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MONITORING AND SAMPLING PERCHED GROUND WATER IN A BASALTIC TERRAIN

J. M. Hubbell

Idaho National Engineering Laboratory
EG&G Idaho, Inc., Idaho Falls, Idaho

ABSTRACT

Perched ground water zones are often overlooked in monitoring plans, but they can provide significant information on water and contaminant movement. This paper presents information about perched ground water obtained from drilling and monitoring at a hazardous and radioactive waste disposal site at the Idaho National Engineering Laboratory. Six of forty-five wells drilled at the Radioactive Waste Management Complex have detected perched water in basalts above sedimentary interbeds. Perched water has been detected at depths of 90 and 210 ft below land surface, approximately 370 ft above the regional water table. Eighteen years of water level measurements from one well at a depth of 210 ft indicate a consistent source of water. Water level data indicate a seasonal fluctuation. The maximum water level in this well varies within a 0.5 ft interval, suggesting the water level reaches equilibrium with the inflow to the well at this height. Volatile organic constituents have been detected in concentrations from 1.2 to 1.4 mg/L of carbon tetrachloride. Eight other volatile organics have been detected. The concentrations of organics are consistent with the prevailing theory of movement by diffusion in the gaseous phase. Results of tritium analyses indicate water has moved to a depth of 86 ft in 17 yr. Results of well sampling analyses indicate monitoring and sampling of perched water can be a valuable resource for understanding the hydrogeologic environment of the vadose zone at disposal sites.

INTRODUCTION

This paper describes the distribution and characteristics of perched ground water at the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering Laboratory (INEL). It discusses perched water below the surficial sediments in wells at the RWMC, the characteristics of chemical constituents found in perched water, the implications for contaminant transport in the unsaturated zone of water, and the lateral extent of perched water. Recommendations are made to increase the probability of detecting and sampling low yield perched water zones.

DESCRIPTION OF THE SITE

The RWMC is located in the southeastern part of the INEL in southeastern Idaho (Figure 1). The INEL covers about 839 mi^2 of the Eastern Snake River Plain; the plain is an arcuate depression that ranges from 30- to 70-mi wide and is approximately 200-mi long. The plain has an average elevation of 4900 ft and is bounded by mountains and high plateaus.

The RWMC was established in 1952 and has served as a disposal site for low-level and transuranic radioactive waste. Hazardous waste, primarily organic solvents, were disposed with the radioactive waste in the 1960s and 1970s. The presence of organic solvents in the ground water was not verified until 1987. The RWMC is made up of two areas: the Subsurface Disposal Area (SDA) and the Transuranic Storage Area (TSA). The SDA contains materials disposed below land surface within the surficial sediments in shallow pits, trenches, and soil vaults. The TSA contains waste materials stored above land surface on asphalt pads either covered with earth materials or stored in buildings.

The INEL has a semiarid climate with an average of 9.07 in. of precipitation per year. Most of the precipitation occurs in May/June and December/January; approximately 30% of the precipitation is received in the form of snow from December through February (Start, 1988).

GEOLOGIC FRAMEWORK

The vadose zone beneath the RWMC is characterized by basaltic lava flows intercalcated with thin sedimentary interbeds. The water table is located at approximately 580-ft below land surface.

The RWMC is in a local depression with 9 to 25 ft of sediments overlying the basalts (Figure 2). The two sedimentary interbeds of greatest interest in the vadose zone are located at a depth of approximately 110 and 240 ft. These

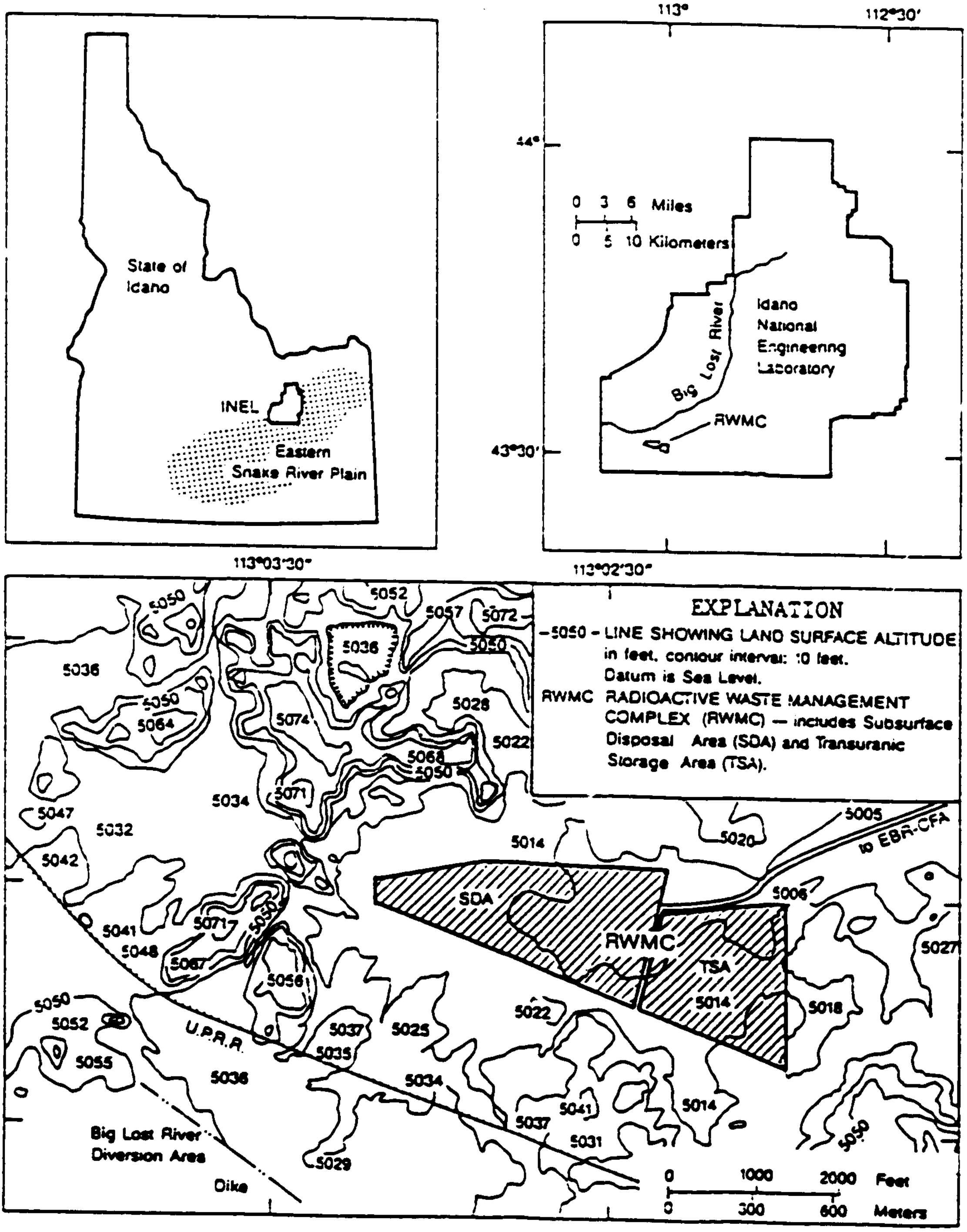

Figure 1. Location of the Radioactive Waste Management Complex.

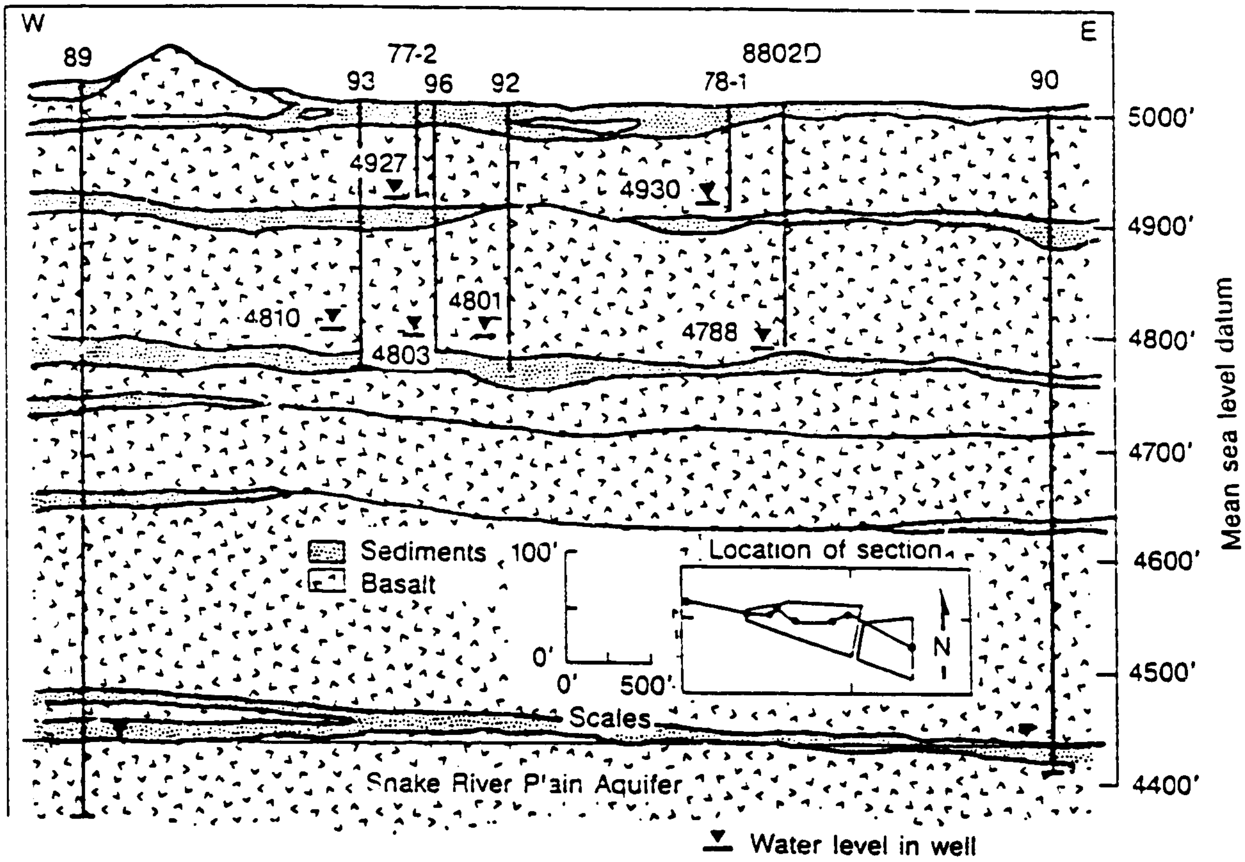

Figure 2. Geologic Section at the Radioactive Waste Management Complex.

interbed deposits range in thickness from 0 to 27 ft and average 12 and 13 ft, respectively. The surficial sediments and sedimentary interbeds are primarily composed of loess, eolian and alluvial sand and lacustrine deposits. The interbeds and surficial sediments are made up of similar materials, with the 110-ft interbed containing generally courser materials than the 240-ft interbed. The upper surface of the interbeds has a uniform gently sloping surface, while the lower surface of the interbeds reflects the undulatory nature of the underlying basalts.

The individual basalt flows average 15-ft thick. The basalt flows generally have a rubbly, vesicular zone 1.5-ft thick at the bottom of the flow, a thicker dense zone in the center of the flow (7.5 ft), and a highly vesicular zone (6 ft) at the top of the flow (Knutson, et al., 1990). The major joint/fractures are vertically oriented cooling joints.

DEFINITION OF PERCHED WATER

For the purposes of this paper, perched water is defined as ground water separated from an underlying body of ground water by unsaturated media. It is a zone where soil pores are filled with water, moisture content equals effective porosity, and fluid pressure is greater than atmospheric.

Figure 3 presents a schematic of a perched water zone in sedimentary media. In this example, a perched water body has formed over a clay layer (low permeability). The well penetrates the perched water table. Perched water zones at the RWMC are similar but occur in a fractured basaltic media.

Perched water zones are formed where there is (a) a contrast in hydraulic conductivity to restrict downward movement of water and (b) sufficient recharge, relative to the contrast in hydraulic conductivity, to fill the pores with water. Hydraulic conductivity must be adequate to allow water to move from the formation into a well in a timely manner for perched water to be detected.

PREVIOUS INVESTIGATIONS

Numerous geologic and hydrologic studies have been performed at the RWMC by the U.S. Geological Survey and contractors for the U.S. Department of Energy. Drilling has been performed at the RWMC since 1972 to determine if radionuclides have migrated to depths below the surficial sediments (Barraclough 1976; McElroy, 1989). Seven wells were drilled outside of the SDA to the aquifer; they are used for monitoring the aquifer for water quality and water level. The remaining wells were drilled at the RWMC to depths of less than 300 ft.

WELL STATUS

Data are available from 45 wells at the RWMC (Figure 4). A total of 13,000 ft of basalt and sediment have been drilled through in these wells. Locations of wells with perched water are presented in Figure 5. Perched ground water has been documented in 6 boreholes with depths of standing water ranging from 1 in. to 11 ft. Table 1 presents the well identification, status, saturated thickness, elevation of perched water, and geology.

The saturated thickness listed in the table may not represent the full saturated thickness of the perched water. For example, in Figure 2, if the well was deepened into the perching layer it would show the same water table elevation but the saturated thickness would appear to be greater. Therefore, the measured saturated thickness may not represent the actual thickness of the perched water layer. During drilling activities at the RWMC, the full thickness of the saturated layer was not always penetrated.

Four of the 6 perched water wells are located in the western portion of the SDA, with 2 remaining wells in the approximate center and eastern portion of the SDA (Figure 5).

Table 1. Wells with perched water at the RWMC.

Well I.D.	Status	Measured Saturated Thickness (Maximum)	Elevation of Water Table (ft)	Geology of Saturated Zone
77-2	Open-Monitored	2 ft	4927	Basalt
78-1	Open-Monitored	2 ft	4930	Basalt
92	Open-Monitored	11 ft	4801	Basalt
93	Cemented-Abandoned	1 in.	4810	Basalt
96	Cemented-Abandoned	1 in.	4803	Basalt
8802D	Open-Monitored	8 in.	4788	Basalt

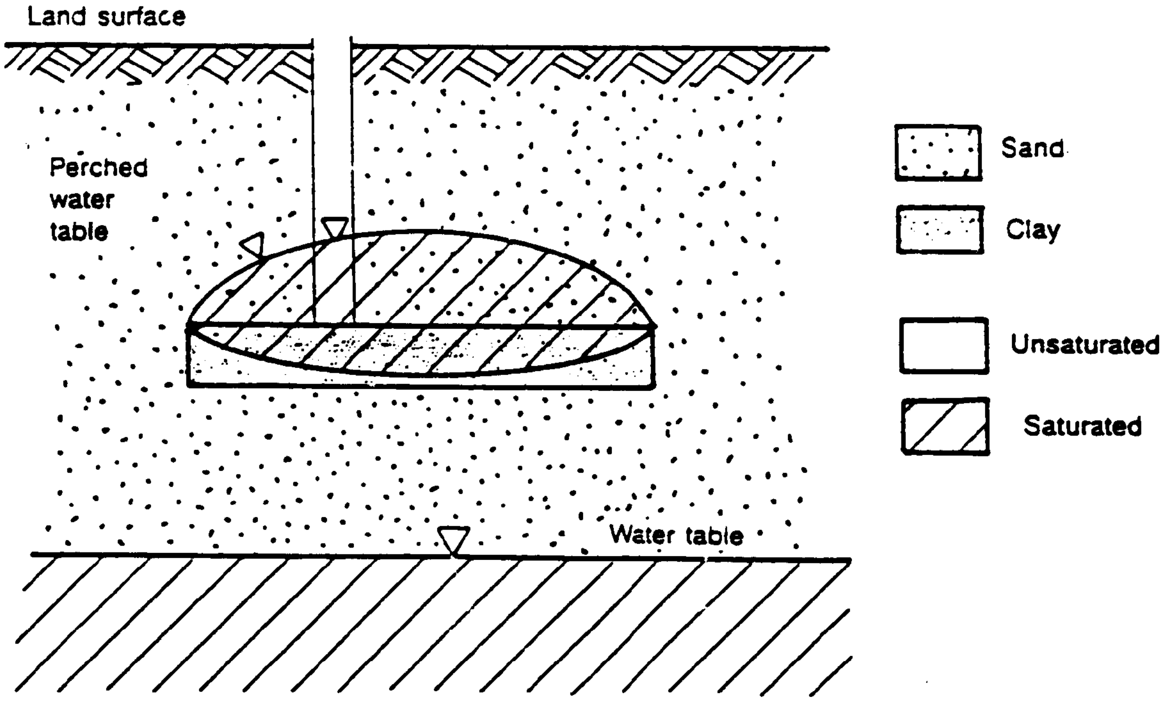

Figure 3. Schematic of perched water table with well (after Freeze and Cherry, 1979).

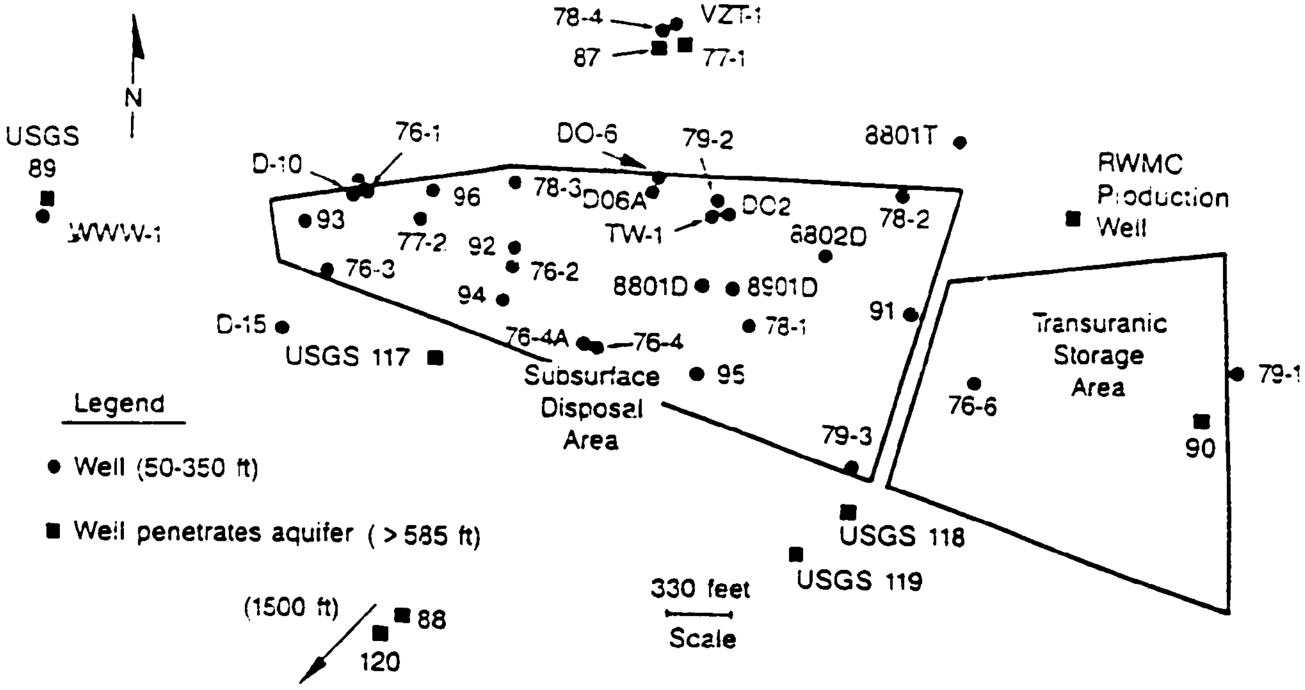

Figure 4. Location of wells drilled at the RWMC

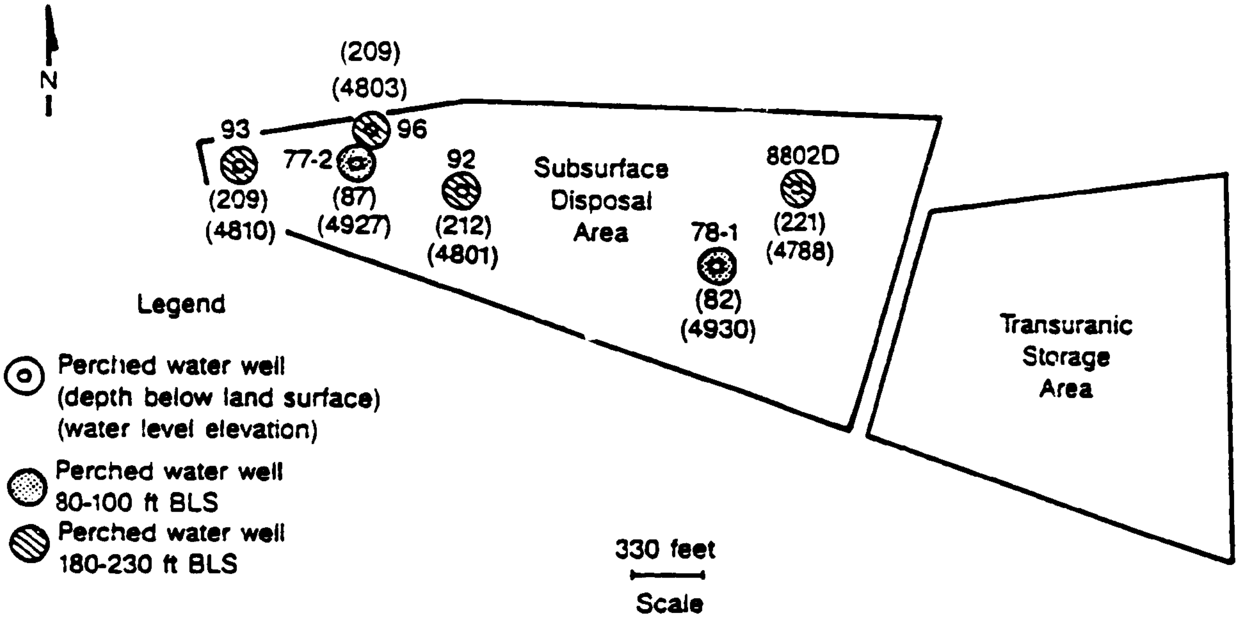

Figure 5. Perched water wells at the RWMC.

The majority of information for perched water has been collected from well 92. Well 92 is located in the west-central portion of the SDA adjacent to a unlined drainage ditch (Figure 4). It was drilled using air-rotary wireline coring methods. Perched water was detected within basalt above the 240-ft interbed. Well 92 has been monitored for water level and selected radionuclides since it was drilled in 1972; volatile organic compounds have been monitored since 1987.

Well 93 is located at the west end of the SDA (Figure 4). One inch of water was detected at an elevation of 4810 ft while drilling in 1972. Perched water was detected within basalt 25 ft above the 240-ft sedimentary interbed. Dry basalt was recorded 5 ft beneath the perched water zone.

Well 96 is located in the northwest portion of the SDA (Figure 4). Perched water was detected 15 ft above the sediment, and the basalt was described as dripping wet down to the interbed. Drilling through the perched water zone was performed in a few hours so not enough time was allowed for water to accumulate in the well. Water might have been perching immediately above the interbed.

Well 77-2 is located in the western part of the SDA (Figure 4). Well 78-1 is located in the south-central portion of the SDA. Wells 77-2 and 78-1 were sealed in 1978 and not monitored until 1989. No water was detected standing at the bottom of the wells in August 1989. Water samples have been obtained from "dry" wells by lowering a bottom-fill porous cup lysimeter to withdraw water from the bottom of the well.

Well 8802D is located in the eastern-central portion of the SDA (Figure 4). This well is located adjacent to an unlined drainage ditch at the RWMC. The well site was chosen, in part, because of the proximity of the well and ditch in an effort to intercept perched water.

WATER LEVELS

Following sampling, the water level in well 92 has recovered to the same approximate elevation since the well was drilled, indicating a consistent source of water (Figure 6). The initial water level was 4795 ft. The water level declined to 4789 ft as a result of water leakage into the interbed. Water was not detected as the drilling continued in the interbed. Cement was placed in the well to seal off the portion of the well adjacent to the interbed and a portion of the basalt. The water level recovered slowly until 1974 when water was sampled. Sudden declines in the water table reflect removal of water for sampling (Figure 6). The maximum water level in this well fluctuates to approximately 4800 ft. Water has been sampled over 20 times since 1974.

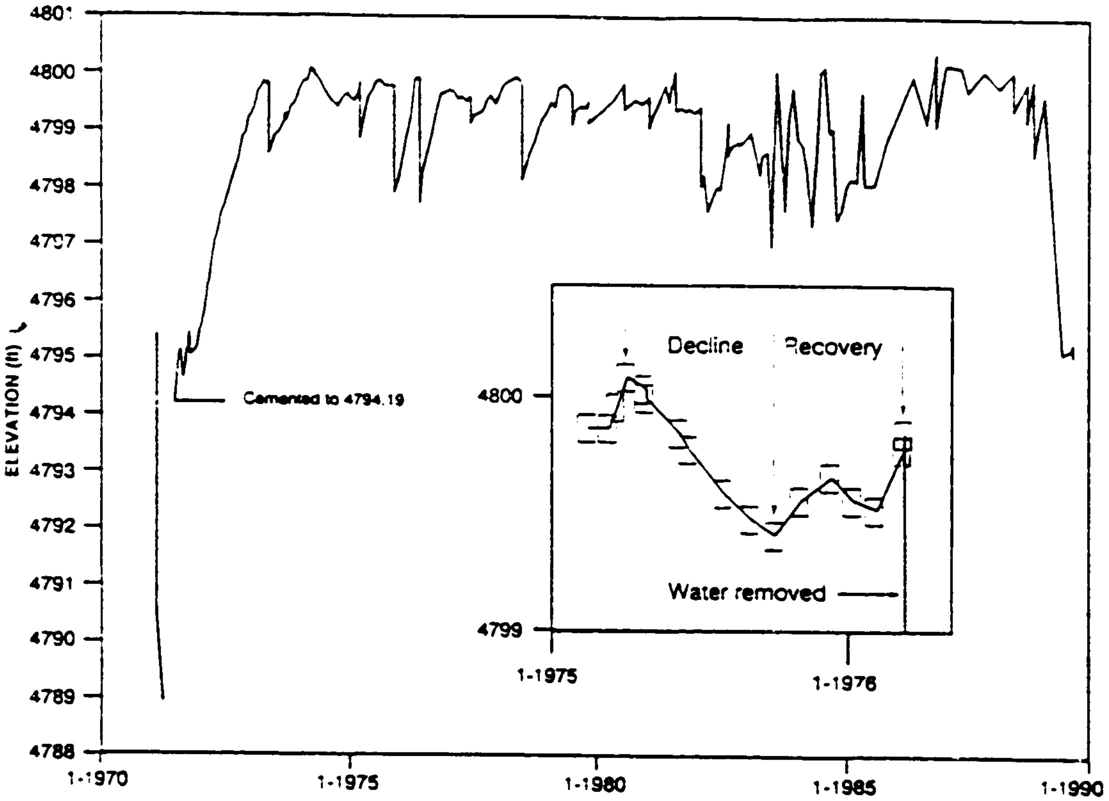

Figure 6. Water level elevation in well 92 for 1970-1990.

The water elevation data were evaluated to determine if naturally reoccurring fluctuations could be detected (Figure 6). Withdrawal of water samples disturbs the water level elevations; therefore, the data were examined looking for times when samples were not withdrawn for extended time periods. The undisturbed data, which would show natural fluctuations, can be taken following the sampling where the water level has recovered to the maximum elevation. Natural water level fluctuations can be charted until the next sample is withdrawn.

The best example of a fluctuation in recharge in well 92 is the water level from February 1975 through January 1976 (Figure 6, insert). In March 1975, the water level declined without water being withdrawn from sampling. This represents a natural decline. The water level declined 0.4 ft from February through October and then increased 0.26 ft from October to January 1976. Unfortunately, water was removed from the well before a full fluctuation was recorded. These data show the perched water recharge varies over time with a net decrease in recharge from March to October and increase in recharge from October to January. Data from other years (1976, 1978, and 1979) reflect a similar trend. A perched well should be dedicated to record fluctuations in water level to understand (a) temporal changes in recharge and (b) processes contributing to deep percolation events.

The water level in well 92 recovers to approximately 4800 ft after water is withdrawn. This recovery indicates recharge to the perched water zone comes into equilibration because of (a) seepage out at this water level elevation or (b) a conduit that allows water above the maximum elevation to overflow away from the perched water zone.

Wells 77-2 and 78-1 were sealed following drilling. Water was not detected in wells 77-2 and 78-2 in August 1989, indicating the presence of perched water can change with time. Perched water bodies form and dissipate, depending on the rate of water inflow into a area versus the rate of outflow through or around the perching layer.

WATER QUALITY

Water samples have been collected from well 92 since 1972. Water samples are collected using a bailer with a closed bottom and open top. Samplers that pump water to land surface are not used because of the limited volume of water in the well and the volume of water that would be left in the tubing leading to the land surface.

Water samples from well 92 are analyzed for tritium, Sr-90, Cs-137, Co-60, Pu-238, Pu-239, Pu-240 and Am-241. From 1972 to 1980, radionuclides were detected in water samples at concentrations of approximately 9E-15 Ci/mL for Co-60, Sr-90, and Cs-137 and 6E-17 Ci for Pu-238 and Am-241 (all are environmental levels). There has been no detection of these radionuclides since 1980. Sediments collected while drilling well 92 at a depth of 223 to 225 ft detected Co-60, Sr-90, and Cs-137. Contact between the backfill cement and water in the well raised the solution pH above 9.0 in the vicinity of the well. The increase in pH promotes carbonate complexation of the radionuclides and thus increases radionuclide mobility. The combination of positive results from the sediments and positive results within the perched water may be related. Drilling probably left sediments on the sidewalls of the well that came in contact with the sampled water. The positive detections may have been due to cross contamination from the drilling process or localized mobilization because of cement-water interactions. The absence of radionuclides since 1980 suggests (a) material may have been carried down the well during drilling and has since been removed by sampling or (b) the change in pH has reduced the mobility of these constituents.

Water samples were withdrawn from well 77-2 and analyzed for radiochemical constituents in 1977. Results of analyses indicate no radionuclides were identified at the detection limits (same as for well 92) except tritium. Tritium was detected at an activity of 1.8E-11 Ci/mL (5508 tritium units). Concentrations measured in well 77-2 in 1977 indicate water had moved from land surface to 86-ft depth in less than 17 yr. The slightly-elevated concentrations suggest a localized source of tritium. Water samples from well 92 at a depth of 210 ft have not detected tritium at the activity of approximately 2E-13 Ci/mL.

Results of volatile organic analyses from well 92 are presented in Table 2. Modeling calculations indicate vapor diffusion is the dominant transport mechanism for the volatile organic constituents detected in well 92 (Walton, et al., 1988). The high concentrations are consistent with movement of the organics by molecular diffusion in the vapor phase. The organics then move into the water, controlled by the partitioning coefficient. Henry's law can be used to calculate concentrations of vapors that are in contact with water. The partition coefficient relating aqueous and air concentrations in a volatile substance are commonly referred to as Henry's constant. The values for Henry's constants used for this paper are presented by Gossett (1987). Henry's law is stated as:

$$[\text{conc}]_{\text{gas}} = H_c[\text{conc}]_{\text{liquid}}$$

where H_c is Henry's constant.

Comparison of the calculated vapor concentrations from well 92 with vapor concentrations measured in well 8801D indicates they are in agreement. The calculated values of the concentrations in air are presented in Table 2 along with measured values from gas sampling ports in 8802D at the same depth. Carbon tetrachloride, chloroform, tetrachloroethylene, and 1,1-dichloroethylene are within an order of magnitude of the calculated value; trichloroethylene and 1,1,1-trichloroethane are within two orders of magnitude of the calculated value; while the analyses for the three remaining constituents were below detection limits or practical quantification levels.

Samples were collected from well 8802D 1 week following drilling, and the samples were analyzed for volatile organic constituents. Concentrations of five organic compounds in these samples were much lower (an order of magnitude) than concentrations found in well 92. These lower concentrations may be due to the introduction of air during the drilling process (750+ ft^3/min). The clean drilling air dilutes and strips organics from the rock being drilled, forming a relatively-clean area around the well. This effect would take time to dissipate and allow original concentrations to re-establish themselves.

Table 2. Vapor concentrations calculated for well 92 using Henry's Law.[a]

Compound	Temperature (°C)	Henry's Constant[b]	Concentration Well 92	Calculated Vapor Concentration	Measured Vapor
Concentration					
Carbon tetrachloride	10.0	0.567	1400	794	530[c]
Chloroform	9.6	0.0645	940	61	40.0
1,1,1-Trichloroethane	9.6	0.00761	250	2	32.0
Trichloroethylene	9.6	0.00378	1100	4	100
Tetrachloroethylene	9.6	0.00682	120	1	1.0[c]
Toluene	10.0	0.16408	0.3	0.05	N.D.
1,1-Dichloroethane	9.6	0.107	22	2	BPQL[d]
1,1-Dichloroethylene	10.0	0.0127	2.6	0	1.0[c]

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[a] All concentrations are in micrograms per liter

[b] Gosset, 1987

[c] Estimated values

[d] BPQL Below practical quantification level (<5 ugm/l)

N.D. = Not detected

DETECTION OF PERCHED WATER

Perched water is difficult to detect while drilling. Wells that penetrate higher conductivity zones may detect the perched water, but those in low conductivity zones will not detect water unless drilling is stopped in time to allow the water level to recover. Air-rotary wireline coring data provide the greatest opportunity to detect perched water zones at the RWMC. It doesn't add water to the core and allows physical and visual examination of intact core for moisture determination. The geologist on the drill must be looking for perched water and be willing to stop the drilling to allow the water level to recover. There should be consistency in field descriptions of moisture content and collection of samples to determine moisture content.

New wells should be drilled following practices that give a high probability of detecting perched water. If perched water is suspected in the well, the well should be allowed to sit overnight to allow water to accumulate. If standing water is detected, the drilling should be discontinued and the well completed as a perched water monitoring well.

LATERAL AND VERTICAL EXTENT OF PERCHED WATER

Perched water zones at the RWMC form in the basalts, where relatively high permeability basalts overlie low permeability zones containing massive basalts or low permeability sediments. Perched water (standing water) has not been verified in the sediments; however, evidence of moisture content equaling porosity has been measured in one well.

The elevations of the uppermost surfaces of the perched water are at approximately 4928 and 4805 ft (depths from 80 to 90 ft and 200 to 221 ft below land surface). Perched ground water was documented in the basalts and not within the sedimentary interbeds. The perched water zones are primarily located above the 110- and 240-ft interbeds, suggesting low conductivity sediments or basalts at these depths restrict the downward flow of water.

All of the perched water wells are located along a narrow band running through the center of the RWMC (Figure 5). This is in part related to the greater drilling density in this area. This may be related to the location of the perched water wells to the runoff channel that allows water infiltration. Two wells obtained water at a elevation of approximately 4927 ft or 85 ft depth. Four perched water wells obtained water at an approximate elevation of 4800 ft or 200 ft depth. The four wells with similar water elevations suggest the presence of a continuous perched water body; however, 8 other wells drilled in the same vicinity of the western portion of the SDA did not record perched water at any elevation (76-3, 96B, D10, 76-1, 76-5, 78-3, 76-2, and 78-5). This suggests the conditions required to form perched water bodies are not present at these locations.

Perched water is controlled by the fracture and joint permeability in the basalt. Water bearing fractures or joints have to be penetrated to detect perched water in the well. Thus, perched water could be detected in one well while nearby wells may not have water, unless a permeable zone is penetrated. Increasing the number of wells will increase the probability that the fracture-controlled perched water body will be detected. The matrix permeability of the basalt is relatively low compared to the fracture permeability; therefore, water would not be expected in wells that did not come in direct contact with water bearing fractures or joints (Knutson, et al., 1990).

CONCLUSIONS

Perched ground water has been detected in 6 of 45 wells drilled at the RWMC. Perched water occurs within basalt formations, primarily at depths of 80 and 220 ft below land surface, over 370 ft above the Snake River Plain aquifer. The thickest perched water body is estimated to be 12-ft thick. These perched water zones do not appear to represent large continuous water zones beneath the RWMC, but rather, discontinuous perched water zones interspersed throughout the RWMC. Monitoring indicates some of the perched water zones have been in existence for over 18 yrs. Analysis of the water level indicates there are seasonal fluctuations in recharge to one of the perched water zones. Five volatile organics have been detected in high concentrations in a well at an depth of 212 ft. Tritium was detected in one well at 85-ft depth indicating water transport from land surface to this depth in 17 yr.

ACKNOWLEDGMENTS

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REFERENCES

Barraclough, J. T., J. B. Robertson, V. J. Janzer and L. G. Saindon, 1976, Hydrology of the Solid Waste Burial Ground as Related to the Potential Migration of Radionuclides, Idaho National Engineering Laboratory. USGS Open File Report, p. 95.

Gosset, J. M., 1987, "Measurement of Henry's Law Constants for C_1 and C_2 Chlorinated Hydrocarbons," Environmental Science Technology, Vol. 21, No. 2, pp. 202-208.

Knutson, C. F., et al., 1990, RWMC Basalt Characterization Program, EG&G Informal Report, in progress.

McElroy, D. L., et al., 1989, Annual Progress Report: FY-1988, Site Characterization Program at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory, DOE/ID-102333, p. 54.

Start, G. E. (ed.), 1984, Climatography of the Idaho National Engineering Laboratory, National Oceanic and Engineering Administration, IDO-12048a and B, October 1984.

Walton, J. C., A. S. Rood, R. G. Baca, and M. D. Otis, 1989, "Model For Estimation of Chlorinated Solvent Release From Waste Disposal Sites," Journal of Hazardous Material, Vol. 21, pp. 15-34.

BIOGRAPHICAL SKETCH

Joel M. Hubbell is a Senior Scientist with the Geosciences Unit at the Idaho National Engineering Laboratory. He received his B.S. degree in Geology from Idaho State University in 1976 and M.S. in Hydrology from the University of Idaho in 1981. Prior to his work in Idaho, he worked with the State of New Mexico, Ground Water and Hazardous Waste Section. His interests are drilling, sampling, and monitoring techniques in the vadose zone.

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