U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS ATLAS HA-738-C

INTRODUCTION

The Regional Aquifer-System Analysis (RASA) program is a series of studies by the U.S. Geological Survey (USGS) to analyze regional ground-water systems that compose a major portion of the Nation's water supply (Sun, 1986). The Northern Rocky Mountains Intermontane Basins is one of the study regions in this national program. The main objectives of the RASA studies are to: (1) describe the ground-water systems as they exist today, (2) analyze the known changes that have led to the system's present condition, (3) combine results of previous studies in a regional analysis, where possible, and (4) provide means by which effects of future ground-water development can be estimated.

The purpose of this study, which began in 1990, was to increase understanding of the hydrogeology of the intermontane basins of the Northern Rocky Mountains area. This report is Chapter C of a three-part series and describes the quality of ground water and surface water in the study area. Chapter A (Tuck and others, 1996) describes the geologic history and generalized hydrogeologic units. Chapter B (Briar and others, 1996) describes the general distribution of ground-water levels in basin-fill deposits.

Water-quality data illustrated in this report represent the distribution of concentrations and composition of dissolved solids in ground water and surface water in the intermontane areas. The chemistry of ground and surface water in the intermontane areas is influenced by the chemical and physical nature of the rocks in the basin deposits of the valleys and surrounding bedrock in the mountains.

LOCATION AND GENERAL FEATURES

The Northern Rocky Mountains Intermontane Basin study area encompasses about 77,500 mi² in western Montana and central and northern Idaho (fig. 1). The study area extends from near the eastern front of the Rocky Mountains in Montana westward to the basalt plains of the Columbia Plateau in western Idaho. In the south, the study area extends from the Snake River Plain in Idaho northward to the United States-Canada border. The Continental Divide separates the study area into two major drainage systems—the Missouri River drainage to the east and the Columbia River drainage to the west. Major tributaries of the Missouri River drainage in the study area include the Beaverhead, Ruby, Big Hole, Jefferson, Madison, and Gallatin Rivers. Major tributaries of the Columbia River drainage in the study area include the Kootenai, Blackfoot, Bitterroot, Flathead, Clark Fork/Pend Oreille, Spokane, Salmon, Selway, Lochsa, South Fork Clearwater, and North Fork Clearwater Rivers.

Topography in the study area is varied. Land-surface altitudes range from about 2,000 ft in the Kootenai River Valley in the northwestern part of the study area to more than 12,000 ft in the Lost River Range in the south-central part of the study area. In northwestern Montana and central Idaho, mountain ranges typically are separated by narrow, steep-sided valleys that have little or no basin-fill deposits. In contrast, the ranges of southwestern Montana and east-central and northern Idaho are separated by wide, relatively level valleys that are deeply filled with sediment. Valley-floor altitudes range from about 2,000 ft in the Kootenai River Valley to about 7,000 ft in the Sawtooth Valley in south-central Idaho.

The climate is characterized by cold winters and mild summers. Annual precipitation ranges from about 8 in. for basins of east-central Idaho to about 100 in. for some mountainous parts of Montana. Most valleys receive about 10 to 30 in. of precipitation per year, with more than one-half falling in winter and spring. Large winter snowpacks in the mountains gradually release their water content as snowmelt that maintains streamflow well into summer.

Major physiographic features in the study area include 54 generally north-south trending intermontane basins (or valleys) (fig. 1). In this report, "basin" refers to topographic as well as geologic structural basins. The perimeters of the basins are approximated from topography, geologic structure, extent of basin fill, and results of previous studies. The intermontane basins range in area from less than 10 mi² to more than 700 mi² and are filled with unconsolidated to poorly consolidated Tertiary to Quaternary continental deposits. Intermontane basins compose about 16 percent of the study area. All basins have through-flowing perennial streams with recent flood plains. In most southern basins, these flood plains are adjacent to older river terraces that grade into pediments or alluvial fans that meet mountain fronts with an abrupt change in slope. In northern basins, recent flood plains are adjacent to glacial deposits that extend to mountain fronts; in some basins, the glacial deposits reach an altitude of as much as 6,000 ft. Mountain fronts commonly coincide with faults or fault systems along which the basins have been down dropped relative to the mountains.

CRITERIA FOR SITE SELECTION

The water-quality information depicted on figure 2 is based on data for ground-water and surface-water analyses retrieved from the USGS National Water-Data Storage and Retrieval System (WATSTORE). The analytical data had to meet certain quality-assurance criteria in order to be used. The criteria included selecting only those analyses that balanced electrochemically to within 5 percent and those that included sufficient chemical parameters to calculate dissolved-solids concentrations if not measured or previously calculated. Only complete major-ion analyses that included all of the following dissolved constituents were used in the data presentation: calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulfate. Some older analyses that included sodium plus potassium as a single constituent also were used. Many analyses also contained data for specific conductance, pH, dissolved silica, and selected trace elements.

Ground-Water Sites

The data base for ground-water chemistry retrieved from WATSTORE consists of information compiled from the USGS, and other Federal, State, and local sources. All data were initially reviewed to assure that the source of water was within or near one of the intermontane basins and the temperature of the water was 25°C or less. Water-quality data for 1,545 wells were compiled for this report. Most samples were collected either as part of this study during 1991-1993 or in the preceding few years. Some water-quality analyses used for this report were collected as early as 1912 (Meinzer, 1914) and 1921 (Pardee, 1925). Most wells had complete chemical analyses for only one water sample; however, some wells had multiple complete chemical analyses, in which case only the most recent analysis was used. Because of the limited number of wells with multiple samples, temporal changes of water quality in the intermontane basins could not be determined. However, the limited data for the multiple samples suggest little significant change in the overall water quality with time. In Montana, 1,108 wells were selected and in Idaho, 437 wells were selected.

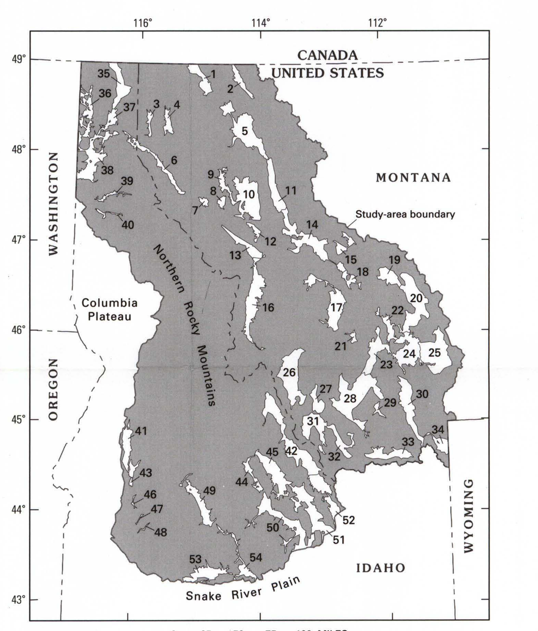
Figure 2 depicts the general distribution of dissolved-solids concentration and water type in the study area and is not intended to show precise concentrations or water types at any given location or well depth. Because the wells are not evenly distributed throughout the intermontane basins and because significant chemical differences may be found in closely spaced wells of similar or dissimilar depths, local variations in dissolved-solids concentrations or water type are not shown on this map.

Surface-Water Sites

The data base for surface-water chemistry was retrieved from WATSTORE and reviewed. Data from 81 sites met the selection criteria and were compiled for this report. Selection of sites was based primarily on location of the site, total number of water samples collected at a site, and the type of water-quality information available. To be selected, a site needed to either be in or near one of the intermontane basins in order to help define possible interactions between surface-water and ground-water quality. The water-quality data needed to contain complete major-ion analyses in order to determine water types and surface-water discharge data had to be available to calculate average discharge-weighted chemical concentrations. In Montana, 49 sites with a total of 2,061 samples were selected. In Idaho, 32 sites with a total of 1,009 analyses were selected. Surface-water samples were collected as early as 1949 and through 1993.

QUALITY OF WATER

As a result of interactions between water and the rock it contacts, water contains a variety of dissolved-inorganic constituents. The dissolved-solids concentration, which is a measure of the total amount of dissolved chemicals in water, is calculated as the sum of the concentrations of the major dissolved-inorganic constituents. In the study area, the major constituents that compose the bulk of dissolved solids are the cations calcium, magnesium, sodium, and potassium, and the anions bicarbonate, chloride, and sulfate. In some areas, dissolved silica, iron,



23. Jefferson River Valley
24. Western Three Forks Valley
25. Gallatin Valley
26. Big Hole Basin
27. Grasshopper Valley
50. Big Lost River Valley
51. Little Lost River Valley
52. Birch Creek Valley
53. Camas Prairie
54. Big Wood River-Silver Creek area

Figure 1. Location of study area and intermontane basins.

Dissolved-Solids Concentrations and Chemical Composition of Surface Water

The average dissolved-solids concentration and chemical composition of surface water at 81 sites is indicated by pie diagrams on figure 2. These pie diagrams are based on the dissolved concentrations of the major cations and anions, in milliequivalents per liter. The cations (calcium, magnesium, and sodium plus potassium) make up the left one-half of the diagram, and the anions (bicarbonate plus carbonate, sulfate, and chloride) make up the right half. The size of the pie diagram is proportional to the dissolved-solids concentration; thus, the larger the circle the larger the dissolved-solids concentration. The number of analyses at the site, the discharge-weighted average dissolved-solids concentration, and the average surface-water discharge in cubic feet per second during sample collections are shown by numbers adjacent to each diagram.

Because the concentrations of ions generally decrease as streamflow increases, a simple average of sample concentrations may not adequately represent the variability associated with seasonal changes in streamflow. A discharge-weighted average more closely represents a concentration proportioned to the total volume of water passing a point during the time period when samples were collected. The discharge-weighted average concentrations shown in the pie diagrams were obtained by multiplying the concentration of individual ions and dissolved solids in the sample by the discharge at the time of sampling, summing the products, and dividing by the sum of the discharges. A discharge-weighted average describes the composition of water relative to the magnitude of discharge, thereby giving greater weight to samples collected during high flows that constitute the bulk of annual streamflow. The number of analyses used in these calculations varies between sites and may not necessarily represent equivalent hydrologic conditions or time periods.

Discharge-weighted average dissolved-solids concentrations at the selected surface-water sites range from 27 mg/L at the Big Hole River near Jackson to 409 mg/L at the Beaverhead River near Twin Bridges in Montana and from 16 mg/L at the North Fork Payette River at McCall to 290 mg/L at Thousands Springs Creek near Chilly in Idaho. At 25 of the 81 sites, the average dissolved-solids concentration was less than 50 mg/L, whereas at 5 other sites the average concentration was greater than 250 mg/L. Average streamflow at the time of sampling ranged from less than 50 ft³/s at about 15 sites to more than 27,000 ft³/s at the Pend Oreille River.

At most of the selected surface-water sites, calcium is the dominant cation and bicarbonate is the dominant anion. At a few sites sulfate is the dominant anion, and at a few other sites sodium is the dominant cation. In general, however, the chemical composition of surface water in the study area is fairly consistent.

General differences in chemical composition between stream sites in the headwaters areas compared to sites farther downstream can be determined from the data in figure 2. Two headwater sites in the Upper Clark Fork Valley of western Montana have streamflow less than 300 ft³/s, dissolved-solids concentrations greater than 300 mg/L, and sulfate as one of the dominant anions. At a downstream site on the Clark Fork in the Missoula Valley below the confluence with the Blackfoot and Bitterroot Rivers, the discharge is greater than 5,000 ft³/s, the dissolved-solids concentration has decreased to about 100 mg/L, and the sulfate concentration has decreased to a level where sulfate is no longer a dominant anion. At two other downstream sites, one in the Lower Clark Fork Valley and one on the Pend Oreille River at the Idaho/Washington State line, the trend of increasing discharge and decreasing dissolved-solids concentrations continues. These changes in chemical composition result from dilution by tributaries discharging large quantities of water having smaller dissolved-ion concentrations. The large percentage of sulfate at the upstream stations could be derived from several probable sources. The upstream area has sulfur-rich bedrock containing base and precious metals that were the object of 100 years of mining. Natural weathering of the bedrock and tailing deposits remaining after mining releases sulfur into the streams. In northern Idaho, the Coeur d'Alene River system shows a downstream change in chemical composition similar to that of the Clark Fork. The South Fork Coeur d'Alene River, which drains a historical metal-mining area, has sulfate as the dominant anion. Below the confluence with the North Fork Coeur d'Alene River, which has a relatively small sulfate percentage and a relatively large discharge, the sulfate percentage in the main Coeur d'Alene River decreases. The Spokane River, downstream from Coeur d'Alene Lake and several large tributaries, has an increased discharge and a decreased dissolved-solids concentration and sulfate percentage compared to the Coeur d'Alene River upstream from the lake.

In the upper Madison River, which originates in Yellowstone National Park, sodium ions are essentially the only significant cation, as indicated on the pie diagram. The source of the sodium ions is geothermal water, which has sodium as the only cation and chloride and bicarbonate as the predominant anions. Weathering of volcanic rocks, which contain little soluble calcium carbonate minerals, may also contribute to the relatively large sodium concentrations. Three downstream sites on the Madison River generally have progressively smaller percentages of sodium and chloride as flow in the river mixes with tributaries whose water contains calcium and bicarbonate in greater proportions. At the Missouri River downstream from the confluence of the Madison, Jefferson, and Gallatin Rivers, sodium and chloride have been substantially diluted and are no longer dominant ions.

In contrast to other streams, the dissolved-solids concentration and chemical composition of the Flathead River changes little as the river flows out of the North Fork Flathead Valley through the Kalispell Valley and Flathead Lake to a site downstream from the Mission Valley. The dissolved-solids concentration remains less than 100 mg/L and calcium and bicarbonate are the dominant ions, thereby indicating that the largest tributaries contribute water of similar chemical composition.

Comparison of the Quality of Ground Water and Surface Water

The relative chemical composition of ground water and surface water in individual basins can be compared using the information shown on figure 2. In most basins, calcium and bicarbonate are the dominant ions in both ground and surface water. Most likely, direct hydraulic connections and similar geochemical influences result in similar chemical composition in ground water and surface water in many basins. The dissolved-solids concentration in surface water generally is less than the concentration in ground water in the same area, probably because surface water has less contact time with soluble minerals and is more directly affected by dilution.

Ground water in the Little Bitterroot, Upper Madison River, and Western Three Forks Valleys in Montana has a significant amount of sodium as does surface water in these areas. In the Upper Madison River Valley upstream from Hebgen Lake, the large percentage of sodium in ground water is probably related to the large sodium concentrations in the Madison River derived from geothermal water. In the Western Three Forks Valley, the sodium in ground water near the river also could be a result of the ground water being at least partially recharged by return flow of Madison River irrigation water. In contrast, the relatively large sodium percentage in the Little Bitterroot River could be a result of ground water and geothermal springs with large sodium concentration flowing into the river. Water in the South Fork Coeur d'Alene River contains a large percentage of sulfate and could be the source of the significant percentage of sulfate in the ground water in the Coeur d'Alene River Valley.

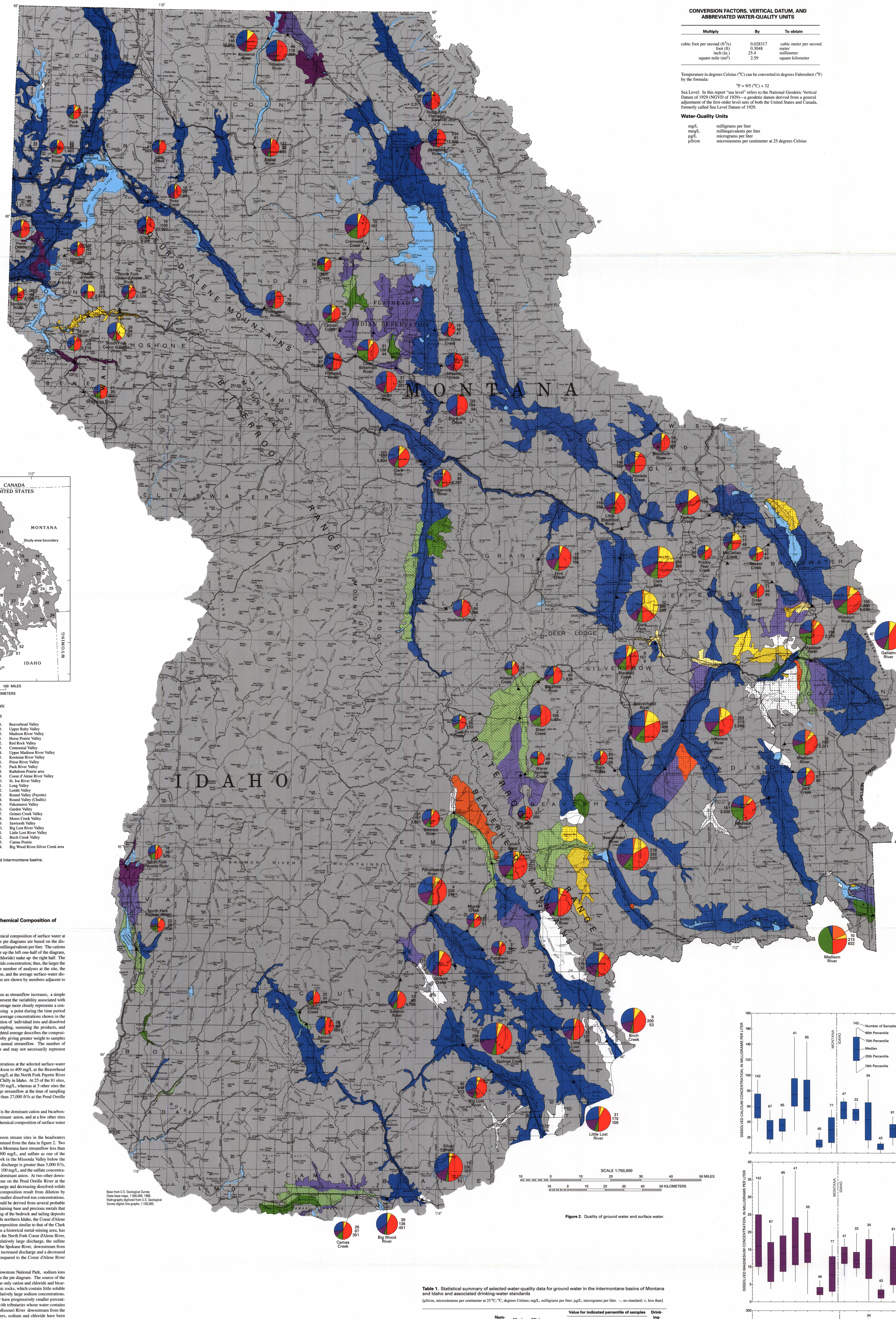


Figure 2. Quality of ground water and surface water.

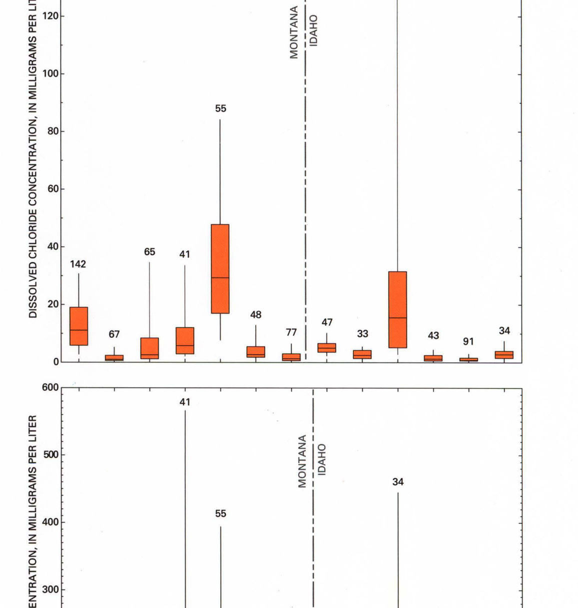


Figure 3. Statistical distribution of dissolved-solids concentration in ground-water samples from 13 selected basins in Montana and Idaho.

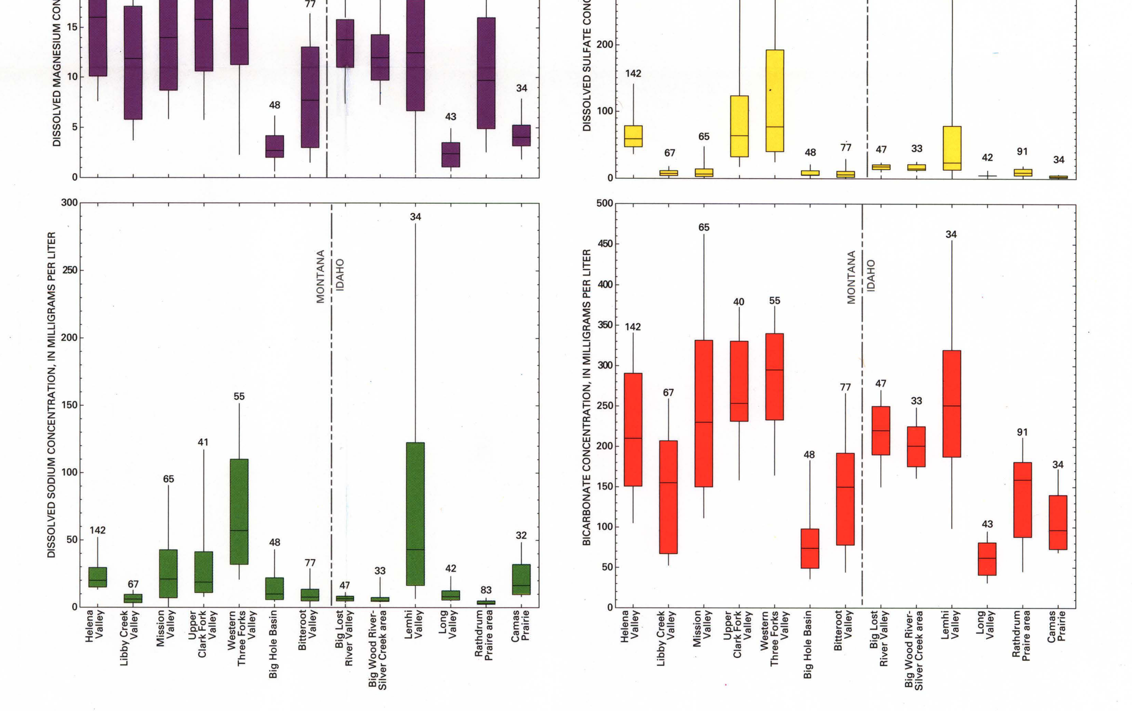


Figure 4. Statistical distribution of dissolved calcium, magnesium, sodium, chloride, sulfate, and bicarbonate concentrations in ground-water samples from 13 selected basins in Montana and Idaho.

QUALITY OF GROUND WATER AND SURFACE WATER IN INTERMONTANE BASINS OF THE NORTHERN ROCKY MOUNTAINS, MONTANA AND IDAHO

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1996