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Moisture and Textural Variations in Unsaturated Soils/Sediments Near the Hanford Wye Barricade

**P. R. Heller
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March 1985

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MOISTURE AND TEXTURAL VARIATIONS IN
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THE HANFORD WYE BARRICADE

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SUMMARY

During November and December 1983, soil samples were collected by Pacific Northwest Laboratory for hydrologic characterization of the partially saturated (vadose) zone sediments from five wells drilled near the Hanford Wye barricade, about 15 km northwest of Richland, Washington.

The samples were taken from each of five boreholes in 1.5-m segments down to the water table or to a depth where further drilling became impossible, whichever was deeper. The samples were collected and handled in such a manner as to minimize water loss through evaporation. The field moisture content was determined for each sample, and for three of the five boreholes the water potential at the field moisture content was also measured. Other characterization included textural analysis, water retention characteristics, hydraulic conductivity, and soil chemistry.

From the laboratory data, travel time (i.e., the time necessary for water to move a distance of 43 m, from the soil surface to the ground water) estimates were calculated: they range from <100 years to >600 years for annual water influx rates that ranged from 0.5 to 5.0 cm/yr.

The soil properties determined in this study will aid in modeling the transport of water and chemicals (e.g., radionuclides) to the ground water at the Hanford site.

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INTRODUCTION

For the past 15 to 20 years, extensive hydrologic studies of the partially saturated (vadose) zone^(a) at the U.S. Department of Energy's Hanford site have centered on using the zone as a long-term radioactive waste storage area (Brownell et al. 1975; Brown and Isaacson 1978; Jones 1978; Jones and Gee 1984; Reisenauer 1963). The vadose zone has also been considered as a buffer or delay zone that could extend the travel time of contaminants that might potentially seep to ground water from waste-processing operations or power-production facilities. The safety of buried radioactive wastes depends in part on the hydrologic isolation of the radionuclides from the fairly deep ground-water table at the Hanford site (Galley 1966; National Academy of Sciences 1957, 1976, 1978).

Past work at the Hanford site indicated that the vadose zone sediments remain fairly dry under the existing arid climate conditions (Enfield, Hsieh and Warrick 1973; Jones 1978; Jones and Gee 1984). However, the soils and sediments at the Hanford site, although highly variable, are generally coarse in texture and drain readily (Newcomb, Strand and Frank 1972; Routson and Fecht 1979). When excess water (from irrigation, liquid waste disposal, or increased precipitation) is applied at the surface, these soils and sediments can readily transmit water downward below the root zone such that further additions of water can be a source for deep drainage to the water table. Recent studies indicate that, when above-normal precipitation occurs, significant amounts of water can be transmitted below the root zone on coarse-textured soils at the Hanford site (Jones and Gee 1984; Kirkham and Gee 1984). Unfortunately, only limited hydrologic characterization has been completed on the Hanford site sediments; hence, the analysis of vadose zone water flow remains incomplete.

(a) The partially saturated (vadose) zone can be defined as the zone of geologic material (e.g., soils, sediments, and rocks) that lies between the land surface and the deepest water table. Generally, water in this zone is under pressure that is less than atmospheric (sometimes called negative pressure). At least some of the soil voids contain air or other gases at or near atmospheric pressure. At the Hanford site, this zone ranges in thickness from 15 m (45 ft) to over 100 m (300 ft).

This report documents a recent effort to hydrologically characterize certain vadose zone sediments at the Hanford site. The report details measurements of field water contents for samples collected from five boreholes drilled a few kilometers northwest of the Hanford Wye barricade and about 15 km northwest of Richland, Washington (Figure 1). Capillary pressure (matric water potential) data were taken on samples from three of the five holes. Laboratory analyses were performed to determine water retention characteristics, hydraulic conductivity, particle size, calcium carbonate content, pH, and electrical conductivity. Results are tabulated by hole and depth, and a discussion is provided concerning the use of this information to estimate rates of flow through the unsaturated zone.

FIGURE 1. Location of Boreholes near the Hanford Wye Barricade

METHODS

FIELD OPERATIONS

Collection of field samples for testing of the unsaturated zone in this area was initiated in November 1983 and completed in late December of the same year. Five sites were selected for collection of samples. These sites are spaced such that none were more than 1 km from each other near the center of the rectangular area shown in Figure 1. The four corner holes were drilled and then backfilled with clean materials. The centrally located test hole (#5) was cased to its entire depth and preserved as a site for repeatable soil moisture analyses using radioactive logging techniques. Samples were collected using a percussion drilling machine and drive-barrel tools. The drive barrel inside diameter was 12.7 cm (5 in.); its length changed over the course of operations because of reforming and refurbishing. The operating procedure was as follows:

1. Set up drill rig over selected hole location.
2. Drive sampler tube to maximum capacity.
3. Measure depth of hole and record.
4. Empty sample tube into sample container.
5. Lower drive sampler back into hole; remeasure depth and record.
6. Repeat steps 2 through 5.

The onsite geologist then marked the sample container and its lid according to well location and sample number. Sample containers were filled to as near capacity as feasible and then sealed to prevent moisture gain or loss during handling. Samples were transported to the laboratory at the end of each drilling day, or as soon as possible. The containers were covered during each intervening sample run to minimize soil moisture changes caused by atmospheric contact. At the four corner locations, a 0.5-m sample was collected from each 1.5-m (5-ft) interval. Continuous sampling was carried out at the central location. Sample volume was a nominal 19 L (5 gal). The target depth for each of the holes was to the regional water table. The method selected was such that, except under extremely adverse conditions, no drilling fluid would be needed. This ensured that the samples obtained were representative of the actual conditions at depth. Heavy gravels were encountered in each of the

holes near the water table. It became necessary to change over from drive-barrel methods to hard tools in four of the five holes. This changeover resulted in the lowermost samples being inappropriate for water-content analysis and biased the particle-size analysis toward the smaller size range. Drilling logs for all five boreholes are included in this report (see Appendix A).

SAMPLING DETAILS

From each core segment taken from a borehole, a 0.5-m section was saved for laboratory analysis in sealed airtight plastic buckets. From borehole #5 (see Figure 1), each core segment was saved in 0.75-m sections for a complete field water content analysis over the entire profile. All other analyses for borehole #5 were performed on only the odd-numbered samples, to be consistent with the other boreholes; that is, a 0.5-m section of every odd-numbered 1.5-m segment was used for analysis.

Samples were collected to the depth of the water table or to the depth where further drilling became impossible, whichever was reached first. For boreholes #2 through #5, water was added as a drilling lubricant at about 25 to 28 m; therefore, no water contents were obtained for the samples taken at and below this level.

Forty samples, eight from each borehole, were chosen for detailed analysis, based on visual texture changes down through the profile. One sample was selected to represent each of the visually distinct layers in the profile.

SOIL PROPERTIES PROCEDURES

Field Moisture Content

Field moisture content was determined on all samples. Samples were taken at the depths indicated in the previous section by core borehole techniques and placed immediately in vapor-tight containers in the field. The samples were first logged into the laboratory using the field log information recorded on the buckets. Before the seal was broken on the lid, the samples were mixed by

rolling the bucket to evenly distribute the water and to readsorb the condensation on the lid. Subsamples for moisture content were taken quickly to ensure minimum water loss caused by evaporation. These subsamples were weighed and oven-dried (16 h or more at 110° C) to determine moisture content according to ASTM procedure D 2216 (ASTM 1980).

Water Potential

When subsamples were taken from boreholes #3 through #5 for the field moisture content analysis, a second set of subsamples was collected to determine the water potential at the field moisture content. A commercial psychrometer sample changer^(a) was used to determine the water potential. The samples were packed into small cups 1.4 cm x 1.2 cm (diameter x height). The cups were put into vapor-tight chambers in the psychrometer sample changer. After approximately 1 h, the relative humidity was measured with a miniature thermocouple psychrometer. The psychrometer measures the wet bulb depression (humidity) in a closed chamber directly above the sample using a miniature thermocouple connected to a microvolt sensing unit. The equilibrium vapor pressure, or relative humidity, can be related directly to the water potential of the water in the sample (Campbell 1977). The relationship between the water potential and the relative humidity can be written as follows:

$$\Psi = -(RT/M) \ln (RH/100) \quad (1)$$

where

ψ = total water potential

R = universal gas constant

T = Kelvin

M = molecular weight of water

RH = relative humidity.

(a) Product of Decagon, Inc., Pullman, WA 99163.

Water Retention

Water retention characteristics were measured at 0.1, 1.0, and 15.0 bars applied pressure for each sample using a pressure plate extractor^(a). Equilibrium water contents were obtained by packing samples in containing rings on a porous ceramic plate where they were saturated and pressure-drained in the extractor.

Both the samples and porous plate were brought to saturation by allowing an excess of water to stand on the surface of the plate for 24 h. On complete saturation, the plate was placed in the extractor vessel and the internal air pressure raised to the desired test level. Equilibrium was reached when the drainage ceased. At the end of the run, the samples were weighed and oven-dried to determine the moisture contents. Water-content data are tabulated in terms of the associated matric water potential expressed in -bars. At equilibrium, the applied pressure is equal to the matric water potential (Richards 1965).

Hydraulic Conductivity

Hydraulic conductivity on each of the 40 predetermined samples was determined using a constant head method (Klute 1965). In this method, the sample is placed in a container (8.5 cm diameter, 9 cm high) and enclosed with lids having an inflow valve at one end and an outflow valve at the other end. The inflow valve is connected to a constant head device; the outflow valve is connected to a collection vessel. The sample is saturated before any test runs are done. An initial time is recorded and water is allowed to flow through the sample for a predesignated amount of time. The amount of discharge is recorded. The hydraulic conductivity is determined using the following equation:

$$K = \frac{L}{\Delta H} \frac{Q}{\Delta t} \quad (2)$$

(a) Product of Soilmoisture Equipment Corporation, Santa Barbara, CA 93105.

where

L = length of the sample

ΔH = hydraulic head difference

Q = volume of water that passes through the sample in known time ' t '

A = cross-sectional area of the sample.

Particle Size

Particle size was determined on two separate bases, depending on whether the particles were larger or smaller than 2 mm. Particle sizes larger than 2 mm were determined by dry sieve analysis using sieve sizes of 3 in., 2 in., 1 in., 3/4 in., 1/2 in., and 4.75 mm and 2.0 mm (No. 4 and No. 10 mesh Tyler numbers, respectively). Size distribution was done in accordance with ASTM procedure D 422 (ASTM 1972). For all samples, sand, silt, and clay distributions were determined based on only the <2-mm-sized particles from each large sample. The 40 predetermined samples were analyzed for a complete distribution curve, except for dispersion of the sample, by ASTM procedure D 422 (ASTM 1972). Sample dispersion was done using an ultrasonic homogenizer for more complete dispersion of the particles.

Chemistry

The cation exchange capacity (CEC) for each of the 40 samples tested was done by sodium saturation and sodium determination by atomic adsorption (Chapman 1965). The CaCO_3 content was determined using a volumetric calcimeter method (Allison and Moodie 1965). The pH and electrical conductivity were determined on a 1:1 soil extract (Bower and Wilcox 1965).

RESULTS AND DISCUSSION

PHYSICAL CHARACTERIZATION

The following physical characteristics for the borehole samples were analyzed: texture, moisture, water potential, hydraulic conductivity, and chemical properties. Travel time estimates were made based on the collected data.

Texture

Tables 1 and 2 list the results of the physical characterization completed for all samples from the five boreholes. Sieve analysis results (see Appendix C) confirm that, at this site, the soils are typically coarse-textured, with clay contents of all samples generally <5% and sand contents ranging from 60 to 90% or more. Silt contents varied considerably, ranging from <10 to >60%. The gravel and stone content of the material was also highly variable, ranging from 0 to over 60% by weight. The particle-size distributions for these materials are presented graphically in Appendix B. The data reflect an extremely heterogeneous profile indicative of the glacial-fluvial processes that were responsible for the formation of the sediment layers (Routson and Fecht 1979).

Moisture

Previous reports (Benson, Nelson and Alkine 1963; McHenry 1957; Routson and Fecht 1979) have documented soil properties. However, none clearly documents the field moisture status of the sediment profiles sampled. The Routson and Fecht (1979) study of 12 wells located south of the 200 East Area reported moisture contents, but indicated that the values (ranging from 0.2 to 3.2 wt%) represented a "minimum moisture;" the authors suggested that most samples had dried during storage, prior to analysis.

As indicated in the description of sampling and methods, we designed the study primarily to assess the moisture content of the sediment profile. The field moisture content values reported in Table 1 are generally higher than those reported by Routson and Fecht (1979). The values that we measured ranged from 2 to 15 wt%. The higher field moisture contents (those above 10%) are

TABLE 1. Moisture Analysis for Core Samples from Five Wells
near the Hanford Wye Barricade

Sample Number	Depth, (m)	Field Moisture (dry wt%)	Water Retention (Water Content - dry wt%)		
			-0.1 Bars	-1.0 Bars	-15.0 Bars
1-26	1.3	4.43	7.37	5.05	3.26
1-1	2.1	3.10	4.81	3.81	3.23
1-2	3.8	3.00	5.14	3.99	3.35
1-3	6.0	7.06	7.48	4.49	3.55
1-4	7.2	14.63	17.65	10.63	8.45
1-5	9.0	9.17	9.16	5.95	4.77
1-6	10.3	8.91	10.49	6.13	4.93
1-7	11.8	8.11	11.79	6.56	5.15
1-8	13.6	9.84	8.46	7.30	6.36
1-9	15.1	2.71	7.29	5.24	3.58
1-10	17.1	2.48	7.55	6.08	3.74
1-11	18.2	2.38	7.86	5.28	3.48
1-12	20.2	2.44	8.21	5.33	3.52
1-13	21.5	2.70	9.48	4.62	3.65
1-14	23.6	4.97	5.75	3.82	2.77
1-15	24.9	3.44	9.11	4.62	2.56
1-16	26.6	2.92	10.00	3.85	2.32
1-17	28.2	3.02	5.89	3.27	1.92
1-18	29.9	3.45	8.93	4.05	2.12
1-19	31.5	3.72	6.86	3.36	1.71
1-20	33.1	3.09	12.00	3.78	0.98
1-21	34.5	2.71	5.87	3.08	1.72
1-22	36.4	2.49	5.38	3.20	0.92
1-23	38.2	2.05	9.82	4.92	2.24
1-24	39.7	1.97	7.63	4.78	2.75
1-25	41.5	1.85	8.72	5.59	2.38
2-1	0.8	5.35	7.70	6.38	5.55
2-2	1.6	3.42	8.74	5.77	4.65
2-3	3.6	5.27	7.08	4.12	3.17
2-4	5.4	4.81	6.01	4.02	3.22
2-5	6.9	3.55	7.36	3.35	2.46
2-6	8.7	12.13	10.29	5.33	4.01
2-7	10.3	5.44	12.88	5.37	3.70
2-8	12.0	4.02	8.40	4.20	2.85
2-9	13.6	3.75	8.05	3.99	2.80
2-10	15.3	3.55	6.98	3.21	2.27
2-11	16.9	3.18	6.35	3.26	2.36
2-12	18.5	3.12	5.93	2.74	1.83
2-13	20.2	2.96	5.38	2.69	2.35
2-14	21.7	2.99	4.65	2.63	2.01
2-15	23.3	2.69	5.05	2.49	2.13
2-16	24.9	2.57	4.73	2.49	1.99
2-17	26.6	2.69	4.38	2.89	2.01

TABLE 1. (contd)

Sample Number	Depth, (m)	Field Moisture (dry wt%)	Water Retention (Water Content - dry wt%)		
			-0.1 Bars	-1.0 Bars	-15.0 Bars
2-18	28.2	3.09	5.22	2.66	2.14
2-19	30.0	2.40	13.38	7.11	4.51
2-20	31.3	2.67	16.48	7.69	5.36
2-21	33.5	--	12.72	7.42	3.34
2-22	34.8	--	14.17	8.66	4.13
2-23	36.4	--	13.93	7.66	3.94
2-24	38.2	--	12.97	7.49	3.70
2-25	39.7	--	13.81	7.56	3.57
2-26	41.3	--	15.64	8.78	5.24
2-27	42.7	--	4.08	2.56	1.63
3-1	1.6	5.87	4.57	2.55	2.35
3-2	3.6	6.67	7.72	3.74	3.38
3-3	5.2	8.74	8.14	4.50	3.43
3-4	6.9	4.80	5.59	3.53	2.77
3-5	8.5	4.23	5.60	3.91	2.68
3-6	10.2	4.55	5.78	4.62	3.35
3-7	11.6	4.89	4.89	3.87	3.19
3-8	13.5	5.53	5.77	4.07	3.21
3-9	15.1	6.16	5.65	4.48	2.95
3-10	16.6	5.32	5.92	3.91	2.68
3-11	18.4	6.78	5.59	4.00	2.89
3-12	20.0	5.50	5.67	3.92	2.90
3-13	21.7	6.47	7.69	2.22	2.70
3-14	23.3	5.02	5.05	2.62	1.64
3-15	24.8	4.07	4.59	3.11	2.54
3-16	26.7	4.00	2.52	2.30	2.12
3-17	28.2	3.54	4.08	3.71	3.10
3-18	30.2	--	13.83	7.00	3.51
3-19	31.5	--	12.56	8.46	4.52
3-20	33.1	--	14.18	8.64	4.14
3-21	34.8	--	12.88	7.37	3.96
3-22	36.4	--	14.30	7.79	3.79
3-23	38.1	--	12.12	6.50	3.46
3-24	39.7	--	12.77	7.47	3.81
3-25	41.3	--	13.26	7.83	4.03
3-26	43.0	--	11.84	6.86	3.41
4-1	1.6	5.63	3.09	2.93	2.79
4-2	3.8	4.36	4.75	4.30	3.77
4-3	5.1	4.68	6.03	5.82	5.32
4-4	7.2	10.86	9.51	8.81	6.50
4-5	8.9	3.68	4.60	4.43	3.70
4-6	10.2	3.17	4.09	3.95	3.19

TABLE 1. (contd)

Sample Number	Depth, (m)	Field Moisture (dry wt%)	Water Retention (Water Content - dry wt%)		
			-0.1 Bars	-1.0 Bars	-15.0 Bars
4-7	12.3	3.52	4.78	3.70	3.62
4-8	13.8	3.82	4.41	3.66	3.61
4-9	13.3	3.97	4.28	3.78	3.69
4-10	16.7	4.14	5.58	4.24	3.51
4-11	18.4	2.79	6.31	3.79	3.19
4-12	19.8	2.27	10.00	5.55	3.40
4-13	21.7	2.35	8.43	4.62	3.11
4-14	23.3	2.46	5.78	3.42	2.50
4-15	25.1	2.49	7.41	4.17	2.38
4-16	26.6	2.25	6.47	3.70	2.86
4-17	28.2	--	15.71	8.82	4.42
4-18	29.9	--	14.09	8.05	4.20
4-19	31.5	--	12.00	8.54	3.56
4-20	33.1	--	14.29	8.21	3.80
4-21	34.8	--	16.28	7.88	3.60
4-22	36.4	--	19.32	8.20	3.81
4-23	38.1	--	18.49	9.68	3.99
4-24	39.5	--	11.17	4.34	2.06
4-25	41.3	--	17.67	8.85	3.31
5-1	1.5	5.41	6.89	5.01	3.56
5-2	2.0	5.47			
5-3	2.5	3.24	7.38	3.93	2.99
5-4	3.3	3.98			
5-5	3.9	4.01	7.48	4.26	3.22
5-6	4.4	4.51			
5-7	5.2	4.93	6.26	3.92	3.04
5-8	5.7	4.51			
5-9	6.6	4.68	8.45	3.56	3.02
5-10	7.2	4.53			
5-11	8.2	4.82	4.92	3.21	2.93
5-12	8.7	4.24			
5-13	9.5	4.42	4.51	3.75	3.20
5-14	10.3	5.48			
5-15	10.8	5.59	4.06	3.23	2.95
5-16	11.6	4.79			
5-17	12.3	7.00	5.12	4.17	3.19
5-18	13.0	8.02			
5-19	13.8	9.64	7.33	6.33	4.87
5-20	14.4	5.57			
5-21	15.4	4.41	5.00	4.02	3.07
5-22	16.1	3.66			
5-23	16.6	4.08	3.92	3.20	2.48
5-24	17.4	3.86			

TABLE 1. (contd)

Sample Number	Depth, (m)	Field Moisture (dry wt%)	Water Retention (Water Content - dry wt%)		
			-0.1 Bars	-1.0 Bars	-15.0 Bars
5-25	18.0	3.70	3.62	2.94	2.28
5-26	18.7	3.54			
5-27	19.2	3.29	3.08	2.56	2.04
5-28	20.0	3.37			
5-29	20.7	3.86	3.29	2.27	1.91
5-30	21.3	3.42			
5-31	21.8	3.96	3.00	2.26	2.23
5-32	22.5	3.86			
5-33	23.1	4.11	3.26	2.12	1.91
5-34	24.0	3.76			
5-35	24.6	3.72	2.90	1.75	1.70
5-36	25.3	3.38			
5-37	25.8	3.08	3.42	2.28	1.85
5-38	26.2	3.15			
5-39	26.9	2.87	3.40	2.12	1.48
5-40	27.4	2.97			
5-41	27.9	2.93	3.37	1.98	1.49
5-42	28.5	2.59			
5-43	29.2	2.71	4.31	2.21	1.61
5-44	29.7	2.54			
5-45	30.2	2.30	6.89	3.21	2.13
5-46	30.7	3.48			
5-47	31.2	3.93	8.91	4.63	2.85
5-48	32.5	--			
5-49	33.6	--	12.46	7.08	4.17
5-50	34.3	--			
5-51	35.4	--	9.55	5.75	4.00
5-52	36.4	--			
5-53	37.1	--	10.72	5.97	4.99
5-54	38.1	--			
5-55	38.9	--	9.62	4.95	3.94
5-56	39.7	--			

TABLE 2. Mechanical Analysis for Core Samples from Five Wells near the Hanford Wye Barricade

Sample Number	Depth, (m)	Amount >2 mm (wt%)	Textural Analysis, (wt%)		
			Sand	Silt	Clay
1-26	1.3	22.00	63.8	31.7	4.5
1-1	2.1	13.38	80.0	17.9	2.0
1-2	3.8	19.77	70.8	26.3	2.9
1-3	6.0	4.62	82.3	15.1	2.7
1-4	7.2	0.00	72.2	22.7	5.1
1-5	9.0	0.00	84.9	12.4	2.7
1-6	10.3	0.00	80.6	16.2	3.2
1-7	11.8	0.00	79.0	17.8	3.2
1-8	13.6	0.00	80.5	15.4	4.1
1-9	15.1	62.89	30.1	65.5	3.5
1-10	17.1	47.80	35.9	58.5	5.6
1-11	18.2	55.70	32.3	63.6	4.2
1-12	20.2	53.30	29.1	63.9	7.0
1-13	21.5	48.06	32.7	62.8	4.6
1-14	23.6	31.96	56.6	39.4	4.0
1-15	24.9	20.38	65.9	30.7	3.4
1-16	26.6	30.01	60.9	36.5	2.6
1-17	28.2	23.81	67.2	30.5	2.3
1-18	29.9	2.20	87.0	10.8	2.2
1-19	31.5	8.21	83.1	14.4	2.5
1-20	33.1	16.21	73.1	24.3	2.5
1-21	34.5	1.34	88.5	9.2	2.3
1-22	36.4	11.71	78.9	18.5	2.6
1-23	38.2	54.87	36.5	59.3	4.3
1-24	39.7	47.54	42.8	53.4	3.7
1-25	41.5	40.35	46.5	49.2	4.3
2-1	0.8	37.21	83.1	13.0	3.9
2-2	1.6	40.11	81.4	13.8	4.8
2-3	3.6	14.74	88.7	9.4	2.0
2-4	5.4	27.41	86.9	11.8	1.3
2-5	6.9	27.06	88.7	8.7	2.7
2-6	8.7	2.67	78.5	17.0	4.5
2-7	10.3	0.50	81.9	14.3	3.8
2-8	12.0	0.86	85.7	11.6	2.7
2-9	13.6	1.58	91.2	6.9	1.5
2-10	15.3	12.30	90.5	9.2	0.3
2-11	16.9	11.57	92.4	6.1	1.5
2-12	18.5	4.69	89.9	8.5	1.6
2-13	20.2	5.08	93.1	6.0	0.9
2-14	21.7	3.26	90.3	7.6	2.2
2-15	23.3	2.56	91.8	6.2	2.1
2-16	24.9	3.37	91.3	7.1	1.6
2-17	26.6	1.73	94.4	3.6	1.9

TABLE 2. (contd)

Sample Number	Depth, (m)	Amount >2 mm (wt%)	Textural Analysis, (wt%)		
			Sand	Silt	Clay
2-18	28.2	1.36	93.8	4.8	1.4
2-19	30.0	55.81	68.0	28.0	4.0
2-20	31.3	45.59	66.2	28.7	5.1
2-21	33.5	36.68	69.7	23.0	7.3
2-22	34.8	24.76	60.6	29.0	10.5
2-23	36.4	15.19	69.8	22.3	8.0
2-24	38.2	26.55	66.5	24.6	8.9
2-25	39.7	13.53	66.8	24.7	8.5
2-26	41.3	0.45	32.4	50.1	17.5
2-27	42.7	14.45	90.7	5.5	3.8
3-1	1.6	0.10	88.6	9.5	1.9
3-2	3.6	0.00	84.8	12.7	2.5
3-3	5.2	0.00	87.0	10.4	2.6
3-4	6.9	4.00	86.9	10.8	2.2
3-5	8.5	9.11	88.4	8.5	3.1
3-6	10.2	14.37	88.2	8.3	3.5
3-7	11.6	8.36	89.0	7.9	3.1
3-8	13.5	1.98	88.3	9.7	2.1
3-9	15.1	6.96	90.6	7.1	2.3
3-10	16.6	13.41	91.6	6.1	2.3
3-11	18.4	4.09	89.8	7.7	2.5
3-12	20.0	11.22	91.4	6.4	2.3
3-13	21.7	0.07	86.7	10.5	2.9
3-14	23.3	0.39	88.6	8.1	3.3
3-15	24.8	4.89	90.6	6.6	2.8
3-16	26.7	5.50	89.6	7.8	2.6
3-17	28.2	39.53	88.2	8.7	3.1
3-18	30.2	30.11	69.2	24.5	6.4
3-19	31.5	21.59	69.6	22.5	7.9
3-20	33.1	25.51	66.9	26.7	6.4
3-21	34.8	30.11	88.4	6.3	5.3
3-22	36.4	27.76	74.2	19.3	6.5
3-23	38.1	40.14	52.4	41.2	6.4
3-24	39.7	33.81	62.9	30.9	6.2
3-25	41.3	37.25	67.7	24.9	7.4
3-26	43.0	18.66	70.6	23.5	5.9
4-1	1.6	0.61	95.4	2.3	2.3
4-2	3.8	9.73	90.0	7.3	2.7
4-3	5.1	39.27	85.1	11.6	3.3
4-4	7.2	0.00	81.0	14.2	4.8
4-5	8.9	1.36	92.8	5.1	2.1
4-6	10.2	5.90	89.1	10.1	0.7

TABLE 2. (contd)

Sample Number	Depth, (m)	Amount >2 mm (wt%)	Textural Analysis, (wt%)		
			Sand	Silt	Clay
4-7	12.3	1.67	88.8	9.0	2.2
4-8	13.8	6.41	90.8	7.1	2.1
4-9	18.3	9.5	90.6	7.2	2.2
4-10	16.7	1.1	90.2	7.7	2.1
4-11	18.4	39.2	77.6	19.2	3.2
4-12	19.8	45.7	67.5	27.2	5.3
4-13	21.7	58.8	71.0	24.6	4.4
4-14	23.3	46.8	80.1	17.2	2.8
4-15	25.1	41.5	73.3	22.1	4.7
4-16	26.6	27.5	78.4	18.2	3.5
4-17	28.2	27.7	62.0	34.9	3.1
4-18	29.9	26.3	64.8	29.2	6.0
4-19	31.5	23.1	65.2	28.8	6.0
4-20	33.1	22.3	66.3	27.6	6.2
4-21	34.8	32.9	67.8	26.5	5.8
4-22	36.4	18.5	62.8	31.8	5.4
4-23	38.1	1.4	64.8	30.1	5.1
4-24	39.5	16.7	82.2	14.9	2.9
4-25	41.3	2.9	63.0	28.7	8.3
5-1	1.5	24.5	90.0	7.5	2.5
5-2	2.0				
5-3	2.5	16.7	90.4	8.6	1.3
5-4	3.3				
5-5	3.9	19.3	94.5	4.3	1.3
5-6	4.4				
5-7	5.2	6.1	92.5	6.2	1.4
5-8	5.7				
5-9	6.6	6.7	93.1	5.0	2.0
5-10	7.2				
5-11	8.2	5.2	93.5	4.8	1.7
5-12	8.7				
5-13	9.5	16.4	92.1	5.3	2.6
5-14	10.3				
5-15	10.8	3.3	84.9	11.9	3.3
5-16	11.6				
5-17	12.3	13.4	83.2	13.4	3.5
5-18	13.0				
5-19	13.8	1.0	74.7	21.6	3.7
5-20	14.4				
5-21	15.4	8.5	86.7	10.1	3.2
5-22	16.1				
5-23	16.6	7.5	88.2	9.4	2.4
5-24	17.4				

TABLE 2. (contd)

Sample Number	Depth, (m)	Amount >2 mm (wt%)	Textural Analysis, (wt%)		
			Sand	Silt	Clay
5-25	18.0	8.2	86.6	10.2	3.2
5-26	18.7				
5-27	19.2	10.0	90.4	7.2	2.4
5-28	20.0				
5-29	20.7	11.1	92.1	5.8	2.1
5-30	21.3				
5-31	21.8	6.2	91.8	5.5	2.7
5-32	22.5				
5-33	23.1	0.6	89.9	6.9	3.2
5-34	24.0				
5-35	24.6	5.0	92.0	5.3	2.7
5-36	25.3				
5-37	25.8	18.0	90.6	6.4	3.0
5-38	26.2				
5-39	26.9	22.2	91.7	5.9	2.5
5-40	27.4				
5-41	27.9	5.0	91.0	6.6	2.4
5-42	28.5				
5-43	29.2	6.8	89.6	8.0	2.5
5-44	29.7				
5-45	30.2	32.7	83.2	13.8	3.0
5-46	30.7				
5-47	31.2	35.8	87.0	9.9	3.2
5-48	32.5				
5-49	33.6	23.5	65.1	27.8	7.1
5-50	34.3				
5-51	35.4	20.7	66.4	27.0	6.7
5-52	36.4				
5-53	37.1	19.4	64.3	27.9	7.9
5-54	38.1				
5-55	38.9	25.9	69.4	23.7	6.8
5-56	39.7				

consistently associated with fine-textured sediments (i.e., samples with higher silt and clay contents). Based on the measured water-retention values, the bulk of the data indicate water content values that are consistent with moisture contents associated with a draining profile (0 to -1.0 bar capillary pressure), particularly in the region from 5 to 20 m deep. Borehole #3, being the most uniform in texture, yielded the most uniformly wet profile, indicating that moisture redistribution and drainage had extended to at least a depth of 25 m. (The moisture data at depths below 25 to 30 m are unavailable in all but

borehole #1 because of difficulties in obtaining core material from the very coarse gravel/soil layers at this location.)

In cases where water contents appear drier than those measured at -1.0 bar on the pressure plate, the data are consistently associated with coarse samples that contain large portions of materials larger than 2 mm in size. Because the water retention values were run on materials <2 mm in size, a correction of either the field water contents or the pressure plate water contents is necessary. The following relationship relates the field water content corrected for gravel (>2 mm-size material) to the laboratory water retention data (for material <2 mm in size).

$$W_C = (W_U - W_G f_G) / (1 - f_G) \quad (3)$$

where

W_C = corrected field water content

W_U = uncorrected field water content

W_G = water content of gravel (>2 mm material)

f_G = dry weight fraction of gravel in sample.

When this correction is applied to the field water contents (using Table 2 data and assuming $f_G \sim 0.01$) virtually all the data below a 5-m depth from all five boreholes can be shown to have water contents that fall within the range of those measured on the pressure plate between 0.1 and 1.0 bar. Field moistures consistently wetter than the measured -1.0 bar capillary pressure suggest that drainage is occurring and that evaporation is likely not occurring at great depths.

Water Potential

Samples were measured for water potential only in boreholes #3, 4, and 5. In boreholes #3 and #5 the measured total water potential was found to be wetter than -1.0 bar for all samples. These data confirm that, in general, the soil remained wet at depth. For 5 samples in borehole #4, the measured water potential was drier than -1.0 bars (ranging from -1.5 to -5.0 bars at depths from 17 to 24 m). All other samples (11) were measured to be wetter than -1.0 bar. Sample desiccation or measurement error are possible explanations

for the observed drier water potential at depth in test borehole #4. Careful and detailed measurement of 17 samples from borehole #3 and 47 samples from borehole #5 indicated that no samples to depths of 29 m had water potentials drier than -1.0 bars. The resolution of the water potential sensing unit is ± 1.0 bar. However, we also determined from pressure plate tests that, in general, samples with total water potentials wetter than -1.0 bar also had matric potentials wetter than -1.0 bar. These data support the concept of a draining profile at this site.

Hydraulic Conductivity

All measurements were made on disturbed samples. The coarse sediments made it impossible to sample without noticeable segregation of material. Table 3 reports hydraulic conductivity values for the <2-mm-size fraction for eight samples from borehole #3. Also included in Table 3 are measured hydraulic conductivity values on five bulk samples, which contained >2-mm-size materials. Note that for these samples, the >2-mm size ranged up to about 20 mm. Coarser material was not sampled. The coarse fraction in each sample is documented in Table 2. The measured conductivities vary from 10^{-2} to 10^{-5} cm/s and reflect moderate-to-high permeabilities indicative of coarse materials with a wide range of particle sizes. The reported values are considered representative of vertical permeabilities of the sediments. Because of the disturbed nature of the samples, no attempt was made to measure differences between vertical and horizontal permeabilities for these materials.

Chemical Properties

Table 4 lists the chemical properties of selected samples from each borehole. No unusual chemical properties were noted in these sediments. They are alkaline with low cation exchange capacities and generally low carbonates. These findings are very similar to those reported by Routson and Fecht (1979) for 200 East Area sediments.

Travel Time Estimates

Travel time in the vadose zone can be defined as the time necessary for water to move from the soil surface to the water table. Travel time is a key

TABLE 3. Hydraulic Conductivities of Eight Core Samples from Borehole #3

<u>Sample Number</u>	<u>Depth, m</u>	<u>Bulk Sample, cm/s</u>	<u><2 mm, cm/s</u>
3-1	1.6	1.2E-03	1.2E-03
3-3	5.2	1.0E-03	1.0E-03
3-6	10.2	1.1E-02	2.5E-02
3-12	20.0	6.8E-03	1.4E-02
3-14	23.3	3.7E-03	3.7E-03
3-17	28.2	4.0E-03	6.0E-03
3-21	34.8	1.2E-04	1.6E-05
3-25	41.3	3.4E-04	4.2E-05

parameter needed to estimate consequences for siting facilities where radioactive waste might be leached to ground water. For radioactive species (e.g., tritium, ruthenium, iodine, or organically complexed species that are sorbed little on soil or sediments), the major mode of concentration reduction is through decay; hence, long travel times are desirable. Travel times can be estimated using the hydrologic properties on the unsaturated sediments. Appendix D details the mathematical expressions needed to calculate the travel times. For unsaturated flow considerations, the major uncertainty is the annual seepage (recharge) rate that occurs at depth, below the zone of evaporation (top 2 to 3 m). Much uncertainty still exists as to the actual recharge rate but, for our calculations, we made travel time estimates assuming 0.5 and 5.0 cm/yr as steady-state recharge values. Table D.2 (see Appendix D) shows that for borehole #3, the measured water contents agree reasonably well with those predicted using exponential relationships of unsaturated conductivity and water retention, and assuming the recharge rates lie between 0.5 and 5.0 cm/yr.

Travel times were analyzed in two ways. The first method assumed that the soil properties could be averaged over the entire depth (43 m). The second method separated the sediments into three zones, based on textural differences, and computed the travel times by summing the travel time in the individual zones. Table 5 tabulates the estimated travel times based on the properties reported for borehole #3, using annual recharge rates of 0.5 and 5.0 cm/yr.

TABLE 4. Chemical Analysis for Core Samples from Five Boreholes near the Hanford Wye Barricade

Sample Number	Depth, m	CEC, meq/L	CaCO ₃ , wt%	pH, units	EC, mmhos/cm
1-26	1.3	8.0	0.20	8.2	0.10
1-2	3.8	9.7	1.37	8.2	0.19
1-8	13.6	13.9	1.04	8.2	0.16
1-12	20.2	8.0	1.30	8.2	0.18
1-16	26.6	6.0	0.86	8.3	0.16
1-19	31.5	4.1	0.91	8.2	0.15
1-22	36.4	4.2	0.96	8.3	0.15
1-24	39.7	5.3	0.98	8.2	0.17
2-1	0.8	11.7	0.84	8.3	0.17
2-4	5.4	9.5	1.09	8.4	0.14
2-6	8.7	12.0	1.26	8.2	0.16
2-10	15.3	6.2	1.27	8.3	0.13
2-16	24.9	3.4	1.17	8.3	0.15
2-19	30.0	6.4	0.67	8.3	0.19
2-22	34.8	5.0	0.29	8.2	0.22
2-25	39.7	3.1	1.38	8.2	0.22
3-1	1.6	4.4	0.38	8.0	0.16
3-3	5.2	8.7	1.54	8.3	0.15
3-6	10.2	8.2	0.76	8.2	0.15
3-12	20.0	7.1	0.71	8.2	0.14
3-14	23.3	3.7	1.15	8.3	0.15
3-17	28.2	4.9	1.21	8.2	0.14
3-21	34.8	4.8	0.46	8.1	0.23
3-25	41.3	4.6	0.58	8.3	0.22
4-1	1.6	4.1	1.30	8.4	0.14
4-3	5.1	21.0	1.35	8.2	0.15
4-4	7.2	15.0	1.54	8.3	0.17
4-8	13.8	7.2	0.69	8.2	0.17
4-13	21.7	7.1	0.60	8.2	0.15
4-19	31.5	5.4	0.45	8.4	0.15
4-23	38.1	4.1	0.57	8.3	0.22
4-25	41.3	10.0	0.26	8.1	0.21
5-1	1.5	7.2	1.28	8.2	0.16
5-15	10.8	7.5	0.54	8.2	0.18
5-17	12.3	7.9	0.68	8.1	0.15
5-23	16.6	7.0	1.38	8.1	0.12
5-33	23.1	3.5	1.29	8.4	0.15
5-45	30.2	3.4	1.07	8.2	0.15
5-51	35.4	4.1	0.29	8.3	0.21
5-55	38.9	3.1	0.41	8.3	0.22

TABLE 5. Estimated Travel Times for Water Movement from Soil Surface to a 43-m-Deep Water Table Using Borehole #3 Soil Characteristics at Two Recharge Rates

Method	Travel Time, yr	
	0.5 cm/yr	5.0 cm/yr
1 - Averaged Soil Values	710	93
2 - Three-Layer System	886	111

The results presented in Table 5 show that travel times depend on both the estimated recharge rates and the method of calculation. Using the layer data, the travel times were found to be 20 to 25% longer than when averaged soil characteristics were used, demonstrating the importance of including individual soil layer characteristics in the calculations. In addition to the uncertainty in the recharge rate, the nonuniformity (spatial variability) present at this site makes it impossible to estimate a single travel time for water flow to the water table. A complete analysis of travel times in the vadose zone awaits more definite measurements of recharge rates and a detailed uncertainty analysis of the hydrologic properties of the layered unsaturated sediments. It is anticipated that over the next few years, ongoing research at the Hanford site will provide detailed measurements and analysis that will complement this initial characterization study.

CONCLUSIONS

Based on the field and lab data, the following conclusions can be made:

- The sediment profiles at this field site are extremely heterogeneous but, in general, the soils are coarse-textured and drain rapidly.
- The sediment profiles were wet to extended depth (>25 m), suggesting that drainage is occurring at this site. Rates of drainage were estimated to lie between 0.5 and 5.0 cm/yr based on a simplified analysis using exponential relationships for both unsaturated conductivity and water retention characteristics (see Appendix D).
- Estimated travel times for water to move through the unsaturated zone to the water table at this site range from less than 100 years to over 800 years for annual water influx rates of 5.0 to 0.5 cm/yr, respectively.
- The soil properties determined here will be useful in modeling the transport of water and chemicals (e.g., radionuclides) to the ground water at this site.

REFERENCES

- Allison, L. E., and C. D. Moodie. 1965. "Carbonate." In Methods of Soil Analysis, Part 2, ed. C. A. Black, pp. 1389-1392. American Society of Agronomy, Madison, Wisconsin.
- ASTM. 1972. "Particle Size Analysis of Soils." Annual Book of ASTM Standards, Part 19, ASTM D 422, American Standard Testing Materials, Philadelphia, Pennsylvania.
- ASTM. 1980. "Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures." Annual Book of ASTM Standards, Part 19, ASTM D 2216, American Standard Testing Materials, Philadelphia, Pennsylvania.
- Benson, D. W., J. L. Nelson and G. J. Alkine. 1963. Chemical and Physical Properties of 100 Area Soils. General Electric Co., Richland, Washington.
- Bower, C. A., and L. V. Wilcox 1965. "Soluble Salts." In Methods of Soil Analysis, Part 2, ed. C. A. Black, pp. 935-940. American Society of Agronomy, Madison, Wisconsin.
- Brownell, L. E., J. G. Backer, R. E. Isaacson and D. J. Brown. 1975. Soil Moisture Transport in Arid Site Vadose Zones. ARH-ST-123, Atlantic Richfield Hanford, Richland, Washington.
- Campbell, G. S. 1977. An Introduction to Environmental Biophysics. Springer-Verlag, New York, New York.
- Chapman, H. D. 1965. "Cation Exchange Capacity." In Methods of Soil Analysis, Part 2, ed. C. A. Black, pp. 891-900. American Society of Agronomy, Madison, Wisconsin.
- Enfield, C. G., J. J. C. Hsieh and A. W. Warrick. 1973. "Evaluation of Water Flux Above a Deep Water Table Using Thermocouple Psychrometers." Soil Sci. Soc. Am. Proc. 37:968-970.
- Galley, J. E. 1966. Report of the Committee on Geologic Aspects of Radioactive Waste Disposal. National Academy of Sciences, National Research Council, Washington, D.C.
- Isaacson, R. E., and D. J. Brown. 1978. Environmental Assessment Related to Hanford Radioactive Waste Burial. RHO-SA-36, Rockwell Hanford Operations, Richland, Washington.
- Jones, T. L. 1978. Sediment Moisture Relations: Lysimeter Project 1976-1977 Water Year. RHO-ST-15, Rockwell Hanford Operations, Richland, Washington.
- Jones, T. L., and G. W. Gee. 1984. Assessment of Unsaturated Zone Transport for Shallow Land Burial of Radioactive Waste. PNL-4747, Pacific Northwest Laboratory, Richland, Washington.

- Kirkham, R. R., and G. W. Gee. 1984. "Measurement of Unsaturated Flow Below the Root-Zone at an Arid Site." Paper presented at the National Water Well Association Conference on Characterization and Monitoring of the Vadose Zone, December 8-10, 1983, National Water Well Association, Las Vegas, Nevada.
- Klute, A. 1965. "Laboratory Measurement of Hydraulic Conductivity of Saturated Soil." In Methods of Soil Analysis, Part 1, ed. C. A. Black, pp. 210-222. American Society of Agronomy, Madison, Wisconsin.
- McHenry, J. R. 1957. Properties of Soils of the Hanford Project. HW-53218, General Electric Company, Richland, Washington.
- National Academy of Sciences. 1957. The Disposal of Radioactive Waste on Land. National Research Council, Washington, D.C.
- National Academy of Sciences. 1976. The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste. National Research Council, Washington, D.C.
- National Academy of Sciences. 1978. Radioactive Wastes at the Hanford Reservation: A Technical Review. Committee on Radioactive Waste Management, National Research Council, Washington, D.C.
- Newcomb, R. C., J. R. Strand and F. J. Frank. 1972. "Geology and Groundwater Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission." Professional Paper 717, U.S. Geological Survey, Washington, D.C.
- Reisenauer, A. E. 1963. "Methods of Solving Problems of Multidimensional Partially Saturated Steady Flow in Soils." J. Geophys. Res. 68(20):5725-5733.
- Richards, L. A. 1965. Physical Condition of Water in Soil. In Methods of Soil Analysis, Part 1, ed. C. A. Black, pp. 128-137. American Society of Agronomy, Madison, Wisconsin.
- Routson, R. C., and K. R. Fecht. 1979. Soil (Sediment) Properties of Twelve Hanford Wells with Geologic Interpretation. RHO-CD-82, Rockwell Hanford Operations, Richland, Washington.

APPENDIX A

DRILLING LOGS

DRILLING LOG

Well Number 1
 Driller: Marvin Bultena
 Geologist: TL Liikala

Date Start 11/18/83
 Date Finish 11/21/83

Depth, m	Sample Interval, m	Sample Number	Lithology
2.1	1.3 - 2.1	1-1	Sand. Brown sand, few small pebbles, 5% granules, 60% very coarse sand, 30% coarse sand, 5% medium sand, low moisture content.
3.8	3.1 - 3.8	1-2	Coarse sand. Brown sand, 5% small pebbles, 20% granules, 50% very coarse sand, 20% coarse sand, 5% medium sand, low moisture content.
6.0	4.9 - 6.0	1-3	Fine sand. Change in lithology, contact at 4.6 m, dark brown fine sand, 40% medium sand, 50% fine sand, 10% very fine sand, low moisture content.
7.2	6.6 - 7.2	1-4	Fine sand. Light brown fine sand, 20% medium sand, 50% fine sand, 30% very fine sand, tightly compacted, low moisture content.
9.0	8.0 - 9.0	1-5	Fine sand. Light brown fine sand as above, thin 1-2 mm silt lenses, low moisture content.
10.3	9.5 - 10.3	1-6	Fine sand. Light brown fine sand, 5% medium sand, 60% fine sand, 35% very fine sand, low moisture content.
11.8	11.2 - 11.8	1-7	Fine sand. Same as above.
13.6	13.0 - 13.6	1-8	Fine sand. Brown, slightly coarser than above, 50% medium sand, 40% fine sand, 10% very fine sand, low moisture content.
15.1	13.8 - 15.1	1-9	Gravel. Brown, sandy, 5% small cobbles, 20% pebbles, 30% granules, 20% very coarse sand, 20% coarse sand, 5% medium sand.
17.1	16.1 - 17.1	1-10	Gravel. Light brown sandy, 5% cobbles, 15% pebbles, 30% granules, 20% very coarse sand, 20% coarse sand, 10% medium sand, low moisture content.

(Well Number 1 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
18.2	17.7 - 18.2	1-11	Gravel. Brown sandy, 5% cobbles, 15% pebbles, 30% granules, 30% very coarse sand, 20% coarse sand, low moisture content.
20.2	19.4 - 20.2	1-12	Gravel. Same as above.
21.5	20.8 - 21.5	1-13	Gravel. Brown sandy, 10% cobbles, 25% pebbles, 35% granules, 20% very coarse sand, 10% coarse sand, low moisture content.
23.6	22.6 - 23.6	1-14	Gravel. Slight change in lithology, less coarse material, lack of cobbles, 5% small pebbles, 60% granules, 30% very coarse sand, 5% coarse sand. Some additional water because of rain down borehole.
24.9	24.3 - 24.9	1-15	Coarse sand. Brown, gravelly, 5% granules, 70% very coarse sand, 20% coarse sand, 5% medium sand, low moisture content.
26.6	25.9 - 26.6	1-16	Coarse sand. Brown, gravelly, 10% granules, 60% very coarse sand, 20% coarse sand, 10% medium sand, low moisture content.
28.2	27.6 - 28.2	1-17	Coarse sand. Same as above.
29.9	29.2 - 29.9	1-18	Coarse sand. Slight change in lithology, 5% granules, 75% very coarse sand, 15% coarse sand, 5% medium sand, very consistent grain size, low moisture content.
31.5	30.8 - 31.5	1-19	Coarse sand. Pepper-colored sand, very consistent grain size, 80% very coarse sand, 15% coarse sand, 5% medium sand, low moisture content.
33.1	32.5 - 33.1	1-20	Coarse sand. Same as above, with <1% granules.
34.9	34.1 - 34.9	1-21	Coarse sand. Same as above.

(Well Number 1 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
36.4	35.8 - 36.4	1-22	Coarse sand. Same as above.
38.2	37.4 - 38.2	1-23	Sand and gravel. Change in lithology, brown sandy gravel, fine brown sand mixed with granules, 5% small pebbles, 40% granules, 5% very coarse sand, 10% coarse sand, 10% medium sand, 30% fine sand, low moisture content, contact at 37.4 m.
39.7	39.7 - 39.7	1-24	Sand and gravel. Light brown sandy gravel, 5% small pebbles, 40% granules, 20% very coarse sand, 10% coarse sand, 20% medium sand, 10% fine sand.
41.5	40.7 - 41.5	1-25	Sand and gravel. Slight increase in grain size, broken cobbles up to 150 mm, 5% small cobbles, 10% pebbles, 40% granules, 10% very coarse sand, 10% coarse sand, 25% medium sand.
41.7			Core barrel will not advance because of heavy gravel layer. Hole terminated.

DRILLING LOG

Well Number 2
 Driller: Marvin Bultena
 Geologist: TL Liikala, K Oster

Date Start 11/21/83
 Date Finish 12/2/83

Depth, m	Sample Interval, m	Sample Number	Lithology
0.8	0.0 - 0.8	2-1	Soil and gravel. 30 cm top soil, brown sandy gravel, scattered (<1%) small cobbles, 5% pebbles, 40% granules, 20% coarse sand, 15% medium sand, contact at 30 cm.
1.6	0.8 - 1.6	2-2	Gravel. Definite increase in grain size, 10% small cobbles (up to 100 mm), 15% pebbles, 40% granules, 30% very coarse sand, 5% coarse sand, low moisture content.
3.6	1.6 - 3.6	2-3	Fine gravel. Black basaltic sand, few small cobbles, 5% small pebbles, 20% granules, 50% very coarse sand, 25% coarse sand, slightly moist.
5.4	4.6 - 5.4	2-4	Fine gravel. Same as above, with scattered basalt and quartz cobbles, slightly moist sample.
6.9	6.2 - 6.9	2-5	Coarse sand. Black and brown, slight decrease in overall grain size, 20% granules, 60% very coarse sand, 20% coarse sand, slightly moist.
8.7	8.0 - 8.7	2-6	Sand. Change in lithology at 8.5 m, fine brown sand, very consistent grain size, 10% coarse sand, 70% medium sand, 10% fine sand, 10% very fine sand.
10.3	9.7 - 10.3	2-7	Sand. Brown, consistent grain size, 80% medium sand, 10% fine sand, 5% very fine sand, 5% silt, low moisture content.
12.0	11.2 - 12.0	2-8	Sand. Slight increase in overall grain size, few basalt cobbles present, 5% granules, 30% very coarse sand, 40% coarse sand, 20% medium sand, 5% silt, silt lenses (up to 10 mm thick) low moisture content.

(Well Number 2 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
13.6	12.8 - 13.6	2-9	Sand. Brown, consistent grain size, 30% very coarse sand, 60% coarse sand, 10% medium sand, low moisture content.
15.3	14.4 - 15.3	2-10	Sand. Brown, contact at 14.8 m, 50% very coarse sand, 40% coarse sand, 10% medium sand, bits and pieces of broken cobbles, low moisture content.
16.9	16.1 - 16.9	2-11	Sand. Brown and white, 5% broken cobbles, 5% granules, 60% very coarse sand, 30% coarse sand, low moisture content.
18.5	17.7 - 18.5	2-12	Sand. Brown and white, <1% pebbles, 10% granules, 60% very coarse sand, 20% coarse sand, 10% medium sand, low moisture content.
20.2	19.4 - 20.2	2-13	Sand. Same as above.
21.7	21.0 - 21.7	2-14	Sand. Slight decrease in overall grain size, brown and white, 5% broken pebbles, 5% granules, 20% very coarse sand, 40% coarse sand, 30% medium sand, low moisture content.
23.3	22.6 - 23.3	2-15	Sand. Same as above.
24.9	24.3 - 24.9	2-16	Sand. Same as above.
26.6	25.9 - 26.6	2-17	Sand. Brown and white, 5% broken pebbles, 5% granules, 40% very coarse sand, 40% coarse sand, 10% medium sand.
28.2	27.6 - 28.2	2-18	Sand. Same as above.
30.0	29.2 - 30.0	2-19	Gravel. Change in lithology at 28.5 m, brown fine sand mixed with gravel, 5% broken cobbles, 10% pebbles, 40% granules, 5% very coarse sand, 5% coarse sand, 5% med. sand, 30% fine sand, low moisture content.

(Well Number 2 cont)

<u>Depth, m</u>	<u>Sample Interval, m</u>	<u>Sample Number</u>	<u>Lithology</u>
31.3	31.0 - 31.3	2-20	Sand and gravel. Brown sand and gravel, 5% broken cobbles, 30% granules, 5% very coarse sand, 5% coarse sand 5% med. sand, 40% fine sand, low moisture content.
31.8			Hard gravel, switched over to hard tools.
33.5	32.5 - 33.5	2-21	Gravel.
34.8	34.0 - 34.8	2-22	Gravel.
36.4	35.8 - 36.4	2-23	Gravel.
38.2	37.6 - 38.2	2-24	Gravel.
39.7	38.5 - 39.7	2-25	Gravel.
41.3	40.7 - 41.3	2-26	Gravel. Some silt.
42.7	42.2 - 42.7	2-27	Sand and gravel. Water table at 42.7 m.

DRILLING LOG

Well Number 3
 Driller: Marvin Bultena
 Geologist: TL Liikala

Date Start 12/5/83
 Date Finish 12/9/83

Depth, m	Sample Interval, m	Sample Number	Lithology
1.6	0.0 - 1.6	3-1	Sand. Brown, medium very consistent size, 100% medium sand, low moisture content.
3.6	3.0 - 3.6	3-2	Sand. Change in lithology, brown sand mixed with black basaltic sand, 20% coarse sand, 80% medium sand, low moisture content, contact at 3.6 m.
5.2	4.6 - 5.2	3-3	Sand. Same as above.
6.9	6.2 - 6.9	3-4	Sand. Black, basaltic, very consistent grain size, 90% coarse sand, 10% medium sand, low moisture content.
8.5	7.9 - 8.5	3-5	Sand. Same as above, contains a few granules.
10.2	9.5 - 10.2	3-6	Sand. Black, basaltic, small pebbles <1%, 5% granules, 30% very coarse sand, 65% coarse sand, low moisture content.
11.6	11.2 - 11.6	3-7	Sand. Slight increase in grain size, black, basaltic, <1% pebbles, 5% granules, 30% very coarse sand, 65% coarse sand, low moisture content.
13.5	12.8 - 13.5	3-8	Sand. Same as above.
15.1	14.4 - 15.1	3-9	Sand. Same as above.
16.6	16.1 - 16.6	3-10	Sand. Black basaltic, 5% granules, 45% very coarse sand, 50% coarse sand, few silt lenses, 1-3 mm thick, low moisture content.
18.4	17.7 - 18.4	3-11	Sand. Same as above.
20.0	19.4 - 20.0	3-12	Sand. Black basaltic, very consistent grain size, 50% very coarse sand, 50% coarse sand, low moisture content.

(Well Number 3 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
21.7	21.0 - 21.7	3-13	Sand. Change in lithology at 6.6 m, brown, consistent grain size, 80% coarse sand, 20% medium sand, low moisture content.
23.3	22.6 - 23.3	3-14	Sand. Same as above.
24.9	24.3 - 24.9	3-15	Sand. Same as above.
26.7	25.9 - 26.7	3-16	Sand. Same as above.
28.2	27.0 - 28.2	3-17	Sandy gravel. Change in lithology at 27.7 m, 20% pebbles, 30% granules, 40% coarse sand, 10% medium sand, low moisture content.
28.9			Change to hard tools, heavy gravel, no sample returns in drive barrel.
30.2	28.0 - 30.2	3-18	Gravel.
31.5	30.0 - 31.5	3-19	Gravel.
33.1	32.0 - 33.1	3-20	Gravel.
34.8	32.0 - 34.8	3-21	Gravel.
36.4	35.4 - 36.4	3-22	Gravel.
38.1	37.1 - 38.1	3-23	Gravel.
39.7	38.8 - 39.7	3-24	Gravel.
41.3	40.4 - 41.3	3-25	Gravel.
43.	42.0 - 43.0	3-26	Gravel. Water table at 42.7 m.

DRILLING LOG

Well Number 4
 Driller: Marvin Bultena
 Geologist: TL Liikala, KR Oster, EJ Jensen

Date Start 12/12/83
 Date Finish 12/16/83

Depth, m	Sample Interval, m	Sample Number	Lithology
1.6	0.0 - 1.6	4-1	Sand. Brown, 100% medium sand, low moisture content.
2.0			Silt. Lenses to 5 cm thick for 30 cm.
2.6			Sand. Change in lithology at 2.6 m, black, 80% very coarse sand, 20% coarse sand.
3.8	3.0 - 3.8	4-2	Sand and gravel. Contact at 3 m, 5% small pebbles, 15% granules, 50% very coarse sand, 30% coarse sand, low moisture content.
5.1	4.4 - 5.1	4-3	Sand and gravel. Black, 10% small pebbles, 25% granules, 45% very coarse sand, 20% coarse sand, silt lenses (up to 5 cm), low moisture content.
7.2	6.2 - 7.2	4-4	Fine sand. Brown, consistent grain size, silt lenses, 70% fine sand, 20% very fine sand, 10% silt, low moisture content.
8.9	7.9 - 8.9	4-5	Coarse sand. Black, basaltic, 70% very coarse sand, 30% coarse sand, low moisture content.
10.2	9.2 - 10.2	4-6	Coarse sand. Same as above.
12.3	11.2 - 12.3	4-7	Coarse sand. Same as above.
13.8	12.8 - 13.8	4-8	Coarse sand. Slight change in lithology at 13.8 m, <1% small pebbles, 30% very coarse sand, 20% coarse sand, 40% medium sand, 10% fine sand, low moisture content.
15.3	14.4 - 15.3	4-9	Coarse sand. Black, basaltic, with some brown, few small pebbles, 40% very coarse sand, 20% coarse sand, 40% medium sand, low moisture content.

(Well Number 4 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
16.7	15.9 - 16.7	4-10	Coarse sand. Same as above.
18.4	17.7 - 18.4	4-11	Sand and Gravel. Brown and black, change in lithology at 18 m, brown sand and gravel, 5% small pebbles, 35% granules, 30% very coarse sand, 20% coarse sand, 10% medium sand, low moisture content.
19.8	19.4 - 19.8	4-12	Sand and gravel. Brown, 20% small pebbles, 20% granules, 10% very coarse sand, 10% coarse sand, 40% fine sand, low moisture content.
21.7	21.0 - 21.7	4-1	Sand and gravel. Brown, 15% medium pebbles, 20% granules, 15% very coarse sand, 10% coarse sand, 40% fine sand, low moisture content.
23.3	22.6 - 23.3	4-14	Sand and gravel. Brown, 10% small pebbles, 20% granules, 20% very coarse sand, 15% coarse sand, 35% fine sand, low moisture content.
25.1	24.3 - 25.1	4-15	Sand and gravel. Same as above.
26.6	25.9 - 26.6	4-16	Sand and gravel. Same as above.
26.6			Drive Barrel caught on casing, lost 5.6 m of hole when casing pulled back. Changed over to hard tools to recover hole.
28.2	27.2 - 28.2	4-17	Sand and gravel. Further description not possible because of hard tool use.
29.9	28.5 - 29.9	4-18	Sand and gravel.
31.5	30.5 - 31.5	4-19	Sand and gravel.
33.1	32.2 - 33.1	4-20	Sand and gravel.
34.8	33.8 - 34.8	4-21	Sand and gravel.
36.4	35.4 - 36.4	4-22	Sand and gravel.

(Well Number 4 cont)

<u>Depth, m</u>	<u>Sample Interval, m</u>	<u>Sample Number</u>	<u>Lithology</u>
38.1	37.1 - 38.1	4-23	Gravel.
39.5	38.9 - 39.5	4-24	Gravel.
41.3	40.4 - 41.3	4-25	Gravel. Water table at 38.4 m.

DRILLING LOG

Well Number 5
 Driller: Marvin Bultena
 Geologist: TL Liikala, EJ Jensen

Date Start 12/20/83
 Date Finish 12/27/83

Depth, m	Sample Interval, m	Sample Number	Lithology
1.5	0.0 - 1.5	5-1	Top soil and coarse sand. Brown, <1% small pebbles, 30% granules, 55% very coarse sand, 5% medium sand, low moisture content.
2.0	1.5 - 2.0	5-2	Very coarse sand. Brown, same as above, with silt lenses to 5 cm, low moisture content.
2.5	2.5 - 3.3	5-3	Coarse sand. Slight change in lithology at 2 m, black and brown, <1% pebbles, 10% granules, 40% very coarse sand, 50% coarse sand, low moisture content.
3.3	2.5 - 3.3	5-4	Coarse sand. Same as above.
3.9	3.3 - 3.9	5-5	Coarse sand. Same as above.
4.4	3.9 - 4.4	5-6	Coarse sand. Black, consistent grain size, 5% granules, 45% very coarse sand, 45% coarse sand, 5% medium sand, low moisture content.
5.2	4.4 - 5.2	5-7	Coarse sand. Same as above.
5.7	5.2 - 5.7	5-8	Coarse sand. Same as above.
6.6	5.7 - 6.6	5-9	Coarse sand. Same as above.
7.2	6.6 - 7.2	5-10	Coarse sand. Slight decrease in grain size, black, basaltic, 30% very coarse sand, 70% coarse sand, low moisture content.
8.2	7.2 - 8.2	5-11	Coarse sand. Same as above.
8.7	8.2 - 8.7	5-12	Coarse sand. Slight increase in grain size, <1% small pebbles, 10% granules, 40% very coarse sand, 50% coarse sand, low moisture content.

(Well Number 5 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
9.5	8.7 - 9.5	5-13	Coarse sand. Black, basaltic, 10% small pebbles, 40% very coarse sand, 50% coarse sand, low moisture content.
10.3	9.5 - 10.3	5-14	Coarse sand. Same as above.
10.8	10.3 - 10.8	5-15	Coarse sand. Same as above.
11.6	10.8 - 11.6	5-16	Gravelly sand. Black, basaltic, 5% small pebbles, 30% granules, 35% very coarse sand, 30% coarse sand, low moisture content.
12.3	11.6 - 12.3	5-17	Gravelly sand/fine sand. Same as above, change in lithology at 12.1 m. Brown, consistent grain size, 100% fine sand, low moisture content.
13.0	12.3 - 13.0	5-18	Fine sand. Brown, 100% fine sand, low moisture content.
13.8	13.0 - 13.8	5-19	Sand. Brown, 50% medium sand, 50% fine sand, low moisture content.
14.4	13.8 - 14.4	5-20	Sand. Slight increase in grain size, 5% granules, 15% very coarse sand, 15% coarse sand, 30% medium sand, 35% fine sand.
15.4	14.4 - 15.4	5-21	Sand. Same as above.
16.1	15.4 - 16.1	5-22	Sand. Same as above.
16.6	16.1 - 16.6	5-23	Coarse sand. Change at 16.4 m. Black, basaltic, 5% granules, 70% very coarse sand, 25% coarse sand, low moisture content.
17.4	16.6 - 17.4	5-24	Coarse sand. Same as above.
18.0	17.4 - 18.0	5-25	Coarse sand. Same as above.

(Well Number 5 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
18.7	18.0 - 18.7	5-26	Coarse sand. Black, basaltic, consistent grain size, 70% very coarse sand, 20% coarse sand, 10% medium sand, low moisture content.
19.2	18.7 - 19.2	5-27	Coarse sand. Same as above.
20.0	19.2 - 20.0	5-28	Coarse sand. Slight increase in grain size, <1% small pebbles, 10% granules, 70% very coarse sand, 20% coarse sand, low moisture content.
20.7	20.0 - 20.7	5-29	Coarse sand. Same as above.
21.3	20.7 - 21.3	5-30	Coarse sand. Same as above.
21.8	21.3 - 21.8	5-31	Coarse sand. Same as above.
22.5	21.8 - 22.5	5-32	Coarse sand. Slight increase in grain size, 55 small pebbles, 10% granules, 70% very coarse sand, 15% coarse sand, low moisture content.
23.1	22.5 - 23.1	5-33	Coarse sand. Black, basaltic, 10% granules, 70% very coarse sand, 20% coarse sand, low moisture content.
24.0	23.1 - 24.0	5-34	Coarse sand. Same as above.
24.6	24.0 - 24.6	5-35	Coarse sand. Same as above.
25.3	24.6 - 25.3	5-36	Coarse sand. Same as above.
25.8	25.3 - 25.8	5-37	Coarse sand. Same as above.
26.2	25.8 - 26.2	5-38	Coarse sand. Slight increase in grain size, 10% pebbles, 10% granules, 60% very coarse sand, 20% coarse sand, low moisture content.
26.9	26.2 - 26.9	5-39	Coarse sand. Black and brown, 5% small pebbles, 10% granules, 60% very coarse sand, 25% coarse sand, low moisture content.

(Well Number 5 cont)

Depth, m	Sample Interval, m	Sample Number	Lithology
27.4	26.9 - 27.4	5-40	Coarse sand. Brown and black, 5% small pebbles, 10% granules, 60% very coarse sand, 25% coarse sand, low moisture content.
27.9	27.4 - 27.9	5-41	Coarse sand. Same as above.
28.5	27.9 - 28.5	5-42	Coarse sand. Same as above.
29.2	28.5 - 29.2	5-43	Coarse sand. Slight increase in grain size, 10% small pebbles, 20% granules, 60% very coarse sand, 10% coarse sand, low moisture content.
29.7	29.2 - 29.7	5-44	Sandy gravel. Change in lithology at 29.2 m. Brown, 40% well-rounded small pebbles, 20% granules, 40% very coarse sand, low moisture content.
30.2	29.7 - 30.2	5-45	Sandy gravel. Brown, 30% well-rounded pebbles, 30% granules, 35% very coarse sand, low moisture content.
30.7	30.2 - 30.7	5-46	Sandy gravel. Brown, 15% pebbles, 40% granules, 35% very coarse sand, 10% coarse sand, low moisture content.
31.2	30.7 - 31.2	5-47	Sandy gravel. Same as above. Change to hard tools, no sample return.
32.5	31.2 - 32.5	5-48	Gravel.
33.6	32.5 - 33.6	5-49	Gravel.
34.3	33.6 - 34.3	5-50	Gravel.
35.4	34.3 - 35.4	5-51	Gravel.
36.4	35.4 - 36.4	5-52	Gravel.
37.1	36.4 - 37.1	5-53	Gravel.
38.1	37.1 - 38.1	5-54	Gravel.
38.9	38.1 - 38.9	5-55	Gravel.

(Well Number 5 cont)

<u>Depth,</u> <u>m</u>	<u>Sample</u> <u>Interval,</u> <u>m</u>	<u>Sample</u> <u>Number</u>	<u>Lithology</u>
39.7	38.9 - 39.7	5-56	Gravel.
40.2			Bottom of hole.

APPENDIX B

PARTICLE-SIZE DISTRIBUTION PLOTS FOR SELECTED CORE SAMPLES FROM FIVE WELLS NEAR THE HANFORD WYE BARRICADE

Note: Numbers at the top of the plots correspond to well numbers and depths as described in Appendix A. Ordinate of each curve is the percentage of the sample less than the particle diameter X .

APPENDIX C

DRY SIEVE ANALYSIS

TABLE C.1. Dry Sieve Analysis for Samples from Five Wells near the Hanford Wye Barricade

Sample	Percentage Less than						
	3 in.	2 in.	1 in.	3/4 in.	1/2 in.	4.75 mm	2.0 mm
1-26	100.0	100.0	99.2	98.2	96.4	89.2	75.4
1-1	100.0	100.0	97.7	97.1	96.4	94.6	85.5
1-2	100.0	100.0	99.2	99.0	97.9	93.9	75.2
1-3	100.0	100.0	100.0	100.0	99.2	98.3	91.6
1-4	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1-5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1-6	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1-7	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1-8	100.0	100.0	100.0	100.0	100.0	100.0	99.9
1-9	100.0	98.1	91.1	84.2	74.0	49.8	31.1
1-10	100.0	98.9	73.8	71.3	64.6	47.1	31.9
1-11	100.0	98.9	92.8	87.5	77.6	51.4	30.5
1-12	100.0	98.8	92.0	87.2	77.9	57.5	38.0
1-13	100.0	95.3	87.6	81.8	74.1	55.5	36.2
1-14	100.0	100.0	98.7	98.1	96.6	86.9	62.2
1-15	100.0	100.0	99.4	98.4	97.3	92.9	77.0
1-16	100.0	98.3	96.1	94.1	92.1	84.9	70.2
1-17	100.0	100.0	100.0	99.9	99.3	94.8	77.7
1-18	100.0	100.0	100.0	99.6	99.5	99.3	96.1
1-19	100.0	100.0	100.0	99.8	99.5	99.1	95.6
1-20	100.0	100.0	98.2	97.5	96.3	93.0	88.5
1-21	100.0	100.0	100.0	100.0	99.7	99.3	96.8
1-22	100.0	100.0	99.5	99.1	98.0	95.4	86.5
1-23	100.0	100.0	99.3	97.1	91.0	63.7	43.5
1-24	100.0	100.0	98.9	96.8	92.6	72.8	53.3
1-25	72.6	64.8	61.2	57.3	53.3	45.8	41.4
2-1	97.2	97.2	90.5	88.0	85.3	79.0	57.1
2-2	100.0	98.5	89.9	86.9	84.2	78.0	59.4
2-3	100.0	98.5	98.3	98.1	97.5	91.3	88.7
2-4	100.0	92.0	85.1	81.7	77.3	71.6	59.6
2-5	100.0	100.0	92.0	89.2	86.0	81.8	70.8
2-6	100.0	100.0	98.7	97.9	97.0	94.2	85.6
2-7	100.0	100.0	100.0	100.0	100.0	100.0	98.7
2-8	100.0	95.8	94.8	94.3	93.9	93.3	91.5
2-9	100.0	100.0	99.1	98.7	98.5	98.0	95.6
2-10	100.0	96.4	94.3	93.3	91.6	88.5	80.5
2-11	100.0	100.0	99.2	98.7	97.7	95.5	87.7
2-12	98.7	98.7	98.3	98.2	97.4	96.3	90.7
2-13	100.0	100.0	99.2	99.0	98.6	97.7	94.4
2-14	100.0	100.0	99.9	99.9	99.8	99.4	97.3
2-15	100.0	100.0	100.0	99.9	99.6	99.0	97.0
2-16	100.0	100.0	99.4	98.9	98.3	97.8	95.8
2-17	100.0	100.0	99.8	99.7	99.3	99.0	97.0
2-18	100.0	100.0	100.0	100.0	100.0	99.9	98.0

TABLE C.1. (contd)

Sample	Percentage Less Than						
	3 in.	2 in.	1 in.	3/4 in.	1/2 in.	4.75 mm	2.0 mm
2-19	100.0	96.7	90.3	87.5	81.7	66.3	49.9
2-20	95.0	88.1	79.0	76.1	70.2	56.0	43.0
3-1	100.0	100.0	100.0	100.0	100.0	100.0	99.1
3-2	100.0	100.0	100.0	100.0	100.0	100.0	99.0
3-3	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3-4	100.0	100.0	100.0	99.5	99.3	98.6	94.7
3-5	100.0	100.0	99.0	98.4	97.8	96.2	89.5
3-6	100.0	100.0	96.7	95.0	93.2	90.8	85.9
3-7	100.0	100.0	99.5	98.8	98.0	96.2	89.2
3-8	100.0	100.0	100.0	99.9	99.6	98.9	95.1
3-9	100.0	100.0	99.7	99.7	99.6	98.7	93.8
3-10	100.0	100.0	99.5	99.4	98.8	96.3	86.0
3-11	100.0	100.0	99.6	98.6	97.6	94.8	87.9
3-12	100.0	100.0	100.0	99.3	98.7	97.1	90.4
3-13	100.0	100.0	100.0	100.0	100.0	100.0	99.1
3-14	100.0	100.0	100.0	100.0	100.0	100.0	98.6
3-15	100.0	100.0	100.0	99.9	99.9	99.6	95.4
3-16	100.0	100.0	100.0	100.0	100.0	99.8	94.1
3-17	100.0	98.5	94.8	89.8	81.9	65.7	54.0
4-1	100.0	100.0	100.0	100.0	100.0	100.0	98.4
4-2	100.0	98.5	94.4	92.3	90.2	86.1	76.3
4-3	100.0	100.0	94.8	91.3	88.7	79.3	60.7
4-4	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4-5	100.0	100.0	100.0	100.0	100.0	100.0	97.9
4-6	100.0	100.0	99.7	99.7	99.7	99.5	93.3
4-7	100.0	98.8	97.5	97.3	97.2	96.9	95.5
4-8	100.0	100.0	99.9	99.2	98.3	96.1	89.6
4-9	100.0	100.0	98.7	97.1	94.6	92.2	87.5
4-10	100.0	98.1	96.0	94.5	93.4	92.4	89.7
4-11	100.0	99.0	96.1	94.4	91.6	80.3	65.1
4-12	100.0	100.0	99.3	97.7	90.2	67.8	50.1
4-13	100.0	100.0	94.8	89.7	82.0	63.9	46.1
4-14	100.0	100.0	96.1	93.5	89.4	75.0	52.2
4-15	100.0	98.8	94.9	90.9	85.0	71.5	51.3
4-16	100.0	99.0	95.1	91.9	87.3	74.6	51.3
5-1	100.0	98.7	97.6	95.7	93.6	87.9	63.3
5-3	100.0	98.9	98.2	97.1	95.1	91.1	74.9
5-5	100.0	100.0	99.9	99.9	99.8	99.0	88.3
5-7	100.0	100.0	99.8	99.8	99.6	98.8	93.3
5-9	100.0	100.0	100.0	100.0	100.0	99.6	96.0
5-11	100.0	100.0	99.7	99.6	99.4	98.7	93.9
5-13	100.0	97.8	93.6	91.4	89.3	86.2	79.7

TABLE C.1. (contd)

Sample	Percentage Less Than						
	3 in.	2 in.	1 in.	3/4 in.	1/2 in.	4.75 mm	2.0 mm
5-15	100.0	100.0	99.4	99.2	98.8	97.1	92.4
5-17	100.0	100.0	98.9	98.6	97.6	91.6	77.2
5-19	100.0	100.0	100.0	99.9	99.9	99.7	99.1
5-21	100.0	100.0	99.6	98.9	97.8	96.4	90.6
5-23	100.0	100.0	99.5	99.1	98.7	97.7	90.2
5-25	100.0	100.0	100.0	99.8	99.5	98.6	92.5
5-27	100.0	100.0	98.5	97.9	96.5	94.2	85.8
5-29	100.0	100.0	98.3	97.9	97.0	95.1	88.4
5-31	100.0	97.5	94.8	94.6	94.1	92.2	85.4
5-33	100.0	100.0	100.0	100.0	100.0	99.7	96.8
5-35	100.0	100.0	99.9	98.9	97.8	94.6	90.9
5-37	100.0	100.0	98.1	96.7	94.8	89.8	84.2
5-39	100.0	100.0	97.5	95.4	92.6	89.6	85.7
5-41	100.0	100.0	98.3	96.6	95.0	93.0	89.5
5-43	100.0	100.0	98.7	96.6	94.3	88.9	85.1
5-45	100.0	100.0	94.5	89.2	80.6	66.1	57.6
5-47	100.0	100.0	86.9	81.0	74.6	63.5	52.8

APPENDIX D

TRAVEL TIMES IN THE UNSATURATED (VADOSE) ZONE

APPENDIX D

TRAVEL TIMES IN THE UNSATURATED (VADOSE) ZONE

In this appendix we show how travel times for water in the unsaturated zone were calculated. The assumptions used in the analysis are presented and example calculations for computing total travel time through layered profiles are given.

1. Flow Condition

We assumed that unit hydraulic gradient conditions prevail:

$$q = K(\theta) \left[1 + \frac{\partial h(\theta)}{\partial z} \right] = K(\theta) \quad (D.1)$$

where

q = water flux in cm/yr (assumed constant)

$K(\theta)$ = unsaturated hydraulic conductivity in cm/yr

h = suction head = $-\psi$ (matric potential)

z = elevation.

2. Hydraulic Properties

We assumed simple analytical relationships between matric potential, ψ , and water content, θ , and between conductivity and water potential (Campbell 1974). These are

$$\psi = \psi_e (\theta_s/\theta)^b \quad (D.2)$$

$$K = K_{sat} (\psi_e/\psi)^n \quad (D.3)$$

$$n = 2 + 3/b \quad (D.4)$$

where

ψ_e = air entry matric potential (-cm)

θ_s = saturated water content (cm^3/cm^3)

θ = field water content (cm^3/cm^3)

b = a constant, determined from the slope of a log-log plot of ψ versus θ

K_{sat} = saturated hydraulic conductivity.

From Equations (D.1), (D.2), and (D.3), the water content, θ , can be expressed in terms of the steady water flux, q , and the saturated hydraulic conductivity, K_{sat} , as follows:

$$\theta = W(q) = \left(\frac{q}{K_{\text{sat}}} \right)^m \theta_s \quad (\text{D.5})$$

where $W(q)$ is the water content of the soil at a given water flux and

$$m = \frac{1}{2b+3} \quad (\text{D.6})$$

3. Travel Time

The water velocity, v , can be defined as follows:

$$v = q/\theta \quad (\text{D.7})$$

and travel time, T , can be defined as follows:

$$T = L/v = L\theta/q \quad (\text{D.8})$$

where L is profile thickness (length in cm).

4. Layered Profile

Assuming there are n layers in the profile, then

$$q = K_i(\theta_i) \quad (i = 1, \dots, n) \quad (\text{D.9})$$

$$\theta_i = W_i(q) \quad (\text{D.10})$$

where i is the soil layer index.

The travel time in a layered system can be expressed in terms of a depth integral as

$$T = \int_0^L \frac{dz}{v(z)} = \frac{1}{q} \int_0^L \theta(z) dz \quad (D.11)$$

where $v(z)$ = velocity as a function of elevation, z .

For discrete layers, we can express the travel time as

$$T_i = \frac{L}{q} W_i(q) f_i \quad (D.12)$$

where f_i = layer profile depth fraction

$$\sum_{i=1}^n f_i = 1 .$$

The total travel time through the profile is the sum of the travel times through individual soil layers times the depth fraction, i.e.,

$$T = \sum_{i=1}^n T_i f_i . \quad (D.13)$$

5. Example Calculations

Data from borehole #3 were used in the calculations. Two methods were used to estimate travel times. For Method 1, average water retention and conductivity values for the entire profile were determined. For Method 2, values for conductivity and water retention were averaged for three distinct layers: 0.0 to 5.2 m, 5.2 to 23.3 m, and 23.3 to 43.0 m. The fractions, f_1 , f_2 , and f_3 were set at 0.12, 0.42, and 0.46, respectively, to illustrate the use of the method. The water table was at 43 m. We

assumed two flux rates, 0.5 and 5.0 cm/yr. The resulting values for the calculations of the hydraulic properties are shown in Table D.1.

Table D.2 shows the water content calculations based on the hydraulic properties in Table D.1 and Equation (D.5).

TABLE D.1. Soil Properties for Travel Time Calculations

Soil	Porosity	θ_s	K_{sat} cm/yr	ψ_e cm	b
3-Ave	0.38	0.34	1.0×10^5	11	2.8
3 A	0.43	0.39	3.4×10^4	7	2.0
3 B	0.39	0.35	2.3×10^5	5	2.1
3 C	0.36	0.32	7.3×10^3	18	4.8

TABLE D.2 Measured and Calculated Water Contents of Average Soil Profile and Selected Layers for a 0.5 and 5.0 cm/yr Recharge Rate

Soil	θ (Field)	Water Content, m ³ /m ³	
		θ (0.5)	θ (5.0)
3-Ave	--	0.082	0.108
3 A	0.117	0.080	0.111
3 B	0.078	0.058	0.079
3 C	--	0.150	0.180

Calculated travel times for Method 1 (average) and Method 2 (layered system) are shown as follows:

a) 0.5 cm/yr:

Method 1. From borehole #3-Ave soil data (Table D.2) and using Equation (D.8),

$$T = \frac{L\theta}{q} = \frac{4300}{0.5} (0.082) = \underline{710 \text{ years}} .$$

Method 2. Using borehole #3 data with layering (A,B,C) from Equation (D.13),

$$T = \frac{4300}{0.5} [(0.080)(0.12) + (0.058)(0.42) + (0.15)(0.46)] = \underline{890 \text{ years}} .$$

b) 5.0 cm/yr:

Method 1. From 3-Ave soil data (Table D.2) and using Equation (D.8),

$$T = \frac{L\theta}{q} = \frac{4300}{5} (0.108) = \underline{93 \text{ years}} .$$

Method 2. Using 3A, B, and C data, and Equation (D.13)

$$T = \frac{4300}{5} [(0.111)(0.12) + (0.079)(0.42) + (0.18)(0.46)] = \underline{110 \text{ years}} .$$

REFERENCE

Campbell, G. S. 1974. "A Simple Method for Determining Unsaturated Conductivity from Moisture Retention Data." Soil Sci. 117:311-314.

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