

## INTRODUCTION

The Regional Aquifer Systems Analysis (RASA) program is a series of studies by the U.S. Geological Survey (USGS) to analyze regional ground-water systems that comprise a major portion of the Nation's water supply (San, 1986). The Northern Rocky Mountains Intermontane Basins is one of the study regions in this national program. The objectives of the RASA studies are to (1) describe the ground-water systems in the study area; (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 (Clark and others, 1990) describes the geologic history and general alluvial hydrologic units. Chapter B (Brier 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 mi<sup>2</sup> 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 head of the Columbia Plateau in western Idaho. In the south, the study area extends from the Snake River Plain in Idaho northwest 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 Bitterhead, Baby, 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/Piedra, Snake, Salmon, Selkirk, Lochsa, South Fork Clearwater, and North Fork Clearwater Rivers.

The topography in the study area is varied. East-surface altitudes range from about 2,000 ft in the Kootenai River Valley in the northwest 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 Snake River Valley in northwestern Idaho.

The climate is characterized by cold winters and mild summers. Annual precipitation ranges from about 1 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 spring meltwater.

Major physiographic features in the study area include 54 generally west-trending intermontane basins (or valleys) (fig. 1). In this report, "basin" refers to topographic as well as geologic structural basins. The perimeter 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 mi<sup>2</sup> to more than 700 mi<sup>2</sup> 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 western 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 front contact consists of 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 1 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 plus 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 1,451 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 (Montana, 1914) and 1921 (Parker, 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, the data base for 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, 343 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 of water type 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 of 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 sites, 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 be defining 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 type and sulfate-sulfate 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 1909 and through 1993.

## QUALITY OF WATER

As a result of interactions between water and the rock's 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 calcium, magnesium, sodium, and potassium, and the anions bicarbonate, chloride, and sulfate. In some areas, dissolved silica, iron, manganese, nitrate, phosphate, and nitrite also are present in significant concentrations. The chemistry of ground water and surface water was classified by calculating percentages of the major cation and anion concentrations, in milliequivalents per liter, relative to the total concentration of all the ions (Mont, 1985, p. 56). Calcium (positively charged ions) and anions (negatively charged ions) are electrically balanced in natural waters. Milliequivalents per liter represent the concentrations of chemical constituents of chemical analysis, and, therefore, more clearly describe the composition of water and the relations between ions in solution than does concentration. Figure 2 shows the distribution of dissolved-solids concentration and water type for ground and surface water throughout the study area.

## Dissolved-Solids Concentrations in Ground Water

Dissolved-solids concentrations were measured or calculated for ground-water samples collected in 1,108 wells in Montana and 343 wells in Idaho. Concentrations ranged from 15 to 4,200 mg/L, and had a median value of 206 mg/L (table 1). Even though dissolved-solids concentrations were available for more than 1,500 wells, areas with sparse data remained. Samples collected from an additional 1,000 wells did not have analyses of dissolved-solids concentration but did have analyses of specific conductance. Specific conductance is proportional to the quantity of dissolved solids in water and can be related mathematically to dissolved-solids concentration. A separate equation to define the relation between dissolved-solids concentration and specific conductance was developed for each intermontane basin having a sufficient number of analyses containing both dissolved-solids concentration and specific conductance. Dissolved-solids concentration calculated from specific conductance using these equations was primarily used to better quantify the dissolved-solids concentration in ground water in areas where dissolved-solids data were sparse.

Patterns in figure 2 revealing the intermontane basins indicate the approximate extent of basins containing water with similar dissolved-solids concentrations. Areas were delineated based on three ranges of dissolved-solids concentrations—less than 250 mg/L, 250 to 500 mg/L, and greater than 500 mg/L. The quantity and distribution of dissolved solids in the aquifers of the intermontane basins are influenced by water from the surrounding mountainous or upland basins, direct precipitation into the basins, weathering of materials within the aquifer, application of irrigation water within the basins, or other human-related land and water uses.

The quality of the ground water in most of the intermontane basins generally is good. Dissolved-solids concentrations were less than 250 mg/L in about 65 percent of the area, 250 to 500 mg/L in about 30 percent of the area, and greater than 500 mg/L in less than 5 percent of the area.

Ground water in most intermontane basins in Idaho has dissolved-solids concentration less than 250 mg/L. Exceptions include the lower reaches of the Little and Big Lost River Valleys, parts of the Lemhi Valley, Broad Valley near Challis, and parts of the Camas Prairie, the Clear Fork Snake Valley, and the Kootenai Valley. Larger concentrations in these basins may be related to the type of materials in the aquifers, the amount of time the water is in contact with these minerals, and possibly human activities such as irrigation practices or mining.

Ground water in most intermontane basins in northeastern Montana has a dissolved-solids concentration less than 250 mg/L, except for the western parts of the Missouri, Kalgipelli, Little Bitterroot, and Tobacco Valleys. Most basins in the northern part of the study area are surrounded or underlain by thickly bedded sedimentary rocks, such as sandstone, shale, mudstone, and sandstone, and some layers of limestone. Clastic-like deposits, the principal aquifer material in these basins, generally contain less soluble minerals than deposits derived mainly from limestone or other carbonate rocks; therefore, the ground water has a smaller dissolved-solids concentration.

Ground water in the basins in southwestern Montana generally has a dissolved-solids concentration in the 250 to 500 mg/L range. The slight increase in dissolved-solids concentration in aquifers in parts of southwestern Montana compared to southwestern Montana primarily may be due to differences in rock composition and perhaps to human activities such as irrigation. This part of the study area was affected by geologic processes different than those that affected the northern part of the study area, and the dissolved-solids concentrations influenced by aquifer material derived in part from deposits and sediments containing larger quantities of soluble minerals. Exceptions are the Big Hole Basin, the Upper Madison River Valley, and large parts of the Madison River, Bitterhead, and Gallatin Valleys, where concentrations generally are less than 250 mg/L.

Some parts of a few basins, including Western Three Forks, Horse Prairie, and Townsend Valleys in Montana and Lemhi Valley in Idaho, have ground water with dissolved-solids concentrations greater than 500 mg/L. The aquifers in most of these areas are composed of sediments associated with alluvial fans or terraces. These areas generally have little ground-water development because the sediments contain fine-grained and typically produce small quantities of water of marginal quality, and because some of the areas are sparsely populated.

A statistical representation (fig. 3) of dissolved-solids concentrations in ground water is presented graphically for 13 basins that represent most geographic, geologic, and hydrologic conditions in the study area. The graph shows the large variation in concentrations in intermontane basins. The largest medians and ranges of concentrations are for the Upper Clark Fork Valley and Western Three Forks Valleys in Montana and the Lemhi Valley in Idaho. Medians and ranges of dissolved-solids concentrations in ground water in the other basins in Montana are variable, whereas the medians and ranges of concentrations in the other basins in Idaho are consistently low.

## Chemical Composition of Ground Water

The chemical composition that indicates the predominant cations and anions that constitute the dissolved solids in the water. Eight different water types were classified within the study area, including some where several different water types were combined (fig. 2). Water-quality samples from 1,451 wells were analyzed for major ions to identify the water types that are represented by the different color areas on the map. If a single ion constituted more than 50 percent of the cation or anion composition, it was considered the dominant ion. If two ions collectively constituted more than 75 percent of the cation or anion composition, with neither ion constituting more than 50 percent, both ions were included in the water-type designation. The areas designated "mixed" contain water with three cations or anions collectively constituting more than 75 percent of the total cation or anion composition.

The predominant water type in the study area is calcium bicarbonate. This water type was determined to about 55 percent of the wells sampled and represents about 10 percent of the area of intermontane basins. As an additional 1 percent of the wells (12 percent of the area) had a mixed-cation bicarbonate water type, and about 7 percent of the wells (9 percent of the area) had a calcium sulfate water type. Only about 6 percent of the wells (6 percent of the area) did not have bicarbonate as the predominant anion.

Areas where the predominant water type is either calcium bicarbonate or calcium sulfate bicarbonate generally are in basins where aquifer sediments primarily are derived from carbonate-rich rocks, such as limestone. In the southern part of the study area, much of the bedrock surrounding the intermontane basins contains limestone or other rocks that are rich in calcium and carbonate. The aquifer sediments in many of these basins are derived from these nearby mountains, and therefore, contain minerals that enrich the ground water in calcium and carbonate ions.

Basins with ground water containing high concentrations of both dissolved sodium and dissolved solids include Horse Prairie, Grapeshopper, and Western Three Forks Valleys in Montana and Lemhi Valley in Idaho. These basins generally consist of relatively fine-grained, undifferentiated deposits of sand, silt, clay, and clay. Ground water in parts of the Camas Prairie in Idaho has a relatively large amount of sodium, primarily due to local sources of sodium-rich rock and possibly from weathering of alkali-feldspar rocks that generally lack sulfate-carbonate material. Other areas such as the Big Hole Basin and Bitterroot Valley in Montana have sodium as a major ion in ground water, but the dissolved-solids concentration generally is less than 250 mg/L.

Areas where ground water is either a mixed water type or contains a large proportion of sulfate also commonly have water with a relatively large concentration of dissolved solids. Many of these areas such as parts of Western Three Forks, Horse Prairie, and Townsend Valleys in Montana and parts of the Lemhi Valley in Idaho have ground water with sulfate, primarily because the aquifers are relatively non-productive and contain water of limited quality.

A statistical representation of concentrations of major cations and anions measured in samples of ground water from 13 selected basins (fig. 4) illustrates the variability of chemical composition within the study area. Basins that have the highest medians and ranges of concentrations are for sodium, chloride, and sulfate. Upper Clark Fork Valley and Horse Prairie Valley also have relatively high concentrations of sodium, chloride, and sulfate. Basins that have the lowest medians and ranges of concentrations are for calcium, magnesium, and bicarbonate. Lemhi Valley, with relatively low concentrations of sodium, chloride and sulfate. Figure 4 also indicates that ground water generally is the least mineralized in the Big Hole Basin and Lost Valley. Western Three Forks, Upper Clark Fork, and Lemhi Valley generally have the most mineralized and variable ground water, as indicated on both Figure 4 and Figure 5.

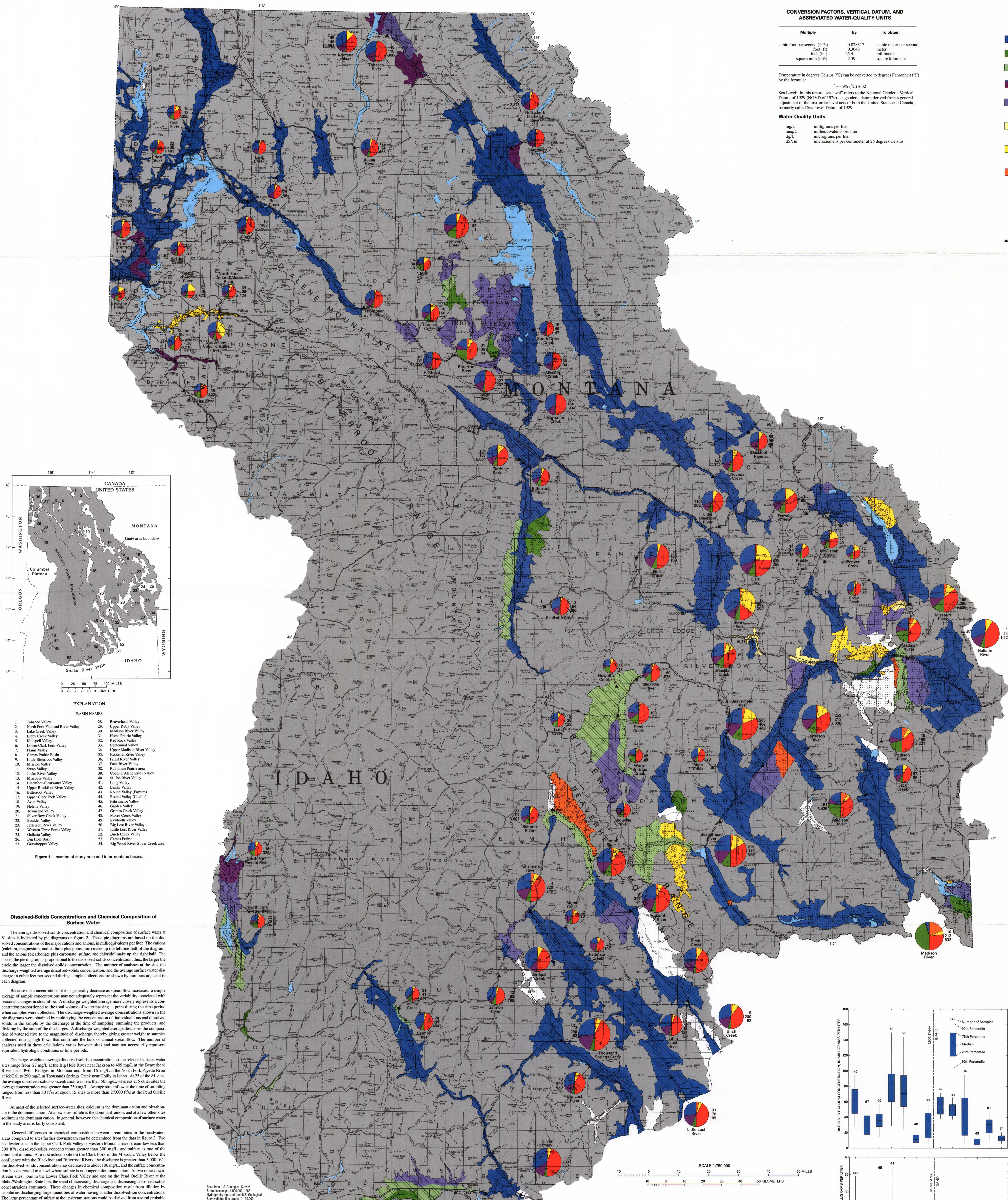


Figure 1. Location of study area and intermontane basins.

## 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 the pie diagrams on figure 2. These pie diagrams are based on the dissolved constituents 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; that is, 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 collection are shown by numbers adjacent to each diagram.

Because the concentrations of ions generally decrease as streamflow increases, a single 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 proportional to the total volume of water passing a point during a given time when samples were obtained. The discharge-weighted average concentrations shown in the pie diagrams were obtained by multiplying the concentration of each ion by the volume of 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, from 27 mg/L at the Big Hole River near Jackson to 400 mg/L at the Bitterhead River near Twin Bridges in Montana and from 16 mg/L at the North Fork Payette River in Idaho to 290 mg/L at Thousand Springs Creek near Challis in Idaho, is 215 mg/L. 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 concentrations at the sites of sampling ranged from less than 50 mg/L at about 15 sites to more than 27,000 mg/L at the Pearl Creek River.

A 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 cfs, 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 Missouri Valley, the discharge-weighted average dissolved-solids concentration is 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.

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Parker, J.T., 1925. Geology of ground water of Townsend Valley, Montana. U.S. Geological Survey Water-Supply Paper 539, 61 p.

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## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
cubic foot per second (ft <sup>3</sup> /s)	0.028317	cubic meter per second
ft <sup>3</sup> /min	0.0438	milliliter
inch (in.)	25.4	millimeter
square mile (mi <sup>2</sup> )	2.59	square kilometer

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the formula:  
°F = 95 (°C) + 32

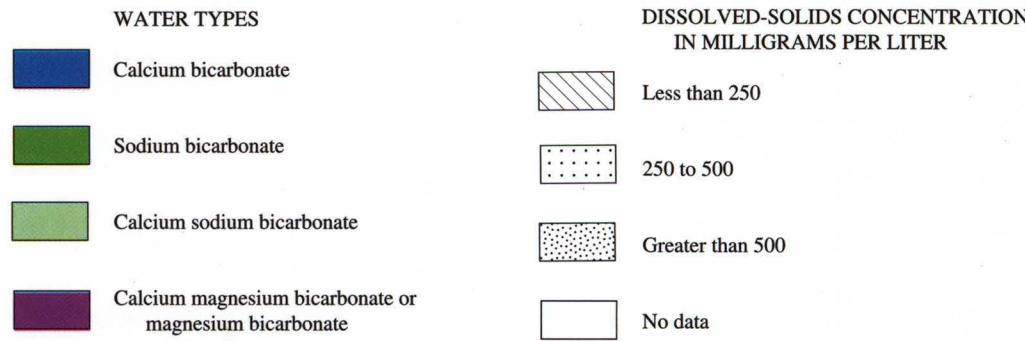
Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geoid datum derived from a mean spheroidal adjustment of the first-order level of both the United States and Canada, formerly called Sea Level Datum of 1929.

## Water-Quality Units

mg/L	milligram per liter
meq/L	milliequivalents per liter
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

## EXPLANATION

### GROUND WATER



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