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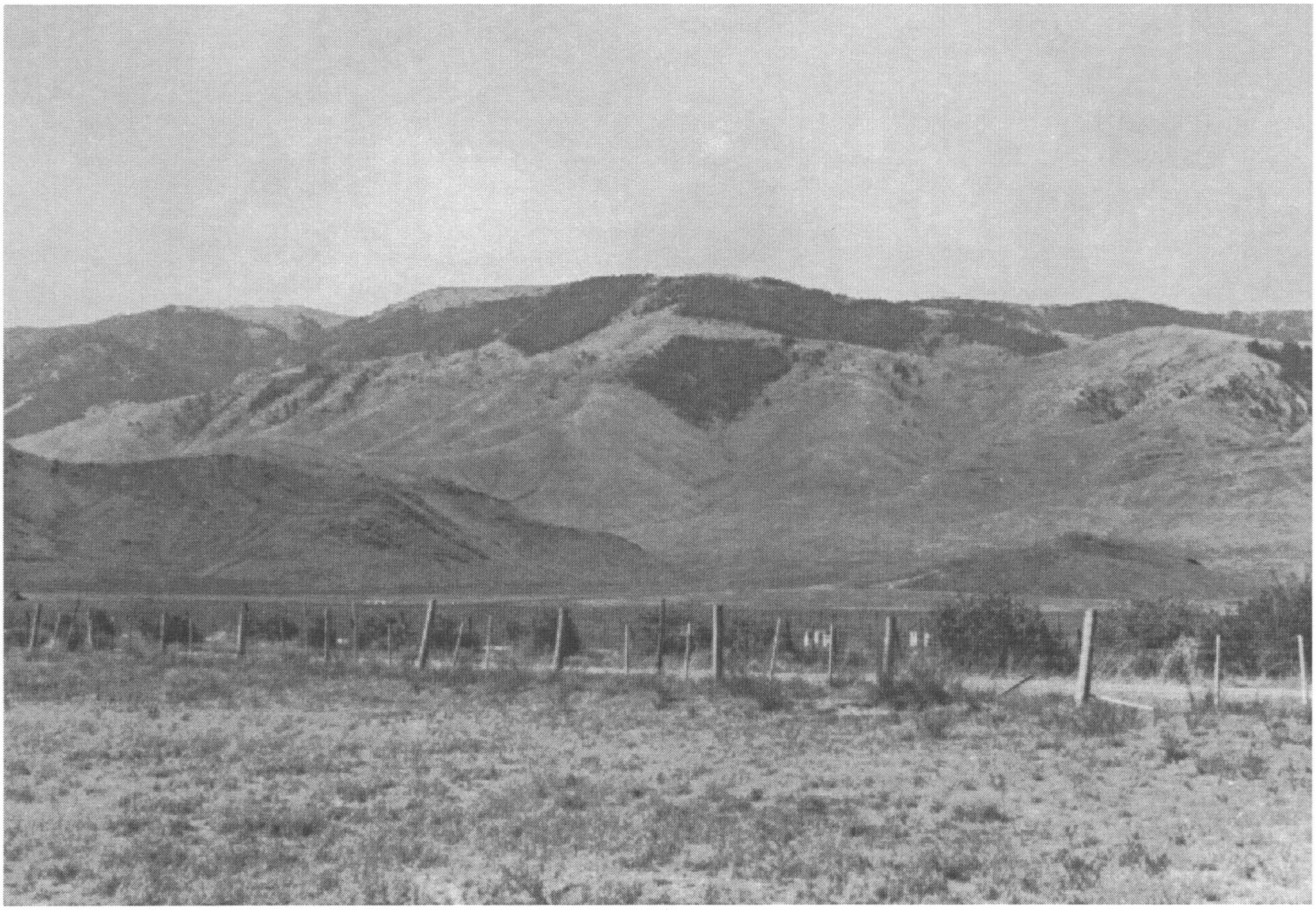
GEOCHEMISTRY OF THE LITTLE LOST RIVER DRAINAGE BASIN, IDAHO

U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS REPORT 02-4120



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Cover: Lost River Range looking west from the Little Lost River north of Howe, Idaho.

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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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Water-Resources Investigation Report 02–4120

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Idaho Falls, Idaho
May 2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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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
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second per mile ((ft^3/s)/mi)	0.01760	cubic meter per second per kilometer
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: µg/L (microgram per liter), mg/L (milligram per liter), mmol/kg (millimoles per kilogram water), moles/kg (moles per kilogram water), ppm (parts per million), ppb (parts per billion), mL (milliliter), µS/cm (microsiemens per centimeter at 25°C).

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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 Snake River Plain aquifer (SRPA) system at and near the Idaho National Engineering and Environmental Laboratory (INEEL) and the effects of these recharge waters on the geochemistry of the SRPA system. Each of these recharge waters has a hydrochemical character related to geochemical processes, especially water-rock interactions, that occur during migration to the SRPA. Results of these studies will benefit ongoing and planned geochemical modeling of the SRPA at the INEEL by providing model input on the hydrochemical character of water from each drainage basin.

For this study, water samples were collected from six wells and two surface-water sites from the Little Lost River drainage basin during 2000 and analyzed for selected inorganic constituents, dissolved organic carbon, stable isotopes, tritium, and selected gross measurements of radioactivity. Four duplicate samples were collected for quality assurance. Results showed that most water from the Little Lost River drainage basin has a calcium-magnesium bicarbonate character. Water in two wells contained elevated chloride concentrations relative to water from the other sites. The computer code NETPATH was used to evaluate geochemical mass-balance reactions in the Little Lost River basin. Attempts to model water from the Little Lost River valley sites to that in the most downgradient wells, Mays and Ruby Farms, were unsuccessful. On closer inspection of these two wells, it was determined that they are much deeper than the other sample locations and the water could reflect the chemistry of the SRPA. Apparently another of the sample locations was contaminated as a result of local agricultural practices. Water in one well contained concentrations that mirrored Little Lost River water. Of all the sites sampled, only two upgradient wells contained water representative of the system. Mass-balance modeling of the system indicated that dissolution of dolomite is the major reaction taking place in the system. Nitrification of ammonium ion to nitrate and dissolution of inorganic fertilizers are chemical processes that also occur in the system. To better understand the geochemistry of the Little Lost River drainage basin, more samples that better represent the natural geochemistry of the basin need to be collected and evaluated.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (DOE), has developed an extensive borehole network for the collection of geohydrologic, hydraulic, geochemical, and radiochemical data to address concerns about contamination of the Snake River Plain aquifer (SRPA) at the Idaho National Engineering and Environmental Laboratory (INEEL) (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 that control their concentration and migration rates, including advection, dispersion, adsorption, dilution, radioactive decay, and chemical 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 solutes in and through the unsaturated zone and the aquifer. Laboratory and field studies are being conducted to include these

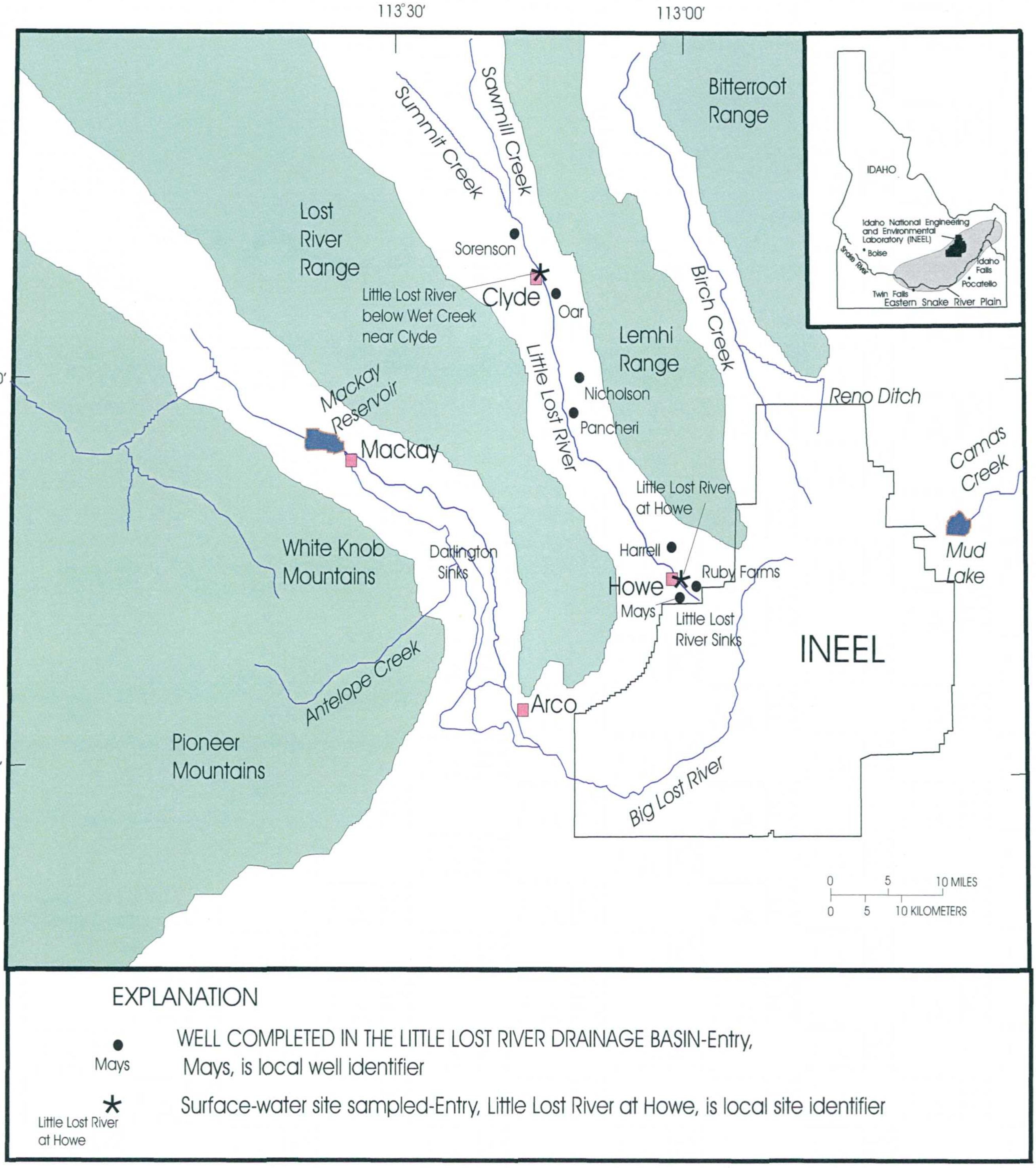

Figure 1. Location of wells and surface-water sites, Little Lost River drainage basin, Idaho.

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. One of these studies is a cooperative effort with Idaho State University (ISU) to evaluate the geochemical characteristics of drainage basins that recharge the SRPA at and near the INEEL.

The Little Lost River drainage basin (fig. 1) contributes recharge as underflow to the SRPA system. The ground water in the Little Lost River drainage basin acquires a unique geochemical character related to the water-rock interactions that occur during migration of the ground water to the SRPA. Ground water from this basin mixes with and changes the chemical character of the SRPA water. This study provides information on the Little Lost River valley. Results from this study and from studies of other SRPA tributary valleys will improve the understanding of the geochemistry of these tributary valleys. Results will directly benefit ongoing and planned geochemical modeling of the SRPA system. In addition, this study provides significant information for use in numerical simulations of ground-water flow, solute transport, and heat-flow transport.

Purpose and Scope

The purpose of this report is to better define the geochemical character of water in the Little Lost River drainage basin to improve understanding of the geochemistry of the SRPA at and near the INEEL. During 2000, water samples were collected from six wells and two surface-water sites for analyses of selected inorganic constituents, dissolved organic carbon (DOC), tritium, and selected gross measurements of radioactive isotopes. Samples were analyzed for trace elements and selected ions at the ISU Department of Chemistry under the direction of Dr. Jeffery J. Rosentreter. Four duplicate samples were analyzed by the USGS National Water Quality Laboratory (NWQL) as a measure of quality assurance. Samples also were analyzed for anions, nutrients, DOC, tritium, gross alpha- and beta-particle radioactivity, and stable isotopes by the NWQL. Water-chemistry data from an additional well (Ruby Farms) was taken from another study (Knobel and others, 1999).

The water-chemistry data were used to describe the ion distribution and hydrochemical facies of the Little Lost River aquifer system. The thermodynamic condition of the ground water was determined by using the computer code NETPATH (Plummer and others 1994). Solid-phase mineralogy data were compiled to help formulate a set of plausible chemical reactions for hypothesis testing. The set of plausible chemical reactions constitute a geochemical model that was tested by using the mass-balance approach contained in NETPATH. The specific techniques of geochemical analysis and modeling used in this study are similar to those used by Knobel and others (1997) and Carkeet and others (2001).

Geohydrologic Conditions

Geohydrologic factors affect the amount and chemical content of water that flows over the surface, becomes soil moisture, or moves underground in the Little Lost River drainage basin. Alluvium and colluvium in the valley areas accept recharge. The basin is underlain mostly by limestones that absorb and transmit large amounts of water (Essig and others, 1998).

Generalized Geology

The many geologic features of the drainage basin were first described by Stearns and others (1938) and later by Mundorff and others (1963) and Essig and others (1998). According to Mundorff and others (1963), the Little Lost River basin was formed by block faulting. The valley was then filled with alluvial deposits composed of limestone, sandstone, shale, and volcanic fragments. The mountainous areas that surround the basin are composed of consolidated strata consisting of limestones, quartzites, and shales that have been folded and faulted. In the upper parts of the basin, there are some Tertiary volcanic intrusions from the Challis Volcanic Formation. These are mostly andesitic or silicic rocks. The altitude of the Little Lost River ranges from 6,600 ft above sea level at

Summit Creek to 4,800 ft at the Little Lost River Sinks (fig. 1). The valley floor is made up of alluvial fans that spread halfway across the valley in some parts. The soil is mostly a gravelly loam texture. The Little Lost River flows on top of alluvium and terminates at the Little Lost River Sinks, where it infiltrates permeable basalt flows of the Eastern Snake River Plain.

Surface Water

The Little Lost River begins at the junction of Sawmill and Summit Creeks about 4 mi northwest of Clyde (fig. 1). The basin is about 50 mi long and 20 mi wide and comprises 963 mi^2 of drainage (Essig and others, 1998).

The Little Lost River receives most of its recharge from periodic precipitation (Mundorff and others, 1963). The area averages about 10 in. of precipitation a year. In general, the tributaries infiltrate into the alluvium before reaching the river and, thus, do not contribute much to the flow of the river. The tributaries contribute to the river only during periods of high flow, such as spring runoff. The average runoff during a 41-year period (1958–99) was 49,820 acre-ft/year at the Little Lost River below Wet Creek near Clyde (Brennan and others, 2000).

Ground Water

The Little Lost River aquifer system is recharged primarily by infiltration of precipitation runoff from surrounding mountains and foothills adjacent to the valley lowlands. Additional recharge occurs as (1) seepage losses from streams, irrigation canals, and drainage ditches; (2) infiltration of irrigation water; (3) interaquifer flow; and (4) leakage from septic tanks and drain wells.

Ground-water/surface-water relations in the valley lowlands are complex. In several areas, the water table is above the stream level and springs augment the surface discharge. For example, Mundorff and others (1963) reported that the valley bottom for 2 to 3 mi below the confluence of Summit and Sawmill Creeks is very swampy, and many springs and seeps discharge into the river, which indicates that the water table is at or near the surface. For the next 7 or 8 mi downstream, the depth of the water table ranges from a few feet to about 15 to 20 ft below the land surface. Near Howe, the water table is about 200 ft below the surface.

Acknowledgments

The authors are grateful to the well owners for granting permission to collect samples. The authors gratefully acknowledge the assistance and cooperation provided by Idaho State University. Special thanks go to Dr. Dennis P. Strommen, Department of Chemistry, for providing laboratory space. The authors are grateful to USGS hydrologists Deborah J. Parliman and Steven K. Sando for technical review of this report.

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 are documented in the ISU laboratory standard operating procedure and generally follow the procedures described in Fishman and Friedman (1989). The cations and trace elements 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 differ depending on the constituents for which analyses are requested. Samples analyzed by the NWQL were placed in containers and preserved according to laboratory requirements specified by Pritt and Jones (1989). Containers and preservatives, supplied by the NWQL, had undergone a rigorous quality control procedure (Pritt, 1989, p. 75) to minimize potential for sample contamination. Samples analyzed by the ISU were placed in NWQL-supplied containers according to the laboratory standard operating procedures. Table 1 lists the containers, preservatives, laboratories, and analyses performed.

Sampling Locations and Sample Collection

Water samples were collected from eight locations (figure 1 and table 2): four domestic wells (Mays, Harrell, Nicholson, and Oar wells); two irrigation wells (Pancheri and Sorenson wells); and two surface water sites (Little Lost River below Wet Creek near Clyde and Little Lost River at Howe). The domestic wells were equipped with dedicated submersible pumps. The irrigation wells were equipped with line-shaft turbine pumps. Chemical data for an additional domestic well (Ruby Farms) located in the study area of this report was taken from a previous study by Knobel and others (1999).

Samples were collected from spigots as close to the well pumps as possible to minimize contact with plumbing materials, and to avoid pressure tanks and treatment systems. Before sample collection, three field properties—pH, specific conductance, and water temperature—were monitored until stable readings, as defined by Mann (1996), were obtained. 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 the sum of 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 (QC) and 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 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). 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 duplicated samples were from the Sorenson, Nicholson, Harrell, and Mays wells.

A quality-assurance blank of inorganic-free water also was analyzed at ISU. In addition, 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 quality-assurance 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 duplicate 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 result:

$$Z = \frac{|x-y|}{\sqrt{((s_x)^2 + (s_y)^2)}}, \qquad (1)$$

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 from three sample measurements for each constituent made on separate days.

Equation 1 was used to determine whether the analytical results for inorganic constituents in the duplicate samples analyzed by NWQL were statistically equivalent to those analyzed by ISU. The results for all seven of the constituents in water from the Sorenson, Nicholson, Harrell, and Mays wells were equivalent; Z-values for all pairs were less than 1.96.

RESULTS OF ANALYSES

Cations, Anions, and Silica

Water samples were analyzed for concentrations of dissolved cations (calcium, magnesium, sodium, and potassium) and dissolved silica by ISU (table 5) and anions (chloride, sulfate, and fluoride) by the NWQL (table 6). Results for the Ruby Farms well were included in the statistical calculations for constituents analyzed by ISU and the NWQL . Field alkalinities expressed as concentrations of bicarbonate also are provided in table 6. The ranges of concentrations, the median concentration, and the mean concentration for each constituent were 27 to 83, 40, and 46 mg/L for calcium; 10 to 45, 15, and 19 mg/L for magnesium; 2.8 to 28, 6.9, and 11 mg/L for sodium; 0.58 to 1.7, 1.1, and 1.2 mg/L for potassium; 9.2 to 23, 17, and 17 mg/L for silica; 2.2 to 143, 7.3, and 27 mg/L for chloride; 5 to 60.3, 15.0, and 22 mg/L for sulfate; 131 to 259, 178, and 186 mg/L for bicarbonate; and <0.1 to 0.16, 0.12, and 0.13 mg/L for fluoride.

Selected Trace Elements

Selected water samples were collected and analyzed for concentrations of dissolved barium, bromide, chromium, iron, lithium, manganese, strontium, and zinc (table 7).

Barium.—Concentrations in nine samples (including Ruby Farms) ranged from 37 to 137 µg/L.

Bromide.—Concentrations in the six samples analyzed by the NWQL ranged from less than 0.01 to 0.1 µg/L.

Chromium.—Concentrations in two samples, Ruby Farms and Mays, were 8 and 49 µg/L, respectively.

Iron.—Concentrations in the five samples (including Ruby Farms) analyzed by NWQL ranged from less than 10 to 14 µg/L. Concentrations in all samples analyzed by ISU were less than 20 µg/L.

Lithium.—Concentrations in two samples, Ruby Farms and Mays, were 5 and 6 µg/L, respectively.

Manganese.—Concentrations in the five samples analyzed by NWQL ranged from less than 1 to 5 µg/L.

Strontium.—Concentrations in nine samples (including Ruby Farms) ranged from 92 to 363 µg/L.

Zinc.—Concentrations in two samples, Ruby Farms and Mays, were 64 and 36 µg/L, respectively.

Nutrients

Concentrations of ammonia as nitrogen, nitrite as nitrogen, nitrite plus nitrate as nitrogen, and orthophosphate as phosphorous in the nine water samples were determined by the NWQL (table 8). Concentrations of ammonia as nitrogen were all less than 0.02 mg/L except for Ruby Farms, which was less than 0.01 mg/L. Concentrations of nitrite as nitrogen were all less than 0.01 mg/L. Concentrations of nitrite plus nitrate as nitrogen ranged from less than 0.05 to 4.2 mg/L. Concentrations of orthophosphate as phosphorous ranged from less than 0.01 to 0.017 mg/L.

Dissolved Organic Carbon

Concentrations of DOC in eight samples were determined by the NWQL (table 8). Concentrations ranged from 0.18 to 1.66 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. Nine water samples were collected and analyzed for tritium by the NWQL (table 9) and the concentrations ranged from 0±25.6 pCi/L to 57.6±25.6 pCi/L.

Gross Alpha- and Gross Beta-Particle Radioactivity

Concentrations of gross alpha- and gross beta-particle radioactivity in nine samples 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 0.34±1.02 pCi/L to 2.7±0.86 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 0.68±1.55pCi/L to 3.09±2.50 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 delta $(\delta)^2$H in nine samples ranged from -141.2 to -133.7 permil. Relative isotopic ratios reported as δ^{18}O in nine samples ranged from -18.35 to -17.59 permil. Relative isotopic ratios reported as δ^{13}C in nine samples ranged from -10.21 to -6.17 permil.

GEOCHEMISTRY

Solid-Phase Description

A summary of the bulk mineralogy for sediment from five samples of channel deposits and two overbank deposits was presented by Bartholomay and Knobel (1989). Mean mineral abundances in the samples were 32 percent quartz, 29 percent total feldspar, 16 percent calcite, 10 percent dolomite, 10 percent clay minerals, and 3 percent pyroxene. Of the 10 percent clay minerals present, illite was dominant, but smectite and kaolinite also were present. Although neither anhydrite nor its hydrated analog, gypsum, was found in the channel deposits, Wood and Low (1988, p. D10) noted that anhydrite is present in eolian dust throughout the Snake River Plain. Potential sources of anhydrite are the sedimentary rocks in the Little Lost River basin (Robertson and others, 1974, p. 50–51).

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 and silica in water from the Little Lost River drainage basin (fig. 2) shows that concentrations both increase and decrease 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

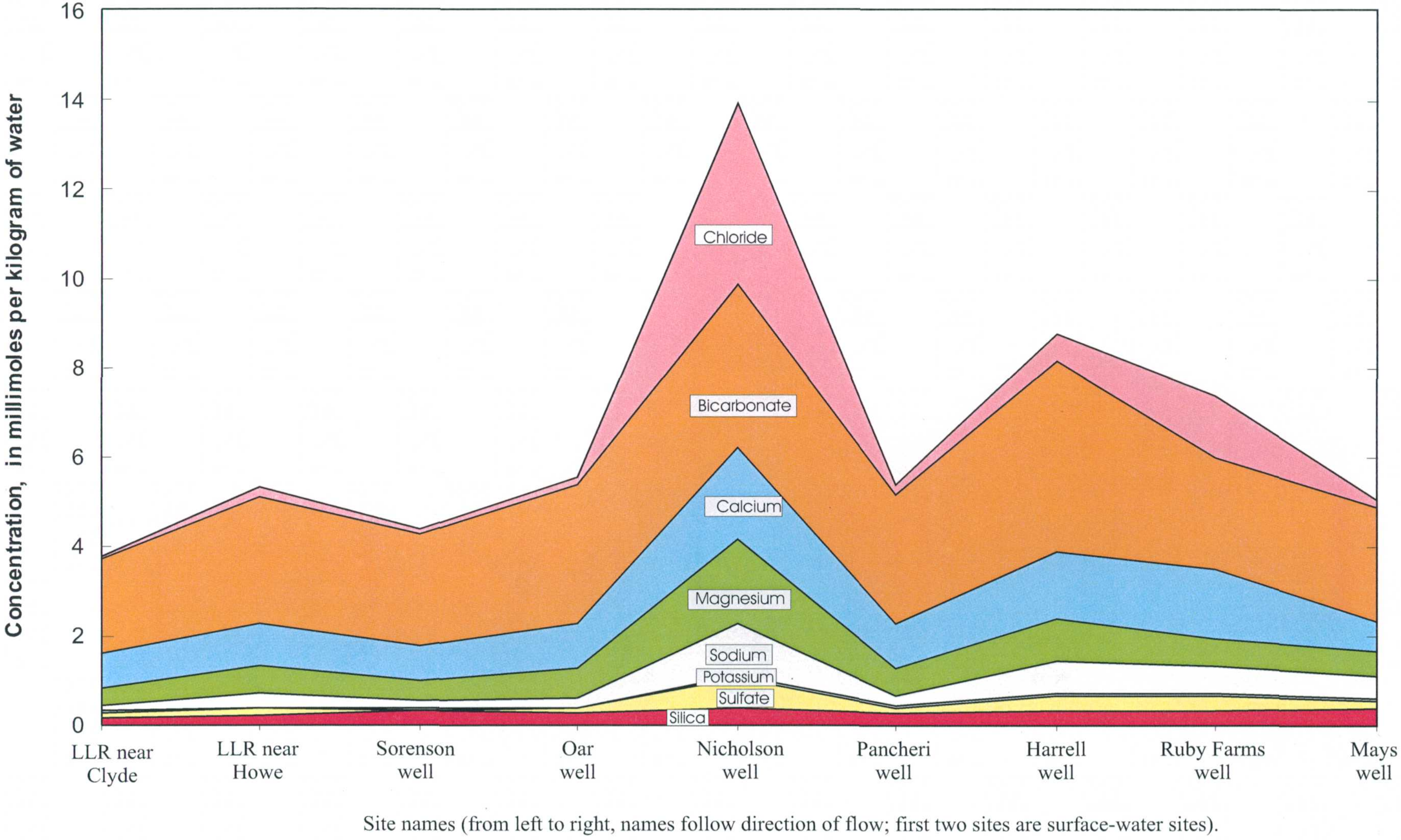

Figure 2. Concentrations of selected ions and silica in water from selected wells and surface-water sites, Little Lost River drainage basin, Idaho. [LLR, Little Lost River]

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. Figure 3 indicates that the water from wells in the Little Lost River drainage basin generally are calcium-magnesium bicarbonate in character. Concentrations of chloride in water from two wells, Nicholson and Ruby Farms, were large compared with concentrations in water from other wells (fig. 3).

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 a 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 -0.100 to 0.100 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. SIs of the six well-water and two surface-water samples were determined by using the computer program WATEQF (Plummer and others, 1978). In addition, the SIs of one previously published Little Lost River well-water sample (Knobel and others, 1999) were used in the modeling. Table 10 gives the SIs of the samples with respect to selected minerals believed to be active in the system. With respect to calcite, water samples from Sorenson, Oar, Nicholson, Pancheri, Harrell, and Mays wells were at equilibrium; samples from Little Lost River near Clyde, Little Lost River near Howe, and the Ruby Farms well were supersaturated. With respect to dolomite, water samples from Sorenson, Oar, Pancheri, Harrell, and Mays wells were undersaturated; samples from Little Lost River near Clyde, Little Lost River near Howe, and Ruby Farms well were supersaturated; the sample from Nicholson well was at saturation. With respect to gypsum and anhydrite, samples from all wells and surface-water sites were undersaturated.

Plausible Chemical Reactions

Plausible chemical reactions are defined in this report as those likely to take place naturally in the Little Lost River 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 caused by interactions between water, calcite, and dolomite. The large chloride concentrations in some of the wells could be explained by the interaction of water with halite.

Dissolution or precipitation of calcite

Calcite is widely distributed in the Little Lost River drainage basin from carbonate rocks along the valley. The SIs (table 10) indicate that the water samples were all at equilibrium or were supersaturated with respect to calcite. This indicates that precipitation of calcite is thermodynamically possible in this system. The chemical reaction model for calcite is

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

where,

$CaCO_3$ = calcite,

CO_2 = carbon dioxide,

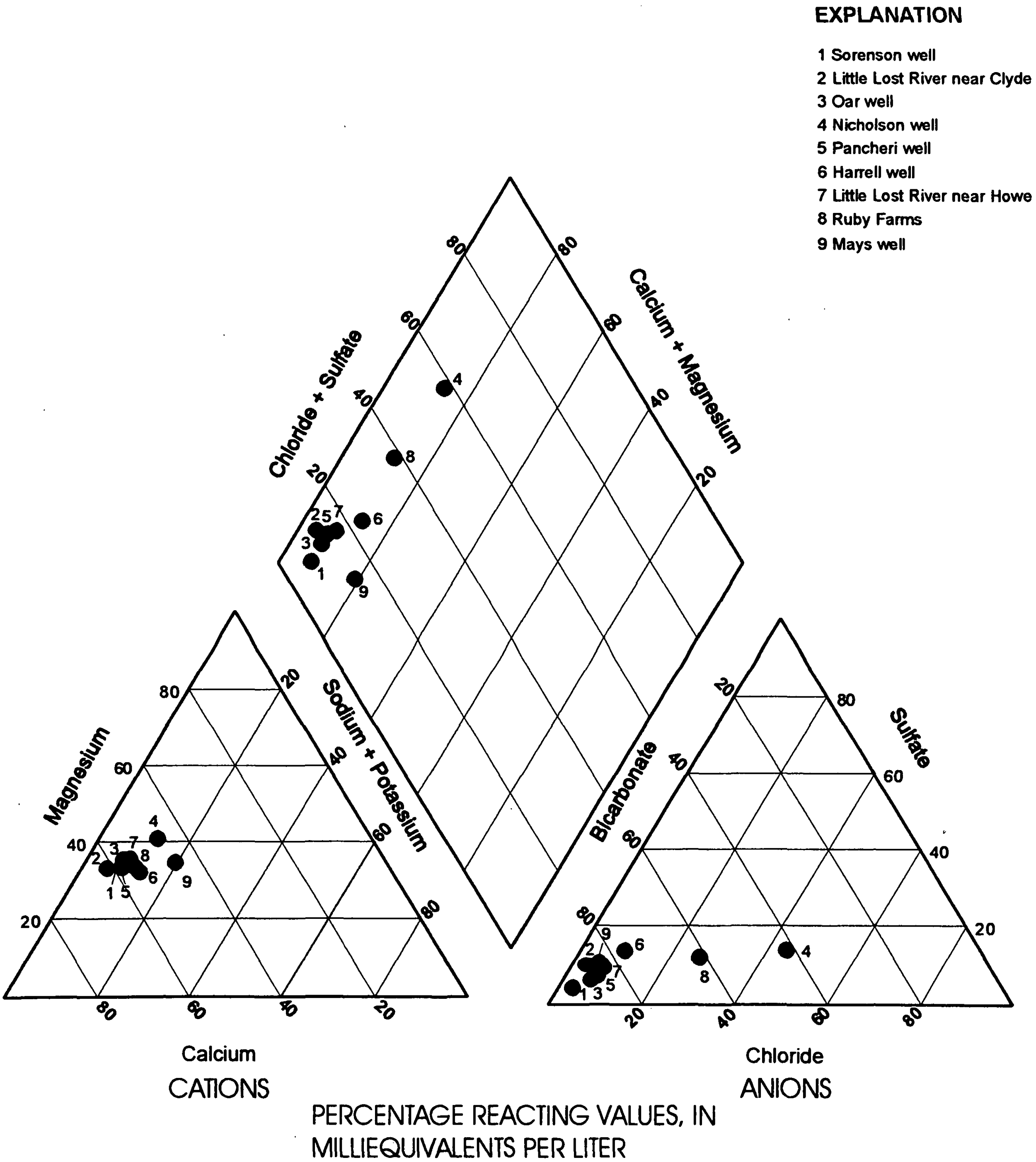

Figure 3. Major-ion composition of water from wells and surface-water sites, Little Lost River drainage basin, Idaho.

H_2O = water,
Ca^{2+} = dissolved calcium, and
HCO_3^- = dissolved bicarbonate.

Dissolution or precipitation of dolomite

Dolomite also is widely distributed in the Little Lost River drainage basin from carbonate rocks along the valley. The SIs (table 10) indicate that water samples varied from undersaturated to supersaturated. This indicates that either precipitation or dissolution of dolomite is thermodynamically possible. The chemical reaction model for dolomite is

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

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.

Dissolution of halite

Metal-salt compounds are present in the Little Lost River drainage basin as a result of agricultural and municipal practices and deposition in the unsaturated zone during evapotranspiration. Because the exact compositions of the salt compounds are unknown, halite was used as a surrogate phase for this study. Because thermodynamic data for halite are not included in the NETPATH speciation program, SIs were not calculated for this phase. To evaluate SI data for halite, a geochemical modeling code called PHREEQE (Parkhurst and others, 1980) was used. The PHREEQE code was modified to include thermodynamic data for halite, and then halite dissolution was modeled to saturation. Halite saturation in seawater occurred at a molality of 6.5 moles/kg for Na^+ and 6.6 moles/kg for Cl^-. For comparison purposes, the most concentrated water from the Little Lost River basin samples was from the Nicholson well, which contained molalities of .0013 moles/kg for Na^+ and .0040 moles/kg for Cl^-. These molalities are less than 0.1 percent of halite saturation and suggest that all Little Lost River basin samples are greatly undersaturated with respect to halite. This implies that dissolution of halite is thermodynamically possible in this system. The chemical reaction model for halite is

$$NaCl \rightarrow Na^+ + Cl^-, \quad (5)$$

where,
$NaCl$ = halite,
Na^+ = dissolved sodium, and
Cl^- = dissolved chloride.

Dissolution of Gypsum

As previously stated, anhydrite is present in eolian dust throughout the Snake River Plain (Wood and Low, 1988, p. D10). Sedimentary rocks in the Little Lost River drainage basin could be the source of anhydrite as stated by Robertson and others (1974, p. 50–51). Anhydrite is not considered as a phase in NETPATH. Gypsum can be used in place of anhydrite because it is the hydrated analog. The chemical reaction model for gypsum is

$$CaSO_4 \cdot 2H_2O \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O \quad (6)$$

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

Geochemical Modeling

The computer code NETPATH (Plummer and others, 1994) was used to model the net geochemical mass-balance reactions in the Little Lost River drainage basin. Selected model results are given in tables 11 and 12.

Many model combinations were run to try to evaluate the geochemistry of the Little Lost River drainage basin; however, many of the models yielded either no results or thermodynamically impossible results. In order to understand the geochemical relations between the wells in the basin, it is important to keep in mind the location, depth, and depth to water for each well. Table 2 gives the well type, depth of well, and depth to water. Three of the wells (Pancheri, Oar, and Sorenson) tap water at shallow depths of about 25 to almost 40 ft below land surface. The Sorenson well is an irrigation well in a swampy area near the confluence of Sawmill and Summit Creeks. The Oar well is a domestic well located near a feedlot on an alluvial bench near the Little Lost River. The Pancheri well is an irrigation well near the Little Lost River in the valley flat.

The Nicholson and Harrell wells are domestic wells that tap water at deeper depths than Pancheri, Oar, and Sorenson (table 2). The Nicholson well is located near a feedlot and irrigated fields and the Harrell well is located by irrigated fields in the valley flat.

The Ruby Farms well and Mays well are domestic wells at the base of the valley. Both wells are much deeper than the other wells sampled for this study, and the depth to water is much greater (table 2). Because of the depth to water in these two wells, they could be part of the down-faulted SRPA system, and thus are not entirely representative of the Little Lost River basin aquifer system.

An evaluation of the water-chemistry data for all the wells sampled showed a large range of values for the major ions (fig. 2). Water in three of the wells (Nicholson, Harrell, and Ruby farms) contained much larger concentrations of the major ions than water in the other wells sampled for this study. Water in the Nicholson well contained concentrations of magnesium, sodium, chloride, and sulfate that are double to triple those in water from other wells in the system (tables 5 and 6). The nitrate concentration in the Nicholson well was also more than double that in the other wells. These larger concentrations probably indicate that the Nicholson well is contaminated by local agricultural practices. The stable-isotope data (table 9) also indicates significant enrichment in this well from evaporation in the local agricultural area. Although the Nicholson well was included in several model runs (tables 11 and 12), it will not be considered further in model discussion because of the suspected local contamination. The Ruby Farms well and Harrell well also contained larger concentrations of several ions, are located in areas of heavily irrigated land, and are probably also slightly contaminated by agricultural practices. Sodium and chloride were added as constraints to attempt to account for irrigation-return flow when modeling these waters.

Evaluation of the major ion chemistry of water in the wells not significantly affected by local agricultural practices indicated that calcium, magnesium, and carbon are the major constraints, and calcite, dolomite, and carbon dioxide (CO_2) gas are the major phases in the system. Sulfur also was considered a constraint in some models because of elevated concentrations in some wells. Because anhydrite is not considered as a phase in NETPATH, the hydrated analog (gypsum) was used as a surrogate phase for modeling.

The changes in ground-water chemistry in the Little Lost River drainage basin between the Sorenson well and the Harrell well (fig. 1) can be explained by a series of chemical models. In some cases, more than one model can be used to explain the changes in observed water chemistry. Each model covers a discrete segment of distance in the general direction of ground-water flow. The concentrations of calcium, magnesium, and bicarbonate in water from the Sorenson well were small relative to those in water from the Oar and Harrell wells. The concentrations of these constituents increased progressively in water from these wells in the direction of ground-water flow. The concentrations of sodium, chloride and sulfate were larger in the Harrell well than in the other two wells. These increases are related partly to water-rock reactions and partly to contamination of ground water by local land uses.

Sorenson-Oar.—Between the Sorenson and Oar wells, the concentrations of calcium, magnesium, and bicarbonate increased from 31 to 40, 11 to 15, and 153 to 191 mg/L, respectively (tables 5, 6). Thermodynamic analysis indicated that water from these wells was nearly at equilibrium with respect to calcite and was undersaturated with respect to dolomite and gypsum (table 10). Dissolution of calcite and dolomite could explain these water-chemistry changes between the two wells. Also, SIs for water from these wells with respect to dolomite are consistent with dissolution. SIs for water in these wells with respect to calcite were so close to equilibrium that calcite dissolution cannot be determined conclusively; however, the SI of -0.02 for water in the Oar well (table 10) suggests that small amounts of calcite may dissolve. If so, then the changes in water chemistry between these wells can be accounted for by dissolving 0.060 mmol/kg calcite and 0.165 mmol/kg dolomite (sixth nonmixing model with calcite, table 11). If dissolution of gypsum is included as part of the model, the water-chemistry changes can be accounted for by dissolving 0.003 mmol/kg calcite, 0.165 mmol/kg dolomite, and 0.057 mmol/kg gypsum (first nonmixing model with calcite, table 11). An additional model (first nonmixing model with exchange, table 11) was found that could explain the water-chemistry. Removing calcite as an active phase and replacing it with exchange of sodium from solution (0.006 mmol/kg) for calcium from the solid phase (0.003 mmol/kg), coupled with dissolution of dolomite (0.165 mmol/kg) and gypsum (0.057 mmol/kg) can explain the changes in water chemistry between these two wells. Any of these three models can explain the changes in water chemistry; however, all three models suggest that dissolution of dolomite is the dominant process in this system because the waters are near equilibrium with respect to calcite. Because of the paucity of gypsum in this system, the second and third models are slightly suspect; because the waters are near equilibrium with respect to calcite, the first model also is slightly suspect. The amount of mass that has to be transferred as a result of calcite or gypsum dissolution is so small that it easily could be accounted for by analytical uncertainties in the measurement of the dissolved species. Also, the exchange reaction in the third model proceeds in a reverse direction from that which normally occurs in dilute ground-water systems. This analysis points out the nonunique character of mass-balance modeling and emphasizes the need to have a good conceptual understanding of the geochemical system. With the information available, it is not possible to determine which of these similar models describes this system; however, all of the models indicate that dissolution of dolomite is the dominant geochemical process taking place between these two wells.

Oar-Harrell.—Between the Oar and Harrell wells, the concentrations of calcium, magnesium, sodium, bicarbonate, sulfate, chloride, and nitrite plus nitrate as nitrogen increased from 40 to 62, 15 to 22, 5.7 to 17, 191 to 259, 10.5 to 34.4, 6.2 to 21.6, and 0.47 to 1.9 mg/L, respectively (tables 5, 6, 8). Thermodynamic analysis indicated that water from these wells was at equilibrium or slightly undersaturated with respect to calcite and was undersaturated with respect to dolomite and gypsum (table 10). In addition, it is probable that the waters were undersaturated with respect to halite. A simple calcite-and-dolomite dissolution model can explain the increases in calcium, magnesium, and bicarbonate between these two wells. This model requires dissolving 0.261 mmol/kg calcite and 0.288 mmol/kg dolomite in the presence of carbon dioxide gas (fifth nonmixing model with calcite, table 11). Because the SIs of the waters were so close to equilibrium with respect to calcite (table 10) and because the model requires a significant amount of calcite dissolution, it is unlikely that this model completely describes the changes in concentrations of calcium, magnesium, and bicarbonate between these wells. The Harrell well is relatively shallow and is located on the valley flat in an irrigated area. Changes in the concentrations of sodium, sulfate, chloride, and nitrite plus nitrate as nitrogen likely are related to agricultural activities. These constituents typically increase in ground water as a result of the dissolution of organic and inorganic fertilizers in an oxidizing system (Donahue, 1961, p. 159–170, table 13; Knobel and others, 1998, p. L43). Because NETPATH does not contain phases directly related to fertilizer dissolution, halite and gypsum were used as surrogate phases for modeling additions of sodium, chloride, and sulfate to this system. Nitrogen added to the soil is in the form of organic and ammonium compounds. Ammonium usually is converted to nitrate, the stable oxidized form of dissolved nitrogen, in the soil zone by a two-step process known as nitrification (Knobel and others, 1998, p. L42–L43). Ammonium ion is oxidized by nitrifying bacteria to nitrite:

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+, \qquad (7)$$

where,

NH_4^+ = dissolved ammonium,
O_2 = dissolved oxygen,
NO_2^- = dissolved nitrite,
H_2O = water, and
H^+ = dissolved hydrogen.

Nitrite then is oxidized to nitrate:

$$NO_2^- + 0.5O_2 \rightarrow NO_3^-, \qquad (8)$$

where,
NO_2^- = dissolved nitrite,
O_2 = dissolved oxygen, and
NO_3^- = dissolved nitrate.

The nitrification process does not add dissolved cations to the ground water other than the dissolved hydrogen ion. Addition of dissolved hydrogen to ground water is consistent with the decrease in pH, from 7.8 to 7.4 (table 3), between these two wells. Nitrification of ammonium by soil bacteria can explain the change in nitrogen between the Oar and Harrell wells; however, to explain the increases in the other ions, changes must be made to the simple calcite-dolomite dissolution model discussed earlier. The addition of gypsum as a surrogate phase and sulfur as a constituent is consistent with fertilizer dissolution in this oxidizing system. This results in a model in which the magnitude of calcite dissolution is more thermodynamically reasonable (0.012 mmol/kg) because gypsum provides a significant portion of the increase in calcium concentration (0.249 mmol/kg) (third nonmixing model with calcite, table 11). If calcite is removed as a phase from the calcite-dolomite-gypsum model and exchange of sodium from solution for calcium on the solid phase is added as a replacement phase (tenth nonmixing model with exchange, table 11), the resulting model predicts changes in concentrations of calcium, magnesium, and sulfur between the two wells that are consistent with the data. As was the case with the Sorenson-Oar exchange model, this model requires that cation exchange would have to proceed in a reverse direction from that which normally occurs in dilute ground-water systems. If halite dissolution is added to this model as a surrogate phase for fertilizer dissolution, then the increases in calcium, magnesium, sulfur, chloride, and bicarbonate can be explained by the resulting model (second nonmixing model with halite, table 11). However, this model has the same problem as the previous model in that cation exchange proceeds in the wrong direction. In an attempt to resolve this difficulty with the cation exchange process, calcite was reintroduced as a phase in the previous model. The resulting model requires dissolution of 0.041 mmol/kg calcite, 0.288 mmol/kg dolomite, 0.249 mmol/kg gypsum, 0.435 mmol/kg halite, and exchange of 0.029 mmol/kg calcium from solution for 0.058 mmol of sodium from the solid-phase exchange sites (first nonmixing model with halite, table 11). This model accounts for the increases in concentrations of dissolved carbon, sulfur, calcium, magnesium, sodium, and chloride between the Oar and Harrell wells and nitrification accounts for the increase in nitrogen concentration. This model is the most likely of the Oar-Harrell models discussed here because it is most consistent with the thermodynamic state of the system. Of the natural water-rock reactions (calcite and dolomite dissolution), dissolution of dolomite is the dominant process. This is consistent with the Sorenson-Oar models, which all indicated that dissolution of dolomite was the dominant geochemical process.

Nicholson well.—This well is located in an agricultural area near a feedlot. Water from this well contained larger concentrations of all major constituents (except for bicarbonate in the Harrell well) than water from the other wells. The lower pH (7.6, table 3) is consistent with nitrification of ammonium ion to nitrate, and the larger nitrate concentration relative to that in other wells indicates that water chemistry at this well undoubtedly is affected by anthropogenic activity. The large sodium, chloride, and sulfate concentrations also suggest that dissolution of fertilizer is likely at this site. The processes occurring at this site are similar to the ones described by the models for the Oar and Harrell wells.

Pancheri well.—The water from this well could be derived by dissolving dolomite and gypsum in water from the Sorenson well while exchanging sodium from solution with calcium on the solid phase (seventh nonmixing model with exchange, table 11). This model has the same problem as the other exchange models which proceed in the wrong direction and suggests that this model is not an accurate representation of the genesis of the water in the Pancheri well. Examination of figure 2 indicates that water from the Pancheri well was nearly identical in composition to water from the Little Lost River at Howe. Because the Pancheri well is a shallow well situated close to the river, it is likely that this well is in direct contact with the river and that its chemistry reflects that of the river.

Ruby Farms-Mays wells.—These wells previously were discussed as not being representative of the Little Lost River aquifer system. They are much deeper than the other wells and their geochemistry likely is affected by the tectonics of the area as described by Morris and others (1965, table 10).

Generalizations.—Several difficulties were encountered in this study. In spite of carefully selecting sampling locations, the samples collected for this study (with the exception of those from the Sorenson and Oar wells) were not representative of the natural geochemistry of this system. Contamination by local agricultural practices effectively limited the use of several well samples for studying the natural geochemistry of the Little Lost River drainage basin. Water from the Pancheri well was not representative of the system because of its apparent direct connection with the Little Lost River. Because of water availability in the upper reaches, the wells are shallow and the water is affected by agricultural practices. At the valley terminus, the wells are much deeper and the water chemistry is not directly comparable to that in valley wells. With the information available, it is not possible to describe accurately the chemical composition of the Little Lost River drainage basin water recharging the Snake River Plain. Collection of chemistry data from additional sites that are more representative of this chemical system would help to enhance the findings of this study. It is important to note that to select wells that are truly representative of this system, detailed well-construction data are required and this could require construction of new wells. However, in spite of these problems, mass-balance modeling of the system identified dissolution of dolomite as the dominant naturally occurring process in this system. The models also indicated that nitrification of ammonium ion to nitrate and dissolution of inorganic fertilizers are important chemical processes at some locations. This information allows for the refinement of working hypotheses and the conceptual geochemical model of this system.

SUMMARY AND CONCLUSIONS

Water samples collected during 2000 from six wells and two surface-water sites in the Little Lost River drainage basin were analyzed for selected inorganic constituents, dissolved organic carbon, stable isotopes, tritium, and selected gross measurements of radioactivity. Four duplicate samples were collected and analyzed by the NWQL. The ranges of concentrations for dissolved cations, anions, and silica follow: calcium, 27 to 83 mg/L; magnesium, 10 to 45 mg/L; sodium, 2.8 to 28 mg/L; potassium, 0.58 to 1.7 mg/L; silica, 9.2 to 23 mg/L; chloride, 2.2 to 143 mg/L; sulfate, 5 to 60.3 mg/L; bicarbonate, 131 to 259 mg/L; and fluoride, <0.1 to 0.16 mg/L.

The ranges of concentration for barium and strontium were 37 to 137 µg/L and 92 to 363 µg/L, respectively. Concentrations of dissolved organic carbon ranged from 0.18 to 1.66 mg/L. Concentrations of nitrite plus nitrate ranged from less than 0.05 to 4.2 mg/L.

Tritium concentrations in the samples ranged from 0±25.6 pCi/L to 57.6±25.6 pCi/L. Concentrations of dissolved gross alpha-particle radioactivity reported as thorium-230 ranged from 0.34±1.02 pCi/L to 2.7±0.86 pCi/L. Concentrations of dissolved gross beta-particle radioactivity reported as cesium-137 ranged from 0.68±1.55 pCi/L to 3.09±2.50 pCi/L. Relative isotopic ratios ranged from -141.2 to -133.7 permil for δ^2H, -18.35 to -17.59 permil for $\delta^{18}O$, and -10.21 to -6.17 permil for $\delta^{13}C$.

A statistical evaluation of the duplicate samples revealed that results for all constituents were not significantly different from results of constituents in the routine samples.

The computer code NETPATH was used to model the net geochemical mass-balance reactions in the Little Lost River drainage basin. Several difficulties were encountered in the study. Contamination by local agricultural practices limited the use of several well samples for studying the geochemistry of the aquifer system. Water from one well, Pancheri, was not representative of the system because of a direct connection with the Little Lost River. Water in the Ruby Farms and Mays wells at the valley terminus could not be modeled satisfactorily from upgradient wells. These wells are much deeper and could represent SRPA water.

In spite of these problems, model attempts for three wells, Sorenson, Oar, and Harrell, revealed that the main reaction taking place in the system is the dissolution of dolomite. Models also indicated that nitrification of ammonium ion to nitrate and dissolution of inorganic fertilizers are important chemical processes at some locations in the system. To better understand the geochemistry of the Little Lost River drainage basin, more samples that better represent the natural geochemistry of the basin need to be collected and evaluated.

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Table 1. Containers and preservatives used for water samples, Little Lost River drainage basin, Idaho

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

	Container		Preservative			
Type of constituent	Type	Size	Type	Size	Other treatment	Analyzing laboratory
Cations and trace elements	polyethylene; acid-rinsed	500 mL	Ultrex HNO_3	4 mL	filter	ISU
Cations and trace elements	polyethylene, acid rinsed	250 mL	Ultrex HNO_3	2 mL	filter	NWQL
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

Table 2. Well location, construction, and approximate depth to water, Little Lost River drainage basin, Idaho

[See figure 1 for location of wells. Abbreviations: LLR, Little Lost River; NA, not applicable; U, unknown]

Site identifier	Latitude	Longitude	Well type	Well depth (feet)	Depth to water (feet)	Diameter of casing (inches)
Sorenson	441052	1131710	Irrigation	127.5	39.6	U
LLR near Clyde	440819	1131439	Surface Water	NA	NA	NA
Oar	440558	1131403	Domestic	80	35	6
Nicholson	440003	1130851	Domestic	126	81	U
Pancheri	435728	1131037	Irrigation	87	24.5	16
Harrell	434940	1130056	Domestic	118	71	U
LLR at Howe	434704	1125947	Surface Water	NA	NA	NA
Ruby Farms	434751	1125718	Domestic	650	259	U
Mays	434558	1125853	Domestic	540	272.9	8

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

[See figure 1 for location of sites. 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; LLR, Little Lost River; NA, not analyzed. Symbol: $CaCO_3$, calcium carbonate]

Site identifier	Date sampled (m/d/y)	Time	pH	Specific conductance	Temperature (°C)	Alkalinity as $CaCO_3$	DO	Dissolved solids, sum (as $CaCO_3$)
Sorenson	7/31/00	1300	8.0	255	7.0	125	7.3	149
LLR near Clyde	6/27/00	1015	8.4	245	12.0	107	9.1	NA
Oar	6/28/00	1350	7.8	346	8.5	157	7.4	NA
Nicholson	7/31/00	1121	7.6	964	11.0	184	7.2	NA
Pancheri	6/26/00	1345	7.8	336	8.0	146	8.2	NA
Harrell	7/31/00	0942	7.4	557	10.5	213	8.3	NA
LLR at Howe	6/27/00	0825	8.1	342	13.5	142	8.0	NA
Ruby Farms	5/10/91	1100	7.9	550	10.0	167	9.6	305
Mays	6/26/00	0935	7.9	290	15.0	128	7.1	175

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

[The range given is in the units designated in the constituents column. In the MPD (most probable deviation) equations, 'Y' is the MPD (most probable deviation) 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 is the ± error for the value. This error should be determined for each sample to verify the overlap of the concentration ranges of the National Water Quality Laboratory and Idaho State University data. MPD, most probable deviation; MRL, minimum reporting level; IDL, instrument detection limit]

	NWQL			ISU	
Constituent	MPD Equation	Range	MRL	Range	IDL
K (ppm)	Y = 0.063x + 0.24	0.45–13.9	0.1	0.2–2	0.10
Ca (ppm)	Y = 0.045x + 0.014	5.13–78.9	.1	20–80	3
Na (ppm)	Y = 0.038x + 0.179	7.19–166	.06	3–30	2
Mg (ppm)	Y = 0.038x + 0.026	1.03–25.3	.004	1–30	.05
Al (ppm)	Y = 0.109x + 4.074	6.66–132	10	NA	1
Fe (ppb)	Y = 0.033x + 5.376	4.30–228	10	10–100	20
Mn (ppb)	Y = 0.046x + 0.661	2.40–423	3	2–20	10
Cr (ppb)	Y = 0.059x + 0.584	0.68–79.0	1	25–100	17
Zn (ppb)	Y = 0.043x + 2.073	5.80–227	20	25–100	40
Pb (ppb)	Y = 0.066x + 0.624	1.00–103	1	NA	16
Si (ppm)	Y = 0.063x + 0.011	1.43–24.0	.1	3–30	.10
Sr (ppb)	Y = 0.046x + 0.512	32.7–705	1	100–500	8
Ba (ppb)	Y = 0.042x + 0.954	7.65–507	1	20–200	2

Table 5. Concentrations of dissolved major cations and silica in water from selected sites, Little Lost River drainage basin, Idaho

[See figure 1 for location of sites. Analytical results in milligrams per liter. Chemical symbols: Ca^{2+}, calcium; Mg^{2+}, magnesium; Na^+, sodium; K^+, potassium; and SiO_2, silica. Abbreviations: ISU, Idaho State University; NWQL, National Water Quality Laboratory; NA, not analyzed; NS, not calculated because duplicate sample not available; QA-2, quality assurance blank of inorganic-free water. Symbols: ±, plus or minus; <, less than. The standard deviation (± value) in each ISU analysis was calculated from three sample measurements made on separate days]

Site identifier	Ca^{2+} ISU	Ca^{2+} NWQL	Z-value	Mg^{2+} ISU	Mg^{2+} NWQL	Z-value	Na^+ ISU	Na^+ NWQL	Z-value	K^+ ISU	K^+ NWQL	Z-value	SiO_2 ISU	SiO_2 NWQL	Z-value
Sorenson	31±.4	32	0.66	11±.05	11	0	4.3±.08	4	0.88	0.87±.21	0.89	0.06	17±.2	17	0
LLR near Clyde	30±.8	NA	NS	10±.1	NA	NS	2.8±.06	NA	NS	.58±.18	NA	NS	9.2±.01	NA	NS
Oar	40±.3	NA	NS	15±.2	NA	NS	5.7±.05	NA	NS	.88±.18	NA	NS	14±.1	NA	NS
Nicholson	83±.9	85	.51	45±.4	45	0	28±.3	27	.81	1.7±.09	1.8	.22	23±.1	23	0
Pancheri	40±.2	NA	NS	14±.1	NA	NS	6.0±.01	NA	NS	.76±.21	NA	NS	15±.1	NA	NS
Harrell	62±.4	63	.35	22±.2	22	0	17±.2	17	0	1.4±.21	1.3	.26	18±.1	19	.82
LLR at Howe	39±.5	NA	NS	15±.2	NA	NS	6.9±.02	NA	NS	1.1±.18	NA	NS	11±.1	NA	NS
Ruby Farms	NA	62	NS	NA	23	NS	NA	14	NS	NA	1.6	NS	NA	19	NS
Mays	27±.2	28	.78	13±.2	13	0	12±.1	12	0	1.6±.18	1.4	.53	23±.2	21	1.48
QA-2	<3			<.05			<2			<.1			<.1		

Table 6. Concentrations of dissolved major anions in water from selected sites, Little Lost River drainage basin, Idaho

[See figure 1 for location of sites. Analyses were performed by the U.S. Geological Survey National Water Quality Laboratory. Results in milligrams per liter. Bicarbonate data were calculated from alkalinity field measurements listed in table 3; the alkalinity (as calcium carbonate) was divided by 0.8202 (Hem, 1985, p. 57)]

Site identifier	Chloride	Sulfate	Bicarbonate	Fluoride
Sorenson	2.6	5.0	153	0.13
LLR near Clyde	2.2	11.4	131	.12
Oar	6.2	10.5	191	<.1
Nicholson	143	60.3	225	<.1
Pancheri	7.3	12.6	178	.12
Harrell	21.6	34.4	259	.16
LLR at Howe	7.8	15.8	173	.12
Ruby Farms	50	32	204	<.1
Mays	5.6	15.0	156	.14

Table 7. Concentrations of dissolved trace elements in water from selected sites, Little Lost River drainage basin, Idaho

[See figure 1 for location of sites. Analytical results in micrograms per liter. Abbreviations: E, estimated value; ISU, Idaho State University; NWQL, National Water Quality Laboratory; LLR, Little Lost River; NA, not analyzed; NS, not calculated because duplicate sample was unavailable; QA-2, quality assurance blank of inorganic-free water. Symbols: ±, plus or minus; <, less than.The standard deviation (± value) in each ISU analysis was calculated from three sample measurements made on separate days]

Site identifier	Barium ISU	Barium NWQL	Z-Value	Bromide NWQL	Chromium NWQL	Iron ISU	Iron NWQL	Lithium NWQL	Manganese ISU	Manganese NWQL	Strontium ISU	Strontium NWQL	Z-Value	Zinc ISU	Zinc NWQL
Sorenson	37±1.1	38	0.36	NA	NA	<20	<10	NA	<10	<2.2	92±1.7	NA	NS	<40	NA
LLR near Clyde	44±.9	NA	NS	<0.01	NA	<20	NA	NA	<10	NA	105±1.8	NA	NS	<40	NA
Oar	60±1.2	NA	NS	.025	NA	<20	NA	NA	<10	NA	126±2.2	NA	NS	<40	NA
Nicholson	58±.8	58	0	NA	NA	<20	13.2	NA	<10	1.7E	363±5.1	NA	NS	<40	NA
Pancheri	63±.6	NA	NS	.029	NA	<20	NA	NA	<10	NA	127±1.5	NA	NS	<40	NA
Harrell	137±1.5	132	.75	NA	NA	<20	<10	NA	<10	5	217±2.7	NA	NS	<40	NA
LLR at Howe	73±.6	NA	NS	<.01	NA	<20	NA	NA	<10	NA	142±1.9	NA	NS	<40	NA
Ruby Farms	NA	110	NS	.100	8	NA	14	5	NA	<1	NA	240	NS	NA	64
Mays	95±1.5	97	.38	0.024	49	<20	<10	6	<10	<2.2	320±4.0	323	.19	<40	36
QA-2	<2					<20			<10		<8			<40	

Table 8. Concentrations of dissolved nutrients and dissolved organic carbon in water from selected sites, Little Lost River drainage basin, Idaho

[See figure 1 for location of sites. Analytical results in milligrams per liter. Analyses were performed by the U.S. Geological Survey National Water Quality Laboratory. Abbreviations: DOC, dissolved organic carbon; LLR, Little Lost River; NA, not analyzed. Symbol: <, less than]

Site identifier	Ammonia as nitrogen	Nitrite as nitrogen	Nitrite plus nitrate as nitrogen	Orthophosphate as phosphorous	DOC
Sorenson	<0.02	<0.01	0.19	0.017	0.78
LLR near Clyde	<.02	<.01	<.05	<.01	1.06
Oar	<.02	<.01	.47	<.01	NA
Nicholson	<.02	<.01	4.2	<.01	1.66
Pancheri	<.02	<.01	.37	<.01	.37
Harrell	<.02	<.01	1.9	<.01	.50
LLR at Howe	<.02	<.01	.11	<.01	1.1
Ruby Farms	<.01	<.01	2.9	<.01	.6
Mays	<.02	<.01	.40	.016	.18

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

[See figure 1 for location of sites. Analyses were performed by the U.S. Geological Survey National Water Quality Laboratory. Analytical results and uncertainties—for example, 51.2±25.6—in indicated units. Analytical uncertainties are reported as 2s except for δ^{2}H, δ^{18}O, and δ^{13}C, which are reported ± amount permil indicated. Abbreviation: LLR, Little Lost River. Units: pCi/L, picocuries per liter; permil, parts per thousand relative to a standard. Symbols: ^{230}Th, thorium-230; ^{137}Cs, cesium-137; δ^{2}H, 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)	Gross-alpha (pCi/L as ^{230}Th)	Gross-beta (pCi/L as ^{137}Cs)	δ^{2}H (±1.5 permil)	δ^{18}O (±1.5 permil)	δ^{13}C (±0.3 permil)
Sorenson	51.2±25.6	1.01±0.87	1.46±1.55	-137.9	-18.06	-9.12
LLR near Clyde	38.4±25.6	.95±1.07	.68±1.55	-137.4	-17.94	-6.57
Oar	51.2±25.6	.59±1.1	2.29±1.98	-138.7	-18.11	-10.21
Nicholson	44.8±25.6	1.39±2.25	2.09±4.52	-133.7	-17.59	-6.17
Pancheri	57.6±25.6	.34±1.02	.84±1.92	-140	-18.22	-7.92
Harrell	35.2±25.6	1.62± 0.98	3.09±2.50	-135.2	-17.93	-9.27
LLR at Howe	38.4±25.6	.62±0.98	1.80±2.00	-137.3	-17.89	-6.94
Ruby Farms	9.6±26	2.7±0.86	2.5±0.96	-138.0	-18.15	-9.1
Mays	0±25.6	1.02±1.26	1.48±1.90	-141.2	-18.35	-7.1

Table 10. Thermodynamic saturation indices for water, with respect to selected minerals, from selected sites, Little Lost River 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 ±0.1 values indicate equilibrium. Abbreviation: LLR, Little Lost River]

Site identifier	Calcite	Dolomite	Gypsum	Anhydrite
Sorenson	-0.00	-0.39	-3.08	-3.33
LLR near Clyde	.33	.34	-2.74	-3.00
Oar	-.02	-.38	-2.69	-2.95
Nicholson	.10	.09	-1.80	-2.06
Pancheri	.00	-.35	-2.61	-2.86
Harrell	-.03	-.39	-2.07	-2.33
LLR near Howe	.36	.49	-2.54	-2.79
Ruby Farms	.30	.30	-2.10	-2.36
Mays	-.05	-.21	-2.69	-2.94

Table 11. Thermodynamically possible models obtained with NETPATH

[See figure 1 for location of sites. Units are in millimoles per kilogram of water. No entry indicates that phase was not included in model. Abbreviations: CO_2, carbon dioxide; -, indicates precipitation; LLR, Little Lost River; nr, near; %, percent of water from each site to obtain results]

NONMIXING MODELS WITH CALCITE

Initial	Final	CO_2 gas	Calcite	Dolomite	Gypsum
Sorenson	Oar	0.32386	0.00279	0.16460	0.05728
Pancheri	Harrell	.97992	-.00705	.32930	.22706
Oar	Harrell	.82309	.01223	.28815	.24892
Pancheri	Harrell	.75286	.22001	.32930	
Oar	Harrell	.57417	.26115	.28815	
Sorenson	Oar	.26658	.06007	.16460	

NONMIXING MODELS WITH EXCHANGE

Initial	Final	CO_2 gas	Dolomite	Gypsum	Exchange
Sorenson	Oar	0.32665	0.16460	0.05728	-0.00279
Oar	Nicholson	-1.69424	1.23493	.51877	.67985
Pancheri	Harrell	.97287	.32930	.22706	.00705
Sorenson	Ruby Farms	-.13522	.49387	.28120	.00115
Sorenson	Mays	-.14618	.08230	.10413	.28623
Sorenson	Nicholson	-1.36759	1.39953	.57605	.67706
Sorenson	Pancheri	.18910	.12345	.07914	-.02207
Sorenson	Harrell	1.16197	.45275	.30620	-.01502
Sorenson	LLR nr Howe	-.00193	.16459	.11246	.07735
Oar	Harrell	.83532	.28815	.24892	-.01223
Oar	LLR nr Howe	-.32858	-.00001	.05518	.08014
Oar	Ruby Farms	-.46187	.32927	.22392	.00394
Pancheri	LLR nr Howe	-.19103	.04114	.03332	.09942
Pancheri	Ruby Farms	-.32432	.37042	.20206	.02322

NONMIXING MODELS WITH HALITE

Initial	Final	CO2 Gas	Dolomite	Gypsum	Halite	Exchange	Calcite
Oar	Harrell	0.79450	0.28815	0.24892	0.43460	0.02859	0.04082
Oar	Harrell	.86980	.27091	.24892	.58519	-.04671	

Table 11. Thermodynamically possible models obtained with NETPATH—Continued.

			MIXING MODELS			
	Initial 1	**Initial 2**	**Final**	**Dolomite**	**CO_2 gas**	**Gypsum**
	Sorenson	LLR nr Clyde	Ruby Farms			
%	97.721	2.279		0.49481	-0.12791	0.27968
	Sorenson	Nicholson	LLR nr Howe			
%	88.576	11.424		.00470	.15431	.04665
	Sorenson	Nicholson	Ruby Farms			
%	99.830	.170		.49149	-.13290	.28022
	Sorenson	Pancheri	Harrell			
%	31.944	68.056		.36873	1.03328	.25234
	Sorenson	LLR nr Howe	Ruby Farms			
%	98.513	1.487		.49142	-.13519	.27953
	Oar	Nicholson	Ruby Farms			
%	99.420	.580		.32211	-.45205	.22091
	Oar	Pancheri	Harrell			
%	36.566	63.434		.31425	.92257	.23505
	Nicholson	Pancheri	Harrell			
%	1.008	98.992		.31643	.98857	.22205
	Nicholson	Pancheri	Ruby Farms			
%	3.321	96.679		.32804	-.27262	.18556

Table 12. Models with thermodynamic impossibilities obtained with NETPATH

[See figure 1 for location of sites. Units are millimoles per kilogram of water. Abbreviations: CO_2, carbon dioxide; -, indicates precipitation; LLR, Little Lost River; nr, near; %, percent of water from each site to obtain results]

NONMIXING MODELS WITH CALCITE

Initial	Final	CO_2 Gas	Calcite	Dolomite	Gypsum
Nicholson	Pancheri	0.85756	0.69913	-1.27608	-0.49691
Harrell	Ruby Farms	-1.28102	-.01617	.04112	-.02500
Harrell	Mays	-1.00690	-.30125	-.37045	-.20207
Ruby Farms	Mays	.27412	-.28508	-.41157	-.17707
LLR nr Clyde	Oar	.59422	.05324	.20576	-.00936
LLR nr Clyde	Pancheri	.43739	.07252	.16461	.01250
Oar	Pancheri	-.17869	.04114	-.04115	

NONMIXING MODELS WITH EXCHANGE

Initial	Final	CO_2 Gas	Dolomite	Gypsum	Exchange
Nicholson	Pancheri	1.55669	-1.27608	-0.49691	-0.69913
Harrell	Ruby Farms	-1.29719	.04112	-.02500	.01617
Harrell	Mays	-1.30815	-.37045	-.20207	.30125
Ruby Farms	Mays	-.01096	-.41157	-.17707	.28508
LLR nr Clyde	Oar	.64746	.20576	-.00936	-.05324
LLR nr Howe	Mays	-.14425	-.08229	-.00833	-.00833
LLR nr Clyde	Pancheri	.50991	.16461	.01250	-.07252
Sorenson	LLR nr Clyde	-.32081	-.04116	.06664	.05045
LLR nr Clyde	Nicholson	-1.04678	1.44069	.50941	.62661
LLR nr Clyde	Harrell	1.48278	.49391	.23956	-.06547
LLR nr Clyde	LLR nr Howe	.31888	.20575	.04582	.02690
LLR nr Clyde	Ruby Farms	.18559	.53503	.21456	-.04930
LLR nr Clyde	Mays	.17463	.12346	.03749	.23578
Oar	Pancheri	-.13755	-.04115	.02186	-.01928
Oar	Mays	-.47283	-.08230	.04685	.28902
Nicholson	Harrell	2.52956	-.94678	-.26985	-.69208
Nicholson	LLR nr Howe	1.36566	-1.23494	-.46359	-.59971
Nicholson	Ruby Farms	1.23237	-.90566	-.29485	-.67591
Nicholson	Mays	1.22141	-1.31723	-.47192	-.39083
Pancheri	Mays	-.33528	-.04115	.02499	.30830
Harrell	LLR nr Howe	-1.16390	-.28816	-.19374	.09237
LLR nr Howe	Ruby Farms	-.13329	.32928	.16874	-.07620
LLR nr Clyde	Sorenson	.32081	.04116	-.06664	-.05045

Table 12. Models with thermodynamic impossibilities obtained with NETPATH—Continued

MIXING MODELS					
Initial 1	**Initial 2**	**Final**	**Dolomite**	**CO_2 Gas**	**Gypsum**
Sorenson	Nicholson	Mays			
% 57.725	42.275		-0.5093	0.43197	-0.13940
LLR nr Clyde	Nicholson	LLR nr Howe			
% 95.707	4.293		.14390	.36382	.02395
LLR nr Clyde	Nicholson	Mays			
% 62.372	37.628		-.41864	.56851	-.15419
LLR nr Clyde	Pancheri	Harrell			
% 9.721	90.279		.34530	1.02244	.22828
Oar	Nicholson	LLR nr Howe			
% 88.212	11.788		-.14558	-.12886	-.00597
Oar	Nicholson	Mays			
% 57.488	42.512		-.60730	.24743	-.17369
Nicholson	Pancheri	LLR nr Howe			
% 14.221	85.779		-.14033	.03034	-.03734
Nicholson	Pancheri	Mays			
% 44.098	55.902		-.60387	.35118	-.19414
Nicholson	Harrell	LLR nr Howe			
% 13.347	86.653		-.41452	-.82629	-.22976
Nicholson	Harrell	Ruby Farms			
% 2.336	97.664		.01900	-1.23809	-.03130
Nicholson	Harrell	Mays			
% 43.528	56.472		-.78257	-.20708	-.31953
Nicholson	LLR nr Howe	Mays			
% 34.830	65.170		-.51242	.33141	-.16980
Nicholson	Ruby Farms	Mays			
% 42.177	57.823		-.79355	.50882	-.30143