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Geologic Isolation Systems

Preliminary Subsurface Hydrologic Considerations: Columbia River Plateau Physiographic Province

M. D. Veatch
Shannon and Wilson, Inc.

April 1980

Prepared for the
Office of Nuclear Waste Isolation
under its Contract with the
U.S. Department of Energy

Pacific Northwest Laboratory
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PRELIMINARY SUBSURFACE HYDROLOGIC CONSIDERATIONS: COLUMBIA RIVER PLATEAU PHYSIOGRAPHIC PROVINCE

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Richland, Washington 99352

PREFACE

Associated with commercial nuclear power production in the United States is the generation of potentially hazardous radioactive waste products. The Department of Energy (DOE), through the National Waste Terminal Storage (NWTS) Program and the Office of Nuclear Waste Isolation (ONWI), is seeking to develop nuclear waste isolation systems in geologic formations. These underground waste isolation systems will preclude contact with the biosphere of waste radionuclides in concentrations which are sufficient to cause deleterious impact on humans or their environments. Comprehensive analyses of specific isolation systems are needed to assess the post-closure expectations of the systems. The Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) Program has been established for developing the capability of making those analyses.

Among the analyses required for the system evaluation is the detailed assessment of the post-closure performance of nuclear waste repositories in geologic formations. This assessment is concerned with aspects of the nuclear program which previously have not been addressed. The nature of the isolation systems (e.g., involving breach scenarios and transport through the geosphere) and the great length of time for which the wastes must be controlled dictate the development, demonstration, and application of novel assessment capabilities. The assessment methodology must be thorough, flexible, objective, and scientifically defensible. Furthermore, the data utilized must be accurate, documented, reproducible, and based on sound scientific principles.

The current scope of AEGIS is limited to long-term, post-closure analyses. It excludes the consideration of processes that are induced by the presence of the wastes, and it excludes the consideration of nuclear waste isolation in media other than geologic formations. The near-field/near-term aspects of geologic repositories are being considered by ONWI/DOE under separate programs. They will be integrated with the AEGIS methodology for the actual site-specific repository safety analyses.

The assessment of repository post-closure safety has two basic components:

- identification and analyses of breach scenarios and the pattern of events and processes causing each breach;
- identification and analyses of the environmental consequences of radionuclide transport and interactions subsequent to a repository breach.

The Release Scenario task is charged with identifying and analyzing breach scenarios and their associated patterns of events and processes.

The Release Scenario task is concerned with evaluating the geologic system surrounding an underground repository and describing the phenomena which alone or in concert could perturb the system and possible cause a loss of repository integrity. Output from the Release Scenario task will establish the boundary conditions of the geology and hydrology surrounding the repository at the time of an identified breach. These bounding conditions will be used as input for the consequence analysis task, which will employ sophisticated hydrological transport models to evaluate the movement of radionuclides through the groundwater system to the biosphere.

AEGIS has contracted with a number of consultants to obtain expert scientific opinion about the geologic processes which could affect an underground repository. The consultants were asked to specify processes and events which might affect potential repository sites and, if possible, to give rates and probabilities for those phenomena. The consultants have also been involved with the description of the system interactions and synergisms.

This report contains information obtained by one of the AEGIS consultants during the FY-1978 research effort. The research described in this document is being continued during FY-1979 and FY-1980. Because of the ongoing nature of the Release Scenario methodology development effort, many of the results and conclusions outlined in this report are subject to change upon completion of additional research and analyses. The information contained in this report is based upon the expert opinion of an individual consultant and should be treated as such.

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ACKNOWLEDGMENT

This research was supported by the Waste Isolation Safety Assessment Program (WISAP) conducted by Pacific Northwest Laboratory. The program was sponsored by the Office of Nuclear Waste Isolation, managed by Battelle Memorial Institute for the Department of Energy under Contract DE-AC06-76RLO-1830. On 1 October 1979, WISAP became the Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) Program and the Waste/Rock Interactions Technology (WRIT) Program. This report was issued by AEGIS.

SUMMARY

This report contains a discussion of the hydrologic conditions of the Columbia River Plateau physiographic province. The Columbia River Plateau is underlain by a thick basalt sequence. The Columbia River basalt sequence contains both basalt flows and sedimentary interbeds. These sedimentary interbeds, which are layers of sedimentary rock between lava flows, are the main aquifer zones in the basalt sequence. Permeable interflow zones, involving the permeable top and/or rubble bottom of a flow, are also water-transmitting zones.

A number of stratigraphic units are present in the Pasco Basin, which is in the central part of the Columbia River Plateau. At a conceptual level, the stratigraphic sequence from the surface downward can be separated into four hydrostratigraphic systems. These are: 1) the unsaturated zone, 2) the unconfined aquifer, 3) the uppermost confined aquifers, and 4) the lower Yakima basalt hydrologic sequence.

The unsaturated zone (UZ) is the zone between the land surface and the water table. Its thickness at the Hanford Site ranges from less than one meter to more than 100 meters. The unsaturated zone consists of silt, sand, and gravel deposits. The moisture content of the unsaturated zone of the Hanford Site is very low.

The unconfined aquifer system (UAS) consists of sand and gravel deposits of glaciofluviatile origin. These deposits rest on the Ringold Formation. The top of the aquifer at any give time is the water table. The base of the aquifer is either the top of the basalt bedrock in some areas or the silt and clay zones of the lower Ringold Formation in other areas. The hydraulic characteristics of the unconfined aquifer system are quite variable.

The uppermost confined aquifer (UCAS) consists of: 1) the sands and gravels of the lower Ringold Formation, 2) the sedimentary interbeds of the upper and middle Yakima basalt sequence, and 3) permeable interflow zones in the top few meters of some flow units. The UCAS is known to be hydraulically

interconnected at places in the Pasco Basin with the overlying unconfined aquifer, and they appear to be in hydraulic equilibrium.

The lower Yakima basalt hydrologic system (LYBHS) is comprised of the basalt flows and interbeds which underlie the Vantage Sandstone Formation. Very little is known about the direction and movement of groundwater through the lower Yakima basalt sequence and its contained interbeds. However, tests indicate that it contains 2 flow regimes: the upper confined flow regime and the lower confined flow regime.

Hydraulic head relationship between the unconfined aquifer system (UAS), uppermost confined aquifer system (UCAS), and the lower Yakima basalt hydrologic system (LYBHS) are known in a general way. The potentiometric surface of the UCAS ranges from less than one meter to four meters higher than the potentiometric surface of the overlying UAS. For initial modeling purposes, it is recommended that head differences ranging from 1 to 10 meters be considered for these two aquifer sequences. The flow potential should be from the UCAS to UAS. The potentiometric surface of the LYBHS is about two meters higher than the overlying UCAS; therefore, the apparent potential for flow is from the LYBHS to the UCAS. Because the head relationships of these two aquifer systems may be reversed at specific sites, it is recommended, for initial modeling purposes, that head fluctuation ranging from 1 to 10 meters be considered, with comparative runs for flow from the LYBHS to the UCAS and from the UCAS to the LYBHS.

The hydraulic gradient in the UAS ranges from about 0.5 meter to 5 meters per km throughout the Pasco Basin. The gradient is highest near recharge sources, such as the waste disposal ponds of the 200 West and East Areas of the Hanford Site. The hydraulic gradient in the UCAS is less well known than the UAS. The range in the hydraulic gradient is probably less, in general, than stated above for the UAS; however, it may be greater near the edge of the Pasco Basin (recharge area) and the Columbia River (discharge area).

Little is known about the hydraulic gradient of the LYBHS. It is probably very low in the central part of the Pasco Basin. For initial modeling simulation runs, a hydraulic gradient range of 0.1 to 1 meter per km is probably the correct order of magnitude.

A conceptual layered earth model (LEM) has been developed. The LEM represents the major types of porous media (LEM units) that may be encountered at a number of places on the Columbia Plateau, and specifically in the Pasco Basin. The conceptual LEM is not representative of the actual three-dimensional hydrostratigraphic sequence and hydrologic conditions existing at any specific site within the Columbia Plateau physiographic province. However, the LEM may be useful for gaining a better understanding of how the hydrologic regime may change as a result of disruptive events that may interact with a waste repository in geologic media.

INTRODUCTION

Repository simulation is one safety assessment approach to evaluating a potential release scenario for a nuclear waste repository in geologic media. Development of properly scaled, conceptually valid, repository simulation models are needed if reliable aqueous transport comparisons and conclusions are to be realized. Such models could provide insight on the significance of aqueous transport associated with potential disruptive phenomena interacting with a radioactive waste repository in geologic media. Many of the disruptive phenomena identified by the staff working on the Assessmnet of Effectiveness of Geologic Isolation Systems (AEGIS) program have hydrologic implications that are of local and/or regional hydrologic significance.

Subsurface hydrologic conditions in the Pacific Northwest are strongly controlled by the structural and stratigraphic framework of subregions. The subregions may encompass hundreds of square miles and are, therefore, large in comparison to the underground space required for a waste repository. The aquifer system or systems may be relatively small within a subregion, compared to the areal extent and volume of geologic media within the subregion. These geologic media can experience a change in state of stress (mechanical and/or hydraulic) due to regional forces. These forces might be imposed by some of the identified disruptive phenomena, such as glaciation, tectonic forces, igneous intrusion and volcanic extrusion.

The subsurface hydrology of the Pacific Northwest is a broad subject. It is briefly discussed below as an introduction to a more site-specific discussion which follows. A significant portion of the Pacific Northwest is underlain by the Columbia River Plateau basalt sequence. If a decision is made to locate a waste repository in the Pacific Northwest, it is reasonable to assume that such a repository may be located in this rock sequence and its associated hydrologic system or systems. Therefore, this discussion is limited to hydrologic conditions as they relate to the Columbia River Plateau physiographic province and specifically to the Pasco Basin in the central part of the province.

GENERAL GEOLOGIC AND SUBSURFACE HYDROLOGIC CONDITIONS

The Columbia River Plateau physiographic province is bounded by the Okanogan Highland to the north, the Clearwater Mountains to the east, the Blue Mountains to the south, and the Cascade Range to the west (Figure 1). This region is a broad structural basin. Its topographical and structural low points occur in the Pasco Basin near Pasco, Washington, in the central part of the Columbia Plateau. From the Pasco Basin, the plateau surface rises gently toward the surrounding highlands.

The geologic history of the Columbia Plateau can be traced back about 15 million years. McKee (1972) suggests that there is obviously a much older story in the rock record beneath the thick basalt sequence. However, geologists can only guess what the pre-Miocene geologic history may be by studying the older rocks that disappear under the basalt flows around the edge of the plateau; no significant windows have been eroded through the Columbia River basalt sequence. The bedrock does not consist entirely of basalt. Between at least some volcanic eruptions, rivers flowed out onto the flood basalt lava plain. They transported and deposited sediments along their course and into shallow lakes. Therefore, layers of sedimentary rock (sedimentary interbeds) occur between lava flows. Furthermore, these interbeds are the main aquifer zones in the basalt sequence of the Pasco Basin.

Strata of Pliocene age overlie the Miocene basalt sequence. The Pliocene strata consist mainly of stream and lake sediments which contain a few interbedded basalt flows. McKee (1972) states that large scale deformation of the region has occurred during the past ten million years. The Columbia River basalt sequence dips away from the surrounding mountains as a result of uplift of the ranges and sinking of the plateau. Many folds and minor faults have locally warped and, in some instances, broken the basalt flows.

The individual lava flows range in thickness from a few meters to over 50 meters. McKee (1972) states that the magma eruptions were not from a single vent but from very long fissures, each of which were many miles long. Therefore, an individual eruption was probably fed by many fissures transporting basaltic magma simultaneously. In the central part of the plateau, the

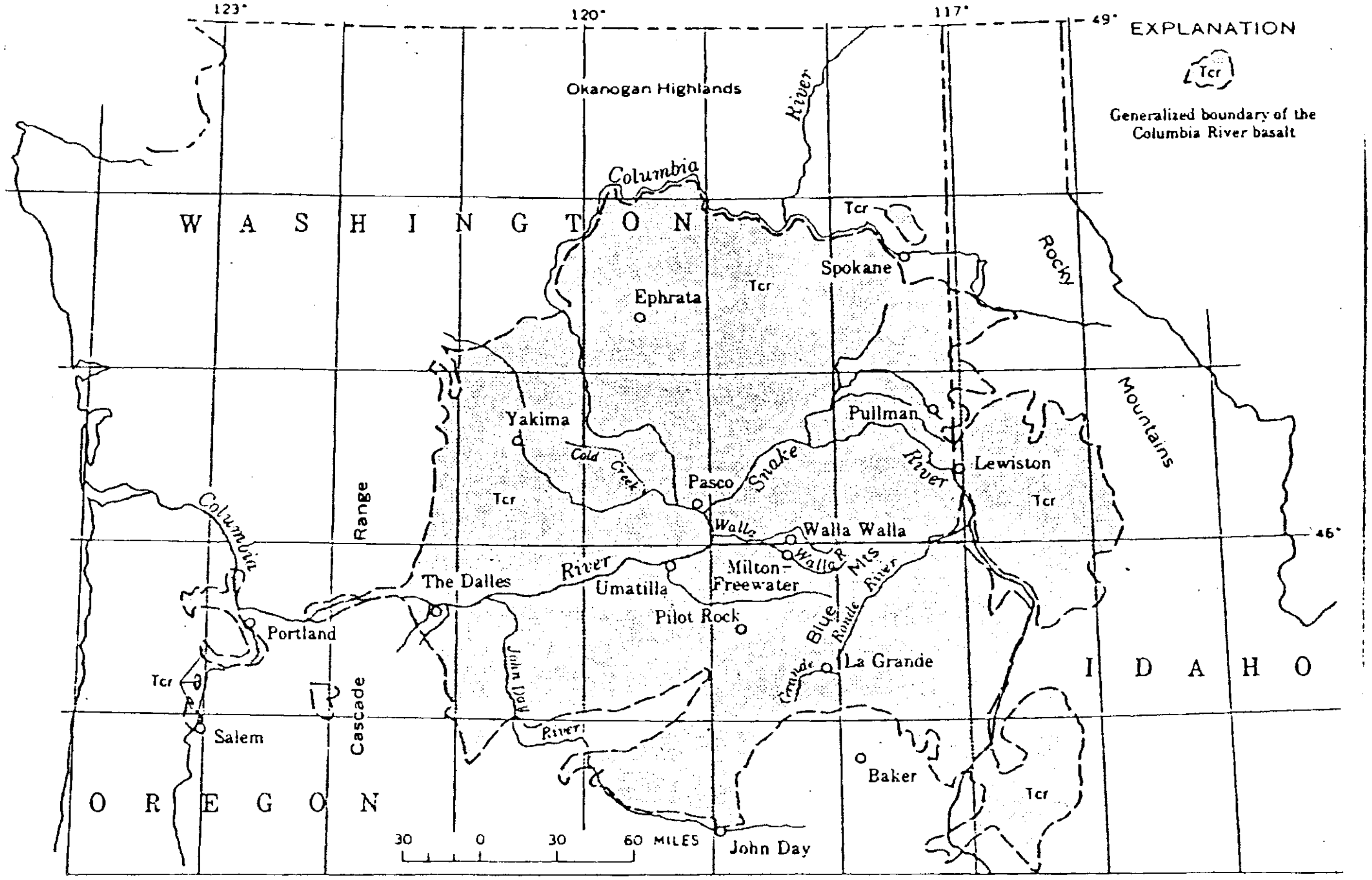


FIGURE 1. Map Showing the Main Area Underlain by the Columbia River Basalt, Washington, Oregon, and Idaho

Source: Newcomb 1961, Figure 1

basalt is known to be more than 3,000 meters thick (La Sala, 1971, 1973). It thins to a zero edge on older rocks at its margins. Newcomb (1961) states that the flows average about 50 feet in thickness, whereas McKee (1972) indicates that a "typical" flow is about 100 feet thick. Newcomb characterized an average flow as consisting of "dense, almost flint-like, partly fractured rock at its base; grades vertically to dense, massive columnar-jointed rock at its center; and then to vesicular - and in some places rubbly-rock at the top."

Systems of fractures cut the rock into irregular columnar, cubical, and platy blocks. These fractures and primary structures were formed when the lava was cooling. McKee (1972) suggests that a typical Columbia River basalt flow may have taken several decades to solidify completely. In each flow the lava crystallized from the bottom upward as well as from the top downward. Crystallization of a flow inward from the bottom and top surfaces may produce two distinct layers. In cliff exposures these two layers have been misinterpreted as two distinct flows. This two-part layering of a flow is shown schematically in Figure 2. The bottom part is known as the colonnade and the top is known as the entablature. These primary structures lead the casual observer to conclude that basalt flows are quite pervious, especially in the vertical plane, when seen at the surface. However, at depth, under the load of overlying rock, fractures are for the most part closed and may transmit little or no groundwater.

Newcomb (1961) has extensively studied the general occurrence and movement of groundwater in the Columbia Plateau. He has concluded that groundwater movement takes place mostly in the permeable zones in the tops of some flows. These permeable zones are about 1 to 3 meters thick. In places, where two permeable interflow zones are separated by a highly-jointed basalt with open joints, the thickness of a single water-bearing zone may be 10 meters or more. One of Newcomb's most pertinent observations is that the massive centers of some basalt flows are relatively impermeable, and in some places zones of rock consisting of several successive flows are tight and non-waterbearing. These impermeable zones can cause perched water bodies to occur above and below the regional water table. They may act as effective confining zones between water-bearing zones of different head.

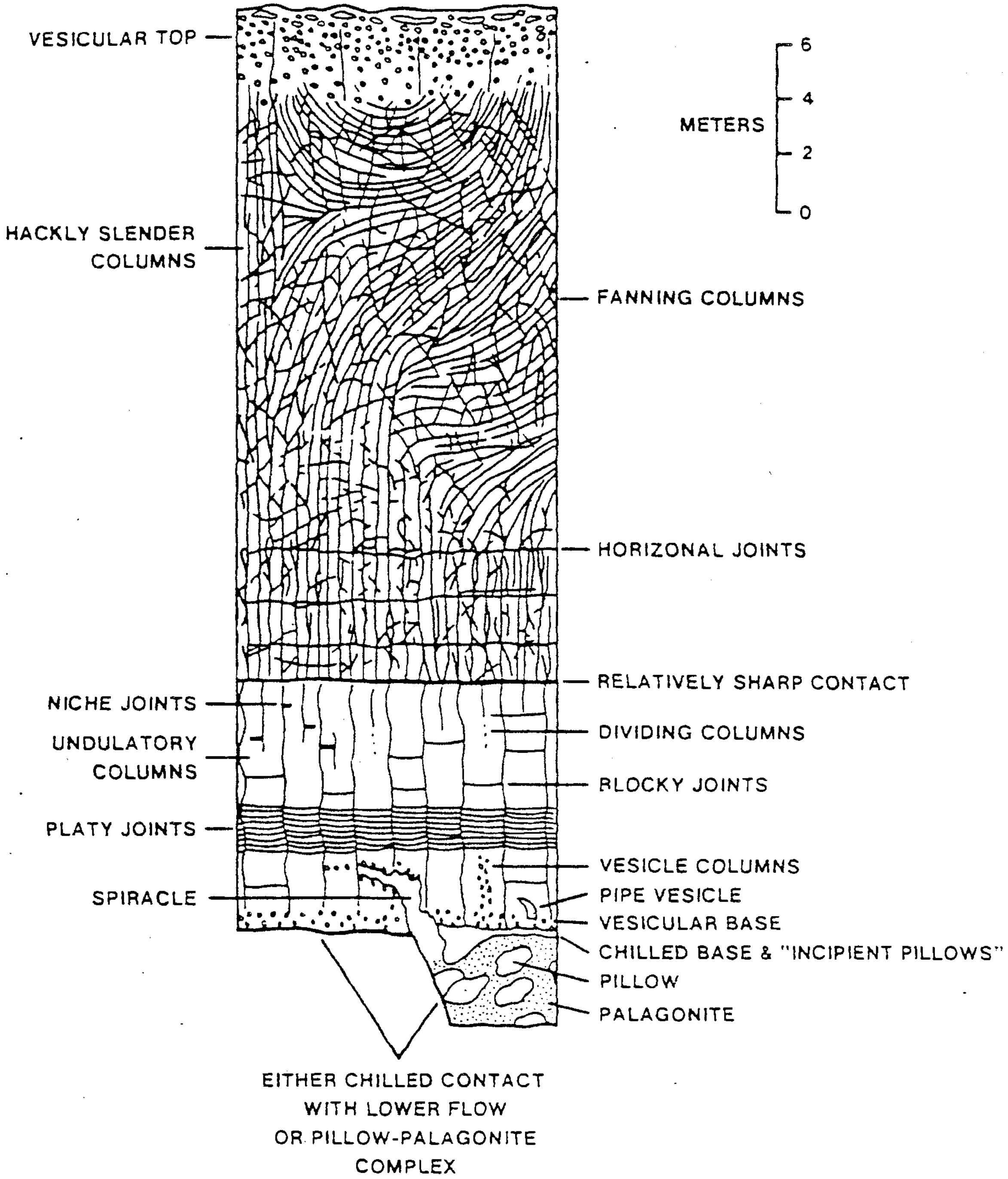


FIGURE 2. Schematic Diagram Showing Macrostructure of a Basalt Flow

Source: ARHCO 1976, Figure 5

Evidence to date suggests that, in general, the most permeable water-transmitting zones are sedimentary interbeds or permeable inter-flow zones involving the permeable and/or rubble bottom of a flow. Some of the sedimentary interbeds are the most prolific water-bearing units of areal extent known to occur. These occur at several horizons in the basalt sequence above the lower Yakima Basalt Formation, as defined by Ledgerwood (1976).

Newcomb's (1961) regional observations, in general, suggest that groundwater movement in the Columbia Plateau region is from upwarped anticlinal areas to downwarped synclinal areas. He notes that many of the highly productive wells in the Columbia River basalts occur in synclinal areas, such as those which occur at Walla Walla, Cold Creek, and Ephrata, Washington; the Dalles, Umatilla, and Pilot Rock, Oregon; and Lewiston, Idaho. Another structural control of regional and local significance observed by Newcomb (1961, 1969) is the fault-barrier boundary condition. The faults range from large shear fractures along which the rocks on opposite sides were displaced several thousand feet to small ones on which little displacement has occurred.

The large faults exist as zones of shattered and broken rock several tens or even hundreds of meters wide rather than as single planes. Smaller faults with displacements of a few meters are zones of sheared and shattered rock, according to Newcomb (1961). Most of the faults are of the normal displacement type.

The water-transmitting characteristics of the fault zones differ markedly from those of unbroken basalt. Fault fracturing may provide a zone of low permeability through which small quantities of water can move vertically. This vertical movement may be either up or down, depending on local head conditions. Permeable interflow zones and sedimentary interbeds, where present, transmit water laterally in a horizontal to sub-horizontal direction. Newcomb (1961) has shown in a number of instances that horizontal movement has been virtually eliminated by the fault zones. Thus, a fault zone may act as a barrier to otherwise normal lateral movement of groundwater from points of higher to lower head in the Columbia River basalt sequence. Barriers to lateral movement of groundwater can also occur along the axes of tight folds due to the disruption of permeable zones by the interflow grinding that accompanies bedding plane movement of one flow over another.

Intrusive dikes can also form barriers to lateral ground-water movement. Dikes are not as numerous as the structural barriers discussed above. However, they are known to occur. They are most effective as barriers when they occur transverse to the direction of lateral ground-water movement.

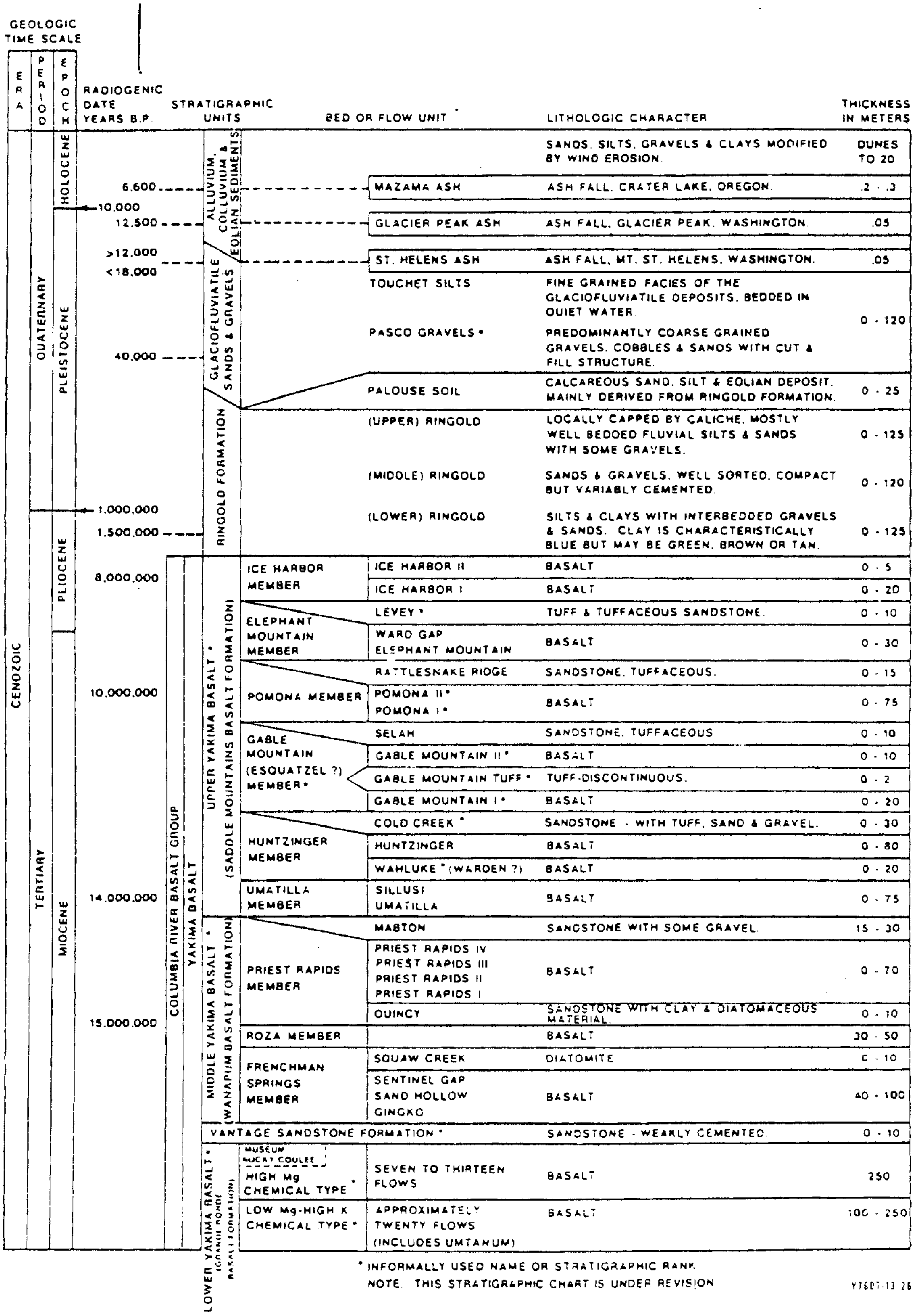
SUBSURFACE HYDROLOGIC CONDITIONS IN THE PASCO BASIN

The detailed hydrogeology of the Columbia Plateau is not well known. General hydrologic information below a depth of 500 meters in the basalt sequence is lacking throughout the Plateau except for the U.S. Department of Energy's (DOE) Hanford Site in the Pasco Basin. The information gained from hydrologic testing on and adjacent to the Hanford Site is discussed briefly below. The purposes of the discussion are: 1) to establish a conceptual layered earth model (LEM) for the types of strata present in the Pasco Basin to a depth of about 1,000 meters, and 2) to set some limits and ranges on the permeabilities and head differences that may be applicable for a generic transport modeling scheme of the LEM.

The stratigraphy of the Pasco Basin is summarized in Figure 3. A number of stratigraphic units are present. At a conceptual level, the stratigraphic sequence from the surface downward can be separated into four hydrostratigraphic systems. They are 1) the unsaturated zone, 2) the unconfined aquifer, 3) the uppermost confined aquifers, and 4) the lower Yakima basalt hydrologic sequence.

UNSATURATED ZONE (UZ)

The unsaturated zone (UZ) is the zone between the land surface and the water table. Perched water bodies may exist within the unsaturated zone. Its thickness at the Hanford Site ranges from less than one meter to more than 100 meters (ARHCO, 1976). The unsaturated zone consists of silt and sand deposits of eolian origin and sand and gravel deposits of glaciofluviatile origin. The moisture content of the unsaturated zone of the Hanford Site is very low. Any transport modeling coupling the unsaturated zone with the saturated zone should simulate two-phase fluid flow to analyze any waste release scenarios that involve the unsaturated zone.



GEOLOGIC TIME SCALE								
ERA	PERIOD	EPOCH	RADIOGENIC DATE YEARS B.P.	STRATIGRAPHIC UNITS		BED OR FLOW UNIT	LITHOLOGIC CHARACTER	THICKNESS IN METERS
CENOZOIC	QUATERNARY	HOLOCENE		ALLUVIUM, COLLUVIUM & EOLIAN SEDIMENTS			SANDS, SILTS, GRAVELS & CLAYS MODIFIED BY WIND EROSION.	DUNES TO 20
			6,600			MAZAMA ASH	ASH FALL, CRATER LAKE, OREGON.	.2 - .3
		PLEISTOCENE	10,000 12,500			GLACIER PEAK ASH	ASH FALL, GLACIER PEAK, WASHINGTON.	.05
			>12,000 <18,000	GLACIOFLUVIATILE SANDS & GRAVELS		ST. HELENS ASH	ASH FALL, MT. ST. HELENS, WASHINGTON.	.05
						TOUCHET SILTS	FINE GRAINED FACIES OF THE GLACIOFLUVIATILE DEPOSITS, BEDDED IN QUIET WATER.	0 - 120
			40,000			PASCO GRAVELS*	PREDOMINANTLY COARSE GRAINED GRAVELS, COBBLES & SANDS WITH CUT & FILL STRUCTURE.	
						PALOUSE SOIL	CALCAREOUS SAND, SILT & EOLIAN DEPOSIT. MAINLY DERIVED FROM RINGOLD FORMATION.	0 - 25
				RINGOLD FORMATION		(UPPER) RINGOLD	LOCALLY CAPPED BY CALICHE, MOSTLY WELL BEDDED FLUVIAL SILTS & SANDS WITH SOME GRAVELS.	0 - 125
						(MIDDLE) RINGOLD	SANDS & GRAVELS, WELL SORTED, COMPACT BUT VARIABLY CEMENTED.	0 - 120
	TERTIARY	PLIOCENE	1,000,000 1,500,000			(LOWER) RINGOLD	SILTS & CLAYS WITH INTERBEDDED GRAVELS & SANDS. CLAY IS CHARACTERISTICALLY BLUE BUT MAY BE GREEN, BROWN OR TAN.	0 - 125
			8,000,000	COLUMBIA RIVER BASALT GROUP YAKIMA BASALT UPPER YAKIMA BASALT* (SADDLE MOUNTAINS BASALT FORMATION)	ICE HARBOR MEMBER	ICE HARBOR II	BASALT	0 - 5
						ICE HARBOR I	BASALT	0 - 20
					ELEPHANT MOUNTAIN MEMBER	LEVEY*	TUFF & TUFFACEOUS SANDSTONE.	0 - 10
		MIOCENE				WARD GAP ELEPHANT MOUNTAIN	BASALT	0 - 30
					POMONA MEMBER	RATTLESNAKE RIDGE	SANDSTONE, TUFFACEOUS.	0 - 15
			10,000,000			POMONA II* POMONA I*	BASALT	0 - 75
					GABLE MOUNTAIN (ESQUATZEL ?) MEMBER*	SELAH	SANDSTONE, TUFFACEOUS	0 - 10
						GABLE MOUNTAIN II*	BASALT	0 - 10
						GABLE MOUNTAIN TUFF*	TUFF-DISCONTINUOUS.	0 - 2
						GABLE MOUNTAIN I*	BASALT	0 - 20
					HUNTZINGER MEMBER	COLD CREEK*	SANDSTONE - WITH TUFF, SAND & GRAVEL.	0 - 30
						HUNTZINGER	BASALT	0 - 80
						WAHLUKE* (WARDEN ?)	BASALT	0 - 20
			14,000,000		UMATILLA MEMBER	SILLUSI UMATILLA	BASALT	0 - 75
				MIDDLE YAKIMA BASALT* (WANAPUM BASALT FORMATION)	PRIEST RAPIDS MEMBER	MABTON	SANDSTONE WITH SOME GRAVEL.	15 - 30
						PRIEST RAPIDS IV PRIEST RAPIDS III PRIEST RAPIDS II PRIEST RAPIDS I	BASALT	0 - 70
			15,000,000			QUINCY	SANDSTONE WITH CLAY & DIATOMACEOUS MATERIAL.	0 - 10
					ROZA MEMBER		BASALT	30 - 50
					FRENCHMAN SPRINGS MEMBER	SQUAW CREEK	DIATOMITE	0 - 10
						SENTINEL GAP SAND HOLLOW GINGKO	BASALT	40 - 100
				VANTAGE SANDSTONE FORMATION*			SANDSTONE - WEAKLY CEMENTED.	0 - 10
				LOWER YAKIMA BASALT* (GRANDE RONDE BASALT FORMATION)	MUSEUM ROCKY COULEE HIGH Mg CHEMICAL TYPE*	SEVEN TO THIRTEEN FLOWS	BASALT	250
					LOW Mg-HIGH K CHEMICAL TYPE*	APPROXIMATELY TWENTY FLOWS (INCLUDES UMTANUM)	BASALT	100 - 250

* INFORMALLY USED NAME OR STRATIGRAPHIC RANK

NOTE. THIS STRATIGRAPHIC CHART IS UNDER REVISION

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FIGURE 3. Stratigraphy of the Pasco Basin

Source: ARHCO 1976, Figure 6

UNCONFINED AQUIFER SYSTEM (UAS)

The unconfined aquifer system (UAS) consists of sand and gravel deposits (Pasco Gravels) of glaciofluviatile origin. These deposits rest unconformably on an interbedded sequence of fluvial silts, sands, and some gravels (upper Ringold Formation) which are locally capped by caliche. These deposits are underlain by variably cemented sand and gravel units (middle Ringold Formation). The top of the aquifer at any given time is the water table. The base of the aquifer may be either the top of the basalt bedrock or the silt and clay zones of the lower Ringold Formation. In places, glaciofluviatile gravel may lie directly on basalt. In such cases, the top of the unconfined aquifer may be in the glaciofluviatile gravel.

The hydraulic characteristics of the unconfined aquifer system are quite variable. This variability is a result of the heterogeneous nature of the aquifer materials in three-dimensional space. The range in the hydraulic conductivity of the unconfined aquifers is summarized in Table 1. Very large hydraulic conductivity values are only representative for the open lattice work gravel strata of the glaciofluviatile deposits.

Natural recharge of the aquifer occurs at the foot of Rattlesnake Hills and Yakima Ridge and by vertical leakage from the underlying uppermost confined aquifer system. Artificial recharge occurs from waste disposal ponds on the Hanford Site. The Yakima River recharges the unconfined aquifer along its reach from Horn Rapids to Richland (ARHCO, 1976). Natural discharge from the aquifer occurs along the Columbia River.

UPPERMOST CONFINED AQUIFER SYSTEM (UCAS)

The uppermost confined aquifer (UCAS) consists of: 1) the sands and gravels of the lower Ringold Formation; 2) the sedimentary interbeds of the upper and middle Yakima basalt sequence; and 3) permeable interflow zones in the top few meters of some flow units. Seven sedimentary interbeds are known to exist in the upper and middle Yakima basalt sequence in the Pasco Basin (Figure 3). The range in the hydraulic conductivity of the UCAS is summarized in Table 2.

TABLE 1. Hydraulic Conductivity of the Unconfined Aquifer Material

Interval Tested	Hydraulic Conductivity ft/day	Hydraulic Conductivity m/day
Glaciofluviatile	500-20,000	150 -5,100
Glaciofluviatile and Ringold	100- 1,000	30 - 300
Ringold (including clay)	1- 200	0.3- 60

Source: ARHCO, 1976; Table 2

TABLE 2. Hydraulic Conductivity of the Uppermost Confined Aquifers

Well Number	Hydraulic Conductivity ft/day	Hydraulic Conductivity m/day
LOWER RINGOLD		
699-84-35P	0.11	0.03
699-24-1P	5	1.5
699-S11-E12	0.5	0.15
699-20-E12P	7	2.1
Mean	3	0.91
Range	0.11-7	0.03-2.1
RATTLESNAKE RIDGE		
199-B3-2P	0.25	0.08
199-H4-2	0.3	0.09
699-14-E6Q	30	9.1
Mean	10	3.0
Range	0.25-30	0.08-9.1
MABTON		
DH-8 Range	20-60	5.0-20.0

Source: ARHCO, 1976; Table 3

Note: The porosity for the uppermost confined aquifers ranges between 0.3 and 0.4 (30 to 40%). The vertical hydraulic conductivity in the interbeds ranges between 5 x 10^{-4} m/day and 20 x 10^{-4} m/day. The storage coefficient approaches the compressibility of water.

The UCAS is known to be hydraulically interconnected at places in the Pasco Basin with the overlying unconfined aquifer. This interconnection occurs where the basalt units have been extensively deformed by folding and differential erosion, such as along major anticlinal axes. Near such folded areas, the basalt flows dip steeply away from the axial plane of the anticline. The ancestral Columbia River deeply eroded away portions of the unconfined aquifer and steeply dipping segments of the uppermost confined aquifer units prior to the deposition of younger strata. Therefore, the hydrologic data collected to date suggest that the unconfined aquifer and the the uppermost confined aquifer appear to be in hydraulic equilibrium (ARHCO 1976). Recharge to the UCAS appears to occur at the ridges and plateaus fringing the Pasco Basin. The eastern third of the Hanford Site appears to be a discharge area for this aquifer system.

LOWER YAKIMA BASALT HYDROLOGIC SYSTEM (LYBHS)

The hydrology of the lower Yakima Basalt sequence is of utmost importance in assessing the hydrologic suitability of a localized, permanent waste-isolation repository in geologic media of the Pasco Basin. The Vantage Sandstone Formation of Figure 3 is the lowermost sedimentary interbed of areal extent known to exist in the Pasco Basin. It separates the lower Yakima Basalt sequence from the overlying middle Yakima Basalt sequence. Approximately 300 meters below the Vantage Sandstone horizon is a basalt interval ("Umtanum") of special interest. Cores and geophysical logs on this interval suggest that it is a very tight, dense, glassy basalt flow that is about 60 meters thick.

Direct measurements of head were first obtained in 1969, in discrete water-bearing zones in Well ARH-DC-1 on the Hanford Reservation (ARHCO 1976). These measurements are summarized in Figure 4. They show that the intervals tested in the lower Yakima Basalt sequence from a depth of about 915 to 1310 meters tend to either have the same head as intervals tested above the "Umtanum" flow unit (depth of 915 meters) or slightly lower heads.

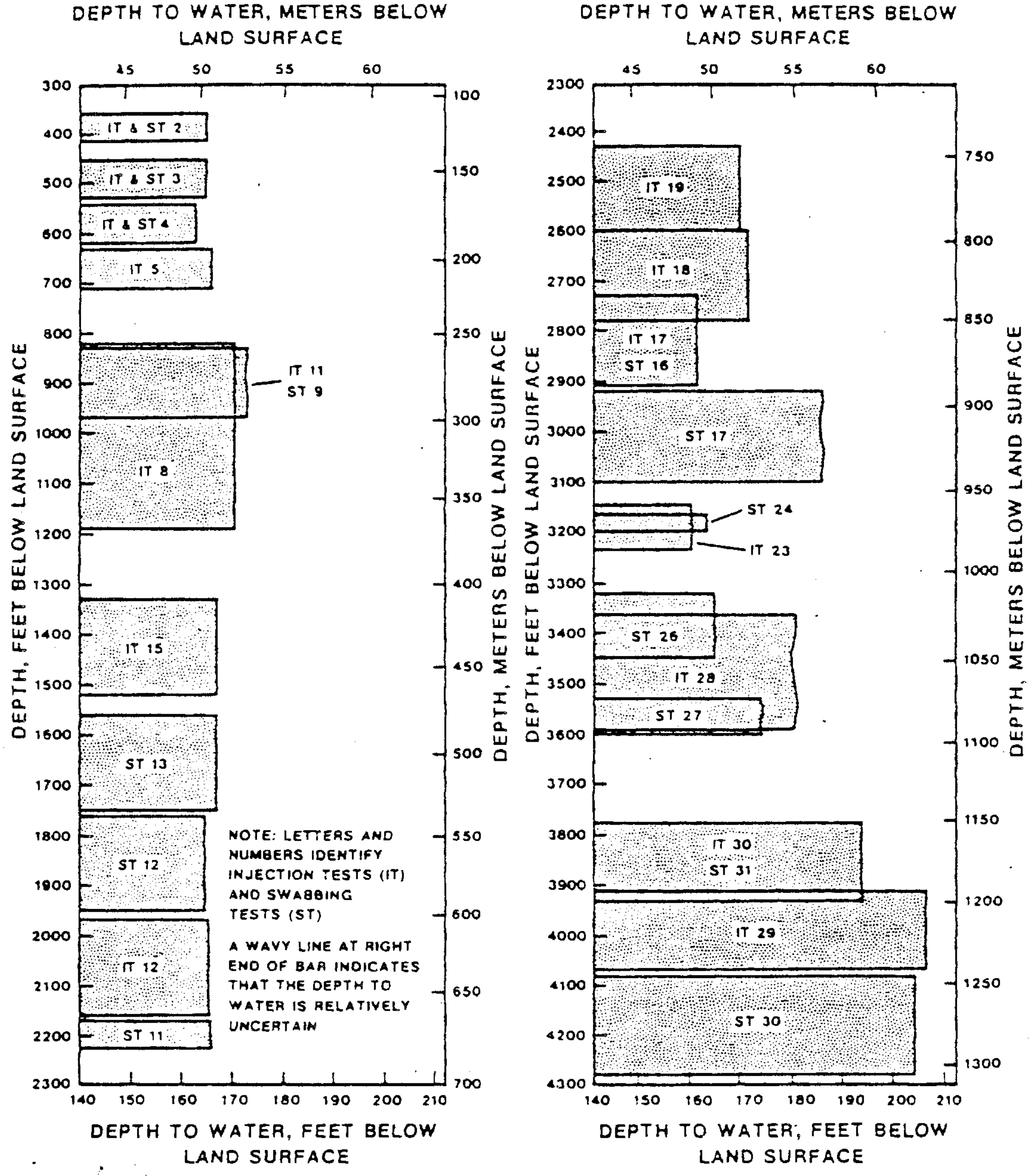


FIGURE 4. Approximate Undisturbed Groundwater Head for Isolated Water-bearing Zones in Well ARH-DC-1 (1969)

Source ARHCO 1976, Figure 10

TABLE 3. Range of Hydrologic Properties of Lower Yakima Basalt Flows and Interbeds

	Hydraulic Conductivity		Effective Porosity *	Storage Coefficient
	ft/day	m/day	Dimensionless	Dimensionless
Dense basalt	$1x10^5$ -$3x10^3$	$3x10^{-6}$-$9x10^{-4}$	0.1-1	$1x10^{-5}$-$1x10^{-6}$
Vesicular basalt	$1x10^{-3}$-$1x10^{-2}$	$3x10^{-4}$-$3x10^{-3}$	5	$1x10^{-4}$
Fractured, weathered or brecciated basalt	$3x10^{-3}$-5	$3x10^{-4}$-1.5	10	$1x10^{-3}$
Interbed	$3x10^{-3}$-10	$9x10^{-4}$-3	20	$1x10^{-2}$

---

* Volume percent

Source: ARHCO 1976, Table 5

TABLE 4. Summary Record of Depths to Water Below the Land Surface in Feet and Meters for Piezometers in ARG-DC-1

Measurement Date	Piezometer Tube									
	1		2		3		4		5	
	ft	m	ft	m	ft	m	ft	m	ft	m
06/09/72	157.33	49.95	158.03	48.16	158.39	48.28	141.37	43.09	163.00	49.68
07/06/72	157.05	47.87	157.71	48.07	158.10	48.19	142.33	43.38	162.82	49.63
07/13/72	157.02	47.86	157.63	48.05	158.00	48.16	143.40	43.71	162.94	49.66
07/20/72	156.91	47.83	157.50	48.01	157.90	48.13	144.24	43.96	163.00	49.68
08/10/72	157.07	47.87	158.00	48.16	158.38	48.27	146.42	44.63	162.78	49.62
08/17/72	157.34	47.96	158.21	48.22	158.58	48.34	147.18	44.86	162.88	49.65
08/24/72	157.27	47.94	158.00	48.16	158.42	48.29	148.28	45.20	162.30	49.47
08/30/72	157.45	47.99	158.17	48.21	158.52	48.32	148.28	45.20	162.30	49.47
09/07/72	157.25	47.93	157.88	48.12	158.26	48.24	148.81	45.36	162.81	49.62
09/21/72	156.97	47.84	157.57	48.03	157.94	48.14	149.69	45.63	162.83	49.63
09/28/72	157.52	48.01	157.75	48.08	158.07	48.18	150.29	45.81	163.06	49.70
10/05/72	157.36	47.96	157.88	48.12	158.25	48.23	150.80	45.96	163.22	49.75
12/30/74	155.73	47.47	156.26	47.63	156.67	47.75	158.90	48.43	162.56	49.55
04/18/75	155.28	47.33	155.60	47.43	156.35	47.66	163.70	49.90	162.24	49.45
09/03/75	155.39	47.36	155.69	47.45	156.44	47.68	164.08	50.01	162.30	50.69
12/16/75	155.59	47.42	155.47	47.39	156.50	47.70	164.96	50.28	163.37	49.80

Source: ARHCO 1976, Table 6

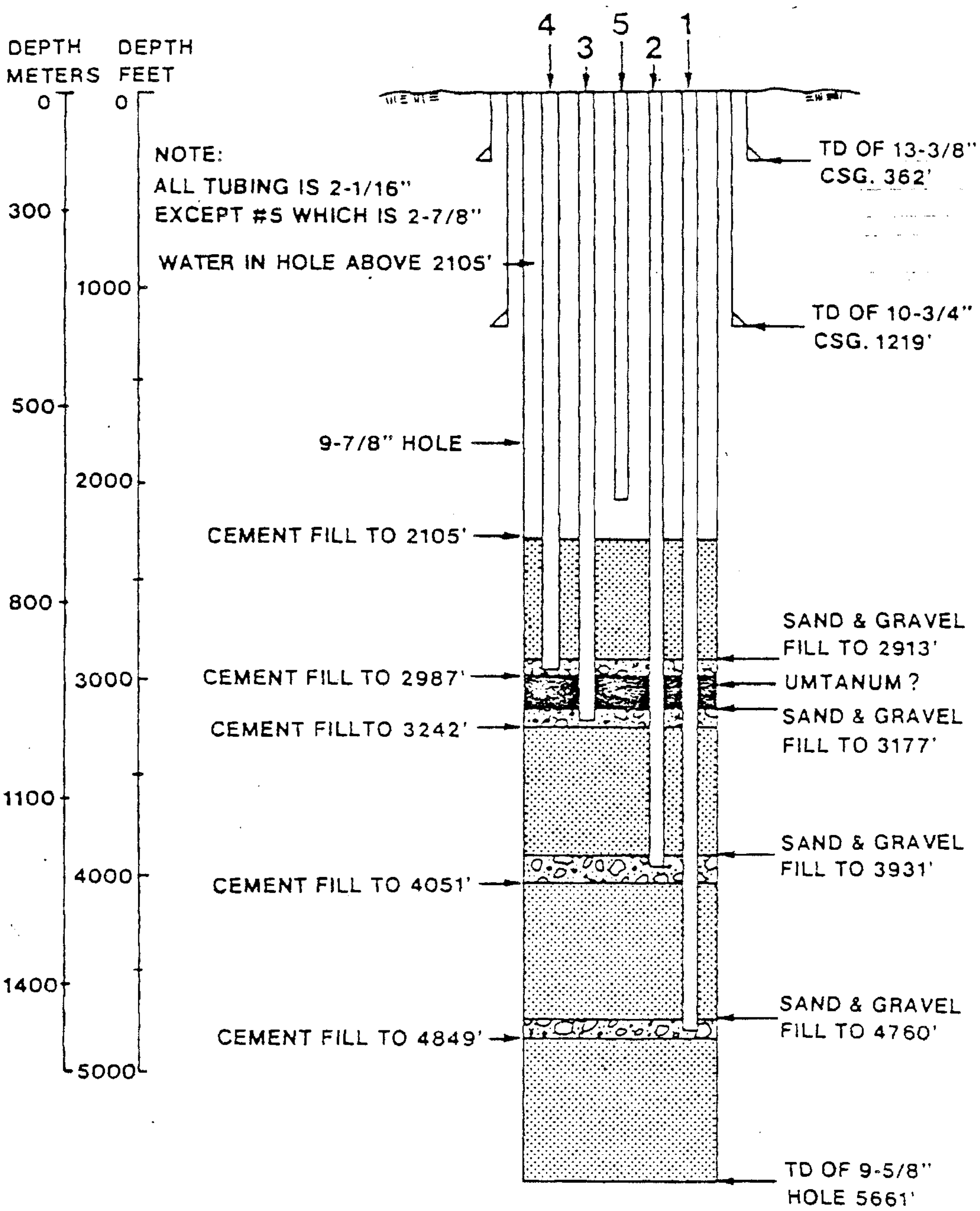


FIGURE 5. Piezometers Installed in ARH-DC-1

Source: ARHCO 1976, Figure 11

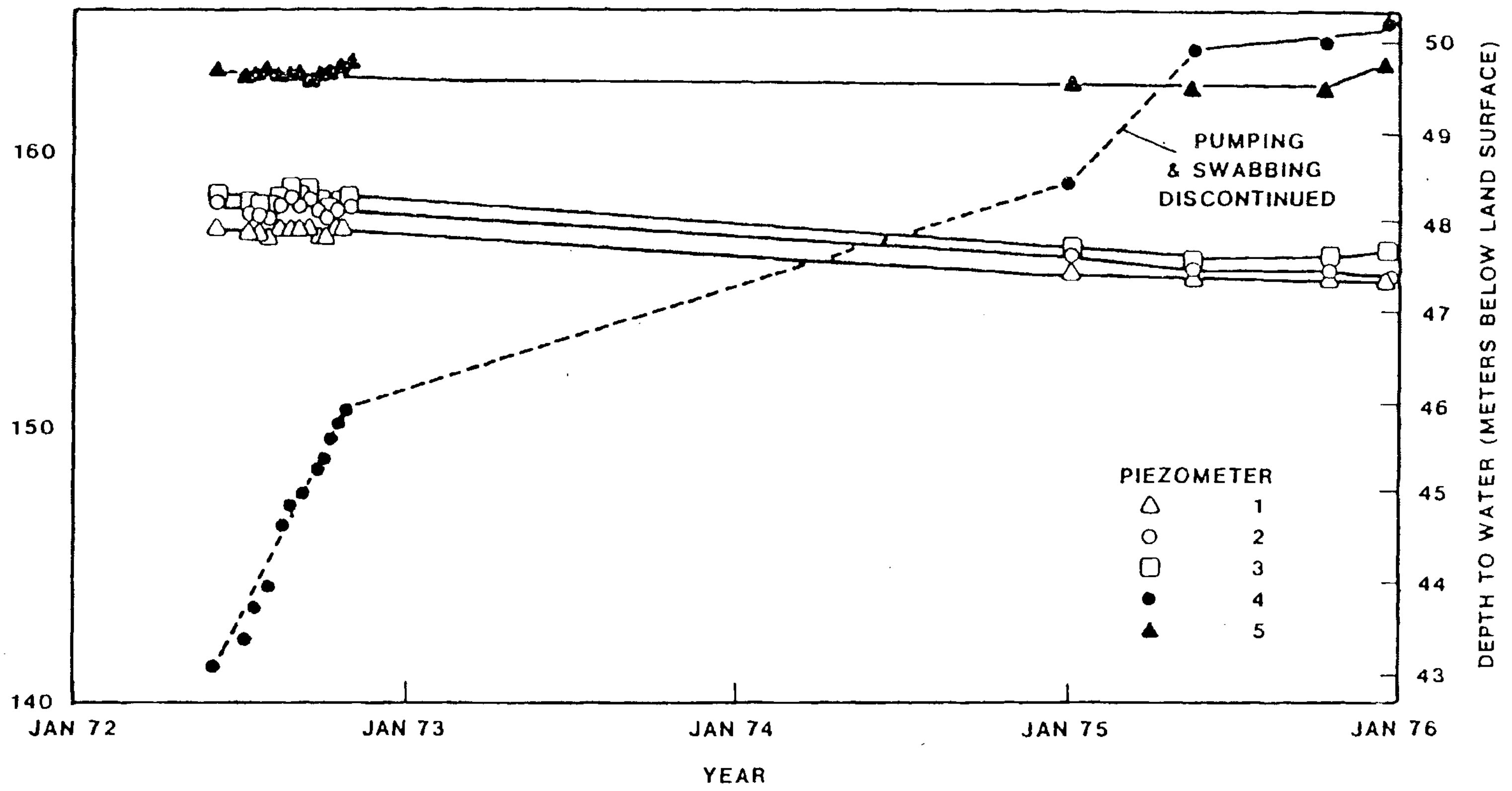


FIGURE 6. Hydrographs of Depths to Water Below the Lava Surface in Feet and Meters for Piezometers in ARH-DC-1

Source: ARHCO 1976, Figure 12

Swabbing and injection tests were conducted by the USGS in Well ARH-DC-1 to determine the transmissivity and storage coefficient of selected intervals downhole (ARHCO 1976). Laboratory analyses on five core samples from the lower Yakima Basalt sequence were obtained. The results of the injection tests are given in Table 3. These data combined with lithologic data allow definition of the hydraulic characteristics of the four principal lithologic types found in the lower Yakima Basalt sequence of the Pasco Basin.

In 1972, five isolated piezometers (Figures 5 and 6) were installed in Well ARH-DC-1. Water-level measurements in these piezometers are summarized in Figure 6 and Table 4. These results suggest that a potential hydraulic interconnection of the basalt and interbeds probably exists above a depth of 915 meters (upper confined flow regime). The flow regimes below 970 meters appear to be connected down to a depth of at least 1480 meters (lower confined flow regime). The "Umtanum" flow unit separates these two hydraulic flow regimes. It would appear that the difference in head between the upper and lower flow regimes is presently about 2 meters, with the potential flow direction being apparently from the lower confined to the upper confined flow regime.

Very little is known about the direction and movement of groundwater through the lower Yakima basalt sequence and its contained interbeds. However, ground-water movement in these deep rock sequences should be influenced by primary and secondary basalt flow solidification structures and tectonic structures, chiefly fractures (joints and faults). Newcomb (1961) has shown that faults can be very effective ground-water flow barriers of regional significance within the Columbia River Plateau physiographic province.

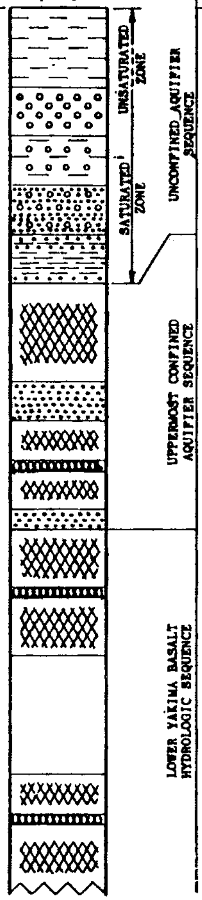
LAYERED EARTH MODEL

The conceptual layered earth model (LEM) represents the major types of porous media (LEM units) that may be encountered at a number of places on the Columbia Plateau, and specifically in the Pasco Basin. The purpose of the LEM is to provide a basis for gauging the effect that disruptive event phenomena of a geologic nature might have on a radioactive waste repository in geologic media of the Columbia Plateau physiographic province. The conceptual LEM is not representative of the actual three-dimensional hydrostratigraphic sequence and hydrologic conditions existing at any specific site within the Columbia Plateau physiographic province. However, the LEM may be useful for gaining a better understanding of how the hydrologic regime, and specifically transport rates, may change as a result of disruptive events that may interact with a waste repository in geologic media.

A conceptual LEM is presented on Figure 7, and Figure 8 summarizes the estimated range in horizontal hydraulic conductivity for various LEM units. The model consists of 18 layers. It does not represent the minimum or maximum number of layers that might be involved in a Columbia Plateau repository site. However, it shows the degree of complexity that is known to exist in the vertical plane.

The estimated range in the hydraulic conductivity of each LEM unit is based on cursory field data acquired at the Hanford Site (ARHCO 1976).

The range in the vertical hydraulic conductivity of the various LEM units is not well known. However, it appears reasonable to assume that the vertical hydraulic conductivity of a specific LEM unit is at least one order of magnitude and possibly two orders of magnitude less than the horizontal hydraulic conductivity. This conclusion is probably not applicable to some of the thinner basalt flows that have a well developed colonnade section; i.e., the vertical permeability may be considerably higher than the horizontal permeability where the depth of burial is relatively shallow.

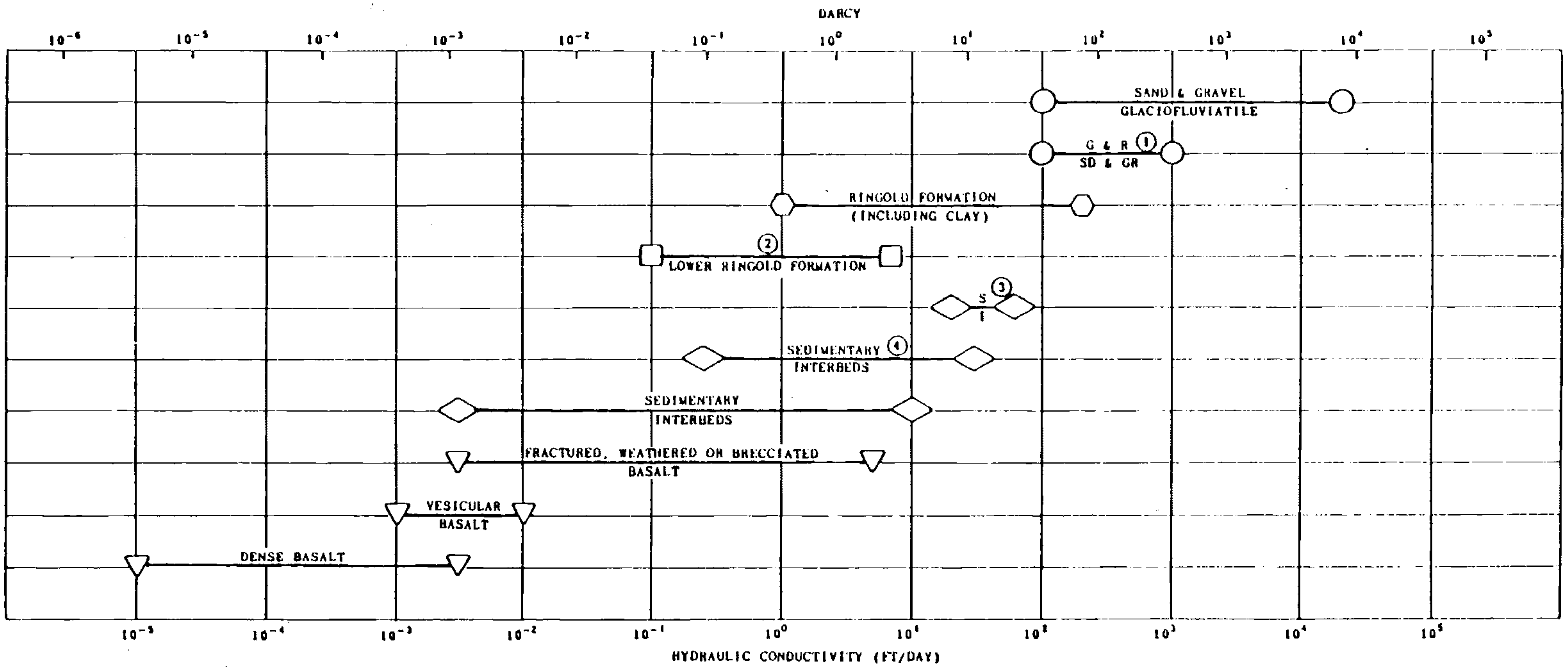


GENERAL LITHOLOGY	LEM UNIT NUMBER	LEM LAYER THICKNESS (METERS)	K_H HORIZONTAL HYDRAULIC CONDUCTIVITY FEET/DAY FROM	TO	DARCY FROM	TO	K_V VERTICAL HYDRAULIC CONDUCTIVITY FEET/DAY FROM	TO	DARCY FROM	TO
SILT & SILTY SAND	①	40	10^{-1}	10	$3.64x10^{-2}$	3.64	K_V IS ESTIMATED TO BE 1 TO 2 ORDER OF MAGNITUDE LESS THAN THE ESTIMATED HORIZONTAL HYDRAULIC CONDUCTIVITY CONDUCTIVITY (K_H)			
SAND & GRAVEL	②	25	10^2	10^4	$3.64x10^1$	$3.64x10^3$				
INTERBEDDED SILT, SAND & GRAVEL	③	25	10^{-1}	10^2	$3.64x10^{-2}$	$3.64x10^1$				
CEMENTED SAND & GRAVEL	④	25	1	10^2	$3.64x10^{-1}$	$3.64x10^1$				
CLAY & SILT WITH INTERBEDDED SAND & GRAVEL	⑤	25	10^{-2}	$5x10^1$	$3.64x10^{-3}$	$1.82x10^1$				
FRACTURED & VESICULAR BASALT	⑥	50	10^{-3}	1	$3.64x10^{-4}$	$3.64x10^{-1}$	$<10^{-3}$	>1	$<3.64x10^{-4}$	$<3.64x10^{-1}$
SEDIMENTARY INTERBED	⑦	30	10^{-1}	10^2	$3.64x10^{-2}$	$3.64x10^1$	$K_V=(0.01$ TO $0.1)K_H$			
FRACTURED & VESICULAR BASALT	⑧	20	10^{-3}	1	$3.64x10^{-4}$	$3.64x10^{-1}$	SAME AS UNIT ⑥			
FRACTURED & WEATHERED BASALT FLOW TOP	⑨	3	10^{-2}	10	$3.64x10^{-3}$	3.64				
FRACTURED & VESICULAR BASALT	⑩	20	10^{-3}	1	$3.64x10^{-4}$	$3.64x10^{-1}$	SAME AS UNIT ⑥			
SEDIMENTARY INTERBED	⑪	10	10^{-2}	10	$3.64x10^{-3}$	3.64	$K_V=(0.01$ TO $0.1)K_H$			
FRACTURED & VESICULAR BASALT	⑫	30	10^{-3}	1	$3.64x10^{-4}$	$3.64x10^{-1}$	SAME AS UNIT ⑥			
FRACTURED & WEATHERED BASALT FLOW TOP	⑬	2	10^{-2}	10	$3.64x10^{-3}$	3.64				
FRACTURED & VESICULAR BASALT	⑭	30	10^{-3}	1	$3.64x10^{-4}$	$3.64x10^{-1}$	SAME AS UNIT ⑥			
DENSE BASALT	⑮	60	10^{-5}	10^{-3}	$3.64x10^{-6}$	$3.64x10^{-4}$	10^{-5}	10^{-3}	$3.64x10^{-6}$	$3.64x10^{-4}$
FRACTURED & VESICULAR BASALT	⑯	20	10^{-3}	1	$3.64x10^{-4}$	$3.64x10^{-1}$	SAME AS UNIT ⑥			
FRACTURED & WEATHERED BASALT FLOW TOP	⑰	5	10^{-2}	10	$3.64x10^{-3}$	3.64	$K_V=(0.1)K_H$			
FRACTURED & VESICULAR BASALT	⑱	35+	10^{-3}	1	$3.64x10^{-4}$	$3.64x10^{-1}$	SAME AS UNIT ⑥			

NOTE: K_V IS GREATLY INFLUENCED BY FRACTURE GEOMETERY, BURIAL DEPTH, AND DEGREE OF FRACTURE CLOSURE BY MINERAL DEPOSITS.

NOTE: LEM IS NOT DRAWN TO SCALE, ACTUAL NUMBER OF LEM UNITS PER AQUIFIER SEQUENCE ARE NOT SHOWN. SEE FIGURE 3 FOR DETAILS ON APPROXIMATE NUMBER OF BASALT FLOW UNITS AND SEDIMENTARY INTERBEDS.

FIGURE 7. LEM Model



SOURCE: ARH-ST-137

NOTES:

1. G&R (PASCO GRAVELS AND RINGOLD GRAVELS)
2. MAINLY CLAY AND SILT WITH INTERBEDDED SAND & GRAVEL
3. MABTON SEDIMENTARY INTERBED
4. RATTLESNAKE RIDGE SEDIMENTARY INTERBED

FIGURE 8. Generalized Range of Horizontal Hydraulic Conductivity for Several Rock Types in Pasco Basin

Source: ARHCO 1976

Some of the basalt flows are highly jointed. Field and rock core evidence, however, suggest that some of these flows may be impervious to water. Inspection of basalt joints and fractures show that secondary minerals, predominantly clays such as beidellite and nontronite, fill the joints and other fractures, effectively sealing them (ARHCO 1976). Newcomb (1961) has observed at other places on the Columbia Plateau that "the massive centers of some flows are relatively impermeable, and in places thick zones of the rock consist of several successive flows which are tight and non-waterbearing." He also observed that "above the water table, these impermeable zones cause water to be perched, and below that level, in places, they cause the water-bearing zones to have no hydraulic continuity and, therefore, to have different water-pressure levels."

Hydraulic head relationships between the unconfined aquifer system (UAS), uppermost confined aquifer system (UCAS), and the lower Yakima Basalt hydrologic system (LYBHS) are known in a general way. The potentiometric surface of the UCAS ranges from less than 1 meter to about 4 meters higher than the potentiometric surface of the overlying UAS (ARHCO 1976). For initial modeling purposes, it is recommended that head differences ranging from 1 to 10 meters be considered for these two aquifer sequences. The flow potential should be from the UCAS to the UAS. The potentiometric surface of the LYBHS is about 2 meters higher than in the overlying UCAS. Therefore, the apparent potential for flow is from the LYBHS to the UCAS. Because the head relationships of these two aquifer systems may be reversed at specific sites, it is recommended for initial modeling purposes that head fluctuation ranging from 1 to 10 meters be considered, with comparative runs for flow from the LYBHS to the UCAS and from UCAS to the LYBHS.

The above outlined head relationships and estimated ranges in head are based on preliminary data reported for the Hanford Site (ARHCO 1976). The actual head relationships existing at other sites or in other regions of the Columbia Plateau may be considerably different than suggested for the Pasco Basin.

The hydraulic gradient in the UAS ranges from about 1 meter to 10 meters per mile throughout the Pasco Basin. This gradient is highest near recharge sources, such as the waste disposal ponds of the 200 West and East area of the Hanford Site . A more in-depth discussion of the flow regime in the UAS is given by Newcomb et al. (1972). The hydraulic gradient in the UCAS is less well known than for the UAS. The range in the hydraulic gradient is probably less, in general, than stated above for the UAS; however, it may be greater near the edge of the Pasco Basin (recharge area) and the Columbia River (discharge area).

Little is known about the hydraulic gradient of the LYBHS. It is probably very low in the central part of the Pasco Basin. For initial modeling simulation runs, a hydraulic gradient range of 0.1 to 1 meter per mile is probably the correct order of magnitude.

FUTURE CONSIDERATIONS FOR THE AEGIS PROGRAM

An initial objective of the AEGIS program was to develop a basalt repository simulation LEM which could be applied to different sites on the Columbia Plateau physiographic province. Careful thought should be given to developing site-specific LEMs. Potential sites on the Hanford Site may require site-specific Pasco Basin LEMs. A valid comparison of the simulated results between these site-specific LEMs may be possible. However, a valid comparison of these site-specific LEM results for the Pasco Basin with some other structural basin within the Columbia Plateau may not be possible, using the idealized generic model approach that has been pursued thus far.

Most ground-water flow transport models in use are two-dimensional, and they treat the porous media (LEM units) as isotropic, homogeneous bodies with respect to their hydraulic characteristics. The anisotropic permeability distribution of most of the LEM units necessitates that further consideration be given to developing three-dimensional, anisotropic site-specific transport models.

Continued research should focus on: 1) selecting the best possible transport model current technology can provide; 2) applying the model to site-specific LEMs for providing preliminary comparisons; and 3) support of basic research directed towards the aqueous transport of radionuclides in anisotropic, heterogeneous media (specifically, the Columbia River basalt sequence). Recently, Streltsova-Adams (1978) discussed the problems associated with well hydraulics in heterogeneous aquifer formations, namely fractured media.

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