of early Pleistocene in age. Quaternary deposits include moraines, landslides, fan deposits and glacial outwash. In the upper Madison valley, Tertiary and Pleistocene sediments are interbedded with basalt flows and tuff



Isopach Interval: 1000 ft

Map Scale 1 500,000

Refer to basin no. 47

Isopach of Cenozoic fill in the Madison Valley

Figure II-22

beds (Gary, 1980). However, in the lower Madison valley, the interbedded volcanics do not occur, and the Tertiary sequence becomes more like that in the Three Forks basin; conglomerates and gravels with a large portion of tuffaceous and fine-grained material and some interbedded sands.

The alluvium bordering the Madison River is the most prolific source of ground water in the Madison valley. The alluvial deposits are comprised of unconsolidated gravels, sands, silts and clays, however, a large percentage of the finer-grained materials has been carried away by stream flow. The result is a fairly well-sorted deposit of coarse-grained sediments that have a high degree of hydraulic conductivity. The thickness of the alluvium is quite variable, and may be as much as 100 feet thick near Jeffers. Well yields from this alluvial aquifer generally average about 30 gpm, but the aquifer has the potential for yields in excess of 100 gpm. Alluvial ground water is of good chemical quality, suitable for domestic and stockwater uses.

Ground water is also derived from Tertiary sediments in the Madison valley. Tertiary deposits are composed of a large percentage of fine-grained material such as tuffaceous and clay-size sediments. These sediments inhibit the movement of ground water and are the reason for the aquifer's relatively impermeable nature. A well located in section 4, T. 11 S., R. 1 E. is reported to have a transmissivity value of only 6,800 gallons per day per foot. This figure appears to be fairly representative of these sediments. Wells drilled in Tertiary sediments usually range from 100 to 250 feet deep and have yields of 15 to 20 gpm, but a number of deeper wells have with yields greater than 50 gpm.

Geothermal waters occur near the town of Ennis. These springs issue from a localized fault system there and their hydrothermal potential is yet unknown.

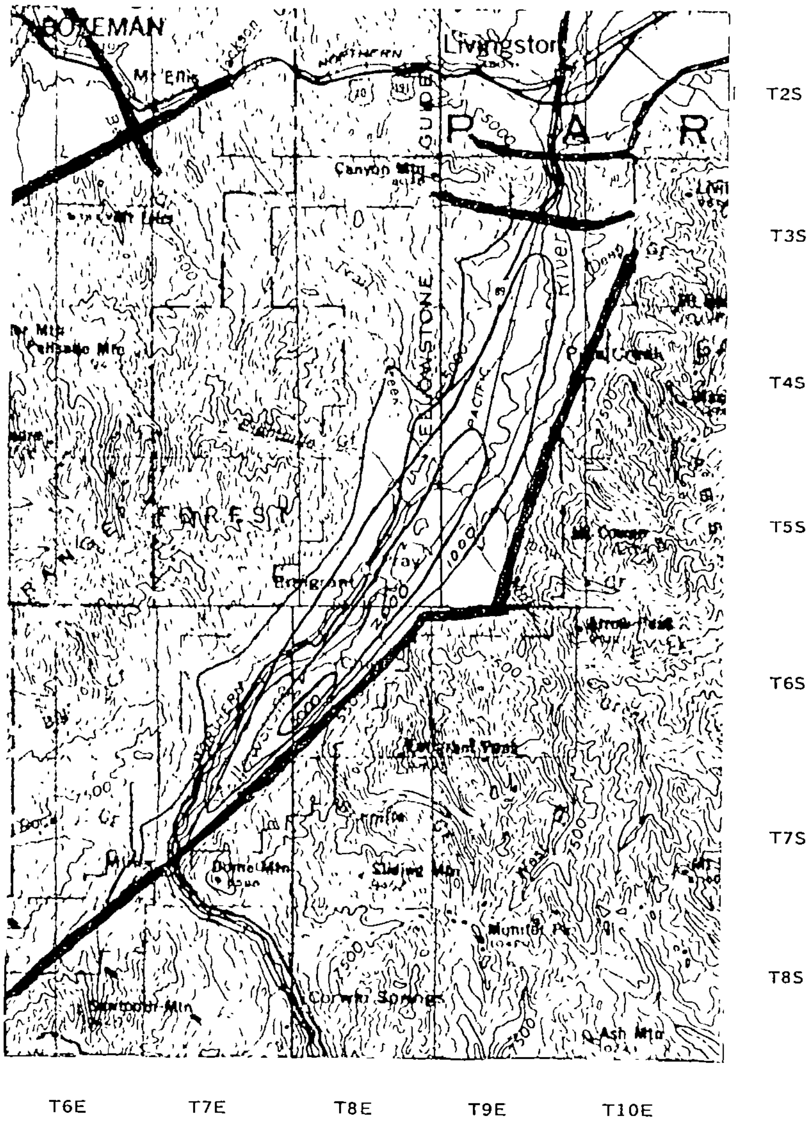
Recharge to aquifers in the Madison valley is from influent streams, rainfall and snowmelt-runoff infiltration. A small percentage also is derived from irrigation return flows, however, the valley is dominantly dryland farmed. Evapotranspiration, effluent streams, springs and wells account for the ground-water discharge in the valley. A comprehensive hydrogeologic study of the Madison valley should be undertaken in order to evaluate the ground-water resources, determine the hydrochemistry of the system and the potential for development of these resources.

Emigrant Valley

The easternmost intermountain basin in Montana, the Emigrant valley, lies between the Gallatin Range on the west, the Snowy Mountains on the southeast and the Absaroka Range on the east. This basin began forming during the Miocene with movement along the Emigrant fault (west side down) and tilting of bedrock and basin-fill strata to the east (Bonini and others, 1972). Seen along the western flanks of the Absaroka Range and Snowy Mountains, this fault constitutes the eastern limit of basin and range faulting in Montana (Reynolds, 1979). Tertiary basin-fill deposits and the Tertiary volcanic bedrock of the basin floor dip 10 to 20 degrees east into this fault. The combination of faulting and tilting has resulted in a maximum basin-fill thickness of 3,000 feet and an average thickness of 2,000 feet along the east side of the valley (see Figure II-23). Movement along the fault has continued up to Holocene time, as shown by broken Pleistocene deposits and hot springs aligned along the fault trace.

To the east of the valley, Precambrian metamorphic rocks predominate and have been intruded by a few Tertiary granites. Paleozoic and Mesozoic sedimentary rocks occur on both sides of the valley at its northern end and also outcrop along the Mill Creek fault zone, an east-west trending fault which intersects the Emigrant fault at Mill Creek. On the west side of the valley, Tertiary volcanics conceal the Paleozoic and Mesozoic rocks that outcrop elsewhere in the Gallatin Range (Bonini and others, 1972).

Late Miocene to early Pliocene deposits in the basin consist of tuffaceous silts and clays with some interbedded sands and gravels. Above these deposits are Pliocene-age stream gravels with well-rounded cobbles in a sandy matrix.



Isopach Interval: 1000 ft

Map Scale. 1:500,000

Refer to basin no. 48

Isopach of Cenozoic fill in the Emigrant Valley

Figure II-23

In the southern part of the Emigrant valley, late Tertiary basalts overlie the gravels. Quaternary deposits in the valley consist of terrace deposits and glacial drift (Horberg, 1940).

Ground water in the Emigrant valley is derived from a variety of geologic sources. North of Pray, Montana the valley floor is veneered with alluvial deposits of the Yellowstone River. These deposits are of an unknown thickness and probably overlie similar Wisconsin-age till which is exposed in the side canyons of the valley. The Yellowstone River alluvium is composed of a heterogeneous mixture of sand, gravel, silt and clay that readily yields water to wells. The Montana Department of Fish, Wildlife and Parks has two campground wells in section 28, T. 4 S., R. 9 E. which are completed in the alluvium. The wells are 41 and 37 feet deep and have yields of 110 and 120 gpm, respectively. General well yields for this aquifer range from 20 to 40 gpm.

South of Pray, Montana the valley lowlands are largely ground moraine of the Yellowstone Glacier of early to late Wisconsin age. These glacial deposits are flanked by Tertiary age terraces. The till is composed of a combination of cobbles and gravels in a silty-clay matrix. The Tertiary sediments are comprised of interbedded fluvial sediments and tuffaceous deposits. Both the glacial till and Tertiary deposits exhibit similar hydraulic properties and, for the most part, can be considered as an aquifer unit. These deposits are semipermeable and, as such, have a limited degree of hydraulic conductivity. Well yields are usually small and average 5 to 15 gpm.

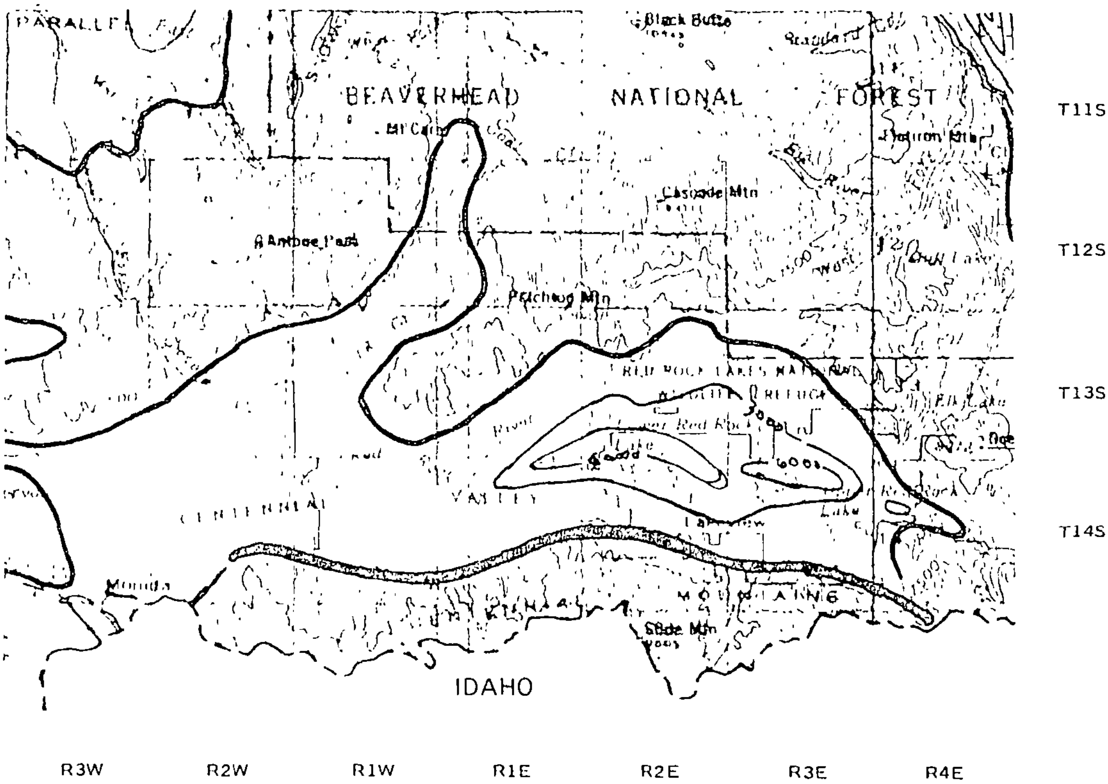
Ground water in the Emigrant valley is of good chemical quality and is used for domestic, recreation and stockwater purposes. It is unknown if there are sufficient yields for irrigation use, as no large capacity wells (in excess of 200 gpm) exist in the valley.

Recharge to the ground-water system is from precipitation and losses from influent streams. Discharge occurs through evapotranspiration, effluent streams, wells, springs and seeps.

Centennial Valley

Unlike the other intermontane basins of western Montana which trend northwesterly, the Centennial valley trends east-west. Situated between the Centennial Mountains (south side) and the Snowcrest and Gravelly Ranges (north side), the Centennial basin is more closely related to Snake River-Yellowstone Plateau structures than to the basin-range faulting activity seen in the rest of southwestern Montana (Myers and Hamilton, 1964). The Centennial fault (north side down) extends for 40 miles along the south side of the valley. From gravity data, other faults (north sides down) are seen to parallel the Centennial fault beneath the basin-fill (Schofield, 1980). Across the valley, a series of faults (south sides down) form the basin fill-bedrock contact. Gravity data indicate more faults may parallel these beneath the valley sediments. In the center of the valley, the basic graben structure is complicated by small northwest-trending faults. To the east of these, other faults trend northeast and align with faults along the trough between the Madison and Centennial valleys (Schofield, 1980). Farther east, the Alaska Basin, a small, roughly circular valley, is bounded on its north, east and southwest sides by faults, each with the basin side downthrown. This basin is rather deep for its size and is filled with about 3,000 feet of Cenozoic sediments. The Centennial valley contains a maximum of 7,000 feet of basin-fill deposited over its irregularly faulted bedrock floor (see Figure II-24).

Paleozoic and Mesozoic sedimentary rocks outcrop in the mountains north and south of the Centennial valley and are overlain in places by abundant Tertiary volcanics. To the east around Alaska Basin, Precambrian schist outcrops. Cenozoic rocks in the Centennial valley consist of basalts, travertine and tuffs interbedded with semi- and unconsolidated sediments. These sediments include a middle Miocene channel sandstone and pebble-rich, poorly-sorted sandstone, a Miocene freshwater limestone, alluvial fan deposits and colluvium, glacial outwash, silts and sands with local interbedded gravels and dune sand



Isopach Interval: 1000 ft.

Map Scale: 1:500,000

Refer to basin no. 51

Isopach of Cenozoic fill in the Centennial Valley

Figure II-24

(Sonderegger and others, 1980; Honkala, 1949).

To date, there exists a paucity of ground-water data concerning both shallow and deep aquifers in the Centennial valley. A review of wells drilled in the valley found only a few well logs recorded for the area. The wells generally ranged between 50 and 100 feet deep and had yields of 15 to 30 gpm. These wells probably attain their water from a number of hydrogeologic units in the valley.

Most of the valley floor is mantled with a veneer of Quaternary alluvial deposits. They are composed of a heterogeneous mixture of gravel, sand, silt and clay of unknown thickness. The northern portion of the valley has been surficially mapped as dune sand, conglomerate and tuffaceous deposits. These deposits normally produce limited amounts of ground water, and it is assumed that their potential yields are 5 to 10 gpm. Ground water is used only for domestic supply and stockwater wells since large capacity irrigation wells are non-existent. The upper thousand feet of valley-fill materials probably have an effective porosity of at least 15 percent; thus, the ground water in storage in this zone is about 150 acre-feet per acre (Sonderegger, 1982). Dissolved solids concentrations in the water are generally less than 400 mg/L and the water is thus suitable for potable use.

Underlying the Quaternary-age deposits are interbedded Tertiary sediments and basalt and rhyolite flows. Tertiary sediments have been previously described and their potential as a ground-water resource is unknown since wells of sufficient depth to penetrate them have not been drilled. There also exist a number of thermal springs in the Centennial valley. Possible heat sources for these springs could be either an intrusive body or deep circulation of water along fractures.

The main source of recharge for the aquifers in the valley is rainfall and snowmelt-runoff and, to some extent, return flow from surface-water irrigation. Ground-water discharge occurs as springs, seeps and wells and is accompanied by evapotranspiration and effluent stream flow. A thorough ground-water resource evaluation should be made for the Centennial valley.

CONSOLIDATED SEDIMENTARY ROCKS

Consolidated sedimentary rocks in the Rocky Mountains region represent, excepting the Silurian, all geologic time periods from Precambrian through Cretaceous (see Figure II-4 for a stratigraphic time scale). These formations have been faulted, folded and occasionally overturned throughout various orogenic intervals. Because individual formations are frequently structurally separated and discontinuous, this entire stratigraphic section is considered a single aquifer system for the ease of evaluation and interpretation. Depositional environments for individual formations have been discussed in section C.1. of this report.

The Precambrian formations, comprising most of the northern half of the Rocky Mountains region, consist of red and green argillites with interventing black, maroon and pink quartzites. There are 15,000 to perhaps as much as 45,000 feet of Precambrian sediments deposited in this portion of the Rocky Mountains region. These sediments are roughly 0.8 to 1.4 billion years old and are collectively known as the Belt Supergroup. The yield from wells completed in Precambrian rocks is variable, but generally small, because these rocks are "tight" and water must be obtained from secondary openings such as joints, fractures, faults and weathered zones of the bedrock. Yields range from 1 to 35 gpm, with 10 gpm being about the average. Water quality from Precambrian sediments is of very good quality, usually having less than 300 mg/L of dissolved solids.

Paleozoic strata are mostly made up of carbonate sediments and shales with some clastic formations such as the Flathead and Quadrant Formations at the base and the top of the section, respectively. Mountain-forming stresses have warped and bent the formations into a series of folds and thrust sheets. As in the

Great Plains region, the Madison Formation is important not only as a source of ground water, but as a place for recharge infiltration. Well yields from Paleozoic strata are highly variable and are dependent not only on the formation drilled to, but also proximity to outcropping of the formation. Water quality is generally good, but can vary depending on the formation drilled, depth and distance from the recharge area. Wells completed in Paleozoic sediments are used primarily for domestic and stockwater, although some larger capacity wells in the Madison Formation are used for irrigation.

Mesozoic strata demonstrate a gradual transition from the chiefly marine beds of the lower formations to mostly terrestrial sediments found in the upper part of the section. These formations have also been subjected to the same tectonic stresses which deformed the underlying Paleozoic sediments. Deformation has not only folded, inclined and overturned the strata, but often vertically and laterally displaced beds hundreds to tens of thousands of feet. The major water-bearing units (aquifers) within the Mesozoic svstem are the Jurassic Swift Sandstones, the basal Cretaceous Kootenai Sandstone and the Eagle Sandstone where erosion has not removed it. Impermeable shale formations are interbedded among the sandstone units and act as confining beds. Faulting, however, has often juxtaposed different formations and the extent of the aquifers are hydraulically interconnected is uncertain. There exists practically no water-quality data for wells drilled in Mesozoic Formations of the Rocky Mountains region, but moderate values of dissolved solids would be expected. Well yields for these aquifers are widely variable, ranging from 5 to 100 gpm and are contingent upon location, attitude of the bedded rocks and proximity to recharge areas. Rainfall and snow-melt water account for nearly all of the recharge for "consolidated sedimentary rocks." Evapotranspiration from dense forests, springs and wells discharge the ground water to keep the system in balance.

The aforementioned Precambrian, Paleozoic and Mesozoic strata comprise all of the mountain ranges north of the "batholithic province" and a substantial number of scattered ranges in the central and southern portions of the Rocky Mountains region. The inaccessibility of the mountain ranges has deterred and prevented development and drilling, thereby yielding only scant ground-water information for this aquifer unit.

METAMORPHIC AND IGNEOUS ROCKS

Metamorphic and igneous rocks comprise a large area of the south-central portion of the Rocky Mountains region. The Boulder and Idaho batholiths of Cretaceous age are the largest plutons, while others such as the Tobacco Root, Pioneer and Flint Creek stocks are of lesser areal extent. These batholiths and their associated contact metamorphic assemblages outcrop or underlie most of this central portion and frequently are referred to as the "batholithic province." The plutons are composed mainly of quartz monzonite and related granitic rocks.

The availability of ground water from granite is rather limited. Water availability from this type of crystalline rock is entirely dependent upon secondary porosity because of insufficient primary porosity. Water from these rocks must be obtained from secondary porosity which is produced by: horizontal pressure release fractures that form as a result of sheet unloading; vertical joint sets which were produced from tension release fracturing; and faults that were a result of tectonic stresses. The combined interconnectedness of these openings will provide space for ground-water storage and conduits for movement. These features are often surficially expressed as lineaments and joint traces, and most of the higher yield wells are located where the fractures intersect. The wells are generally between 100 and 200 feet deep because permeability generally decreases with depth. Average well yields for granitic rocks are approximately 2 to 5 gpm. There is a paucity of water quality data from igneous rocks, but values of 300 mg/L of dissolved solids are common.

Proximal to these large batholiths and stocks are various Cretaceous and Tertiary extrusive rocks. The Elkhorn Mountain and Lowland Creek volcanics outcrop over considerable areas and are composed mainly of rhyolites and latites. These rocks are a source of potable water for many rural families. Wells from extrusive rocks generally have low yields because of their dependence on fracture openings. This aquifer is mainly recharged from precipitation, and wells and springs are the primary types of discharge.

Lying south and east of the batholithic province is an extensive area that contains pre-Belt metamorphic rocks (2.7 to 1.7 billion years old). The Beartooth and Ruby Ranges and part of the Tobacco Root Mountains are composed of this metamorphic assemblage. They are mainly granitic gneisses and schists that have been fractured enough to allow ground-water storage. Well yields tend to be very small, but water quality is good (though often has some iron concentrations). These rocks are therefore an important domestic source of ground water in the southern portions of the Rocky Mountains region. Recharge and discharge for this aquifer are also through precipitation and wells and springs, respectively.

III. GROUND-WATER USE

Information on water use in Montana prior to 1980 is extremely limited because accurate data on withdrawal rates is practically non-existent. Communities have the best opportunity to record water use, but 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 those values. Montana, however, 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 ground-water and surface-water use will become available after that date. The Department is also compiling a 1980 water-use and quantification survey which is yet to be released.

Major uses of ground water in the Rocky Mountains region are for irrigation, municipalities, industry, rural-domestic and livestock. Table II-4 summarizes, by county, the various well uses of this region. Most of these wells are completed in the Quaternary alluvial or glacial aquifers, although Tertiary and bedrock aquifers are exploited locally. An estimate of the cumulative ground water withdrawn from the Rocky Mountains region is approximately 146.14 million gallons per day (mgd) or 448.65 acre-feet per day. This value for ground water withdrawn represents about 3 percent of the total amount of water diverted within the Rocky Mountains region, a figure that is believed to be a conservative estimate. Even though current ground-water use is small, it 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 II-4

WELL USE BY COUNTY, ROCKY MOUNTAINS REGION
August 1981

COUNTY	COM	DOM	D+S	IRR	IND	PUB	STK	MU	OTH	NOT RPT	TOTAL
Beaverhead	11	663	168	42	4	14	258	53	30	6	1249
Broadwater	0	308	145	43	1	8	191	33	28	1	758
Deerlodge	3	532	59	16	6	4	23	22	14	2	681
Flathead	19	2631	696	81	37	34	41	233	82	8	3862
Gallatin	15	2101	568	48	18	27	189	95	95	2	3158
Glacier	8	130	153	1	20	4	104	10	10	0	440
Granite	4	348	72	9	1	4	36	13	30	0	517
Jefferson	1	556	90	15	6	25	85	46	23	1	848
Lake	2	885	437	18	3	20	52	94	26	2	1539
Lewis and Clark	10	2121	297	67	15	36	149	135	142	4	2976
Lincoln	11	1091	89	7	6	15	14	31	39	2	1305
Madison	2	685	219	18	3	14	158	26	28	0	1153
Meagher	0	87	63	1	2	5	53	20	11	2	244
Mineral	5	210	25	6	3	8	6	12	18	2	295
Missoula	14	2354	292	47	65	60	47	153	103	48	3183
Park	1	564	183	25	9	11	65	57	36	10	961
Powell	1	363	100	15	3	6	71	28	8	2	597
Ravalli	10	3338	348	193	18	30	95	550	481	2	5065
Sanders	5	479	193	61	2	8	43	80	27	1	899
Silver Bow	5	552	58	28	10	4	28	22	23	2	732
Total	127	19998	4255	741	232	337	1708	1713	1254	97	30462

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.

AGRICULTURE

Agriculture, specifically crop irrigation and livestock watering, uses the most ground water in the Rocky Mountains region. Tertiary uses which are agriculturally oriented include fish farming and wildlife refuges.

Irrigation

There are approximately 1,244,000 acres of irrigated land in the Rocky Mountains region. Most of the irrigated cropland in the region is hayland, while small grains and potatoes account for a substantial portion of the remainder. Other crops in the region dependent upon irrigation are sweet and tart cherry orchards, tree farms and mint plantations. The percentage of this acreage that is irrigated in any given year is uncertain. Roughly 4.89 billion gallons per day (bgd) are diverted for this acreage, of which 1 percent is withdrawn from ground-water sources. Almost all irrigation wells are completed in the unconsolidated alluvial aquifer, but a few other large-capacity wells obtain water from Tertiary aquifers.

Requirements for diversion are more than double the consumptive use, resulting in a return flow 53 percent of the total diversion (DNRC, 1974). Consumptive use varies with irrigation efficiency, rates of application and other factors such as the crop, soil, precipitation, growing season and ambient temperature. Nearly all irrigation is used for raising feed crops to support the livestock industry.

Livestock

Stock consumptive use of ground water in the Rocky Mountains region is estimated to be 8.5 mgd, of which 5 percent is withdrawn from ground-water sources. Cattle and sheep account for most of the water consumed, with average daily consumption values of 15 and 3 gallons per head per day, respectively. Pigs, horses and other livestock use the remainder of stockwater consumed.

About 1700 wells are used for stockwatering only and another 4300 rural wells are used jointly for domestic and stockwater purposes. Most stockwater wells derive ground water from the alluvial aquifers; Tertiary and bedrock aquifers also offer viable sources for sufficient amounts of ground water. Springs and seeps are another source for stockwater within the reigon, but are not well identified because their source and discharge rate are often unknown. Typical stock wells and springs usually have sustained yields of 10 to 15 gpm. Stockwater wells are an integral part of the livestock ranching industry within the Rocky Mountains region.

Aquaculture is a new and increasingly popular aspect of the agricultural industry. Many privately owned fish farms have recently begun operations in this region. Although these businesses use ground water non-consumptively, they totally rely on springs and wells to maintain their livelihood. State-owned fish hatcheries are also dependent upon ground-water sources in much the same way.

MUNICIPAL AND DOMESTIC

A computer listing produced by the Montana Department of Health and Environmental Services in 1980 showed that there were 65 communities in the Rocky Mountains region of Montana that have a municipal water-supply system. The total number of public-supply systems in this region is about 330 if trailer courts, nursing homes and other institutional systems are included. Of the 65 communities, 16 rely exclusively on surface water, another 16 use both surface and ground water and the remaining 33 communities depend solely on wells or springs for their water supply. Of the 393,625 people who reside within the Rocky Mountains region of Montana, approximately 259,700 live in municipalities. Of these, 93,070 depend exclusively upon ground water for their drinking and household needs; they withdraw a total of about 30.01 million gallons of water per day.

Quaternary alluvium is the primary aquifer used for municipal wells in the Rocky Mountains region supplying, perhaps, as much as 70 percent of the water withdrawn. Tertiary and glacial deposits provide most of the remainder.

The quality of water used by most of the communities in the Rocky Mountains region of Montana is usually excellent, and all systems tested had fewer dissolved solids than the maximum recommended by the EPA. Iron is sometimes a problem in trailer court water supplies; as an example Wilsall had a concentration of 2.9 mg/L of iron in its water supply. Several water systems had measureable trace elements in the water they supplied. The highest lead value was 0.18 mg/L in water from a trailer court near Big Sky. Arsenic measured 0.6 mg/L in water supplied by Three Forks and mercury was highest near West Glacier and Coram, 0.33 and 0.35 mg/L, respectively. Most community water supplies had low nitrate values. Water from the supply system at Alberton, however, had 4.4 mg/L; White Sulphur Springs had 4.8 mg/L and Wilsall had 11.8 mg/L. Many trailer courts had nitrates exceeding 5.0 mg/L in their water supplies.

Domestic water is that ground water used by all persons not served by a municipal or community water system. For the most part, domestic wells primarily are used by rural residents, although many subdivision units also have individual wells. The approximately 20,000 domestic wells comprise the largest single category (65%) of permitted wells in the Rocky Mountains region. It is estimated that an average withdrawal of 33.86 million gallons is consumed daily in the Rocky Mountains region.

Because most residential settlements are within valleys, the Quaternary alluvial aquifer is the primary ground-water source. An example of this is the Gallatin Valley where new subdividions with their accompanying wells are being constructed throughout the valley. The Tertiary aquifer is also an important source of ground water for many rural residents as in the Bitterroot Valley; the Sunset Bench subdivision attains its potable supply from this aquifer. As evidenced by the large percentage of domestic wells, ground water is dominantly relied on for rural habitation.

INDUSTRY

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.

It is estimated that 28 mpg of ground water are withdrawn for industrial use in the Rocky Mountains region, of which 30 percent is consumed. The water that is not consumed is either discharged as surface-water flow, or treated and recycled for re-use or disposed through injection wells.

Industrial water use in the Rocky Mountains region is dominated by the minerals industry. The Anaconda Company operations at Butte and Columbia Falls account for a major portion of the ground water withdrawn in the region. The Butte operation withdraws roughly 7.5 mgd for mine dewatering and processing the copper ore. Much of this water is recycled and the exact amount consumed is unknown as it is dependent upon daily operations. The Anaconda Aluminum Plant at Columbia Falls withdraws approximately 4.63 mgd of which 0.18 mgd are consumed for either refining or cooling uses. Another mineral industry that withdraws large quantities of ground water is the Stauffer Chemical Company. One million gallons per day are withdrawn for their phosphate-processing operations of which one-fourth is consumed. The remaining minerals processing industries use very small amounts of water.

Other large industrial water uses include the Horner-Waldorf pulp mill and the White Pine Sash Company of Missoula. Horner-Waldorf has an intake rate of 16 mgd of which 15 percent is consumed, whereas the White Pine Sash Company is estimated to consume 0.14 mgd as steam.

Lesser amounts of ground water are withdrawn also for a variety of other uses such as geothermal heating, sanitation and boiler feeding.

Of the total amount of water diverted for industry in the Rocky Mountains region about 40 percent is ground water. Most industrial wells tap the Quaternary alluvial aquifer, however, some obtain water from Pleistocene glacial deposits. Both of these aquifers are a prolific source of good quality water for industrial use.

IV. WATER QUALITY

Data Sources

More than 3,000 water-quality analyses contained in the computer files at the Montana Bureau of Mines and Geology (MBMG) were reviewed for the UIC Project: approximately 375 of these analyses are from the Rocky Mountains region. Additional analyses are contained in MBMG and U.S. Geological Survey (USGS) bulletins, memoirs, open-file reports, professional papers and unpublished reports.

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 in Helena, Montana, and the U.S. Forest Service (USFS). The USGS and the MBMG Hydrology Division furnish water samples taken from ground-water sources within the state of Montana to the MBMG laboratory for analysis; the results of these analyses have become part of an integrated data bank.

Previously published geologic and hydrologic reports for the intermontane basins of the Rocky Mountains region contain water-quality analyses. The most recent USGS publication, Open-File Report 80-1102 by Moreland and Leonard (1980), discusses ground-water characteristics of the Helena Valley. The water-quality data contained in this report were processed at the MBMG laboratory during 1979 and 1980 and are contained in the listing of water quality data in Appendix E. Older reports including those written by Coffin and others (1971) on the Tobacco and Upper Stillwater Valleys; Hackett and others (1960) on the Gallatin Valley; Konizeski and others (1968) on the Kalispell Valley; McMurtrey and others (1972) on the Bitterroot Valley; and McMurtrey and others (1965) on the Missoula Basin all contain water-quality analyses and descriptions of ground water for their respective areas. An ongoing project at the MBMG is to assimilate these previously published analyses in the data-management system.

Appendix E contains a tabulation of those analyses in the water-quality system selected for this project. These analyses have been sorted by formation or aquifer and by township, range and section; many 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 previously published data are not computerized and because the listings may include data created since the compilation of the maps.

General Water Quality

Ground-water quality data for three aquifers or aquifer groups in the Rocky Mountains region were extracted. These aquifers include:

1) Cenozoic basin fill deposits
2) Early Tertiary through Precambrian consolidated sedimentary rocks
3) Igneous and Metamorphic rocks

Table II-5 compares selected elements and ions to drinking water quality standards published by the U.S. Environmental Protection Agency (EPA). However, since no standard has been established for sodium plus potassium, an arbitrary value of 250 mg/L has been selected as a reference point.

Based on these data, ground water in the Rocky Mountains region is generally of better quality than that recommended by the EPA's standards. In the three aquifer groups, 97 percent of the samples had dissolved solids concentrations of less than 500 mg/L; less than one percent of the samples had nitrate (as N) concentrations greater than 10 mg/L; approximately 99 percent of the analyses reported sulfate concentrations of less than 250 mg/L; and there were no chloride concentrations greater than 250 mg/L. Manganese and iron are the two

TABLE II-5

COMPARISON OF SELECTED ELEMENTS AND IONS IN WATERS OF THE ROCKY MOUNTAINS REGION, MONTANA TO DRINKING WATER QUALITY STANDARDS[4]

AQUIFER	CONSTITUENTS AND STANDARDS	NUMBER OF VALUES REPORTED	% GREATER THAN STANDARD	% LESS THAN STANDARD	AVERAGE CONCENTRATION IN MG/L
Cenozoic Basin Fill Deposits	Na+K(250)[1]	305	< 1	> 99	33.
	Fe(.3)[2]	304	12	88	.3
	Mn(.05)[2]	305	23	77	.09
	Cl(250)[2]	305	< 1	> 99	11.
	SO_4(250)[2]	305	3	97	.44
	N(10)[3]	304	< 1	> 99	1.
	Ds(500)[2]	305	7	93	264.
Early Tertiary through Pre-Cambrian Consolidated Sediments	Na+K(250)[1]	27	4	96	83.
	Fe(.3)[2]	27	11	89	.1
	Mn(.05)[2]	27	7	93	.017
	Cl(250)[2]	27	0	100	13.
	SO_4(250)[2]	27	0	100	59.
	N(10)[3]	27	0	100	.4
	Ds(500)[2]	27	0	100	316.
Igneous and Metamorphic Rocks	Na+K(250)[1]	42	0	100	21.
	Fe(.3)[2]	42	5	95	.1
	Mn(.05)[3]	42	12	88	.032
	Cl(250)[2]	42	0	100	7.
	SO_4(250)[2]	42	0	100	30.
	N(10)[3]	42	0	100	.5
	Ds(500)[2]	42	2	98	195.

[1] No standard has been set. A concentration of 250 Mg/L has been selected as a point of reference.

[2] Secondary drinking water standard in Mg/L

[3] Primary drinking water standard in Mg/L

[4] Source: U.S. Environmental Protection Agency, 1976

most likely elements to exceed the water quality standards with 13 percent and 9 percent of the reported values, respectively, being greater than the standards. In some areas, such as unconsolidated sediments in the Bitterroot Valley, dissolved iron concentrations commonly exceed .3 mg/L and often are several mg/L. In areas such as these, iron staining of household fixtures and clothing are common.

Cenozoic Basin-Fill Deposits

Most of the 305 analyses in this group are for ground water from unconsolidated to semiconsolidated, Holocene to Tertiary sediments deposited in the intermontane basins. The geographic distribution of these data is uneven as certain locales, such as the Helena Valley or the Little Bitterroot Valley have been sampled extensively during MBMG or USGS projects and other areas, such as the Beaverhead Valley, have had only a few water samples collected.

Dissolved solids in the Cenozoic basin-fill and alluvial deposits range from a high of 1,273 mg/L for water from a 1,498 feet deep geothermal test well producing water from Tertiary sediments at the Warm Springs State Hospital in T. 5 N., R. 10 W., sec. 13DCC in Deer Lodge County to a low of 27 mg/L for water from a USGS research well completed in glacial deposits in T. 28 N., R. 33 W., sec. 9BDDB in Sanders County near Libby. The average dissolved solids for all analyses from this group is 260 mg/L.

Figure II-25 is a plot of dissolved solids versus the number of occurrences for the samples in this group. The majority of the analyses plotted represent calcium bicarbonate type but some sodium bicarbonate type waters occur in almost every dissolved solids range. The lowest dissolved solids value in the group is for a calcuim bicarbonate water while the highest reported dissolved solids value is for a calcuim sulfate type water.

Numerous older analyses exist for basin-fill and unconsolidated alluvial

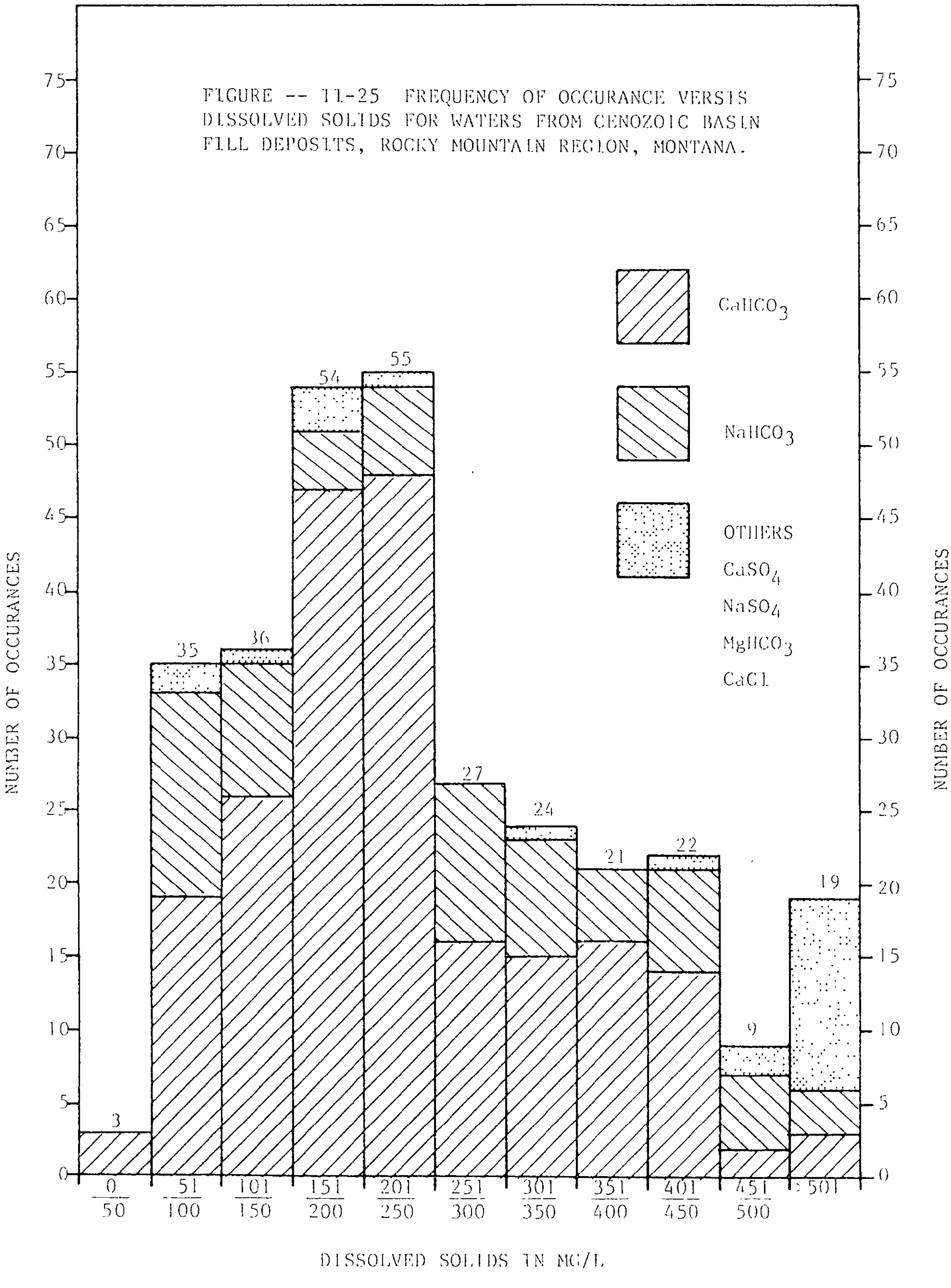


FIGURE -- 11-25 FREQUENCY OF OCCURANCE VERSIS DISSOLVED SOLIDS FOR WATERS FROM CENOZOIC BASIN FILL DEPOSITS, ROCKY MOUNTAIN REGION, MONTANA.
CaHCO3
NaHCO3
OTHERS
CaSO4
NaSO4
MgHCO3
CaCl
NUMBER OF OCCURANCES
3
35
36
54
55
27
24
21
22
9
19
0 50
51 100
101 150
151 200
201 250
251 300
301 350
351 400
401 450
451 500
>501
DISSOLVED SOLIDS IN MG/L

deposits in the Rocky Mountains region. Coffin and others (1971) report that waters in the Tobacco and Upper Stillwater Valleys of northwestern Mountana range in dissolved solids from 80 to 1,500 mg/L. The waters are generally calcium bicarbonate type and iron concentrations range from below the detection limit to .07 mg/L and occasionally cause problems. Based on 58 analyses, Hackett and others (1960) report that waters in the Gallatin Valley are predominately calcuim bicarbonate type and range from 154 to 597 mg/L dissolved solids. Konizeski and others (1968) report that Quaternary aquifers in the Kalispell Valley produce water ranging in dissolved solids from 132 to 788 mg/L. Water types are generally calcium bicarbonate, but iron concentrations as high as 14.1 mg/L are reported. McMurtrey and others (1965) in discussing the hydrology of the Missoula Basin report dissolved solids concentrations range from 94 to 326 mg/L. Iron concentrations range from .04 to 6.9 mg/L. Calcium and bicarbonate are generally the most common cation and anion present. McMurtrey and others (1972) report dissolved solids concentrations for the Bitterroot Valley south of Missoula range from 42 to 748 mg/L. Iron concentrations range from .01 to 4.1 mg/L and can cause problems by staining clothing and household fixtures. Dissolved solids concentrations along the west side of the valley often are lower than those for the east side because the granitic rocks to the west contain fewer soluble minerals than the sedimentary and igneous rocks to the east. Moreland and Leonard (1980) describe the qualities and types of ground water for the Helena Valley. These waters are generally calcium bicarbonate type and range in dissolved solids from 111 to 936 mg/L with an approximate average of 330 mg/L. Anomalous samples from T. 10 N., R. 3 W., sections 16, 17, and 18 show evidence of poor sewage disposal practices and/or leachate from a landfill.

Early Tertiary Through Precambrian Consolidated Sedimentary Rocks

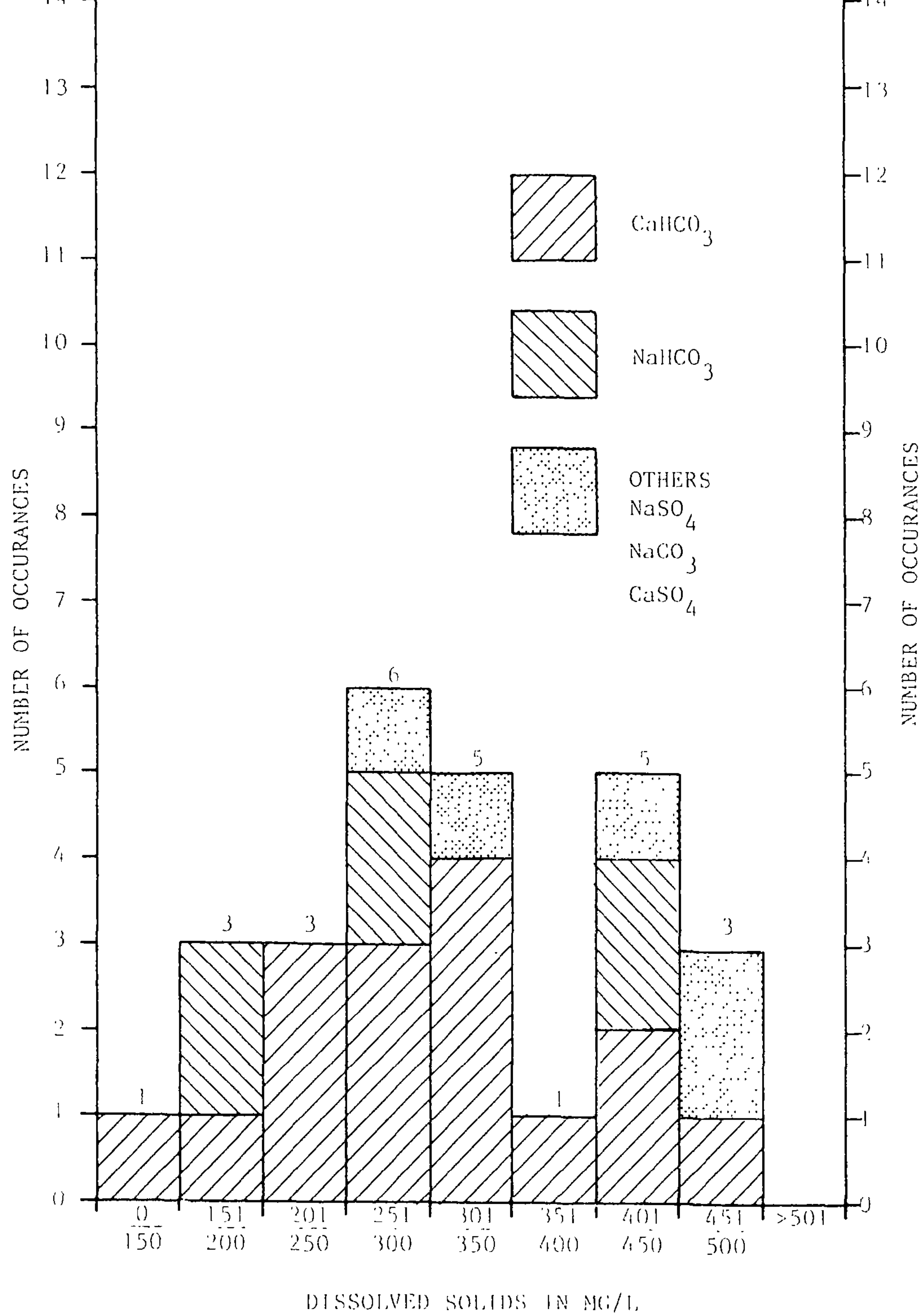
There are only 20 analyses recorded for ground water from Early Tertiary through Precambrian consolidated rocks in the MBMG data system. The average value of dissolved solids for these samples is 316 mg/L. A major reason for the small number of analyses is that relatively few people live in areas underlain by these materials resulting in few wells. Most of the ground-water development in the Rocky Mountains region has occurred in the intermontane basins and stream valleys where water is obtained from basin fill deposits or alluvium. Dissolved solids concentrations range from 481 mg/L for water from McMenomy warm springs in T. 9 S., R. 10 W., sec. 29AAAC in Beaverhead County to 106 mg/L for water from a spring in T. 4 S., R. 13 E., sec. 5ADCB in Sweetgrass County. Both of these springs represent discharge from Madison Group rocks but illustrate differing circulation regimes. The higher dissolved solids waters from the McMenomy spring represent waters from a deep circulation system accounting for its calcium sulfate character and relatively warm temperature (19 degrees C). The lower dissolved solids water from the spring in Sweetgrass County is a calcuim bicarbonate type and is from a shallow circulation system in the Madison group.

Figure II-26 is a plot of dissolved solids versus the number of occurrences for ground water from Late Tertiary through Precambrian consolidated sedimentary rocks. As can be seen from the patterns representing water types, calcum bicarbonate waters are most common followed by sodium bicarbonate waters.

Igneous and Metamorphic Rocks

There are 42 analyses of water from igneous and metamorphic rocks which also represent portions of the Rocky Mountains region where relatively little ground-water development has taken place. Dissolved solids concentrations average 195 mg/L and range from a high of 672 mg/L in water from a 6,970 feet deep geothermal test well in T. 12 N., R. 6 W., sec. 32ABD near Marysville in

FIGURE -- II-26 FREQUENCY OF OCCURANCE VERSIS DISSOLVED SOLIDS FOR WATERS FROM EARLY TERTIARY THROUGH PRECAMBRIAN CONSOLIDATED ROCKS, ROCKY MOUNTAIN REGION, MONTANA.



Lewis and Clark County to a low of 28 mg/L in water from a spring in T. 13 S., R. 2 E., sec. 31CADD in the Centennial Valley in Beaverhead County. The higher dissolved solids water from the geothermal test is a sodium bicarbonate sulfate type produced by plutonic rocks and represents a deep, warm-water circulation system. The lower dissolved solids water is a calcium bicarbonate type and is discharged from metamorphic rocks.

Figure II-27 is a plot of dissolved solids versus the number of occurrences for ground water from igneous and metamorphic sources. As can be seen from the patterns representing the various water types, the majority of the analyses are for calcium bicarbonate type waters.

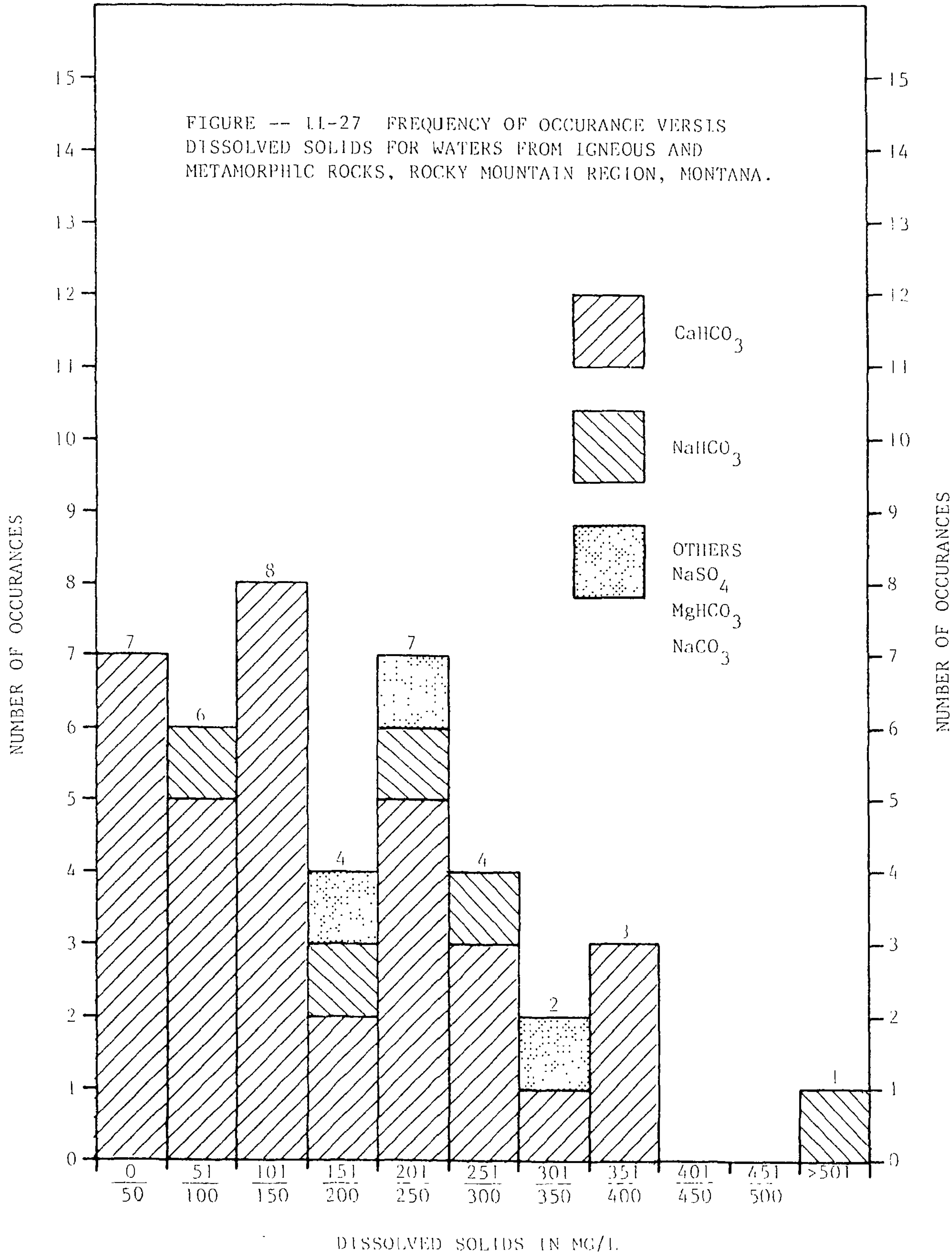


FIGURE -- II-27 FREQUENCY OF OCCURANCE VERSUS DISSOLVED SOLIDS FOR WATERS FROM IGNEOUS AND METAMORPHIC ROCKS, ROCKY MOUNTAIN REGION, MONTANA.
CaHCO3
NaHCO3
OTHERS
NaSO4
MgHCO3
NaCO3
NUMBER OF OCCURANCES
NUMBER OF OCCURANCES
0 / 50
51 / 100
101 / 150
151 / 200
201 / 250
251 / 300
301 / 350
351 / 400
401 / 450
451 / 500
>501
DISSOLVED SOLIDS IN MG/L

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)