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ANALYSIS OF PERCHED GROUNDWATER BODIES BENEATH THE RADIOACTIVE WASTE MANAGEMENT COMPLEX AT THE IDAHO NATIONAL ENGINEERING LABORATORY

by

Alan V. Jones

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1995

ABSTRACT

The migration of radionuclides and volatile chemicals through a thick sequence of unsaturated basalts and sedimentary interbeds has been documented in the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering Laboratory (INEL). The three mechanisms by which this migration may have occurred are seasonal infiltration from the ground surface within the SDA; flood events in 1962, 1969, and 1982; and the lateral movement of water from the spreading areas located nearby. It is currently thought that the contaminants migrated through the unsaturated sediments and basalt flows during the three flood events.

Transducers were used to monitor water level changes in seven wells: Two completed in a perched zone associated with an interbed at 110 feet (34 meters), and five completed in a perched zone associated with an interbed at 240 feet (73 meters). The data suggest that one of the wells completed in the perched zone associated with the interbed at 110 feet receives recharge from seasonal infiltration at the ground surface. This recharge occurs primarily from February to May. Snowmelt is the major source of water for infiltration.

One water sample was taken from this well, one water sample was taken from snowmelt at the surface within the SDA, and one water sample was taken from the Big Lost River, which is the source of water diverted into the spreading areas. The three water samples were analyzed for major ions, minor ions, and trace constituents. The water sample from the well was more similar chemically to the water sample from the snowmelt than to the water sample from the Big Lost River. The chemical data support the conclusion that the snowmelt is the source of recharge to the perched zone associated with the interbed at 110 feet.

The transducer data from the five wells completed in the perched zone associated with the interbed at 240 feet indicate that one well is dry, and one well has standing water that showed virtually no change in water level. Two of the remaining wells showed seasonal recharge, probably from precipitation. These two wells, and the remaining well, showed rapid water-level rises, and declines, shortly after 157 acre-feet (194,000 m^3) of water were diverted into the spreading areas. The perched water body associated with the interbed at 240 feet probably receives recharge from both precipitation and from water diverted into the spreading areas.

(110 pages)

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I thank my parents for instilling in me a desire to gain an education and to accomplish my goals. They always gave encouragement and helped out when they could. My wife's parents were also very supportive throughout this endeavor and I truly appreciate their support.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Statement of the Problem

The Idaho National Engineering Laboratory (INEL) was established by the United States Department of Energy (DOE) in 1952 for the development and testing of nuclear reactors for atomic energy. The INEL is located on the northern edge of the eastern Snake River Plain (Figure 1). The Snake River Plain is about 400 miles (640 kilometers [km]) long and 40 to 60 miles (64 to 96 km) wide. It covers most of southern Idaho, and consists mainly of basaltic lava flows (Palmer, 1991). Beneath the eastern half of the plain is one of the most permeable large aquifers in the world. This aquifer has an estimated storage capacity of 200 million acre-feet (250 billion cubic meters [m^3]) and flow rates approaching 6 feet per day (ft/day) (0.002 centimeters per second [cm/sec]) (Hackett et al., 1986).

Radioactive waste was disposed of at the INEL in an area known as the Radioactive Waste Management Complex (RWMC) (Figures 1, 2, and 3). In addition to the radioactive waste, 88,400 gallons (335 m^3) of organic-sludge waste from the Rocky Flats plant, Colorado, was disposed of at the RWMC from 1966 to 1970. This waste material was comprised of approximately 24,000 gallons (91 m^3) of carbon tetrachloride, 39,000 gallons (148 m^3) of machine oil, and 25,000 gallons (95 m^3) of miscellaneous volatile organic compounds (VOCs). The waste was transported to the RWMC in

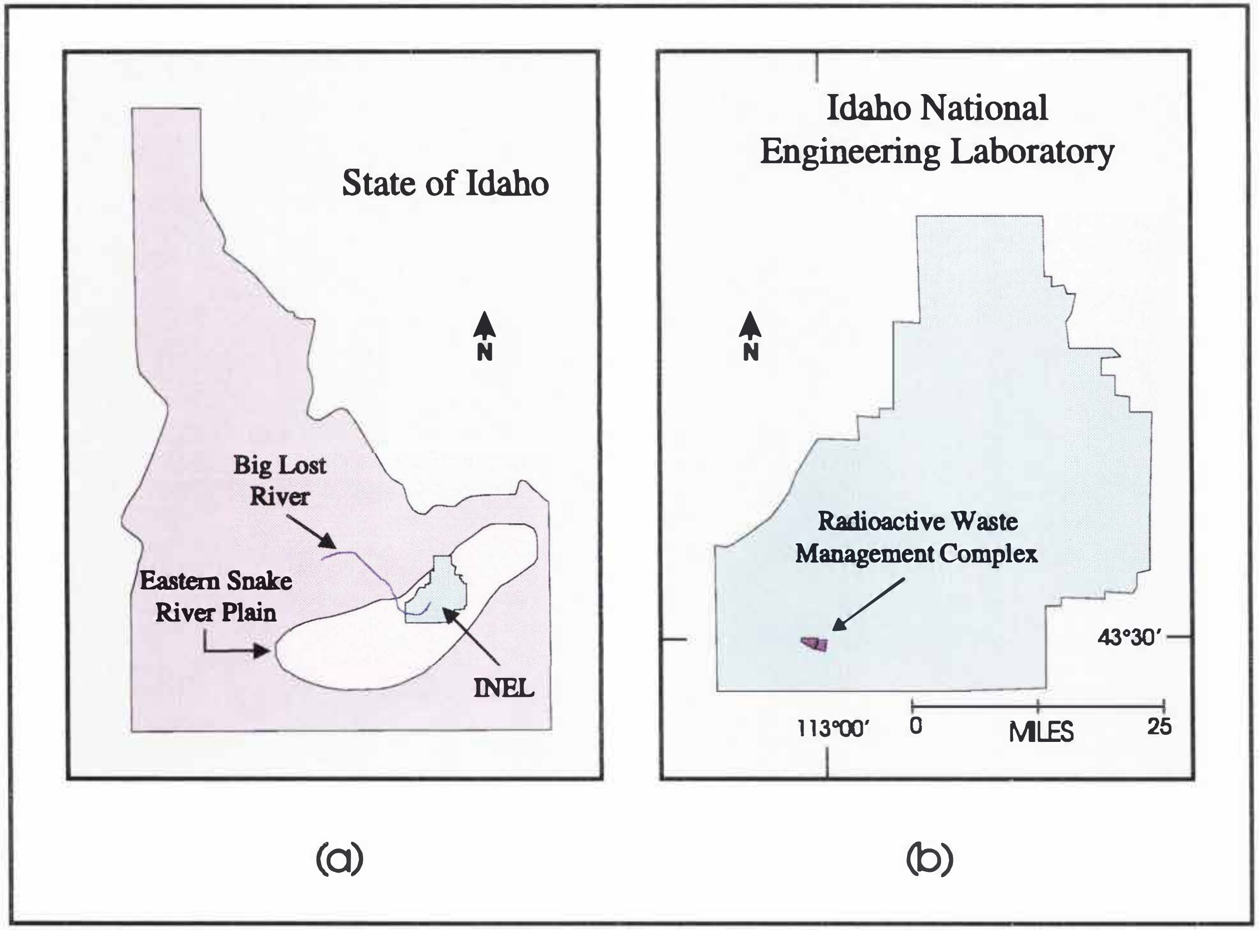

Figure 1. Locations of: (a) the Idaho National Engineering Laboratory, the eastern Snake River Plain, and the Big Lost River within the state of Idaho; and (b) The Radioactive Waste Management Complex within the Idaho National Engineering Laboratory.

Figure 2. Low-angle oblique aerial photo of the Radioactive Waste Management Complex. View is to the east toward Eastern Butte (left) and Northern Butte (right).

Figure 3. Low-angle oblique aerial photo of the Radioactive Waste Management Complex. View is to the south toward Big Southern Butte.

barrels, and the barrels containing the waste were buried in shallow, unlined pits (McElroy et al., 1989). In the late 1970s and early 1980s, concern about aquifer contamination from the subsurface migration of radionuclides beneath the RWMC led to the Subsurface Investigation Program (SIP) (U.S. DOE, 1983). The initial objectives of the SIP were to predict long-term radionuclide migration and to measure the actual migration to date (Laney et al., 1988). In 1987 purgeable organic compounds were discovered in the groundwater at the RWMC (Mann and Knobel, 1987). This led to the creation of the RWMC Site Characterization Program as a continuation of the SIP, and the scope of the SIP was broadened to include hazardous and radionuclide contaminants in the subsurface in response to the need to meet regulatory requirements (McElroy et al., 1989).

Purpose and Objectives

In order for contaminants to reach the Snake River Plain aquifer, they must migrate through thick sequences of unsaturated basalts and sedimentary interbeds. Some study of the hydraulic properties of the vadose zone beneath the RWMC has been done, and it is currently thought that little or no downward migration of water from seasonal precipitation occurs (Hubbell, 1990). The contamination that has been detected is assumed to have migrated through the basalts and unsaturated sediments during local major flood events in 1962, 1969, and 1982. Since 1982, flood-control structures have been constructed that are assumed to eliminate future floods and, thus, further contamination is considered unlikely (J. M. Hubbell, 1993, oral communication). However, perched groundwater has been documented in one well, and two other wells drilled within the RWMC show the possible existence of perched groundwater with seasonal recharge (Hubbell, 1990).

Such seasonal recharge may be responsible for the migration of radionuclides through the vadose zone into perched groundwater bodies that may be more laterally extensive than is currently believed. No study of the concentrations of major cations and anions has previously been conducted at the site. The results of such a study should help determine the source of recharge to the perched groundwater and, thus, lead to a better understanding of the mechanism of contaminant transport and migration.

The purpose of this investigation is to assess the subsurface migration of radionuclides and organic chemicals beneath the RWMC. The objectives are to: 1) evaluate the possibility that one or more large, continuous bodies of perched groundwater underlie the RWMC; 2) evaluate how laterally extensive each perched groundwater body is; 3) determine the source of recharge to these perched groundwater bodies; and 4) determine if the recharge to each perched groundwater body is seasonal in nature.

Location, Setting, and Previous Investigations

The Idaho National Engineering Laboratory occupies about 890 square miles (2,300 km^2) on the northwestern side of the eastern Snake River Plain (Figure 1). It is located about 40 miles (64 km) west of Idaho Falls, and is set in semiarid sagebrush-covered terrain (Davis and Pittman, 1990). The annual precipitation at the RWMC is 9.07 inches (23.04 cm) per year (Start, 1984). About 30% of the precipitation at the RWMC is snow, which falls mainly from November through February (Hubbell, 1990).

The first published report on the hydrogeology of southeastern Idaho was a basin-wide study focusing on irrigation (Mundorff et al., 1964). Because of its emphasis on irrigation, it is of little use for assessing contaminant migration.

Interest in the subsurface migration of radionuclides at the INEL began in the 1970s (Schmalz, 1972; Robertson et al., 1974; Barraclough et al., 1976). Much of these early studies was focused on the potential for radionuclide migration based on the site hydrogeology.

Later studies relied on soil and groundwater samples collected from the subsurface to determine the actual extent of radionuclide migration (Burgus and Maestas, 1976; Humphrey and Tingey, 1978; Humphrey, 1980; Leenheer and Bagby, 1982). These studies showed that little radionuclide migration had actually occurred outside of the RWMC, and as a result, further studies were focused in this area. A plan was prepared for further study of radionuclide migration beneath the RWMC (U.S. DOE, 1983), and annual progress reports documenting the activities completed to date have been published (Hubbell et al., 1986; Hubbell et al., 1987; Laney et al., 1988; McElroy et al., 1989).

Hubbell (1990) looked more narrowly at the hydrogeologic properties of the perched groundwater beneath the RWMC. McElroy (1990) conducted a detailed study of the vadose zone beneath the RWMC.

Besides the studies conducted on radionuclide migration, the U. S. Geological Survey (USGS) has conducted several investigations characterizing the hydrogeology of the RWMC (Kuntz, 1978; Kuntz et al., 1980; Mann and Knobel, 1987; Rightmire and Lewis, 1987; Anderson and Lewis, 1989; Bartholomay et al., 1992). One of the these studies (Mann and Knobel, 1987) detected purgeable organic compounds in the Snake River Plain aquifer within a one-mile (1.6-km) radius of the RWMC. As a direct result of these findings, a draft RCRA Facility Investigation (RFI) work plan was submitted in September of 1988 as part of a Consent Order and Compliance Agreement (COCA) with the U.S. Environmental Protection Agency (EPA) and the State of Idaho (Chantrill, 1988).

Geology and Hydrogeology

The RWMC is underlain by the basalt sequence that comprises the Snake River Plain. These basalts are overlain by and interbedded with sedimentary layers that were deposited between major eruptive periods. Well logs show ten flow groups in the upper 700 feet (210 meters [m]) that range in age from 100,000 to 600,000 years old (Anderson and Lewis, 1989). The sedimentary interbeds consist of clay, silt, and fine sands deposited by fluvial, lacustrine, and eolian processes during the thousands of years between major eruptive periods.

The unsaturated zone extends to a depth of approximately 600 feet (180 m). The saturated portion comprises the uppermost part of the Snake River Plain aquifer. The tops of three important interbeds are at 30, 110, and 240 feet (9, 34, and 73 m) below the surface (Rightmire and Lewis, 1987). The uppermost of these interbeds is predominantly eolian sediments, whereas the lower two units are comprised of fluvial deposits that entered the Snake River Plain from adjacent basins (McElroy et al., 1989).

Nine hydrogeologic units can be identified beneath the RWMC (Figure 4): (1) surface sediments, which Rightmire and Lewis (1987) believed are fine alluvium, but McElroy et al. (1989) referred to as eolian; (2) the basalt flow(s) immediately below the surface sediments; (3) the interbed at 30 feet (9 m), which ranges from 0 to 11 feet (0 to 3 m) thick and averages 5 feet (1.5 m) thick; (4) the basalt flow(s) beneath the interbed at 30 feet (9 m) and above the interbed at 110 feet (34 m); (5) the interbed at 110 feet (34 m), which ranges from 0 to 40 feet (0 to 12 m) thick and averages 13 feet (4 m) thick; (6) the basalt flow(s) beneath the interbed at 110 feet (34 m) and above the interbed at 240 feet (73 m); (7) the interbed at 240 feet (73 m), which ranges from 5 to 32 feet (1.5 to 10 m) thick and averages 17 feet (5 m) thick; (8) unsaturated basalt beneath the interbed at 240 feet (73 m); and (9) the saturated basalts that make up the upper part of the Snake River Plain aquifer (McElroy et al., 1989; Anderson and Lewis, 1989).

Before 1990, 6 of 45 wells drilled in the RWMC had detected perched water. Two wells were completed into the interbed at 110 feet (34 m) and the other four were completed into the interbed at 240 feet (73 m) (Hubbell, 1990). Since 1990, two additional wells were completed into the interbed at 240 feet that detected perched water (J. M. Hubbell, 1993, oral communication).

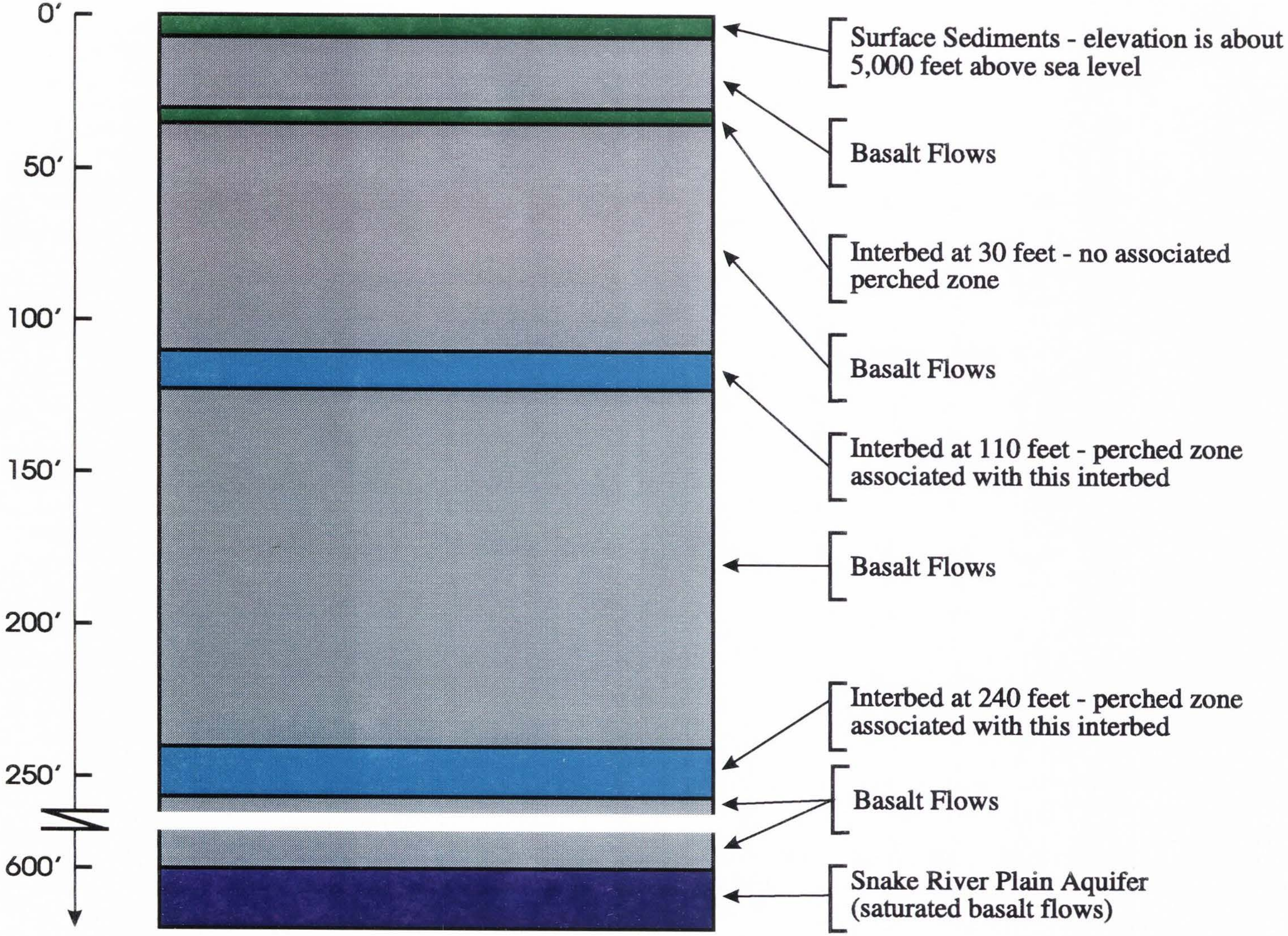

Figure 4. Stratigraphic column of the unsaturated zone beneath the RWMC based on average unit thicknesses.

The perched water body at 240 feet has been known for some time, but was thought to extend only for a short distance (Mann and Knobel, 1987). However, recent water-level data have shown that this body might be more laterally expansive than was originally thought (Hubbell, 1990).

It is not known exactly where the units of low hydraulic conductivity that create the perched water bodies are located. It is known that perched zones are associated with the interbeds at 110 and 240 feet. Lee (1990) noted that both of these interbeds are immediately overlain by dense, low-permeability basalts that are fractured and facilitate the formation of perched zones above the interbeds. Lee further pointed out that the water may move into the tops of the interbeds and be perched by clay layers within the interbeds. Thus, the perched aquifer is formed in the fractured basalts immediately overlying the interbeds, and may or may not be formed in the upper portion of each interbed.

The hydraulic properties of the surface sediments and basalts have been measured in the laboratory from cores obtained while drilling. These results show that the material beneath the RWMC is heterogeneous in nature. The sediment samples varied in hydraulic conductivity from 2.3×10^{-5} to 2.6×10^{2} ft/sec (8.1×10^{-9} to 9.2×10^{-2} cm/sec), whereas the basalts ranged from 3.9×10^{-6} to 3.2×10^{-4} ft/sec (1.4×10^{-9} to 1.1×10^{-7} cm/sec). Effective porosities (the porosity that is effective in transmitting water) of the basalt samples ranged from 12% to 24% (McElroy et al., 1989).

Sources of Recharge to the Perched Zones

There are three possible sources from which the perched water might originate. The first and most widely accepted source is the three floods, in 1962, 1969, and 1982 (Hubbell, 1990). A flood is here defined as water flowing through a failed barrier into an area where it was not designed to go. Under this definition, runoff from an unusually large amount of precipitation is not considered a flood unless it flows into the RWMC from another area (J. M. Hubbell, 1993, oral communication).

The second possible source is precipitation falling directly on the RWMC. The annual precipitation at the RWMC is 9.07 in./yr (23.04 cm/yr) (Start, 1984). About 30% of the precipitation at the RWMC is snow, which falls mainly from November through February. The total volume of snowmelt is 21.7 million gallons (82,150 m^3) per year (Hubbell, 1990). Because the snow melts in the spring when evapotranspiration rates are low, there is a distinct possibility that some will recharge the groundwater system.

The third possible source is water from the spreading areas. The Big Lost River passes about 1 mile (1.6 km) northwest of the RWMC (Figure 5). During the spring when flows in the Big Lost River are high, or in the winter when ice dams may form in the lower reaches of the river, the river is diverted into the spreading areas (Figure 5) to prevent flooding of INEL facilities. The spreading areas have a surface storage capacity of approximately 38,000 acre-feet (47 million m^3) (Wood, 1989). All water diverted into the spreading areas is lost to either infiltration or evapotranspiration. Infiltration rates range

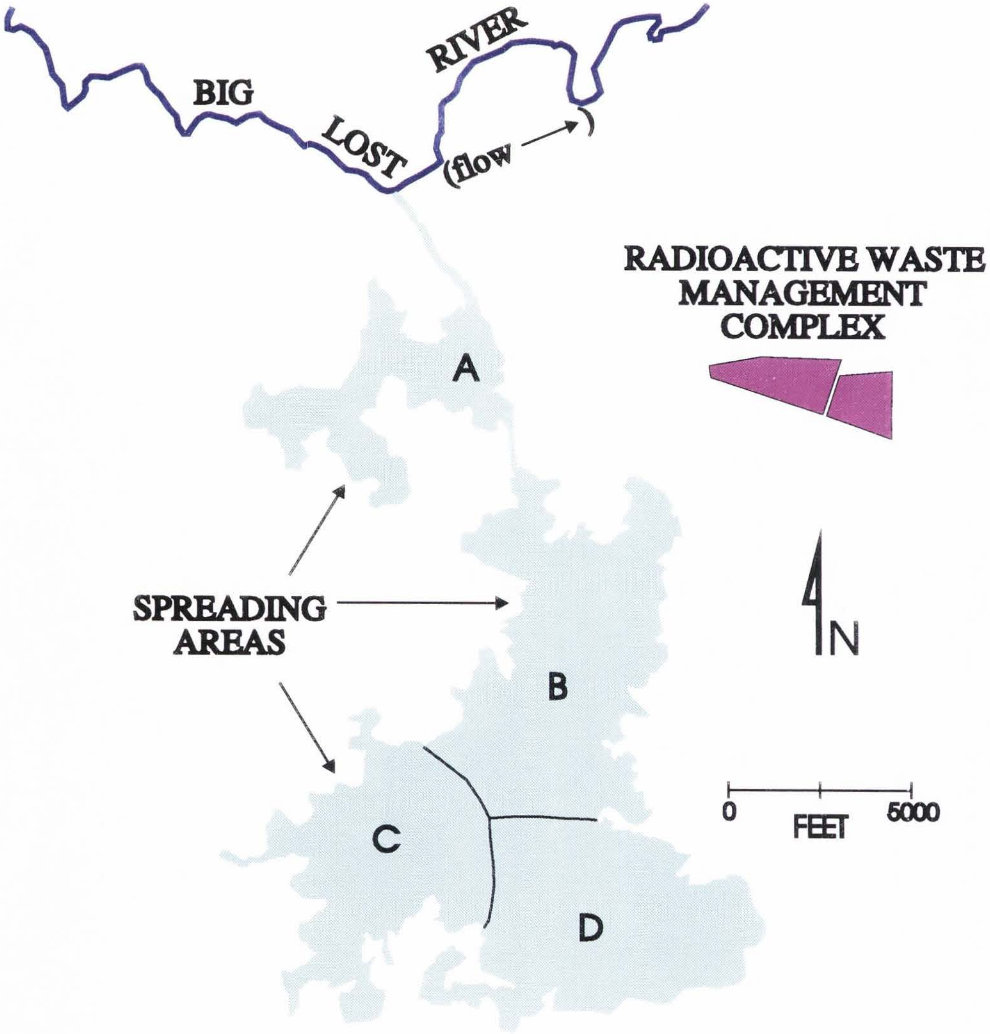

Figure 5. Locations of the spreading areas with respect to the Radioactive Waste Management Complex and the Big Lost River

from 0.7 to 2.6 cubic feet per square foot (ft^3/ft^2) (0.2 to 0.8 m^3/m^2) per day (Barraclough et al., 1967).

Since 1958, over 1 million acre-feet (1.2 billion m^3) of water have been diverted, but the diversions are not consistent (Hubbell, 1990). For example, from 1987 to 1992 no water was diverted (J. M. Hubbell, 1993, oral communication). In 1993, 157 acre-feet (194,000 m^3) of water were diverted, and again in 1994 no diversions were made into the spreading areas, as all water was diverted upstream for irrigation.

Generally, it is rare for groundwater to move laterally over great distances in the vadose zone, but lateral movements of 3,000 to 5,000 feet (900 to 1,500 m) have been documented in other areas at the INEL (Hubbell, 1990). Thus, it might be possible for water to migrate the mile or so from beneath the spreading areas to beneath the RWMC.

METHODS

Wells

Nine wells within the RWMC are completed into the perched zones (Figure 6). Four are completed into the perched zone associated the interbed at 110 feet and the remaining five into the perched zone associated with the interbed at 240 feet.

Each of the wells appears similar at the surface (Figure 7). They each have a concrete slab around the well casing. Usually the slab is about four feet by four feet (1.3 m by 1.3 m). Yellow corner posts protect the well. The well usually (not always) has an outer casing with a locked cap. Removal of the cap reveals the well casing, which is usually steel, stainless steel, galvanized steel, or PVC.

The following is a more detailed description of each well. The well-completion data are summarized in Table 1.

Wells Completed into the Interbed at 240 Feet

Well 92

Water levels in this well have been measured since it was drilled in 1972, so this well is the primary source of historical data for analyses of perched water from this level. Well 92 lies in the west-central portion of the SDA (Figure 6) and has a surface elevation of 5,007.7 feet (1,526.35 m) above mean sea level.

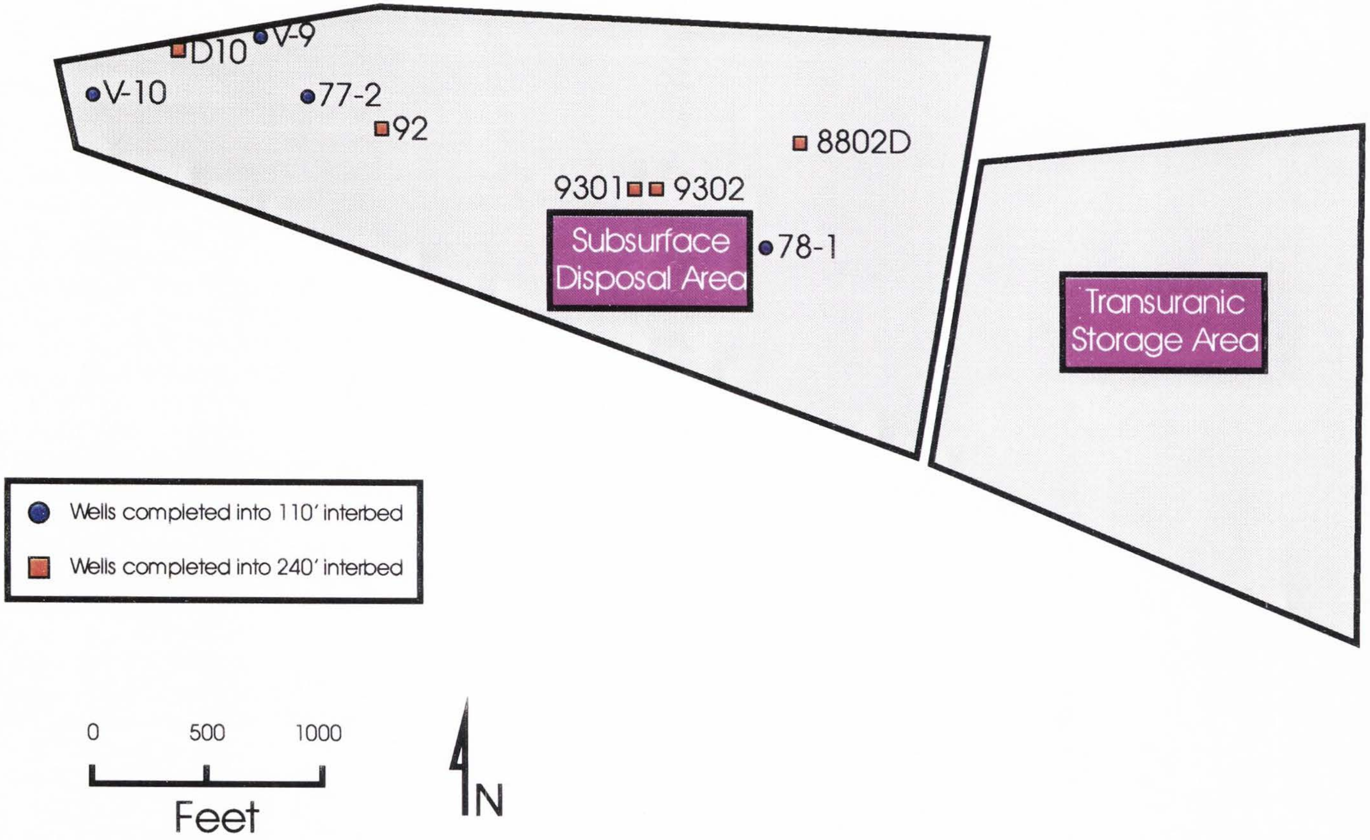

Figure 6. Locations of the wells monitored within the Radioactive Waste Management Complex.

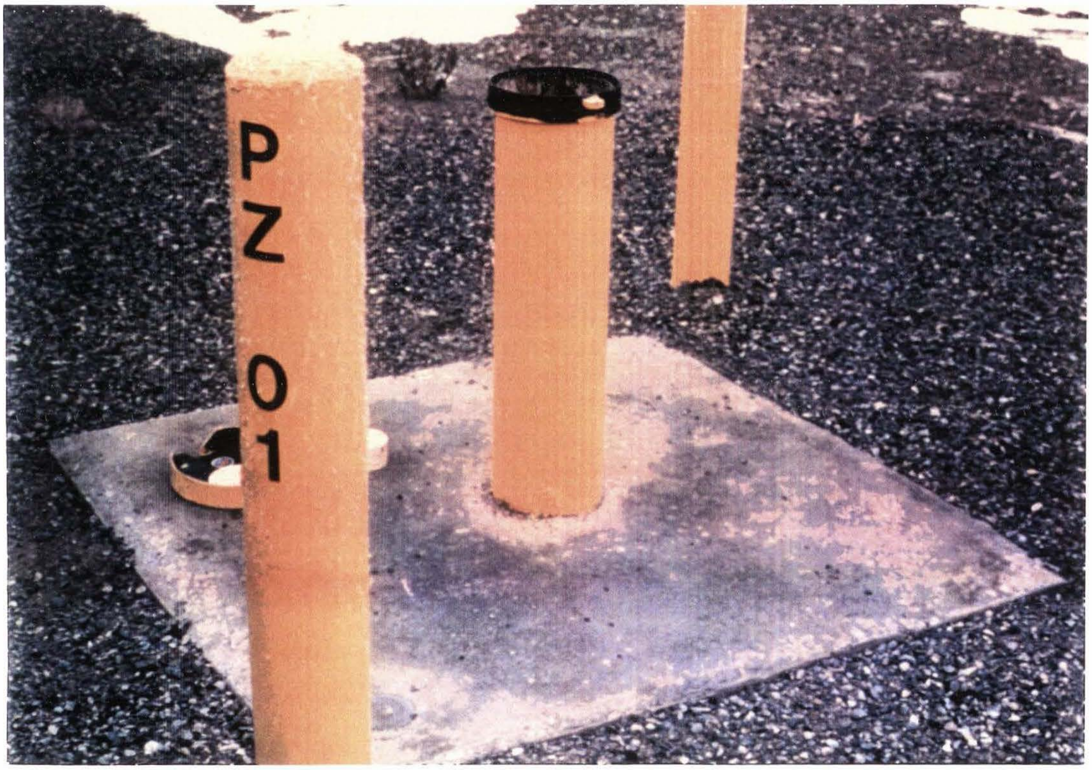

Figure 7. Typical surface completions of wells at the Radioactive Waste Management Complex.

Table 1. Well-Completion Information

	Year Drilled	Surface Elevation [feet (m) above MSL]	Total Depth [feet (m)]	Open Interval [feet (m) below surface]	Borehole Diameter [inches (cm)]
Well 92	1972	5,007.70 (1,526.35)	247 (75.3)	19 (5.8) to 213.5 (65.1)	3.25 (8.255)
Well D-10	1987	5,014.01 (1,528.27)	238 (72.5)	~200 (61) to 203 (61.9)	7.875 (20.003)
Well 8802D	1988-1989	5,008.16 (1,526.49)	220.6 (67.2)	210.6 (64.2) to 220.6 (67.2)	7.875 (20.003) [surface to 107' (32.6 m)] 5.875 (14.923) [107' (32.6 m) to 220.6' (67.2 m)]
Well 9301	1992	5,015.96 (1,528.86)	238 (72.5)	224 (68.3) to 228 (69.5)	7.875 (20.003)
Well 9302	1992	5,015.76 (1.528.80)	238 (72.5)	224 (68.3) to 228 (69.5)	7.875 (20.003)
Well 77-2	1977	5,013.61 (1,528.15)	87 (26.5)	~86 (26.2) to 87(26.5)	4.85 (12.319)
Well 78-1	1978	5,009.28 (1,526.83)	82 (25.0)	~81 (24.7) to 82 (25.0)	4.85 (12.319)

	Casing Type	Casing Diameter (I.D.) [inches (cm)]	Casing Depth [feet (m) below surface]	Type of Screen	Screen Diameter [inches (cm)]
Well 92	steel	6 (15.24)	19 (5.8)	none	na
Well D-10	steel steel	10 (25.40) 6 (15.24)	13.6 (4.1) 200 (61)	none	na
Well 8802D	steel stainless steel	10 (25.40) 2 (5.08)	10.7 (3.3) 210.6 (64.2)	wire wrapped	2 (5.08)
Well 9301	steel galvanized steel	8 (20.32) 1 (2.54)	20.6 (6.3) 228 (69.5)	saw slotted	1 (2.54)
Well 9302	steel galvanized steel	8 (20.32) 1 (2.54)	28.6 (8.7) 228 (69.5)	saw slotted	1 (2.54)
Well 77-2	steel steel PVC	24 (60.96) 5 (12.70) 3 (7.62)	18.8 (5.7) 18.8 (5.7) 86 (26.2)	none	na
Well 78-1	steel steel PVC	8 (20.32) 6 (15.24) 3 (7.62)	18.8 (5.7) 18.8 (5.7) 81 (24.7)	none	na

Well 92 was drilled using air-rotary, wireline-core drilling methods (Hubbell, 1990). The well has a 6-inch (15-cm) inside diameter (I.D.) surface casing installed to the surface-sediment/basalt interface at a depth of 19 feet (6 m), and was drilled open hole (uncased) to 247 feet (75 m) (Barraclough et al., 1976). The sedimentary interbed at 240 feet was cored, and then cement was poured into the bottom of the hole to decrease its depth to 213.5 feet (65.1 m) (Hubbell, 1990).

During drilling, perched water was detected at 212 feet (65 m), and drilling was temporarily halted at a depth of 223 feet (68 m). The day after drilling was halted, 11 feet (3 m) of standing water was observed in the hole (Barraclough et al., 1976). After the hole was drilled to 247 feet (75 m), and before it was cemented, a neutron log was run on the hole. The neutron log kicked to the left from 212 to 224 feet (65 to 68 m), indicating an increase in moisture at this depth (Hubbell, 1990). This suggests that the perched zone is about 12 feet (4 m) thick in Well 92.

Well 92 lies in a small topographic depression that allows standing water to accumulate around the well for short periods of time following snowmelt or large precipitation events. This depression was created during topographic recontouring in 1985 (Hubbell, 1990).

Well D-10

Well D-10 was drilled in 1987 using air-rotary drilling methods. This well lies in the western portion of the SDA (Figure 6). The surface elevation at Well D-10 is 5,014.01 feet (1,528.27 m) above mean sea level.

The surface casing is 10-inch (25-cm) I.D. steel, and extends from the surface to the surface-sediment/basalt contact at 13.6 feet (4.15 m). The well was originally drilled to a depth of 238 feet (72.5 m). Cement was poured into the bottom 35 feet (11 m) of the hole. Six-inch (15-cm) I.D. casing was welded at the surface and the casing hangs to 200 feet (61 m) below the ground surface. There is about 3 feet (1 m) of open space between the top of the concrete in the bottom of the well and the bottom of the casing for water to enter the well. Some water-level fluctuations were observed shortly after the well was drilled, but it has remained constant during recent years. Due to this behavior, there is some debate as to whether the water in this well is left from the drilling or is actually perched water (J. M. Hubbell, 1993, oral communication).

Well 8802D

Well 8802D lies in the northeastern portion of the SDA (Figure 6) adjacent to an unlined drainage ditch exiting the RWMC (Hubbell, 1990). The well was placed here because of proximity to the ditch, and was drilled to monitor perched water (Hubbell, 1990). This is the only well that was completed specifically for the study of perched water (J. M. Hubbell, 1995, oral communication).

This well was drilled in 1988 and 1989 using air-rotary, wireline-core methods. It has a surface elevation of 5,008.16 feet (1,526.49 m) above mean sea level. It has 10-inch (25-cm) I.D.steel casing which extends from the surface to the surface-sediment/basalt contact at 10.7 feet (3.26 m). Two-inch (5-cm) I.D.stainless-steel casing extends from the surface to 220.6 feet (67.24 m) below ground surface. The final 10 feet (3 m) of the casing (210.6 to 220.6 feet [64.19 to 67.24 m] below ground surface) consists of a wire-wrapped screen. The hole was drilled 8 inches (20 cm) in diameter, and the annular space between the screen and the borehole is filled with a 8-12 (U. S. Standard Sieve Series) silica sand in the bottom 14.1 feet (4.3 m) of the hole. The annular space between the casing and the borehole was filled with granular bentonite through the next 7.7 feet (2.30 m). Above this, the annular space between the casing and the borehole was filled with a bentonite slurry, which formed a dense grout and extended to the surface.

Wet cores were recovered during the drilling, and so the hole was allowed to sit overnight. The following morning 6 inches (15 cm) of standing water were in the hole and no further drilling took place (Hubbell, 1990).

Wells 9301 and 9302

Wells 9301 and 9302 were drilled in 1992 for use as vapor-vacuum-extraction monitoring holes. A down-hole hammer was used as the drilling method for both wells. Like the other wells, these two wells have a 4-foot square (1.3 m by 1.3 m) concrete pad around the well casing, but these wells have a small wood-framed building on the concrete pad.

Well 9301 has steel outer casing with an I.D. of 8 inches (20 cm) that extends to 20.6 feet (6.28 m) below the surface. The inner casing is 1-inch (2.5-cm) I.D. galvanized steel that extends from the surface to a depth of 228 feet (69.5 m). This stainless-steel casing has a saw-slotted screen from 224 to 228 feet (68.3 to 69.5 m), and the total depth of the hole is 238 feet (72.5 m). Well 9301 has a surface elevation of 5,015.96 feet (1,528.86 m) above mean sea level.

Well 9302 was completed at the same time as Well 9301 and was completed identically, with the exception that the 8-inch (20-cm) I.D. outer casing of Well 9302 extends to a depth of 28.6 feet (8.72 m). It too has a saw-slotted screen from 224 to 228 feet (68.3 to 69.5 m), and a total hole depth of 238 feet (72.5 m). The surface elevation of Well 9302 is 5,015.76 (1,528.80 m). Both wells lie in the central portion of the SDA (Figure 6). Well 9302 is 85 feet (26 m) due east of Well 9301.

Wells Completed into the Interbed at 110 Feet

Well 77-2

Well 77-2 was drilled in the western part of the SDA (Figure 6) in 1977. It was drilled in an area known as the Early Waste Retrieval Area, and the reason for drilling it was to penetrate into the zone beneath buried transuranic waste in deteriorated containers (Humphrey and Tingey, 1978).

This well was drilled using an air-rotary, wireline-core drilling rig. Due to an unstable drillhole that resulted in caving, plaster of paris (semihydrated calcium sulfate, $CaSO_4 \cdot \frac{1}{2}H_2O$) was placed in the hole to stabilize the well walls (Hubbell, 1990). After drilling through the plaster, 1 to 2 feet (0.3 to 0.6 m) of water was measured at a depth of 87 feet (27 m).

This well was completed at the surface with 24-inch (61-cm) I.D. steel casing that was filled with concrete and drilled out, and the drilled hole was lined with steel casing 5 inches (13-cm) I.D. The larger and smaller casings, and the concrete filling the annular space between them, extend to the surface sediment/basalt contact at 18.8 feet (5.73 m) below the surface.

Well 77-2 was capped and buried during topographic recontouring at the SDA in 1985. In August 1989 the casing was excavated, extended to the ground surface, and a locking cap was added. Three-inch (7.6-cm) I.D. PVC pipe was placed inside the smaller casing, and was held just off the bottom of the well. Rags were stuffed into the annular space between the smaller casing and the PVC, and cement was poured into the annular space; thus, the PVC was hung inside of the well. The present surface elevation of this well is 5,013.61 feet (1,528.15 m) above mean sea level.

Standing water was detected in this well in March of 1990 (Hubbell, 1990). By July of 1990, this well was dry, and has remained dry since (J. M. Hubbell, 1993, oral communication).

Well 78-1

Well 78-1 lies in the southeastern portion of the SDA (Figure 6). It was drilled using air-rotary, wireline-core drilling methods. It lies in an area where radioactive waste was retrieved. The pit that was excavated subsequently was filled with clean fill (Hubbell, 1990). One to 2 feet (0.3 to 0.6 m) of water were detected at 82 feet (25 m) while the well was being drilled in 1978.

Well 78-1 has 8-inch (20-cm) I.D. and 6-inch (15-cm) I.D. steel casings, with concrete filling the annular between them and extending from the surface to the surface-sediment/basalt contact at a depth of 18.8 feet (5.73 m).

This well was also capped and buried during topographic recontouring. It too was excavated in August 1989, had 3-inch (7.6-cm) I.D. PVC casing hung inside it, and was made accessible. The PVC casing extends from the surface nearly to the bottom of the hole. Water is able to enter the well through the small gap between the bottom of the casing and the bottom of the hole. Its current ground-surface elevation is 5,009.28 (1,526.83 m) above mean sea level.

Wells V-9 and V-10

During the summer of 1994, after the data for this study were collected, two additional wells were drilled into the perched zone associated with the interbed at 110 feet, and water was detected in both wells (J. M. Hubbell, 1995, oral communication). No water-level data, completion data, or chemical data are available for these two wells. The only use of these two wells in this study is to help determine the lateral extent of the upper perched zone.

Field Work

Monthly trips were made to the RWMC beginning in July of 1993, and continued until June of 1994. On each monthly trip, the data logger at each well was down-loaded. The data loggers were installed in March of 1993, by INEL personnel. If there appeared to be any problems with the data loggers, these problems were relayed to INEL personnel who addressed them.

Manual water-level measurements were made on each of these monthly visits. Well D-10 was visited first each time, and a manual water level was taken with both a steel tape and a Solinst well sounder. The well sounder stretched as it was lowered down the well, and, by taking measurements with both instruments, the stretch in the Solinst was corrected. The Solinst was used to take manual measurements in each of the other six wells.

The down-loaded data were taken to the office where any drift in the transducers was corrected by means of the corrected manual measurements. This was the primary reason for taking manual water-level measurements.

On February 22, 1994, an attempt was made to take a sample from Well 78-1. A semiporous stainless-steel pressure sampler provided by INEL was used. This sampler had a negative pressure applied to it, and then was lowered into the water at the bottom of the well. The negative pressure was supposed to draw water through the semiporous stainless-steel cap. However, after 2 hours only 70 milliliters (ml) of water was obtained.

On March 22, 1994, another attempt was made to sample Well 78-1. This time a ball-valve stainless-steel bailer from Utah State University was used. Approximately 1 liter of water was obtained. It must be noted that, due to the small volume of water available, the well was not purged, and thus the water sample was probably exposed to the atmosphere and the well casing for some time.

During this same visit, snow on the ground surface was collected in a large beaker. It was melted by means of the heater in the truck. This melted water was analyzed as a snowmelt sample.

On June 14, 1994, a sample of water was taken from the Big Lost River where Highway US-93 crosses it about 6 miles (10 km) north of Darlington, Idaho. This site is approximately 30 miles (48 km) upstream of the spreading areas. The Big Lost River was sampled at this location rather than at the spreading areas because, during 1994, all of the water in the Big Lost River was diverted for irrigation and none of it reached the INEL. The original plan was to sample the Big Lost River where it is diverted into the spreading areas. However, this sampling site was the nearest one possible.

A detailed cation-anion study was planned, but, because of the small amount of water available in the wells and due to INEL restrictions, only one groundwater sample could be obtained. The analyses of this groundwater sample and the two surface-water samples, and water-level measurements from seven wells for 14 months comprise the data collected for this investigation.

Geochemical Methods

The water samples were collected in a large beaker in the field, filtered through a 0.45-micron Teflon positive-pressure filter, and then poured in equal portions into three polyethylene sample bottles. One portion was preserved by acidifying with nitric acid (NHO_3) to a pH of 2. Another portion was acidified with sulfuric acid (H_2SO_4) to a pH of

2. The final portion was not treated. All three portions of each sample were placed on ice in an ice chest. They were taken to Utah State University and stored in a refrigerator until they could be delivered to the laboratory for analysis. The samples were again placed on ice in an ice chest and delivered to the Earth Science Laboratory at the University of Utah Research Institute (UURI) in Salt Lake City, within 5 days of being collected, to be analyzed for total dissolved solids (TDS), electrical conductivity (EC), pH, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), bicarbonate (HCO_3), carbonate (CO_3), fluoride (F), sulfate (SO_4), total iron (Fe), aluminum (Al), silica (SiO_2), chloride (Cl), boron (B), phosphate (PO_4), lithium (Li), strontium (Sr), zinc (Zn), silver (Ag), arsenic (As), gold (Au), barium (Ba), beryllium (Be), bismuth (Bi), cadmium (Cd), cerium (Ce), cobalt (Co), chromium (Cr), copper (Cu), lanthanum (La), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), tin (Sn), antimony (Sb), tellurium (Te), thorium (Th), titanium (Ti), uranium (U), vanadium (V), tungsten (W), and zirconium (Zr).

A small portion of the sample was retained in the field and measured for alkalinity, electrical conductivity, temperature, and pH. The alkalinity was measured with a Hach Alkalinity Test Kit model AL-AP, which is accurate to within 25 milligrams per liter (mg/l) of $CaCO_3$. The alkalinity was then converted to bicarbonate for comparison with the laboratory value of bicarbonate. EC and temperature measurements were taken with a YSI model 33 EC/salinity/temperature meter, and pH measurements were taken with an Orion model 230A pH meter.

RESULTS

Water-Level Data

The seven monitored wells were equipped with Hermit model SE 1000c or Well Sentinel model LTM 3000 data loggers manufactured by InSitu, Inc., attached to down-hole transducers. The data loggers began recording water elevations on March 29, 1993, and recorded at 4-hour intervals until May 31, 1994.

Wells Completed into the Interbed at 240 Feet

The five wells completed into the interbed at 240 feet are Well 92, Well D-10, Well 8802D, Well 9301, and Well 9302.

Well 92

Well 92 was equipped with a Well Sentinel model LTM 3000 data logger. Each manual measurement revealed standing water in this well. The plot of the data collected is shown in Figure 8.

Figure 8 shows a trend that would generally be expected based on recharge from precipitation. A gradual decline in water level occurred from late March 1993 to late October 1993, and a gradual rise occurred from early November 1993 through early March 1994.

Two portions of the plot do not show what is expected. First, in July of 1993 there was a sudden rise in water level. Such a rise might be expected due to precipitation, but July is typically dry in this area, and this rise persisted throughout the month. It

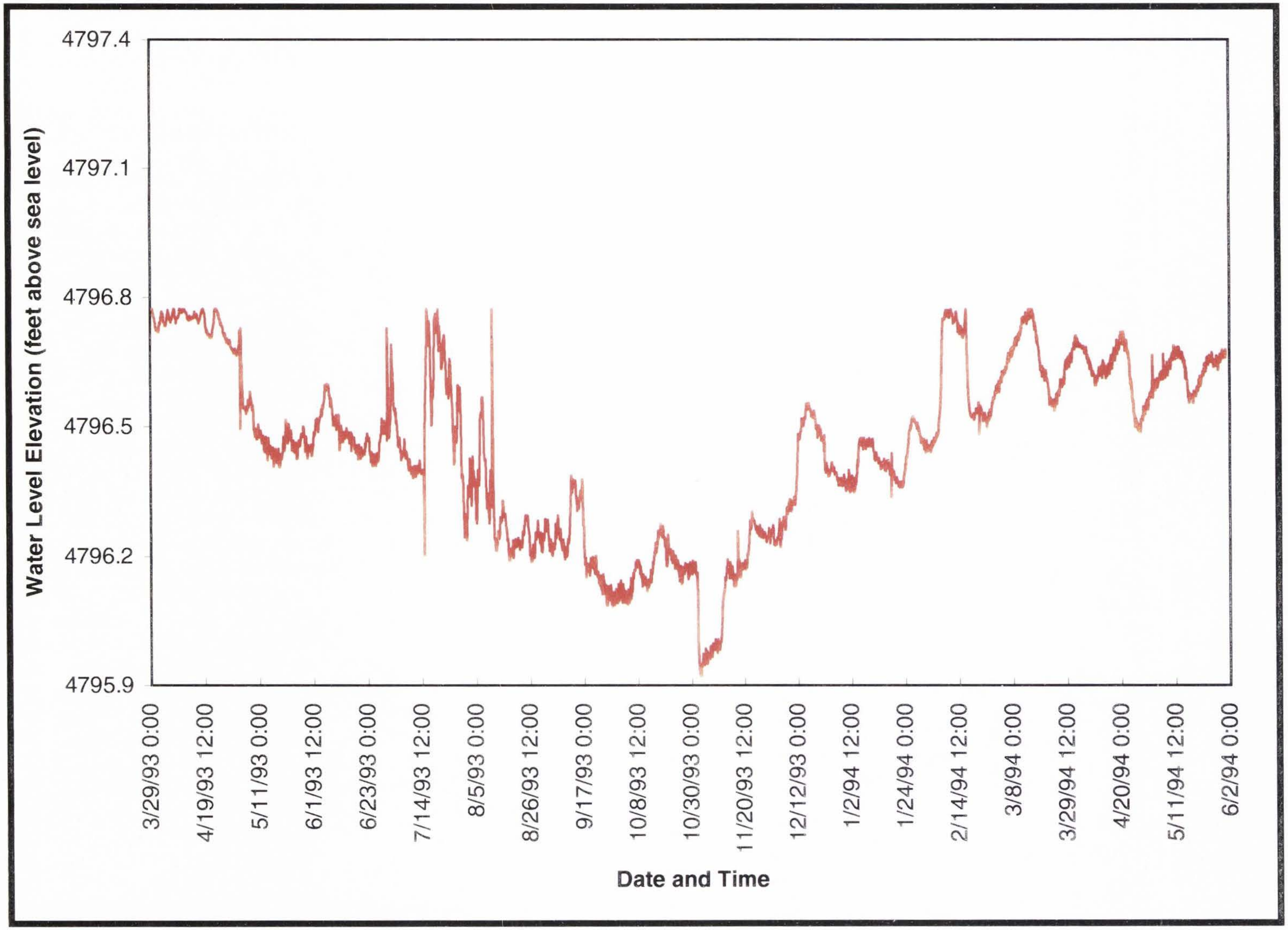

Figure 8. Water levels recorded for Well 92, March 29, 1993 to May 31, 1994.

appears that a slug of water moved through the interbed at 240 feet in this area at this time.

Secondly, from February of 1994 through May of 1994, there are several relatively large fluctuations in the water level. This could be due to cyclic precipitation events and/or large temperature fluctuations that led to uneven snowmelt. These fluctuations could also be due to changes in barometric pressure, but this seems unlikely. Although the magnitudes of the fluctuations are comparable to what would be expected due to changes in barometric pressure, the durations are too long. Typically, barometric pressure fluctuations last for a few days, but the fluctuations observed here last on the order of 3 weeks.

Well D-10

Well D-10 was also equipped with a Well Sentinel model LTM 3000 data logger. This data logger malfunctioned, and did not record data from January 18, 1994, until February 14, 1994. An inspection of the data from this well (Figure 9) suggests that no vital data were lost.

Each manual measurement of the water level in this well revealed standing water. This well was always measured manually with both a steel tape and a well sounder.

The data collected from this well (Figure 9) indicate that this well was not recharged during the period of study. During the 14 months that data were collected, the water-level elevations recorded by the data logger differed by only 0.058 foot (1.77 cm), and the manual water-level elevations differed by only 0.06 foot (1.83 cm). This is

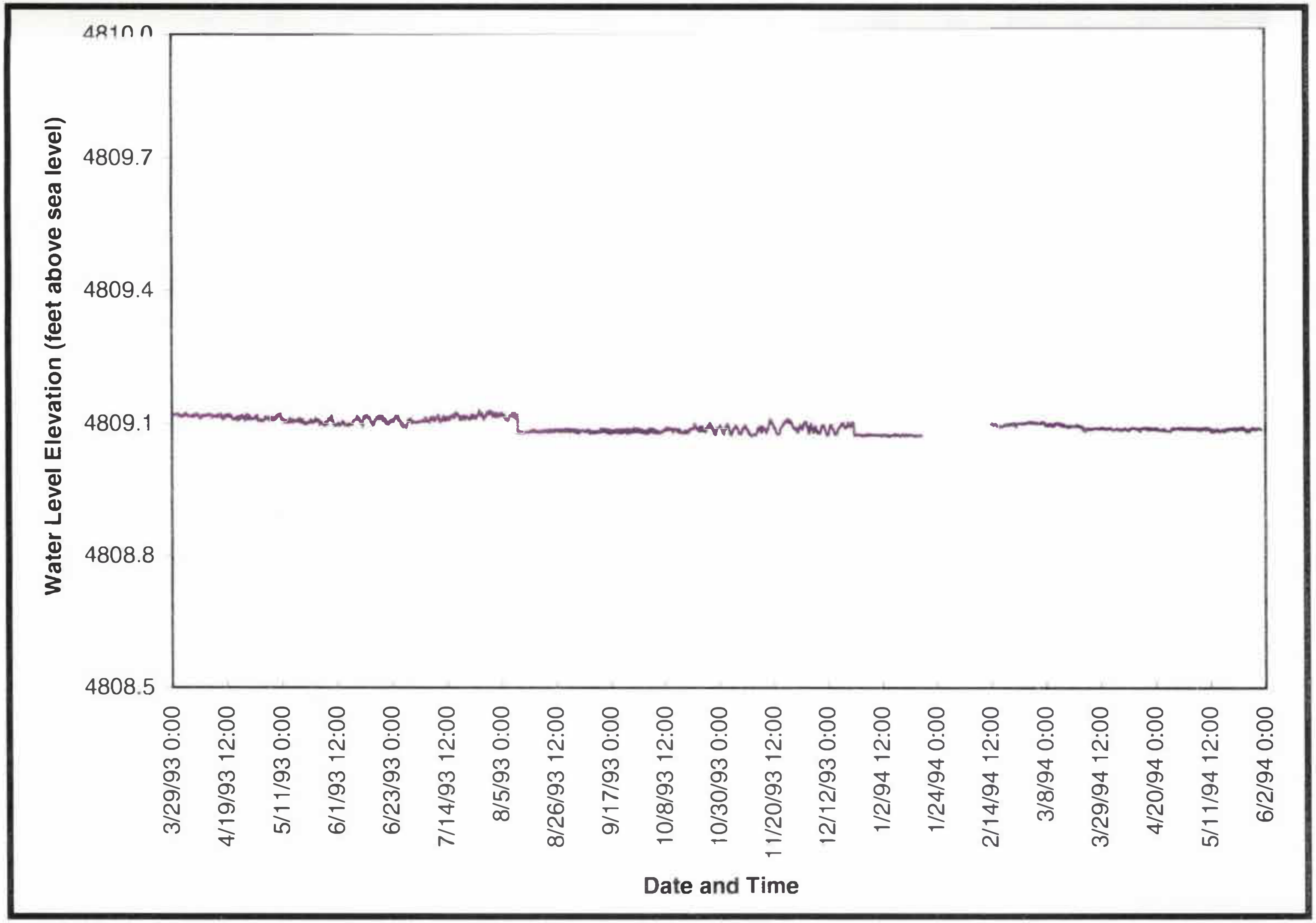

Figure 9. Water levels recorded for Well D-10, March 29, 1993 to May 31, 1994.

significant because three other wells drilled to this depth had fluctuations on the order of 1 foot (30 cm) (one well had no water throughout the period of the study). Also, the three other wells with water in them had standing water at an elevation between 4,780 and 4,795 feet (1,457 to 1,462 m) above mean sea level, whereas Well D-10 had a water-level elevation of roughly 4,809 feet (1,466 m) above mean sea level. Thus, three wells with standing water had water-level elevations within a range of 15 feet (4.6 m) and showed fluctuations on the order of 1 foot (30 cm), but the water level in Well D-10 was 14 feet (4.3 m) above the range of 15 feet (4.6 m) of the other three wells and it had fluctuations of only about 0.06 feet (1.8 cm). Furthermore, some INEL personnel believe that the water in well D-10 is left over from drilling and is not actually perched water. For these reasons, the standing water in Well D-10 probably does not indicate the existence of a perched water body at this location and depth.

Well 8802D

Well 8802D was equipped with a Well Sentinel model LTM 3000 data logger. This data logger malfunctioned, and gave erroneous results from February 22, 1994 to May 31, 1994. An unsuccessful attempt was made to correct these data. Only two manual measurements were available during this period, and this was an insufficient number of points with which to make the necessary corrections. The two data points were connected with a straight line that shows an overall decline during this time.

The data gathered from this well are plotted in Figure10. The data plotted on Figure10 suggest that the water level in this well peaked at 4,787.93 feet (1,459.36 m) on

February 18, 1994, and then underwent an initial rapid decline, which was probably followed by a more gradual decline. The peak on February 18, 1994 seems odd when viewed within the context of the rest of the plot, but a rise in water level in the early spring would be expected due to precipitation and snowmelt.

Another peak water-level elevation in February of 1993 (prior to data collection) and a general overall water-level decline from then until the late fall or early winter of 1993 would be expected if this well is recharged exclusively by precipitation. However, this does not appear to be the case. A general decline is observed from late July to mid-November of 1993, as expected, but several large fluctuations occurred during the late spring (March 29) to mid summer (late July) rather than the expected decline. It should also be noted that the last of these fluctuations lasted longer than any of the previous ones. This final fluctuation began to rise on about July 17, peaked on August 8, and then continued to decline until about November 15. As in Well 92, this water-level rise appears to be unrelated to precipitation.

Well 9301

Well 9301 was dry on each visit. The well was equipped with the Hermit model SE 1000c data logger. The data logger also demonstrated that no standing water was in Well 9301 during the period of this study.

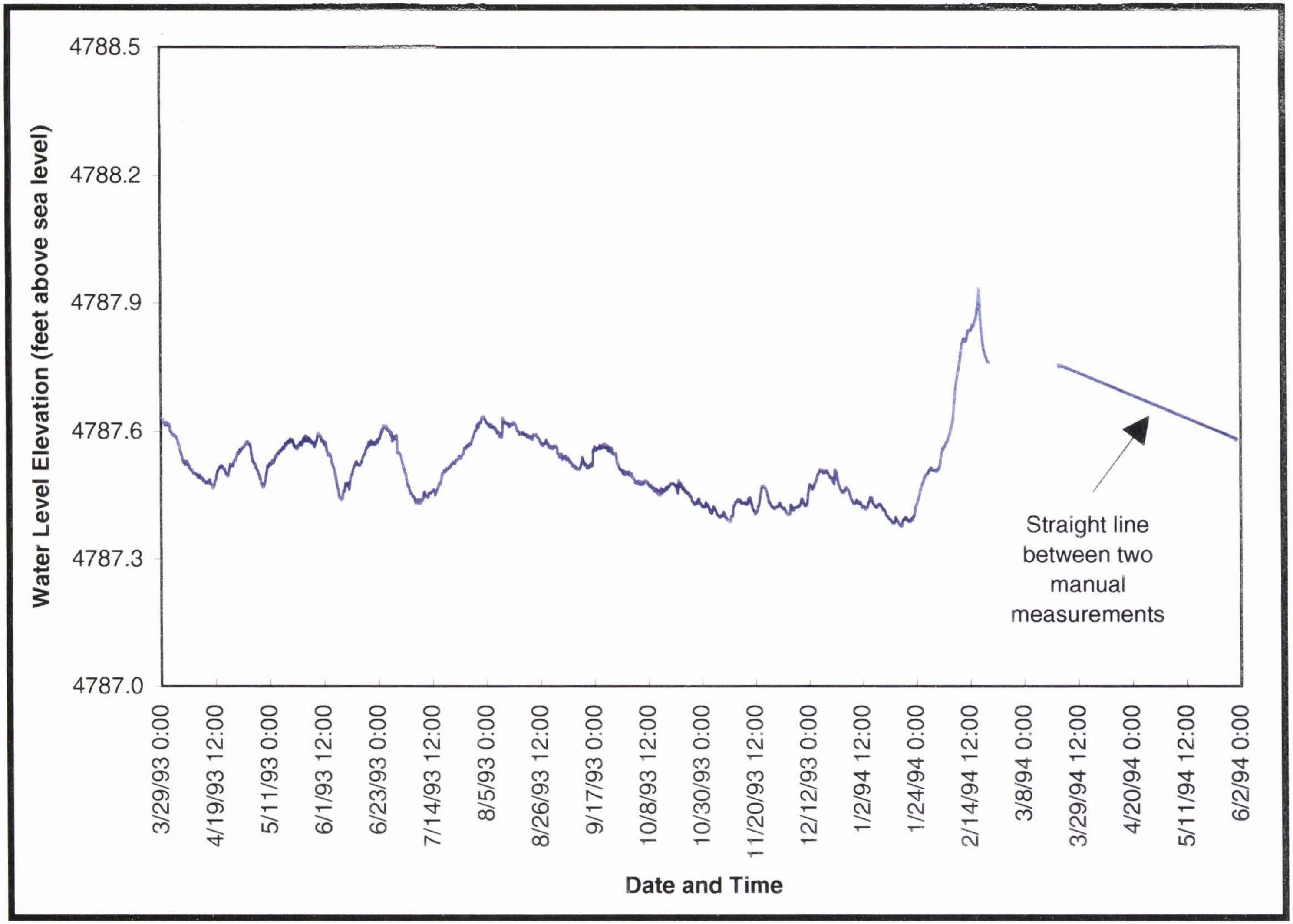

Figure 10. Water levels recorded for Well 8802D, March 29, 1993 to May 31, 1994.

Well 9302

Well 9302 was equipped with a Well Sentinel model LTM 3000 data logger. The data logger and manual measurements agreed that this well was dry for part of the study period.

The data from Well 9302 are plotted on Figure11. This well was dry until late June of 1994, when water appeared in the well and rose fairly rapidly. The water level peaked on August 11, 1993, and then began to decline. After some decline, the water level began to fluctuate until the well finally went dry in February of 1994.

The data also show that the well went dry for a few weeks between November 24 and December 16, 1993, when the well received another slug of water. Field visits were made on November 17 and December 22, 1993, and both visits revealed small amounts of water in the well.

The field visit on February 22, 1994 showed a small amount of water in the bottom of the well, but it was such a small amount (~0.02 foot [0.6 cm]) that it was not measurable with the well sounder and had to be measured with the steel tape. This is the same day that the data logger recorded the well going dry.

This well does not seem to be affected by precipitation, but apparently is influenced by some other source of water. The typical decline in water level from winter to summer and increase in water level during the winter and early spring observed in Wells 92 and 8802D are not seen here. Instead, a rapid rise in water level in the mid summer is observed.

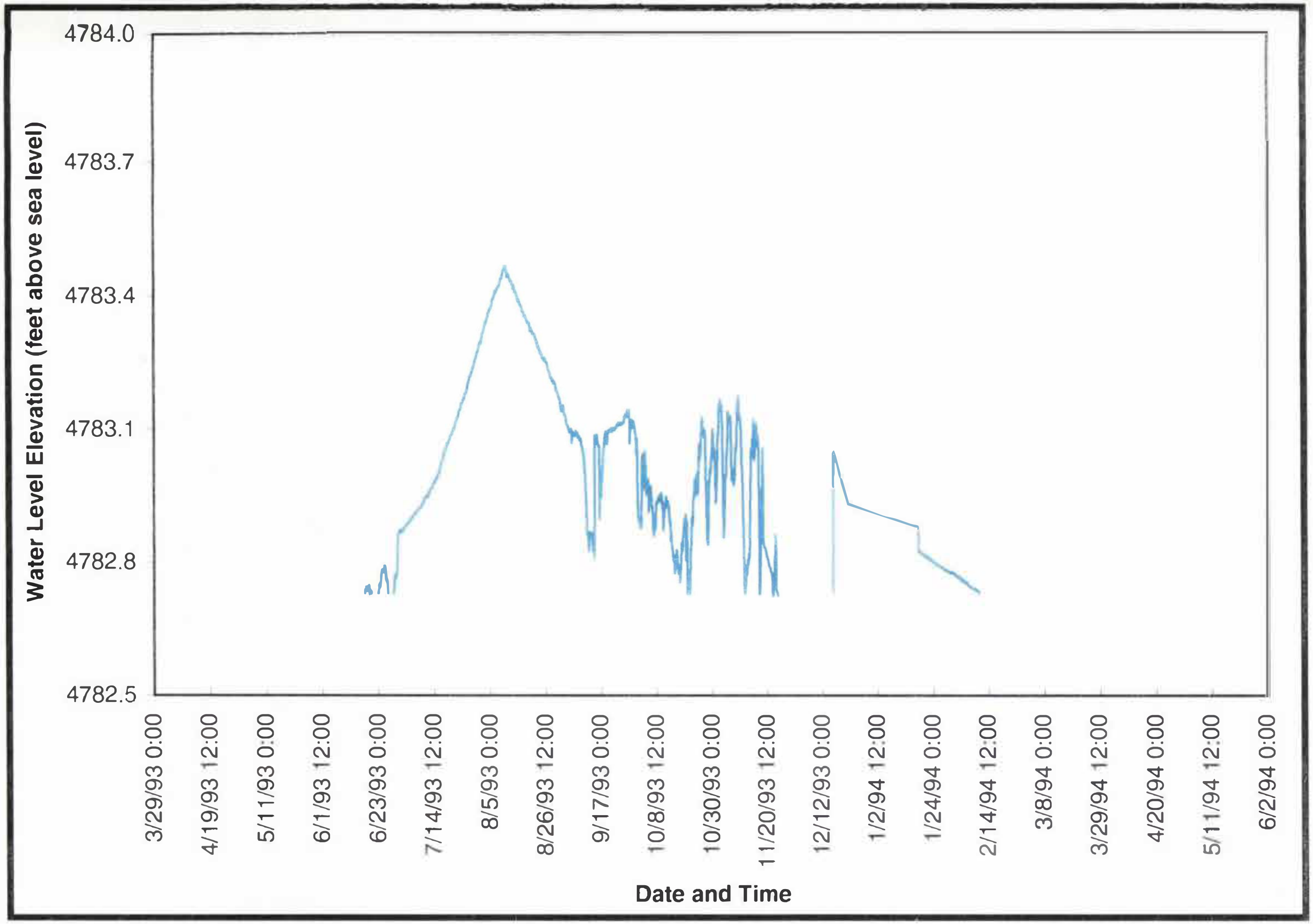

Figure 11. Water levels recorded for Well 9302, March 29, 1993 to May 31, 1994.

Wells Completed into the Interbed at 110 Feet

Four wells are completed into the interbed at 110 feet. These wells are 77-2, 78-1, V-9, and V-10. No water-level data are available for Wells V-9 and V-10.

Well 77-2

Well 77-2 was equipped with a Hermit model SE 1000c data logger. Both the data logger and manual measurements showed the well to be dry throughout the period of this study.

Well 78-1

Well 78-1 also was equipped with a Hermit model SE 1000c data logger. A plot of the data collected from this well is shown in Figure12.

This well is probably the most critical well in this study because it is the only well in the interbed at 110 feet that contained any water, and it is the only well that was sampled. Despite the importance of this well, its data logger suffered two malfunctions. The first was from June 2 to July 7, 1993, and the second was from November 25, 1993, to February 14, 1994. The first malfunction occurred when the well was dry, but the second malfunction was significant. A slug of water began moving into the well in late October of 1993 and remained until mid-April of 1994. The data for a large portion of this time were not recorded due to the second malfunction.

The data from this well indicate that it is probably affected by precipitation. The water level in this well increased in the late fall and winter, and declined in mid to late

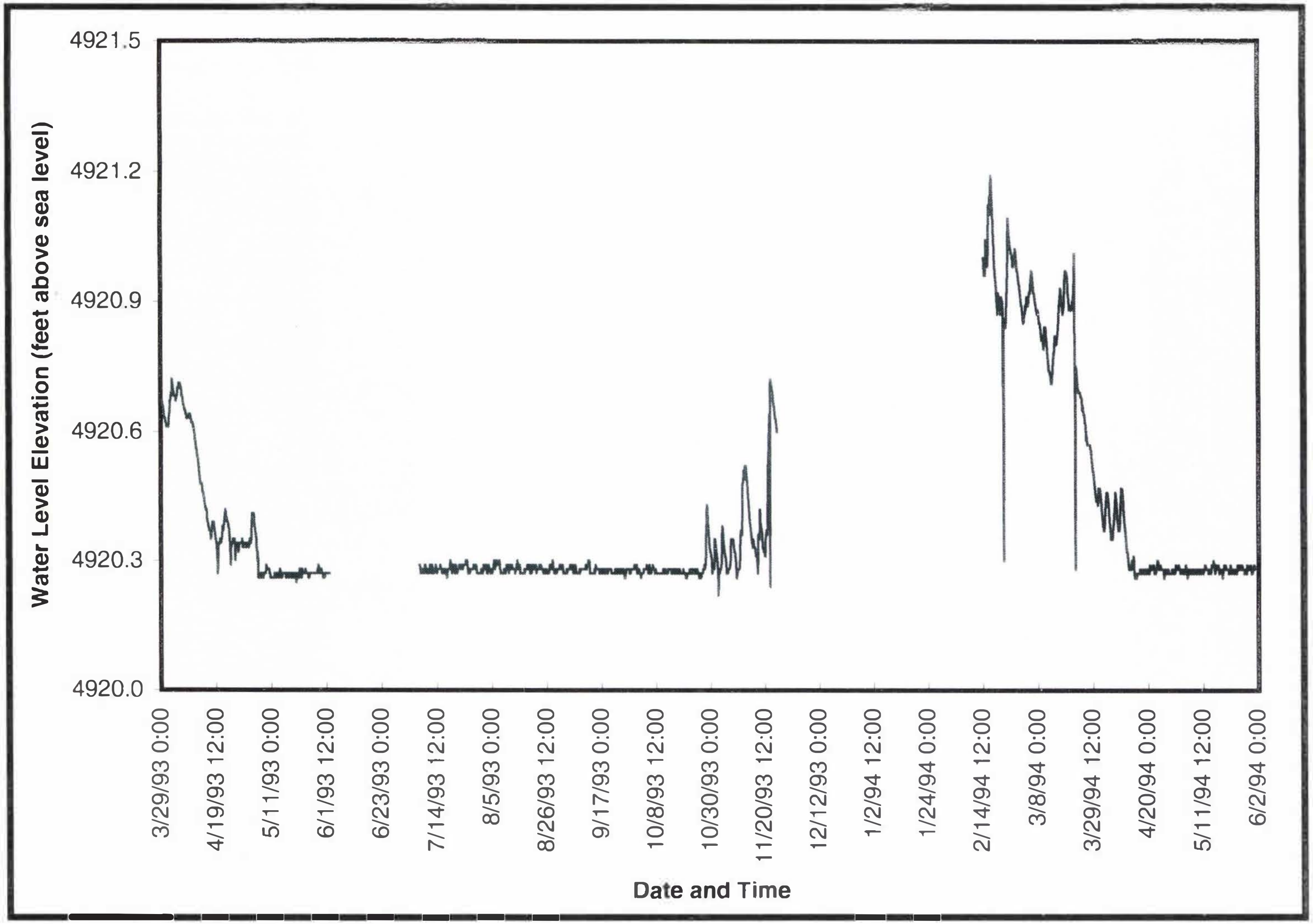

Figure 12. Water levels recorded for Well 78-1, March 29, 1993 to May 31, 1994.

spring. Late fall, winter, and early spring are the times of greatest precipitation, and spring is the time when snowfall melts in southeastern Idaho. Thus, the water level in this well follows a typical precipitation-recharge pattern.

Figure13 shows the details of a smaller portion of the data collected from Well 78-1. On two occasions between February 14 and April 11, 1994, there were major drops in the water level. Both of these drops were due to the removal of water for samples.

The significant observation is how quickly the well recovered. This indicates that the material comprising the perched aquifer near the bottom of this well has a relatively high hydraulic conductivity.

Geochemical Data

Three water samples were obtained during this study. One was taken from Well 78-1, which is completed in the perched zone associated with the interbed at 110 feet, on March 22, 1994. The second was obtained by melting snow from the ground surface within the SDA on March 22, 1994. The third sample was taken on June 14, 1994, from the Big Lost River where Highway US-93 crosses it about 6 miles (10 km) north of Darlington, Idaho.

Alkalinity, EC, pH, and Temperature

Field measurements for alkalinity were consistent with laboratory measurements (Table 2). The differences between field and laboratory measurements of alkalinity ranged from 2 mg/l, for the snowmelt sample, to 18 mg/l, for the Big Lost River sample. This

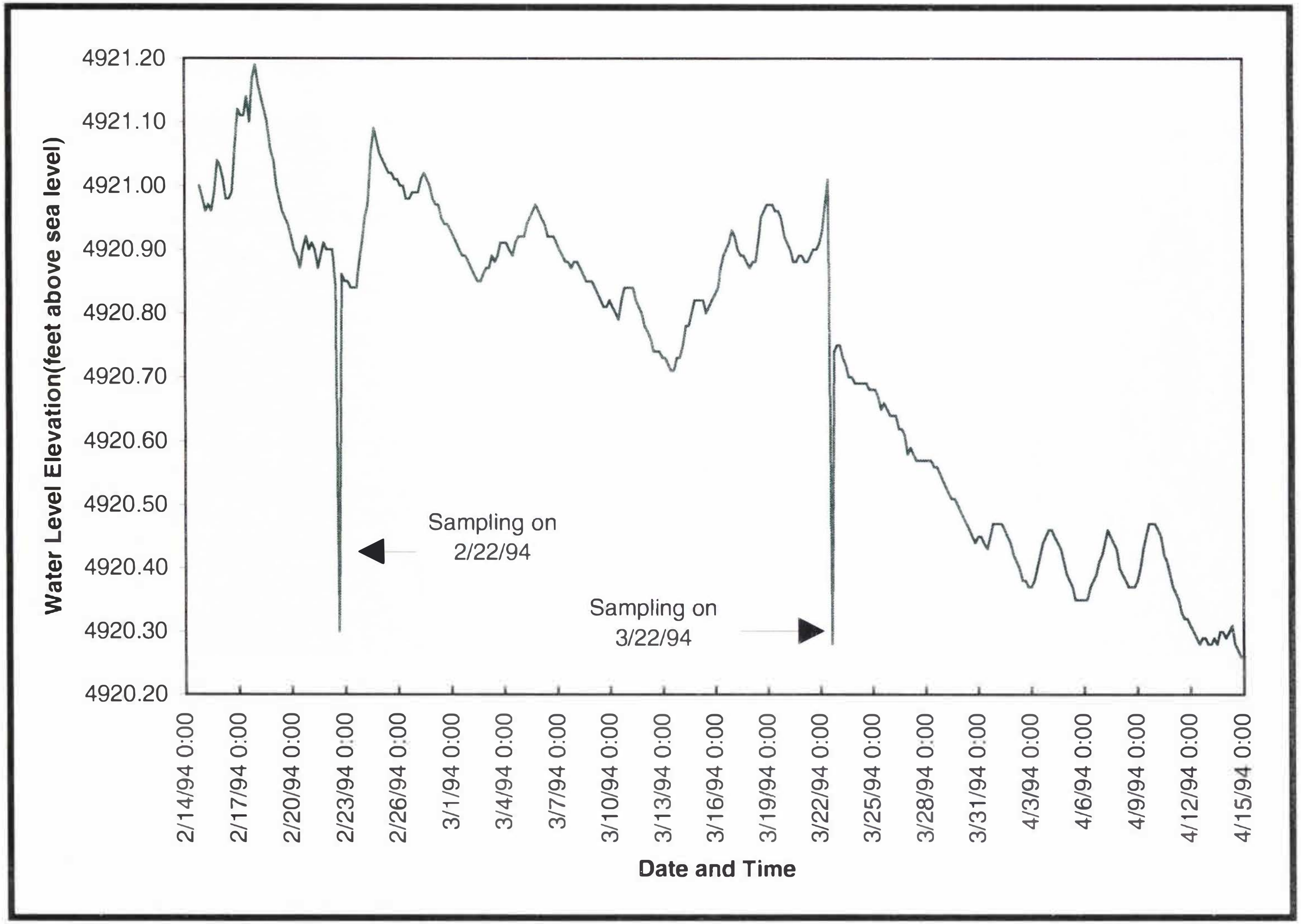

Figure 13. Water levels recorded for Well 78-1, February 14, 1994 to April 14, 1994, with the times when sampling took place.

Table 2. Field and Laboratory Values of Alkalinity, EC, pH, and Temperature

		Well 78-1	Snowmelt	Big Lost River
Field Measurements	Alkalinity (mg/l)	100.00	15.00	145.00
	EC (u mohs/cm)	145	20	102
	pH	7.55	7.37	8.09
	Temperature (C)	8.0	not measured	12.4
Laboratory Measurements	Alkalinity (mg/l)	109.00	13.00	163.00
	EC (u mohs/cm)	250	33	320
	pH	7.80	7.56	8.05

difference is slight and suggests good reliability of the field alkalinity test despite its use of a titration where each drop of titrate equals 5 mg/l of alkalinity, and the point of complete titration is based on a subjective determination of a change in the color of the solution.

The kit used to make alkalinity determinations in the field uses a pH indicator that assumes that the only species buffering the solution are carbonate and bicarbonate. Bicarbonate is the dominant species because the pH values are below nine, and this correlates with the analyses of major ions (Table 3).

Laboratory measurements of EC were considerably higher than those measured in the field by 65% to 214%. The response of EC to temperature is different for different ions, so a completely accurate temperature compensation is not feasible. However, EC values rise by about 2% with each rise in temperature of one degree Celsius (Hem, 1992).

Table 3. Concentrations of Major and Minor Ions and Trace Constituents of Water Samples

		Well 78-1 (ppm)	Snowmelt (ppm)	Big Lost River (ppm)
Major Ions	Na	11.26	0.59	4.52
	K	11.80	2.34	1.22
	Ca	26.00	3.51	42.63
	Mg	5.04	0.54	10.38
	HCO_3	109.00	13.00	163.00
	Cl	6.30	2.80	5.70
	SO_4	20.00	<1.00	17.00
Minor Ions and Trace Constituents	F	0.21	0.15	0.63
	Fe	0.05	< 0.02	< 0.02
	SiO2	7.71	4.81	18.76
	B	0.16	< 0.05	0.44
	Sr	0.09	0.01	0.21
	As	< 0.49	0.69	< 0.49

Even if field values are adjusted to 25°C, the temperature to which laboratory values are adjusted, the values are still significantly different.

Carbon dioxide from the air can be dissolved into distilled water. The resulting bicarbonate and hydrogen ions can significantly affect EC values (Hem, 1992). These samples were by no means distilled, but each bottle had significant head space which might allow some of this type of dissolution activity to take place. However, the most likely reason for the difference in field and laboratory measurements is instrument error.

Values of pH measured in the field were slightly lower than those measured in the laboratory. The difference between the field and laboratory pH values for the sample taken from the Big Lost River was only 0.04. The difference between the field and laboratory pH values for the other two samples was 0.19 for the snowmelt and 0.25 for Well 78-1. The field measurement was higher for the sample from the Big Lost River, and lower for the other two samples. The Big Lost River sample was taken about a month later, and was delivered to the lab within 2 days. The other two samples were delivered to the lab within 5 days. The different sampling times, and different periods of storage before delivery to the laboratory, could allow for these slight differences due to instrument error.

Major and Minor Ions and Trace Constituents

Each of the three water samples was analyzed for major and minor ions and trace constituents. The major ions consist of positively charged cations and negatively charged anions. In these samples, the major cations detected are Na^+, K^+, Ca^{2+}, and Mg^{2+}, and the major anions detected are alkalinity as HCO_3^-, Cl^-, and SO_4^{2-}. The minor ions and trace constituents detected are F^-, total Fe, SiO_2, B, Sr, and As. The analytical-chemistry data are presented in Table 3 and in Table 5, Appendix A. The concentrations of each major ion are plotted on a Schoeller (1955, 1962) semi-logarithmic graph in Figure14.

Figure14 indicates that the Big Lost River and well samples have similar concentrations of the major ions except for sulfate and sodium. In addition, the shape of the plot of the snowmelt sample is similar to the shape of the plots of the other samples. This indicates that the ratios of the major ions in the snowmelt sample are similar to those of the other samples. The fact that the values of the snowmelt sample plot on a different

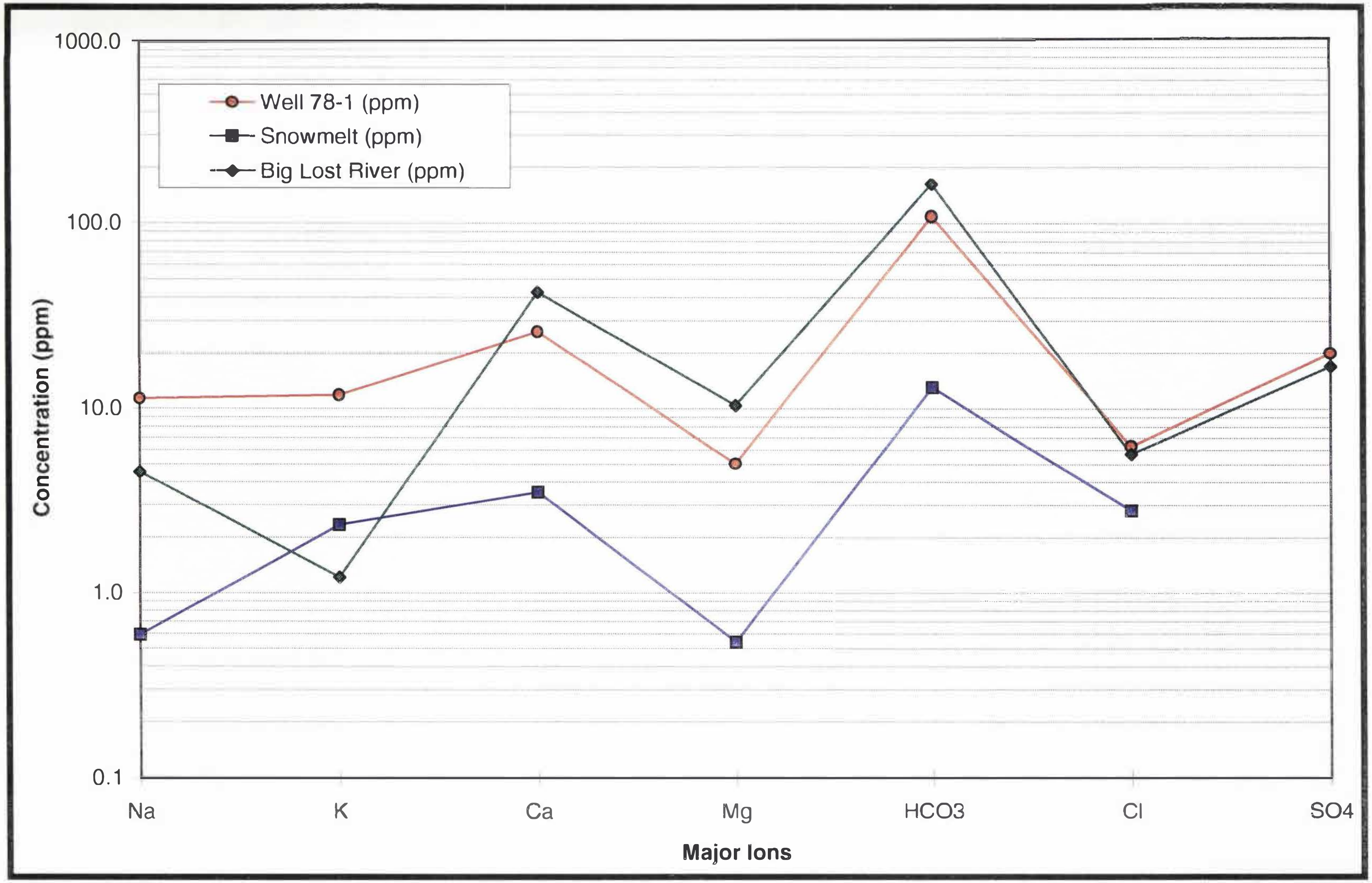

Figure 14. Schoeller (1955, 1962) semi-logarithmic plot of concentrations of major ions in the water samples.

part of the graph indicates that the actual concentrations differ. The difference in concentrations is about one order of magnitude. Also, the snowmelt contained no detectable sulfate.

Further analysis of the major ions can be done by plotting them on a trilinear (Piper, 1944) graph, as presented in Figure15. The most noticeable thing on this plot is that the percentage of major ions in the well is closest to that of the snowmelt. This is observed by looking at the total percentages in the diamond-shaped portion of the graph. Examination of the cation triangle shows a stronger similarity between the water from the snowmelt and the water from Well 78-1. However, the anion triangle reveals that the concentrations of anions in the well water are more similar to the concentrations of anions in water from the Big Lost River than in the water from snowmelt.

The minor ions and trace constituents are presented on a Schoeller (1955, 1962) semi-logarithmic graph on Figure16. From this graph, the well sample appears very similar to the sample from the Big Lost River and less similar to the snowmelt sample. Iron is detected only in the well sample. The snowmelt has arsenic and lacks boron. The other two samples lack detectable arsenic and have similar concentrations of boron. All three samples have strontium, but the concentration in the snowmelt is about one order of magnitude lower than those in the other two samples. This relationship is similar to that seen in the major ions. All three samples contain similar concentrations of fluoride and silica.

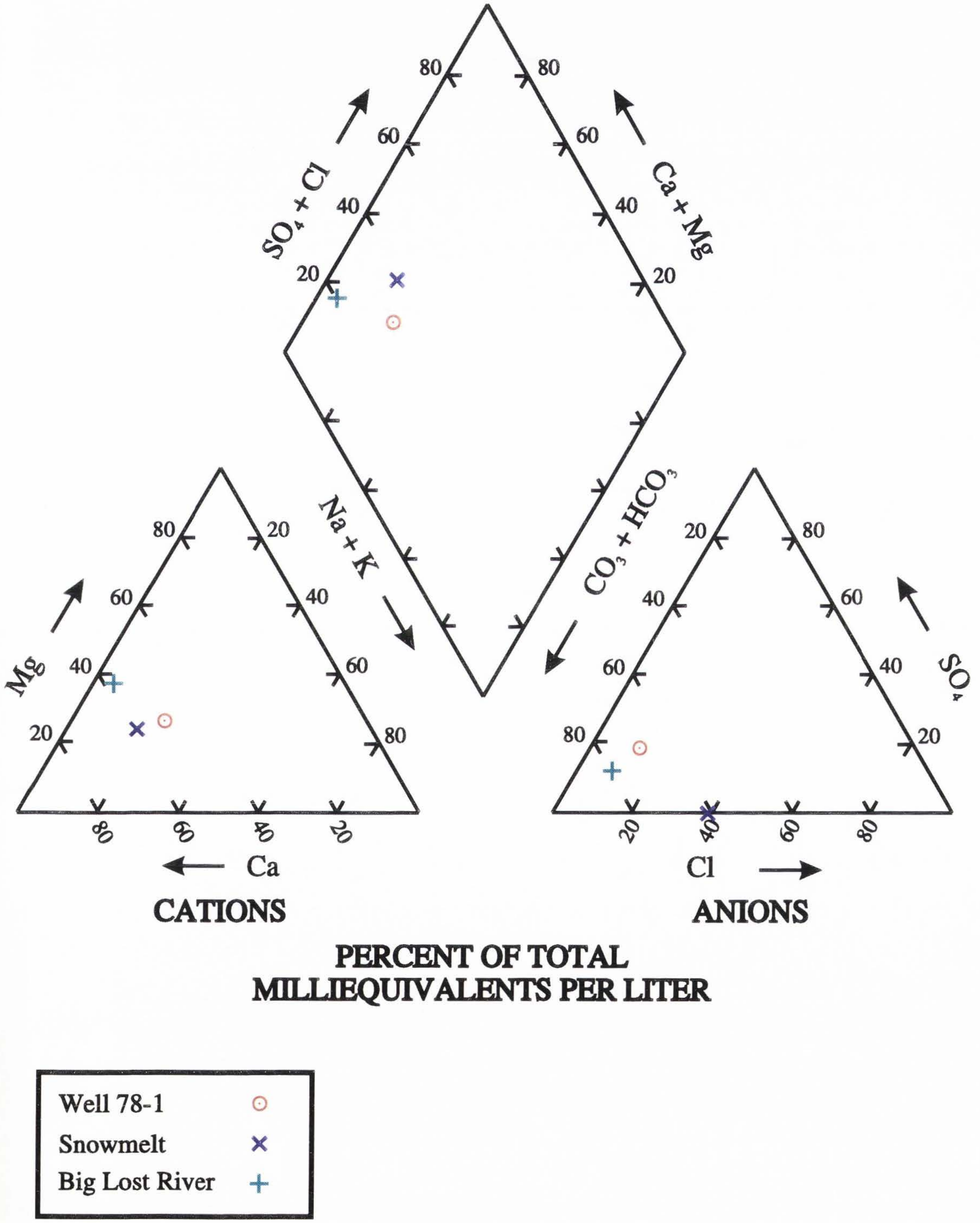

Figure 15. Trilinear (Piper, 1944) diagram showing major ions in the water samples.

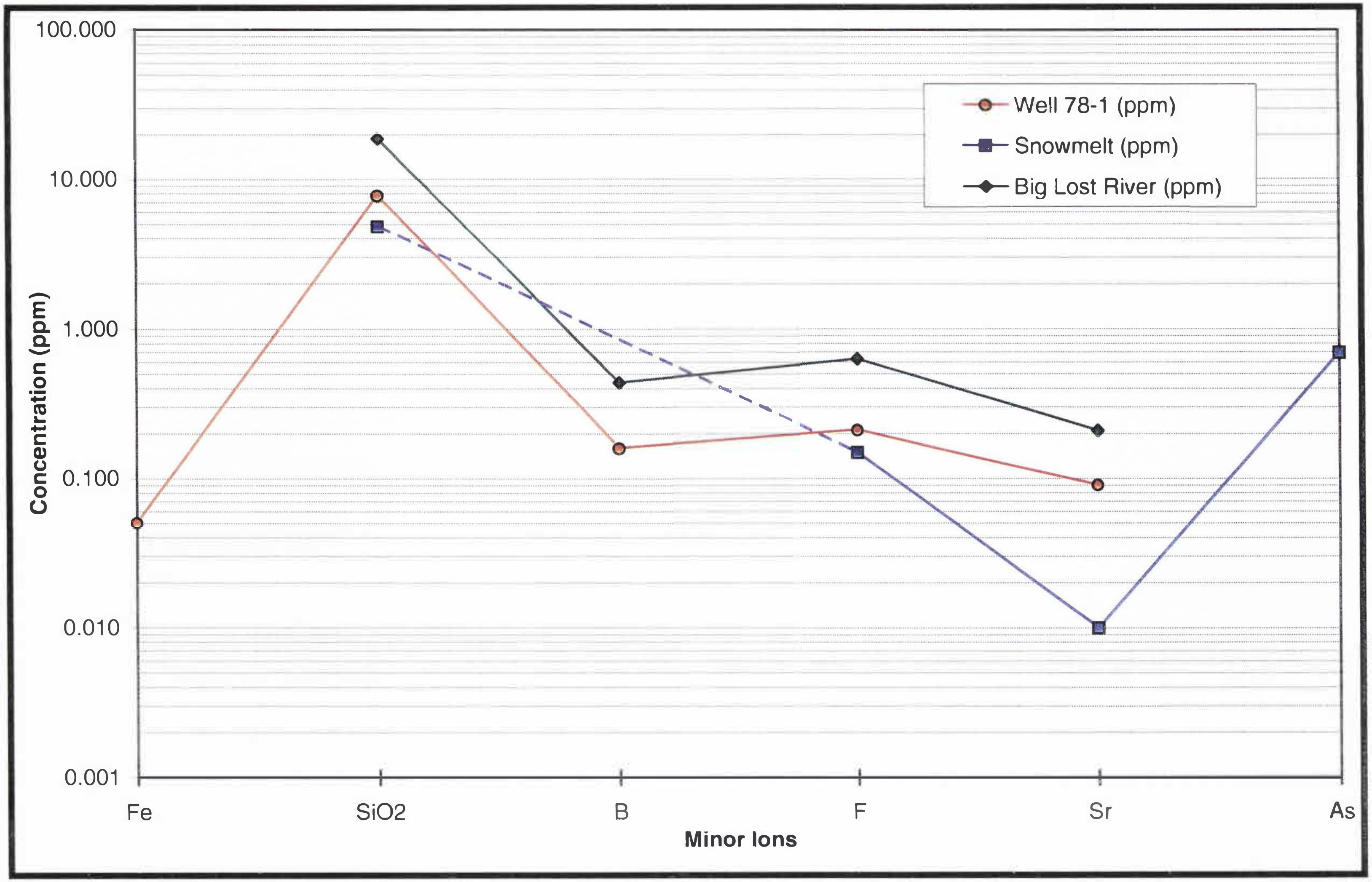

Figure 16. Schoeller (1955, 1962) semi-logarithmic plot of concentrations of minor ions and trace constituents in the water samples.

DISCUSSIONS AND INTERPRETATIONS

Lower Perched Zone

The perched zone associated with the interbed at 240 feet appears to be recharged both by water diverted into the spreading areas and by precipitation at the surface. All three wells completed into this perched zone that had measureable water during the period of study (Wells 92, 8802D and 9302) showed a considerable rise in water level around July 1, 1993, and the high water level remained throughout the month of July.

Figure17 shows the water levels for Wells 92, 8802D, and 9302 superimposed. The rise was greatest in Well 9302 (~0.75 ft) and least in Well 8802D (~0.20 ft). The rise in water level began first in Well 9302 , later in Well 92, and last in Well 8802D. Well 92 is closer to the spreading areas than Well 9302, and Well 8802D is farthest (Figure 6). For this reason, Well 92 would be expected to respond first to lateral subsurface flow from the spreading areas. However, the subsurface is undoubtedly heterogeneous, and this probably explains why the response showed up first in Well 9302.

The timing of this phenomenon is unusual in that the snow had completely melted in early March of 1993 (Figure18). There was considerable precipitation in mid-May and in early June (Figure19), but the sum of this precipitation seems inadequate to explain the 08-foot (24-cm) water-level rise observed in Well 9302. Furthermore, precipitation appears to have had no effect on the water level of Well 9302 at any other time during this study.

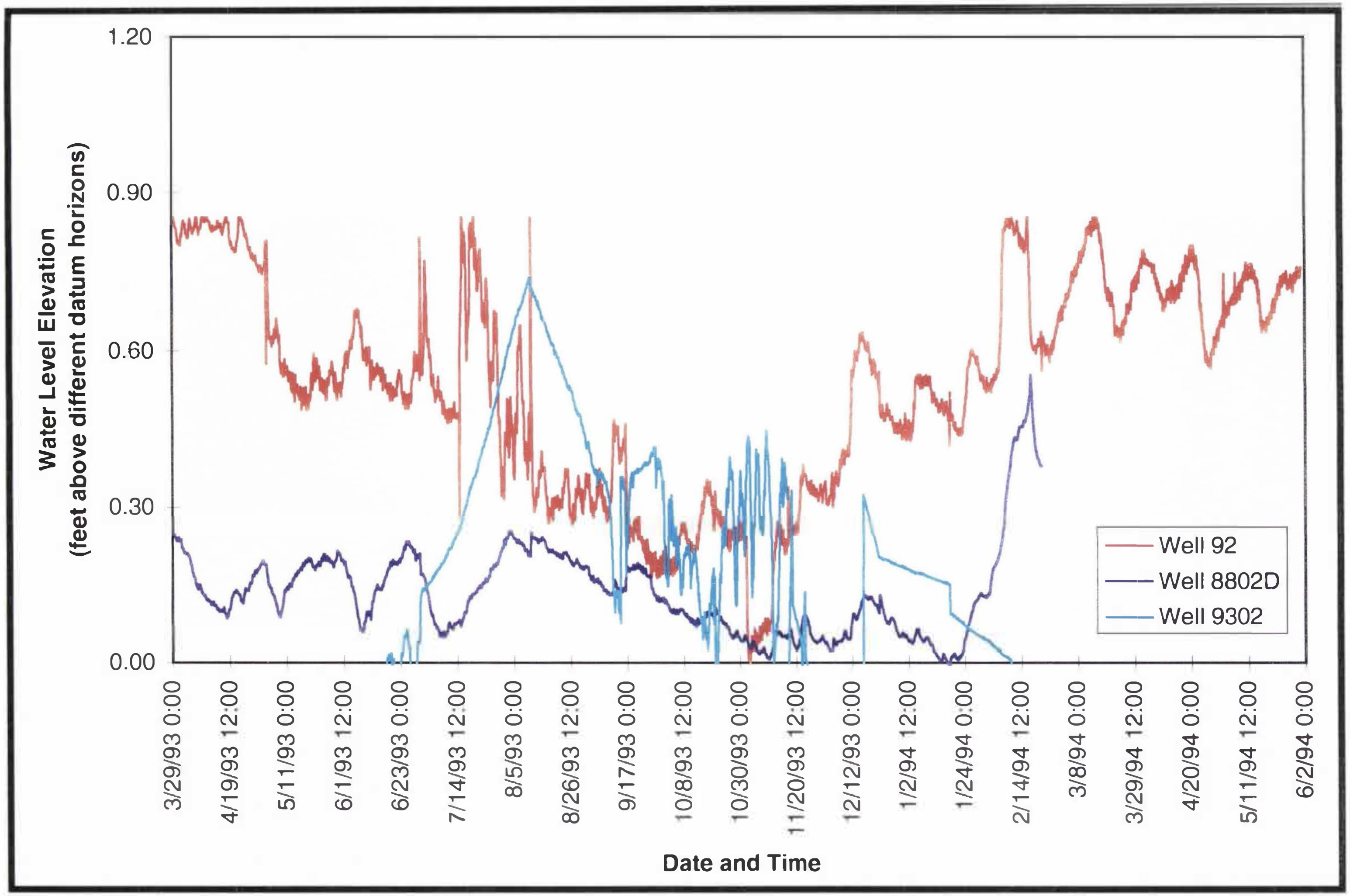

Figure 17. Superposition of the water levels recorded for Wells 92, 8802D, 9302, March 29, 1993 to May 31, 1994. Lowest water elevation from each well was set to zero.

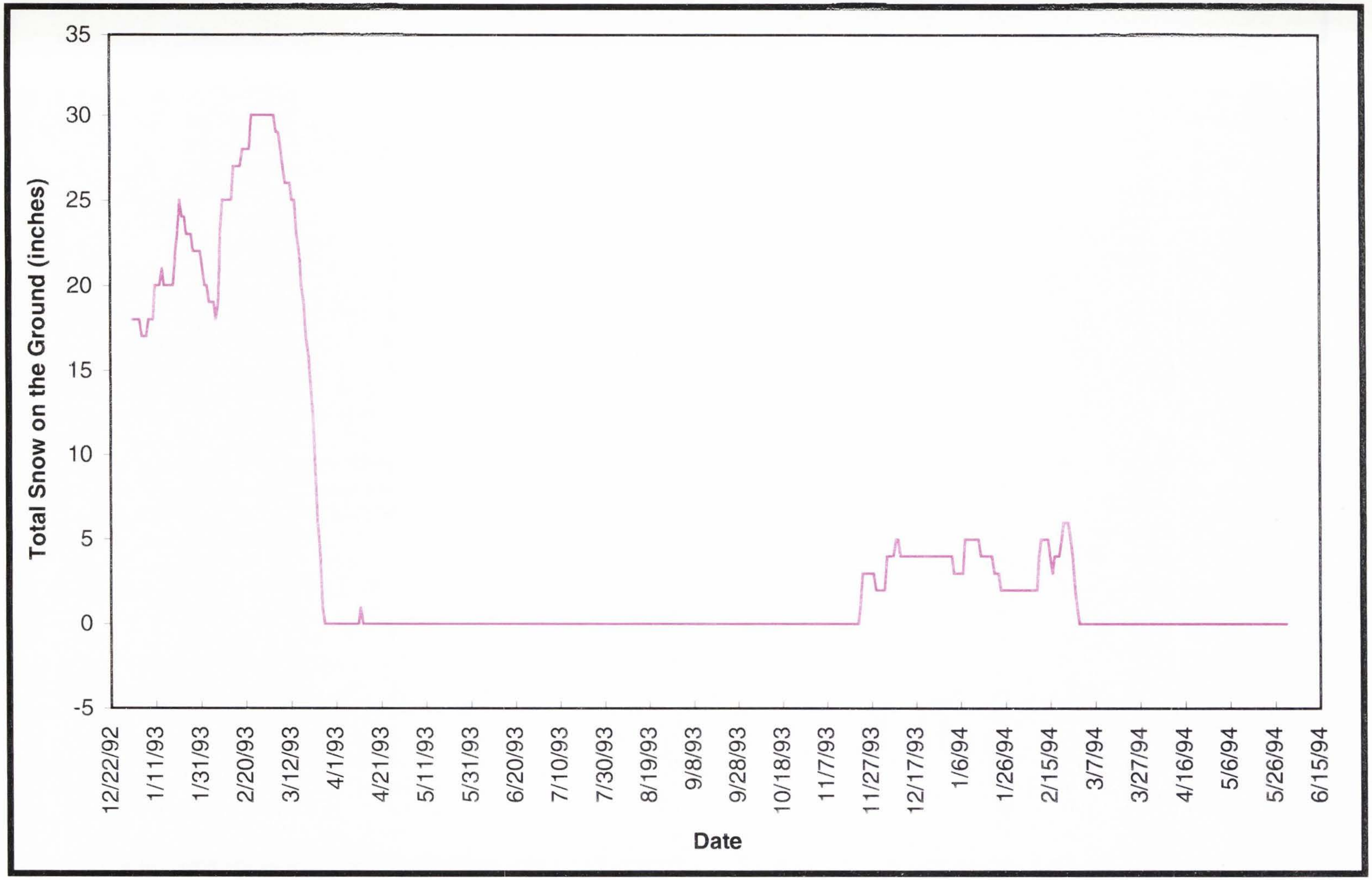

Figure 18. Total daily amount of snow on the ground at the Central Facilities Area, January 1, 1993 to May 31, 1994 (N. Hukari, 1994, electronic communication).

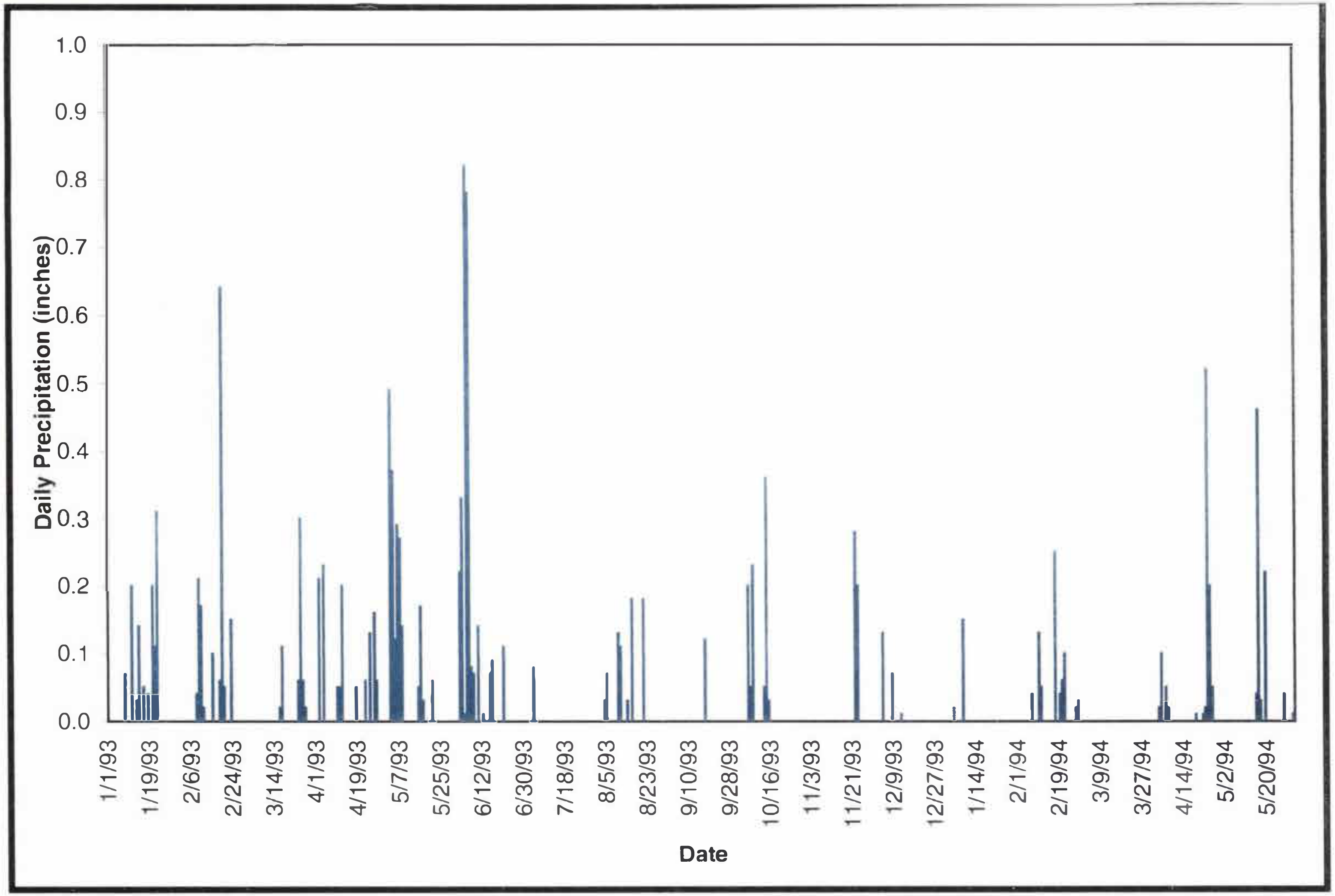

Figure 19. Total daily precipitation at the Central Facilities Area, January 1, 1993 to May 31, 1994 (N. Hukari, 1994, electronic communication).

On June 7-9, 1993, 157 acre-feet (194,000 m^3) of water were diverted from the Big Lost River into the spreading areas. All of this water was contained within spreading area A (Figure 5). This is the most likely source of the observed rise in water levels. Infiltration rates in the spreading areas have been measured at 0.7 to 2.6 ft^3/ft^2 (0.2 to 0.8 m^3/m^2) per day (Barraclough et al., 1967), and, during the 1982 flood, water levels in Well 92 showed a response in 6 days (Hubbell, 1990). This indicates that all three of the wells could respond to the water diverted into the spreading areas within 3 weeks.

Relatively large water-level fluctuations occurred in Wells 92 and 8802D throughout the study period, but these fluctuations failed to mask a general decline in water levels from the late spring to the late fall, and a general rise in water levels from the early winter to the early spring. This general trend would be expected from the distribution of precipitation primarily as snowfall. No such trend is evident in Well 9302.

From these data, it appears that all three wells (92, 8802D, and 9302) were recharged to some degree by water diverted from the Big Lost River into spreading area A. Well 9302 appears to have been recharged exclusively by water diverted into spreading area A. It further appears that Wells 92 and 8802D were also recharged by precipitation. Well 9301 had no standing water; thus, it received no recharge. Well D-10 is assumed not to be completed into the perched zone.

These data also suggest that the perched zone associated with the interbed at 240 feet extends at least 6,000 feet (1,800 m) from east to west. This is the approximate distance from the edge of spreading area A to Well 8802D (Figures 5 and 6). The lateral extent of this perched zone from north to south cannot be determined, as Wells 92 and 8802D lie due east-west of each other, and Well 9302 is about 200 feet (60 m) south of the line between Wells 92 and 8802D (Figure 6).

Upper Perched Zone

The perched zone associated with the interbed at 110 feet appears to be recharged by precipitation falling directly on the RWMC. Well 78-1 is the only well completed into this zone from which data were collected, and it displayed a water-level rise beginning in October of 1993 that peaked in February of 1994, and declined by mid-April (Figure12). The well was dry both before and after this event.

Figure12 also shows the final portion of the water-level decline from the previous year (1993). In 1993, the well had water in it until early May. This seems reasonable, as the winter of 1992-1993 was much wetter than the winter of 1993-94 (Figures 18 and 19).

The fact that the well was dry for a portion of the year before water began to rise seems to eliminate flooding as an exclusive source of recharge, since no flooding has occurred since 1982. Vigil (1988) estimated that 8.9 million gallons (34,000 m^3) of water flooded into the SDA in 1962, 11.4 million gallons (43,000 m^3) in 1969, and 2.7 million gallons (10,000 m^3) in 1982. The total for the three events is 23 million gallons (87,000 m^3). The annual amount of precipitation that falls directly on the SDA is 21.7 million gallons (82,000 m^3) (Hubbell, 1990). Although much of this is undoubtedly removed by evapotranspiration, there is still a considerable amount of water available for recharge by precipitation.

In addition, Barraclough et al. (1976) list the following reasons why the SDA is susceptible to the infiltration of precipitation.

1) The RWMC is a natural topographic depression that collects water from the surrounding area.

2) Areas left open for waste disposal are depressions that can collect water from precipitation. This water can infiltrate rapidly into the sediments and basalt.

3) Compaction and subsequent subsidence in waste-disposal areas provide the potential for water to collect in local depressions and infiltrate rapidly into the waste, below the depth of active evapotranspiration. This subsidence occurs in the spring at the time when the snow melts.

4) The natural depositional pattern of sediments has been disturbed in the process of disposing of waste, and this disturbance tends to increase the porosity and vertical hydraulic conductivity of sediments.

5) In disposing of waste, vegetation is destroyed. This decreases the amount of potential transpiration.

6) Much of the precipitation is available for recharge in the winter and early spring when evapotranspiration rates are low.

No response that would indicate that water diverted from the Big Lost River into spreading area A recharged Well 78-1 can be identified in the water-level data from Well 78-1. Unlike the wells in the lower perched zone, this well remained dry throughout July of 1993.

Chemical data also support the conclusion that precipitation falling directly onto the RWMC is the primary source of recharge to the upper perched zone. All three water samples are similar (Figures 14, 15, and 16), but the snowmelt sample appears to be more like the sample from Well 78-1 than does the Big Lost River sample.

The proportions of the concentrations of major ions in the snowmelt sample were virtually identical to the well sample (Figure15), although the actual concentrations differed by nearly an order of magnitude (Figure14). The only noticeable differences between the proportions of the concentrations of major ions in the Well 78-1 sample and the snowmelt sample are that the snowmelt has a considerably lower proportion of sodium and no measurable sulfate.

The Big Lost River sample was also similar to the well sample. Not only were the proportions of the concentrations of major ions similar (Figure15), but the actual concentrations were nearly the same (Figure14). The main differences were significantly lower potassium concentrations and lower sodium concentrations, and higher calcium, magnesium, and bicarbonate concentrations in the river sample.

Water gains ions from being in contact with geologic material (Hem, 1992). Sodium is highly soluble, and quite common in natural waters and geologic media (Driscoll, 1986). The well sample has the highest sodium concentration. The water infiltrating from snowmelt at the surface or from the Big Lost River could easily gain the necessary amount of sodium from the surface sediments and sedimentary interbeds by the time it reached the well. However, sodium concentrations slightly favor the river as the recharge source because the concentration of sodium in the river is much closer to the concentration in the well sample than it is to the concentration in the snowmelt.

Potassium is less common than sodium in igneous rocks. Sodium tends to remain in solution once it is released. Potassium, on the other hand, ". . . is liberated with greater difficulty . . . and exhibits a strong tendency to be reincorporated into solid weathering products" (Hem, 1992, p. 104). The fact that potassium is more difficult to dissolve and more likely to remain in weathering products indicates that its concentration should not increase significantly. Both the snowmelt and the river samples have considerably less potassium than the well sample. If snowmelt is the recharge source, its concentration of potassium would have to increase by a factor of five times. This is unlikely, but it is more likely than the ten-fold increase which the Big Lost River water would have to undergo. Futhermore, the sodium concentration in the well is similar to the potassium concentration. For the Big Lost River to attain this same relationship, it must dissolve much more potassium than sodium. This is contrary to the relationship between sodium and potassium noted by Hem (1992) and quoted above. However, if the snowmelt is the recharge source, it can dissolve more sodium than potassium and still have similar concentrations of sodium and potassium by the time it reaches the well. Thus, the potassium concentrations favor snowmelt as the recharge source.

Magnesium is common in dark-colored ferromagnesian minerals associated with mafic igneous rocks. Once magnesium is brought into solution, it is difficult to precipitate (Hem, 1992). The Big Lost River has a higher concentration of magnesium than the well water does, and it is unlikely that the concentration would decrease. The concentration of magnesium in the snowmelt water is much lower than that of the well water, and it is far more likely that the snowmelt would dissolve magnesium than it is that the river water would precipitate magnesium. Thus, the magnesium concentrations strongly favor snowmelt as the recharge source.

Water from the Big Lost River has a higher concentration of calcium than the well water does. For the river to recharge the well, it must precipitate calcium in some form. WATEQF (Plummer et al., 1976), a computer program that calculates chemical equilibra of natural waters, was used to analyze the three water samples, and these analyses (Appendix B) indicate that the river water is supersaturated with respect to calcite ($CaCO_3$), with a saturation index of 0.317. In addition, it is possible that calcium could be removed from the water by cation exchange with sodium. The snowmelt water has a significantly lower concentration of calcium than the well water does. The WATEQF analysis indicates that the snowmelt is undersaturated with respect to calcite, as it has a saturation index of -0.264. Thus, the snowmelt water could dissolve calcium from geologic media as it passes from the surface to the perched zone if it is the recharge source. Calcium is a major constituent of igneous rock minerals (especially basalt) and is present in most sedimentary rocks (Hem, 1992), so calcium is probably available to be dissolved by the snowmelt water.

The Big Lost River also has a higher concentration of bicarbonate than the well water does. This is reasonable, as the bicarbonate concentration should decrease along with the calcium concentration, because bicarbonate should combine with calcium to precipitate calcite (Drever, 1988). The snowmelt water has a much lower concentration of bicarbonate than the well water. This water could dissolve bicarbonate along with calcium if calcite is present in the surface sediments and sedimentary interbeds. A more likely scenario is that the snowmelt, which has a concentration of bicarbonate nearly equal to that of atmospheric CO_2, dissolves CO_2 from pore spaces in the vadose zone. Then the CO_2 is converted to bicarbonate. This would allow snowmelt to easily reach the concentrations observed in the well.

Each mole of calcium present in the river water should combine with one mole of bicarbonate to precipitate one mole of calcite. A similar, but opposite, relationship should exist for the snowmelt water, where one mole of calcium and one mole of bicarbonate should be dissolved for each mole of calcite. By converting ppm concentrations to millimoles per liter (mmol/l), a comparison of these relationships can be made. The river water has 0.41575 mmol/l more calcium and 0.885246 mmol/l more bicarbonate than the well water. This means that the river would have to lose 2.1 times more bicarbonate than calcium in order to reach the concentrations observed in the well water. It is unlikely that the river water could lose bicarbonate in addition to that which would be precipitated as calcite. The snowmelt has 0.56225 mmol/l less calcium and 1.57377 mmol/l less bicarbonate than the well. Thus, if the snowmelt is the recharge source, it would have to dissolve 2.8 times more bicarbonate than calcium. This indicates that the snowmelt water would have to gain bicarbonate from a source other than calcite. A possible additional source of bicarbonate is from CO_2 in the pore spaces of the vadose zone. The partial pressure of atmospheric CO_2 is $10^{-3.5}$ (Drever, 1988), which is nearly identical to the P_{CO2} of the snowmelt as calculated by the WATEQF analysis, which is $10^{-3.4}$. Drever also stated that the partial pressure of CO_2 in the vadose zone ranges from $10^{-1.3}$ to 10^{-2}. The WATEQF analysis indicates that the P_{CO2} of the well water is $10^{-2.6}$, which is less than vadose zone concentrations; hence, all of the excess bicarbonate could come from the CO_2 in the vadose zone. In fact, all of the bicarbonate could come from CO_2 in the vadose zone, and the calcium could come from Ca-rich plagioclase in the basalt flows rather than from calcite. This indicates that the concentration of bicarbonate strongly favors the snowmelt as the recharge source and the calcium concentrations favor neither recharge source.

Chloride concentrations in the river water are virtually identical to those in the well water. Chloride is more closely associated with evaporites than with igneous rocks, and chloride tends to exist in natural waters as free ions (Hem, 1992). If the Big Lost River is the recharge source, the chloride concentrations would be expected to remain virtually the same. If the snowmelt is the recharge source, this water must dissolve chloride from somewhere, as the chloride concentration in the snowmelt is considerably less than it is in the well water. If evaporites are associated with the surface sediments and sedimentary interbeds, which is reasonable because of the semiarid nature of the area, then an increase in the chloride concentration of this magnitude would not be unusual. Chloride concentrations slightly favor the Big Lost River as the recharge source.

Sulfate is commonly associated with the evaporite minerals gypsum ($CaSO_4 \bullet 2H_2O$) and anhydrite ($CaSO_4$), and it is common in igneous groundwater systems in concentrations of less then 100 parts per million (ppm) (Driscoll, 1986). Because of the semiarid setting of the area, evaporites would be expected in the surface sediments and perhaps also in the interbeds at 30 feet (9 m), 110 feet (34 m), and 240 feet (73 m). Water infiltrating from snowmelt at the surface has no initial sulfate concentration, but it possibly could gain the necessary amount of sulfate if evaporites are present in the surface sediments and sedimentary interbeds. The river water has a slightly lower concentration of sulfate. Thus, it must also gain some sulfate in order to reach the concentrations found in the well water. The WATEQF analysis indicates that the river water is greatly undersaturated with respect to gypsum and anhydrite, as the saturation indices for these two minerals are -2.433 and -2.801, respectively. Thus, the river water would tend to dissolve these minerals, which would increase the sulfate concentration. Sulfate concentrations strongly favor river water as the recharge source.

From an initial glance, Figure16 suggests that concentrations of the minor ions and trace constituents would favor the Big Lost River over snowmelt as the recharge source, because the concentrations of minor ions and trace constituents from Well 78-1 appear more similar to the Big Lost River than to the snowmelt . However, upon careful examination, the minor ions and trace constituents indicate that the snowmelt is the more likely recharge source.

Iron is present only in the well sample. This iron is probably from the well casing. The well was not purged, so the water sample was in contact with the casing for some time. Iron could also come from the basalt flows. The basalt flows in this area have iron contents of about 3% (J. M. Hubbell, 1995, oral communication). Sufficient iron is available from the well casing and the basalt that either the snowmelt or the Big Lost River waters could reach the observed concentrations as they moved through the vadose zone. Iron concentrations favor neither the snowmelt nor the Big Lost River as a recharge source.

Silicon is the second most abundant element in the earth's crust, and oxygen is the most abundant. Silicon and oxygen readily combine alone or with other elements to form a wide variety of minerals, many of which are associated with igneous rocks. Despite the abundance of silica in the earth's crust, it is not readily dissolved in water (Driscoll, 1986). The river water has a higher concentration of silica and the snowmelt water has a slightly lower concentration of silica than does the well water. The WATEQF analyses indicate that both the river water and the snowmelt water are undersaturated with respect to amorphous silica (gel), but saturated with respect to quartz (SiO_2). The well water is also undersaturated with respect to amorphous silica and supersaturated with respect to quartz. Because the ". . . direct precipitation of quartz is unlikely to control the solubility of silica in most natural waters at earth surface temperatures" (Hem, 1992, p. 71), both recharge sources would tend to dissolve silica and increase their concentrations. The source of the silica is probably not quartz because quartz is highly insoluble. A more likely source of silica is probably some form of feldspar ($MAl(Al,Si)_3O_8$, where M can be K, Na, Ba, Rb, Sr or Fe). However, if the Big Lost River was the recharge source, it would have to experience a decrease in the silica concentration of more than a factor of two, which is unlikely, whereas the snowmelt water would have to experience an increase of less than a factor of two. For these reasons silica concentrations strongly favor snowmelt as the recharge source.

Nearly all of the fluorine present at the earth's surface is tied up in rocks. It is common in the minerals fluorite (CaF_2) and apatite ($Ca(Cl, F, OH)(PO_4)_3$), and in amphiboles and micas where it replaces the hydroxide ions. All of these minerals are associated with igneous rocks, but fluoride compounds tend to be insoluble (Hem, 1992). The well water and the snowmelt had nearly identical concentrations of fluoride. The water from the Big Lost River had fluoride concentrations about five times greater than the well water. It is unlikely that the river water would precipitate sufficient fluoride to reduce its concentration by a factor of five. Thus, the fluoride concentrations strongly favor snowmelt as the recharge source.

Boron, which tends to form complexes (Hem, 1992), is present in the river water at a higher concentration than in the well water, and is absent in the snowmelt. Boron is generally found in the mineral tourmaline, which is highly resistant, and as an accessory element in biotite and amphiboles (Hem, 1992). Probably the most common source of boron, and the likely source of it in the river, is sodium tetraborate, also known as borax. Borax is used as a cleaning aid, and is present in sewage and industrial waste. The species of boron generally present in water tend to be volatile, and so the concentration of boron in the river water could easily be reduced to those found in the well. However, snowmelt could easily gain boron as it migrated through the surface sediments if borax in present the buried wastes. Boron concentrations slightly favor the river water as the recharge source.

Strontium is present in all three samples. The river water has a higher concentration than the well water, and the snowmelt water has the lowest concentration. Strontium behaves in a similar manner as calcium, and is present in carbonate sedimentary rocks and in igneous rocks (Hem, 1992). The WATEQF analyses indicate that the river water is undersaturated with respect to strontianite ($SrCO_3$), as it has a saturation index of -1.473. Thus, the river water would tend to dissolve more strontium rather than precipitate $SrCO_3$. This eliminates the river as a possible recharge source, because it has a higher Sr concentration than the well water. If the snowmelt is the recharge source, strontium would have to be dissolved from strontianite along with calcium from calcite, dissolved in trace amounts directly from calcite, or dissolved directly from the igneous rocks. This would account for the increase in strontium as the snowmelt moved from the surface to the perched zone. Strontium concentrations strongly favor the snowmelt as the recharge source.

Arsenic is only present in the snowmelt sample. Arsenic is volatile, and is common in pesticides (Hem, 1992). It is likely that the snow picked up the arsenic from the air as it fell and that the arsenic was transferred into the snowmelt water. Arsenic will precipitate as metal arsenides or sulfates (Hem, 1992), so it is possible that the arsenic has been removed from the snowmelt water as it traveled through the subsurface by this process. However, the detection limit for arsenic is rather high, so arsenic may be present in the well and/or the river water but could not be detected. Although it is possible that small arsenic concentrations are present but undetected in the river and well samples, the arsenic concentrations slightly favor the Big Lost River as a recharge source.

In addition to WATEQF analyses, SNORM (Bodine and Jones, 1986) analyses were conducted on the three samples. SNORM is a computer program that calculates the salt norm from the chemical composition of natural water. The salt norm is defined as the ". . . quantitative ideal equilibrium assemblage that would crystallize if the water evaporated to dryness . . ." (Bodine and Jones, 1986, p. 1) under standard conditions. The salt norm can be thought of as the solid residue left after all liquid has been evaporated, but SNORM calculates the salt assemblages directly from the solute concentrations without proceeding along an evaporation path so that the brine-solid interactions are ignored. Because of this calculation method, the salt norm may help to identify the lithologic source of natural waters.

The SNORM analyses are included in Appendix C. These data indicate that the well sample, upon desiccation, should precipitate dolomite ($CaMg(CO_3)_2$), calcite ($CaCO_3$), aphthilalite ($K_3Na(SO_4)$), pirssonite ($Na_2Ca(CO_3)_2 \cdot 2H_2O$), halite ($NaCl$), thenardite ($Na_2SO_4$), borax ($NaB_4O_7 \cdot 10H_2O$), villiaumite ($NaF$), and strontianite ($SrCO_3$). The snowmelt sample, upon desiccation, should precipitate calcite, sylvite (KCl), dolomite, halite, villiaumite, fluorite (CaF_2), and strontionite. The river sample, upon desiccation, should precipitate dolomite, calcite, anhydrite ($CaSO_4$), halite, syngenite ($CaK_2(SO_4)_2 \cdot H_2O$), glauberite ($CaNa_2(SO_4)_2$), and ulexite ($CaNaB_5O_9 \cdot 8H_20$).

Given these data, the well water and the snowmelt sample will precipitate five of the same salts: calcite, dolomite, halite, villiaumite, and strontianite. The river water and the well water will only precipitate three common salts: calcite, dolomite, and halite. This indicates that the snowmelt sample and the well sample are more similar than are the river water and the well water. This further supports the conclusion that the snowmelt is the most likely recharge source.

The chemical data support the conclusion that precipitation as snowmelt is the primary recharge source to the upper perched zone (Table 4). Potassium, magnesium, bicarbonate, silica, fluoride, and strontium concentrations indicate that snowmelt is the more likely source of recharge. Sodium, chloride, sulfate, boron, and arsenic concentrations favor the Big Lost River as the source of recharge. Calcium and iron favor neither source. In order for the snowmelt to reach the concentrations measured in the water sample from Well 78-1, the snowmelt must dissolve four of the five constituents favoring the river water (Na, Cl, SO_4, and B). On the other hand, if the river water is to reach the concentrations measured in the water sample from Well 78-1, the river water must precipitate five of the six constituents favoring the snowmelt (Mg, HCO_3, F, SiO_2, and Sr). It is far more likely that the dissolution of Na, Cl, SO_4, and B will take place rather than the precipitation of Mg, HCO_3, F, SiO_2, and Sr. Sodium, chloride, and sulfate are probably available to be dissolved from evaporite deposits in the surface sediments and

Table 4. Qualitative Summary of Chemical Analyses

		Strongly Favors Snowmelt	Slightly Favors Snowmelt	Favors Neither	Slightly Favors River	Strongly Favors River
Major Ions	Na				X	
	K		X			
	Ca			X		
	Mg	X				
	HCO_3	X				
	Cl				X	
	SO_4					X
Minor Ions and Trace Constituents	Fe			X		
	SiO_2	X				
	F	X				
	B				X	
	Sr	X				
	As				X	

in the sedimentary interbeds. Furthermore, the snowmelt water is undersaturated with respect to all three constituents, so that the dissolution of all three constituents by the snowmelt is possible (Hem, 1992). Boron, if contained in the buried wastes, would also be available for the snowmelt to dissolve. On the other hand, magnesium once brought into solution is difficult to precipitate (Hem, 1992). The river sample had a higher magnesium concentration than the well sample. Calcium could be dissolved by the snowmelt from calcite or from Ca-rich plagioclase in the basalt, and bicarbonate could be dissolved by the snowmelt from CO_2 gas in the pore spaces within the vadose zone or from calcite. However, the river must precipitate calcium and bicarbonate as calcite, but then it would have significant bicarbonate left over. Fluoride and silica tend to be rather insoluble (Hem, 1992), but the river sample had a higher concentration of both constituents than the well sample did, and both water samples were undersaturated with respect to fluoride and silica, so their precipitation is unlikely. Although strontium is soluble (Hem, 1992), the river water was undersaturated with respect to strontianite and the river sample had a higher concentration than the well sample did. Therefore, strontium concentrations in the river cannot be decreased to the necessary level. Additionally, the potassium concentration in the well was five times greater than in the snowmelt and ten times greater than in the river. Potassium is relatively insoluble and usually reincorporated into weathering products (Hem, 1992), so it is much more difficult for the river water to reach the necessary potassium levels. Neither the well sample nor the river sample had detectable arsenic, and the concentration in the snowmelt was just slightly over the detection limit. Although mostly inconclusive, arsenic concentrations favor the river.

The lateral extent of the upper perched zone is at least 2,600 feet (790 m) from east to west. This is the approximate distance from Well 78-1 to Well V-10. In the north-south direction, all that can be determined is that this zone extends at least a couple of hundred feet (~60 m), as all four wells are within this distance of each other. The upper perched zone is probably not as extensive as the lower perched zone. The upper perched zone is apparently not recharged by spreading area A, so it probably does not extend under the spreading areas. By this same reasoning, it is probable that the precipitation recharging the perched zone at 240 feet does not fall directly on the SDA, but falls onto the area surrounding the SDA. The precipitation that falls directly on the SDA probably is intercepted by the upper perched zone and recharges the lower perched zone indirectly as it flows through discontinuities and off the edges of the upper perched zone.

Migration Pathways

Water will migrate vertically downward until a layer of low hydraulic conductivity is reached, at which time it will migrate horizontally (Freeze and Cherry, 1979). This is most likely the pathway that the water diverted into spreading area A followed. It migrated vertically to the vicinity of the interbed at 240 feet and then horizontally to the area beneath the RWMC where it was detected in the wells.

Precipitation falling on the SDA would not directly recharge the perched zone at 240 feet. Water falling on the SDA would migrate vertically downward until the interbed at 110 feet is reached, where it would begin to migrate horizontally. It will likely begin to migrate vertically when discontinuities in, or the edges of, the upper perched zone are reached. This vertical migration will probably continue until the layer of low hydraulic conductivity associated with the lower perched zone is reached. Thus, precipitation falling on the SDA should recharge the lower perched zone indirectly. In addition, flood waters within the SDA will be intercepted by the upper perched zone, so they will not directly recharge the lower perched zone. However, precipitation and flooding outside of the SDA might recharge the lower perched zone directly.

Flooding within the SDA, when it occurs, will likely recharge the upper perched zone. However, the fact that in a given year nearly as much water falls directly on the

SDA by precipitation as inundated this area during all three flood events makes it more likely that precipitation is the primary source of recharge.

The upper perched zone pinches out in some areas beneath the RWMC (McElroy et al., 1989). The lower perched zone probably also has discontinuities. Both perched zones appear to be finite in lateral extent. Consequently, the perched water should migrate downward out of these perched zones and probably eventually reaches the Snake River Plain aquifer.

Because radioactive and hazardous wastes were buried in shallow unlined pits (less than 30 feet [9 m] deep), and precipitation appears to be the primary source of recharge to the interbed at 110 feet beneath the SDA, there is a distinct possibility that radionuclides and organic chemicals are migrating downward through the subsurface beneath the RWMC. This study by no means proves conclusively that this subsurface migration occurs, but it does indicate that the potential exists.

CONCLUSIONS AND RECOMMENDATIONS

Seven wells within the SDA were monitored during a 14-month period for the presence of perched water. Two of these wells are completed into the perched zone associated with the interbed at 110 feet and the remaining five wells are completed into the perched zone associated with the interbed at 240 feet. Each of these wells was equipped with a data logger, which recorded water levels every 4 hours during the period of the study. Monthly manual water levels were measured using a well sounder and/or steel tape. The manual measurements were used to verify the data logger results.

A water sample was obtained from one of the wells completed into the interbed at 110 feet. Water was also collected from snowmelt on the surface of the SDA and from the Big Lost River. These three water samples were analyzed for major and minor ions and trace constituents, and a comparison of these chemical data was made.

Conclusions

The most important conclusions drawn from the data collected are listed below.

1) Two perched groundwater bodies exist beneath the RWMC. The first is associated with an interbed 110 feet (34 m) beneath the ground surface. The second is associated with an interbed 240 feet (73 m) beneath the surface.

2) The primary recharge source to the perched groundwater body associated with the interbed at 110 feet is direct precipitation on the SDA. Water-level data confirm this conclusion because the water levels in Well 78-1 displayed typical seasonal fluctuations;

i.e., water levels rose during the wet season and fell during the dry season. Chemical data further support this conclusion because the water in Well 78-1 was more similar chemically to that collected from snowmelt at the ground surface than to that collected from the Big Lost River.

3) The perched groundwater body associated with the interbed at 240 feet probably has multiple recharge sources. Water-level data displayed typical seasonal fluctuations in Wells 92 and 8802D. In addition, these two wells and Well 9302 displayed rather large water-level rises in July of 1993, shortly after water was released into spreading area A. This indicates that both precipitation and water diverted from the Big Lost River into spreading area A are likely sources of recharge.

4) The perched zone associated with the interbed at 240 feet appears to extend at least 6,000 feet (1,800 m) from east to west, because the water diverted into spreading area A recharges Well 8802D 6,000 feet (1,800 m) away. Its extent from north to south can only be confirmed to be at least 200 feet (60 m) from the data collected in this study. However, it is probably greater than 200 feet (60 m) from north to south.

5) The perched groundwater body associated with the interbed at 110 feet is not recharged by spreading area A. This indicates that it is less extensive than the perched groundwater body associated with the interbed at 240 feet.

6) Precipitation that falls on the SDA may not recharge the lower perched groundwater body directly. It is assumed that most of the precipitation falling on the SDA is intercepted by the upper perched zone. However, because the lower perched zone is

more laterally extensive, it intercepts precipitation that falls some distance beyond the SDA.

7) The historical view that floods in 1962, 1969, and 1982 were the only sources of recharge to both perched zones is probably incorrect. Although such floods definitely will recharge the upper perched groundwater body, and probably will recharge the lower perched zone, direct precipitation appears to be the primary recharge source for the upper perched zone, and a combination of precipitation and water diverted into spreading area A seems to be the primary sources of recharge to the lower perched zone.

8) Flood waters will recharge the upper perched zone following the same pathway as the precipitation and snowmelt. This pathway is characterized by downward vertical migration until the layer of low hydraulic conductivity associated with the interbed at 110 feet is encountered, where horizontal migration becomes dominant. Due to the infrequent nature of the floods, floodwaters probably should be considered a secondary recharge source.

9) Flood waters probably do not directly recharge the lower perched zone beneath the SDA, but are intercepted by the upper perched zone. Flood waters may eventually reach the lower perched zone through discontinuities in the upper perched zone.

10) Because radioactive and hazardous wastes were buried in shallow unlined pits within the SDA, and precipitation appears to be the primary source of recharge to the interbed at 110 feet beneath the SDA, the potential for the downward migration of radionuclides and organic chemicals exists and cannot be ignored.

Recommendations

The following are recommendations for future work.

1) The data-collection system that is in place and was used for this study should continue to be monitored. Fourteen months of records of water levels and hydrologic data are not sufficient to make long-term evaluations. Furthermore, larger amounts of Big Lost River water will undoubtedly be diverted into the spreading areas in the future and, although it is unlikely, future floods may occur. The water-level responses in wells during such events will be important in understanding more completely the migration pathways of hazardous and radioactive contaminants.

2) The sampling needs to be broadened in both the number of samples to be analyzed and the constituents to be analyzed for. Precipitation, river, and well samples should be taken several times a year if water quantities allow. Quarterly samples would be ideal. The data collected during this study indicate that there is enough water in Well 78-1 during the winter months to allow two or three samples to be taken at 1- or 2-month intervals. Also, water samples should be obtained from wells completed in the lower perched zone (i.e., Wells 92 and 8802D).

The analyses of water samples taken as part of this study looked at the concentrations of the major and minor ions and trace constituents. Future samples should continue to be analyzed for these constituents, but the analyses might be broadened to include a more detailed analysis of minor ions and trace constituents with high detection limits (i.e., arsenic, aluminum, molybdenum, bismuth, antimony, tellurium, thorium, uranium, and vanadium), and possibly some stable and/or radioactive isotopes that would not be affected by the wastes buried at the SDA. In addition, there are some production wells in the area. These could be used to set up tracer tests by intentionally filling the spreading areas with water from these wells and adding some type of tracer to the water. Such tests are difficult to justify within the SDA because of the hazardous and radioactive wastes buried there.

3) A sufficient number of wells exist within the SDA, but more wells need to be completed into the two perched zones in the area surrounding the SDA in order to determine the lateral extent of the layers of low hydraulic conductivity associated with these two perched zones. Of particular interest would be two to four wells into each zone between the RWMC and spreading areas. This could help determine the lateral extent of the upper zone and provide additional water samples from both zones. Tracer tests also could be conducted with any new wells installed in this area. Such wells and tests should display responses similar to those observed in wells completed within the SDA but without the risk of spreading contaminants. Additional wells might also be drilled to the north and south of the SDA in order to evaluate the extent of the layers of low hydraulic conductivity in these directions, and then be used to conduct further tracer tests and for additional samples.

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APPENDICES

Appendix A. Analytical Chemistry Data

Table 5. Field Parameters and Laboratory Measurements

	Well 78-1	Snowmelt	Big Lost River	Detection Limits
Field Temp (^{o}C)	8.0	*	12.4	
Field pH	7.55	7.37	8.09	
Field EC (μmohs/ cm)	145	20	102	
Field Alkalinity (ppm)	100	15	145	
Lab pH	7.80	7.56	8.05	
Lab EC (μmohs/ cm)	250	33	320	
TDS	118.00	16.00	174.00	4.00
Lab Alkalinity as HCO_3 (ppm)	109.00	13.00	163.00	1.00
Lab Alkalinity as CO_3 (ppm)	ND	ND	ND	1.00
Cl (ppm)	6.30	2.80	5.70	1.00
F (ppm)	0.21	0.15	0.63	0.05
SO_4 (ppm)	20.00	ND	17.00	1.00
PO_4 (ppm)	ND	ND	ND	1.84
Na (ppm)	11.26	0.59	4.52	0.49
K (ppm)	11.80	2.34	1.22	0.61
Ca (ppm)	26.00	3.51	42.63	0.18
Mg (ppm)	5.04	0.54	10.38	0.16
Fe (ppm)	0.05	ND	ND	0.02
Al (ppm)	ND	ND	ND	0.61
SiO_2 (ppm)	7.71	4.81	18.76	0.52
B (ppm)	0.16	ND	0.44	0.05
Li (ppm)	ND	ND	ND	0.04
Sr (ppm)	0.09	0.01	0.21	0.01
Zn (ppm)	ND	ND	ND	0.06
Ag (ppm)	ND	ND	ND	0.05
As (ppm)	ND	0.69	ND	0.49
Au (ppm)	ND	ND	ND	0.10
Ba (ppm)	ND	ND	ND	0.31
Be (ppm)	ND	ND	ND	0.00
Bi (ppm)	ND	ND	ND	2.44
Cd (ppm)	ND	ND	ND	0.05
Ce (ppm)	ND	ND	ND	0.24

ND -- Indicates that this species was not detected

* -- This measurement was not taken in the field because the sample was melted from snow

Table 5. (cont.)

	Well 78-1	Snowmelt	Big Lost River	Detection Limits
Co (ppm)	ND	ND	ND	0.02
Cr (ppm)	ND	ND	ND	0.12
Cu (ppm)	ND	ND	ND	0.06
La (ppm)	ND	ND	ND	0.12
Mn (ppm)	ND	ND	ND	0.24
Mo (ppm)	ND	ND	ND	0.61
Ni (ppm)	ND	ND	ND	0.12
Pb (ppm)	ND	ND	ND	0.24
Sn (ppm)	ND	ND	ND	0.12
Sb (ppm)	ND	ND	ND	0.49
Te (ppm)	ND	ND	ND	1.22
Th (ppm)	ND	ND	ND	2.44
Ti (ppm)	ND	ND	ND	0.12
U (ppm)	ND	ND	ND	6.10
V (ppm)	ND	ND	ND	1.22
W (ppm)	ND	ND	ND	0.12
Zr (ppm)	ND	ND	ND	0.12

ND -- Indicates that this species was not detected

Appendix B. WATEQF Analyses

Well 78-1

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                              ----------------
                              INITIAL SOLUTION
                              ----------------


          TEMPERATURE =   8.00 DEGREES C    PH =  7.550
          ANALYTICAL EPMCAT =    2.507    ANALYTICAL EPMAN =    2.392
          CHARGE BALANCE ERROR =  1.96 %

     ***** OXIDATION - REDUCTION *****

 DISSOLVED OXYGEN =   .000 MG/L
 EH MEASURED WITH CALOMEL =  9.9000 VOLTS         FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION =  9.9000 VOLTS     3    0      4      1
 CORRECTED EH =  9.9000 VOLTS
 PE COMPUTED FROM CORRECTED EH = 100.000



               *** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

                        TOTAL               LOG TOTAL            TOTAL
        SPECIES        MOLALITY             MOLALITY           MG/LITRE
        -------        --------             --------           --------

        CA         2    6.48831E-04          -3.1879          2.60000E+01
        MG         2    2.07346E-04          -3.6833          5.04000E+00
        NA         1    4.89879E-04          -3.3099          1.12600E+01
        K          1    3.01834E-04          -3.5202          1.18000E+01
        CL        -1    1.77735E-04          -3.7502          6.30000E+00
        SO4       -2    2.08241E-04          -3.6814          2.00000E+01
        HCO3      -1    1.78673E-03          -2.7479          1.09000E+02
        SIO2 TOT   0    1.28344E-04          -3.8916          7.71000E+00
        FE         2    8.95480E-07          -6.0479          5.00000E-02
        SR         2    1.02737E-06          -5.9883          9.00000E-02
        F         -1    1.10557E-05          -4.9564          2.10000E-01
        B TOT      0    1.48040E-05          -4.8296          1.60000E-01
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Well 78-1

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                    *** CONVERGENCE ITERATIONS ***

ITERATION  S1-ANALCO3   S2-SO4TOT    S3-FTOT     S4-PTOT    S5-CLTOT

     1      1.528E-05   2.207E-05  1.085E-07  0.000E+00  0.000E+00
     2      1.451E-07   1.753E-07  9.135E-10  0.000E+00  0.000E+00


                    ****DESCRIPTION OF SOLUTION ****

         ANAL.     COMP.         PH          ACTIVITY H2O =   .9999
EPMCAT     2.51      2.46       7.550        PCO2=  2.475671E-03
EPMAN      2.39      2.35                    LOG PCO2 =  -2.6063
                             TEMPERATURE     PO2 =  1.057526E-59
EH = 9.9000  PE =    .000      8.00 DEG C    PCH4 =  3.609623E-38
PE CALC S =  100.000                         CO2 TOT =  1.925050E-03
PE CALC DOX=100.000         IONIC STRENGTH   DENSITY =   1.0000
PE SATO DOX=100.000          3.416561E-03    TDS =     197.6MG/L
TOT ALK =  1.787E+00 MEQ                     CARB ALK =  1.786E+00 MEQ
ELECT   =  1.160E-01 MEQ

IN COMPUTING THE DISTRIBUTION OF SPECIES,
PE =    .000     EQUIVALENT EH =   .000VOLTS
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Well 78-1

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                        -----------------------
                        DISTRIBUTION OF SPECIES
                        -----------------------

  I  SPECIES           PPM        MOLALITY    ACTIVITY    LOG ACT     GAMMA

   1 CA        2  2.5129E+01  6.2709E-04  4.9173E-04  -3.308   7.8414E-01
   2 MG        2  4.8982E+00  2.0151E-04  1.5839E-04  -3.800   7.8601E-01
   3 NA        1  1.1242E+01  4.8910E-04  4.5988E-04  -3.337   9.4025E-01
   4 K         1  1.1791E+01  3.0160E-04  2.8329E-04  -3.548   9.3929E-01
  64 H         1  3.0223E-05  2.9989E-08  2.8184E-08  -7.550   9.3982E-01
   5 CL       -1  6.3000E+00  1.7774E-04  1.6694E-04  -3.777   9.3929E-01
   6 SO4      -2  1.8452E+01  1.9212E-04  1.5041E-04  -3.823   7.8288E-01
   7 HCO3     -1  1.0784E+02  1.7677E-03  1.6636E-03  -2.779   9.4111E-01
  18 CO3      -2  1.3836E-01  2.3060E-06  1.8090E-06  -5.743   7.8445E-01
  86 H2CO3     0  8.8428E+00  1.4260E-04  1.4273E-04  -3.845   1.0009E+00
  27 OH       -1  1.5909E-03  9.3562E-08  8.7931E-08  -7.056   9.3982E-01
  62 F        -1  2.0806E-01  1.0954E-05  1.0295E-05  -4.987   9.3982E-01
  19 MGOH      1  8.1857E-05  1.9815E-09  1.8622E-09  -8.730   9.3982E-01
  23 MGSO4 AQ  0  3.0990E-01  2.5750E-06  2.5770E-06  -5.589   1.0008E+00
  22 MGHCO3    1  2.5462E-01  2.9845E-06  2.8049E-06  -5.552   9.3982E-01
  21 MGCO3 AQ  0  1.7740E-02  2.1042E-07  2.1059E-07  -6.677   1.0008E+00
  20 MGF       1  3.0806E-03  7.1143E-08  6.6861E-08  -7.175   9.3982E-01
  29 CAOH      1  5.8417E-05  1.0235E-09  9.6189E-10  -9.017   9.3982E-01
  32 CASO4 AQ  0  1.7583E+00  1.2917E-05  1.2928E-05  -4.888   1.0008E+00
  30 CAHCO3    1  7.6970E-01  7.6149E-06  7.1665E-06  -5.145   9.4111E-01
  31 CACO3 AQ  0  1.2084E-01  1.2076E-06  1.2028E-06  -5.920   9.9607E-01
  49 CAF+      1  1.8198E-03  3.0810E-08  2.8955E-08  -7.538   9.3982E-01
  44 NASO4    -1  4.1009E-02  3.4453E-07  3.2380E-07  -6.490   9.3982E-01
  43 NAHCO3    0  3.6099E-02  4.2988E-07  4.3022E-07  -6.366   1.0008E+00
  42 NACO3    -1  5.4836E-04  6.6081E-09  6.2104E-09  -8.207   9.3982E-01
  94 NACL      0  4.4825E-33  7.6713E-38  7.6774E-38 -37.115   1.0008E+00
  46 KSO4     -1  3.1431E-02  2.3259E-07  2.1859E-07  -6.660   9.3982E-01
  95 KCL       0  3.5225E-33  4.7257E-38  4.7294E-38 -37.325   1.0008E+00
  63 HSO4     -1  2.6877E-05  2.7694E-10  2.6027E-10  -9.585   9.3982E-01
  24 H4SIO4AQ  0  1.2312E+01  1.2812E-04  1.2822E-04  -3.892   1.0008E+00
  25 H3SIO4   -1  2.0951E-02  2.2033E-07  2.0707E-07  -6.684   9.3982E-01
  26 H2SIO4   -2  1.9367E-07  2.0585E-12  1.6059E-12 -11.794   7.8015E-01
   8 FE        2  4.9131E-02  8.7991E-07  6.8646E-07  -6.163   7.8015E-01
   9 FE        3  2.2814E-15  4.0860E-20  2.3372E-20 -19.631   5.7200E-01
  10 FEOH      2  1.7268E-10  2.3707E-15  1.8495E-15 -14.733   7.8015E-01
  11 FEOH      1  1.5490E-04  2.1266E-09  1.9986E-09  -8.699   9.3982E-01
  12 FE(OH)3  -1  1.5823E-11  1.4809E-16  1.3918E-16 -15.856   9.3982E-01
  77 FE(OH)2   1  1.6181E-05  1.8010E-10  1.6926E-10  -9.771   9.3982E-01
  78 FE(OH)3   0  7.5327E-06  7.0499E-11  7.0554E-11 -10.151   1.0008E+00
  79 FE(OH)4  -1  3.2988E-06  2.6635E-11  2.5032E-11 -10.602   9.3982E-01
  80 FE(OH)2   0  1.1315E-08  1.2594E-13  1.2604E-13 -12.900   1.0008E+00
  15 FESO4     1  3.1704E-15  2.0875E-20  1.9618E-20 -19.707   9.3982E-01
  16 FECL      2  5.2827E-18  5.7873E-23  4.5149E-23 -22.345   7.8015E-01
  28 FECL2     1  3.1061E-20  2.4510E-25  2.3035E-25 -24.638   9.3982E-01
  33 FECL3     0  6.1407E-25  3.7865E-30  3.7895E-30 -29.421   1.0008E+00
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Well 78-1

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                               --------------------------------
                               DISTRIBUTION OF SPECIES (cont.)
                               --------------------------------

  I  SPECIES          PPM       MOLALITY   ACTIVITY    LOG ACT    GAMMA

 34 FESO4      0  2.0039E-03  1.3194E-08  1.3205E-08  -7.879  1.0008E+00
 36 H3BO3 AQ   0  9.0085E-01  1.4572E-05  1.4583E-05  -4.836  1.0008E+00
 37 H2BO3     -1  1.4112E-02  2.3206E-07  2.1810E-07  -6.661  9.3982E-01
 88 SR         2  8.5911E-02  9.8069E-07  7.6508E-07  -6.116  7.8015E-01
 69 SRHCO3     1  1.7203E-03  1.1576E-08  1.0880E-08  -7.963  9.3982E-01
 97 SRCO3      0  7.8870E-05  5.3435E-10  5.3477E-10  -9.272  1.0008E+00
 89 SROH       1  4.3994E-08  4.2057E-13  3.9526E-13 -12.403  9.3982E-01



  MOLE RATIOS FROM          MOLE RATIOS FROM
 ANALYTICAL MOLALITY        COMPUTED MOLALITY        LOG ACTIVITY RATIOS
---------------------    ---------------------    ---------------------
CL/CA   =  2.7393E-01    CL/CA   =  2.8343E-01    LOG CA/H2 =   11.7917
CL/MG   =  8.5719E-01    CL/MG   =  8.8201E-01    LOG MG/H2 =   11.2997
CL/NA   =  3.6281E-01    CL/NA   =  3.6339E-01    LOG NA/H1 =    4.2126
CL/K    =  5.8885E-01    CL/K    =  5.8930E-01    LOG K/H1  =    4.0022
CL/AL   =  1.7774E+26    CL/AL   =  1.7774E+26    LOG AL/H3 =   22.6500
CL/FE   =  1.9848E+02    CL/FE   =  2.0199E+02    LOG FE/H2 =    8.9366
CL/SO4  =  8.5351E-01    CL/SO4  =  9.2511E-01    LOG CA/MG =     .4920
CL/HCO3 =  9.9475E-02    CL/HCO3 =  1.0055E-01    LOG NA/K  =     .2104
CA/MG   =  3.1292E+00    CA/MG   =  3.1120E+00
NA/K    =  1.6230E+00    NA/K    =  1.6217E+00
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Well 78-1

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      PHASE      IAP       KT       LOG IAP  LOG KT    IAP/KT  LOG IAP/KT

  18 ANHYDRIT 7.396E-08 6.406E-05   -7.131   -4.193 1.155E-03   -2.938
  22 ARAGONIT 8.895E-10 5.665E-09   -9.051   -8.247 1.570E-01    -.804
 151 ARTIN    3.381E-27 4.804E-19  -26.471  -18.318 7.038E-09   -8.153
  20 BRUCITE  1.225E-18 3.567E-12  -17.912  -11.448 3.433E-07   -6.464
  13 CALCITE  8.895E-10 3.949E-09   -9.051   -8.404 2.253E-01    -.647
 144 CELEST   1.151E-10 2.458E-07   -9.939   -6.609 4.681E-04   -3.330
  98 CHALC    1.282E-04 1.873E-04   -3.892   -3.728 6.848E-01    -.164
  21 CHRYSOTL                      -61.520  -53.023             -8.497
  30 CLENSTIT 1.571E-22 6.826E-18  -21.804  -17.166 2.301E-05   -4.638
 100 SILGEL   1.282E-04 1.138E-03   -3.892   -2.944 1.127E-01    -.948
  29 DIOPSIDE                      -43.116  -37.155             -5.961
  12 DOLOMITE 2.549E-19 2.129E-17  -18.594  -16.672 1.197E-02   -1.922
 113 FEOH3A   1.044E+03 7.674E+04    3.019    4.885 1.360E-02   -1.866
  63 FLUOR    5.211E-14 6.780E-12  -13.283  -11.169 7.686E-03   -2.114
  28 FORSTRIT                      -39.716  -28.326            -11.390
 111 GEOTH                         -40.799  -45.330              4.531
 112 GREENA                        -68.609  -63.190             -5.419
  19 GYPSUM   7.395E-08 2.378E-05   -7.131   -4.624 3.110E-03   -2.507
  65 HALITE   7.677E-08 3.478E+01   -7.115    1.541 2.207E-09   -8.656
 109 HEMATI   1.090E+06 2.291E-03    6.037   -2.640 4.755E+08    8.677
 118 HUNTITE  2.092E-38 4.283E-30  -37.679  -29.368 4.885E-09   -8.311
  39 HYDMAG                        -56.083  -36.689            -19.395
  99 MAGADI   5.732E-24 5.012E-15  -23.242  -14.300 1.144E-09   -8.942
 110 MAGHEM   1.090E+06 2.344E+06    6.037    6.370 4.648E-01    -.333
  11 MAGNESIT 2.865E-10 1.080E-08   -9.543   -7.967 2.653E-02   -1.576
 108 MAGNET   3.206E+01 1.726E-08    1.506   -7.763 1.857E+09    9.269
  67 MIRABI   3.179E-11 1.110E-02  -10.498   -1.955 2.863E-09   -8.543
  59 NAHCOL   7.650E-07 1.937E-01   -6.116    -.713 3.950E-06   -5.403
  61 NATRON   3.823E-13 9.798E-03  -12.418   -2.009 3.902E-11  -10.409
 150 NESQUE   2.865E-10 1.111E-05   -9.543   -4.954 2.579E-05   -4.589
 102 QUARTZ   1.282E-04 5.240E-05   -3.892   -4.281 2.447E+00     .389
  37 SEPIOLIT                      -47.500  -41.276             -6.224
  10 SIDERITE 1.242E-12 5.037E-11  -11.906  -10.298 2.466E-02   -1.608
 101 SILGLAS  1.282E-04 6.112E-04   -3.892   -3.214 2.098E-01    -.678
 143 STRONT   1.384E-12 5.059E-10  -11.859   -9.296 2.736E-03   -2.563
  38 TALC                          -69.304  -64.287             -5.016
  66 THENAR   3.181E-11 7.020E-01  -10.497    -.154 4.531E-11  -10.344
  62 THRNAT   3.825E-13 1.775E+00  -12.417     .249 2.155E-13  -12.667
  32 TREMOLIT                     -155.535 -144.299            -11.237
  60 TRONA    2.926E-19 1.006E+00  -18.534     .003 2.908E-19  -18.536
 154 SEP PT                        -47.500  -37.212            -10.288
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Snowmelt

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                              ----------------
                              INITIAL SOLUTION
                              ----------------


      TEMPERATURE =    .10 DEGREES C    PH =  7.370
      ANALYTICAL EPMCAT =     .305    ANALYTICAL EPMAN =     .292
      CHARGE BALANCE ERROR =   .83 %

   ***** OXIDATION - REDUCTION *****

DISSOLVED OXYGEN =   .000 MG/L
EH MEASURED WITH CALOMEL =  9.9000 VOLTS         FLAG CORALK PECALC IDAVES
MEASURED EH OF ZOBELL SOLUTION =  9.9000 VOLTS     3    0      4      1
CORRECTED EH =  9.9000 VOLTS
PE COMPUTED FROM CORRECTED EH = 100.000


              *** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

                           TOTAL             LOG TOTAL          TOTAL
    SPECIES              MOLALITY            MOLALITY         MG/LITRE
    -------              --------            --------         --------

    CA         2     8.75773E-05           -4.0576        3.51000E+00
    MG         2     2.22119E-05           -4.6534        5.40000E-01
    NA         1     2.56643E-05           -4.5907        5.90000E-01
    K          1     5.98451E-05           -4.2230        2.34000E+00
    CL        -1     7.89800E-05           -4.1025        2.80000E+00
    HCO3      -1     2.13060E-04           -3.6715        1.30000E+01
    SIO2  TOT  0     8.00557E-05           -4.0966        4.81000E+00
    SR         2     1.14132E-07           -6.9426        1.00000E-02
    F         -1     7.89540E-05           -4.1026        1.50000E-01
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Snowmelt

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                        *** CONVERGENCE ITERATIONS ***

ITERATION  S1-ANALCO3   S2-SO4TOT    S3-FTOT     S4-PTOT    S5-CLTOT

     1      2.728E-07   0.000E+00   0.000E+00   0.000E+00   0.000E+00
     2      6.255E-10   0.000E+00   0.000E+00   0.000E+00   0.000E+00


                        ****DESCRIPTION OF SOLUTION ****

         ANAL.     COMP.         PH            ACTIVITY H2O =  1.0000
EPMCAT      .31       .31       7.370          PCO2=  4.316976E-04
EPMAN       .29       .29                      LOG PCO2 =  -3.3648
                              TEMPERATURE      PO2 =  1.713214E-63
EH = 9.9000  PE =    .000       .10 DEG C      PCH4 =  3.675116E-36
PE CALC S =  100.000                           CO2 TOT =  2.463367E-04
PE CALC DOX=100.000          IONIC STRENGTH    DENSITY =   1.0000
PE SATO DOX=100.000           4.083605E-04     TDS =      27.6MG/L
TOT ALK =  2.130E-01 MEQ                       CARB ALK =  2.130E-01 MEQ
ELECT   =  1.332E-02 MEQ

IN COMPUTING THE DISTRIBUTION OF SPECIES,
PE =    .000     EQUIVALENT EH =   .000VOLTS
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Snowmelt

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                          ----------------------
                          DISTRIBUTION OF SPECIES
                          ----------------------

 I  SPECIES          PPM       MOLALITY    ACTIVITY    LOG ACT     GAMMA

  1 CA         2  3.5050E+00  8.7452E-05  8.0047E-05  -4.097  9.1533E-01
  2 MG         2  5.3888E-01  2.2166E-05  2.0295E-05  -4.693  9.1562E-01
  3 NA         1  5.8993E-01  2.5661E-05  2.5097E-05  -4.600  9.7802E-01
  4 K          1  2.3400E+00  5.9845E-05  5.8522E-05  -4.233  9.7789E-01
 64 H          1  4.3967E-05  4.3620E-08  4.2658E-08  -7.370  9.7796E-01
  5 CL        -1  2.8000E+00  7.8980E-05  7.7234E-05  -4.112  9.7789E-01
  7 HCO3      -1  1.2968E+01  2.1254E-04  2.0789E-04  -3.682  9.7814E-01
 18 CO3       -2  7.5410E-03  1.2567E-07  1.1504E-07  -6.939  9.1540E-01
 86 H2CO3      0  2.0776E+00  3.3497E-05  3.3500E-05  -4.475  1.0001E+00
 27 OH        -1  4.7313E-04  2.7820E-08  2.7207E-08  -7.565  9.7796E-01
 19 MGOH       1  2.8414E-06  6.8768E-11  6.7252E-11 -10.172  9.7796E-01
 22 MGHCO3     1  3.8005E-03  4.4541E-08  4.3559E-08  -7.361  9.7796E-01
 21 MGCO3 AQ   0  1.2814E-04  1.5197E-09  1.5199E-09  -8.818  1.0001E+00
 29 CAOH       1  2.6592E-06  4.6582E-11  4.5555E-11 -10.341  9.7796E-01
 30 CAHCO3     1  1.1407E-02  1.1284E-07  1.1037E-07  -6.957  9.7814E-01
 31 CACO3 AQ   0  1.2584E-03  1.2573E-08  1.2567E-08  -7.901  9.9953E-01
 43 NAHCO3     0  2.4640E-04  2.9338E-09  2.9341E-09  -8.533  1.0001E+00
 42 NACO3     -1  1.1534E-06  1.3897E-11  1.3591E-11 -10.867  9.7796E-01
 24 H4SIO4AQ   0  7.6893E+00  8.0003E-05  8.0011E-05  -4.097  1.0001E+00
 25 H3SIO4    -1  4.9897E-03  5.2466E-08  5.1309E-08  -7.290  9.7796E-01
 26 H2SIO4    -2  8.0080E-09  8.5104E-14  7.7844E-14 -13.109  9.1470E-01
 88 SR         2  9.9870E-03  1.1398E-07  1.0426E-07  -6.982  9.1470E-01
 69 SRHCO3     1  2.1487E-05  1.4456E-10  1.4137E-10  -9.850  9.7796E-01
 97 SRCO3      0  5.4172E-07  3.6696E-12  3.6699E-12 -11.435  1.0001E+00
 89 SROH       1  1.6799E-09  1.6057E-14  1.5703E-14 -13.804  9.7796E-01



  MOLE RATIOS FROM          MOLE RATIOS FROM
 ANALYTICAL MOLALITY       COMPUTED MOLALITY         LOG ACTIVITY RATIOS
---------------------     ---------------------     ---------------------
CL/CA   =  9.0183E-01     CL/CA   =  9.0313E-01     LOG CA/H2 =   10.6433
CL/MG   =  3.5558E+00     CL/MG   =  3.5632E+00     LOG MG/H2 =   10.0474
CL/NA   =  3.0774E+00     CL/NA   =  3.0778E+00     LOG NA/H1 =    2.7696
CL/K    =  1.3197E+00     CL/K    =  1.3197E+00     LOG K/H1  =    3.1373
CL/AL   =  7.8980E+25     CL/AL   =  7.8980E+25     LOG AL/H3 =   22.1100
CL/FE   =  7.8980E+25     CL/FE   =  7.8980E+25     LOG FE/H2 =    8.5766
CL/SO4  =  7.8980E+25     CL/SO4  =  7.8980E+25     LOG CA/MG =     .5960
CL/HCO3 =  3.7069E-01     CL/HCO3 =  3.7160E-01     LOG NA/K  =    -.3677
CA/MG   =  3.9428E+00     CA/MG   =  3.9454E+00
NA/K    =  4.2884E-01     NA/K    =  4.2880E-01
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Snowmelt

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     PHASE       IAP        KT       LOG IAP  LOG KT    IAP/KT  LOG IAP/KT

 22 ARAGONIT 9.208E-12 6.049E-09  -11.036   -8.218  1.522E-03   -2.818
151 ARTIN    5.456E-31 5.285E-19  -30.263  -18.277  1.032E-12  -11.986
 20 BRUCITE  1.502E-20 3.414E-12  -19.823  -11.467  4.401E-09   -8.356
 13 CALCITE  9.208E-12 4.153E-09  -11.036   -8.382  2.217E-03   -2.654
 98 CHALC    8.001E-05 1.475E-04   -4.097   -3.831  5.425E-01    -.266
 21 CHRYSOTL                      -67.663  -53.643             -14.021
 30 CLENSTIT 1.202E-24 4.832E-18  -23.920  -17.316  2.488E-07   -6.604
100 SILGEL   8.001E-05 8.563E-04   -4.097   -3.067  9.344E-02   -1.029
 29 DIOPSIDE                      -47.244  -37.629              -9.615
 12 DOLOMITE 2.150E-23 3.470E-17  -22.668  -16.460  6.196E-07   -6.208
 28 FORSTRIT                      -43.743  -28.435             -15.308
 65 HALITE   1.938E-09 3.317E+01   -8.713    1.521  5.845E-11  -10.233
118 HUNTITE                       -45.931  -28.789             -17.142
 39 HYDMAG                        -66.350  -36.115             -30.235
 99 MAGADI   2.880E-26 5.012E-15  -25.541  -14.300  5.746E-12  -11.241
 11 MAGNESIT 2.335E-12 1.486E-08  -11.632   -7.828  1.571E-04   -3.804
 59 NAHCOL   5.218E-09 1.598E-01   -8.283    -.796  3.265E-08   -7.486
 61 NATRON   7.245E-17 4.338E-03  -16.140   -2.363  1.670E-14  -13.777
150 NESQUE   2.335E-12 1.499E-05  -11.632   -4.824  1.558E-07   -6.807
102 QUARTZ   8.001E-05 3.798E-05   -4.097   -4.420  2.107E+00     .324
 37 SEPIOLIT                      -51.937  -41.872             -10.065
101 SILGLAS  8.001E-05 4.858E-04   -4.097   -3.314  1.647E-01    -.783
143 STRONT   1.199E-14 4.571E-10  -13.921   -9.340  2.624E-05   -4.581
 38 TALC                          -75.857  -65.300             -10.557
 62 THRNAT   7.246E-17 2.052E+00  -16.140     .312  3.531E-17  -16.452
 32 TREMOLIT                     -170.346 -146.326             -24.020
 60 TRONA    3.780E-25 2.555E+00  -24.422     .407  1.480E-25  -24.830
154 SEP PT                        -51.937  -37.212             -14.725
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Big Lost River

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                         ----------------
                         INITIAL SOLUTION
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        TEMPERATURE =  12.40 DEGREES C    PH =  8.090
        ANALYTICAL EPMCAT =     3.214    ANALYTICAL EPMAN =    3.186
        CHARGE BALANCE ERROR =   .37 %

    ***** OXIDATION - REDUCTION *****

 DISSOLVED OXYGEN =    .000 MG/L
 EH MEASURED WITH CALOMEL =  9.9000 VOLTS          FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION =  9.9000 VOLTS     3     0      4      1
 CORRECTED EH =  9.9000 VOLTS
 PE COMPUTED FROM CORRECTED EH = 100.000


            *** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

                        TOTAL              LOG TOTAL            TOTAL
      SPECIES          MOLALITY            MOLALITY           MG/LITRE
      -------          --------            --------           --------

      CA        2     1.06390E-03           -2.9731          4.26300E+01
      MG        2     4.27062E-04           -3.3695          1.03800E+01
      NA        1     1.96661E-04           -3.7063          4.52000E+00
      K         1     3.12087E-05           -4.5057          1.22000E+00
      CL       -1     1.60819E-04           -3.7937          5.70000E+00
      SO4      -2     1.77016E-04           -3.7520          1.70000E+01
      HCO3     -1     2.67208E-03           -2.5732          1.63000E+02
      SIO2 TOT  0     3.12308E-04           -3.5054          1.87600E+01
      SR        2     2.39735E-06           -5.6203          2.10000E-01
      F        -1     3.31607E-05           -4.4794          6.30000E-01
      B TOT     0     4.07138E-05           -4.3903          4.40000E-01
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Big Lost River

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                    *** CONVERGENCE ITERATIONS ***

ITERATION  S1-ANALCO3   S2-SO4TOT    S3-FTOT     S4-PTOT    S5-CLTOT

     1       6.584E-05   3.128E-05  0.000E+00   0.000E+00   0.000E+00
     2       8.253E-07   3.191E-07  0.000E+00   0.000E+00   0.000E+00
     3      -3.622E-08  -1.602E-08  0.000E+00   0.000E+00   0.000E+00




                   ****DESCRIPTION OF SOLUTION ****

         ANAL.     COMP.         PH          ACTIVITY H2O =   .9999
EPMCAT     3.21      3.12       8.090        PCO2=  1.088753E-03
EPMAN      3.19      3.09                    LOG PCO2 =  -2.9631
                              TEMPERATURE    PO2 =  6.618826E-56
EH = 9.9000  PE =     .000     12.40 DEG C   PCH4 =  0.000000E+00
PE CALC S =  100.000                         CO2 TOT =  2.693521E-03
PE CALC DOX=100.000          IONIC STRENGTH  DENSITY =   1.0000
PE SATO DOX=100.000           4.703090E-03   TDS =     263.9MG/L
TOT ALK =  2.672E+00 MEQ                     CARB ALK =  2.667E+00 MEQ
ELECT   =  2.761E-02 MEQ

IN COMPUTING THE DISTRIBUTION OF SPECIES,
PE =    .000     EQUIVALENT EH =   .000VOLTS
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Big Lost River

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                         ------------------------
                         DISTRIBUTION OF SPECIES
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  I  SPECIES          PPM       MOLALITY    ACTIVITY    LOG ACT    GAMMA

   1 CA         2  4.0744E+01  1.0168E-03  7.6653E-04   -3.115  7.5383E-01
   2 MG         2  9.9969E+00  4.1130E-04  3.1105E-04   -3.507  7.5626E-01
   3 NA         1  4.5113E+00  1.9628E-04  1.8269E-04   -3.738  9.3077E-01
   4 K          1  1.2192E+00  3.1188E-05  2.8988E-05   -4.538  9.2946E-01
  64 H          1  8.8058E-06  8.7383E-09  8.1283E-09   -8.090  9.3020E-01
   5 CL        -1  5.7000E+00  1.6082E-04  1.4948E-04   -3.825  9.2946E-01
   6 SO4       -2  1.4980E+01  1.5598E-04  1.1732E-04   -3.931  7.5216E-01
   7 HCO3      -1  1.5761E+02  2.5836E-03  2.4077E-03   -2.618  9.3190E-01
  18 CO3       -2  8.1985E-01  1.3666E-05  1.0307E-05   -4.987  7.5420E-01
  86 H2CO3      0  3.3456E+00  5.3953E-05  5.4020E-05   -4.267  1.0012E+00
  27 OH        -1  8.2525E-03  4.8536E-07  4.5148E-07   -6.345  9.3020E-01
  19 MGOH       1  8.7833E-04  2.1263E-08  1.9779E-08   -7.704  9.3020E-01
  23 MGSO4 AQ   0  5.3873E-01  4.4766E-06  4.4815E-06   -5.349  1.0011E+00
  22 MGHCO3     1  7.4583E-01  8.7429E-06  8.1327E-06   -5.090  9.3020E-01
  21 MGCO3 AQ   0  2.1228E-01  2.5182E-06  2.5209E-06   -5.598  1.0011E+00
  29 CAOH       1  4.8812E-04  8.5526E-09  7.9557E-09   -8.099  9.3020E-01
  32 CASO4 AQ   0  2.2274E+00  1.6365E-05  1.6383E-05   -4.786  1.0011E+00
  30 CAHCO3     1  1.9827E+00  1.9617E-05  1.8281E-05   -4.738  9.3190E-01
  31 CACO3 AQ   0  1.1062E+00  1.1055E-05  1.0995E-05   -4.959  9.9460E-01
  44 NASO4     -1  1.3241E-02  1.1125E-07  1.0349E-07   -6.985  9.3020E-01
  43 NAHCO3     0  2.0748E-02  2.4709E-07  2.4736E-07   -6.607  1.0011E+00
  42 NACO3     -1  1.6033E-03  1.9322E-08  1.7973E-08   -7.745  9.3020E-01
  94 NACL       0  1.5938E-33  2.7279E-38  2.7308E-38  -37.564  1.0011E+00
  46 KSO4      -1  2.7594E-03  2.0421E-08  1.8995E-08   -7.721  9.3020E-01
  63 HSO4      -1  6.8562E-06  7.0651E-11  6.5719E-11  -10.182  9.3020E-01
  24 H4SIO4AQ   0  2.9776E+01  3.0988E-04  3.1021E-04   -3.508  1.0011E+00
  25 H3SIO4    -1  2.3125E-01  2.4321E-06  2.2623E-06   -5.645  9.3020E-01
  26 H2SIO4    -2  1.4310E-05  1.5212E-10  1.1389E-10   -9.944  7.4869E-01
  36 H3BO3 AQ   0  2.3725E+00  3.8379E-05  3.8420E-05   -4.415  1.0011E+00
  37 H2BO3     -1  1.4199E-01  2.3350E-06  2.1721E-06   -5.663  9.3020E-01
  88 SR         2  1.9994E-01  2.2825E-06  1.7089E-06   -5.767  7.4869E-01
  69 SRHCO3     1  6.5318E-03  4.3956E-08  4.0888E-08   -7.388  9.3020E-01
  97 SRCO3      0  1.1426E-03  7.7415E-09  7.7499E-09   -8.111  1.0011E+00
  89 SROH       1  5.2616E-07  5.0302E-12  4.6791E-12  -11.330  9.3020E-01
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Big Lost River

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  MOLE RATIOS FROM           MOLE RATIOS FROM
 ANALYTICAL MOLALITY         COMPUTED MOLALITY        LOG ACTIVITY RATIOS
---------------------      ---------------------     ---------------------
CL/CA   =  1.5116E-01      CL/CA    =  1.5815E-01    LOG CA/H2 =   13.0645
CL/MG   =  3.7657E-01      CL/MG    =  3.9100E-01    LOG MG/H2 =   12.6728
CL/NA   =  8.1775E-01      CL/NA    =  8.1932E-01    LOG NA/H1 =    4.3517
CL/K    =  5.1530E+00      CL/K     =  5.1564E+00    LOG K/H1  =    3.5522
CL/AL   =  1.6082E+26      CL/AL    =  1.6082E+26    LOG AL/H3 =   24.2700
CL/FE   =  1.6082E+26      CL/FE    =  1.6082E+26    LOG FE/H2 =   10.0166
CL/SO4  =  9.0850E-01      CL/SO4   =  1.0310E+00    LOG CA/MG =     .3917
CL/HCO3 =  6.0185E-02      CL/HCO3  =  6.2245E-02    LOG NA/K  =     .7995
CA/MG   =  2.4912E+00      CA/MG    =  2.4723E+00
NA/K    =  6.3015E+00      NA/K     =  6.2935E+00
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Big Lost River

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     PHASE       IAP        KT       LOG IAP  LOG KT    IAP/KT  LOG IAP/KT

  18 ANHYDRIT 8.993E-08 5.690E-05   -7.046   -4.245  1.581E-03   -2.801
  22 ARAGONIT 7.900E-09 5.417E-09   -8.102   -8.266  1.458E+00     .164
 151 ARTIN    1.234E-24 4.566E-19  -23.909  -18.340  2.702E-06   -5.568
  20 BRUCITE  6.340E-17 3.652E-12  -16.198  -11.437  1.736E-05   -4.760
  13 CALCITE  7.900E-09 3.806E-09   -8.102   -8.419  2.076E+00     .317
 144 CELEST   2.005E-10 2.530E-07   -9.698   -6.597  7.926E-04   -3.101
  98 CHALC    3.103E-04 2.127E-04   -3.508   -3.672  1.459E+00     .164
  21 CHRYSOTL                      -55.610  -52.692              -2.918
  30 CLENSTIT 1.967E-20 8.205E-18  -19.706  -17.086  2.398E-03   -2.620
 100 SILGEL   3.103E-04 1.325E-03   -3.508   -2.878  2.342E-01    -.630
  29 DIOPSIDE                      -39.021  -36.902              -2.118
  12 DOLOMITE 2.533E-17 1.641E-17  -16.596  -16.785  1.543E+00     .188
  28 FORSTRIT 1.247E-36 5.401E-29  -35.904  -28.268  2.310E-08   -7.636
  19 GYPSUM   8.991E-08 2.434E-05   -7.046   -4.614  3.694E-03   -2.433
  65 HALITE   2.731E-08 3.567E+01   -7.564    1.552  7.656E-10   -9.116
 118 HUNTITE  2.603E-34 2.105E-30  -33.585  -29.677  1.237E-04   -3.908
  39 HYDMAG                        -50.174  -36.995             -13.180
  99 MAGADI   9.866E-22 5.012E-15  -21.006  -14.300  1.969E-07   -6.706
  11 MAGNESIT 3.206E-09 9.110E-09   -8.494   -8.040  3.519E-01    -.454
  67 MIRABI   3.913E-12 1.874E-02  -11.408   -1.727  2.087E-10   -9.680
  59 NAHCOL   4.399E-07 2.146E-01   -6.357    -.668  2.050E-06   -5.688
  61 NATRON   3.437E-13 1.513E-02  -12.464   -1.820  2.272E-11  -10.644
 150 NESQUE   3.205E-09 9.468E-06   -8.494   -5.024  3.385E-04   -3.470
 102 QUARTZ   3.103E-04 6.220E-05   -3.508   -4.206  4.988E+00     .698
  37 SEPIOLIT                      -42.921  -40.958              -1.962
 101 SILGLAS  3.103E-04 6.909E-04   -3.508   -3.161  4.491E-01    -.348
 143 STRONT   1.761E-11 5.238E-10  -10.754   -9.281  3.362E-02   -1.473
  38 TALC                          -62.627  -63.748               1.121
  66 THENAR   3.916E-12 6.910E-01  -11.407    -.160  5.667E-12  -11.247
  62 THRNAT   3.440E-13 1.643E+00  -12.463     .216  2.094E-13  -12.679
  32 TREMOLIT                     -140.668 -143.218               2.550
  60 TRONA    1.513E-19 6.126E-01  -18.820    -.213  2.470E-19  -18.607
 154 SEP PT          -42.921 -37.212      -5.709
```

Appendix C. SNORM Analyses

```
 field data from inel
water from well 78-1                                                                                                    well78-1
-----------------------------------------------------------------------------------------------------------------------------------

Solution properties:          ph =  7.55          density =  nd

    Water composition (analytical units: mg/kg)               Mole ratios        Concentrations adjusted to achieve charge balance
 -------------------------------------------------                               -------------------------------------------------
          molal      g/kgW       M/kg      mg/kg            Ca/Mg 3.13E+00                molal      g/kgW      M/kg      mg/kg
                                                             K/Na 6.16E-01
 Mg     2.074E-04  5.041E-03  2.074E-04  5.040E+00     Mg+Ca/Na+K 1.08E+00       Mg     2.031E-04  4.937E-03  2.031E-04  4.936E+00
 Ca     6.488E-04  2.600E-02  6.487E-04  2.600E+01      alk./hal. 4.45E+00       Ca     6.355E-04  2.547E-02  6.353E-04  2.546E+01
 Sr     1.027E-06  9.002E-05  1.027E-06  9.000E-02        HCO3/Cl 1.01E+01       Sr     1.006E-06  8.816E-05  1.006E-06  8.815E-02
 Na     4.899E-04  1.126E-02  4.898E-04  1.126E+01         SO4/Cl 1.17E+00       Na     4.798E-04  1.103E-02  4.797E-04  1.103E+01
 K      3.019E-04  1.180E-02  3.018E-04  1.180E+01           F/Cl 6.22E-02       K      2.956E-04  1.156E-02  2.956E-04  1.156E+01
 F      1.106E-05  2.100E-04  1.105E-05  2.100E-01           B/Cl 8.33E-02       F      1.129E-05  2.146E-04  1.129E-05  2.145E-01
 Cl     1.777E-04  6.301E-03  1.777E-04  6.300E+00          Mg/Cl 1.17E+00       Cl     1.816E-04  6.437E-03  1.815E-04  6.435E+00
 HCO3   1.787E-03  1.090E-01  1.786E-03  1.090E+02          Ca/Cl 3.65E+00       HCO3   1.821E-03  1.111E-01  1.821E-03  1.111E+02
 CO3        -          -          -          -              Sr/Cl 5.78E-03       CO3    3.661E-06  2.197E-04  3.661E-06  2.197E-01
 SO4    2.082E-04  2.000E-02  2.082E-04  2.000E+01          Na/Cl 2.76E+00       SO4    2.127E-04  2.043E-02  2.127E-04  2.043E+01
 B      1.480E-05  1.600E-04  1.480E-05  1.600E-01           K/Cl 1.70E+00       B      1.512E-05  1.635E-04  1.512E-05  1.634E-01
        ---------  ---------  ---------  ---------                                      ---------  ---------  ---------  ---------
 Total  3.848E-03  1.899E-01  3.847E-03  1.899E+02                               Total  3.861E-03  1.917E-01  3.860E-03  1.917E+02

     Charge balance:  sum[+]/sum[-] = 1.0430                           Note: borate charge of - .500 per boron.

Normative salt assemblage                                                                             Simple salts
-------------------------                                                                             ------------

                                       per kilogram of solution       normative salts - percent                       percent
                                    -----------------------------  -----------------------------                ------------------- 
                                      moles      mg     mg (anhy)     mole     weight  wt.(anhy)                   mole     weight

Dolomite        CaMg(CO3)2          2.031E-04 3.745E+01 3.745E+01    21.44398  26.94783  27.61854        Na2Cl2   7.45976   7.90387
Calcite         CaCO3               3.575E-04 3.578E+01 3.578E+01    37.74442  25.74479  26.38556        K2SO4   12.14758  19.18787
Aphthitalite    K3Na(SO4)2          9.853E-05 3.275E+01 3.275E+01    10.40335  23.56588  24.15242        Na2SO4   5.33339   6.86688
Pirssonite      Na2Ca(CO3)2.2H2O    7.477E-05 1.810E+01 1.541E+01     7.89516  13.02628  11.36368        Na2CO3   6.14591   5.90473
Halite          NaCl                1.815E-04 1.061E+01 1.061E+01    19.16592   7.63326   7.82325        MgCO3   16.69285  12.75807
Thenardite      Na2SO4              1.562E-05 2.219E+00 2.219E+00     1.64971   1.59683   1.63657        CaCO3   52.22052  47.37859
Borax           Na2B4O7.10H2O       3.779E-06 1.441E+00 7.605E-01      .39906   1.03713    .56083
Villiaumite     NaF                 1.129E-05 4.741E-01 4.741E-01     1.19219    .34113    .34962
Strontionite    SrCO3               1.006E-06 1.485E-01 1.485E-01      .10622    .10686    .10952
                                    --------- --------- ---------   --------- --------- ---------               --------- ---------
                         Total      9.471E-04 1.390E+02 1.356E+02   100.00000 100.00000 100.00000               100.00000 100.00000
-----------------------------------------------------------------------------------------------------------------------------------
NOTES: 1. Solute mole ratios calculated from initial analytical data; alkali/halide ratio excludes lithium and fluoride.
       2. Analytical data in per kg units; density not determined.
       3. g/kgW = grams per kilogram water.
```

```
 field data from inel
snow melt sample                                                                                                           sn-1
-------------------------------------------------------------------------------------------------------------------------------------

Solution properties:           ph =  nd            density =  nd

    Water composition (analytical units: mg/kg)                Mole ratios        Concentrations adjusted to achieve charge balance
 --------------------------------------------------                               --------------------------------------------------
          molal      g/kgW        M/kg      mg/kg            Ca/Mg 3.94E+00                molal      g/kgW       M/kg      mg/kg
                                                              K/Na 2.33E+00
 Mg     2.222E-05  5.400E-04  2.222E-05  5.400E-01      Mg+Ca/Na+K 1.28E+00       Mg     2.202E-05  5.352E-04  2.202E-05  5.352E-01
 Ca     8.758E-05  3.510E-03  8.757E-05  3.510E+00       alk./hal. 1.08E+00       Ca     8.680E-05  3.479E-03  8.680E-05  3.479E+00
 Sr     1.141E-07  1.000E-05  1.141E-07  1.000E-02         HCO3/Cl 2.70E+00       Sr     1.131E-07  9.912E-06  1.131E-07  9.912E-03
 Na     2.566E-05  5.900E-04  2.566E-05  5.900E-01            F/Cl 1.00E-01       Na     2.544E-05  5.848E-04  2.544E-05  5.848E-01
 K      5.985E-05  2.340E-03  5.985E-05  2.340E+00           Mg/Cl 2.81E-01       K      5.932E-05  2.319E-03  5.932E-05  2.319E+00
 F      7.896E-06  1.500E-04  7.895E-06  1.500E-01           Ca/Cl 1.11E+00       F      7.967E-06  1.514E-04  7.966E-06  1.513E-01
 Cl     7.898E-05  2.800E-03  7.898E-05  2.800E+00           Sr/Cl 1.45E-03       Cl     7.969E-05  2.825E-03  7.969E-05  2.825E+00
 HCO3   2.131E-04  1.300E-02  2.131E-04  1.300E+01           Na/Cl 3.25E-01       HCO3   2.150E-04  1.312E-02  2.150E-04  1.312E+01
        ---------  ---------  ---------  ---------            K/Cl 7.58E-01              ---------  ---------  ---------  ---------
 Total  4.954E-04  2.294E-02  4.953E-04  2.294E+01                                Total  4.963E-04  2.302E-02  4.963E-04  2.302E+01

     Charge balance:  sum[+]/sum[-] = 1.0180

Normative salt assemblage                                                                              Simple salts
-------------------------                                                                              ------------

                                        per kilogram of solution      normative salts - percent                         percent
                                     ------------------------------ ------------------------------                ------------------
                                       moles      mg      mg (anhy)     mole     weight  wt.(anhy)                    mole     weight

Calcite         CaCO3                6.333E-05 6.339E+00 6.339E+00    36.89064  38.75711  38.75711         Na2Cl2   6.91780   7.43421
Sylvite         KCl                  5.932E-05 4.422E+00 4.422E+00    34.55460  27.04014  27.04014         K2Cl2   20.14714  27.61878
Dolomite        CaMg(CO3)2           2.202E-05 4.061E+00 4.061E+00    12.82762  24.82921  24.82921         MgCO3   14.95835  11.59552
Halite          NaCl                 2.037E-05 1.190E+00 1.190E+00    11.86480   7.27846   7.27846         CaCO3   57.97670  53.35149
Villiaumite     NaF                  5.068E-06 2.128E-01 2.128E-01     2.95235   1.30120   1.30120
Fluorite        CaF2                 1.449E-06 1.131E-01 1.131E-01      .84409    .69177    .69177
Strontionite    SrCO3                1.131E-07 1.670E-02 1.670E-02      .06589    .10211    .10211
                                     --------- --------- ---------   --------- --------- ---------                ---------  ---------
                          Total      1.717E-04 1.635E+01 1.635E+01   100.00000 100.00000 100.00000                 99.99999 100.00000
-------------------------------------------------------------------------------------------------------------------------------------
NOTES: 1. Solute mole ratios calculated from initial analytical data; alkali/halide ratio excludes lithium and fluoride.
       2. Analytical data in per kg units; density not determined.
       3. g/kgW = grams per kilogram water.
```

```
 field data from inel
big lost river sample                                                                                                      blr-1
-------------------------------------------------------------------------------------------------------------------------------------

Solution properties:          ph =  8.09           density =  nd

    Water composition (analytical units: mg/kg)                Mole ratios        Concentrations adjusted to achieve charge balance
 --------------------------------------------------                               --------------------------------------------------
          molal      g/kgW     M/kg       mg/kg              Ca/Mg 2.49E+00                molal      g/kgW       M/kg       mg/kg
                                                              K/Na 1.59E-01
 Mg     4.272E-04  1.038E-02  4.271E-04  1.038E+01      Mg+Ca/Na+K 6.54E+00       Mg      4.304E-04  1.046E-02  4.303E-04  1.046E+01
 Ca     1.064E-03  4.264E-02  1.064E-03  4.263E+01       alk./hal. 1.42E+00       Ca      1.072E-03  4.296E-02  1.072E-03  4.295E+01
 Sr     2.397E-06  2.101E-04  2.397E-06  2.100E-01         HCO3/Cl 1.66E+01       Sr      2.415E-06  2.116E-04  2.415E-06  2.116E-01
 Na     1.967E-04  4.521E-03  1.966E-04  4.520E+00          SO4/Cl 1.10E+00       Na      1.981E-04  4.555E-03  1.981E-04  4.554E+00
 K      3.121E-05  1.220E-03  3.120E-05  1.220E+00            F/Cl 2.06E-01       K       3.145E-05  1.230E-03  3.144E-05  1.229E+00
 F      3.317E-05  6.302E-04  3.316E-05  6.300E-01            B/Cl 2.53E-01       F       3.292E-05  6.254E-04  3.291E-05  6.253E-01
 Cl     1.608E-04  5.701E-03  1.608E-04  5.700E+00           Mg/Cl 2.66E+00       Cl      1.596E-04  5.659E-03  1.596E-04  5.657E+00
 HCO3   2.672E-03  1.630E-01  2.671E-03  1.630E+02           Ca/Cl 6.62E+00       HCO3    2.633E-03  1.607E-01  2.633E-03  1.606E+02
 CO3        -          -          -          -               Sr/Cl 1.49E-02       CO3     1.892E-05  1.135E-03  1.891E-05  1.135E+00
 SO4    1.770E-04  1.700E-02  1.770E-04  1.700E+01           Na/Cl 1.22E+00       SO4     1.757E-04  1.688E-02  1.757E-04  1.687E+01
 B      4.071E-05  4.401E-04  4.070E-05  4.400E-01            K/Cl 1.94E-01       B       4.041E-05  4.368E-04  4.040E-05  4.367E-01
        ---------  ---------  ---------  ---------                                        ---------  ---------  ---------  ---------
 Total  4.805E-03  2.458E-01  4.804E-03  2.457E+02                                Total   4.795E-03  2.448E-01  4.794E-03  2.448E+02

     Charge balance:  sum[+]/sum[-] =  .9851                             Note: borate charge of - .600 per boron.

Normative salt assemblage                                                                               Simple salts
-------------------------                                                                               ------------
                                        per kilogram of solution       normative salts - percent                        percent
                                     ------------------------------  -----------------------------                ------------------- 
                                       moles      mg      mg (anhy)      mole     weight  wt.(anhy)                   mole     weight

Dolomite        CaMg(CO3)2           4.303E-04 7.935E+01 7.935E+01    34.88035  47.87881  48.30068         Na2Cl2   5.02377   5.81250
Calcite         CaCO3                4.745E-04 4.750E+01 4.750E+01    38.46587  28.65869  28.91121         CaSO4    8.95966  12.07372
Anhydrite       CaSO4                1.114E-04 1.516E+01 1.516E+01     9.02616   9.14691   9.22751         K2SO4     .98980   1.70728
Halite          NaCl                 1.596E-04 9.326E+00 9.326E+00    12.93487   5.62713   5.67671         Na2SO4    .95852   1.34764
Syngenite       CaK2(SO4)2.H2O       1.572E-05 5.163E+00 4.879E+00     1.27424   3.11499   2.97006         MgCO3   27.09436  22.61265
Glauberite      CaNa2(SO4)2          1.522E-05 4.235E+00 4.235E+00     1.23396   2.55513   2.57764         CaCO3   56.97389  56.44622
Ulexite         CaNaB5O9.8H2O        8.079E-06 3.274E+00 2.110E+00      .65487   1.97544   1.28410
Fluorite        CaF2                 1.646E-05 1.285E+00 1.285E+00     1.33393    .77526    .78210
Celestite       SrSO4                2.415E-06 4.436E-01 4.436E-01      .19575    .26764    .26999
                                     --------- --------- ---------   --------- --------- ---------                ---------- ---------
                          Total      1.234E-03 1.657E+02 1.643E+02   100.00000 100.00000  99.99998                100.00000 100.00000
-------------------------------------------------------------------------------------------------------------------------------------
NOTES: 1. Solute mole ratios calculated from initial analytical data; alkali/halide ratio excludes lithium and fluoride.
       2. Analytical data in per kg units; density not determined.
       3. g/kgW = grams per kilogram water.
```

```
SUMMARY OF REQUIRED CALCULATIONS

  field data from inel

  1. well78-1                  water from well 78-1
    Salt-pair tests =   360        Assemblage tests =  12       Inversions =  13

  2. sn-1                      snow melt sample
    Salt-pair tests =   964        Assemblage tests =  48       Inversions =  39

  3. blr-1                     big lost river sample
    Salt-pair tests =  8574        Assemblage tests = 147       Inversions = 131
```