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267

VERTICAL VARIATION IN GROUNDWATER CHEMISTRY INFERRED FROM FLUID SPECIFIC-CONDUCTANCE WELL LOGGING OF THE SNAKE RIVER PLAIN BASALT AQUIFER, IDAHO NATIONAL ENGINEERING LABORATORY, SOUTHEASTERN IDAHO

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ABSTRACT

Well logging of electrical fluid specific conductance (C_s) shows that permeable zones yielding ground water to intrawell flows and the water columns in some wells at INEL have highly different chemistry, with as much as a two-fold variation in C_s. This suggests that dedicated-pump sampling of ground water in the aquifer may not be representative of the chemistry of the waste plumes migrating southwest of the nuclear facilities. Natural background C_s in basalt-aquifer ground water of this part of the Snake River Plain aquifer is less than 325µS/cm (microSiemans/cm), and total dissolved solids in mg/L units, (TDS) $\approx 0.6 C_s$. This relationship underestimates TDS for waters with chemical waste, when C_s is above 800 µS/cm.

At well 59 near the ICPP water of 1115 µS/cm ($\approx$670+ mg/L TDS) enters the well from a permeable zone between 521 and 537 ft depth; the zone being 60 ft below the water level and water of 550 µS/cm. At the time of logging (9/14/93) the 1115µS/cm water was flowing down the well, mixing with less concentrated waters and exiting at 600 or 624-ft depth. Waste water disposed of down the injection well at ICPP until 1984 was estimated to have a C_s of 1140 µS/cm, identical to the water detected in logging.

At well OW2, the highest C_s water (760µS/cm) is in the upper 30 feet of the water column: water from two flow zones below have different chemistry with lower values of C_s. The Site 14 well and USGS 83 show uniform values throughout the water column. The water column in Site 14 is dominated by a downward flow of 50 gal/min probably entering between 475 and 500 ft depth and exiting near the bottom of the well at 700 ft depth.

Impeller flowmeter and precision temperature logging are used to define and quantify temperature variations and intrawell flows. At well 59 (depth=657 ft) and OW2 (depth=996 ft), are downward decreasing temperatures in the bottom zones of no flow, suggesting that major flow zones lie beneath the deepest parts of these wells.

INTRODUCTION

Fluid temperature, electrical specific conductance, and spinner-flowmeter logs were run in four wells within the saturated zone of the eastern Snake River Plain basalt aquifer (Figures 1

and 2). This reconnaissance logging was done to identify wells in which to deploy packer systems to hydraulically test and sample ground water from the aquifer - a project of the State of Idaho Oversight Program of U.S. Government nuclear facilities at the Idaho National Engineering Laboratory. Identification of the major permeable conduits in the stack of Quaternary lavas, sediments and basalt bodies that make up the aquifer is a major goal of the project. Knowledge of the major permeable zones, and determining the position of waste water in the aquifer is important to monitoring plumes of waste water, and to design a strategy for diverting plumes or recovering and reprocessing waste waters should that become necessary or feasible in the future.

Thickness of the Quaternary basalt section exceeds 2,500 ft (760 m) beneath parts of the Idaho National Engineering Laboratory (Figure 3). A K-Ar age of 820 Ma is obtained from basalt at 2321-ft (708 m) deep in well NRF 89-04, and ages of 200-650 Ma are common for the sequence (Lanphere and others, 1993. The lava sequence that comprises the saturated aquifer contains several thin but very transmissive zones which we believe to be mostly lava-flow tops - although not all flow tops are highly permeable. Well tests of the upper 150 to 500 ft (45 to 150 m) of the aquifer show very small drawdowns for large flows, from which are derived some of the highest transmissivity values known in the world, ranging up to 2,400,000 ft^2/day (220,000 m^2/day) (Garabedian, 1992, p. F12). Typical value is 60,000 ft^2/day (5580 m^2/day) (Ackerman, 1991). We do not yet know the typical thickness of the highly transmissive zones, but we suspect that several zones of only a few meters of fractured or rubbly flow-top basalt may dominate the response of the wells to pumping. Much of the eastern Snake River Plain basalt is near-vent and tube-fed pahoehoe lava (Kuntz and others, 1992). We have been impressed by the apparent permeability of coarse rubble and sequences of shelly pahoehoe in the upper few meters of flows with partings typically spaced a few centimeters. Downgradient ground water velocities are estimated at 4 to 20 ft/day at a gradient of 10 ft/mile (0.0019) (Robertson and others, 1974).

The wells are situated on the Quaternary basalt fields of the eastern plain and were drilled for various groundwater monitoring and experimental programs associated with nuclear facilities at the Idaho National Engineering Laboratory (INEL). The Site 14 well is upgradient of injection wells, disposal ponds and waste ponds that have introduced low-level waste radionuclides and other constituents into the southwest migrating ground water. Well 59 is within a plume of waste constituents attributed mostly to the injection well at the Idaho Chemical Processing Plant (ICCP), a disposal-well practice that was discontinued in 1984. Well 83 is down gradient, within the track of the waste water plume area, but shows low Tritium (0.1±0.3 pCi/mL)in contrast to surrounding wells which are above 2 pCi/mL (Knobel and Mann, 1988). [(note that 1 pCi/mL ≈ 312 TU = 2.25 ^{3}H-disintegrations/min/mL), where 1 TU = isotope ratio ^{3}H/ ^{2}H of 10^{-18} = = 0.0032 pCi/mL (Rhodehamel and others, 1971, p. 4), and that values of less than 5 TU are considered natural, pre-atmospheric testing of thermonuclear devices in the period 1953-69 (Freeze and Cherry, 1979)]. Well OW-2 was drilled in 1993 south of the Radioactive Waste Management Complex (RWMC) for the purpose of monitoring the saturated zone during a large scale infiltration experiment (Norell and Wood, 1993).

METHODS

Well logging was conducted with Boise State University's Series 3000 Mount Sopris Instruments Company 4-conductor wireline unit with data acquisition using the ACQUIRE

software and interface electronics. We used the bi-directional Halliburton (formerly Gearhart-Owen, Mineral Logging Service) 1 7/16-inch-(36.5 mm)-diameter impeller flowmeter with a low-density plastic impeller spinning on jewelled pivots (Figure 4). The impeller has an embedded magnet that allows the electronics in the sonde to sense the direction of spin and change polarity of the pulses according to spin direction. The impeller has a stall speed of about 11 ft/minute for down-wash flow, and about 8 ft/minute of up-wash flow. In order to detect small flows the tool is trolled at speeds of 15 to 25 feet/minute. The least noisy signal is obtained on down trolled runs (up-wash). Noise level is about 2 to 3 feet per minute (Figures 6 to 9) on account of the somewhat jerky nature of the revolutions of the impeller. Calibration is obtained by trolling at various speeds in casing. Counts per second [cps] response have a linear relationship to troll speed in the range 15 ft/min to 25 ft/min. For uptroll (downwash): ft/min = 8.00·[cps] + 11.00, and for downtroll (upwash): ft/min = 6.06·[cps] + 6.80.

Intrawell flows detected by flowmeter, in terms of ft/min can be converted to volumetric flow, by multiplying by the cross-sectional area of the borehole, which for a 6-inch well is 0.20 ft^2, and for an 8-inch well is 0.35 ft^2 to give flow in terms of ft^3/min. One cubic foot is 7.5 gallons, so that for a 6-inch well, 1 ft/min = 1.5 gal/min; and for an 8-inch well, 1 ft/min = 2.6 gal/min. A uniform volumetric flow fluctuates with borehole diameter, so that in break-out intervals or constrictions seen on caliper logs, the flow will vary on account of borehole size.

Fluid electrical resistivity and temperature are recorded simultaneously by logging with the Mount Sopris Instruments MLP-4280 probe. Temperature and fluid resistivity response of the tool is calibrated by immersing the sonde in 6-gallon buckets of waters for which the temperature and resistivity have been determined using a Prestotech Corp. meter previously calibrated to an ASTM thermometer to an accuracy of ± 0.1 °C and to standard solutions so that absolute resistivity is ± 2.0 ohm-meters. When fluid resistivity is converted to specific conductance (C_s), the absolute values are accurate to ± 20 µS/cm (microSiemans/cm) over the range 100 to 1300 µS/cm.

The logged values of fluid resistivity are corrected for temperature to the standard 25°C using the Arps' equation (Serra, 1984, p. 9): $R_{T2} = R_{T1}[(T_1 + 21.5)/(T_2 + 21.5)]$ where temperature (T_1) and resistance R_{T1} are the pair of logged values. Units on the formula are degrees centigrade, and resistivity is in ohm-meters. The resulting R_{T2} is converted to specific conductance (C_s) in µS/cm units by the formula: C_s 10,000/R_w, where R_w is the water resistivity in ohm-meter units. These calculations are most simply done for the entire fluid resistivity log by importing the ASCII-format well-log files into a spread-sheet program.

error corrected.

The reported temperatures on the log are accurate to ± 0.2°C, and the values of C_s to ± 20 µS/cm, and relative changes of 0.02°C and 10µS/cm are reproducible on repeated logging runs. As discussed later, C_s is about 1.6 x (total dissolved solids expressed in mg/L). This implies that relative changes in electrolyte concentrations of about 10 mg/L are detectable with the calculated C_s log from the MLP logging tool.

TEMPERATURE PROFILES

Temperature gradients observed in wells at INEL are of three types. The simplest is one in which the temperature increases with depth as is expected for solid conduction of the heat of the earth vertically outward to the surface. Variations in gradients of this type can occur in a

steady-state heat-flow situation where the lithology changes are associated with a significant change in thermal conductivity of the rocks. This type of gradient is observed below 200 m in INEL GT-1, where the deep geothermal gradient is 40°C/km, and heat flow is calculated to be 109 W/m²s (2.6μcal/cm²s) (Brott and others, 1981; Blackwell, 1989). Thermal conductivity for the deep rhyolite section ranges from 1.9 to 2.76 W/m°K, and for the stratified basalt and sediment section, thermal conductivity is 1.4 to 1.6 W/m°K. Lower geothermal gradients indicate that some of the deep heat flow has been conducted away by groundwater flow (Brott and others, 1981), and low gradients are indeed observed in most wells in the basalt aquifer at INEL.

A common feature of wells in the basalt aquifer are isothermal intervals caused by water flowing vertically in a well, having entered at one permeable zone, and exiting at another permeable zone of lower head.

Many wells at INEL show a geothermal gradient that decreases downward (negative gradient). This situation occurs where a major zone of groundwater flow lies beneath the interval penetrated by the well. Such gradients are indicators of zones of colder-water flow beneath the bottom of the well.

FLUID SPECIFIC CONDUCTIVITY

The fluid specific electrical conductivity (C_s) is due to concentrations of ions dissolved in the ground water. The conductivity contribution of each ion depends upon the product of its valence, mobility, and concentration, so that double valence, high mobility ions have a large contribution. Conductivity of dilute electrolyte solutions can be calculated from the following formula from Daniels and Alberty (1961):

$$C = F[z_1 u_1 c_1/M_1 + z_2 u_2 c_2/M_2 + \cdots\cdots + z_i u_i c_i/M_i]$$

where C = electrical conductance in S/cm
              F = 96,493 coulombs/equiv (Faraday constant)
              z_i = valence of ion
              u_i = ion mobility, @ 25°C, cm²/V·s units
              c^i = ion concentration in mg/L units
              M^i = molecular weight of ion in mg/mmole units

The major contributors to electrical conductivity of natural ground waters at INEL are HCO_3^-, Ca^{2+}, Mg^{2+}, and Na^+, because they dominate the concentration of dissolved solutes, expressed in terms of milliequivalents/liter. Contribution of each ion to specific conductance can be readily calculated from concentration in mg/L using the factors $Fz_i u_i/M_i$ given in Table 1. The contributions to conductivity of concentrations of Ca and Mg are disproportionately large relative to other ions on account of their +2 valence.

Specific conductance of water from basalt aquifers at INEL can be used to approximate total dissolved solids (TDS in mg/L), in the range 220 to 800 μS/cm, by the relationship (Robinson and others, 1974):

$$TDS \ (mg/L) \approx 0.6 \ C_s \ (\mu S/cm)$$

At higher values of C_s, (>800 µs/cm) which are in most cases influenced by waste water, the above equation underestimates TDS by as much as 200 mg/L.

Table 1. Contribution to specific conductance (C_s) of major solutes in ground water.

solute species	z_i	M	u_i x 10^5	F z_i u_i / M
	mequiv per mmole	mg per mmole	ion mobility @ 25°C in cm²/V·s [1]	contribution to conductance(µS/cm) per mg/L concentration
HCO_3^{-1}	1	61.0	46	0.73
SO_4^{-2}	2	96.0	82.7	1.66
Cl^-	1	35.5	79.0	2.15
Ca^{+2}	2	40.1	61.6	2.96
Na^{+1}	1	23.0	52.0	2.18
K^{+1}	1	39.1	76.2	1.88
Mg^{+2}	2	24.3	55	4.37
•SiO_2	-		-	0.0•

[1]from Maron and Lando (1974, p. 516)

F = Faraday constant = 96,493 coulombs/equiv

•SiO_2 is not significantly ionized for pH below 8.5. At low pH SiO_2 is entirely as undisassociated $H_4SiO_4^°$. From equations in Krauskopf (1979, p. 133) it can be shown that at 25°C, the pH dependency of the mole ratio of ionized silica to non-ionized silica is expressed as: $\{H_3SiO_4^{-1}\}/\{H_4SiO_4^°\} = 10^{[pH-9.9]}$. The highest pH for basalt aquifer waters at INEL is pH=8.3, so that the ratio of ionized to non-ionized silica is 1/40.

VARIATIONS IN WATER CHEMISTRY

Spatial variation in groundwater chemistry at INEL was systematically mapped by Robert Schoen in the study by Robertson and others (1974). He speculated that the recharge water from the northwest mountains is enriched in Ca, Mg, and HCO_3 on account of being derived from mountains underlain by Paleozoic carbonate rocks, whereas recharge water from the northeast is enriched in Na, F, and SiO_2. These waters appear to mix along a northeast-striking zone through central INEL. Recharge water from the Mud Lake area has high dissolved solids (300 to 500 + mg/L) on account of evaporation of irrigation water, being particularly high in Ca, Mg, K, Na, Cl, SO_4, and NO_3 as shown by concentration lobes extending from Mud Lake to about well no. 21.

Schoen (in Robertson and others, 1974, p. 74-76) was aware that significant changes in water chemistry occur vertically in the aquifer in some wells. He recognized in some wells, a body of relatively fresh water (C_s of 100 to 200 µS/cm) at the top of the water table, as much as 50 feet thick , though usually much thinner, underlain by normal groundwater with a C_s of

300 to 400 µS/cm. It was initially thought to be direct recharge from on-site percolation, but it was later noticed that the zone only occurred in cased wells, and then only above the level of perforations. He surmised that it may be a layer of condensed water from the humid air within cold steel casing, but was not satisfied with either explanation.

Significantly different water was obtained from well 7 for the interval 214 -698 ft, than from 212 - 1200 ft with the deeper water exhibiting an eightfold increase in F, a doubling of SiO_2, together with small reductions in Ca, Mg, and HCO_3, and a ninefold increase in NO_3 (Robertson and others, 1974). The deeper water was attributed to silicic volcanic rocks at depth. The INEL-1 well (completed in 1979) penetrated silicic volcanic rocks at depth of 2435 ft, and waters from those rocks have greater than 900 mg/l TDS, and F above 12 mg/L. In the section from 1511 ft to 2206 ft, and in the nearby water-supply well drawing from 395-595 ft, TDS is less than 390 mg/L, and F less than 1.1 mg/L (Mann, 1986).

Waste water with industrial or chemical and radioactive wastes has been disposed to the Snake River Plain aquifer by various means since 1952. The greatest volumes have been injected in disposal wells at the Test Reactor Area (TRA) and the Idaho Chemical Processing Plant (ICCP). These and other facilities (notably the National Reactor Facility (NRF), Test Area North (TAN), Central Facilities Area (CFA), Special Power Excursion Reactor Test (SPERT), Experimental Breeder Reactor II (EBR) have also disposed of lesser volumes of waste through various seepage ponds, sewage lagoons, drainage ditches, and septic tanks (see Table XIII in Robertson and others, 1974, p. 142). Major dissolved inorganic waste products are NaCl, H_2SO_4, NaOH, and smaller amounts of sodium sulphates, sodium phosphates, and hexavalent chromium (Robertson and others, 1974). South and southwest-oriented plumes of waste water are detected by mapping the groundwater concentrations of Cl, Na, and ^3H, as well as specific conductance, and appear to emanate mostly from the ICCP, NTF, and the TRA areas. By 1985 the ^3H 0.5pCi/ml value had reached the INEL south border, a distance of 14 km south of the ICCP, and by 1988, it had retreated north somewhat on account of radioactive decay, dilution, and curtailment of injection (Pittman and others, 1988; Mann and Cecil, 1990). A chlorine plume defined by values over 20 mg/L had reached a point 9 miles south of the ICCP by 1994, as had the specific conductance plume defined by values within the 325 µS/cm isopleth (Pittman and others, 1988). Beasley and others (1993) have reported that detectable ^{36}Cl from nuclear-fuel reprocessing facilities occurs in ground water sampled from well 108, on the south border of INEL, 14 km south of ICCP, as of 1992.

Specific conductance of waste effluent injected into the disposal well at the ICCP has been estimated at 960 to 1140 µS/cm by Robertson and others (1974, p. 159). They considered natural background to be 300 to 325 µS/cm and show that specific conductance is a fairly sensitive waste parameter. They map the plumes of anomalous C_s for the years 1962, 1966, 1968, and 1970. Pittman and others (1988) contoured values for the October, 1985 set of samples from monitor wells and show a maximum value of 700 µS/cm at the head of the plume at the NRF, and a maximum value of 500 µS/cm at the head of the plume at ICCP.

Pittman and others (1988) report large fluctuations of C_s from wells 87,88, 89, and 90 near the RWMC. Values ranged from 240 to 290 µS/cm . In well 88 the values ranged from 330 to 669 µS/cm, and high values correlate with high water levels. In the case of well 88, C_s which had formerly been 522 µS/cm jumped to 1650 µS/cm after cement grouting casing down to 587 ft below land surface (8/20/72). It is also documented that C_s changed again after rising water table levels began in June, 1983, when C_s jumped from a June value of 350 µS/cm to a July value of 550 µS/cm, accompanying a water level rise from 590 to

580 feet below land surface. Over the next 2 years water level rose to 520 feet and then dropped to 550 feet, and the specific conductance has remained above 500 µS/cm. They attributed the high value in 1972 to effects of the cement chemistry, but allowed that some of the chemical fluctuation may be the result of waste material buried at the Radioactive Waste Management Complex that migrated to the water table as a result of local flooding of the area in 1982.

INTRAWELL FLOWS

It has been established that many wells at INEL have significant intrawell flows, up to 20 feet/minute (and up to 60 gallons/minute) between vertically separated permeable zones with small head differences (Morris and others,1963; Morris and others, 1964; Barraclough and others, 1965; Bennecke and Wood, 1992, Bennecke and others, 1993; Morin and others, 1993; Barrash and others, 1993). The flows enter and exit in intervals that are permeable zones less than 20 feet thick, and in some cases the intervals are less than the 1-foot depth resolution of the impeller flowmeter.

In the vicinity of the large production well at ICPP ($\approx$3,000 gallon/minute) intrawell flows reverse direction of flow and establish a constant flow magnitude within tens of seconds of the pump turning on or turning off (Bennecke and others, 1993). Away from large pumping wells the intrawell flows are thought to be steady, and possibly due to natural vertical-head gradients within the aquifer system, but we have not studied the intrawell flows extensively at these distant sites for more than a few hours.

Where these ambient intrawell flows are present, the flowmeter logs clearly identify permeable zones in the well. One can also pump the well to induce flow, and troll the impeller flowmeter to identify permeable zones. It is tempting to try to derive hydraulic conductivity or transmissivity over narrow intervals using a flowmeter, and measuring pumpage (Moltz and others, 1989; Morin and others, 1993); however, one does not know the vertical head profile in the well — and the assumption of a uniform head drop throughout the well bore may not always be appropriate. Nevertheless, the flowmeter is a useful tool to locate flow zones and determine relative permeability of zones.

SITE 14 WELL

The Site 14 well was cable-tool drilled to 717 ft in 1956. Well construction is important to interpreting the logs run in the afternoon of 9/13/93 (Figure 5b). Water flows into the well at the top of an 8-inch-casing riser at 315 ft and flows down the casing and down the open interval at a rate of 20 ft/min (50 gal/min) and exits into an enlarged diameter zone 701 to 717 ft (exceeding 35 inches diameter as shown on the caliper log [a 1960 caliper log is published by Bartholomay, 1990, p. 331]. A slight shift in the temperature of 0.1°C in the zone 475 to 500 ft suggests that water enters at that point and flows upward in the annulus between the 8-inch casing and the borehole wall.

The temperature log shows an abrupt increase downward starting at 652 feet and a small peak at 670 ft, and then increases in the lower part of the hole about 2°C to 18.4°C (Figure 5a). There is a slight increase in downward flow at 685 ft, which is apparently warmer water entering at that point and mixing with the downward flow. The downward flow exits abruptly at 702 ft. Water appears to be stagnant below 702 feet to the total depth logged of 716 feet.

The C_s log shows a uniform 365 µS/cm throughout the hole (Figure 5a). The ≈ 16.3° water presumed to enter at 475 to 500 ft appears to be the same C_s as the 18.4° water at the bottom of the hole. In this well, the dedicated pump sample from below 315 ft would appear to be representative of the flow zone at about 475-500 ft.

The logged values compare closely to water from a thief sample taken at 275 ft on 2/20/62, from which a temperature of 16.7° and C_s of 322 µS/cm are reported (Robertson and others, 1974). The temperatures are among the highest reported for the INEL area. Robertson and others (1974) show a belt of relatively high temperature > 14°C, about 5 km wide, trending from Atomic City north-northeast to between TAN and the east border of INEL. The belt is approximately parallel to ground water flow lines inferred from the slope of the piezometric surface. Robertson and others (1974) thought the warm waters were the result of sun-warmed summer irrigation water in the Mud Lake area that recharged the aquifer. However, the belt does not parallel the group wells showing a trend of high total dissolved solids and nitrates emanating from Mud Lake, a trend thought to be related to evaporation of irrigation water prior to recharge. If this is not warm irrigation water it may be geothermal water from depth flowing laterally in a permeable intraflow zone. Neither explanation is totally satisfying at this point in our examination of the data.

WELL USGS 59 (IDAHO CHEMICAL PROCESSING PLANT AREA)

The USGS 59 well was cable-tool drilled near the southeast corner of the ICCP in 1960 to a depth of 657 feet. Eight-inch steel casing extends from the surface to 464 ft below which is 6-inch open hole. Water level when logged on the afternoon of 9/14/93 was 461 feet.

The flowmeter log shows stagnant water from 461 to 521 feet (Figure 6). Flowing water enters the hole from a 16-ft thick zone from 521 to 537 feet. The water flows down the hole at a rate of 7 ft/min (10 gal/min). At 570 feet additional flowing water enters the hole and boosts the downward flow to 11 ft/min (16 gal/min). At 600 ft all of the downward flow exits, and water below 600 feet appears to be stagnant on the flowmeter log.

The temperature log confirms that the upper water from 460 to 521 is relatively stagnant, and that colder water (13.9°C) enters at 521 and flows downward (Figure 6). Additional water entering at 570 is slightly cooler and mixes, and apparently flows down. There is discrepancy between the two logging runs, for the T-C_s log indicates flow exits at 624, whereas the previously run flowmeter indicated the downgoing flow abruptly exited at 600 ft. Because logs were run an hour apart, there could have been a flow regime change caused by the pump cycle at the ICPP production wells, but the discrepancy remains unexplained at this point. Below 624 ft the water appears to be stagnant; however the temperature profile shows a decreasing downward gradient the significance of which is discussed below.

Most remarkable is the specific conductance log which shows a value of 550 µS/cm in the upper 30 ft of the stagnant zone (from 461 to 491 ft), and an increase to 1115 µS/cm caused by the inflow from the zone 521 to 537 ft (Figure 6). This is among the highest values of C_s for INEL ground water , and is the same at that reported for the original waste water pumped down the ICPP disposal well (Robertson and others, 1970, p. 159). This downflowing water of high-C_s apparently mixes with water of lower C_s entering at 575 ft, which dilutes the downflowing water in the well to about 850 µS/cm. This downflowing water mixes with water from lower down the well of high C_s over a zone from 610 to 624 ft

and then exits at 624 feet. The lower stagnant water in the well has a high C_s of 1020 μS/cm.

This profile of C_s dramatically shows major vertical variations in chemistry in the water in this well that would not be correctly sampled by a dedicated pump set 50 feet below the water level. In fact, monthly samples from this well would not detect the high values of dissolved solids that occurs in the most dynamic part of the aquifer.

In other wells we have logged in the vicinity of ICPP and those logged by Morin and others (1992) the temperature profiles show increasing temperature downward in the lower parts of wells (generally below the permeable zone at the top of the "I" group of flows - using stratigraphy of Anderson (1991). In this well, the lower 28 feet, from 624 to 652 shows decreasing temperature suggesting that a flow zone of cooler water lies below 652 feet (Figure 6). This supports the speculation of Barrash and others (this volume) that an important flow zone lies below the level of most monitor wells in the ICCP area, one that was probably penetrated by well 123 and well 48.

WELL USGS 83

Well USGS 83 was cable-tool drilled to 752 feet in 1962. The well has 6-inch steel casing from the surface to 516-foot depth, below which it is open hole. When logged on 79/23/93 water level was at 503, and the well was obstructed below 720.

No major flow was detected by flowmeter logging (Figure 7). There is a slight shift in the temperature log 645 to 650 ft ($\approx 0.03°C$) which corresponds to a shift to slight downward flow on the flowmeter, but the flow measurement is within the noise level of the impeller flowmeter, and it has questionable significance. The C_s log does not show significant vertical variations suggesting water in the well bore may be of uniform major-ion chemistry. The temperature log shows an increasing gradient downward of 0.3°C/100 ft (10°C/km) typical of a well that does not intersect major flow zones.

The saturated zone from 503 to 720 feet appears from these logs to be relatively impermeable, explaining perhaps why the water samples from this well have traditionally shown low ^3H (0.1±0.3 pCi/mL)in contrast to surrounding wells which show above 2 pCi/mL (Knobel and Mann, 1988). This may be an area of low permeability, and the waste plume has flowed around without affecting the water in the vicinity of well USGS 83.

WELL OW-2 (RADIOACTIVE WASTE MANAGEMENT COMPLEX AREA)

Well OW-2 was air-rotary drilled in September and October, 1993, to a depth of 996 ft, about 2 weeks prior to logging on 10/19/93. The well is a monitoring well for the large-scale infiltration and pump test to be conducted about 1 mile (1.6 km) south of the RWMC, and about 500 ft southeast of well USGS 120. At time of logging the well was an open 8-inch-diameter hole from 50 feet to total depth, and the water level stood at 619 ft.

The flowmeter log indicates no flow in the upper 70 feet of the well, the interval from 619 to 690 ft (Figure 8). At 692 ft a small flow enters and by 700 ft the downward flow is about 2 to 3 ft/min. Small fluctuations in detected flow from 700 to 768 ft are due to borehole diameter variation in the enlarged-diameter interval from 744 to 772 ft where the caliper log shows excursions up to 18 inches (see caliper log in paper by Hegmann and Wood, this volume). The large excursion at 768 ft is produced by two opposing flows exiting

at that point in the well. Below 768 is an upward flow of 3 ft/min, which enters the hole gradually over the interval 805 to 790 ft. Below 805 feet the water appears stagnant. Thus flows set up by a lower head in the 768-ft zone are coming from 805-790, and from 692-700 ft.

The temperature log shows that the water entering at 692 is 10.7°C, and the water entering at 790 ft is 10.6°C, a small but detectable difference (Figure 8). Below 790 ft the well shows a negative geothermal gradient profile with inflections possibly related to small flows at 835 and at 895 ft. Temperature of the bottom of the hole is 9.2°C

The specific conductance log shows that the relatively stagnant water in the top interval from the water level down to about 650 ft has a high value, up to 760 µS/cm, at the water level (Figure 8). Water entering and flowing down from the 692-700 ft interval has a lower value of 520 µS/cm, and water entering at 805 and flowing up has a still smaller value of 430 µS/cm. Below 805 ft, the water has the same uniform value of 430 µS/cm. All of these values are above the value of 300 to 325 µS/cm considered background by Robertson and others (1974). The vertical variations in C_s show that a dedicated pump sampling program in this well would not obtain a sample representative of the aquifer, because three intervals have different chemistry.

The negative temperature gradient from 805 to the bottom of the hole at 996 ft suggests that a major flow zone lies beneath 996 ft (Figure 8). It has been suggested that the negative geothermal gradient may be an artifact of drilling; however, water introduced into the well during drilling in September and October would most likely have been warmer than the ground water, and would have warmed the lower part of the hole, rather than cooled the lower hole, as the temperature log shows.

CONCLUSIONS

Flowmeter, temperature, and specific conductance logging of borehole fluid show that the chemistry of ground waters varies vertically from flow zone to flow zone in many wells the penetrate 300 feet or less into the Snake River Plain aquifer beneath INEL. Monitoring the aquifer with dedicated pump samples is only meaningful if one knows the permeable flow zone from which the water actually entered the well. In wells 59 and OW-2 the value of specific conductance varies vertically by a factor of 2. This would suggest that historic sampling and mapping of the waste plumes may not be showing the maximum waste level in certain zones of the aquifer.

The Site 14 borehole fluid is entirely fluid entering from one zone and flowing down the well. Well 83 appears to be in a relatively less permeable section and does not show significant flow zones or variations in specific conductance.

Profiles of downward decreasing temperatures are observed at the bottom of wells 59 and OW-2 suggesting that a major flow zone lies beneath the bottoms of these wells.

It is recommended that flowmeter, temperature, specific conductance logs combined with previously obtained caliper, natural gamma, and calibrated- density logs be used to design a monitoring program using a downhole wireline thief sampler to obtain ground water for analysis from specific flow zones encountered by wells. Fluid specific conductance logs give an indication of chemical variation, but the actual constituents need to be analyzed from water samples taken by thief sampler or from zones isolated by packers.

ACKNOWLEDGEMENTS

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Figure 1. Map showing location of the eastern Snake River Plain basalt aquifer system and the Idaho National Engineering Laboratory.
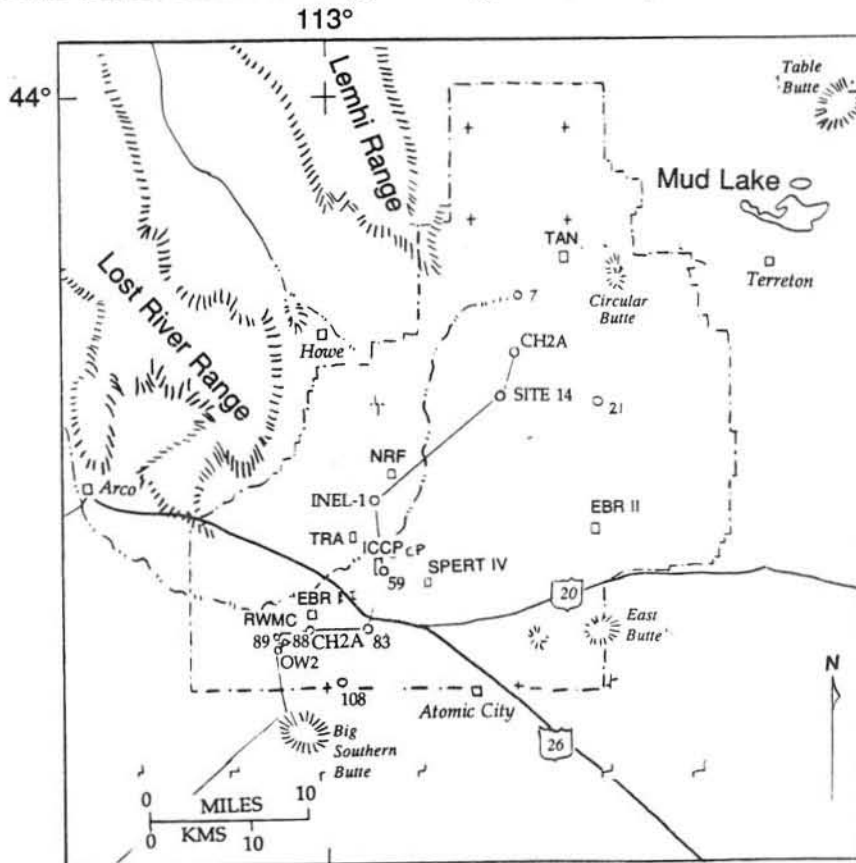

Figure 2. Map showing location of cross section (Figure 3) and wells discussed in this report, and boundaries of the Idaho National Engineering Laboratory.
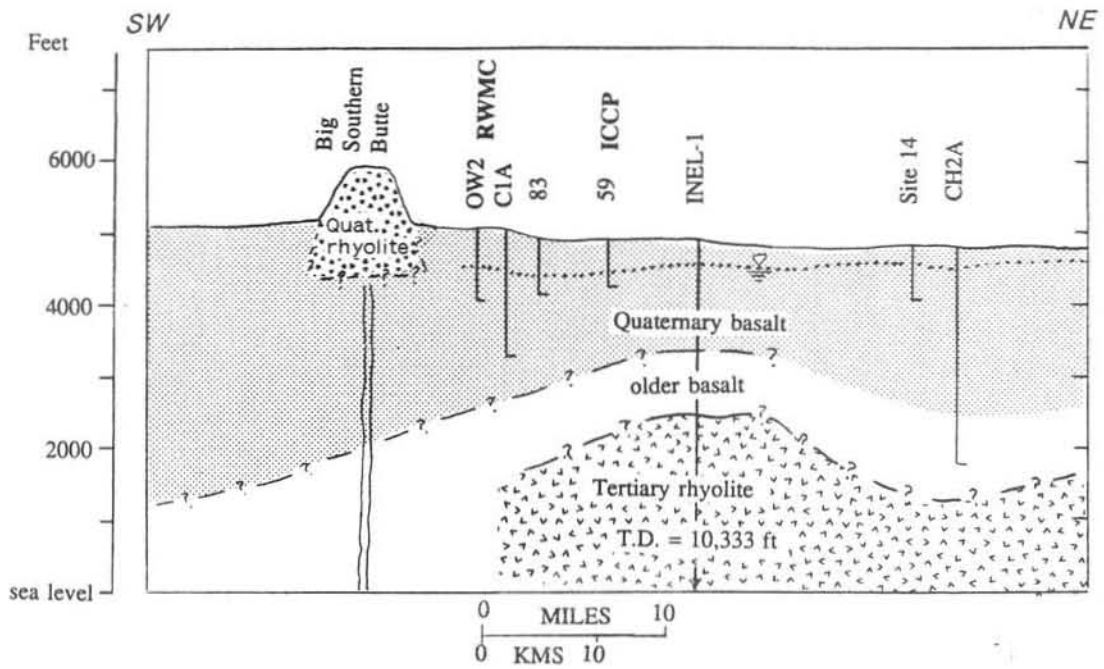
280

Figure 3. Generalized geologic cross section of selected wells at INEL (exaggerated vertical scale). Water level in wells indicated by dotted line (depth of basalt south of Big Southern Butte is from resistivity soundings reported by Whitehead (1992).

Figure 4. Photograph of Halliburton (Gearhart-Owen) bi-directional impeller flowmeter (36.5 mm diameter), and the thermistor-housing end of the Mt. Sopris combination fluid-resisitivity and temperature logging tool (51 mm diameter).

Scale in feet and 0.1-ft units.
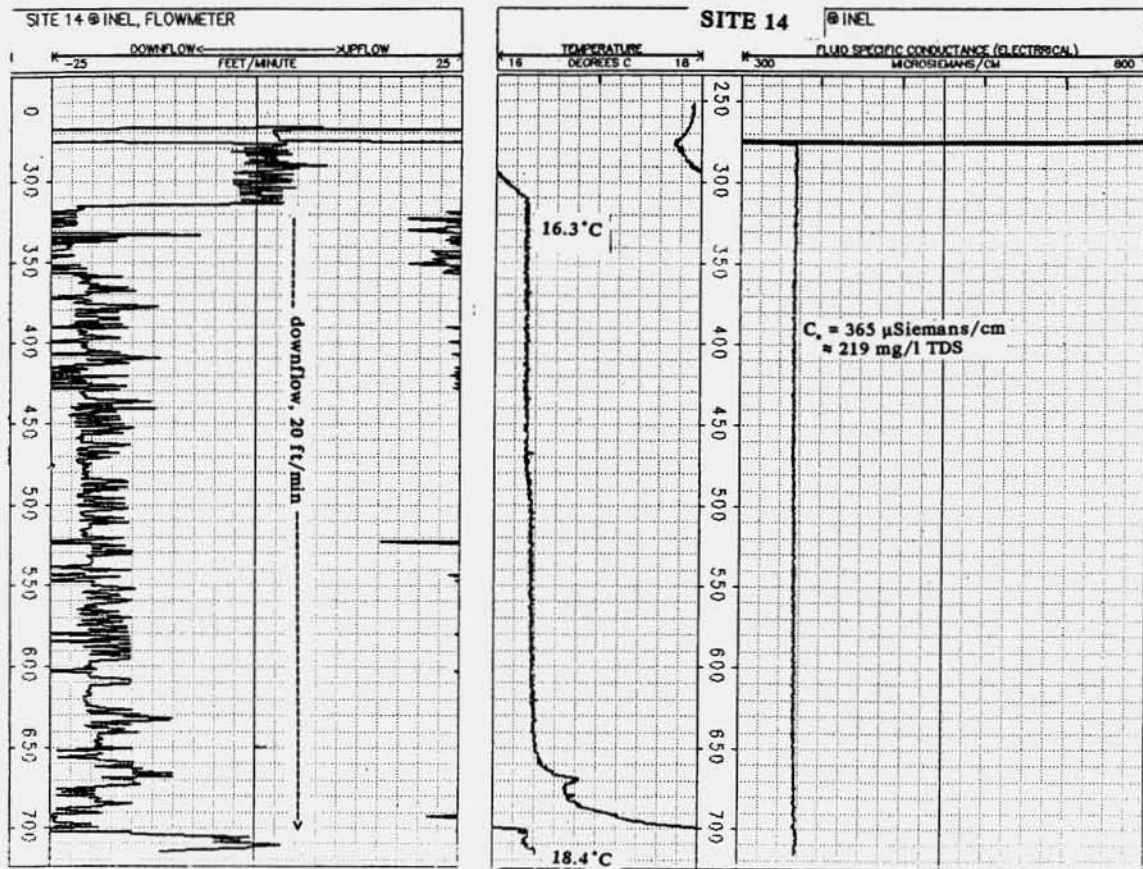
Figure 5a. Site 14 impeller flowmeter, temperature, and specific conductance logs. Flowmeter shows downward flow of 20 ft/min (50 gal/min) from top of 8-inch riser pipe at 315 feet exiting near bottom of well at 702 feet.
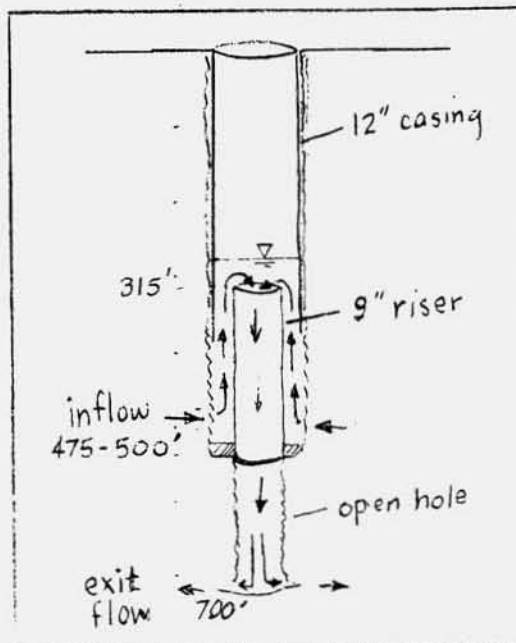
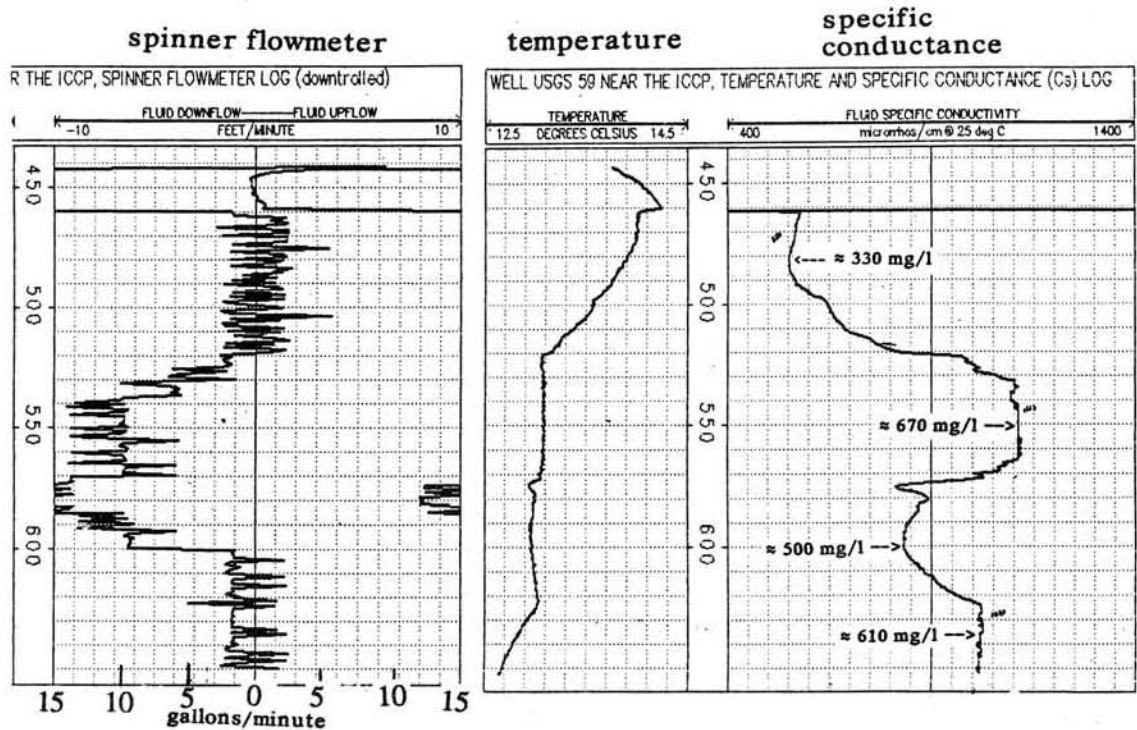**Figure 5b. Sketch of well construction and interpretation of flow at Site 14.**

spinner flowmeter   temperature   specific conductance

Figure 6. Well 59 impeller flowmeter, temperature and specific conductance logs showing major differences in water chemistry in the water column. Flowmeter shows downward flow of water with a C_s of 1115 µS/cm mixing and diluted by additional downward flow entering at 570-ft depth. Flow appears to exit at 600 or 624 ft.
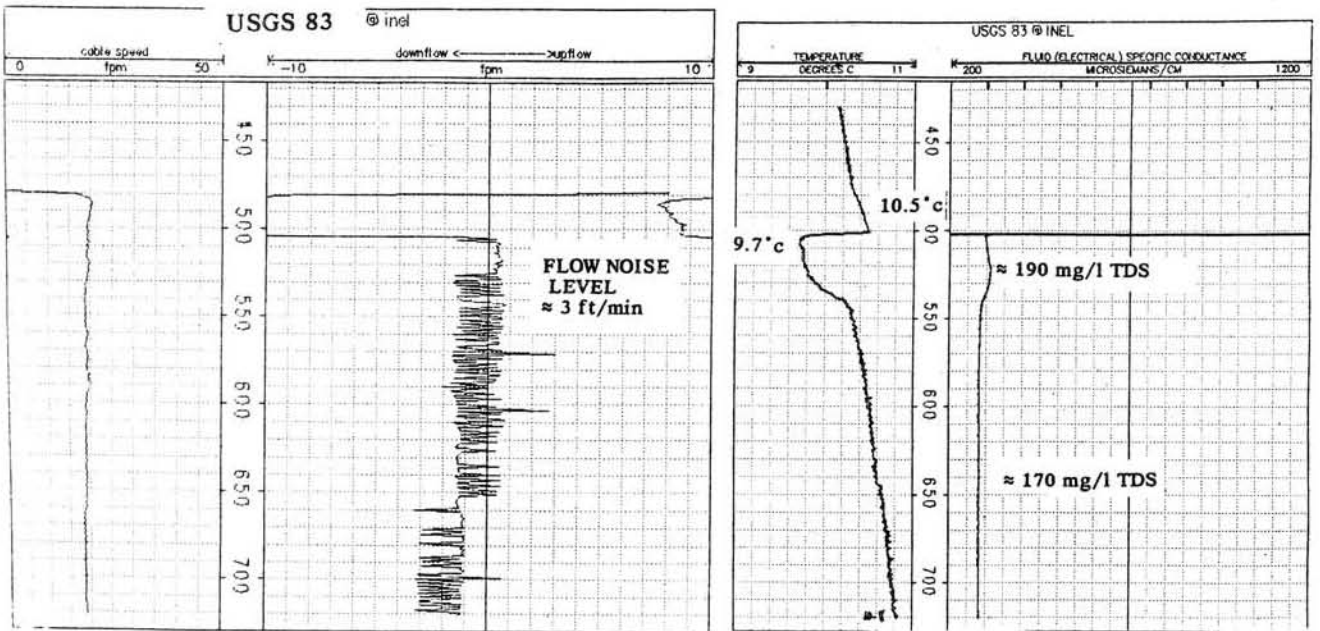

Figure 7. Well 83 impeller flowmeter, temperature, and specific conductance logs showing no significant flow, a positive temperature gradient, and uniform specific conductance of 280 µS/cm.

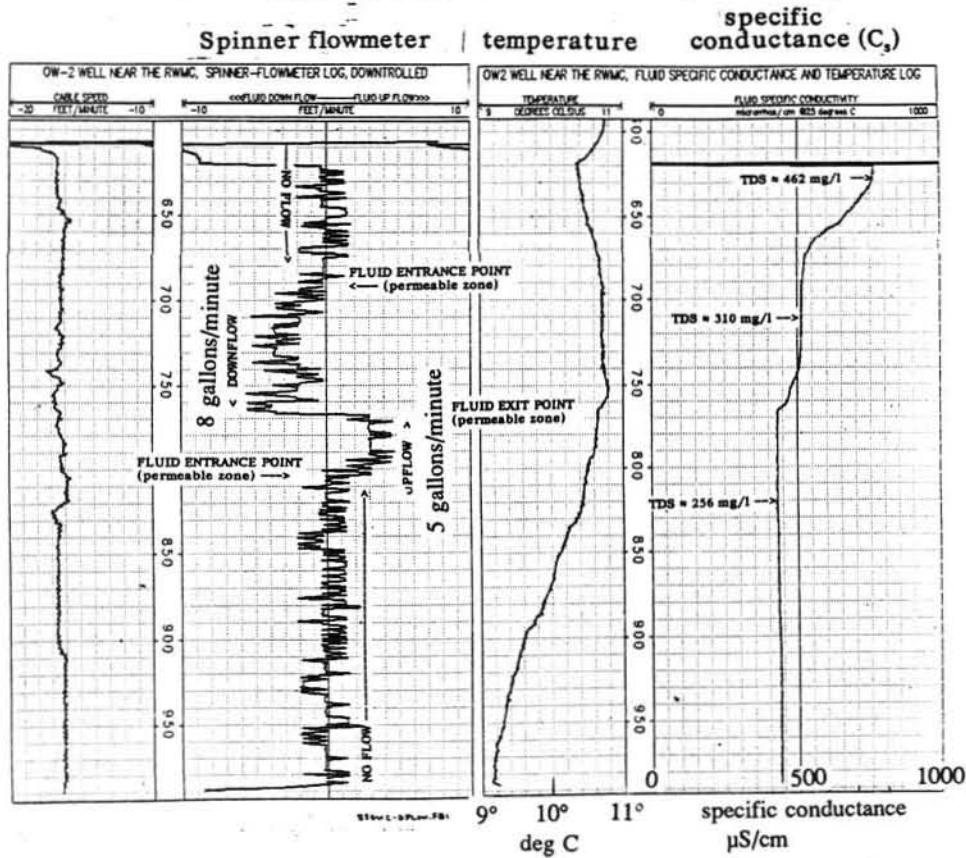well no. OW-2 near the Radioactive Waste Management Complex

Figure 8. Well OW2 spinner flowmeter, temperature, and specific conductance logs. Opposing intrawell flows exit at 768-depth. Water of three different chemistries are apparent from the specific conductance log, with the highest value at the top of the water column. The negative temperature gradient suggests a major flow zone lies beneath the bottom of the well (996 ft deep)