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Geochemistry of the Birch Creek Drainage Basin, Idaho

Water-Resources Investigations Report 03-4272

U.S. Department of the Interior
U.S. Geological Survey

Cover: Birch Creek diversion channel downstream from the diversion. View looking west toward the Lemhi Range, Idaho.

GEOCHEMISTRY OF THE BIRCH CREEK DRAINAGE BASIN, IDAHO

By Shawn A. Swanson and Jeffrey J. Rosentreter, Idaho State University, and Roy C. Bartholomay and LeRoy L. Knobel, U.S. Geological Survey

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U.S. GEOLOGICAL SURVEY

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Idaho Falls, Idaho
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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
gallon	3.785	liter
picocurie per liter (pCi/L)	0.037	becquerel per liter

For temperature, degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) by using the formula
°F = (1.8) (°C) + 32.

Sea Level: in this report, “sea level” refers to the National Geodetic Vertical Datum of 1929, a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called “Sea Level Datum of 1929.”

Abbreviated units used in report: L, (liter), µg/L (microgram per liter), mg/L (milligram per liter), atm (standard atmosphere), mmol/kg (millimole per kilogram water), ppm (parts per million), ppb (parts per billion), mL (milliliter), µS/cm (microsiemens per centimeter at 25°C), and mol/L (moles per liter).

GEOCHEMISTRY OF THE BIRCH CREEK DRAINAGE BASIN, IDAHO

By Shawn A. Swanson and Jeffrey J. Rosentreter, Idaho State University, and Roy C. Bartholomay and LeRoy L. Knobel, U.S. Geological Survey

Abstract

The U.S. Geological Survey and Idaho State University, in cooperation with the U.S. Department of Energy, are conducting studies to describe the chemical character of ground water that moves as underflow from drainage basins into the eastern Snake River Plain aquifer (ESRPA) system at and near the Idaho National Engineering and Environmental Laboratory (INEEL) and the effects of these recharge waters on the geochemistry of the ESRPA system. Each of these recharge waters has a hydrochemical character related to geochemical processes, especially water-rock interactions, that occur during migration to the ESRPA. Results of these studies will benefit ongoing and planned geochemical modeling of the ESRPA at the INEEL by providing model input on the hydrochemical character of water from each drainage basin.

During 2000, water samples were collected from five wells and one surface-water site in the Birch Creek drainage basin and analyzed for selected inorganic constituents, nutrients, dissolved organic carbon, tritium, measurements of gross alpha and beta radioactivity, and stable isotopes. Four duplicate samples also were collected for quality assurance. Results, which include analyses of samples previously collected from four other sites, in the basin, show that most water from the Birch Creek drainage basin has a calcium-magnesium bicarbonate character.

The Birch Creek Valley can be divided roughly into three hydrologic areas. In the northern part, ground water is forced to the surface by a basalt barrier and the sampling sites were either surface water or shallow wells. Water chemistry in this area was characterized by simple evaporation models, simple calcite-carbon dioxide models, or complex models involving carbonate and silicate minerals. The central part of the valley is filled by sedimentary material and the sampling sites were wells that are deeper than those in the northern part. Water chemistry in this area was characterized by simple calcite-dolomite-carbon dioxide models. In the southern part, ground water enters the ESRPA. In this area, the sampling sites were wells with depths and water levels much deeper than those in the northern and central parts of the valley. The calcium and carbon water chemistry in this area was characterized by a simple calcite-carbon dioxide model, but complex calcite-silicate models more accurately accounted for mass transfer in these areas.

Throughout the geochemical system, calcite precipitated if it was an active phase in the models. Carbon dioxide either precipitated (outgassed) or dissolved depending on the partial pressure of carbon dioxide in water from the modeled sites. Dolomite was an active phase only in models from the central part of the system. Generally the entire geochemical system could be modeled with either evaporative models, carbonate models, or carbonate-silicate models. In both of the latter types of models, a significant amount of calcite precipitated relative to the mass transfer to and from the other active phases. The amount of calcite precipitated in the more complex models was consistent with the amount of calcite precipitated in the simpler models. This consistency suggests that, although the simpler models can predict calcium and carbon concentrations in Birch Creek Valley ground and surface water, silicate-mineral-based models are required to account for the other constituents. The amount of mass transfer to and from the silicate mineral phases was generally small compared with that in the carbonate phases. It appears that the water chemistry of well USGS 126B represents the chemistry of water recharging the ESRPA by means of underflow from the Birch Creek Valley.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy, has developed an extensive network of boreholes for the collection of geohydrologic, hydraulic, geochemical, and radiochemical data to address concerns about contamination of the eastern Snake River Plain aquifer (ESRPA) at the Idaho National Engineering and Environmental Laboratory (INEEL) in eastern Idaho (fig. 1). These data are used in interpretive studies to describe the temporal and spatial distribution of the radioactive- and chemical-waste solutes and to define and describe the processes

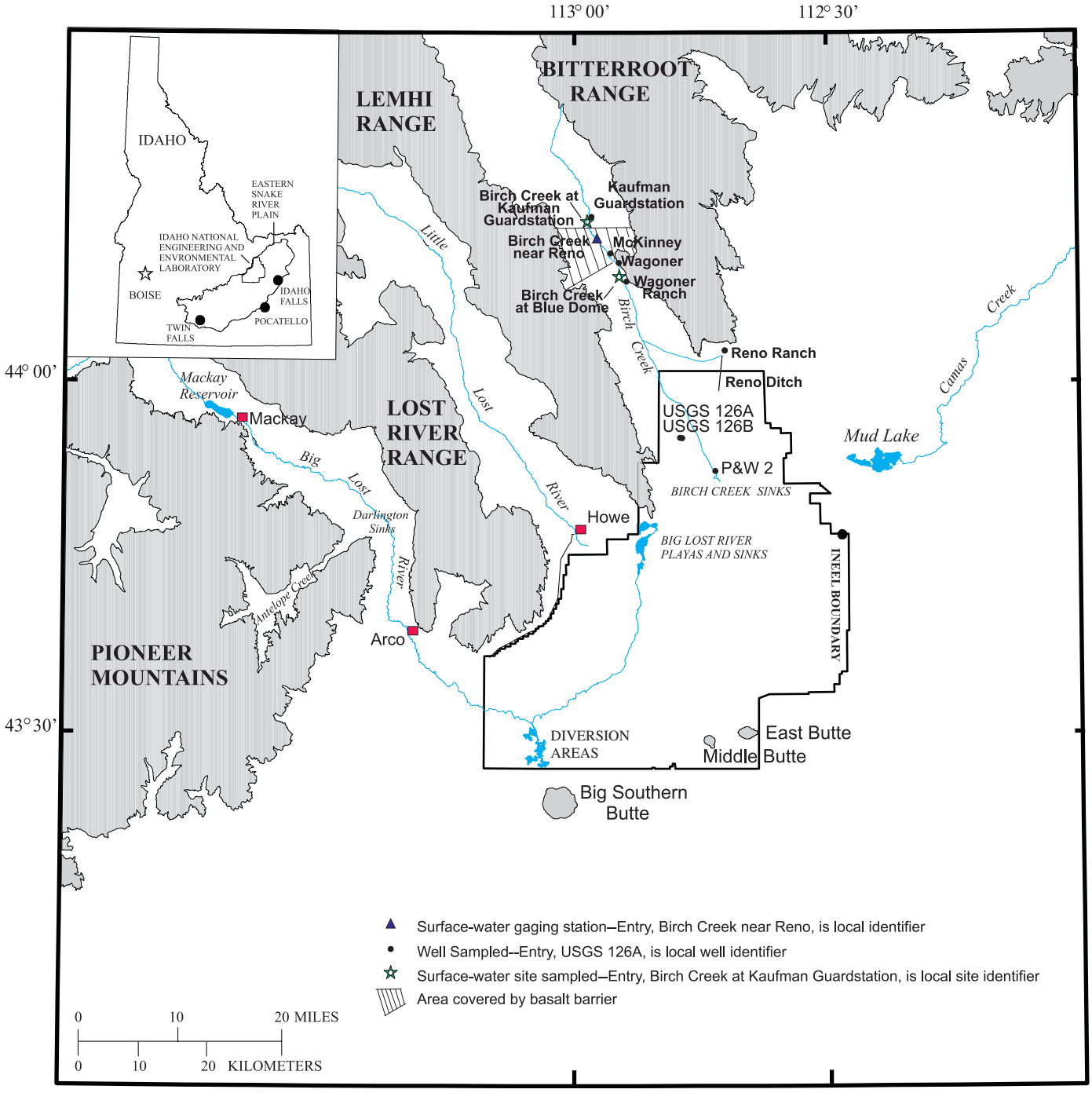

Figure 1. Location of wells and surface-water sites in the Birch Creek drainage basin, Idaho.

that control their concentration and migration rates, including advection, dispersion, adsorption, dilution, radioactive decay, and chemical and biological reactions.

Chemical and radiochemical constituents in ground water at the INEEL are derived from natural and anthropogenic processes involving reactions between the solid, liquid, and gaseous phases. These reactions are an important control on the fate and mobility of waste solutes in and through the unsaturated zone and the aquifer. Laboratory and field studies are being done to facilitate inclusion of these geochemical and physical processes in a solute-transport model. Studies to describe the geochemistry and to quantify model input include calculations of the thermodynamic state of the water-rock system and reaction-path modeling of processes in the subsurface, and an evaluation of the mixing of conservative constituents in recharge waters entering along model boundaries. One USGS study at the INEEL is a cooperative study with Idaho State University (ISU) to evaluate the geochemical characteristics of surface-water drainage basins that recharge the ESRPA at and near the INEEL. These drainage basins include Birch Creek, Big Lost River, and Little Lost River (fig. 1).

The focus of this study is the Birch Creek drainage basin, which contributes recharge to the ESRPA system as underflow near the northern part of the INEEL. Ground water in the Birch Creek drainage basin acquires a unique geochemical character from water-rock interactions that take place during migration of the ground water to the ESRPA. Ground water from this basin mixes with and changes the chemical character of the ESRPA water. Results of this study and studies of other tributary valleys will improve the basic knowledge of the geochemistry of the valleys. Results will directly benefit ongoing and planned geochemical modeling of the ESRPA system. In addition, this study provides information for use in numerical simulations of ground-water flow and solute transport.

Purpose and Scope

The purpose of this report is to define the geochemical character of the Birch Creek drainage basin and its effect on the geochemistry of the ESRPA at and near the INEEL. During 2000, water samples were collected from five wells (Kaufman Guardstation, Wagoner Ranch, Reno Ranch, USGS 126A, and 126B) and one surface-water site (Birch Creek at Kaufman Guardstation) (fig. 1) for analysis of selected inorganic constituents, nutrients, tritium, measurements of gross alpha and beta radioactivity, and stable isotopes of oxygen, hydrogen, and carbon. Samples were analyzed for cations, silica, and selected trace elements at the ISU Department of Chemistry under the direction of Dr. Jeffrey J. Rosentreter. Four quality-assurance duplicates were sent to the National Water Quality Laboratory (NWQL) for analyses as a measure of quality assurance. Samples also were analyzed for anions, nutrients, DOC, tritium, gross alpha- and beta-particle radioactivity, and stable isotopes at the NWQL or the USGS stable-isotope laboratory in Reston, Va. Additional water-chemistry data for two wells (McKinney and P&W2) were taken from Knobel and others (1999), and data for one well (Wagoner) and one surface-water site (Birch Creek at Blue Dome) were taken from Busenberg and others (2000) (fig. 1).

The water-chemistry data were used to describe the ion distribution and the hydrochemical facies of the Birch Creek ground-water system. The thermodynamic condition of the ground water was determined using the computer code NETPATH (Plummer and others, 1994). Solid-phase mineralogy data were compiled to facilitate formulation of a set of plausible chemical reactions for hypothesis testing. The set of plausible chemical reactions constitutes a series of geochemical models that were tested using the mass-balance approach contained in NETPATH. The specific techniques of geochemical analysis and modeling used in this study were similar to those used by Knobel and others (1997) for studying the ESRPA at INEEL, by Carkeet and others (2001) for studying the geochemistry of the Big Lost River drainage basin, and by Swanson and others (2002) for studying the Little Lost River drainage basin.

Geohydrologic Setting

Geologic factors affect the amount and chemical content of water that flows over the surface, becomes soil moisture, or moves underground in the Birch Creek drainage basin. Alluvium and colluvium in the valley areas accept recharge and transmit large volumes of water.

The Birch Creek drainage basin is located north of the eastern Snake River Plain (fig. 1). The basin is 40 mi long and from 5 to 10 mi wide and is surrounded by mountains of the Lemhi and Bitterroot Ranges that reach altitudes of 10,000 to 11,000 ft. The mountains are composed mostly of limestone and shale, and the basin is thought to be of the same composition covered with alluvial fill. In the center of the basin, there is a large outcrop of basaltic lava (fig. 1). The outcrop dips upstream in the basin and acts as a barrier to ground-water flow (Mundorff, 1962).

Birch Creek drains the mountainous area north of the INEEL that includes parts of the Lemhi Range and Bitterroot Range. Natural flow in Birch Creek infiltrates to the ESRPA along its channel and at sinks and playas at the creek's terminus (Stearns and others, 1939, p. 47). In the early 1900's, the upper part of the Birch Creek channel was straightened to increase the velocity of the stream (Vinson, 1988). About that same time, an irrigation diversion was constructed to use Birch Creek to irrigate the area around Reno Ranch or to return water to the Reno Ditch when not used for irrigation. In 1987, the diversion was relocated and a power station was added near Reno Ranch (fig. 1). Ninety-five percent of the water was diverted to the power station while the remaining 5 percent was allowed to enter the Birch Creek channel downstream from the diversion

(fig. 1). The diversion channel was lined with polyvinyl chloride and covered with 0.4 m of valley fill (Vinson, 1988). This effectively decreased the infiltration of water into the alluvial fill in the valley. The water that exits the powerhouse is used mostly for irrigation during the summer and is directed through Reno Ditch towards the Birch Creek Sinks the remainder of the year (Vinson, 1988).

Flow in Birch Creek arises from a large number of springs that discharge from alluvium in a basinal area covering a few square miles immediately upstream from the basalt barrier (Mundorff, 1962). The flow is derived mostly from ground-water inflow. A channel exists upstream from the springs but is very shallow and is rarely filled. The creek has carved a path through the basalt barrier. Data from a gaging station at Birch Creek near Reno indicate that the flow is uniform throughout the year and varies only slightly as a result of snowmelt (Mundorff, 1962).

The aquifer in the basin is split essentially into two parts: above the basalt barrier and below the basalt barrier. Above the basalt barrier, the aquifer is recharged primarily by snowmelt and rainfall that subsequently discharges to the springs and forms the headwater of Birch Creek. Below the barrier, recharge probably is derived from leakage from Birch Creek, from surface and underground inflow of tributary streams below the barrier, and from possible leakage through the barrier (Mundorff, 1962). Even though this two-part system effectively limits ground-water flow between the upper and lower parts of the basin, underflow from the Birch Creek drainage basin accounts for an estimated 4 percent by volume of the ESRPA recharge at the INEEL (Daniel J. Ackerman, USGS, written commun., 2001).

Three sample sites are associated with the basalt barrier. Two are just upgradient from the barrier: Birch Creek at Kaufman Guardstation and Kaufman Guardstation (fig. 1). The other sample site, the McKinney well, is near the southeastern edge of the basalt barrier and has a shallow depth to water (table 1). The rest of the sample sites are downstream from the basalt barrier in the alluvial fill of the valley or in the ESRPA. Because of the basalt barrier, depths to water in wells in the upper part of the valley are very shallow and range from 5 to 12 ft; depths to water in wells downstream from the basalt barrier range from about 11 to 535 ft (table 1).

Acknowledgments

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GUIDELINES, METHODS, AND QUALITY ASSURANCE

The methods used for collecting water samples and conducting analyses for selected chemicals generally followed the guidelines established by the USGS (Goerlitz and Brown 1972; Stevens and others, 1975; Wood, 1981; Claassen, 1982; W.L. Bradford, USGS, written commun., 1985; Wershaw and others, 1987; Fishman and Friedman, 1989; Hardy and others, 1989; Faires, 1992; Fishman, 1993; and Wilde and others, 1998). The laboratory methods used at the ISU laboratory generally followed the procedures described in Fishman and Friedman (1989). The cation and trace-element concentrations were determined by using inductively coupled plasma spectrometry. The methods used in the field and quality-assurance practices are described in the following sections.

Sample Containers and Preservatives

Sample containers and preservatives differed depending on the constituents for which analyses were requested. Samples analyzed by the NWQL were placed in containers and preserved in accordance with laboratory requirements specified by Timme (1995). All containers and preservatives used for this study were supplied by the NWQL and had undergone a rigorous quality-control procedure (Pritt, 1989, p. 75) to minimize potential for sample contamination. Samples analyzed at ISU were placed in containers in accordance with laboratory requirements specified by the laboratory standard operating procedures. Table 2 lists the types of constituents, containers, preservatives, and laboratories.

Sampling Locations and Sample Collection

Water samples were collected from six locations for this study (figure 1 and table 1): three domestic wells (Kaufman Guardstation, Wagoner Ranch, and Reno Ranch); two observation wells (USGS 126A and USGS 126B); and one surface-water site (Birch Creek at Kaufman Guardstation). The domestic and observation wells were equipped with dedicated submersible pumps. Chemical data from three additional wells (McKinney, Wagoner, and P&W 2) and one surface-water site (Birch Creek at Blue Dome) located in the study area for this report were taken from previous studies by Knobel and others (1999), and Busenberg and others (2000).

Samples were collected from spigots as close to the pumps at the wells as possible to minimize contact with plumbing materials. Prior to sample collection, three field parameters were monitored until stable readings, as defined by Mann (1996), were obtained: pH, specific conductance, and water temperature. Between sample collections, all portable equipment was cleaned with deionized water. After collection, sample containers were sealed with laboratory film, labeled,

and stored under secure conditions. Containers with water samples to be analyzed by the NWQL were placed in ice chests and the ice chests were sealed. The ice chests were shipped by overnight-delivery mail to the NWQL. Containers with water samples to be analyzed by ISU were hand-delivered to the laboratory.

Conditions at the sampling site during sample collection were recorded in a field logbook, and a chain-of-custody record was used to track samples from the time of collection until delivery to the analyzing laboratory. These records are available for inspection at the USGS INEEL Project Office. The results of field measurements for pH, specific conductance, water temperature, alkalinity, and dissolved oxygen, and laboratory calculations of hardness and dissolved solids are listed in table 3.

Guidelines for Interpreting Results of Analyses

Concentrations of inorganic and organic constituents are reported with reference to minimum reporting levels. The minimum reporting level is the smallest measured concentration of a nonradioactive constituent that can be reliably reported using a given analytical method (Timme, 1995). Because of unpredictable matrix effects on detection limits, the laboratory minimum reporting levels are set somewhat higher than the analytical method detection limits. The analytical method detection limit is the smallest concentration of a substance that can be identified, measured, and reported with 99-percent confidence that the concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the substance (Timme, 1995). Results from ISU are reported with reference to the instrument detection limit, which is the average concentration of a constituent in a blank sample calculated from the results of three measurements made on separate days, plus three times the standard deviation of the three measurements.

Concentrations of radionuclides are reported with an estimated sample standard deviation, **s**, obtained by propagating sources of analytical uncertainty in measurements. Guidelines for interpreting analytical results for radionuclides are based on an extension of a method by Currie (1984) and are given in a report by Knobel and others (1999).

As a matter of convention, concentrations of stable isotopes are reported as relative isotopic ratios (Toran, 1982). A more detailed description of stable isotope data is presented in a report by Knobel and others (1999).

Quality Assurance

Detailed descriptions of internal quality control and of the overall quality assurance (QA) practices used by the NWQL are provided in reports by Friedman and Erdmann (1982) and Jones (1987). Water samples were collected in accordance with a QA plan for quality-of-water activities conducted by personnel assigned to the INEEL Project Office; the plan was finalized in June 1989, updated in 1992 and in 1996 (Mann, 1996), and is available for inspection at the USGS INEEL Project Office. Comparative studies to determine agreement between analytical results for individual water-sample pairs by laboratories involved in the INEEL Project Office QA program were summarized by Wegner (1989) and Williams (1996, 1997). Additional QA for this sampling program included one full-suite replicate water sample collected from the Wagoner Ranch well. The routine and replicate samples were collected sequentially, marked with different identifiers, and sent to the laboratories. Analytical results from the QA replicate and similar data are discussed in subsequent sections of this report. Concentrations of the replicate were not included in the computation of descriptive statistical parameters. In addition to the QA replicate, four duplicate cation and trace-element samples were collected and sent to the NWQL for analysis to assure the quality of the ISU laboratory data. The samples duplicated were from the Kaufman Guardstation, Reno Ranch, USGS 126A, and USGS 126B wells. Furthermore, the ISU laboratory participates in the USGS Branch of Technical Development and Quality System's standard reference water sample (SRWS) program. This program is an extensive interlaboratory comparison program in which approximately 150 laboratories are evaluated on the basis of results of their analyses of SRWS.

EVALUATION OF QUALITY ASSURANCE DATA

The duplicate QA samples were compared by using Z-values as explained by Williams (1997). Test statistics were used to determine whether analytical results of the duplicate samples were statistically equivalent. When the standard deviations are known, it is possible to determine, within a specified confidence level, whether the results of a replicate pair of samples are statistically equivalent. When the standard deviations are unknown, approximations of the standard deviations are used for the statistical comparison. The comparison can be made by using an adaptation of the equation to determine the standard deviate, Z, or the number of standard deviations the variable deviates from the mean (Volk, 1969, p. 55), where Z is the ratio of the absolute value of the difference between the two results and the square root of the sum of the squares of the standard deviations (the pooled standard deviation). In this way, two analytical results can be compared on the basis of the precision, or an approximation of the precision, associated with each of the results:

$$Z = \frac{|x - y|}{\sqrt{((S_x)^2 + (S_y)^2)}} \qquad (1)$$

where
x is the result of the water-quality sample analyzed at ISU,
y is the result of the sample analyzed at the NWQL,
s_x is the standard deviation of x, and
s_y is the standard deviation of y.

When the population is distributed normally and the standard deviation is known, the analytical results of replicate pairs can be considered statistically equivalent at the 95-percent confidence level if the Z-value is less than or equal to 1.96. When the population is not distributed normally or an approximation of the standard deviation is used, a Z-value less than or equal to 1.96 must be considered a guide when testing for equivalence. At the 95-percent confidence level, the probability of error is 0.05. In other words, when a Z-value is less than or equal to 1.96, the results are within approximately two standard deviations of each other.

Equation 1 cannot be applied directly to results for which standard deviations are unknown. Because the NWQL did not report standard deviations for the constituents analyzed for this study, approximations of standard deviations, or most probable deviations calculated by the SRWS program for NWQL data (table 4), were used for these constituents. The standard deviations for ISU data were calculated for each constituent from three sample measurements made on separate days.

Equation 1 was used to determine whether the analytical results for the replicate sample were statistically equivalent to those for the routine sample from the Wagoner Ranch well. Results for all 20 constituents (tables 5–9) were equivalent; Z-values for all pairs were 1.96 or less. Because the NWQL reported radiochemical results at two standard deviations, it was necessary to divide the value by two to compute the one standard deviation required by equation 1. Duplicate cation, silica, and trace-element samples were analyzed by the NWQL for comparison with results determined by ISU. The results in samples from the Kaufman Guardstation, Reno Ranch, USGS 126A, and USGS 126B wells for all eight constituents with calculated Z-values (table 5) were found to be equivalent; Z-values for all pairs were less than or equal to 1.96.

RESULTS OF ANALYSES

Cations, Anions, and Silica

Water samples were filtered and analyzed for concentrations of cations (calcium, magnesium, sodium, and potassium) and silica by ISU (table 5) and anions (chloride, sulfate, and fluoride) by the NWQL (table 6). Field alkalinities expressed as concentrations of bicarbonate also are provided in table 6. Results for the McKinney, Wagoner, and P&W 2 wells, and Birch Creek at Blue Dome (that were taken from previous studies by Knobel and others (1999) and Busenberg and others (2000)) also are given in tables 5 and 6 and were included in the statistical calculations for constituents analyzed by ISU and the NWQL. Results for the replicate sample (QA-1) were not included in the statistical calculations.The ranges of concentrations, the median concentration, and the mean concentration for each constituent were 29 to 49, 41, and 42 mg/L for calcium; 14 to 24, 15, and 17 mg/L for magnesium; 5.1 to 17, 8.35, and 8.6 mg/L for sodium; 0.88 to 6.5, 1.15, and 2.1 mg/L for potassium; 7.7 to 70, 13, and 22 mg/L for silica; 3.2 to 12, 6.75, and 7.2 mg/L for chloride; 3.9 to 34, 25.5, and 24 mg/L for sulfate; 162 to 235, 182.5, and 192 mg/L for bicarbonate; and 0.18 to 1.5, 0.22, and 0.38 mg/L for fluoride.

Selected Inorganic Constituents

Water samples were filtered and analyzed for concentrations of barium, bromide, chromium, iron, lithium, manganese, strontium, and zinc (table 7).

Barium.—Concentrations in the ISU samples ranged from 42 to 165 µg/L and concentrations in the USGS samples ranged from 39 to 164 µg/L.

Bromide.—Concentrations in 10 samples analyzed by the USGS ranged from 7 to 42 µg/L.

Chromium.—Concentrations in eight samples analyzed by the USGS ranged from less than 1 to less than 5 µg/L. All samples analyzed by ISU were less than 17 µg/L.

Iron.—Concentrations in eight samples analyzed by the USGS ranged from less than 10 to 67 µg/L. All samples analyzed by ISU were less than 11 µg/L.

Lithium.—Concentrations in eight samples analyzed by the USGS ranged from 3.1 to 25 µg/L.

Manganese.—Concentrations in the eight samples analyzed by the USGS ranged from less than 1 to 39 µg/L and concentrations in the ISU samples ranged from less than 4 to 35 µg/L.

Strontium.—Concentrations in eight samples analyzed by the USGS ranged from 140 to 347 µg/L and concentrations in the ISU samples ranged from 143 to 352 µg/L.

Zinc.—Concentrations in eight samples analyzed by the USGS ranged from less than one to 1,560 µg/L. All samples analyzed by ISU were less than 25 µg/L.

Nutrients

Concentrations of ammonia as nitrogen, nitrite as nitrogen, nitrite plus nitrate as nitrogen, and orthophosphate as phosphorous in water samples from eight sites and in one QA replicate sample (QA-1) were determined by the NWQL (table 8). In addition, water samples from the Wagoner well and Birch Creek at Blue Dome were analyzed by the USGS common use laboratory in Reston, Va. (Busenberg and others, 2000) for concentrations of nitrite plus nitrate as nitrogen (table 8).

Concentrations of ammonia as nitrogen ranged from less than 0.01 to 0.077 mg/L. Concentrations of nitrite as nitrogen were less than 0.01 mg/L. Concentrations of nitrite plus nitrate as nitrogen ranged from less than 0.05 to 0.8 mg/L. Concentrations of orthophosphate as phosphorous ranged from less than 0.01 to 0.018 mg/L.

Dissolved Organic Carbon

Concentrations of DOC in 10 samples and one QA replicate were determined by the USGS (table 8). Concentrations ranged from 0.15 to 0.75 mg/L.

Tritium

Tritium, a radioactive isotope of hydrogen, is formed in nature by interactions of cosmic rays with gases in the upper atmosphere. Tritium also is produced in thermonuclear detonations and is a waste product of the nuclear-power industry. Water samples from nine sites and one QA replicate sample were analyzed for tritium by the NWQL (table 9). The concentrations (excluding the QA replicate) ranged from -6.4±19.2 pCi/L to 38.4±25.6 pCi/L.

Gross Alpha- and Gross Beta-Particle Radioactivity

Concentrations of gross alpha- and gross beta-particle radioactivity in samples from eight sites and one QA replicate sample were determined by the NWQL (table 9).

Gross alpha-particle radioactivity.— Gross alpha-particle radioactivity is a measure of the total radioactivity given off as alpha particles during the radioactive decay process. For convenience, laboratories report the radioactivity as if it were all given off by one radionuclide. In this report, concentrations are reported as thorium-230 in picocuries per liter and ranged from 0.25±1.09 pCi/L to 3.24±1.66 pCi/L.

Gross beta-particle radioactivity.— Gross beta-particle radioactivity is a measure of the total radioactivity given off as beta particles during the radioactive decay process. For convenience, laboratories report the radioactivity as if it were all given off by one radionuclide or a chemically similar pair of radionuclides in equilibrium. In this report, concentrations are reported as cesium-137 in picocuries per liter and ranged from 0.46±1.92 pCi/L to 5.11±2.65 pCi/L.

Stable Isotopes

Water samples were analyzed for relative concentrations of stable isotopes of hydrogen (H), oxygen (O), and carbon (C) by the NWQL (table 9). Relative isotopic ratios reported as δ^2H in 10 samples and one QA replicate sample ranged from -141.7 to -138.9 permil. Relative isotopic ratios reported as $\delta^{18}O$ in 10 samples and one QA replicate sample ranged from -18.62 to -18.13 permil. Relative isotopic ratios reported as $\delta^{13}C$ in nine samples and one QA replicate sample ranged from -11.14 to -5.9 permil.

GEOCHEMISTRY

Solid Phase Description

A summary of the bulk mineralogy for sediment from five channel deposit samples and one overbank deposit was presented by Bartholomay and Knobel (1989). Mean mineral abundances of 44 percent quartz, 28 percent calcite, 15 percent total feldspar, 8 percent clay minerals, 4 percent dolomite, and 1 percent pyroxenes were found. Of the clay minerals present, illite was dominant. The samples also contained trace amounts of smectite and kaolinite.

Ion Distribution

The distribution of major ions in ground water is controlled partially by the solubilities of minerals in the aquifer and by the ground-water flow system. Concentrations of solutes in ground water generally increase in the direction of ground-water flow until equilibrium between the solid, liquid, and gaseous phases is established. Once equilibrium is established, concentrations remain relatively constant until the equilibrium of the system is disrupted by other factors such as microbial activity, industrial or agricultural waste disposal, a change in mineralogy, or mixing with water from another source. A plot of major ions in water from the Birch Creek drainage basin (fig. 2) shows that there are increases and decreases in the concentrations of all of the constituents in the direction of ground-water flow. These fluctuations indicate disruptions in the equilibrium of the system.

Hydrochemical Facies

Hydrochemical facies are useful tools for describing the chemical character of ground water. The format for the hydrochemical facies diagram used in this report (fig. 3) was developed by Piper (1944) and is similar to one designed by Hill (1940). This diagram allows the plotting of relative concentrations of major anions and cations and the chemical character of multiple water samples. Freeze and Cherry (1979, p. 249–250) and Hem (1985, p. 178–179) briefly described the diagram and its uses. The hydrochemical facies of water in the Birch Creek system is calcium-magnesium bicarbonate in character, which is similar to that of the ESRPA (Knobel and others, 1997).

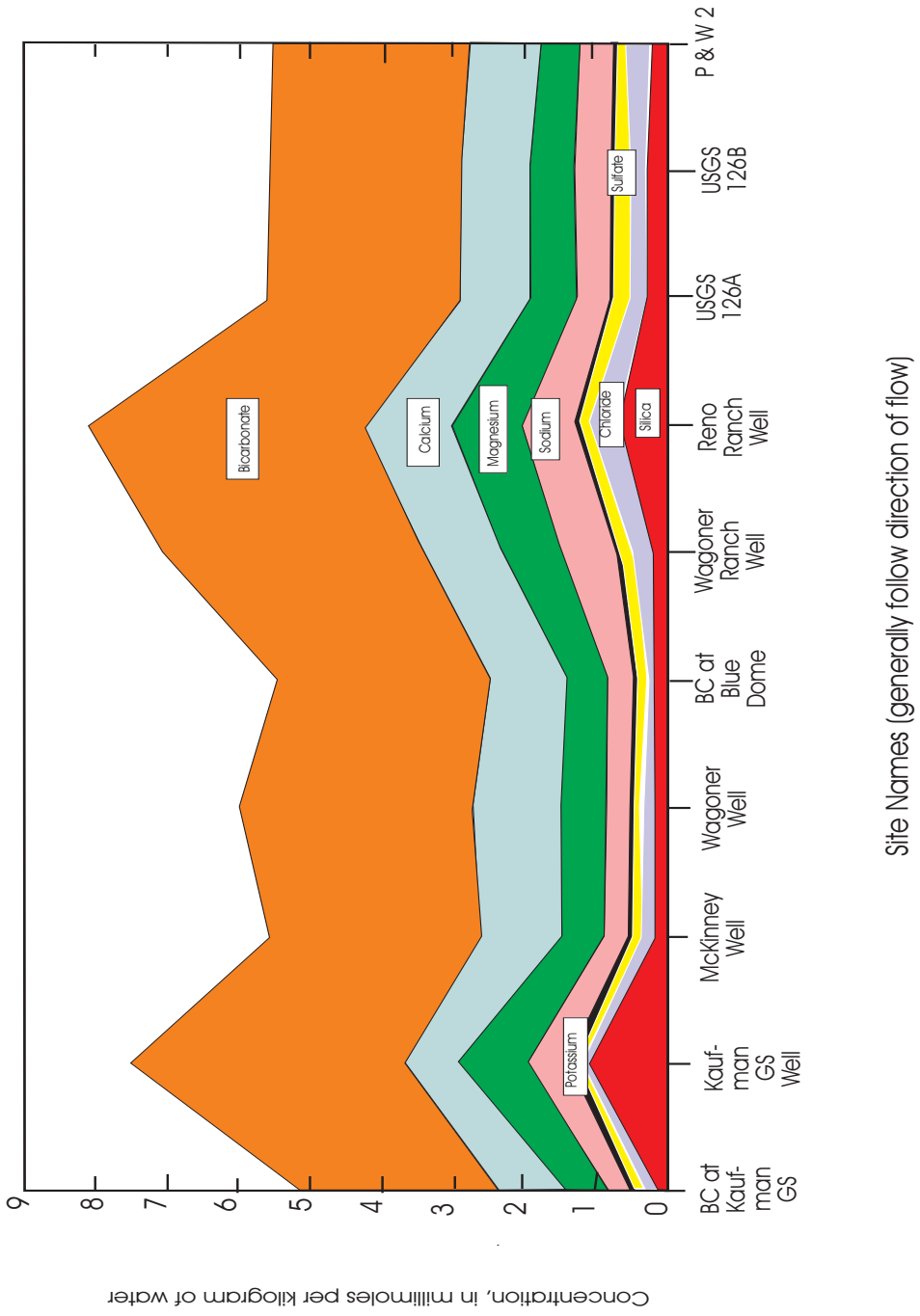

Figure 2. Concentrations of selected ions and silica in water from wells and surface-water sites, Birch Creek drainage basin, Idaho.

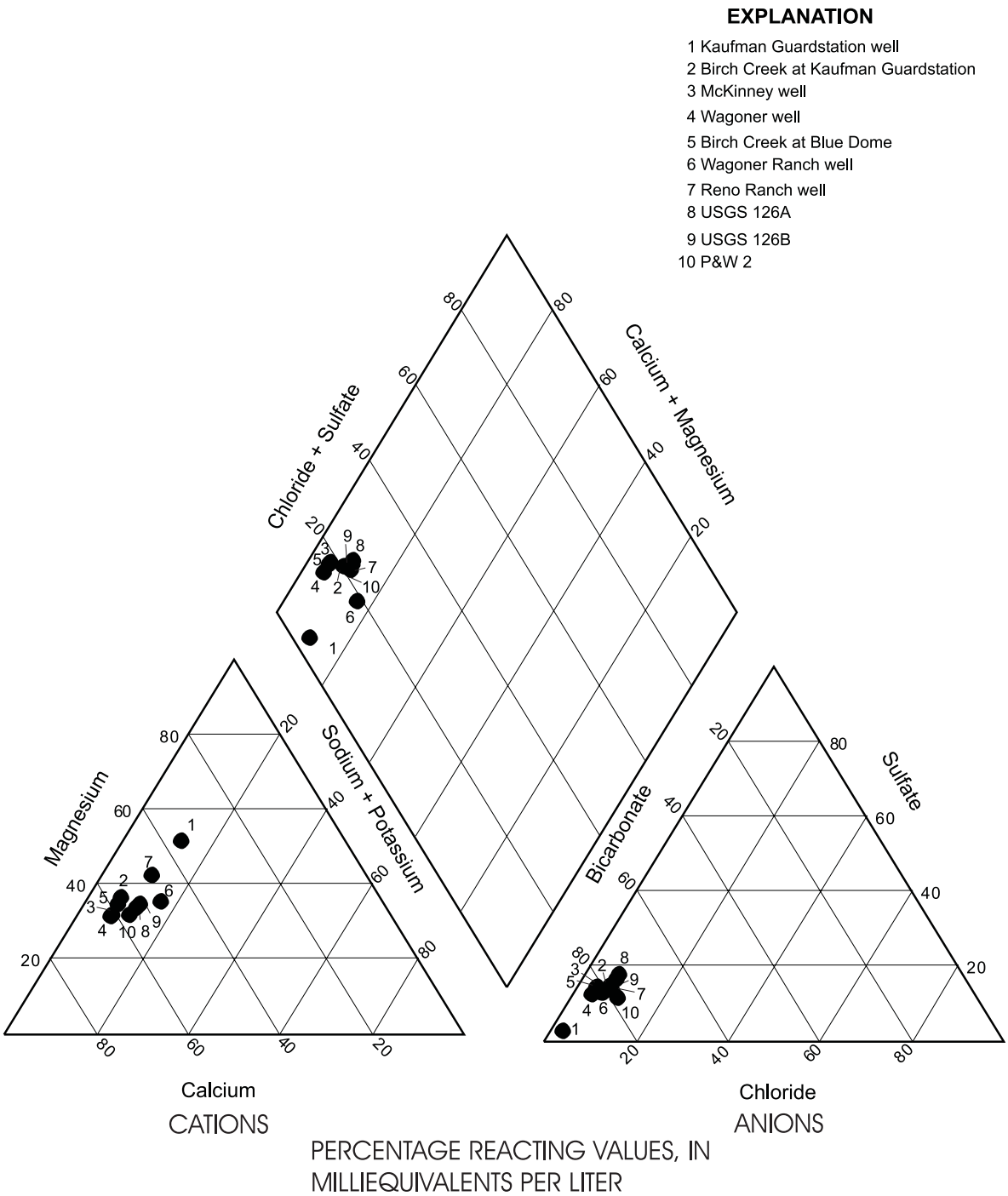

Figure 3. Major-ion composition of water from wells and surface-water sites, Birch Creek drainage basin, Idaho.

Thermodynamic Considerations

Chemical equilibrium is attained when a chemical system, under constant pressure and temperature conditions, is at its smallest possible energy level. This occurs when the free energy of the system is zero. Chemical systems tend to give off energy by means of chemical reaction until equilibrium is achieved. The deviation of a system from equilibrium can be expressed by determining the saturation index (SI) of water that has a given chemical composition with respect to a mineral. SI is defined as follows:

$$SI = \log \frac{IAP}{K} \qquad (2)$$

where,

IAP = ion activity product, and

K = the equilibrium constant for the reaction.

A SI of zero indicates that the water is in equilibrium with respect to a reaction. The range from -0.1 to 0.1 also can be considered at equilibrium (Langmuir, 1971). A more negative SI indicates that the water is undersaturated, and a more positive SI indicates that the water is supersaturated. SI's of the eight well-water and two surface-water samples were determined by using the computer program WATEQF (Plummer and others, 1978). Table 10 gives the SI of the samples with respect to selected minerals believed to be active in the system. With respect to calcite, water samples from wells Reno Ranch, Wagoner, and Wagoner Ranch were at equilibrium; well-water samples from Kaufman Guardstation, McKinney, USGS 126A, USGS 126B, and P&W 2, and surface-water samples from Birch Creek at Kaufman Guardstation and from Birch Creek at Blue Dome were supersaturated. With respect to dolomite, well-water samples from Reno Ranch and P&W 2 were at equilibrium; well-water samples from Kaufman Guardstation, USGS 126A, USGS 126B, and surface-water samples from Birch Creek at Kaufman Guardstation and Birch Creek at Blue Dome were supersaturated; well-water samples from Wagoner, McKinney, and Wagoner Ranch were undersaturated. With respect to gypsum and anhydrite, all samples were undersaturated.

Carbon dioxide dissolves in water until equilibrium with atmospheric carbon dioxide is achieved. This occurs at a carbon dioxide partial pressure of $10^{-3.5}$ atm. Partial pressures larger than this value are supersaturated with respect to the atmosphere and values that are smaller are undersaturated. The base-10 logarithm of the equilibrium carbon dioxide partial pressure of $10^{-3.5}$ is -3.5. The shorthand notation for this value is log PCO_2. The log PCO_2 values listed in table 10 were calculated by the computer program NETPATH (Plummer and others, 1994) and indicate that water from Birch Creek at Blue Dome is undersaturated with respect to the partial pressure of atmospheric carbon dioxide. Water from Birch Creek at Kaufman Guardstation is at equilibrium, and water from all of the wells is supersaturated.

The minerals and gas discussed above dissolve congruently and the calculated SI values are reliable because they are based on well-known thermodynamic data. Complex aluminosilicate minerals, such as the feldspar minerals, dissolve incongruently and form residual clay minerals. The solid-phase thermodynamic data for such reactions are not well known and calculated SI values are less reliable predictors of mineral stability. In addition, concentrations of dissolved aluminum are required to calculate SI values, and aluminum is difficult to measure in water samples because of its chemical affinity for colloidal material and the small concentrations at which it exists. To avoid these difficulties, stability of aluminosilicate minerals commonly is evaluated by plotting water-chemistry data on diagrams depicting the stability fields of the solid phases in a given chemical system. For example, in the system microcline-muscovite-gibbsite-kaolinite, $\log_{10} [K^+]/[H^+]$ is plotted as a function of $\log_{10} [Si(OH)_4]$ (the brackets indicate ion activity, K^+ indicates potassium, H^+ indicates hydrogen, $Si(OH)_4$ indicates silicon hydroxide). This technique avoids the analytical problems associated with measuring aluminum concentrations. Water-chemistry data for samples from the Birch Creek drainage basin were superposed on stability diagrams (fig. 4) for the potassium system. All the data plotted in the kaolinite stability field, this indicates that for water associated with microcline, muscovite, and gibbsite, kaolinite is the stable solid phase.

In a similar fashion, $\log_{10}[Na^+]/[H^+]$ is plotted as a function of $\log_{10}[Si(OH)_4]$ in figure 5 and $\log_{10}[Ca^{2+}]/[H^+]^2$ is plotted as a function of $\log_{10}[Si(OH)_4]$ in figure 6 (Na^+ indicates sodium, Ca^{2+} indicates calcium). Figure 5 indicates that for water associated with albite or gibbsite, either kaolinite or sodium montmorillonite are the stable solid phases. Similarly, figure 6 indicates that for water associated with anorthite or gibbsite, kaolinite or calcium montmorillonite are the stable solid phases.

The actual chemical composition of plagioclase in the Birch Creek drainage basin lies between the end-member compositions for albite and anorthite; hence, the phase boundaries involving plagioclase in figures 5–6 should be considered approximate. Variability in the chemical composition of potassium minerals causes a similar uncertainty in the location of the phase boundaries shown in figure 4. Because of the uncertainties associated with aluminosilicate-mineral-stability diagrams, conclusions about water equilibrium and mineral stability that are based solely on the diagrams should be considered tentative. A detailed discussion of sources of uncertainty in mineral-stability diagrams was provided by Drever (1988, p. 113–114).

The sample from Birch Creek at Blue Dome was analyzed for aluminum and had a concentration of 0.004 mg/L. As a result, SI's of this water were calculated. This water was saturated with respect to kaolinite and undersaturated with

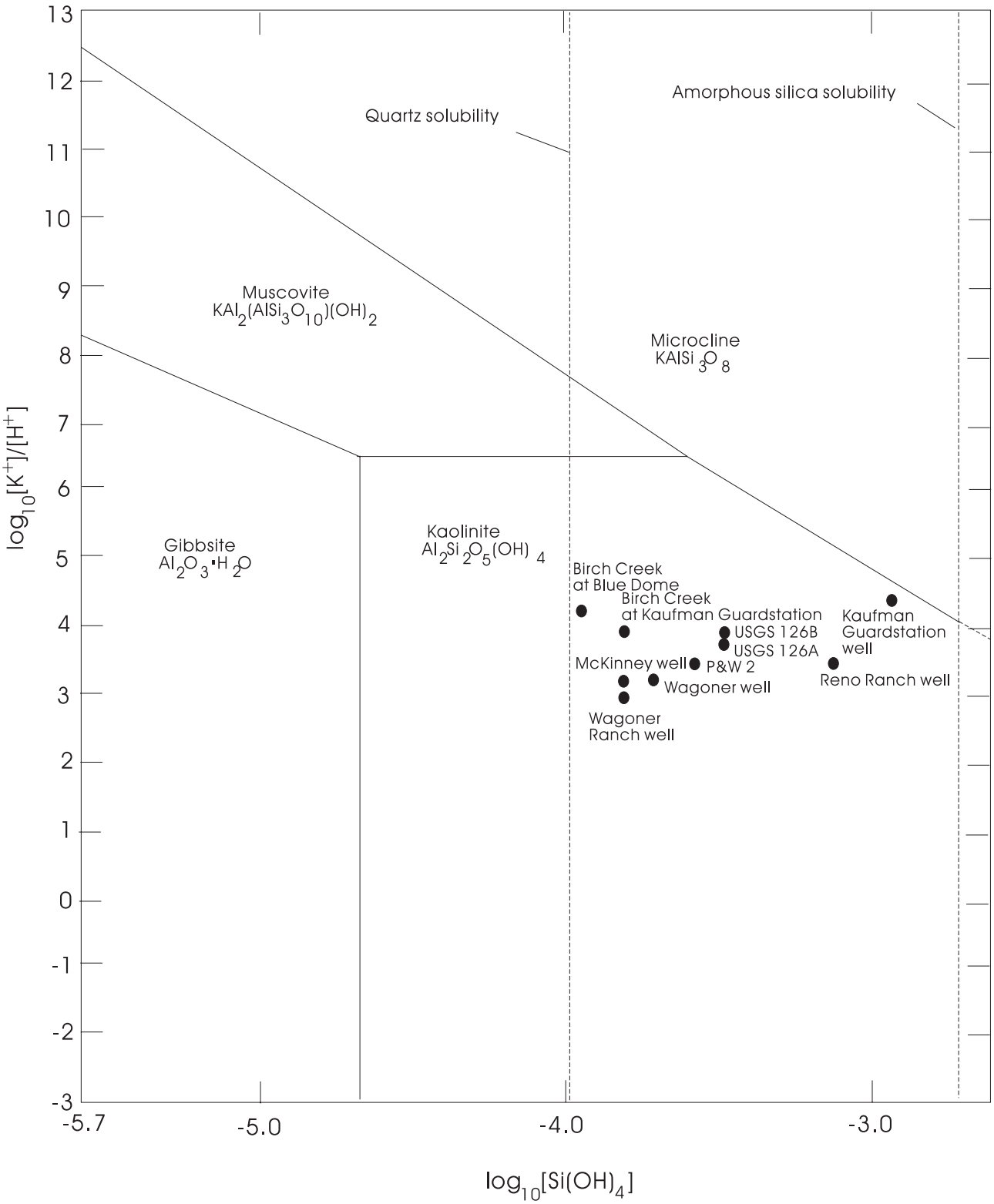

Figure 4. Stability relations among microcline, muscovite, gibbsite, and kaolinite with superposed compositions of water samples from the Birch Creek drainage basin, Idaho (modified from Freeze and Cherry, 1979, p. 272). Brackets indicate thermodynamic activity of indicated species.

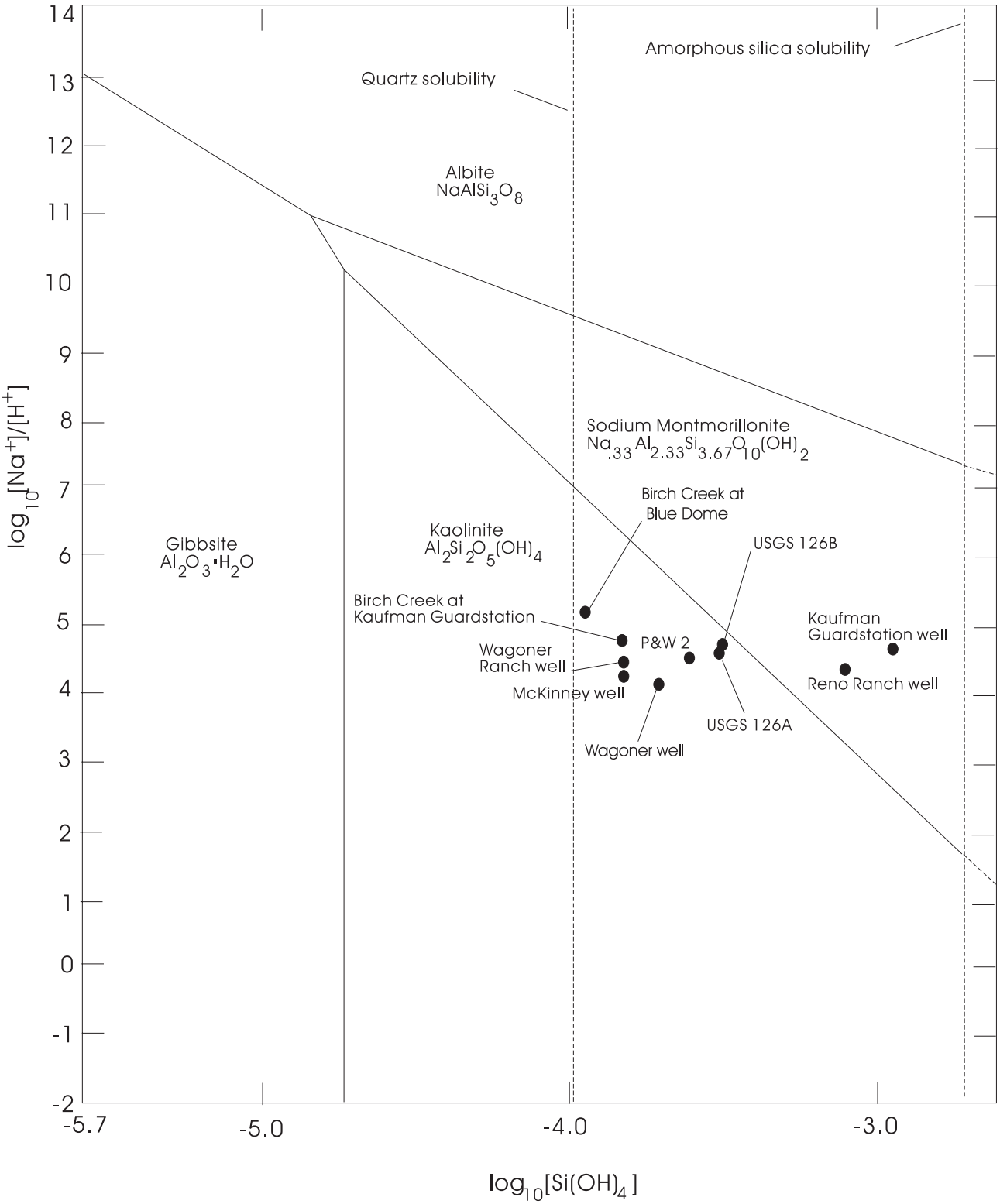

Figure 5. Stability relations among albite, gibbsite, kaolinite, and sodium montmorillonite with superposed compositions of water samples from the Birch Creek drainage basin, Idaho (modified from Freeze and Cherry, 1979, p. 272). Brackets indicate thermodynamic activity of indicated species.

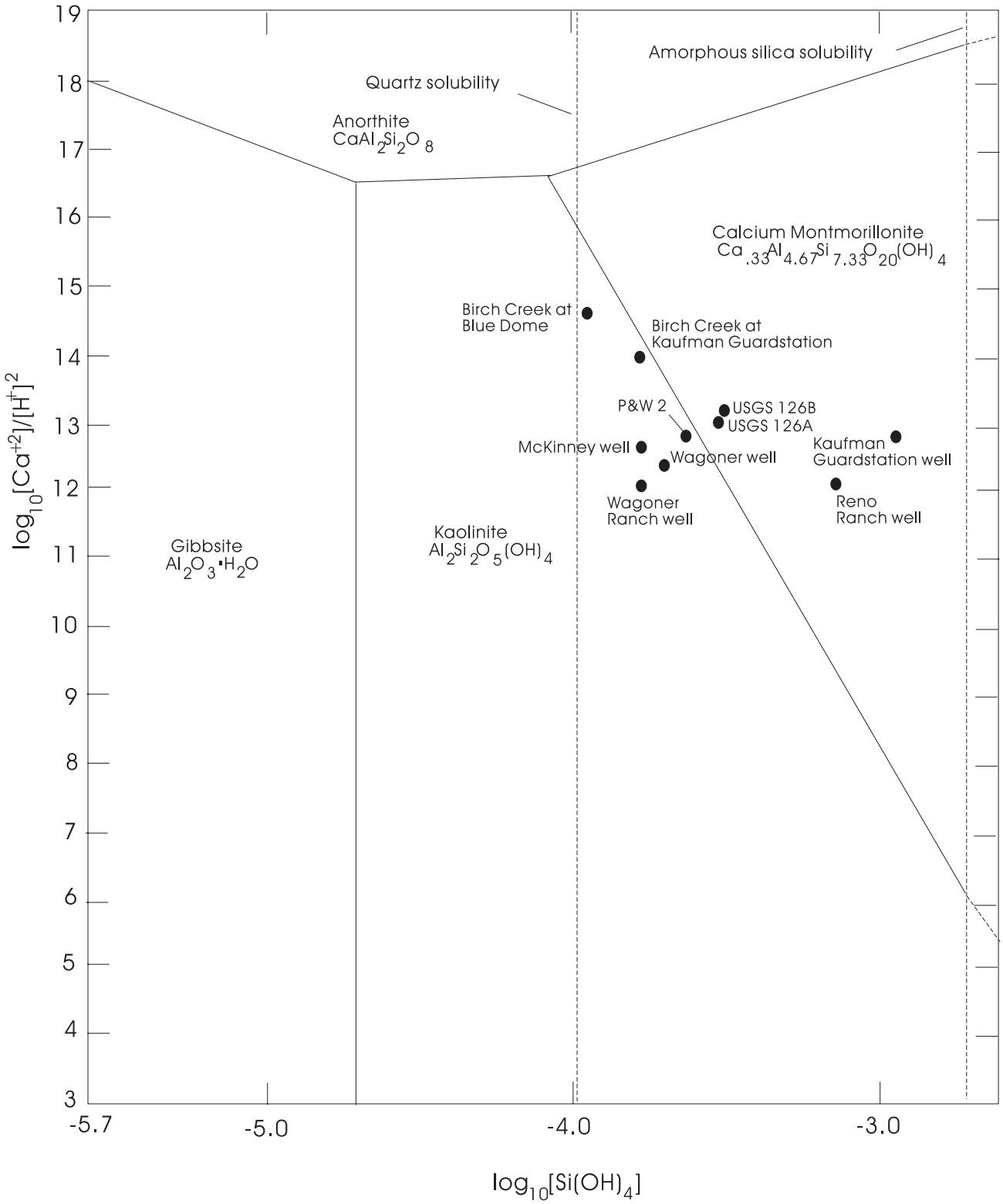

Figure 6. Stability relations among anorthite, gibbsite, kaolinite, and calcium montmorillonite with superposed compositions of water samples from the Birch Creek drainage basin, Idaho (modified from Freeze and Cherry, 1979, p. 272). Brackets indicate thermodynamic activity of indicated species.

respect to albite, anorthite, potassium feldspar, and illite. Montmorillonite was near equilibrium (-0.055). These data are consistent with the mineral-stability diagrams in figures 4–6.

Plausible Chemical Reactions

Plausible chemical reactions are defined in this report as those likely to take place naturally in the Birch Creek drainage basin because (1) the requisite source minerals, liquids, and gases are present in the system; (2) thermodynamic conditions allow the reaction to proceed; and (3) the dissolved-, gaseous-, or solid-phase products either are present or can be accounted for by processes that remove them from the system. The presence of the calcium-magnesium bicarbonate water suggests that the predominant chemical reactions taking place in the system are a result of interactions between water, calcite, and dolomite.

Dissolution or precipitation of calcite

The chemical reaction model for calcite is

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^-, \quad (3)$$

where,
$CaCO_3$ = calcite,
CO_2 = carbon dioxide,
H_2O = water,
Ca^{2+} = dissolved calcium, and
HCO_3^- = dissolved bicarbonate.

Dissolution of dolomite

The chemical reaction model for dolomite is

$$CaMg(CO_3)_2 + 2H_2O + 2CO_2 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-, \quad (4)$$

where,
$CaMg(CO_3)_2$ = dolomite,
H_2O = water,
CO_2 = carbon dioxide,
Ca^{2+} = dissolved calcium,
Mg^{2+} = dissolved magnesium, and
HCO_3^- = dissolved bicarbonate.

Sulfate concentrations (table 6) differ between sample sites. The changes in sulfate may be caused by dissolution of anhydrite. Robertson and others (1974) indicated that anhydrite increases in mountain ranges north of the INEEL. Gypsum was used in modeling efforts as an analog to anhydrite to model changes of sulfate in the system.

Dissolution of gypsum

The chemical reaction model for gypsum is

$$CaSO_4{\cdot}2H_2O \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O, \quad (5)$$

where,
$CaSO_4{\cdot}2H_2O$ = gypsum,
Ca^{2+} = dissolved calcium,
SO_4^{2-} = dissolved sulfate, and
H_2O = water.

The presence of plagioclase feldspar, diopside, and olivine in the basalt barrier and the ESRPA indicates the possibility of silicate-mineral weathering. The presence of these same minerals along with potassium feldspar and illite in the alluvium (Bartholomay and Knobel, 1989) indicates that reactions of these phases may also take place in this system.

Dissolution of olivine

The chemical reaction model for olivine is

$$(Mg, Fe)_2SiO_4 + 2CO_2 + 0.25O_2 + 2.5H_2O \rightarrow Mg^{2+} + 2HCO_3^- + SiO_2 + Fe(OH)_3, \quad (6)$$

where,
$(Mg, Fe)_2SiO_4$ = olivine,
CO_2 = carbon dioxide,
O_2 = oxygen,
H_2O = water,
Mg^{2+} = dissolved magnesium,
HCO_3^- = dissolved bicarbonate,
SiO_2 = silicon dioxide,
$Fe(OH)_3$ = iron(III) hydroxide.

Dissolution of diopside

The chemical reaction model for diopside is

$$CaMgSi_2O_6 + 4CO_2 + 6H_2O \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^- + 2H_4SiO_4, \quad (7)$$

where,
$CaMgSi_2O_6$ = diopside,
CO_2 = carbon dioxide,
H_2O = water,
Ca^{2+} = dissolved calcium,
Mg^{2+} = dissolved magnesium,
HCO_3^- = dissolved bicarbonate,
H_4SiO_4 = silica.

Dissolution of labradorite

The chemical reaction models for labradorite are

$$Na_{.5}Ca_{.5}Al_{1.5}Si_{2.5}O_8 + 1.29CO_2 + 1.29H_2O \rightarrow 0.645\ Na_{.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + .50Ca^{2+} + .29Na^+ + 1.29\ HCO_3^- + .135SiO_2, \quad (8)$$

$$Na_{.5}Ca_{.5}Al_{1.5}Si_{2.5}O_8 + 1.28CO_2 + 1.28\ H_2O \rightarrow 0.32\ Ca_{.33}Al_{4.67}Si_{7.33}O_{20}\ (OH)_4 + .5\ Na^+ + .39Ca^{+2} + 1.28HCO_3^- + .16SiO_2, \text{ and} \quad (9)$$

$$Na_{.5}Ca_{.5}Al_{1.5}Si_{2.5}O_8 + 1.5CO_2 + 2.25H_2O \rightarrow 0.75Al_2Si_2O_5\ (OH)_4 + SiO_2 + 0.5\ Na^+ + 0.5Ca^{+2} + 1.5HCO_3^-, \quad (10)$$

where,
$Na_{.5}Ca_{.5}Al_{1.5}Si_{2.5}O_8$ = labradorite,
CO_2 = carbon dioxide,
H_2O = water,
$Na_{.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2$ = sodium montmorillonite
$Ca_{.33}Al_{4.67}Si_{7.33}O_{20}(OH)_4$ = calcium montmorillonite
$Al_2Si_2O_5\ (OH)_4$ = kaolinite
SiO_2 = silicon dioxide,
Na^+ = dissolved sodium,
Ca^{2+} = dissolved calcium,
HCO_3^- = dissolved bicarbonate.

Dissolution of potassium feldspar

The chemical reaction model for orthoclase is

$$KAlSi_3O_8 + CO_2 + 1.5H_2O \rightarrow 0.5Al_2Si_2O_5(OH)_4 + 2SiO_2 + K^+ + HCO_3^-, \quad (11)$$

where,
$KAlSi_3O_8$ = orthoclase,
CO_2 = carbon dioxide,
H_2O = water,
$Al_2Si_2O_5(OH)_4$ = kaolinite,
SiO_2 = silicon dioxide,
K^+ = dissolved potassium,
HCO_3^- = dissolved bicarbonate.

Dissolution of illite

The chemical reaction model for illite is

$$K_{.6}Mg_{.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2 + 1.1CO_2 + 1.85H_2O \rightarrow 1.155Al_2Si_2O_5(OH)_4 + 0.6K^+ + 0.25Mg^{2+} + 1.1HCO_3^- + 1.2SiO_2, \quad (12)$$

where,
$K_{.6}Mg_{.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2$ = illite,
CO_2 = carbon dioxide,
H_2O = water,
$Al_2Si_2O_5(OH)_4$ = kaolinite,
K^+ = dissolved potassium,
Mg^{2+} = dissolved magnesium,
HCO_3^- = dissolved bicarbonate
SiO_2 = silicon dioxide.

Cation exchange

The physicochemical reaction for cation exchange is

$$(1\text{-}X)Ca^{2+} + XMg^{2+} + Na_2 \bullet Ex \leftrightarrow 2Na^+ + (Ca_{1-x}Mg_x) \bullet Ex, \quad (13)$$

where,
X = a stoichiometric variable that ranges from 0 to 1,
Ca^{2+} = dissolved calcium,
Mg^{2+} = dissolved magnesium,
Na^+ = dissolved sodium,
Ex = exchanging substrate.

The combination of two or more of these reactions constitutes a geochemical model that can be tested with the mass- and energy-conservation techniques imbedded in the computer program NETPATH (Plummer and others, 1994).

Geochemical Modeling

The computer code NETPATH (Plummer and others, 1994) was used to model the net geochemical mass-balance reactions in the Birch Creek drainage basin. Four geochemical models (as described below) were tested from each site to all down-gradient sites. This resulted in a total of 188 modeling solutions. Of these, 34 were thermodynamically possible (table 11). These modeling solutions also are shown in fig. 7. The remaining 154 modeling solutions were possible from a mass-balance point of view but were thermodynamically impossible. Selected modeling solutions that were thermodynamically impossible are listed in table 12.

Initial modeling was done using minerals present in the system as phases and the major ions present in the system as chemical constraints. The mineral phases chosen for the first geochemical model were based on the mineralogy of the basin (Bartholomay and Knobel, 1989) and included calcite, carbon dioxide gas, dolomite, gypsum, and labradorite (a form of plagioclase). The corresponding chemical constituents that were used were calcium, carbon, magnesium, sulfate, and silica. Six modeling solutions were found to be thermodynamically possible using these mineral phases and chemical constraints (table 11, MS 1–6). Table 11 indicates labradorite dissolution in five of the six modeling solutions. With the exception of two modeling solutions for which Reno Ranch is the final location, the amount of labradorite dissolution was less than 0.06 millimoles per kilogram of water (mmol/kg) (table 11). The modeling solutions ending at the Reno Ranch location required dissolution of 0.22 or 0.23 mmol/kg of labradorite (table 11); however, the Reno Ranch location is outside the Birch Creek drainage basin and only receives surface water diverted from

A: Geochemical model 1	Kaufman GS	McKinney	Wagoner	BC at Blue Dome	Wagoner Ranch	Reno Ranch	USGS 126A	USGS 126B	P&W2
BC at Kaufman GS									
Kaufman GS									
McKinney									
Wagoner									
BC at Blue Dome									
Wagoner Ranch									
Reno Ranch									
USGS 126A									
USGS 126 B									

B: Geochemical model 2	Kaufman GS	McKinney	Wagoner	BC at Blue Dome	Wagoner Ranch	Reno Ranch	USGS 126A	USGS 126B	P&W2
BC at Kaufman GS									
Kaufman GS									
McKinney									
Wagoner									
BC at Blue Dome									
Wagoner Ranch									
Reno Ranch									
USGS 126A									
USGS 126 B									

C: Geochemical model 3	Kaufman GS	McKinney	Wagoner	BC at Blue Dome	Wagoner Ranch	Reno Ranch	USGS 126A	USGS 126B	P&W2
BC at Kaufman GS									
Kaufman GS									
McKinney									
Wagoner									
BC at Blue Dome									
Wagoner Ranch									
Reno Ranch									
USGS 126A									
USGS 126 B									

D: Geochemical model 4	Kaufman GS	McKinney	Wagoner	BC at Blue Dome	Wagoner Ranch	Reno Ranch	USGS 126A	USGS 126B	P&W2
BC at Kaufman GS									
Kaufman GS									
McKinney									
Wagoner									
BC at Blue Dome									
Wagoner Ranch									
Reno Ranch									
USGS 126A									
USGS 126 B									

Figure 7. Site combinations and mineral phases used for geochemical models 1–4 [BC, Birch Creek; GS, Guardstation]
Gray boxes indicate the sample site listed in first column could be modeled to the sample site listed in the first row. (A) Phases used: calcite, carbon dioxide gas, dolomite, gypsum, and labradorite, (B) Phases used: calcite, carbon dioxide gas, dolomite, and gypsum, (C) Phases used: calcite, carbon dioxide gas, and dolomite, (D) Phases used: calcite and carbon dioxide gas.

Birch Creek through the Reno Ditch (fig. 1). It is likely that the geochemistry of the Reno Ranch site is more complex than that at other sites and it will be discussed in more detail later in this report. Because labradorite and silica appeared to have minimal effect on the geochemistry of the Birch Creek system, they were eliminated from the second through fourth geochemical models (table 11).

Six modeling solutions (table 11, MS 7–10, 12, 13) that correspond to the six previous modeling solutions (table 11, MS 1–6) were found to be thermodynamically possible when labradorite and silica were eliminated (table 11, geochemical model 2). An additional modeling solution (table 11, MS 11) also was identified as being thermodynamically possible in this simplified geochemical system. The amount of gypsum dissolving was less than 0.13 mmol/kg in all seven modeling solutions (table 11). This observation suggests that dissolution of gypsum probably does not significantly affect the water chemistry in the Birch Creek system.

In order to test this hypothesis, gypsum and sulfur were eliminated and geochemical model 3 (table 11) was run using the mineral phases calcite, carbon dioxide gas, and dolomite. The corresponding chemical constraints were calcium, carbon, and magnesium. Once again, seven modeling solutions (table 11, MS 14–20) that correspond to the seven previous modeling solutions (table 11, MS 7–13) were found to be thermodynamically possible. In three of the seven modeling solutions, dolomite neither precipitated nor dissolved. Even though significant amounts of dolomite dissolved in the other four modeling solutions, dolomite and magnesium were eliminated from geochemical model 4 (table 11).

Using geochemical model 4, a total of 14 modeling solutions were found to be thermodynamically possible when only calcite and CO_2 gas were used as phases (table 11, MS 21–34). The three modeling solutions without dolomite precipitation or dissolution did not change (table 11, compare MS 16, 17, and 20 with MS 22, 23, and 34); however, it was no longer possible to obtain modeling solutions for McKinney to Wagoner Ranch or to Reno Ranch. With the simplification of the geochemical system, 11 new modeling solutions became thermodynamically possible (table 11, MS 21, 24–33).

The five modeling solutions in table 11 (MS 2–6) that were thermodynamically possible and that required labradorite dissolution represented water in direct association with either the basalt barrier (McKinney site) or the basalt flows of the ESRPA (Reno Ranch, USGS 126A, or USGS 126B). These modeling solutions predicted the measured concentrations of calcium, carbon, magnesium, sulfate, and dissolved silica in water from the downgradient sites. Dissolution of gypsum was a relatively minor reaction (compared with reactions between calcite, dolomite, and carbon dioxide) in all of the thermodynamically possible modeling solutions that included it as a phase (table 11, MS 1–13). Generally, the calcium, carbon, and magnesium chemistry of ground water in the Birch Creek drainage basin could be modeled using a calcite-carbon dioxide-dolomite model and the calcium and carbon chemistry could be modeled using a calcite-carbon dioxide model. These results were expected because of the ground-water chemistry (fig. 3) and mineralogy of the valley fill (Bartholomay and Knobel, 1989) and were consistent with the findings of similar studies of the Big Lost River drainage basin (Carkeet and others, 2001) and the Little Lost River drainage basin (Swanson and others, 2002).

Although much of the water chemistry of the Birch Creek drainage basin can be explained using geochemical models 1–4, additional geochemical models were required to explain changes in concentrations of constituents (such as sodium and potassium) that were not included in the previously evaluated models. The additional geochemical models generally were considered in a stepwise progression from upgradient to downgradient sites and the modeling results are discussed below.

Birch Creek at Kaufman Guardstation-Kaufman Guardstation Well.—The Birch Creek headwaters are a group of springs in the area of Kaufman Guardstation (fig. 1). North of this area, the Birch Creek channel is dry and water moves through the subsurface. Just south of Kaufman Guardstation, a series of basalt flows block the valley and act as a barrier to ground-water flow (fig. 1). The basalt barrier forces ground water to the surface where it discharges as springs. The spring discharge has formed a channel across the basalt barrier to the barrier's southern edge just north of the Wagoner well. The water that surfaces as spring discharge previously has equilibrated with the mineralogy of the valley fill north of the springs. The chemistry of the spring discharge was represented by water collected from Birch Creek at Kaufman Guardstation. As ground water surfaces to discharge at the springs, some of the water flows through fractures and rubble zones in the basalt barrier and reacts with the basalt. The chemistry of this water was represented by water taken from the Kaufman Guardstation well.

To evaluate the geochemical system between these sites, a complex geochemical model was formulated that encompassed silicate hydrolysis and carbonate dissolution reactions (table 13, geochemical model 5). Because the mineralogy of the basalt barrier is similar to the mineralogy of the basalt flows making up the ESRPA (Lisa Morgan, USGS, oral commun., 2002), reactions involving the same minerals were used. The principal reactive minerals in the basalt are plagioclase (labradorite), pyroxene (diopside), and forsterite (olivine). Incongruent dissolution of labradorite to form sodium montmorillonite (eq. 8) and calcium montmorillonite (eq. 9), and congruent dissolution of diopside (eq. 7) and olivine (eq. 6) are consistent with this mineralogy. Feldspars (both plagioclase and microcline) also are present in the sedimentary material that makes up the valley fill, and illite is the most common clay mineral in these sediments (Bartholomay and Knobel, 1989). As a result, kaolinite formation from the weathering of potassium feldspar (eq. 11) and illite (eq. 12) were considered

as potentially active phases in this model. Because clays that form as residues of these reactions are efficient cation-exchange substrates, an exchange reaction was included to account for calcium and magnesium replacing sodium on exchange sites (eq.13). Precipitation of calcite (eq. 3) was included in the model because the water from both sites was supersaturated with respect to this mineral. Finally, dissolution of carbon dioxide was included as a phase because it is involved in all the reactions except dissolution of gypsum and the exchange reaction (eqs. 3–12). The formulation of this chemical model was consistent with the thermodynamics of the system as indicated in figures 4–6 and table 10. Additional saturation information was taken from NETPATH output. Water samples from all wells and surface-water sites in the basin that contained concentrations of aluminum also were undersaturated with respect to illite. Carbon dioxide in the spring discharge was at equilibrium with atmospheric carbon dioxide ($10^{-3.5}$ atm), but water from the Kaufman Guardstation well, was supersaturated with carbon dioxide ($10^{-2.8}$ atm). These SI's were consistent with carbon dioxide dissolution.

To test geochemical model 5, the phases and constraints included in the reactions were loaded into NETPATH to determine all of the possible mass-balance solutions for the model. The program produced 67 modeling solutions that were consistent with conservation of mass in this system. Of these 67 modeling solutions, many were thermodynamically impossible and were eliminated. To accomplish this, the modeling solutions were examined for consistency with the reactions. First, 24 modeling solutions were eliminated because they indicated dissolution of a feldspar with no corresponding precipitation of a clay mineral (eqs. 8–9, 11). Second, 26 modeling solutions were eliminated because calcium montmorillonite and/or sodium montmorillonite were precipitating and the source mineral (labradorite) was not dissolving (eqs. 8–9). Third, seven modeling solutions were eliminated because they indicated dissolution of illite with no corresponding precipitation of kaolinite (eq. 12). Fourth, five modeling solutions were eliminated because kaolinite was dissolving when it should have been precipitating (fig. 4, eqs. 11–12). Finally, two modeling solutions were eliminated because they indicated reverse ion exchange. Because of ion selectivity for exchange sites, calcium and magnesium should replace sodium on exchange sites (eq. 13) in freshwater environments (Chapelle and Knobel, 1983). These two modeling solutions showed sodium replacing calcium and magnesium, which is known as reverse ion exchange. After elimination of these modeling solutions, only three modeling solutions remained and all three were thermodynamically possible (table 13).

The three thermodynamically possible modeling solutions were similar in that they all indicated that cation exchange took place with calcium and magnesium from solution replacing sodium on the solid phase. Dissolution of carbon dioxide gas and precipitation of calcite and kaolinite also occurred in all three modeling solutions. The differences were that in two of the modeling solutions kaolinite formation was the result of illite dissolution, and in the other modeling solution it formed as the result of potassium feldspar dissolution. Also, forsterite dissolved in one of the modeling solutions and diopside dissolved in the other two. The last modeling solution (table 13) requiring dissolution of illite was consistent from a thermodynamic and mineralogic point of view; however, the amount of mass precipitating as kaolinite was unreasonable given the amount of illite dissolving (eq. 12). The remaining two modeling solutions were consistent with the water chemistry at these two sites and with the thermodynamic condition of the two waters. Both modeling solutions were reasonable representations of the processes that are likely occurring at these sites. Of these two modeling solutions the second had a better clay-mineral mass balance, but it was not possible, with available information to differentiate which modeling solution was most accurate. It can be concluded that calcite precipitation and cation exchange are important processes in this environment. The first two modeling solutions presented in table 13 also were consistent with the geochemical model 4 modeling solution for water moving from Birch Creek at Kaufman Guardstation to the Kaufman Guardstation well (table 11, MS 21), because all three models indicated calcite precipitation.

Kaufman Guardstation Well—Downgradient Sites.—The geochemistry of the Kaufman Guardstation well was discussed in the previous section. It was not possible to formulate any thermodynamically possible modeling solutions from this site to downgradient sites (tables 11–12) and it is not likely that the chemistry of water from this site has an effect on water at the downgradient sites. The probable reason is that the basalt barrier restricts ground-water flow and limits any transport of chemical constituents by means of subsurface flow. Any mixing of ground water with surface water from the springs or from Birch Creek would probably result in assimilation and dilution of the ground water to the point that it would be indistinguishable from the surface water.

Birch Creek at Kaufman Guardstation—Downgradient Sites.—The chemistry of water from Birch Creek at Kaufman Guardstation is represented by the chemistry of the spring discharge that forms the headwaters of Birch Creek. The headwaters are collected by Birch Creek and flow across the basalt barrier and onto the alluvium that forms the valley fill (fig. 1). The McKinney site is located on the basalt barrier in material deposited by Birch Creek. The well at this location is shallow and the depth to water is only about 12 ft below land surface (table 1). The chemistry of water from this well was similar to the chemistry of water from Birch Creek at Kaufman Guardstation (tables 5–9) and it is likely that the well has a hydraulic connection with Birch Creek. Water from the McKinney well contained larger concentrations of calcium, bicarbonate, and sulfate than those in water from Birch Creek at Kaufman Guardstation. The respective concentrations changed from 38 to 45, 164 to 182, and 23 to 26 mg/L (tables 5–6). There were no thermodynamically possible modeling solutions in

table 11 that described these water-chemistry changes; however, an evaporation model formulated to include calcite, carbon dioxide, dolomite, and gypsum as phases, and calcium, carbon, magnesium, and sulfur as constraints was evaluated using NETPATH. The results indicate that an evaporation factor of 1.007 (which indicates that 1.007 L of spring water would have to evaporate to 1 L of McKinney water) would produce the concentrations of calcium, carbon, magnesium, and sulfur in water from the McKinney well. This would require dissolution of 0.14 mmol/kg calcite, 0.30 mmol/kg carbon dioxide, and 0.03 mmol/kg gypsum. It is clear that the evaporation model was consistent with the SI's for carbon dioxide gas (partial pressure of carbon dioxide increases) and gypsum (table 10); however, it is less clear that the evaporation model was consistent with respect to calcite because the McKinney water was close to equilibrium with respect to calcite. Although not conclusive, this model suggests that evaporation of spring water may control the chemistry of water from the McKinney well.

The Wagoner site is located south of the basalt barrier (fig. 1). The Wagoner well is a shallow domestic well with a water level about 11 ft below land surface (table 1). Chemistry of water in this well was similar to that of water at Birch Creek at Kaufman Guardstation and was saturated with respect to calcite. The concentrations of calcium and bicarbonate increase from 38 to 49 mg/L and 164 to 201 mg/L, respectively (tables 5 and 6). It was not possible to formulate a thermodynamically possible modeling solution describing the change in chemistry between these sites using the types of geochemical models listed in table 11; however, an evaporation model was formulated that was similar to the model used at the McKinney site. Specifying calcite and carbon dioxide gas as phases and calcium and carbon as constraints in an evaporative model yielded a modeling solution with an evaporation factor of 1.344 and required precipitation of 0.05 mmol/kg calcite. The same formulation yielded an additional modeling solution with an evaporation factor of 1.279 that required dissolution of 0.09 mmol/kg carbon dioxide. Both of these modeling solutions were consistent with the thermodynamic condition of the waters and, although not conclusive, suggest that evaporation and small amounts of mineral reactions control the water chemistry at the Wagoner well. The problem with these models is that evaporation would have to reduce the volume of water from Birch Creek at Kaufman Guardstation by about 20 to 25 percent and this might be an unreasonably large reduction.

The Birch Creek at Blue Dome surface-water site is located south of the basalt barrier (fig. 1); water chemistry was similar to that of Birch Creek at Kaufman Guardstation (tables 5–9). The concentrations of calcium and bicarbonate increased slightly from 38 to 42 mg/L and from 164 to 183 mg/L, respectively (tables 5–6). It was not possible to formulate a thermodynamically possible modeling solution describing the change in chemistry between these sites using the types of geochemical models listed in table 11; however, an evaporation model was formulated that was similar to the model used at the McKinney site. Specifying calcite and carbon dioxide gas as phases and calcium and carbon as constraints in an evaporative model yielded an evaporation factor of 1.043 and required precipitation of 0.03 mmol/kg calcite. This was consistent with the thermodynamic condition of the waters and suggests that evaporation and small amounts of mineral reactions control the water chemistry at Birch Creek at Blue Dome.

It was not possible to formulate thermodynamically possible modeling solutions describing the change in water chemistry between Birch Creek at Kaufman Guardstation and other downgradient sites (tables 11–12).

McKinney Well— Downgradient Sites.—The McKinney site is a shallow well finished in Birch Creek alluvium that is deposited on top of the basalt barrier. Chemistry of water in this well was similar to that of Birch Creek and most likely resulted from evaporation of spring discharge. The next downgradient site is the Wagoner well. The Wagoner well is a slightly deeper domestic well with a shallow depth to water (table 1). The terminus of the basalt barrier is between the McKinney and Wagoner wells. At the terminus, the Birch Creek valley fill thickens and is dominated largely by carbonate minerals and quartz (Bartholomay and Knobel, 1989). Because of the increased availability of carbonate minerals (calcite and dolomite) relative to the basalt barrier, these minerals should have a larger effect on the geochemistry of water downgradient from the McKinney well. Examination of table 11 confirms this hypothesis. The McKinney well had thermodynamically possible modeling solutions for water moving to all downgradient wells (except the Wagoner well) using the carbonate models listed in table 11. In general, the dominant chemical reactions in the valley between the basalt barrier and the Snake River Plain are dissolution and precipitation reactions between water, dolomite, calcite, and carbon dioxide gas. Once the water reaches the Snake River Plain, the dominant reactions are precipitation of calcite and carbon dioxide gas (table 11, MS 22–24). Although water moving from the McKinney well to ESRPA wells (USGS 126A, USGS 126B, P&W 2) could be modeled with the calcite-carbon dioxide gas model in table 11 (geochemical model 4), a more complex model that included silicate minerals accounted more accurately for the changes in other constituents. The silicate model (geochemical model 5) used for water moving from Birch Creek at Kaufman Guardstation to the Kaufman Guardstation well was modified for modeling between the McKinney well and USGS 126B (geochemical model 6). Sodium montmorillonite was eliminated and plagioclase was allowed to weather to kaolinite (eq. 10). Sodium montmorillonite was eliminated because it is not a stable weathering product at USGS 126B (fig. 5) and the plagioclase-kaolinite reaction was added because kaolinite is a stable weathering product (fig. 5). USGS 126B was chosen as the downgradient site for modeling purposes because it is shallower than USGS 126A (table 1) and the water chemistry was nearly identical to that in USGS 126A (fig. 2). Also, because the partial pressure of carbon dioxide gas was less at USGS 126A than it was at the McKinney site ($10^{-3.1}$ and $10^{-2.8}$

atm, respectively), it was necessary to precipitate carbon dioxide gas. It is possible to develop similar models by using USGS 126A as the downgradient site.

To test geochemical model 6, the phases and constraints included in the reactions were loaded into NETPATH to determine all of the possible mass-balance solutions for the model. The program produced 40 modeling solutions that were consistent with conservation of mass in this system. Of these 40 modeling solutions, many were thermodynamically impossible and were eliminated. To accomplish this, the modeling solutions were examined for consistency with the reactions. Modeling solutions were eliminated because they required dissolution of a feldspar with no corresponding precipitation of a clay mineral (eqs. 8–11), because calcium montmorillonite was precipitating and the source mineral (labradorite) was not dissolving (eq. 9), because the models required dissolution of illite with no corresponding precipitation of kaolinite (eq. 12), and because kaolinite was dissolving when it should have been precipitating (fig. 4, eqs. 10–12). After elimination of these modeling solutions, only five modeling solutions remained and all five were thermodynamically possible (table 14).

These five modeling solutions were consistent with water chemistry at these two sites and with the thermodynamic condition of the two waters. All five modeling solutions were reasonable representations of the processes that likely are occurring at these sites; however, the mass balance of the second modeling solution presented in table 14 was most consistent with the reactions. It can be concluded that calcite precipitation and cation exchange are important processes in this environment and that labradorite and illite probably are dissolving incongruently to form kaolinite.

Wagoner Well—Downgradient Sites.—The Wagoner well is the most upgradient site that is south of the basalt barrier (fig.1). Water from the Wagoner well was saturated with respect to calcite and undersaturated with respect to dolomite and gypsum. The water was saturated ($10^{-2.6}$ atm) with carbon dioxide relative to the atmosphere. The Wagoner well is situated in the carbonate-rich alluvial valley fill; therefore, models of water moving to downgradient wells should include carbonate reactions. Because of the proximity of this well to Birch Creek at Blue Dome, evaporative models with carbonate reactions were attempted, and it was possible to model the calcium and carbon dioxide composition of the Wagoner well starting with water from Birch Creek at Blue Dome. Two evaporative modeling solutions were thermodynamically possible. The evaporation factors were 1.289 and 1.262 and required precipitation of 0.02 mmol/kg calcite or 0.04 mmol/kg carbon dioxide, respectively. Both of these modeling solutions however, required evaporation of about 20 percent of the initial water, and this amount may be unreasonably large. It was thermodynamically possible to model the chemistry of water at Birch Creek at Blue Dome using a calcite-carbon dioxide model starting with Wagoner well water (table 11, MS 25). This modeling solution required precipitation of 0.25 mmol/kg calcite and 0.51 mmol/kg carbon dioxide; however, this modeling solution was not possible because of hydrologic reasons, Birch Creek is a losing stream at this location.

The Wagoner Ranch well is the closest ground-water site downgradient from the Wagoner well. The Wagoner Ranch well is deeper than the Wagoner well (295 ft) and the depth to water relative to the land surface is greater (250 ft) (table 1). The water was near equilibrium with respect to calcite and was undersaturated with respect to dolomite and gypsum. The water was even more saturated ($10^{-2.4}$ atm) with respect to atmospheric carbon dioxide ($10^{-3.5}$ atm) than water from the Wagoner well ($10^{-2.6}$ atm). Thermodynamically possible modeling solutions for water moving from the Wagoner well to the Wagoner Ranch well are shown in table 11 (MS 11, 18, 26). These modeling solutions all showed precipitation of calcite and dissolution of carbon dioxide. Two of the modeling solutions required dissolution of dolomite and one required dissolution of gypsum. All three of these modeling solutions predicted the chemistry of water at the Wagoner Ranch well and were consistent with the mineralogy of the valley fill.

All of the wells downgradient from the Wagoner Ranch well are situated in the ESRPA. Three of the wells are near the mouth of the valley (USGS 126A, USGS 126B, and P&W 2) (fig. 1). The fourth well (Reno Ranch), which is southeast of the toe of the Bitterroot Range (fig. 1) will be discussed separately in the section, "Reno Ranch Well." USGS 126A, USGS 126B, and P&W 2 are about 90 to 350 ft deeper than the deepest well in the Birch Creek Valley and the depths to water are about 60 to 160 ft deeper (table 1). Water in all three wells was saturated or at equilibrium with respect to calcite and dolomite and undersaturated with respect to gypsum (table 10). Water in all three wells was saturated with respect to atmospheric carbon dioxide (about 10^{-3} atm) but less saturated than the Wagoner well ($10^{-2.6}$ atm). Chemistry of water moving to these three wells from the Wagoner well was modeled by using a calcite-carbon dioxide model (table 11, geochemical model 4), in which both calcite and carbon dioxide precipitate (table 11, modeling solutions 27–29).

Chemistry of water moving from the Wagoner well to USGS 126B could be modeled with a silicate-mineral model (table 15, geochemical model 7) similar to the McKinney-USGS 126B model (table 14, geochemical model 6). To test geochemical model 7, the phases and constraints included in the reactions were loaded into NETPATH to determine all of the possible mass-balance solutions for the model. The program produced 19 modeling results that were consistent with conservation of mass in this system. Of these 19 modeling solutions, many were thermodynamically impossible and were eliminated. To accomplish this, the modeling solutions were examined for consistency with the reactions. Modeling solutions were eliminated because a feldspar was dissolving with no corresponding precipitation of a clay mineral (eqs. 8–11), because calcium montmorillonite was precipitating and the source mineral (labradorite) was not dissolving (eq. 9), because

the modeling solutions required dissolution of illite with no corresponding precipitation of kaolinite (eq. 12), and because kaolinite was dissolving when it should have been precipitating (fig. 4, eqs. 10–12). After elimination of these modeling solutions, only one modeling solution remained and it was thermodynamically possible (table 15).

The remaining modeling solution was consistent with water chemistry at these two sites and with the thermodynamic condition of the two waters. The modeling solution was a reasonable representation of the processes that likely are occurring at these sites; however, the amount of kaolinite precipitating (less than 0.01 mmol/kg) as a result of dissolution of labradorite and potassium feldspar (sum should equal about 0.02 mmol/kg) suggests that this model is not as reasonable as the McKinney-USGS 126B model.

Reno Ranch Well.—Thermodynamically possible modeling solutions for water moving from several upgradient sites (McKinney well, Wagoner well, Wagoner Ranch well) were formulated (table 11, MS 2, 5, 8, 12, 15, 19, 30); however, these modeling solutions were rejected for hydrologic reasons. All water that moves from the Birch Creek Valley to the Reno Ranch site is surface water diverted from Birch Creek. Nearly the entire flow of Birch Creek is diverted from the stream channel by means of a canal to a power-generating plant. After the water is used to generate power, it is used for irrigation near Reno Ranch during the growing season. When the water is not being used for irrigation, it is returned to the Reno Ditch (fig. 1) and transported back to the northern part of the INEEL. As a result, any attempt to model the chemistry of water at the Reno Ranch well would require starting with surface water from Birch Creek. The surface-water site closest to the diversion site is Birch Creek at Blue Dome; chemistry of water from Birch Creek at Blue Dome was assumed to be representative of the chemistry of the diverted surface water. It was not possible to formulate thermodynamically possible modeling solutions for water moving from Birch Creek at Blue Dome to the Reno Ranch well using geochemical models 1–4 (table 11).

To evaluate the chemistry of water moving from Birch Creek at Blue Dome to the Reno Ranch well, the same complex geochemical model used for Birch Creek at Kaufman Guardstation to the Kaufman Guardstation well was used (table 13, geochemical model 5). The formulation used exactly the same phases and constraints as that model because all of the same reactive phases are present. To test geochemical model 8 (table 16), the phases and constraints included in the reactions were loaded into NETPATH to determine all of the possible mass-balance solutions for the model. The program produced 116 modeling solutions that were consistent with the conservation of mass in this system. Of these 116 modeling solutions, many were thermodynamically impossible and were eliminated. To accomplish this, the same process was followed as in the model for Birch Creek at Kaufman Guardstation to the Kaufman Guardstation well. After elimination of these modeling solutions, only six modeling solutions remained and all six were thermodynamically possible (table 16). The third and fourth modeling solutions (table 16) that required dissolution of potassium feldspar and cation exchange were consistent from thermodynamic and mineralogic criteria; however, the amount of mass precipitating as kaolinite was unreasonable given the amounts of potassium feldspar that dissolved (eq. 11). A similar argument can be made for the three illite dissolution modeling solutions requiring the formation of kaolinite while only dissolving 0.12 mmol/kg illite. The remaining modeling solution (listed at the top of table 16) required a more reasonable mass transfer of feldspars to kaolinite (eqs. 10–11) and sodium montmorillonite (eq. 8), and dissolution of forsterite and carbon dioxide. This model was the most reasonable representation of this system.

Birch Creek at Blue Dome (Reno Ditch)-USGS 126B.—When water diverted from Birch Creek to the Reno Ranch area is not being used for irrigation, it is transported through Reno Ditch (fig. 1) to the northern part of the INEEL. The Reno Ditch terminates near USGS 126A, USGS 126B, and P&W 2, and some of the water probably infiltrates to form local recharge to the ESRPA. To test this hypothesis, the same silicate-mineral model used between the McKinney site and USGS 126B was used to model water from the Reno Ditch to USGS 126B, except that this model (table 17, geochemical model 9) required dissolution of carbon dioxide (the partial pressure of carbon dioxide increases from $10^{-3.8}$ to $10^{-3.1}$ atm). The chemistry of water in Reno Ditch was assumed to be the same chemistry as that at Birch Creek at Blue Dome, and the latter was used as the starting point for this formulation. To test geochemical model 9, the phases and constraints included in the reactions were loaded into NETPATH to determine all of the possible mass-balance solutions for the model. The program produced 57 modeling solutions that were consistent with the conservation of mass in this system. Of these 57 modeling solutions, many were thermodynamically impossible and were eliminated. To accomplish this, the modeling solutions were examined for consistency with the reactions. Modeling solutions were eliminated because feldspar was dissolving with no corresponding precipitation of a clay mineral (eqs. 8–11), because calcium montmorillonite was precipitating and the source mineral (labradorite) was not dissolving (eq. 9), because the modeling solutions required dissolution of illite with no corresponding precipitation of kaolinite (eq. 12), because kaolinite was dissolving when it should have been precipitating (fig. 4, eqs. 10–12), and because carbon dioxide was not present or was precipitating when it should have been dissolving. After elimination of these modeling solutions, only four modeling solutions remained and all four were thermodynamically possible (table 17). The remaining four modeling solutions were consistent with the chemistry of water at these two sites and with the thermodynamic condition of the two waters. All four modeling solutions were reasonably good representations of the processes that likely are occurring at these sites. It can be concluded that calcite precipitation, dissolution of carbon dioxide, incongruent dissolution of labradorite and possibly

potassium feldspar and illite to form kaolinite, are the most important reactions in these modeling solutions. These four modeling solutions also describe water from Birch Creek infiltrating into the valley fill and moving through the subsurface to recharge the ESRPA as underflow from the Birch Creek Valley.

Other Models.—Examination of table 11 shows that it is possible to explain the slight change in water chemistry between USGS 126A and USGS 126B by precipitating 0.02 mmol/kg each of calcite and carbon dioxide; however these changes are small and the chemistry of water in these two wells was effectively the same. Also it is possible to formulate modeling solutions from the Reno Ranch well to either USGS 126A, USGS 126B, or P&W 2 by precipitating calcite and carbon dioxide (table 11). These three modeling solutions were rejected because of the hydrology of the aquifer in this area. On the basis of available data, it is believed that ground water flowing to the three wells probably originates from the Birch Creek Valley rather than the Reno Ranch area (Daniel Ackerman, USGS, oral commun., 2002).

SUMMARY AND CONCLUSIONS

Water samples collected during 2000 from five wells and one surface-water site in the Birch Creek drainage basin were analyzed for selected inorganic constituents, nutrients, dissolved organic carbon, tritium, measurements of gross alpha and beta radioactivity, and stable isotopes. Four quality-assurance duplicates also were collected and analyzed by the NWQL. Data from other reports on an additional three wells and one surface-water site were included. The ranges of concentrations for dissolved cations, anions, and silica follow: calcium, 29 to 49 mg/L; magnesium, 14 to 24 mg/L; sodium, 5.1 to 17 mg/L; potassium, 0.88 to 6.5 mg/L; silica, 7.7 to 70 mg/L; chloride, 3.2 to 12 mg/L; sulfate, 3.9 to 34 mg/L; bicarbonate, 162 to 235 mg/L; and fluoride, 0.18 to 1.5 mg/L. Results show that most water from the Birch Creek drainage basin has a calcium-magnesium bicarbonate character.

The ranges of concentrations of barium and strontium in the ISU samples were 42 to 165 µg/L and 143 to 352 µg/L, respectively. Lithium concentrations in the USGS samples ranged from 3.1 to 25 µg/L. Concentrations of nitrite plus nitrate as nitrogen ranged from less than 0.05 to 0.8 mg/L. Concentrations of dissolved organic carbon ranged from 0.15 to 0.75 mg/L.

Tritium concentrations in the samples ranged from -6.4±19.2 pCi/L to 38.4±25.6 pCi/L. Relative isotopic ratios ranged from -141.7 to -138.9 permil for δ^2H; -18.62 to -18.13 permil for $\delta^{18}O$; and, -11.14 to -5.9 permil for $\delta^{13}C$.

A statistical evaluation of the duplicate samples revealed that all the results were equivalent.

The Birch Creek Valley can be roughly divided into three hydrologic areas: (1) the northern part, where ground water is forced to the surface by the basalt barrier and the sampling sites were either surface water or shallow wells. Water chemistry in this area was characterized by simple evaporation models, simple calcite-carbon dioxide models, or complex models involving carbonate and silicate minerals; (2) the central part, where the valley is filled by sedimentary material and the sampling sites were wells that are deeper than those in the northern part. Water chemistry in this area was characterized by simple calcite-dolomite-carbon dioxide models; and (3) the southern part is where the ground water enters the ESRPA. In this area, the sampling sites were wells with depths and water levels much deeper than those in the northern and central parts of the Birch Creek Valley. The calcium and carbon water chemistry is this area was characterized by a simple calcite-carbon dioxide model, but more complex calcite-silicate models more accurately accounted for mass transfer in this area.

Throughout the system, calcite precipitated if it was an active phase, except in one modeling solution, Wagoner Ranch to Reno Ranch, that was rejected for hydrologic reasons. Carbon dioxide either precipitated (outgassed) or dissolved depending on the partial pressure of carbon dioxide in water from the modeled sites. Dolomite was an active phase only in modeling solutions from the central part of the system (other than Reno Ranch modeling solutions); however, changes in magnesium concentration could be explained by dissolution of silicate minerals or ion-exchange reactions. Generally the entire system could be modeled with either evaporative models, carbonate models, or carbonate-silicate models. The latter two types of models generally have a significant amount of calcite precipitation relative to the mass transfer to and from the other active phases. The amount of calcite precipitated in the more complex modeling solutions was similar to the amount of calcite precipitated in the simpler modeling solutions. This similarity suggests that, although the simpler modeling solutions can predict the calcium and carbon concentrations in Birch Creek Valley ground- and surface-water, silicate-mineral-based models are required to account for the other constituents. The amount of mass transfer to and from the silicate-mineral phases was generally small compared with that in the carbonate phases. It appears that the water chemistry of well USGS 126B represents the chemistry of water recharging the ESRPA by means of underflow from the Birch Creek Valley.

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Table 1. Site location and type, well construction, and approximate depth to water in wells, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Abbreviations: BC, Birch Creek; GS, Guardstation; NA, not applicable; *, owner of well thinks well depth is 150 feet]

Site identifier	Latitude	Longitude	Site type	Well depth (feet)	Depth to water (feet)	Diameter of casing (inches)
BC at Kaufman GS	441354	1125824	Surface water	NA	NA	NA
Kaufman GS Well	441406	1125826	Domestic well	28	5	5
McKinney Well	441113	1125606	Domestic well	43	12	6
Wagoner Well	440957	1125443	Domestic well	150*	10.7	6
BC at Blue Dome	440914	1125424	Surface water	NA	NA	NA
Wagoner Ranch Well	440813	1125322	Domestic well	295	250	8
Reno Ranch Well	440142	1124255	Domestic well	540	535	8
USGS 126A	435529	1124713	Observation well	648	411.21	5
USGS 126B	435529	1124714	Observation well	452	411.93	10
P&W 2	435419	1124531	Observation well	386	307	10

Table 2. Containers and preservatives used for water samples, Birch Creek drainage basin, Idaho.

[Units: mL, milliliter; L, liter. Symbols: HNO_3, nitric acid; °C, degrees Celsius. Other treatment: pore size of filter is 0.45 micrometers. Analyzing laboratory: ISU, Idaho State University chemistry laboratory; NWQL, U.S. Geological Survey National Water Quality Laboratory]

Type of constituent	Container		Preservative		Other treatment	Analyzing laboratory
	Type	Size	Type	Size		
Cations and trace elements	polyethylene; acid-rinsed	500 mL	Ultrex HNO_3	4 mL	filter	ISU
Carbon isotopes	polyethylene	1 L	none	none	none	NWQL
Oxygen/deuterium isotopes	glass	60 mL	none	none	none	NWQL
Tritium	polyethylene	250 mL	none	none	none	NWQL
Gross alpha / beta	polyethylene; acid-rinsed	1 L	Ultrex HNO_3	8 mL	filter	NWQL
Dissolved organic carbon	glass, amber	125 mL	none	none	silver filter; chill 4°C	NWQL
Nutrients	polyethylene; amber	125 mL	none	none	filter; chill 4°C	NWQL
Anions	polyethylene	250 mL	none	none	filter	NWQL
Specific Conductance	polyethylene	250 mL	none	none	none	NWQL
Cations and trace elements	polyethylene, acid-rinsed	250 mL	Ultrex HNO_3	2 mL	filter	NWQL

Table 3. Results of field measurements for pH, specific conductance, temperature of water, alkalinity, and dissolved oxygen, and laboratory calculations of total hardness and dissolved solids in water from selected sites, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Data for site identifiers shown in boldface are from Busenberg and others (2000) or Knobel and others (1999). Units: pH, negative base-10 logarithm of hydrogen ion activity in moles per liter; specific conductance, microsiemens per centimeter at 25°C (degrees Celsius); temperature, °C; other measurements in milligrams per liter. Abbreviations: m/d/y, month/day/year; DO, dissolved oxygen; BC, Birch Creek; GS, Guardstation; NA, not analyzed; UNK, unknown. Symbols: $CaCO_3$, calcium carbonate; <, less than]

Site identifier	Date sampled (m/d/y)	Time	pH	Specific conductance	Temperature (°C)	Alkalinity as $CaCO_3$	DO	Total hardness	Dissolved solids, sum (as $CaCO_3$)
BC at Kaufman GS	6/27/00	1350	8.6	320	16.5	134	10.0	NA	134
Kaufman GS Well	6/27/00	1455	8.1	373	11.0	193	<0.2	170	193
McKinney Well	6/13/91	1125	7.9	352	8.0	149	5.4	170	199
Wagoner Well	5/22/97	1455	7.8	376	7.0	173	NA	NA	NA
BC at Blue Dome	6/28/95	UNK	8.5	UNK	9.4	165	UNK	UNK	UNK
Wagoner Ranch Well	6/28/00	1045	7.6	443	11.0	182	8.4	NA	182
Reno Ranch Well	6/28/00	0850	7.6	481	14.0	190	6.4	220	190
USGS 126A	11/8/00	1250	8.1	344	11.0	135	13.8	NA	150
USGS 126B	11/8/00	1050	8.2	344	10.5	133	10.3	NA	160
P&W 2	5/22/91	1405	8.0	348	10.5	139	9.7	160	194

Table 4. Most probable deviation equations and instrument detection limits for constituents analyzed by the National Water Quality Laboratory and Idaho State University.

[Constituents units are parts per million (ppm) unless otherwise noted. In the most probable deviation (MPD) equations, Y is the MPD and x is the concentration value obtained from the inductively coupled plasma analysis. The concentration for a particular sample can be plugged in as x and the Y obtained as the plus or minus error for the value. Determination of Y for each sample can be used to verify the overlap of the concentration ranges of the National Water Quality Laboratory (NWQL) and the Idaho State University (ISU) data. Ranges are in the units designated in the Constituent column. Abbreviations: MRL, minimum reporting level; IDL, instrument detection limit; NA, not analyzed; ppb, part per billion]

	NWQL			ISU	
Constituent (unit)	**MPD Equation**	**Range**	**MRL**	**Range**	**IDL**
Potassium	Y = 0.063x + 0.24	0.45-13.9	0.1	0.2-2	0.10
Calcium	Y = 0.045x + 0.014	5.13-78.9	.1	20-80	3
Sodium	Y = 0.038x + 0.179	7.19-166	.06	3-30	2
Magnesium	Y = 0.038x + 0.026	1.03-25.3	.004	1-30	.05
Aluminum (ppb)	Y = 0.109x + 4.074	6.66-132	10	NA	1
Iron (ppb)	Y = 0.033x + 5.376	4.30-228	10	10-100	20
Manganese (ppb)	Y = 0.046x + 0.661	2.40-423	3	2-20	10
Chromium (ppb)	Y = 0.059x + 0.584	0.68-79.0	1	25-100	17
Zinc (ppb)	Y = 0.043x + 2.073	5.80-227	20	25-100	40
Lead (ppb)	Y = 0.066x + 0.624	1.00-103	1	NA	16
Silicon	Y = 0.063x + 0.011	1.43-24.0	.1	3-30	.10
Strontium (ppb)	Y = 0.046x + 0.512	32.7-705	1	100-500	8
Barium (ppb)	Y = 0.042x + 0.954	7.65-507	1	20-200	2
Chloride	Y = 0.02x + 0.972	17.0-132	.1	NA	NA
Fluoride	Y = 0.067x + 0.007	0.23-2.12	.1	NA	NA
Sulfate	Y = 0.036x + 0.409	5.5-621	.1	NA	NA
Nitrite plus nitrate as nitrogen	Y = 0.045x + 0.013	0.036-1.93	.05	NA	NA
Ammonia	Y = 0.058x + 0.012	0.024-1.33	.02	NA	NA
Orthophosphate	Y = 0.041x + 0.004	0.038-1.59	.01	NA	NA

Table 5. Concentrations of dissolved major cations and silica in water from selected sites, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Data for site identifiers shown in boldface are from Busenberg and others (2000) or Knobel and others (1999). Analytical results in milligrams per liter. Symbols: Ca^{2+}, calcium; Mg^{2+}, magnesium; Na^{+}, sodium; K^{+}, potassium; SiO_2, silica; ±, plus or minus. Abbreviations: ISU, Idaho State University (errors in ISU analyses were calculated by the standard deviations of the average values from three days of analyses); USGS, U.S. Geological Survey (all samples were analyzed by the USGS National Water Quality Laboratory except those from the Wagoner well and Birch Creek at Blue Dome, which were analyzed by the USGS common use laboratory in Reston, Va. (Busenberg and others, 2000)); BC, Birch Creek; GS, Guardstation; NA, not analyzed; NS, not calculated because duplicate sample was not available; QA-1, replicate of Wagoner Ranch well]

Site identifier	Ca^{2+} ISU	Ca^{2+} USGS	Z-value	Mg^{2+} ISU	Mg^{2+} USGS	Z-value	Na^{+} ISU	Na^{+} USGS	Z-value
BC at Kaufman GS	38±1.33	NA	NS	15±.32	NA	NS	5.1±.11	NA	NS
Kaufman GS Well	29±.82	29	0	24±1.61	24	0	11±.31	12	1.42
McKinney Well	NA	45	NS	NA	15	NS	NA	5.4	NS
Wagoner Well	NA	49	NS	NA	16	NS	NA	5.1	NS
BC at Blue Dome	NA	42	NS	NA	15	NS	NA	5.2	NS
Wagoner Ranch Well	46±1.48	NA	NS	19±.23	NA	NS	17±.25	NA	NS
QA-1	45±1.62	NA	NS	19±.23	NA	NS	17±.20	NA	NS
Reno Ranch Well	49±.66	49	0	23±.42	24	.97	12±.12	12	0
USGS 126A	39±1.47	35	1.85	15±.24	14	1.65	8.8±.20	8.4	.75
USGS 126B	38±.97	38	0	15±.06	15	0	9.0±.10	8.7	.58
P&W 2	NA	40	NS	NA	14	NS	NA	7.9	NS
QA-1 Z-value			.46			0			0

Table 5. Concentrations of dissolved major cations and silica in water from selected sites, Birch Creek drainage basin, Idaho.—Continued

Site identifier	K^{+} ISU	K^{+} USGS	Z-value	SiO_2 ISU	SiO_2 USGS	Z-value
BC at Kaufman GS	0.88±0.11	NA	NS	10±0.1	NA	NS
Kaufman GS Well	6.5±1.11	5.2	1.04	70±1.3	62	1.94
McKinney Well	NA	1.0	NS	NA	10	NS
Wagoner	NA	1.1	NS	NA	12	NS
BC at Blue Dome	NA	0.9	NS	NA	7.7	NS
Wagoner Ranch Well	1.1±.14	NA	NS	10±.1	NA	NS
QA-1	1.1±.28	NA	NS	10±.2	NA	NS
Reno Ranch Well	3.6±.65	2.9	.90	45±.5	41	1.51
USGS 126A	1.8±.60	1.6	.29	18±.21	16	1.92
USGS 126B	2.5±.42	2.3	.35	19±.45	18	0.81
P&W 2	NA	1.2	NS	NA	14	NS
QA-1 Z-value			0			0

Table 6. Concentrations of dissolved major anions in water from selected sites, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Data for site identifiers shown in boldface are from Busenberg and others (2000) or Knobel and others (1999). Samples were analyzed by the U. S. Geological Survey National Water Quality Laboratory, except those from the Wagoner well and BC at Blue Dome, which were analyzed by the USGS common use laboratory in Reston, Va. (Busenberg and others, 2000). Bicarbonate data were calculated from alkalinity field measurements listed in table 3; the alkalinity (as calcium carbonate) was divided by 0.8202. Abbreviations: BC, Birch Creek; GS, Guardstation]

Site identifier	Chloride	Sulfate	Bicarbonate	Fluoride
BC at Kaufman GS	4.6	23	164	0.22
Kaufman GS Well	3.2	3.9	235	.58
McKinney Well	5.4	26	182	.2
Wagoner Well	5.5	22	201	.22
BC at Blue Dome	4.8	25	183	.18
Wagoner Ranch Well	9.6	29	222	.19
QA-1	10	29	222	.22
Reno Ranch Well	12	34	232	1.5
USGS 126A	8.0	29	165	.22
USGS 126B	8.2	29	162	.23
P&W 2	11	21	169	.3
QA-1 Z-value	.24	0	0	1.02

Table 7. Concentrations of dissolved trace elements in water from selected sites, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Data for site identifiers shown in boldface type are from Busenberg and others (2000) or Knobel and others (1999). Analytical results in micrograms per liter. Abbreviations: ISU, Idaho State University (errors in ISU analyses were calculated by the standard deviations of the average values from three days of analyses); USGS, U.S. Geological Survey (all samples were analyzed by the USGS National Water Quality Laboratory except those from the Wagoner well and Birch Creek at Blue Dome, which were analyzed by the USGS common use laboratory in Reston, Va. (Busenberg and others, 2000)); BC, Birch Creek; GS, Guardstation; NA, not analyzed; NS, not calculated because duplicate sample was not collected; NC, not calculated because of less than value; QA-1, replicate of Wagoner Ranch well. Symbols: ±, plus or minus; <, less than]

Site identifier	Barium ISU	Barium USGS	Z-Value	Bromide USGS
BC at Kaufman GS	62±.72	NA	NS	16
Kaufman GS Well	165±3	164	0.12	17
McKinney Well	NA	64	NS	10
Wagoner Well	NA	69	NS	NA
BC at Blue Dome	NA	61	NS	7
Wagoner Ranch Well	78±1.47	NA	NS	35
QA-1	80±1.67	NA	NS	35
Reno Ranch Well	115±4	114	.14	42
USGS 126A	42±1.05	39	1.07	33
USGS 126B	47±2.87	46	.25	35
P&W 2	NA	43	NS	20
QA-1 Z-value			.90	

Table 7. Concentrations of dissolved trace elements in water from selected sites, Birch Creek drainage basin, Idaho.—Continued

Site identifier	Chromium ISU	Chromium USGS	Z-Value	Iron ISU	Iron USGS	Z-Value	Lithium USGS
BC at Kaufman GS	<17	NA	NS	<11	NA	NS	NA
Kaufman GS Well	<17	0.8	NC	<11	67	NC	12
McKinney Well	NA	<1	NS	NA	7	NS	5
Wagoner Well	NA	<1	NS	NA	48	NS	3.3
BC at Blue Dome	NA	<1	NS	NA	28	NS	3.1
Wagoner Ranch Well	<17	NA	NS	<11	NA	NS	NA
QA-1	<17	NA	NS	<11	NA	NS	NA
Reno Ranch Well	<17	0.7	NC	<11	<10	NC	25
USGS 126A	<17	2	NC	<11	<10	NC	4.7
USGS 126B	<17	1.9	NC	<11	<10	NC	5.5
P&W 2	NA	<5	NS	NA	18	NS	6

Table 7. Concentrations of dissolved trace elements in water from selected sites, Birch Creek drainage basin, Idaho.—Continued

Site identifier	Manganese ISU	Manganese USGS	Z-Value	Strontium ISU	Strontium USGS	Z-Value	Zinc ISU	Zinc USGS	Z-value
BC at Kaufman GS	<4	NA	NS	143±2	NA	NS	<25	NA	NS
Kaufman GS Well	35±3	39	1.03	352±7	347	0.28	<25	20	NC
McKinney Well	NA	<1	NS	NA	170	NS	NA	8	NS
Wagoner Well	NA	2.7	NS	NA	163	NS	NA	367	NS
BC at Blue Dome	NA	<1	NS	NA	150	NS	NA	<1	NS
Wagoner Ranch Well	<4	NA	NS	177±2	NA	NS	<25	NA	NS
QA-1	<4	NA	NS	179±2	NA	NS	<25	NA	NS
Reno Ranch Well	<4	9	NC	330±3	322	.51	<25	1,560	NC
USGS 126A	<4	<3.2	NC	196±3	178	1.96	<25	554	NC
USGS 126B	<4	<3.2	NC	205±2	201	.40	<25	227	NC
P&W 2	NA	<1	NS	NA	140	NS	NA	61	NS
QA-1 Z-value						.71			

Table 8. Concentrations of dissolved nutrients and dissolved organic carbon in water from selected sites, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Data for site identifiers shown in boldface are from Busenberg and others (2000) or Knobel and others (1999). Analytical results in milligrams per liter. Samples were analyzed by the U.S. Geological Survey (USGS) National Water Quality Laboratory, except those from the Wagoner well and Birch Creek at Blue Dome, which were analyzed by the USGS common use laboratory in Reston, Va. (Busenberg and others, 2000). The Z-value for dissolved organic carbon (DOC) was calculated from the relative standard deviation reported by Wershaw and others (1987, p. 15) Abbreviations: BC, Birch Creek; GS, Guardstation; NA, not analyzed; QA-1, replicate of Wagoner Ranch Well; NC, not calculated because of less than value. Symbol: <, less than]

Site identifier	Ammonia as nitrogen	Nitrite as nitrogen	Nitrite plus nitrate as nitrogen	Orthophosphate as phosphorous	DOC
BC at Kaufman GS	<0.02	<0.01	0.146	<0.01	0.676
Kaufman GS Well	.077	<.01	<.05	.011	.474
McKinney Well	.02	<.01	.28	<.01	.4
Wagoner Well	NA	NA	.8	NA	.75
BC at Blue Dome	NA	NA	.6	NA	.75
Wagoner Ranch Well	.05	<.01	.418	.011	.492
QA-1	<.02	<.01	.414	<.01	.382
Reno Ranch Well	<.02	<.01	.566	.012	.432
USGS 126A	.041	.006	.524	.018	.15
USGS 126B	.041	.006	.531	.018	.3
P&W 2	<.01	<.01	.38	<.01	.4
QA-1 Z-value	NC	0	.09	NC	.60

Table 9. Concentrations of tritium, gross alpha- and gross beta-particle radioactivity, and selected stable isotopes in water from selected sites, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Data for site identifiers shown in boldface are from Busenberg and others (2000) or Knobel and others (1999). Samples were analyzed by the U.S. Geological Survey National Water Quality Laboratory. Analytical results and uncertainties—for example, 22.4±25.6, in indicated units. Analytical uncertainties are reported as 2**s** except for δ^2H, δ^{18}O, and δ^{13}C, which are reported ± amount permil indicated. Units: pCi/L, picocuries per liter; permil, parts per thousand relative to a standard. Abbreviations: BC, Birch Creek; GS, Guardstation; ND, not determined; QA-1, replicate of Wagoner Ranch well. Symbols: ^{230}Th, thorium-230; ^{137}Cs, cesium-137; δ^2H, delta notation for stable hydrogen isotope ratios; δ^{18}O, delta notation for stable oxygen isotope ratios; δ^{13}C, delta notation for stable carbon isotope ratios; ±, plus or minus]

Site identifier	Tritium pCi/L	alpha (pCi/L as ^{230}Th)	beta (pCi/L as ^{137}Cs)	δ^2H ± 1.5 permil	δ^{18}O ± 1.5 permil	δ^{13}C± 0.3 permil
BC at Kaufman GS	22.4±25.6	1.65±1.23	0.46±1.92	-141.2	-18.57	-5.92
Kaufman GS Well	32±25.6	.25±1.09	5.11±2.65	-139.7	-18.39	-11.14
McKinney Well	-3.2±26	2.4±0.80	1.5±0.76	-141.0	-18.55	-7.9
Wagoner Well	14.7±0.96	ND	ND	-141.7	-18.13	-8.97
BC at Blue Dome	ND	ND	ND	-140.1	-18.62	ND
Wagoner Ranch Well	38.4±25.6	2.72±1.58	2.31±2.51	-139.2	-18.35	-7.37
QA-1	64±25.6	2.83±1.77	1.53±2.41	-138.9	-18.38	-7.09
Reno Ranch Well	25.6±25.6	3.24±1.66	2.5±2.51	-139	-18.2	-7.09
USGS 126A	-6.4±19.2	1.96±1.13	3.04±1.84	-141.1	-18.44	-5.9
USGS 126B	6.4±19.2	1.97±1.06	4.02±1.81	-140.9	-18.44	-6.41
P&W 2	16±26	3.0±0.86	1.9±0.84	-140.0	-18.55	-8.0
QA-1 Z-value	1.41	.09	.45	.14	.01	.66

Table 10. Mineral/water thermodynamic saturation indices and log PCO_2 values for water from selected sites, Birch Creek drainage basin, Idaho.

[See figure 1 for location of sites. Saturation indices are log IAP/K (ion activity product/equilibrium constant); positive values indicate saturation, negative values indicate undersaturation, and zero plus or minus 0.1 values indicate equilibrium. Unit: log PCO_2, base-10 logarithm of carbon dioxide partial pressure; log PCO_2 values larger than -3.5 indicate supersaturation with respect to the atmosphere, values smaller than -3.5 indicate undersaturation with respect to the atmosphere. Abbreviations: BC, Birch Creek; GS, Guardstation]

Site identifier	Calcite	Dolomite	Gypsum	Anhydrite	Carbon dioxide ($logPCO_2$)
BC at Kaufman GS	0.80	1.43	-2.40	-2.65	-3.48
Kaufman GS Well	0.28	0.62	-3.28	-3.54	-2.82
McKinney Well	0.12	-0.15	-2.26	-2.52	-2.75
Wagoner Well	.08	-.27	-2.31	-2.57	-2.61
BC at Blue Dome	1.05	1.89	-2.35	-2.61	-3.79
Wagoner Ranch Well	-0.04	-0.34	-2.24	-2.49	-2.35
Reno Ranch Well	0.03	-0.07	-2.17	-2.42	-2.31
USGS 126A	0.26	0.24	-2.28	-2.53	-2.98
USGS 126B	0.33	0.39	-2.29	-2.54	-3.09
P&W 2	0.18	0.04	-2.40	-2.65	-2.86

Table 11. Thermodynamically possible modeling solutions obtained with NETPATH, geochemical models 1-4.

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Abbreviations: MS no., modeling solution number; BC, Birch Creek; GS, Guardstation. Symbols: CO_2, carbon dioxide; -, indicates precipitation]

MS no.	SAMPLE SITE		MINERAL PHASES USED				
	Initial	Final	Calcite	CO_2 Gas	Dolomite	Gypsum	Labradorite
			[Geochemical model 1]				
1	McKinney	Wagoner Ranch	-0.17086	0.64578	0.16463	0.03126	0.00000
2	McKinney	Reno Ranch	-.41548	.70509	.32927	.08335	.22854
3	McKinney	USGS 126A	-.20448	-.15678	.00000	.03124	.05223
4	McKinney	USGS 126B	-.23239	-.17458	.00000	.03124	.05876
5	Wagoner	Reno Ranch	-.50952	.47272	.29634	.12604	.21613
6	USGS 126A	USGS 126B	-.02791	-.01780	.00000	.00000	.00653
			[Geochemical model 2]				
7	McKinney	Wagoner Ranch	-.17086	.64578	.16463	.03126	
8	McKinney	Reno Ranch	-.31264	.60225	.32927	.08335	
9	McKinney	USGS 126A	-.18098	-.18028	.00000	.03124	
10	McKinney	USGS 126B	-.20595	-.20102	.00000	.03124	
11	Wagoner	Wagoner Ranch	-.27048	.41899	.13170	.07395	
12	Wagoner	Reno Ranch	-.41226	.37546	.29634	.12604	
13	USGS 126A	USGS 126B	-.02497	-.02074	.00000	.00000	
			[Geochemical model 3]				
14	McKinney	Wagoner Ranch	-.13960	.61452	.16463		
15	McKinney	Reno Ranch	-.22929	.51890	.32927		
16	McKinney	USGS 126A	-.14974	-.21152	.00000		
17	McKinney	USGS 126B	-.17471	-.23226	.00000		
18	Wagoner	Wagoner Ranch	-.19653	.34504	.13170		
19	Wagoner	Reno Ranch	-.28622	.24942	.29634		
20	USGS 126A	USGS 126B	-.02497	-.02074	.00000		
			[Geochemical model 4]				
21	BC at Kaufman GS	Kaufman GS Well	-.22453	1.50682			
22	McKinney	USGS 126A	-.14974	-.21152			
23	McKinney	USGS 126B	-.17471	-.23226			
24	McKinney	P&W 2	-.12480	-.11118			
25	Wagoner	BC at Blue Dome	-.25211	-.50977			
26	Wagoner	Wagoner Ranch	-.06483	.47674			
27	Wagoner	USGS 126A	-.23960	-.51383			
28	Wagoner	USGS 126B	-.26457	-.53467			
29	Wagoner	P&W2	-.21466	-.41359			
30	Wagoner Ranch	Reno Ranch	.07495	.06902			
31	Reno Ranch	USGS 126A	-.24972	-1.05969			
32	Reno Ranch	USGS 126B	-.27469	-1.08043			
33	Reno Ranch	P&W 2	-.22478	-.95935			
34	USGS 126A	USGS 126B	-.02497	-.02074			

Table 12. Thermodynamically impossible modeling solutions obtained with NETPATH, geochemical models 1-4.

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Abbreviations: GS, Guardstation; BC, Birch Creek. Symbols: CO_2, carbon dioxide; -, indicates precipitation]

SAMPLE SITE		MINERAL PHASES USED				
Initial	Final	Calcite	CO_2 Gas	Dolomite	Gypsum	Labradorite
		[Geochemical model 1]				
Kaufman GS	BC at Kaufman GS	0.57646	-1.10971	-0.37452	0.19888	-0.39176
Kaufman GS	McKinney	.71581	-.80247	-.37039	.23013	-.39176
Kaufman GS	Wagoner Ranch	.54495	-.15669	-.20576	.26139	-.39176
Kaufman GS	Reno Ranch	.30033	-.09738	-.04112	.31348	-.16322
Kaufman GS	USGS 126A	.51133	-.95925	-.37039	.26137	-.33953
Kaufman GS	USGS 126B	.48342	-.97705	-.37039	.26137	-.33300
Kaufman GS	P&W 2	.67248	-.91282	-.41154	.17806	-.36565
BC at Kaufman GS	Wagoner Ranch	-.03151	.95302	.16876	.06251	.00000
BC at Kaufman GS	McKinney	.13935	.30724	.00413	.03125	.00000
BC at Kaufman GS	Reno Ranch	-.27613	1.01233	.33340	.11460	.22854
BC at Kaufman GS	P&W 2	.09602	.19689	-.03702	-.02082	.02611
McKinney	P&W 2	-.04333	-.11035	-.04115	-.05207	.02611
Wagoner Ranch	USGS 126A	-.03362	-.80256	-.16463	-.00002	.05223
Wagoner Ranch	USGS 126B	-.06153	-.82036	-.16463	-.00002	.05875
Wagoner Ranch	P&W 2	.12753	-.75613	-.20578	-.08333	.02611
USGS 126A	P&W 2	.16115	.04643	-.04115	-.08331	-.02612
USGS 126B	P&W 2	.18906	.06423	-.04115	-.08331	-.03264
Reno Ranch	USGS 126B	.18309	-.87967	-.32927	-.05211	-.16978
Reno Ranch	P&W 2	.37215	-.81544	-.37042	-.13542	-.20243
		[Geochemical model 2]				
Kaufman GS	McKinney	.53952	-.62618	-.37039	.23013	
Kaufman GS	Wagoner Ranch	.36866	.01960	-.20576	.26139	
Kaufman GS	Reno Ranch	.22688	-.02393	-.04112	.31348	
Kaufman GS	USGS 126A	.35854	-.80646	-.37039	.26137	
Kaufman GS	USGS 126B	.33357	-.82720	-.37039	.26137	
Kaufman GS	P&W 2	.50794	-.74828	-.41154	.17806	
Kaufman GS	McKinney	.13935	.30724	.00413	.03125	
BC at Kaufman GS	USGS 126A	-.04163	.12696	.00413	.06249	

Table 12. Thermodynamically impossible modeling solutions obtained with NETPATH, geochemical models 1-4.—Continued

SAMPLE SITE		MINERAL PHASES USED			
Initial	Final	Calcite	CO_2 Gas	Dolomite	Gypsum
		[Geochemical model 2--continued]			
BC at Kaufman GS	USGS 126B	-.06660	.10622	.00413	.06249
BC at Kaufman GS	Wagoner Ranch	-.03151	.95302	.16876	.06251
BC at Kaufman GS	Reno Ranch	-.17329	.90949	.33340	.11460
BC at Kaufman GS	P&W 2	0.10777	0.18514	-0.03702	-0.02082
McKinney	P&W 2	-.03158	-.12210	-.04115	-.05207
Wagoner Ranch	USGS 126A	-.01012	-.82606	-.16463	-.00002
Wagoner Ranch	USGS 126B	-.03509	-.84680	-.16463	-.00002
Wagoner Ranch	P&W 2	.13928	-.76788	-.20578	-.08333
Reno Ranch	USGS 126A	.13166	-.78253	-.32927	-.05211
Reno Ranch	USGS 126B	.10669	-.80327	-.32927	-.05211
Reno Ranch	P&W 2	.28106	-.72435	-.37042	-.13542
USGS 126A	P&W 2	.14940	.05818	-.04115	-.08331
USGS 126B	P&W 2	.17437	.07892	-.04115	-.08331
		[Geochemical model 3]			
Kaufman GS	BC at Kaufman GS	.59905	-1.13230	-.37452	
Kaufman GS	McKinney	.76965	-.85631	-.37039	
Kaufman GS	Wagoner Ranch	.63005	-.24179	-.20576	
Kaufman GS	Reno Ranch	.54036	-.33741	-.04112	
Kaufman GS	USGS 126A	.61991	-1.06783	-.37039	
Kaufman GS	USGS 126B	.59494	-1.08857	-.37039	
Kaufman GS	P&W 2	.68600	-.92634	-.41154	
BC at Kaufman GS	McKinney	.17060	.27599	.00413	
BC at Kaufman GS	Reno Ranch	-.05869	.79489	.33340	
BC at Kaufman GS	USGS 126A	.02086	.06447	.00413	
BC at Kaufman GS	USGS 126B	-.00411	.04373	.00413	
BC at Kaufman GS	P&W 2	.08695	.20596	-.03702	
McKinney	P&W 2	-.08365	-.07003	-.04115	
Wagoner Ranch	USGS 126A	-.01014	-.82604	-.16463	
Wagoner Ranch	USGS 126B	-.03511	-.84678	-.16463	
Wagoner Ranch	P&W 2	.05595	-.68455	-.20578	
Reno Ranch	USGS 126A	.07955	-.73042	-.32927	
Reno Ranch	USGS 126B	.05458	-.75116	-.32927	
Reno Ranch	P&W 2	.14564	-.58893	-.37042	
USGS 126A	P&W 2	.06609	.14149	-.04115	
USGS 126B	P&W 2	.09106	.16223	-.04115	
		[Geochemical model 4]			
Kaufman GS	BC at Kaufman GS	.22453	-1.50682		
Kaufman GS	McKinney	.39926	-1.22670		
Kaufman GS	Wagoner Ranch	.42429	-.44755		
Kaufman GS	Reno Ranch	.49924	-.37853		
Kaufman GS	USGS 126A	.24952	-1.43822		
Kaufman GS	USGS 126B	.22455	-1.45896		
Kaufman GS	P&W 2	.27446	-1.33788		
BC at Kaufman GS	McKinney	.17473	.28012		

Table 12. Thermodynamically impossible modeling solutions obtained with NETPATH, geochemical models 1-4.—Continued

SAMPLE SITE		MINERAL PHASES USED	
Initial	Final	Calcite	CO_2 Gas
[Geochemical model 4—Continued]			
BC at Kaufman GS	Wagoner Ranch	.19976	1.05927
BC at Kaufman GS	Reno Ranch	.27471	1.12829
BC at Kaufman GS	USGS 126A	.02499	.06860
BC at Kaufman GS	P&W 2	.04993	.16894
McKinney	Wagoner Ranch	.02503	.77915
McKinney	Reno Ranch	.09998	.84817
Wagoner Ranch	USGS 126A	-.17477	-.99067
Wagoner Ranch	USGS 126B	-.19974	-1.01141
Wagoner Ranch	P&W 2	-.14983	-.89033
Reno Ranch	USGS 126A	-.24972	-1.05969
Reno Ranch	USGS 126B	-.27469	-1.08093
Reno Ranch	P&W 2	-.22478	-.95935
USGS 126A	P&W 2	.02494	.10034
USGS 126B	P&W 2	.04991	.12108

Table 13. Thermodynamically possible modeling solutions obtained with NETPATH for water moving from Birch Creek at Kaufman Guardstation to the Kaufman Guardstation well, geochemical model 5.

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Symbols: CO_2, carbon dioxide; -, indicates precipitation]

Calcite	CO_2Gas	Potassium feldspar	Kaolinite	Illite	Diopside	Forsterite	Cation exchange
-0.61883	1.90112	0.14379	-0.16479	0.00000	0.44860	0.00000	0.12838
-.55892	1.84121	.00000	-.30858	.23965	.38869	.00000	.12838
-.17023	1.45252	.00000	-.01706	.23965	.00000	.19434	.12838

Table 14. Thermodynamically possible modeling solutions obtained with NETPATH for water moving from the McKinney well to USGS 126B, geochemical model 6.

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Symbols: CO_2, carbon dioxide; -, indicates precipitation]

Calcite	CO_2Gas	Potassium feldspar	Kaolinite	Illite	Diopside	Forsterite	Labradorite	Cation exchange
-0.30286	-0.10411	0.03837	-0.34574	0.00000	0.00000	0.00000	0.28478	0.00000
-.21193	-.19504	.00000	-.21207	.06395	.00000	.00000	.13731	.04506
-.15814	-.24883	.03837	-.01351	.00000	.03087	.00000	.00000	.07832
-.14215	-.26482	.00000	-.05188	.06395	.01489	.00000	.00000	.07832
-.12727	-.27970	.00000	-.04072	.06395	.00000	.00744	.00000	.07832

Table 15. Thermodynamically possible modeling solution obtained with NETPATH for water moving from the Wagoner well to USGS 126B, geochemical model 7.

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Symbols: CO_2, carbon dioxide; -, indicates precipitation]

Calcite	CO_2Gas	Potassium feldspar	Kaolinite	Labradorite	Cation exchange
-0.21611	-0.58313	0.03581	-0.00068	0.00475	0.08353

Table 16. Thermodynamically possible modeling solutions obtained with NETPATH for water moving from Birch Creek at Blue Dome to the Reno Ranch well, geochemical model 8.

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Symbols: CO_2, carbon dioxide; -, indicates precipitation]

Calcite	CO_2Gas	Potassium feldspar	Kaolinite	Illite	Diopside	Forsterite	Labradorite	Sodium montmorillonite	Cation exchange
0.00000	1.31776	0.07165	-0.46475	0.00000	0.00000	0.17287	0.58273	-0.08762	0.00000
.00000	1.31776	.00000	-.55879	.11942	.00000	.15794	.58273	-.08762	.00000
.00000	1.31776	.07165	-.15676	.00000	.34442	.03246	.00000	.00000	.14580
-.06492	1.38268	.07165	-.20545	.00000	.40934	.00000	.00000	.00000	.14580
.00000	1.31776	.00000	-.25080	.11942	.34442	.01753	.00000	.00000	.14580
-.03507	1.35283	.00000	-.27710	.11942	.37949	.00000	.00000	.00000	.14580

Table 17. Thermodynamically possible modeling solutions obtained with NETPATH for water moving from Birch Creek at Blue Dome (Reno Ditch) to USGS 126B, geochemical model 9.

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Symbols: CO_2, carbon dioxide; -, indicates precipitation]

Calcite	CO_2Gas	Potassium feldspar	Kaolinite	Illite	Diopside	Forsterite	Labradorite	Cation exchange
-0.16065	0.12329	0.04349	-0.36001	0.00000	0.01647	0.00000	0.29271	0.00000
-.14418	.10682	.04349	-.34766	.00000	.00000	.00824	.29271	.00000
-.14418	.10682	.00396	-.39954	.06588	.00000	.00000	.29271	.00000
-.13479	.09743	.00000	-.38574	.07248	.00000	.00000	.27748	.00419