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Hydrology of the Separations Area

M.J. Graham

Environmental Technologies Group

Environmental Analysis and
Monitoring Department

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Prepared for the United States
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HYDROLOGY OF THE SEPARATIONS AREA

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July 1981

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ABSTRACT

The unconfined aquifer underlying the Separations Area is contained within the Ringold and Hanford formations. Hydraulic conductivity ranges from 3 to 3,000 meters/day (9 to 10,000 feet/day), storage coefficients range from 0.002 to 0.07. The higher values are associated with the Hanford formation, the lower values with the Ringold formation. A textural unit near the bottom of the aquifer acts as a separate confined aquifer. Measured anisotrophy values range from 13 to 16.

Artificial recharge from liquid waste disposal is estimated at 10 times the natural recharge to the Separations Area. The artificial recharge has created large ground-water mounds under U Pond and B Pond and induced two artificial flow systems. Horizontal gradients resulting from the ground-water mounds are up to 10 meters/kilometer (50 feet/mile); downward vertical gradients are as high as 10%. Travel time estimates from 200 West Area to the Columbia River range from 80 to 120 years.

The prevalent chemical character of the aquifer is calcium bicarbonate. Sodium bicarbonate and calcium sulfate waters are also present. Contamination plumes indicate directions of flow to the east and southeast.

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EXECUTIVE SUMMARY

The major radioactive waste storage and disposal facilities on the Hanford Site are located within the Separations Area. Hydrologic characterization of this area is necessary to effectively monitor the ground water for possible contamination from liquid waste disposal sites, and to predict the impacts of changes in liquid waste disposal practices on the environment. The purpose of this document is to integrate present knowledge on the hydrology of the Separations Area and to hydrologically characterize the area.

An understanding of the unconfined aquifer underlying the Separations Area is necessary for effective waste management. The unconfined aquifer is contained within the Ringold formation, a sedimentary unit; and the Hanford formation, a glaciofluvial deposit overlying the Ringold. In 200 West Area the aquifer is in the Ringold formation, in 200 East Area the aquifer extends into the Hanford formation. The hydraulic conductivity and storativity values, parameters that indicate the aquifer's ability to transmit and store water, are over an order of magnitude higher for the Hanford formation than the Ringold. Thus ground-water flow is much slower from 200 West Area than 200 East Area.

The total volume of water added to the aquifer per year by liquid waste disposal to the ground is approximately 10 times the natural inflow to the area from precipitation and irrigation waters infiltrating to the west. Percolating water from U-Pond and B-Pond has resulted in the formation of ground-water mounds under these sites. Three distinct flow systems are identified: the underlying natural flow system, a 200 West Area flow system, and a 200 East Area flow system. The 200 West Area flow system intercepts the flow out of 200 East Area, thus changes in liquid waste disposal practices in 200 West Area will impact the flow out of 200 East Area. Ground-water flow out of the Separations Area is primarily toward the southeast to the Columbia River. Additional outflow is to the east and north. Ground-water chemistry and the movement

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of contaminants follow these ground-water flow directions. Analysis of data from the ground-water monitoring network indicates that contamination levels in ground water migrating out of the Separations Area are below U. S. Department of Energy Manual Chapter 0524 concentration guides for water in an uncontrolled area.

Ground-water flow velocities are estimated as less than 1 meter/day out of 200 West Area and as high as 27 meters/day out of 200 East Area. The travel time from 200 East Area disposal sites to the Columbia River is estimated at 30 years; from 200 West Area disposal sites, these estimates range from 80 to 120 years.

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1.0 INTRODUCTION AND BACKGROUND
by M. J. Graham

1.1 INTRODUCTION

The U. S. Department of Energy (DOE) Hanford Site has served as an integrated nuclear facility since 1943. The site occupies 1476 square kilometers (570 square miles) in south-central Washington (Figure 1).

The Separations Area is situated near the center of the Hanford Site (Figure 1). Located within this area are the irradiated uranium fuels processing facilities, plutonium separation facilities and the major radioactive waste storage and disposal facilities. This area covers 210 square kilometers (82 square miles), encompassing 200 East and West Areas, major disposal ponds and significant hydrologic boundaries (Plate 1).

1.2 PURPOSE AND OBJECTIVES

The purpose of this effort is to integrate present knowledge to characterize the hydrologic system of the Separations Area. There are three reasons why this work is needed. First, previous studies in the Separations Area have dealt principally with the determination of the geologic environment, the measurement of ground-water levels, and the distribution of radionuclides in the sediments. Although these studies are important in waste management, they are not directed to defining the hydrologic system. Second, most published works on hydrology at Hanford have focused on the site as a whole, and do not specifically relate to the Separations Area. Third, there exists a large body of unpublished hydrologic data on the Separations Area. The objectives of this task are to collect, evaluate, interpret and organize the existing data pertaining to the hydrology of the Separations Area.

1.3 SITE DESCRIPTION

1.3.1 Geology

1.3.1.1 Introduction. The Hanford Site is located within the Pasco Basin, a structural and topographic basin in south-central Washington State. The boundaries of the Pasco Basin are defined by anticlinal

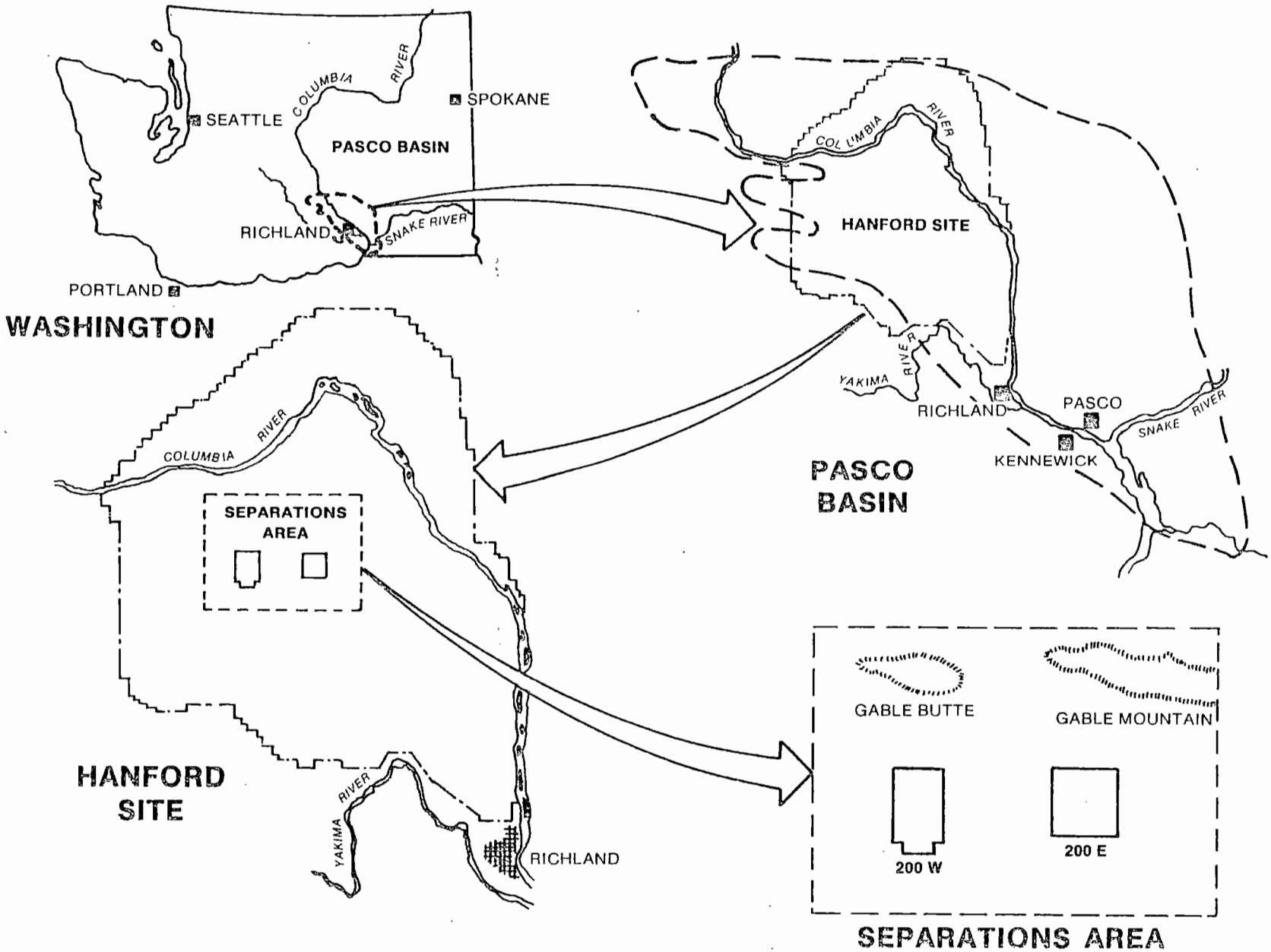

FIGURE 1. Separations Area Location Map.

structures of basalt rock. These are the Saddle Mountains to the north; the Umtanum Ridge, Yakima Ridge, and Rattlesnake Hills to the west; and the Rattlesnake Hills and a series of doubly plunging anticlines merging with the Horse Heaven Hills to the south (Figure 2).

The major geologic units beneath the Hanford Site are, in ascending order: basement rocks of undetermined origin, the Columbia River basalt group with intercalated sediments of the Ellensburg formation (consisting of four units), the Ringold formation, the early "Palouse" soil, and the Hanford formation (informal name) (Tallman, et al., 1979). River deposited sediments, landslide debris and eolian sediments locally veneer the surface of the Pasco Basin (Figure 3).

The Separations Area is situated on the south flank of the Umtanum - Gable Mountain structure (Fecht, 1978). The basalt bedrock dips to the southwest; sediments increase in thickness to the south where they reach a maximum in the Cold Creek syncline (Routson and Fecht, 1979).

1.3.1.2 Stratigraphy. The stratigraphy beneath the Separations Area consists of the Yakima basalt subgroup, composed of the Grande Ronde, Wanapum, and Saddle Mountains formations (Ledgerwood, et al., 1978). The Saddle Mountains basalt within the area consists of four basalt flows separated by interbedded sediments. The basalt members are, in ascending order: the Umatilla, Esquatzel, Pomona, and Elephant Mountain (ibid). In the eastern part of the area, a fifth member, the Asotin, is present. The major interbedded sediments are the Mabton, Cold Creek, Selah, and Rattlesnake Ridge, which are part of the Ellensburg formation (ibid). These interbeds and basalt interflow zones form an extensive confined aquifer system.

The Ringold formation overlies the Elephant Mountain member, except in the northeast corner of the Separations Area where these sediments have been removed by erosion (Brown, 1959). The Ringold formation can generally be divided into four units on the basis of texture: the sand and gravel of the basal Ringold unit; the clay, silt and fine sand with lenses of gravel of the lower Ringold unit; the occasionally cemented sand and gravel of the middle Ringold unit; and the silt and fine sand of the upper Ringold unit (Tallman, et al., 1979). There is a general thinning of the Ringold formation from west to east (Figure 4).

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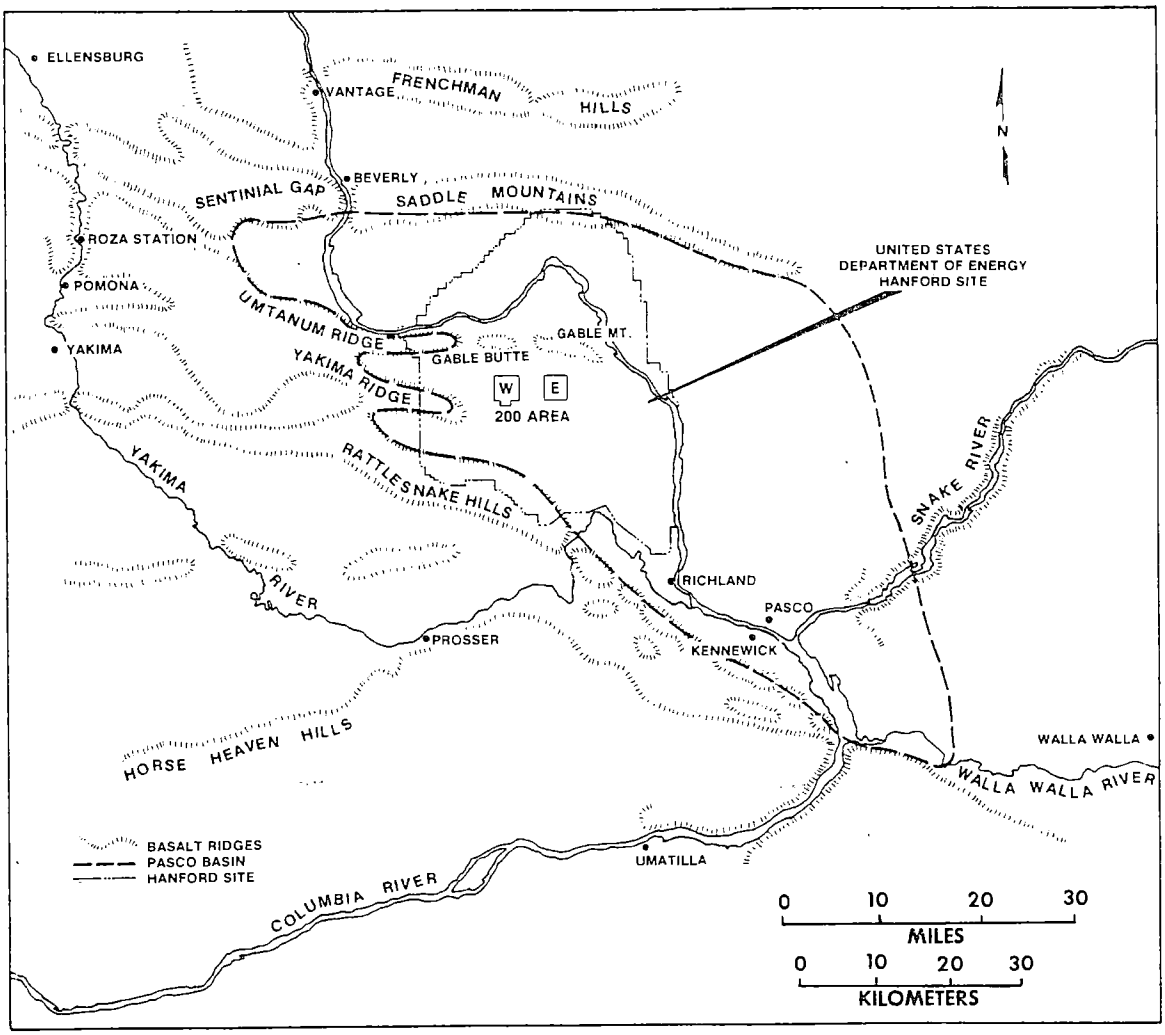

FIGURE 2. Map of the Pasco Basin and Surrounding Features.

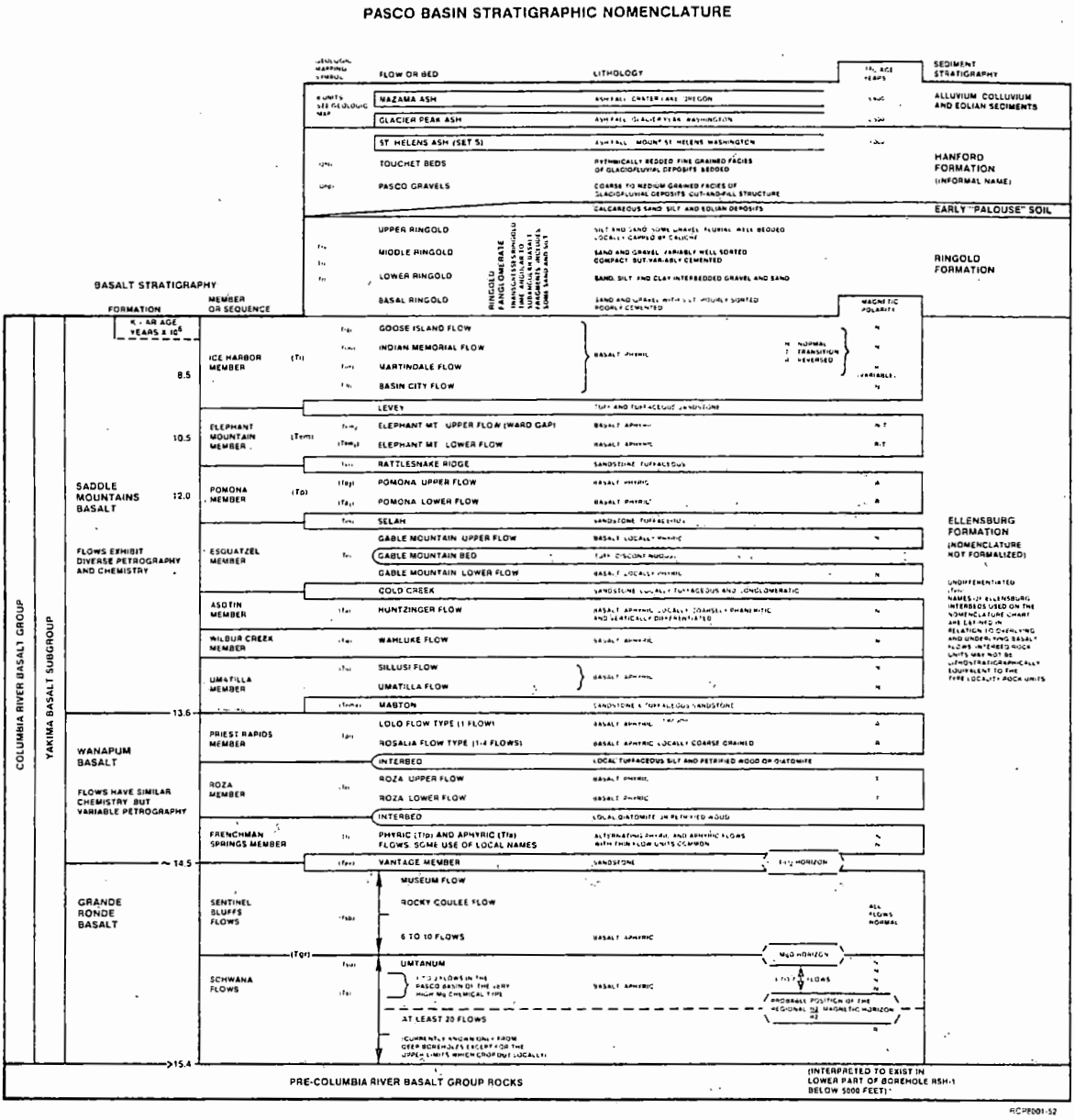

FIGURE 3. Pasco Basin Stratigraphic Nomenclature (from Myers/Price, et al., 1979).

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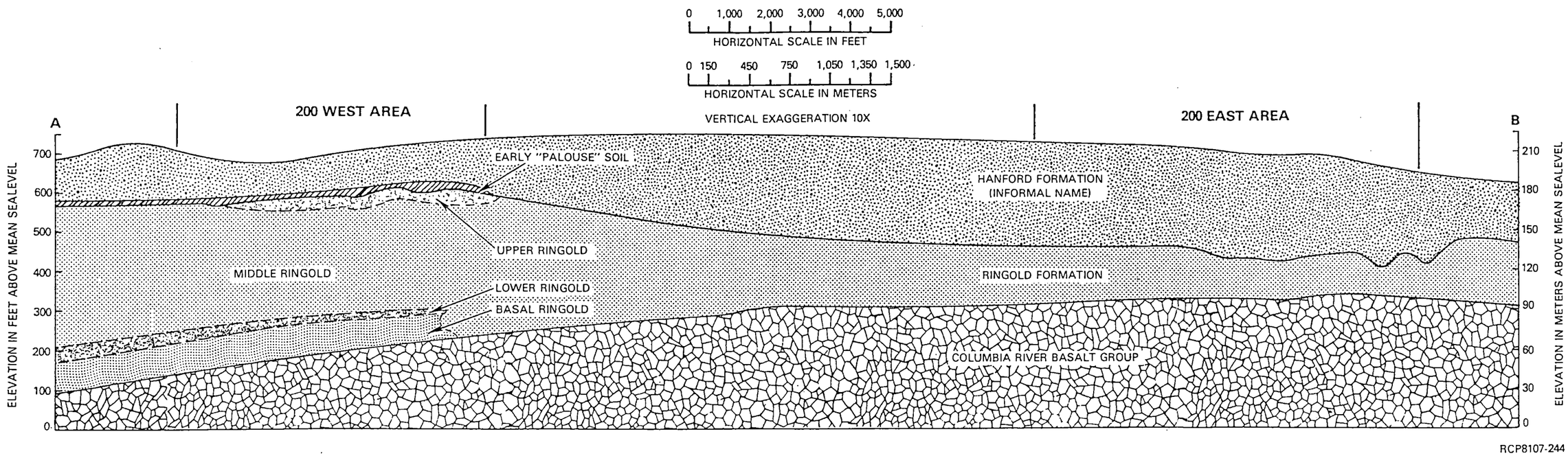

FIGURE 4. Stratigraphic Cross Section A-B. (Modified from Tallman et al., 1979.) Refer to Plate 2 for Location of Cross Section.

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The early Palouse soil is a buried eolian deposit overlying the Ringold formation in some areas (Brown, 1960). This loess, present in the western part of the Separations Area, is up to 15 meters (50 feet) thick (Tallman, et al., 1979).

The glaciofluvial sediments, informally named the Hanford formation, are deposited on the Columbia River basalt group and Ringold formation. These sediments can be divided into the coarser sand and gravel, which are referred to as the Pasco gravels (Brown, 1975), and the finer sand and silt units called the Touchet beds (Flint, 1938).

Loess deposits veneer most of the Separations Area; sand dunes are present in the southern portion of the area. The eolian deposits are composed of reworked Hanford formation sediments and volcanic ash (Tallman, et al., 1979).

1.3.1.3 Geomorphology. The Separations Area lies on a broad bar formed when Pleistocene catastrophic flood waters spread out beyond the Umtanum-Gable Mountain structure, depositing the sand and gravel of the Hanford formation (ibid). This flood bar is roughly defined by the 700-foot contour line (Plate 1). As these flood waters receded, channels were developed at the lower levels and later abandoned. A network of abandoned channels has been defined near Gable Mountain (Fecht, 1978). Subsequent to flooding, the major geomorphic process has been eolian deflation and deposition, resulting in dune fields and loess veneer.

1.3.2 Climate

The overall climate of the Hanford Site is detailed in Stone, et al., (1972). The climate at Hanford is dominated by the movement of storm fronts from the Pacific Ocean eastward over the Cascade Mountains. Summers are sunny, warm, and dry; most precipitation occurs in the relatively mild winters.

At the Hanford Meteorology Station, located in the Separations Area, average annual precipitation is 16 centimeters (6.25 inches). Over 30% of this precipitation occurs during November, December, and January;

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whereas roughly 10% occurs in July, August, and September. Almost 50% of the moisture falling during the months of December through February is in the form of snow.

1.4 PREVIOUS STUDIES

Several past investigations have provided important geologic, geophysical, hydrologic, and hydrochemical data to assist in the detailed characterization of the hydrologic environment in the Separations Area. Significant early studies by Bierschenk (1957a, 1959a and b), Parker and Piper (1949), and Newcomb and Strand (1953) focused on the characterization of the hydrology and geology of the Hanford Site. More recent works (Newcomb, et al., 1972; LaSala and Doty, 1975) build on these earlier efforts. The environmental impact statement for the Hanford Site (Liverman, 1975) includes a discussion of hydrology. A recent effort bringing together existing information on the hydrology of the Columbia Plateau (Gephart, et al., 1979) emphasizes the Hanford Site.

The effects of large volumes of liquid waste disposal on the water table are discussed by Bierschenk (1957b and c), McConiga (1955), and Bierschenk and McConiga (1957). Historical water-table contour maps and well hydrographs for the Hanford Site are presented by Kipp and Mudd (1974). Early studies by Brown and Ruppert (1948, 1950) focus on the impacts of various disposal sites in the Separations Area. A later characterization study further quantifies the impacts of specific disposal facilities on ground-water quality (Smith, 1980). The input and decayed values of radioactive liquid wastes discharged to the ground in the Separations Area through 1971 are reviewed by Hanson et al., (1978). All subsequent discharge summaries are based on their findings.

Veatch (1971) analyzes the probable effect on the water table of increasing liquid waste discharges to the ground in 200 West Area. The sensitivity of the water table beneath the Separations Area, due to the creation of several water-table mounds across the major flow paths, is investigated by Tomlinson, et al., (1970). Gephart, et al., (1976) use a

numerical flow model to predict ground-water levels in response to increasing discharges to Gable Mountain Pond and B-Pond. This study stems from the findings of Ledgerwood and Deju (1975), indicating that hydraulic leakage may occur under West Lake between the uppermost confined aquifers and the overlying unconfined aquifer.

Aquifer tests have been performed on the unconfined aquifer over most of the Hanford Site (Honstead, et al., 1955; Bierschenk, 1957a, 1959a and b; Brown and Rowe, 1960; Raymond and McGhan, 1960; Kipp and Mudd, 1973; Deju, 1974). Results of these tests are evaluated and the aquifer properties over the entire site are inferred by Deju and Summers (1975) and Cearlock et al., (1975.) Newcomb et al., (1972) use the shape of the western ground-water mound to calculate aquifer properties in the 200 West Area.

Several thousand wells have been constructed on the Hanford Site, the highest density being within the Separations Area. A compilation of most of these wells is in McGhan and Damschen (1979). Many of these wells were drilled to obtain detailed geologic and granulometric data on the sediments beneath cribs and tank farms (Price and Fecht, 1976; Fecht, et al., 1978). (These are two of many similar papers.) Other wells were constructed for purposes of monitoring ground-water contamination and, as such, have been used routinely to assess the status of subsurface contamination (Denham, 1970; Kipp, 1972; Myers, 1978; Eddy and Wilbur, 1980; Wheeler and Law, 1980).

1.5 WASTE DISPOSAL AND STORAGE FACILITIES

1.5.1 High-Level Liquid Waste Storage

High-level radioactive waste produced in the chemical processing of irradiated uranium fuels is stored in large underground tanks. The acidic wastes are neutralized for storage, resulting in a salt, a sludge, and a supernatant liquid. Between 1952 and 1958 depleted uranium was recovered from these tanks. Since 1952, waste volume reduction has been the primary objective of high-level waste management at Hanford.

Initially, 64 single-shell tanks were constructed for high-level waste storage. An additional 85 single-shell tanks were constructed between 1946 and 1964. The single-shell tanks have a capacity of 200,000 or 3,800,000 liters (55,000 or 1,000,000 gallons). Starting in the late sixties, storage tanks for high-level waste were built with two carbon steel liners—the double-shell tanks. All single-shell tanks have been stabilized by removing the supernatant. The high-level liquid wastes are now stored in double-shell tanks.

1.5.2 Low-Level Liquid Waste Disposal

Starting in the mid-forties, small volumes of selected low-level radioactive wastes were discharged to the ground by means of subsurface structures. The rate of low-level liquid waste discharged to the ground increased steadily and reached a peak of 8.34×10^5 curies per year in 1955 (Hanson, et al., 1978). Thereafter, the quantity of low-level wastes discharged has decreased as ground disposal of radionuclides was minimized through process improvements and shutdown of obsolete plants.

There have been 195 subsurface disposal facilities constructed in the Separations Area. The following types of facilities have been utilized for liquid waste disposal at Hanford:

- cribs - liquid dispersal systems, used for disposal process, condensate and lab wastes
- trenches - unlined excavations, generally used for short periods on a specific retention basis for the disposal of high-salt waste or waste containing complexed radionuclides
- French drains - covered or buried gravel-filled encasements with open bottoms, used for the disposal of small volumes of low-level waste
- reverse wells - buried or covered encased drilled holes with the lower end perforated or open, used for the disposal of process waste (Parker, 1954).

The large volumes of cooling water and steam condensates from chemical processing facilities and the evaporator-crystallizers are discharged to surface ponds and ditches. Normally, the radionuclide concentrations average below maximum permissible concentration guides, but occasional, nonroutine, releases of higher-level wastes have occurred. Ponds are natural or diked surface depressions which allow the liquid effluent to percolate into the underlying sediment. The major disposal ponds are U-Pond, B-Pond and Gable Mountain Pond (Plate 1). Ditches are unlined excavations used for conveying the low-level liquid waste to the ponds.

1.5.3 Solid Waste Burial

A total of 2 million curies of solid wastes have been buried in the Separations Area. About 1.9×10^5 cubic meters (6.7×10^6 cubic feet) of contaminated solids have been buried in the area since the start of chemical processing operations (Isaacson and Brown, 1976). These wastes consist of dry waste, (comprised of soiled clothing, laboratory supplies, tools, etc.) packaged in cardboard, wood, or metal containers; and industrial waste (primarily items of failed process equipment) packaged in plastic shrouds, wood, metal or concrete boxes (Liverman, 1975).

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2.0 REGIONAL HYDROLOGY

2.1 UNCONFINED AQUIFER by M. J. Graham

2.1.1 Introduction

In this section, the general characteristics of the regional hydrology are described. An excellent discussion of the regional hydrologic setting is detailed by Gephart, et al., (1979). The unconfined aquifer lies within the boundaries of the Pasco Basin, contained within glaciofluvial sands and gravels and the Ringold silts and gravels. The aquifer is dominated by the middle member of the Ringold formation, consisting of sorted sands and gravels of varying induration. The bottom of the aquifer is the basalt surface or, in some areas, the clay zones of the lower member of the Ringold formation. The aquifer is over 70 meters (230 feet) thick in some areas, and thins to zero thickness along the flanks of the bordering structures. Some local basalt highs within the basin extend above the water table, the most notable of which are Gable Mountain and Gable Butte on the Hanford Site (Plate 2).

2.1.2 Recharge

Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia Rivers. The principal source of recharge occurs along the periphery of the basin where precipitation and runoff infiltrate to the water table. Small ephemeral streams draining the western slopes, such as Cold Creek and Dry Creek, lose water to the ground as they spread out on the valley plain. The Yakima River recharges the unconfined aquifer along its reach from Horn Rapids to Richland. During high stages of the Columbia River, river water is transferred to bank storage as ground water. Fluctuations in the stages of the Columbia affect the water table up to 4.8 kilometers (3 miles) inland (Raymond and Brown, 1963). Within the basin, upward leakage from the lower basalt aquifers may enter the unconfined aquifer. Little, if any, recharge to the ground water occurs from percolating rainfall on the broad areas of the desert terrain due to a high rate of evapotranspiration.

Artificial or synthetic recharge to the ground water occurs in the basin from two sources, agricultural irrigation and waste disposal operations at Hanford. Agricultural irrigation on the eastern and northern sides of the Columbia River and in Cold Creek Valley to the west of the Hanford Site causes an undetermined amount of recharge to the system. Possibly as much as 40% of this irrigation water reaches the water table (U.S. Bureau of Reclamation, 1971). Synthetic recharge from Hanford waste disposal practices occurs principally within the Separations Area. Although these discharges have been concentrated in U-Pond, B-Pond, and Gable Mountain Pond, the effects on the flow system have been widespread. Compare the pre-Hanford water-table map (Plate 3) with the 1979 water table map (Plate 2). Beneath the Separations Area, two ground-water mounds have developed in response to large volumes of discharge to U-Pond and B-Pond. Under U-Pond, the water table has risen in excess of 26 meters (85 feet) since the start of disposal operations. The mound under B-Pond has risen more than 9 meters (30 feet). By the end of 1979, both U-Pond and B-Pond had received approximately the same volumes of waste water (1×10^{11} liters). The eastern mound, although fed by about the same volume of discharge as the western mound, is less than one-half the western mound's height. This is due to the higher transmissivities of the saturated sediments under 200 East Area.

2.1.3 Movement

From the recharge areas, the ground water flows downgradient to the discharge areas, primarily the Columbia River. This general flow pattern is interrupted locally by the two ground-water mounds in the Separations Area and one ground-water mound north of the city of Pasco, Washington, resulting from artificial recharge of irrigation waters. These mounds alter the flow around them as evidenced by the ground-water mound beneath 200 West Area (Plate 2).

2.1.4 Discharge

Ground-water discharge from the unconfined aquifer is principally to the Columbia River. There are lesser amounts of discharge to the Snake and Yakima Rivers. Discharge of the unconfined aquifer flowing under

Hanford is almost exclusively to the Columbia River north of Richland, Washington. Downward leakage to lower confined aquifers may be occurring under the eastern ground-water mound. The rise in the water table above the potentiometric surface of the confined aquifer provides the potential for this leakage.

2.1.5 Hydraulic Properties

The geologic and hydraulic properties of the Pasco Basin sediments are highly variable. The range of hydraulic conductivities can be several orders of magnitude. There have been numerous aquifer tests performed in the Pasco Basin, the majority of which were done on the Hanford Site. Gephart, et al., (1979) present results from more than 100 tests on the Pasco Basin. These results are summarized in Table 1.

TABLE 1. Representative Hydraulic Properties of the Unconfined Aquifer (Modified from Gephart et al., 1979).

Stratigraphic Interval	Hydraulic Conductivity	
	(m/day)	(ft/day)
Hanford Formation (informal name)	150-6,100	500-20,300
Undifferentiated Hanford and Middle Ringold Unit	30-2,100	100-7,000
Middle Ringold Unit	6-180	20-600
Lower Ringold Unit	0.03-3.0	0.1-10.0

2.1.6 Water Quality

Water quality data of the unconfined aquifer in the Pasco Basin were obtained from the U.S. Geological Survey (USGS). These data are from samples collected from wells outside the Hanford Site. Chemical analyses are available for well samples collected at Hanford between the years 1974 and 1979 by the USGS and Pacific Northwest Laboratory (PNL). These analytical results are reported in annual documents by PNL (Raymond, et al., 1976; Myers, et al., 1976, 1977; Myers, 1978; Eddy, 1979; Eddy and Wilbur, 1980). The means, standard deviations, and ranges for the various constituents of the two data sets are given in Table 2.

TABLE 2. Water Quality of the Unconfined Aquifer for the Pasco Basin and the Hanford Site.

Constituent	Location	η	$\bar{x}$	s	Range
Temperature Degrees Celsius	Pasco Basin	193	13.5	2.6	3.1-21.2
	Hanford	89	19.2	3.2	14.5-39.1
Spec. Cond. µmhos/cm	Pasco Basin	184	323	162	125-1,250
	Hanford	99	409	117	194-927
pH pH Units	Pasco Basin	3	7.6	0.5	7.2-8.1
	Hanford	104	7.9	0.3	7.0-9.4
Ca^{++} mg/l	Pasco Basin	15	31.5	9.2	20.0-54.0
	Hanford	101	41.4	12.5	12.0-92.0
Mg^{++} mg/l	Pasco Basin	15	11.6	4.0	6.9-23.0
	Hanford	101	11.1	3.7	3.1-29.0
Na^{+} mg/l	Pasco Basin	17	15.8	9.6	5.9-43.0
	Hanford	101	22.6	10.4	2.9-64.0
K^{+} mg/l	Pasco Basin	16	3.1	1.0	1.4-4.9
	Hanford	101	6.2	1.9	1.9-13.0
HCO_3^{-} mg/l	Pasco Basin	16	166	44	82-244
	Hanford	101	146	38	53-314
Cl^{-} mg/l	Pasco Basin	16	4.7	4.1	2.6-19.0
	Hanford	101	11.1	6.6	2.5-32.0
$SO_4^{=}$ mg/l	Pasco Basin	16	10.9	9.2	5.1-43.0
	Hanford	100	47.2	33.5	2.7-190.0
NO_3 as NO_3 mg/l	Pasco Basin	(not available)			
	Hanford	101	26.0	39.0	0.05-270.0

The waters are principally a calcium-bicarbonate type, although a considerable variability in chemical composition exists between individual samples. This is primarily attributed to natural variability of water chemistry within the aquifer. The chemical character of the ground water is influenced by its proximity to recharge areas, its rate of movement, and the chemical and physical nature of the sediments it flows through.

For example, on the Hanford Site in Well 699-10E-12 (Plate 2), samples collected from the glaciofluvial sediments and the basal Ringold have different chemical character (Table 3). The basal Ringold water is sodium-bicarbonate in nature whereas the glaciofluvial water is primarily a calcium-bicarbonate type.

Some of the variation between the Hanford ground-water samples and the Pasco Basin ground-water samples is attributed to liquid waste disposal at Hanford. Thermal pollution is evident from the significantly higher mean temperature of the Hanford aquifer water compared to the mean temperature of the Pasco Basin aquifer water. An isothermal map of the Hanford Site is given in Eddy (1979). The equivalent parts per million (EPM) of the average composition of the Hanford and Pasco Basin unconfined waters are compared in Figure 5. Although nitrate data for the Pasco Basin are not available, it is assumed that the concentrations are low. The high nitrate concentrations in the Hanford waters are result of waste disposal; Eddy and Wilbur (1980) present a nitrate isopleth map for the Hanford Site.

2.2 CONFINED AQUIFER by S. R. Strait

2.2.1 Introduction

The confined aquifer consists of sedimentary interbeds and/or interflow zones which occur between dense basalt flows in the Columbia River basalt group. The main water-bearing portion of the interflow zone occurs within a network of interconnecting vesicles and fractures of the flow tops or flow bottoms. The confining layers are dense basalt flows. Vertical cooling joints and fractures within the confining layers can permit localized leakage. This appears to be more prevalent in near-surface basalt flows.

Confined aquifers are known to underlie the Separations Area to a depth of 1,700 meters (5660 feet) as evidenced from borehole ARH-DC-1 (Figure 6). Additional aquifers may exist at greater depths. The confined aquifers are continuous throughout most of the Pasco Basin except where the aquifers have been eroded or stratigraphically pinch out. The thicknesses of the aquifers vary from over 52 meters (170 feet) with the Mabton interbed, to a few centimeters in some basalt flow contacts.

TABLE 3. Water Quality of Samples Collected from the Basal Ringold and the Glaciofluvial Sediments in Well 699-10E-12.

	Glaciofluvial		Basal Ringold	
pH	7.5		7.9	
Sp. Conductance μmhos/cm	223		285	
Constituents	mg/l	EPM*	mg/l	EPM
HCO_3^-	120.0	1.967	188.0	3.081
Cl^-	5.70	0.161	14.2	0.400
$SO_4^=$	24.0	0.500	3.0	0.062
NO_3^- as NO_3^-	16.8	0.271	0.22	0.004
Total Anions		2.898		3.548
Na^+	20.5	0.892	55.0	2.392
K^+	7.1	0.182	8.60	0.220
Ca^{++}	22.0	1.098	12.0	0.599
Mg^{++}	6.8	0.559	3.7	0.304
Total Cations		2.73		3.516

*EPM = Equivalent parts per million.

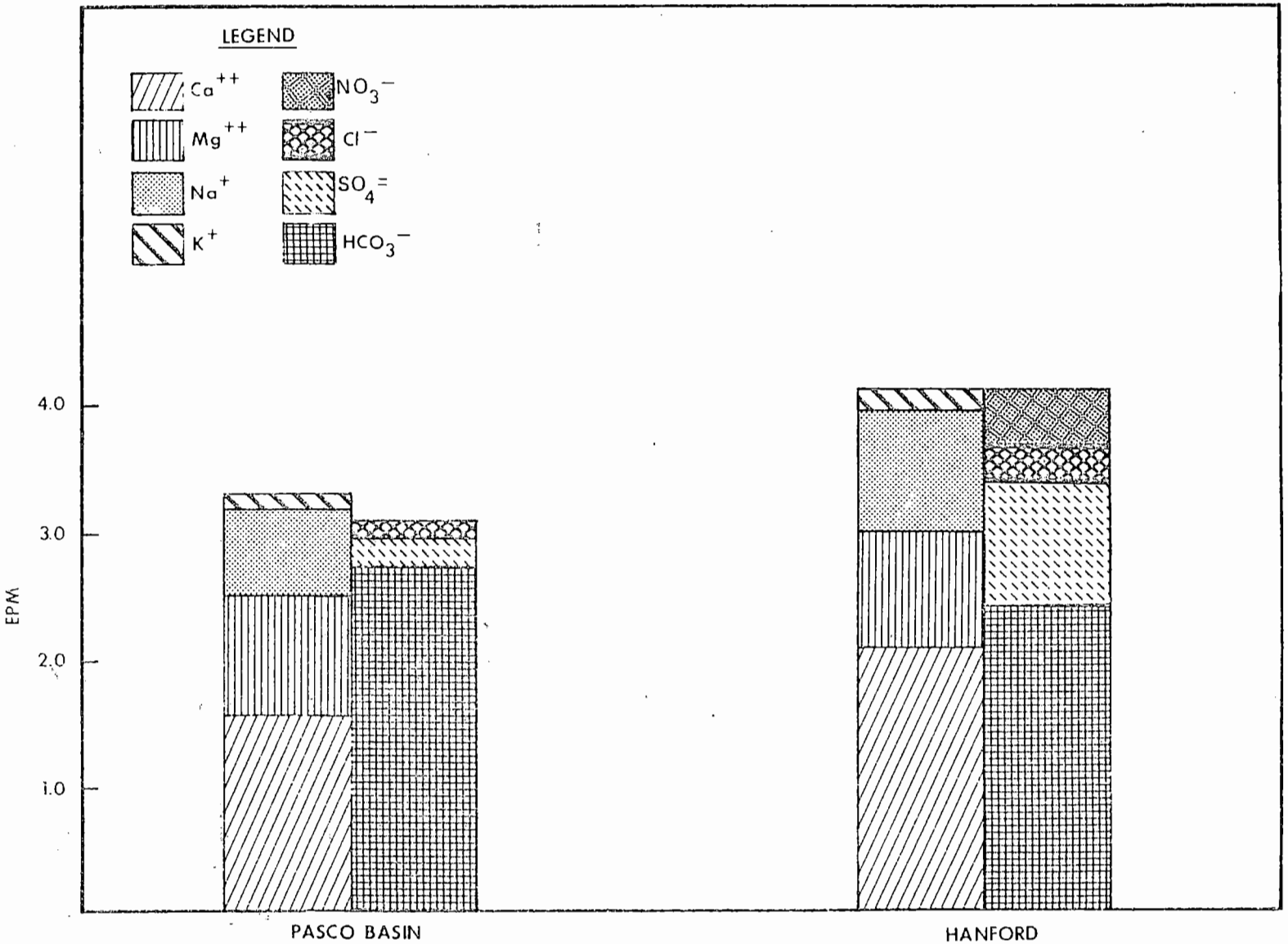

FIGURE 5. EPM Comparison of Hanford and Pasco Basin Unconfined Aquifer Waters.

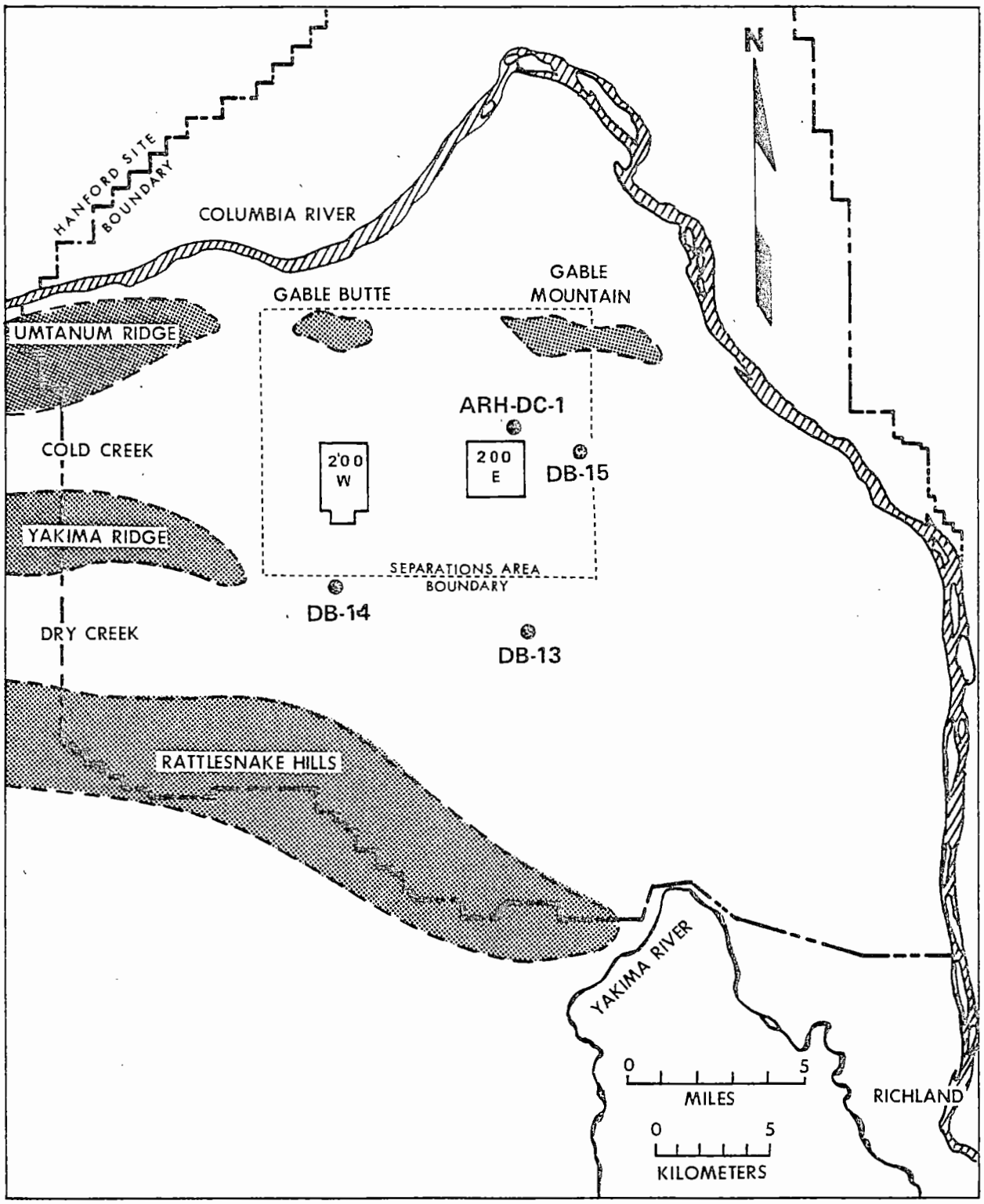

FIGURE 6. Location of Wells DB-13, DB-14, DB-15, and ARH-DC-1.

2.2.2 Recharge

Recharge to the Saddle Mountains basalt occurs primarily where the basalt formations are at or near ground levels, as water infiltrates from precipitation and stream runoff. These recharge areas are the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, and the Saddle Mountains (Figure 2). Artificial recharge occurs from irrigation and irrigation runoff along the eastern and northeastern sections of the Pasco Basin.

2.2.3 Movement

The potentiometric surface is influenced by the areas of recharge and discharge for the confined aquifer; the gradient indicates the ground-water flow direction. In the Pasco Basin, this movement is assumed to conform closely with the regional dip of the basalts. However, in the Separations Area flow is toward the Gable Mountain-Gable Butte area. Present day water levels show that the water table lies above the potentiometric surface of the Rattlesnake Ridge under major disposal ponds, creating the potential for aquifer leakage from the unconfined to the confined aquifers in these areas.

2.2.4 Discharge

The major discharge area for the Saddle Mountains basalt aquifers is presently assumed to be the Columbia River near Richland, Washington (Gephart, et al., 1979). In this area, the potentiometric surface lies above the mean stage of the river. Minor discharge also occurs to the Yakima River west of Richland and the Columbia River north of Umtanum Ridge.

2.2.5 Hydraulic Properties

Hydraulic conductivity values for the Saddle Mountains basalt aquifers were obtained primarily by pump tests conducted at wells within the Hanford Site (Figure 6). The ranges of hydraulic properties for the confined aquifers in these wells are presented in Table 4 (Gephart, et al., 1979).

TABLE 4. Ranges of Hydraulic Properties of the Confined Aquifer from Wells DB-13, DB-14, DB-15, and ARH-DC-1.

Aquifer	Transmissivity		Thickness		Hydraulic Conductivity	
	m^2/day	ft^2/day	m	ft	m/day	ft/day
Elephant Mtn. interflow[a]	569	6120	0.9	3	622	2040
Rattlesnake Ridge interbed	0.8-28.5	8-307	15-25	50-82	0.03-1.8	0.10-6
Selah interbed	0.8-43	9-462	6-11	20-36	0.1-7	0.4-23
Cold Creek interbed	13-774	141-8326	14-29	46-94	0.5-55	1.50-181
Umatilla interflow[b]	116	1253	1.8	6	55	179
Mabton interbed	13-177	136-1900	26-34	86-111	0.5-6	1.6-20

[a] from Well DB-13
[b] from Well DB-15

2.2.6 Water Quality

Table 5 lists the mean and range of major chemical constituent concentrations for the ground water in the Mabton interbed. The Mabton interbed is used to represent the confined aquifer system of the Saddle Mountains basalt since it is extensive throughout the Pasco Basin and contains the most reported chemical analyses (Gephart, et al., 1979). On the average, the confined system contains much lower total dissolved solids than the unconfined aquifer and is of a sodium-bicarbonate chemical type. The confined aquifer is also characteristically low in nitrate because of its isolation from surface contaminants. However, in the B-Pond/Gable Mountain Pond area, intermixing of ground water from the unconfined aquifer has occurred, as indicated from elevated nitrate and tritium concentrations in the uppermost confined aquifer.

TABLE 5. Mean and Range of Major Chemical Constituent Concentrations within Ground Water of the Mabton Interbed (Modified Gephart, et al., 1979).

Constituent	Concentration	
	Range mg/l	Mean mg/l
Anions		
HCO_3^-	169-267	217
Cl^-	4.3-63	20
$SO_4^=$	0.3-18	4.0
NO_3^-	<0.5	<0.5
F^-	0.1-8	2.2
Cations		
Na^+	36-122	83
K^+	7.7-14	11
Ca^{++}	0.5-22	4.7
Mg^{++}	0.1-12	1.8

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3.0 HYDROLOGY OF THE SEPARATIONS AREA

3.1 INTRODUCTION

A thorough understanding of the unconfined aquifer underlying the Separations Area is necessary for the effective management of low-level wastes at the Hanford Site. Characterization of the ground-water flow and the movement of contaminants within the aquifer is needed to determine the locations and open intervals of monitoring wells. Also, ground-water flow and transport models can be used to predict the impacts of changes in recharge (due to liquid waste disposal, irrigation west of the Hanford Site or climatic changes) on the movement of contamination out of the Separations Area to the Columbia River. In this section, the various hydrologic components of the unconfined aquifer in the Separations Area are discussed in detail. The hydraulic properties of the unconfined aquifer are deduced from an analysis of published and unpublished aquifer test data. The validity of aquifer testing techniques and the methods of data analysis are discussed. The ground-water flow system is investigated in three dimensions; natural and artificial recharge, discharge, and rates of ground-water movement are addressed. The water quality section includes a discussion of the prevalent chemical character of the unconfined ground water and the extent of contamination plumes. The influence of the flow system and the hydraulic properties of the saturated sediments on the distribution of contaminants are also investigated.

3.2 AQUIFER PROPERTIES by M. D. Hall

3.2.1 Introduction

Over the past 35 years, characterization of the unconfined aquifer at Hanford has been conducted through the use of various aquifer tests. Prior to 1976, most aquifer tests were of relatively short duration (less than 1 day) while more recent tests have been longer (1 to 2 days). It is important to examine the old and new test data in order to determine the validity of the data for use in aquifer simulation. The purpose of

this section is to present the historical data derived from both published and unpublished tests, discuss the validity of the tests, and give a summary of various properties of the unconfined aquifer.

3.2.1.1 Aquifer Properties - Definition. The principal hydrologic properties of the unconfined aquifer are the coefficient of storage (S), specific yield (Sy), hydraulic conductivity (K) and transmissivity (T).

The coefficient of storage (storativity) is defined as the volume of water instantaneously released from storage per unit drawdown of the water table per horizontal area of aquifer.

The specific yield is defined as the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table. The specific yield can be visualized as the amount of water that could be drained by gravity from an unconfined aquifer and thus is equal to the total porosity of the aquifer minus specific retention.

Hydraulic conductivity is defined as the volume of water that will move in unit time under a unit hydraulic gradient through a unit area of an aquifer measured at a right angle to the direction of flow.

Transmissivity is defined as the rate at which water moves through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity can be mathematically expressed as the hydraulic conductivity multiplied by the saturated thickness of the aquifer.

Other properties of the unconfined aquifer that are important in understanding how the flow system operates include effective porosity and anisotropy.

Effective porosity is defined as the ratio between the volume of interconnected pore space in a unit volume of aquifer to the unit volume of aquifer.

Anisotropy is defined as the ratio of horizontal hydraulic conductivity to the vertical hydraulic conductivity (Kh/Kv).

2 2 1 2 4 6 2 2 1 0 9

All of these parameters provide a means of estimating the ability of an aquifer to store and transmit water. With a knowledge of the distribution of these parameters, a quantitative estimate of ground-water flow velocity, discharge through the aquifer, and direction of ground-water flow can be made.

3.2.1.2 Methods of Unconfined Aquifer Testing. Several different methods exist for determining hydrologic properties of unconfined aquifers. The basic field procedures for determining aquifer properties can be classified as pumping or nonpumping field tests (Table 6). Of all the different types of tests that exist for determining aquifer properties, the constant discharge test is the most often used. The majority of aquifer parameters have been estimated using this testing method.

TABLE 6. Field Testing Procedures for Determining Unconfined Aquifer Properties.

Test	Discharge	Parameters That Can be Analyzed[a]	Commonly Used at Hanford
Pumping			
Constant Discharge	Steady	T, K, and S can be measured with observation well.	Yes
Step-Multirate	Variable	T can be estimated-frictional head loss can be measured.	Yes
Specific Capacity	Steady	T, K	No
Nonpumping			
Recovery	-	T, K	Yes
Slug	-	T, K, S	No
Tracer	-	Direction of ground-water flow and velocity.	No

[a] S = storage
T = transmissivity
K = hydraulic conductivity.

3.2.1.3 Methods for Analyzing Field Test Data. The different analysis techniques used at Hanford to examine drawdown data in a pumping or observation well are listed below.

- Theis (1935) used the analogy between heat and ground-water flow to develop an equation that describes theoretical drawdown in a confined aquifer at a distance from a pumping well over an interval of time. The Theis analytical technique involves curve matching of field data with the analytical solution in order to calculate transmissivity and storativity. This method of analysis is theoretically limited to confined aquifers, but can be used in unconfined systems where drawdown in the discharge well is small relative to the total saturated thickness of the aquifer. Limiting assumptions of this model include isotropy, homogeneity, infinite lateral extent of aquifer, and full penetration of discharging well.
- Cooper and Jacob (1946) developed a semilogarithmic approach to determining confined aquifer properties. The Cooper-Jacob time drawdown plot can be used for analyses of test results in unconfined aquifers. Jacob (1950) has shown that this approach satisfactorily predicts drawdown over time in unconfined systems as long as drawdown is small in comparison with the saturated thickness of the aquifer and the Dupuit assumption of horizontal flow is valid.
- Boulton (1963) developed the concept of delayed yield from storage. Significant improvement of Boulton's initial work was made by Neuman (1972) when a physical interpretation was given to delayed yield phenomena. Neuman's analytical technique is a Theis type of solution that involves the matching of field data with analytical curves. Drawndown characteristics can vary with time in an unconfined aquifer; Boulton and Neuman consider these variations. The Theis assumptions apply for this model.

- Recovery testing allows a Cooper-Jacob type of analysis to be made of the time-drawndown data. Storativity cannot be directly calculated using this method. This analysis allows a qualitative estimate of well casing influences on the calculation of transmissivity based on information derived from a constant discharge test.

  Most field test information at Hanford has been analyzed using the Theis, Cooper-Jacob semilogarithmic method, and the analogous recovery method. The Boulton and other analysis techniques have been used to a lesser extent. Boulton and Neuman's techniques have been used to analyze pump tests at wells 699-47-35 and 699-37-82. Delayed yield has been noticeably absent from most pump tests in the unconfined aquifer, but was noted during the pump tests at these wells.

3.2.2 Summary of Test Results 1945 to 1976

Although many pump tests have been conducted at Hanford, few pump tests have been conducted within the Separations Area. Not only have there been few tests in the Separations Area, but testing procedures have changed over the last 35 years. Prior to 1976, most aquifer tests were less than 1 day in duration, and typically were 8 hours or less. Later tests have been 1 or 2 days in duration. Thus, pump test data from these periods have been separated, based on this difference in testing procedure.

The results of the short duration testing performed between 1945 and 1976 are given in Table 7. The results clearly show the high transmissivity of the Hanford formation at wells 299-E28-15 and 699-55-50. Hanford formation gravel and cobbles are physical evidence of this aquifer's ability to transmit water. Although the middle Ringold formation is thought to be tested along with the Hanford formation at well 299-E28-15, the high transmissivity calculated at this well can be attributed to the Hanford formation. Middle Ringold sediments have a generally lower hydraulic conductivity (Table 7) than the Hanford formation. The lower Ringold has a relatively low transmissivity when compared to the Hanford formation.

TABLE 7. Summary of Pump Test Results in the Unconfined Aquifer in the Separations Area Between 1945 and 1976.

Data Source[a]	Test Year	Well Location	Interval Tested[b]	Hydraulic Conductivity		Transmissivity		Coefficient of Storage	Test Type[c]	Duration, hr	Analysis Technique
				m/day	ft/day	m^2/day	ft^2/day				
1	1969	299-W21-1	MR	8.2	27	502	5,400		CD, R	4	T, RA
Unpub. data	1968	299-E28-15	MR-H	1,123	3,685	12,540	135,000		CD	7	-
2	1970	699-28-40	LR	<1	1	<1	5		R		RA
2	1959	699-31-53	MR	37	120	1,300	14,000	0.06	CD, R	8	T, RA
1	1969	699-32-77	MR	6.4	21	420	4,500		CD, R	6	T, RA
2	1958	699-33-56	MR	70	230 (R)	1,930	21,000 (R)		CD, R	8	T, RA
2	1969	699-36-61	MR	13	43	260	2,800	0.05	CD, R	8	CJ, RA
1	1969	699-36-61	MR	4.3	14	90	970		T, RA	8	
1	1969	699-43-88	MR	2.7	9	186	2,000	0.016	CD, R	24	T, RA
1	1969	699-47-60	MR	7.6	25	93	1,000		CD	7	CJ
2	1956	699-55-50	H	2,773	9,100	55,200	594,000	0.07	CD, R	48	CJ, RA

[a] 1 = Kipp and Mudd (1969)
2 = Deju (1974)

[b] H = Hanford formation
MR = Middle Ringold Formation
LR = Lower Ringold Formation

[c] CD = Constant Discharge
R = Recovery
T = Theis Analysis
CJ = Cooper-Jacob Analysis
RA = Recovery (Jacob) Analysis

3.2.3 Summary of Test Results 1976 to 1980

During the last 4 years, interest has been directed towards the determination of the storage coefficient in the unconfined aquifer at Hanford. Generally this has involved longer tests using one or more observation wells. A lack of available data is evident from the summary of test results between 1976 and 1980 (Table 8). Only four locations have been tested within the Separations Area in the last 4 years. Other tests have been conducted, but not in the Separations Area and vicinity. Table 8, shows the relatively low values for hydraulic conductivity of the lower Ringold. The pump test data and analyses are given in Appendix A.

3.2.4 Validity of Test Results

The validity of all pump tests conducted at Hanford needs to be addressed. The analytical techniques that have been used to calculate aquifer properties of the unconfined aquifer include the Cooper-Jacob, Theis, Boulton, Neuman and various modifications of these techniques. It is generally acceptable to analyze unconfined aquifers with confined aquifer analysis techniques if the following criteria are true:

- the drawdown in the observation or pumping well is small in relation to the total saturated thickness of the aquifer
- leakage is small
- delayed yield is not observed.

These three criteria are generally fulfilled at Hanford.

The accuracy of short duration unconfined aquifer tests (1 day) needs examination. One well, 699-43-88(89) has been pump tested on at least three different occasions. The results of these different test analyses are given in Table 9.

TABLE 8. Summary of Pump Test Results in the Unconfined Aquifer in the Separations Area Between 1976 and 1980.

Data Source	Test Year	Well Location	Interval Tested[a]	Hydraulic Conductivity		Transmissivity		Coefficient of Storage	Test Type[b]	Duration, hr	Analysis Technique[c]
				m/day	ft/day	m^2/day	ft^2/day				
Unpub. data	1979	699-37-82	LR	2.7	9	25	270	0.02	CD	48	MCJ, B
Unpub. Data	1979	699-43-88	LR	3	10	90	970	0.05	CD	21	T
Unpub. Data	1980	699-43-88	LR	2.4	8	74	800	0.04	CD	24	T, CJ
Unpub. Data	1979	699-47-35	LR	3.7	12	49	530	0.002	CD	49	B, N
Unpub. Data	1978	699-60-57	MR	43	140	910	9,800	0.05	CD	8	CJ

[a]MR = Middle Ringold
LR = Lower Ringold

[b]CD = Constant Discharge

[c]MCJ = Modified Cooper-Jacob Analysis
B = Boulton Analysis
T = Theis Analysis
CJ = Cooper-Jacob Analysis
N = Neuman Analysis

TABLE 9. Pump Test Results for Well 699-43-88(89).

Test Year	Duration, hr	Method of Analysis	Hydraulic Conductivity		Transmissivity		Coefficient of Storage
			m/day	ft/day	m^2/day	ft^2/day	
1969	10	Theis	2.4	8	72	780	0.013
1969	24	Theis	2.7	9	186	2,000	0.016
1979	21	Theis	3	10	90	970	0.05
1980	24	Theis	2.4	8	74	800	0.04
1980	24	Cooper-Jacob	2.4	8	77	830	0.002

Another well, 699-62-43 has been pump tested at least twice. The results of the tests analyses are given in Table 10.

TABLE 10. Pump Test Results for Well 699-62-43.

Test Year	Duration, day	Method of Analysis	Hydraulic Conductivity		Transmissivity		Coefficient of Storage
			m/day	ft/day	m^2/day	ft^2/day	
1957	7	Theis	520	1,700	4,650	50,000	0.06
1976	1	Theis	550	1,800	5,400	58,000	not determined

In contrasting these two examples, it does appear that transmissivity calculated using either the Cooper-Jacob or Theis solutions is not particularly sensitive to the time duration of the tests. In using the log-log Theis solution, increasing the duration of the test has little effect on the determination of transmissivity. The Cooper-Jacob formulation is more sensitive to test duration than the Theis method; increasing the duration of data collection during a constant discharge test does improve the calculation of representative aquifer transmissivity. Two or more transmissivities commonly can be calculated from the Cooper-Jacob semilog plot of drawdown versus time in unconfined aquifers.

The initial transmissivity calculated from the early test data (0 to 6 hours) represents an early type of aquifer response that is influenced by pump discharge fluctuations and frictional head losses associated with movement of water through the well casing. Late time data can be used to calculate a second transmissivity which is more representative of the aquifer's properties over extended periods of pumping (small u in Jacob formulation). Water-level fluctuations associated with the start of a pump test do not influence the calculation of transmissivity using late time data.

To establish the transmissivity and storativity range of an aquifer, tests of different duration, type and associated analysis technique need to be performed at the same well location. Although longer tests do provide more precise information as to representative aquifer transmissivity, the short duration tests give an order of magnitude estimate of this parameter. Note that parameters calculated from aquifer tests and associated analyses will be used to define a range of values that are used in aquifer simulations. Usually the transmissivity and storage coefficient are varied in the computer analysis of a ground-water system in order to historically match head values. It is the range of the aquifer parameter that is important, not the absolute value.

Therefore, most tests performed at Hanford are believed to be acceptable from either a theoretical or practical point of view. The analytical techniques used to examine the test data are generally valid for use in unconfined systems and the tests have been performed over adequate lengths of time. Tests that have been run less than 6 hours have questionable merit.

If delayed yield from storage, leakage or any other unusual phenomenon is anticipated, or observed during testing, the aquifer test should be extended in order to calculate transmissivity. The storage coefficient is a very sensitive parameter in modeling analyses and should be calculated from long duration tests with one or more observation wells. In the future, it is recommended that aquifer tests be run for at least 24 hours.

3.2.5 Summary of Aquifer Properties

Large differences in hydraulic conductivity are evident between the Hanford formation and the middle member of the Ringold formation, the major geologic units of the unconfined aquifer. The Hanford formation consists of loose, permeable sands and gravels; whereas the middle Ringold contains more fine-grained material, is more compact, and occasionally is semiconsolidated. The Hanford formation normally exhibits a hydraulic conductivity between 600 and 3000 meters/day (2000 and 10,000 feet/day); the middle Ringold averages 30 meters/day (100 feet/day) (Table 11). The large difference in the range of hydraulic conductivities for these geologic horizons suggest that it is reasonable to utilize results of pumping tests to aid in determining the horizon being tested. Analysis of data from a short pumping test conducted in the 200 East Area gives a hydraulic conductivity of 1100 meters/day (3700 feet/day) for the aquifer. Though the horizon tested is thought to be composed of Ringold sediments, the large hydraulic conductivity is more representative of Hanford formation gravels.

Aquifer properties can also be delineated based on location (Table 11). In general, the 200 West Area unconfined system displays a lower transmissivity than the 200 East Area. This lower value can be attributed to the thickening of the Ringold formation in the 200 West Area. Higher transmissivities in the unconfined system in the 200 East Area can be attributed to the presence of the Hanford formation gravels and cobbles (Figure 4).

The ranges of transmissivities and hydraulic conductivities that describe the Hanford and middle Ringold sediments fall into the range of values typically reported for unconfined aquifers. The lower Ringold calculated range of transmissivity is within the range of confined aquifer values. The high barometric efficiencies associated with wells completed through the Ringold substantiate this conclusion. Although barometric water-level fluctuations have been observed in water-table aquifers, high barometric efficiencies are usually restricted to confined systems. The barometric efficiency of the aquifer at well 699-47-35 was calculated to be above 70%. This well was completed through to the lower Ringold and indicates the confined nature of the horizon.

TABLE 11. Ranges of Hydraulic Properties of the Unconfined Aquifer in the Separations Area.

Interval Tested	Hydraulic Conductivity	
	m/day	ft/day
Hanford formation	600-3,000	2,000-10,000
Middle Ringold Unit	3-70	9-230
Lower Ringold Unit	1-3.6	1-12
Region	**Transmissivity**	
	m/day	ft^2/day
200 West	28-500	300-5400
200 East	0.5-12,500	5-135,000

Within the unconfined aquifer, storativity ranges from 0.002 to 0.07, the lowest value associated with the lower Ringold formation and the higher value associated with the Hanford formation. Specific yield has been estimated at two locations, wells 699-47-35 and 699-37-82, where values of 0.15 and 0.18 were calculated. Storativity generally decreases as the confined nature of the aquifer system increases; again, this parameter indicates the confined nature of the lower Ringold since 0.002 falls into the range of values commonly reported for confined aquifers.

The effective porosity for the sediments in the unconfined aquifer ranges between 10% and 30%. The lower value can be correlated with sediments of the lower Ringold, while the upper range approaches the total porosity of the Hanford formation sediments.

The anisotropic character of the unconfined aquifer has been suspected from various testing results and well log examinations. The anisotropic nature of the unconfined aquifer was quantified at well 699-47-35 where Kh/Kv was determined to range between 16 and 13. This high value gives an indication of preferred horizontal flow through the unconsolidated sediments rather than vertical flow through the aquifer. Vertical flow occurs in the unconfined aquifer, but apparently is inhibited by clay, silt, and fine sand lenses.

3.2.6 Conclusions

The following conclusions have been reached on the aquifer properties in the Separations Area.

- Pump test analyses such as Theis and Cooper-Jacob, which are usually used in the analysis of confined aquifer systems, can be used to estimate transmissivity in the unconfined aquifer at Hanford.
- Although longer pump tests give a more realistic picture as to representative aquifer properties, short duration tests (8 to 12 hours) can be used to estimate transmissivity. Tests conducted less than 6 hours have questionable merit.
- Ranges of values for transmissivity, hydraulic conductivity, and storativity are of greater worth in aquifer analyses than absolute values. Multiple testing procedures and analyses should be adopted as standard procedure for future work in order to delineate a range of values of aquifer simulations.
- Transmissivity can be correlated to lithology and location within the Separations Area. The Hanford formation has an associated range of hydraulic conductivities an order of magnitude higher than the middle Ringold. The lower Ringold transmissivity has the lowest formational hydraulic conductivity. Transmissivities tend to increase from west to east throughout the Separations Area due to the thinning of the Ringold formation.
- Data exist suggesting that the lower and basal Ringold act as a confined aquifer. Transmissivity, hydraulic conductivity, storativity, barometric efficiency, and pump test data all point to this conclusion. The lower Ringold should be examined in the future as a confined system adjacent to an unconfined system.

3.3 FLOW DYNAMICS by M. J. Graham

3.3.1 Recharge

3.3.1.1 Introduction. Natural recharge to the unconfined aquifer under the Separations Area is from the Cold Creek and Dry Creek Valleys to the west of the Separations Area (Plate 2). It is estimated that, prior to 1952, 3,700,000 liters/day (980,000 gallons/day) recharge entered the area from these valleys (Newcomb et al., 1972). Of this total, approximately 59% is attributed to infiltration from irrigation and leakage into the unconfined aquifer from faulty water supply wells tapping the confined aquifers. These wells were repaired in 1952 and irrigation was discontinued in 1954. After this time, recharge of the unconfined aquifer occurred by infiltration of water from Cold Creek and Dry Creek. Newcomb et al., (1972) estimate recharge of 1,000,000 liters/day (268,000 gallons/day) from Cold Creek and 500,000 liters/day (132,000 gallons/day) from Dry Creek.

The hydrograph of the unconfined well 699-43-104 in Cold Creek Valley indicates the decline of water levels from 1958 to 1969 in response to the cessation of irrigation practices (Figure 7). The continual rise in the water table since the early seventies indicates the response to renewed irrigation in the Cold Creek Valley since that time.

Artificial recharge from waste disposal practices in the Separations Area has had a profound effect on the flow system of the unconfined aquifer. As of the end of 1979, approximately 6×10^{11} liters (1.6×10^{11} gallons) of liquid wastes had been discharged to the ground. The onset of waste cooling water disposal to ponds in late 1944 began to artificially recharge the unconfined aquifer at a rate which exceeded the ability of the sediments to transmit this water. This caused the formation of ground-water mounds under the high volume disposal sites. The water table has responded to the varying discharges to those disposal sites over the past 36 years. See Kipp and Mudd (1974) for historical water-table maps. The present day water-table configuration is dominated by artificial recharge mounds under U-Pond and B-Pond (Plate 2).

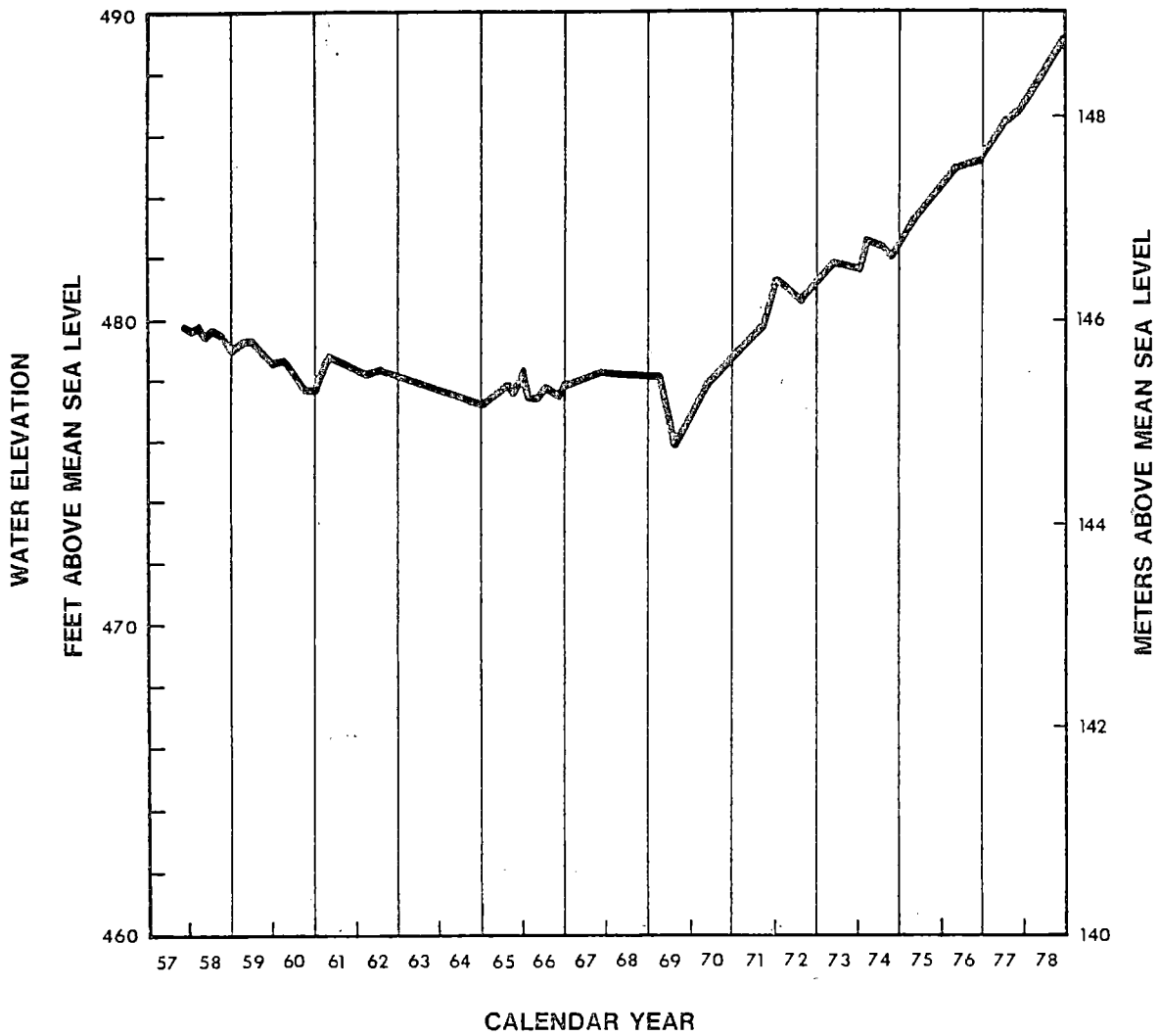


FIGURE 7. Water-Level History Well 699-43-104.

3.3.1.2 Natural Recharge. Recharge or inflow into the Separations Area from Cold Creek Valley is estimated from hydraulic gradients and aquifer properties in the following equation:

$$Q = K\ m\ I\ L,$$

where

Q = quantity of water entering the area
K = the hydraulic conductivity
m = thickness of aquifer
I = hydraulic gradient
L = length of boundary

The hydraulic conductivity is taken as 12 meters/day (40 feet/day); the thickness along the boundary is approximately 60 meters (200 feet), the gradient is about 0.002 (Plate 2); and the length is 3,000 meters (10,000 feet). From equation 1 a natural recharge of 5×10^6 liters/day (1.3×10^6 gallons/day) is estimated for the Separations Area from Cold Creek Valley.

3.3.1.3 Artificial Recharge. Artificial recharge is assumed to be the total volume of liquid wastes discharged to the ground. Evaporation losses are considered to be within the error of the calculated discharges and thus are not considered. A total of 2×10^{10} liters of waste water was discharged to the ground in the Separations Area in 1979. This is a daily average of 55×10^6 liters/day (15×10^6 gallons/day), or approximately 10 times the estimated natural recharge rate.

3.3.2 Movement

3.3.2.1 Introduction. Prior to Hanford disposal practices, the natural direction of ground-water flow through the Separations Area was west to east (Plate 3). Horizontal flow gradients were on the order of 0.3 to 1.0 meter/kilometer (1.5 to 6 feet/mile). Vertical gradients were probably negligible, as the area was not immediately adjacent to recharge or discharge areas. Present day horizontal gradients exceed 10 meters/kilometer (50 feet/mile); downward vertical gradients exceed 10% in some areas.

The conceptual model of unconfined ground-water flow presented herein is based upon a study of the present day horizontal and vertical potential gradients. Knowledge of the hydraulic properties of the saturated sediments and the migration characteristics of contamination away from waste disposal facilities also aided in the formulation of this model. Horizontal gradients are obtained from a detailed plot of the water-table elevation in December, 1979 (Plate 4). (Data used to construct Plate 4 are given in Appendix B). The vertical gradients are obtained from a piezometer network initiated in 1974 (Appendix C).

3.3.2.2 Conceptual Flow Model. Flow lines are drawn perpendicular to the water-table contour, equipotential, lines indicating directions of flow (Plate 4). Ground-water flow patterns are dominated by the ground-water mounds under U-Pond and B-Pond. The movement of ground water from west of U-Pond is redirected around the mound. Flow from U-Pond is primarily toward the east; gradients are extremely steep, greater than 10 meters/kilometer (50 feet/mile). Between the 200 East and 200 West Areas the gradient abruptly flattens out. This is attributed to an increase in the hydraulic conductivity of the sediments and a drop in the basalt surface which causes almost a 40% increase in the thickness of the saturated zone. This essentially causes a "pooling" of the ground water in this area. The flow system in 200 East Area is complex due to this change in the aquifer thickness and hydraulic properties, the influence of B-Pond, and the complicated structures of the Gable Mountain-Gable Butte area. The configuration of the basalt above the water table is construed from Plate 3-4a, Myers/Price et al., (1979). Flow out of 200 East Area is to the north, through Gable Gap and south along a ground-water trench defined by the 402 foot contour interval (Plate 4). Flow from B-Pond is radially outward to the east and combines with the flow paths out of 200 East Area.

The vertical flow components of the system are investigated along a cross section (Figure 8) from Cold Creek to the Columbia River (see Plate 2 for location). Natural recharge is evident from the downward gradients in Cold Creek Valley. The natural flow system is intercepted by the 200 West Area artificial flow system. Flow from U-Pond and other

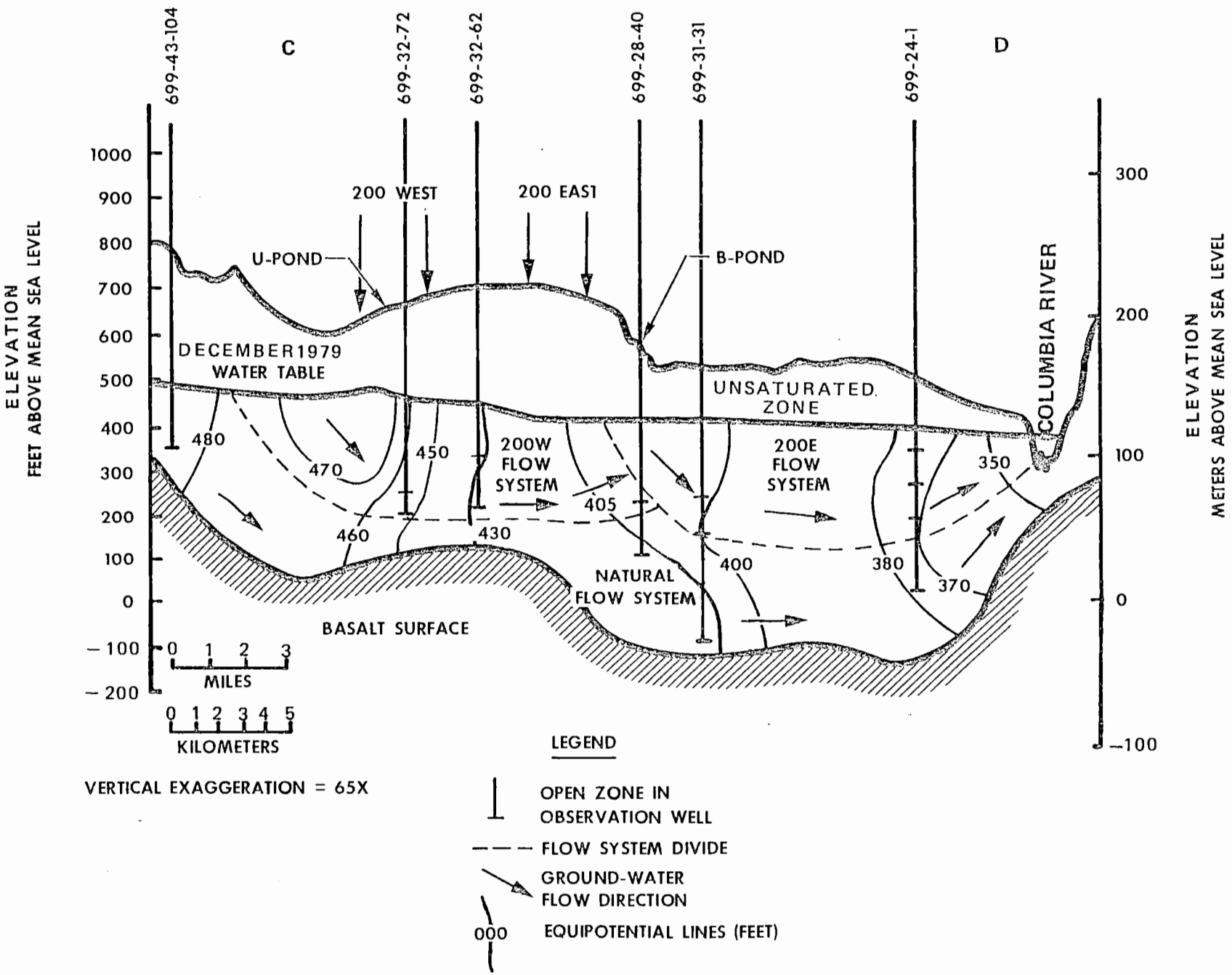


FIGURE 8. Equipotential Lines and Flow Systems Along Cross Section C-D. Refer to Plate 2 for Location of Cross Section.

disposal facilities in 200 West Area moves downward and to the east (right on Figure 8). Flow lines rotate to horizontal between East and West Areas. This is probably due to the confining nature of the lower Ringold formation. The beds of this formation act as aquitards, restricting the flow from deeper sections of the aquifer. The flow lines then trend upward, intercepting the 200 East flow system. South of the 200 East Area, the flow paths from B-Pond and 200 East may be restricted to the upper reaches of the aquifer by the influence of the 200 West Area flow system. The flow from both systems then moves east toward the Columbia River. The natural flow system operates under these artificial flow systems and may be a separate confined system in some areas.

3.3.2.3 Flow Velocities. Tracer tests run east of the Separations Area (Bierschenk, 1959a) give flow velocities averaging 25 meters/day (82 feet/day). Movement of tritium out of the 200 East Area also gives an indication of ground-water velocities in this area. The contamination plume had moved approximately 13 kilometers (8 miles) in 24 years (Denham, 1970). This indicates an average flow on the order of 1.5 meters/day (5 feet/day). This is still much lower than the velocities calculated from Bierschenk's tracer tests, which run as high as 27 meters/day (90 feet/day). The velocity calculated from the movement of tritium averaged more than 13 kilometers; lower and higher velocities in places along the flow path are to be expected. Tritium contamination out of the 200 West Area has apparently migrated only 4 kilometers (2.5 miles) since startup of disposal practices (Eddy and Wilbur, 1980). This indicates a flow velocity of 0.3 meter/day (1.0 foot/day). This velocity seems low; even though the sediments are less permeable than in 200 East Area, the hydraulic gradients are much steeper. The contamination plumes are defined only for the top of the aquifer (see Section 3.4). Therefore, the contamination could have migrated away from U-Pond farther than these plumes indicate, that is, along flow lines to deeper parts of the aquifer.

Based on computer simulation and dye tracing, Brown et al. (1979) estimate travel time to the Columbia River from West Area as 120 years, with an average flow velocity of 0.61 meter/day (2 feet/day). Using the flow velocities calculated from the tritium migration, travel time from 200 West Area to the western boundary of 200 East Area, where the aquifer extends into the Hanford formation, is 50 years (5,500 meters ÷ 110 meters/year). The travel time from 200 East Area to the Columbia River is similarly calculated as 30 years (1600 meters ÷ 540 meters/year). Thus the travel time from 200 West Area to the Columbia River is estimated as 80 years. These estimates can be refined by dye tracing studies along the entire flow path from 200 West area to the Columbia River.

3.3.3 Discharge

Discharge out of the Separations Area is predominantly toward the east and southeast to the Columbia River (Plate 4), where the water table extends into the Hanford formation. There is some discharge out of the area to the north through the Gable Gap area. Flat hydraulic gradients and the complex flow system prevent a quantification of discharge at this time, although the discharge will equal recharge over a period of time. The driving force for this downward leakage is that water-table elevations are higher than piezometric surface elevations, due to waste disposal practices. This potential probably exists over much of the Separations Area.

3.4 WATER QUALITY

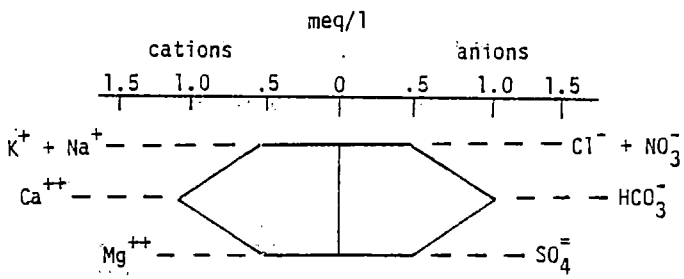
3.4.1 Introduction

Inorganic water quality data for the unconfined aquifer in the Separations Area were obtained primarily from samples taken by the U.S. Geological Survey and PNL (refer to Section 2.1.6). Data on the

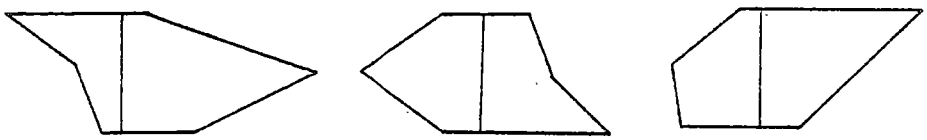
radionuclide concentrations were obtained through the Rockwell ground-water monitoring network in 1979 (Wheeler and Law, 1980). All of these wells are completed in the top section of the aquifer.

3.4.2 Inorganic Water Quality

In the Separations Area the chemical composition of unconfined waters can be classed as calcium-bicarbonate, sodium-bicarbonate and calcium-sulfate. The chemical data for individual wells are displayed graphically by Stiff diagrams (Plate 5). The shape and size of the Stiff diagram gives an indication of the composition of the water and the concentrations of the various constituents. The Stiff diagrams on Plate 5 are constructed by plotting the milliequivalents per liter (meq/l) of the anions on the right and the cations on the left in the following fashion:



This water would be chemically classified as calcium-bicarbonate in nature. The other types of ground-waters are shown on the following generalized Stiff diagrams.



sodium-bicarbonate calcium-sulfate nitrate contamination

Overall, the prevalent chemical character of the unconfined ground-water in the Separations Area is calcium-bicarbonate. Although there are not adequate data to define flow paths, inferences can be

drawn. Calcium-sulfate waters are located in the northern part of the area, above 200 West Area and the western half of 200 East Area. The calcium-sulfate is probably due to the dissolution of gypsum. East of Well 699-49-55, the water changes abruptly to a calcium-bicarbonate type. This may be due to the change in flow direction from eastward to northward in this area (Plate 4).

The water south of 200 West Area is predominantly calcium-bicarbonate in nature. Sodium-bicarbonate waters are prevalent to the east of 200 East Area. There is a gradual change from sodium to calcium-bicarbonate waters southeast of East Area (Wells 699-37-43 to 699-34-39A to 699-28-40). This is probably due to the mixing of the sodium-bicarbonate water moving southeast out of 200 East Area and B-Pond with the calcium-bicarbonate water moving from the east (Plate 5).

These inferences are based upon limited data. As more data on the flow system and the hydrochemistry are obtained, the movement and mixing of waters can be better defined.

3.4.3 Contamination Plumes

As part of the Surveillance and Maintenance Program at Rockwell, a ground-water monitoring network is maintained. Over 100 wells in the Separations Area are sampled on a regular basis, ranging from monthly to semi-annually. These samples are selectively analyzed for total alpha, total beta, strontium-90, cesium-137, cobalt-60, ruthenium-106, tritium, uranium, and nitrate. Pacific Northwest Laboratory maintains a similar monitoring network for the entire Hanford Site. Results from these two monitoring programs for total beta, nitrate, and tritium concentrations (Wheeler and Law, 1980; Eddy and Wilbur, 1980) are shown on Plates 6, 7, and 8. The isopleth lines are based upon the known distribution of the contaminant concentrations and an understanding of the flow system. The purpose of this effort is to examine the present-day extent of ground-water contamination in the Separations Area and the general relationships between contamination distribution and the flow system. The sources of contamination and the movement of these contaminants from their sources are being examined in detail.

The contamination of the ground water originates from various liquid waste disposal facilities. Nitrate, tritium, and total beta contamination have migrated away from these sites in a general west to east direction (Plates 6, 7 and 8) along major flow lines (Plate 4). Data used to construct Plates 6, 7, and 8 are given in Appendix D. Analysis of data from the ground-water monitoring network indicates that contamination levels in ground water migrating out of the Separations Area are below DOE Manual Chapter (MC) 0524 concentration guides for water in an uncontrolled area. The contamination from U-Pond and 200 West Area has not migrated as far and appears to have dispersed less than contamination originating from 200 East Area and B-Pond. This difference is attributed to the flow system and the change in hydraulic properties from west to east. Underflow from U-Pond (Figure 8) may be carrying contamination away from the pond to deeper parts of the aquifer under the open interval of the monitoring wells. The wells of the monitoring network tap only the upper section of the aquifer, typically the top 12 meters (40 feet). This is further evidenced by the abrupt disappearance of contamination from well 699-38-70 to well 699-38-65 (Plate 5) along a major flow line from U-Pond. The flow lines in the 200 West Area flow system trend upward under the area south of 200 East Area (Figure 8). This flow system may then be "holding up" the contamination from 200 East Area and B-Pond in the upper sections of the aquifer where the highly transmissive Hanford formation sediments are dominant. Thus, the rapid migration of contaminants away from 200 East Area and B-Pond may be due to a combination of highly transmissive sediments and the influence of the flow system from U-Pond.

At the time the monitoring wells were constructed, it was felt that the contamination was restricted to the upper reaches of the aquifer. In a study of vertical contamination (Eddy, et al., 1978), concentrations were found to be relatively higher near the surface of the flow system. This study was conducted southeast of 200 East Area where upward flow is indicated (Figure 8). There is evidence of contamination in the bottom of the aquifer in 200 East Area (Smith, 1980).

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4.0 SUMMARY

The Separations Area, located near the center of the Hanford Site, contains the major radioactive waste storage and disposal facilities. A thorough understanding of the unconfined aquifer underlying this area is necessary for the effective management of radioactive wastes. The purpose of this document is to integrate present knowledge to characterize the hydrologic system underlying the Separations Area.

The unconfined aquifer is contained within the Ringold formation, a Pliocene sedimentary unit with some lacustrine sediments; and glacio-fluvial sediments informally named the Hanford formation. Based upon texture, the Ringold formation is divided into four major units: the basal, lower, middle, and upper units with the aquifer dominated by the middle Ringold unit. The bottom of the unconfined aquifer is the basalt surface of the Saddle Mountains basalt or, in some areas, the clay zones of the lower member of the Ringold formation.

Large differences in hydraulic conductivity exist between the Hanford formation and the middle member of the Ringold formation. The lower Ringold acts as a separate confined aquifer system. The Hanford formation exhibits a hydraulic conductivity between 600 and 3,000 meters/day (2,000 and 10,000 feet/day) the middle Ringold ranges 3 to 70 meters/day (9 to 230 feet/day). Storage coefficents range from 0.002 to 0.07; the lowest value being associated with the lower Ringold, the highest value with the Hanford formation. The unconfined aquifer is highly anisotropic, with horizontal to vertical conductivity ratios of 13 to 16.

Natural recharge to the Separations Area is from Cold Creek Valley. Artificial recharge, assumed to be the total volume of liquid wastes discharged to the ground, is estimated at 10 times the natural recharge rate. Discharge out of the Separations Area is predominantly toward the southeast to the Columbia River. Ground-water flow patterns are dominated by the ground-water mounds under U-Pond and B-Pond. Horizontal gradients resulting from these mounds are up to 10 meters/kilometers (50 feet/mile); downward vertical gradients are as high as 10%. Three

distinct flow systems exist in the unconfined aquifer: a 200 West Area flow system which does not penetrate the entire thickness of the aquifer and which intercepts flow out of 200 East Area; a 200 East Area flow system which is restricted to the upper reaches of the aquifer due to the influence of the 200 West Area flow system and the anisotropy of the aquifer; and a natural flow system operating underneath the artificial flow systems. Flow velocity estimates for the 200 West Area average less than 1 meter/day. For 200 East Area, in the more transmissive Hanford sediments, these estimates range from 2 to 27 meters/day (7 to 90 feet/day). Travel times from 200 West Area to the Columbia River range from 80 to 120 years.

The chemical composition of the unconfined waters can be classed as calcium bicarbonate, sodium bicarbonate, and calcium sulfate. Overall, the prevalent chemical character of the unconfined ground water in the Separations Area is calcium bicarbonate. The distribution of the chemical compositions is used to infer flow paths. The contamination from 200 East and 200 West Area facilities indicate directions of flow. The contamination from 200 West Area has not migrated as far and appears to have dispersed less than contamination originating from 200 East Area. This difference is attributed to the flow system and the change in hydraulic properties from west to east. Analysis of data from the ground-water monitoring network indicates that contamination levels in ground water migrating out of the Separations Area (200 Areas) are below DOE MC 0524 concentration guides for water in an uncontrolled area.

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APPENDIX A

PUMPING TEST ANALYSES

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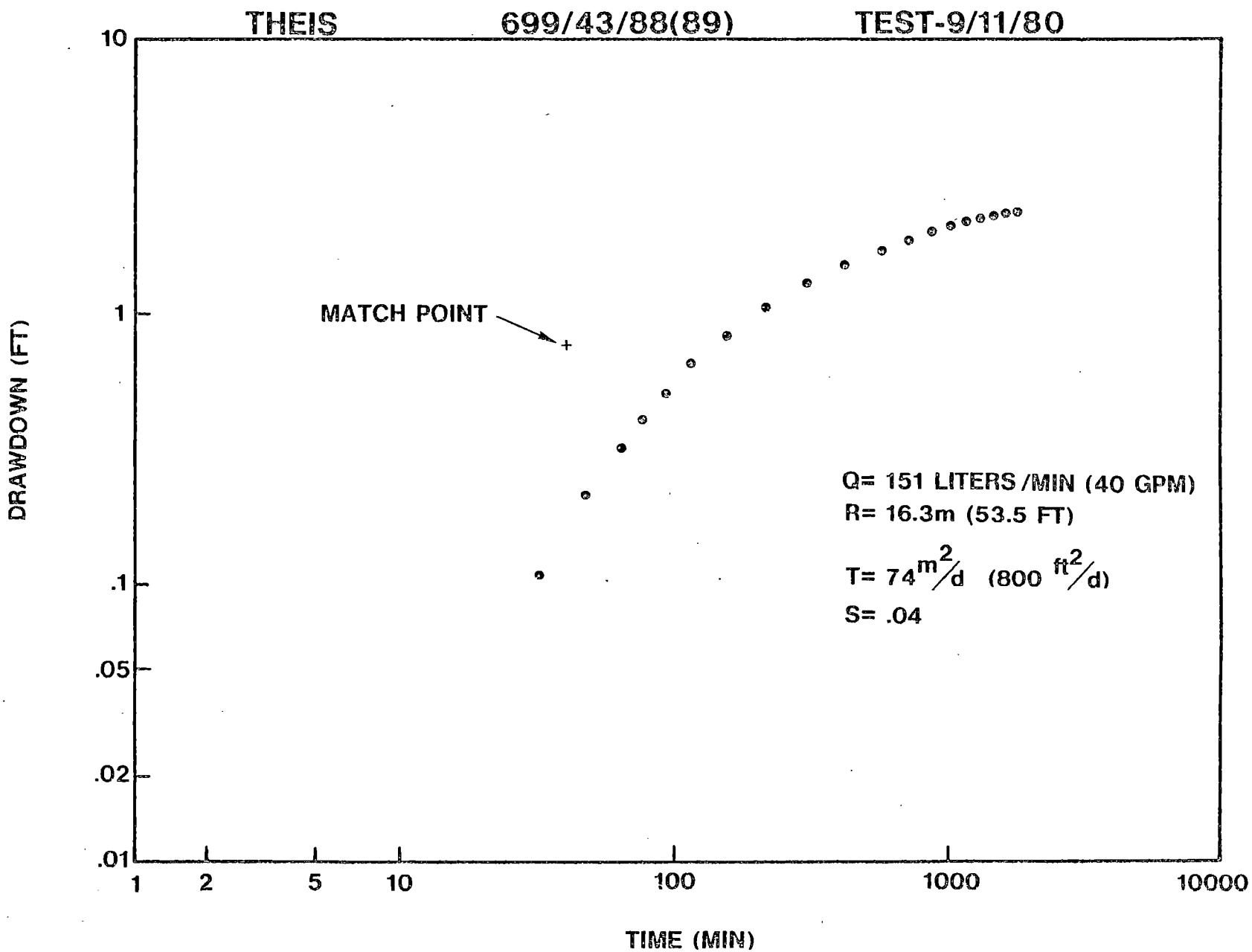

FIGURE A-2. Pumping Test Analysis Well 699-43-88(89).

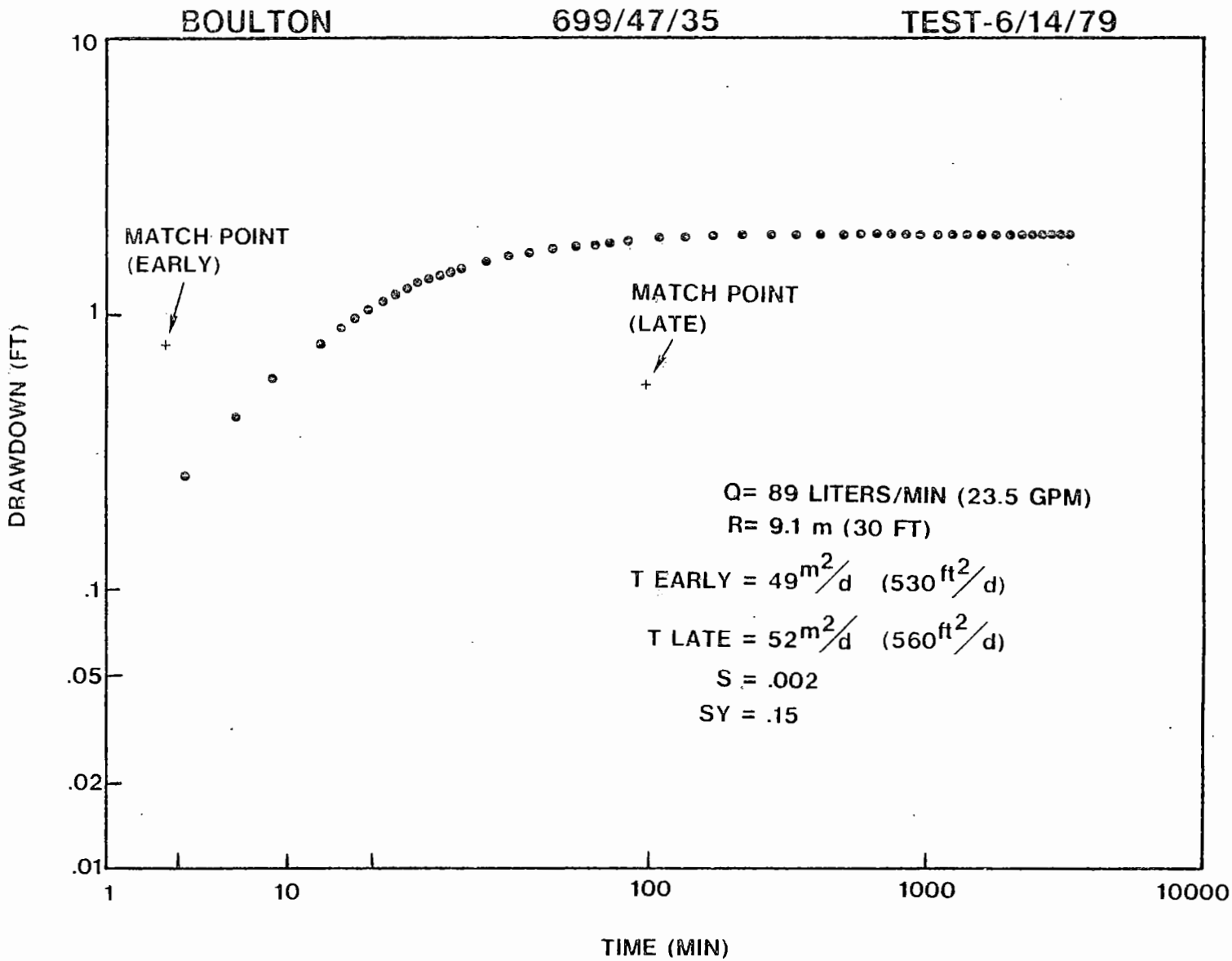

FIGURE A-2. Pumping Test Analysis Well 699-47-35.

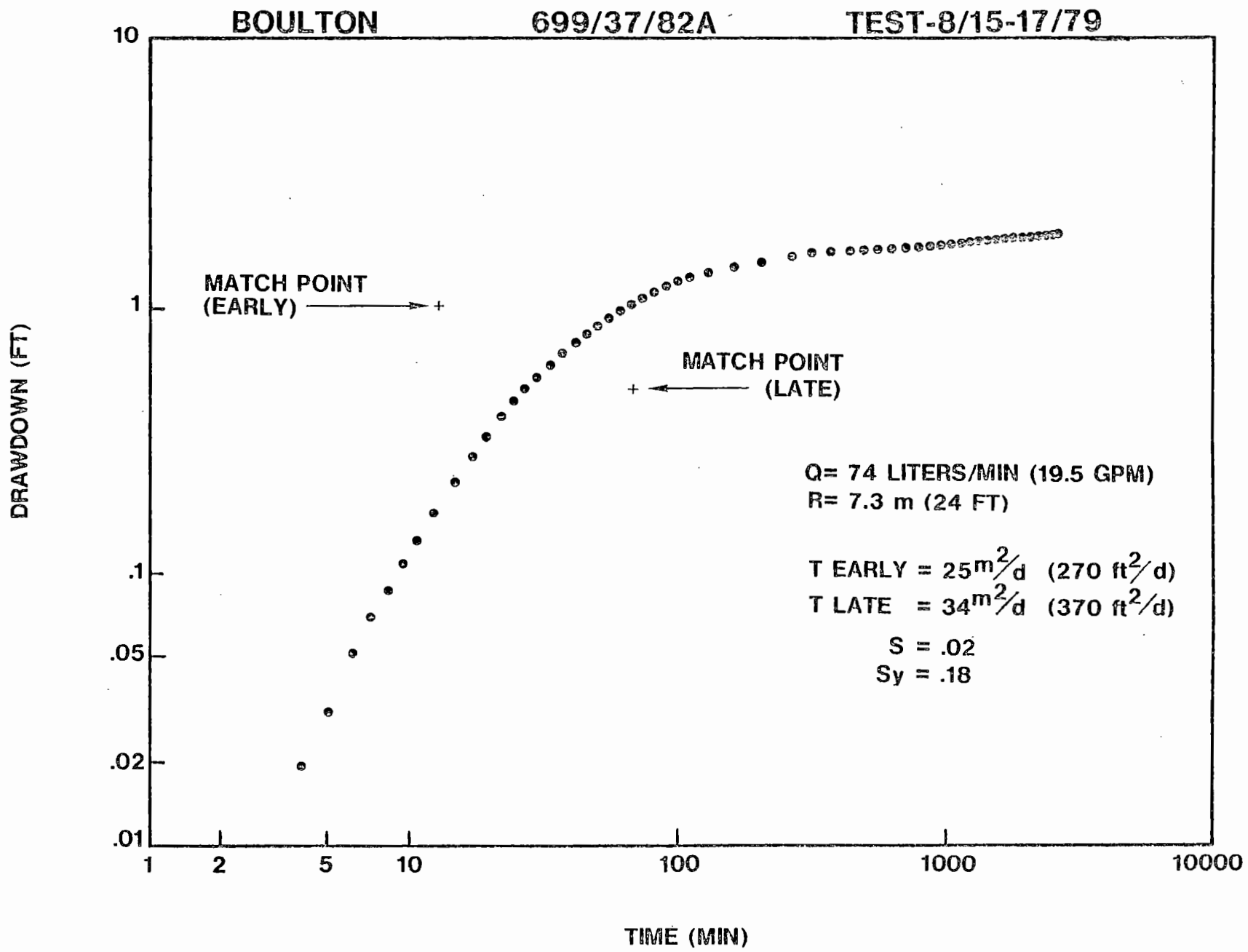

FIGURE A-3. Pumping Test Analysis Well 699-37-82A.

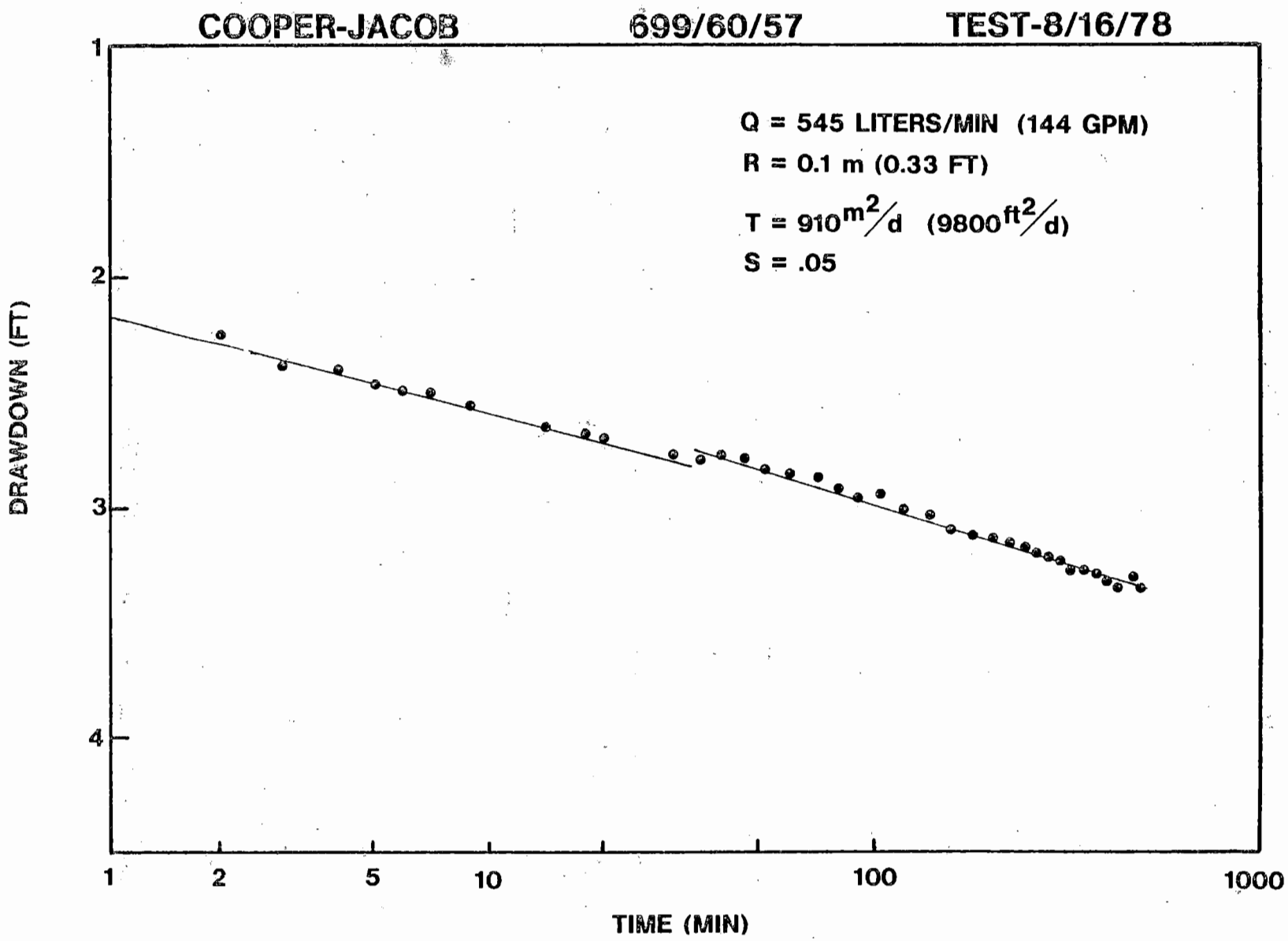

FIGURE A-4. Pumping Test Analysis Well 699-60-57.

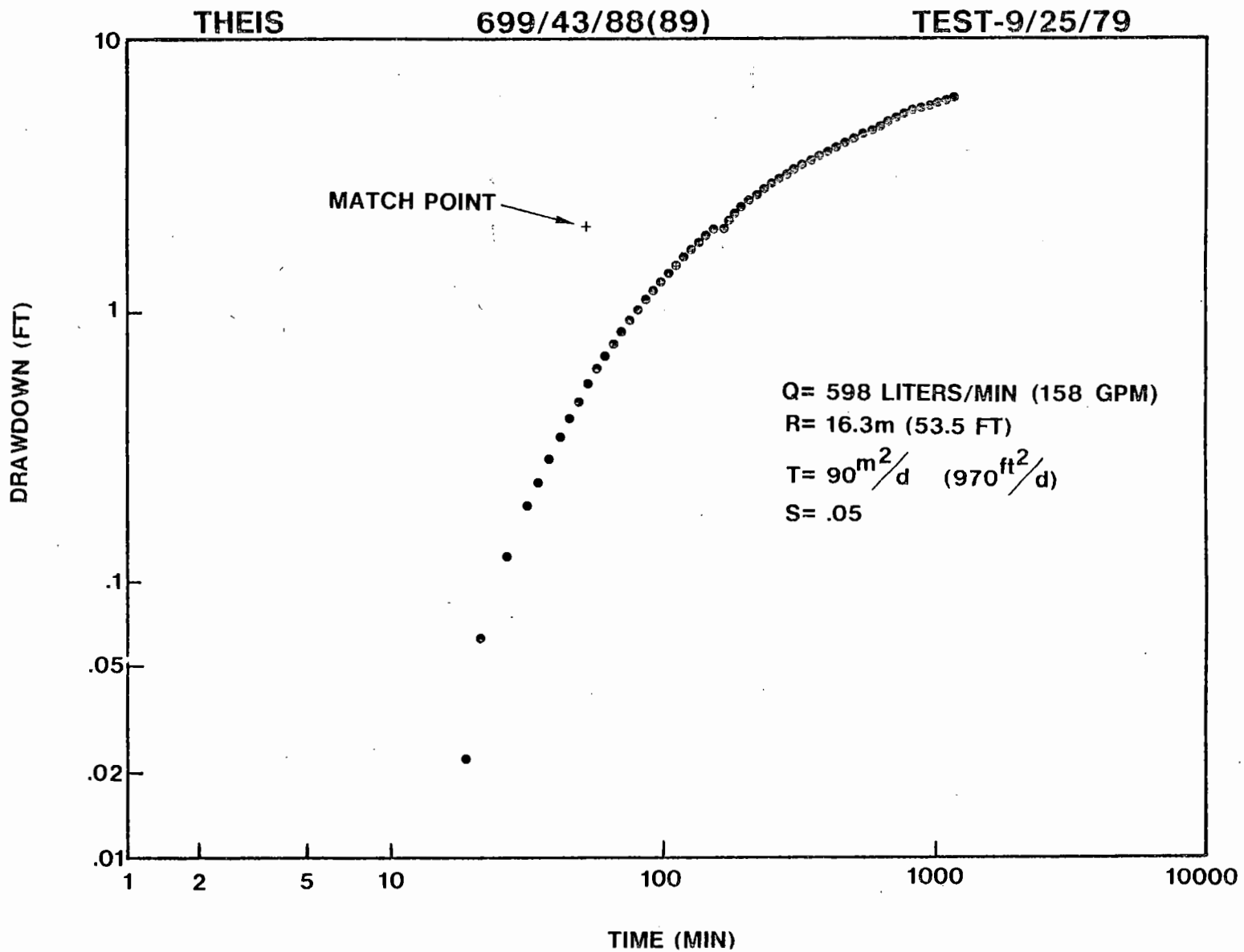

FIGURE A-5. Pumping Test Analysis Well 699-43-88(89), 9/25/79.

APPENDIX B

WATER-LEVEL ELEVATIONS

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TABLE B-1. Water Level Elevations.

Well Number	Casing Elevation	Depth to Water	Water Level Elevation
299-E13-3	741.48	338.40	403.08
299-E13-12	731.34	328.29	403.05
299-E13-14	742.85	339.50	403.35
299-E16-1(R)	696.40	294.03	402.37
299-E16-2	680.56	278.18	402.38
299-E17-1	718.88	316.41	402.47
299-E19-1	736.00	331.89	404.11
299-E23-1	709.65	306.88	402.77
299-E23-7(0)	721.00	318.47	402.53
299-E24-4	697.00	294.26	402.74
299-E24-7	716.32	313.56	402.76
299-E24-3	691.81	288.98	402.83
299-E25-4	659.39	254.86	404.53
299-E25-11	681.51	278.58	402.93
299-E26-1	616.25	214.15	403.10
299-E26-4	645.50	244.39	403.11
299-E27-1	681.05	278.19	402.86
299-E27-3(0)	683.53	280.80	402.73
299-E28-7	685.91	283.99	401.92
299-E28-8	668.52	265.82	402.70
299-E28-18	692.58	289.87	402.71
299-E32-1	656.17	253.49	402.68
299-E33-7	625.99	224.22	401.77
299-E33-8	648.04	245.28	402.76
299-E33-12	623.60	219.41	404.19
299-E33-14	622.12	219.34	402.78
299-E33-17	631.66	229.00	402.66
299-E34-1	629.42	226.69	402.73
229-W6-1	702.53	241.68	460.85

TABLE B-1. Water Level Elevations (Continued).

Well Number	Casing Elevation	Depth to Water	Water Level Elevation
229-W10-2	674.33	204.50	469.83
229-W10-5	672.31	200.82	471.49
229-W10-8	680.33	210.77	469.56
229-W11-2(0)	714.75	250.02	464.73
229-W11-7	709.11	238.60	470.51
229-W11-9	722.94	261.10	461.84
229-W11-10	728.89	269.95	458.94
229-W11-12	679.58	210.25	469.33
229-W11-13(0)	692.27	222.53	469.74
229-W11-23	686.12	216.54	469.58
229-W12-1	726.46	273.30	453.16
229-W14-1	665.83	194.70	471.13
229-W15-2	690.71	217.60	473.11
229-W15-4	662.00	186.86	475.14
229-W19-1	674.04	192.61	481.43
229-W19-3	695.12	221.27	473.85
229-W19-4(0)	715.52	250.80	464.72
229-W21-1	699.26	238.48	460.78
229-W22-7	687.41	219.88	467.53
229-W22-17	672.00	196.86	475.14
229-W22-22	690.38	223.83	466.55
229-W22-33	675.00	204.11	470.89
229-W22-35	681.00	204.12	476.88
229-W23-4	662.82	180.86	481.96
229-W23-11	664.14	184.58	479.56
699-24-46	591.47	187.85	403.62
699-25-55	676.55	264.50	412.05
699-25-70	629.58	177.74	451.84
699-28-40	599.44	157.66	401.78
699-28-52	684.67	275.50	408.97
699-29-78	647.05	176.28	470.77

TABLE B-1. Water Level Elevations (Continued).

Well Number	Casing Elevation	Depth to Water	Water Level Elevation
699-32-43	516.62	114.52	402.10
699-32-70	666.61	210.59	456.02
699-32-72	668.16	209.06	459.10
699-32-77	653.74	183.30	470.44
699-33-42	518.00	113.80	402.20
699-33-56	717.03	313.43	403.60
699-34-39A	537.07	135.06	402.01
699-34-41	570.89	168.70	402.19
699-34-42	540.20	138.00	402.20
699-34-51	736.76	333.86	402.90
699-35-66	725.65	284.37	441.28
699-35-70	693.72	283.03	455.69
699-35-78	660.65	182.55	478.10
699-36-46R	705.13	302.56	402.57
699-36-61A	748.11	339.99	408.12
699-37-43	690.17	287.58	402.59
699-38-65	753.33	320.96	432.37
699-38-70	710.67	253.49	457.18
699-39-39	536.66	129.42	407.24
699-39-79(0)	674.27	195.47	478.80
699-40-62	747.78	342.54	405.24
699-44-64	725.57	319.53	406.04
699-45-42	577.33	163.83	413.50
699-45-69	725.46	276.46	448.85
699-47-35B	476.65	68.47	408.18
699-47-46	580.14	176.64	403.50
699-47-60	649.85	247.35	402.50
699-48-71	688.15	241.74	446.41
699-49-55	530.14	127.66	402.48
699-49-57	552.81	150.32	402.49
699-49-79	688.59	230.47	458.12

TABLE B-1. Water Level Elevations (Continued).

Well Number	Casing Elevation	Depth to Water	Water Level Elevation
699-50-42	466.84	58.96	407.88
699-50-53	556.30	153.78	402.52
699-51-63	671.84	167.06	404.78
699-51-75	641.51	191.78	449.73
699-53-47	438.28	29.96	411.32
699-53-55B	576.13	173.24	402.89
699-54-42	511.49	115.80	395.69
699-54-45	494.25	97.60	396.65
699-55-44	519.67	125.74	393.90
699-55-50C	444.43	41.48	402.95
699-55-70	569.04	138.53	430.51
699-55-76(0)	583.50	140.15	443.35
699-60-60	512.03	109.95	402.08

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APPENDIX C

PIEZOMETER NETWORK DATA

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TABLE C-1. Piezometer Network Data.

Well Number	Open Piezometric Interval Elevations		Head Value November - December 1979 Above Mean Sea Level		Observed Head Value Range December 1977 to November/December 1979	
	Meters	Feet	Meters	Feet	Meters	Feet
699-2-33A						
Open Casing	123.86 - 108.62	406.37 - 356.37	122.78	402.76	0.20	0.66
P	56.79 - 50.70	186.35 - 166.35	123.09	403.87	0.04	0.13
Q	72.13 - 65.94	236.35 - 216.35	123.06	403.74	0.05	0.16
699-10-E12						
Open Casing	113.03 - 27.69	370.86 - 90.86	108.46	355.86	1.12	3.68
P	21.59 - 20.07	70.86 - 65.86	114.68	376.26	4.09	13.45
Q	108.46 - 106.94	355.86 - 350.86	111.88	367.08	11.83	38.84
699-S12-29						
Open Casing	123.34 - 95.30	404.68 - 312.68	123.35	404.70	0.08	0.25
P	95.25 - 90.73	302.68 - 297.68	122.91	403.28	0.28	0.95
Q	102.31 - 100.79	335.68 - 330.68	123.09	403.85	0.18	0.58
699-14-E6						
P	-9.61 - 12.66	-31.56 - -41.56	115.17	377.86	4.39	14.41
Q	5.15 - 2.10	16.91 - 6.91	115.15	377.80	4.37	14.34
R	24.73 - 21.68	81.14 - 71.14	114.67	376.23	5.87	19.29
S	52.96 - 49.91	173.77 - 163.77	109.84	360.40	3.66	12.01
T	105.88 - 102.83	347.38 - 337.38	111.09	364.47	1.55	5.09
699-14-38						
Open Casing	123.41 - 32.27	404.89 - 105.89	122.76	402.76	0.08	0.26
P	30.44 - 28.92	99.89 - 94.89	123.94	406.64	0.05	0.18
699-20-E5						
P	6.71 - 3.66	22.04 - 12.04	115.69	379.59	2.36	7.74
Q	17.94 - 14.90	58.89 - 48.89	111.66	366.37	0.24	0.79
R	51.95 - 48.91	170.47 - 160.47	112.48	369.04	0.16	0.54
S	78.20 - 75.15	256.58 - 246.58	112.79	370.05	0.41	1.34
T	108.10 - 105.06	354.69 - 344.69	112.79	370.06	0.05	0.18

TABLE C-1. Piezometer Network Data (Continued).

Well Number	Open Piezometric Interval Elevations		Head Value November - December 1979 Above Mean Sea Level		Observed Head Value Range December 1977 to November/December 1979	
	Meters	Feet	Meters	Feet	Meters	Feet
69-20-30						
Open Casing	124.96 - -16.16	409.98 - -53.02	122.43	401.68	0.07	0.22
P	-20.73 - -23.78	-68.02 - -78.02	124.48	408.40	0.18	0.62
699-24-1						
P	8.70 - 5.65	28.55 - 18.55	115.70	379.60	1.77	5.83
Q	45.19 - 42.15	148.29 - 138.29	113.04	370.89	0.93	3.06
R	52.43 - 49.38	172.03 - 162.03	113.15	371.24	0.11	0.39
S	80.85 - 77.80	265.27 - 255.27	113.92	373.76	0.10	0.34
T	107.14 - 104.10	351.54 - 341.54	114.10	374.54	0.16	0.54
699-28-40						
Open Casing	124.79 - 72.98	409.44 - 239.44	122.49	401.89	0.12	0.42
P	32.74 - 29.69	107.44 - 97.44	124.11	407.19	0.17	0.57
Q	66.88 - 63.83	219.44 - 209.44	122.52	401.97	0.17	0.59
699-31-31						
Open Casing	120.18 - 79.04	394.32 - 259.32	122.31	401.29	0.11	0.37
P	-18.49 - -21.54	-60.68 - -70.68	123.83	406.28	0.14	0.46
Q	51.60 - 48.56	169.32 - 159.32	121.89	399.91	0.13	0.45
699-32-62						
Open Casing	131.70 - 111.88	432.09 - 367.09	*	*	*	*
P	66.16 - 64.64	217.09 - 212.09	130.66	428.67	0.19	0.63
Q	104.26 - 102.74	342.09 - 337.09	132.17	433.65	0.16	0.55

*No Measurement Taken.

TABLE C-1. Piezometer Network Data (Continued).

Well Number	Open Piezometric Interval Elevations		Head Value November - December 1979 Above Mean Sea Level		Observed Head Value Range December 1977 to November/December 1979	
	Meters	Feet	Meters	Feet	Meters	Feet
699-32-72						
Open Casing	139.64 - 77.16	458.16 - 253.16	139.93	459.10	0.32	1.04
P	61.92 - 60.39	203.16 - 198.16	138.07	452.99	0.22	0.74
699-38-65						
Open Casing	162.55 - 95.50	533.33 - 313.33	131.78	432.37	0.17	0.55
P	77.21 - 74.16	253.33 - 243.33	131.62	431.85	0.40	1.29
699-43-104						
Open Casing	217.64 - 123.77	714.07 - 406.07	149.44	490.29	0.47	1.56
P	105.48 - 103.95	346.07 - 341.07	147.97	485.48	0.21	0.69
699-50-42						
Open Casing	126.13 - 122.78	413.84 - 402.84	124.32	407.88	0.20	0.66
P	108.76 - 107.24	356.84 - 351.84	124.31	407.85	0.29	0.94
699-50-85						
Open Casing	138.48 - 123.24	454.35 - 404.35	139.04	456.17	0.71	2.34
P	66.85 - 65.33	219.35 - 214.35	136.18	446.81	0.27	0.87
699-51-75						
Open Casing	137.62 - 123.90	451.51 - 406.51	137.09	449.73	0.12	0.37
P	82.75 - 81.23	271.51 - 266.51	137.02	449.57	0.16	0.51
699-53-55A						
Open Casing	125.15 - 93.14	410.60 - 305.60	122.63	402.36	0.27	0.90
P	74.85 - 73.33	245.60 - 240.60	122.74	402.70	0.26	0.85
699-55-70						
Open Casing	131.98 - 118.75	433.03 - 389.60	131.20	430.47	0.10	0.32
P	115.52 - 114.00	379.03 - 374.03	131.21	430.50	0.14	0.47

TABLE C-1. Piezometer Network Data (Continued).

Well Number	Open Piezometric Interval Elevations		Head Value November - December 1979 Above Mean Sea Level		Observed Head Value Range December 1977 to November/December 1979	
	Meters	Feet	Meters	Feet	Meters	Feet
699-60-60						
Open Casing	125.58 - 122.53	412.03 - 402.03	122.55	402.08	0.61	2.01
P	119.49 - 117.96	392.03 - 387.03	122.56	402.12	0.26	0.84
699-67-51						
Open Casing	129.26 - 107.92	424.09 - 354.09	121.58	398.89	0.36	1.18
P	89.63 - 88.11	294.09 - 289.09	121.01	397.04	0.21	0.68
Q	103.65 - 100.61	340.09 - 330.09	121.55	398.79	0.15	0.49
699-96-49						
Open Casing	119.26 - 109.51	391.29 - 359.29	116.36	381.76	0.35	1.15
P	103.72 - 100.67	340.29 - 330.29	116.33	381.69	0.48	1.50

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APPENDIX D

AVERAGE CONCENTRATIONS OF NITRATE, TRITIUM AND BETA CONTAMINATION BY WELL NUMBER

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TABLE D-1. Average Concentrations of Nitrate, Tritium and Beta Contamination by Well Number.

Well Number	Average Concentration		
	Nitrate (NO_3) mg/l	Tritium pCi/ml	Beta pCi/ml
299-E13-5		<6.08E-01	a
299-E13-8			a
299-E13-14			7.90E-02
299-E13-19			a
299-E13-20			a
299-E16-1			a
299-E16-2			a
299-E17-1	8.30E+00		a
299-E17-2			<8.52E-02
299-E17-5	3.28E+01		9.63E-02
299-E17-6			a
299-E17-8			1.00E-01
299-E17-9	2.00E+02		a
299-E19-1	8.30E+00	<6.27E-01	9.88E-02
299-E23-1	1.73E+01	1.25E+01	a
299-E23-2	5.55E-01	1.03E+01	a
299-E24-1		3.25E+02	a
299-E24-2		2.96E+02	a
299-E24-4			a
299-E24-7	1.68E+01	5.23E+00	a
299-E24-8	5.95E+00	2.65E+01	a
299-E24-12			1.07E-01
299-E24-13			a
299-E25-2	5.85E+00	1.24E+02	a
299-E25-3			a
299-E25-6		6.17E+02	a
299-E25-9			a

a =< 7.50E-02

TABLE D-1. Average Concentrations of Nitrate, Tritium and Beta Contamination by Well Number (Continued).

Well Number	Average Concentration		
	Nitrate (NO_3) mg/l	Tritium pCi/ml	Beta pCi/ml
299-E25-10			a
299-E25-11			a
299-E25-13			a
299-E26-1	<5.00E-01	1.30E+00	a
299-E26-2			a
299-E26-3	5.68E+00	4.88E+01	a
299-E26-4		1.21E+02	a
299-E27-1	7.58E+00	1.48E+01	a
299-E27-5			a
299-E28-1	9.37E+00	1.00E+01	8.33E-02
299-E28-5	2.10E+01	<8.20E-01	a
299-E28-12		1.09E+02	a
299-E28-16	5.20E+00		a
299-E28-18			8.55E-02
299-E28-21			a
299-E32-1	6.70E+01	3.65E+01	8.20E-02
299-E33-1			1.64E+00
299-E33-3		6.10E+01	2.67E+00
299-E33-5			1.60E+00
299-E33-7			3.70E+00
299-E33-8			8.36E-02
299-E33-9	5.06E+02		2.91E-01
299-E33-10	4.26E+01	8.42E+00	1.16E-01
299-E33-14	2.45E+01	1.23E+00	8.38E-02
299-E33-18			1.23E-01
299-E33-21			a
299-E33-24			2.92E+00

a =< 7.50E-02

TABLE D-1. Average Concentrations of Nitrate, Tritium and Beta Contamination by Well Number (Continued).

Well Number	Average Concentration		
	Nitrate (NO_3) mg/l	Tritium pCi/ml	Beta pCi/ml
299-E33-26			2.03E+00
299-E33-27		3.33E+01	3.87E+00
299-E34-1	5.55E-01	9.80E-01	a
299-W6-1	1.70E+02	4.23E+01	a
299-W10-1			9.75E-02
299-W10-4			1.47E-01
299-W10-5	1.33E+02	3.15E+01	a
299-W10-8			1.01E-01
299-W10-9			7.93E-02
299-W11-9	7.75E-01	2.83E+00	1.41E-01
299-W11-11			1.12-E01
299-W11-13	2.65E+02	9.30E+01	1.05E-01
299-W11-15			a
299-W11-18			8.70E-02
299-W11-23			a
299-W11-24			1.18E-01
299-W12-1	1.93E+02	6.45E-01	a
299-W14-2	2.18E+02		9.75E-02
299-W14-5		2.83E+01	a
299-W14-6			a
299-W15-2	1.75E+01	8.13E-01	a
299-W15-3			8.67E-02
299-W15-4	6.58E+02	2.13E+03	a
299-W15-5	1.21E+01	2.25E+00	a
299-W15-6	7.33E+00		a
299-W15-7			1.17E-01
299-W15-10			1.50E-01

a =< 7.50E-02

TABLE D-1. Average Concentrations of Nitrate, Tritium and Beta Contamination by Well Number (Continued).

Well Number	Average Concentration		
	Nitrate (NO_3) (mg/l)	Tritium pCi/ml	Beta pCi/ml
299-W15-11			8.26E-02
299-W18-3	2.08E+00	4.50E+00	a
299-W18-5			a
299-W18-7			a
299-W18-12			8.40E-02
299-W19-2	1.22E+02	8.28E+01	7.66E-02
299-W19-3	5.33E+00	2.37E+00	1.30E-01
299-W19-4	1.09E+01	1.13E+00	a
299-W19-5	2.24E+00	2.07E+00	a
299-W21-1	9.08E+01	4.90E+03	2.75E-01
299-W22-1		2.21E+03	1.71E+01
299-W22-7	<5.00E-01	2.58E+03	a
299-W22-9	5.50E-01	1.14E+04	a
299-W22-12	7.00E+00	1.92E+03	a
299-W22-20			1.27E-01
299-W22-21	2.97E+00		1.17E-01
299-W22-22			a
299-W22-26		6.57E+02	7.85E-02
299-W22-27	2.90E+00	5.10E+00	a
299-W23-1			a
299-W23-2			a
299-W23-3			a
299-W23-4	<5.00E-01	7.28E+00	7.50E-02
299-W23-9		6.16E+02	7.79E-02
299-W23-10		1.02E+03	9.54E-02
299-W26-3	6.68E-01	8.17E-01	a

a =< 7.50E-02

TABLE D-1. Average Concentrations of Nitrate, Tritium and Beta Contamination by Well Number (Continued).

Well Number	Average Concentration		
	Nitrate (NO_3) mg/l	Tritium pCi/ml	Beta pCi/ml
699-24-46	<5.00E-1	6.63E-01	
699-25-55	9.67E+00	5.20E-01	
699-25-70	6.75E+00	8.30E-01	
699-28-40	6.70E+00	1.75E+01	
699-28-40P	4.45E+00	1.13E+01	
699-28-52	<5.00E-01	<7.25E-01	
699-29-78	2.65E+00	9.90E-01	
699-32-42	4.98E+00	3.15E+02	
699-34-43	1.60E+01	6.58E+01	
699-32-62	2.70E+01	1.23E+00	
699-32-70	1.35E+01	2.13E+02	a
699-32-72	2.63E+00	2.85E+02	
699-32-77	1.76E+01	1.00E+00	a
699-33-42	1.93E+01	2.03E+02	7.93E-02
699-33-56	6.80E+00	<4.90E-01	a
699-34-39A	2.83E+01	4.53E+02	8.28E-02
699-34-41	3.80E+01	4.25E+02	
699-34-42	2.93E+01	3.35E+02	9.57E-02
699-34-51	7.23E+00	2.16E+00	a
699-35-70	2.00E+01	6.47E+03	8.33E-02
699-35-78	5.80E-01	1.45E+00	a
699-36-46P	<5.00E-01	<6.40E-01	
699-36-46Q	<5.00E-01	<6.40E-01	
699-36-61A	1.40E+01		
699-36-61B	<5.00E-01	8.22E-01	a

a =<7.50E-02

TABLE D-1. Average Concentrations of Nitrate, Tritium and Beta Contamination by Well Number (Continued).

Well Number	Average Concentration		
	Nitrate (NO_3) mg/l	Tritium pCi/ml	Beta pCi/ml
699-37-43	8.75E+00	6.85E+01	a
699-37-82A	4.20E+01	1.02E+00	
699-38-65	8.17E+01	8.80E+01	
699-38-70	2.83E+02	1.36E+01	2.87E-01
699-39-39	<5.00E-01	<6.40E-01	a
699-39-79	6.88E-01	9.10E-01	a
699-40-62	1.93E+01	6.67E+00	
699-44-64	1.57E+01	<7.50E-01	
699-45-42	5.43E+00	2.35E+02	a
699-45-69	2.80E+01	1.14E+00	a
699-47-35A	7.15E-01	8.38E-01	
699-47-46	1.16E+01	1.61E+00	a
699-47-60	1.55E+01	1.37E+00	
699-48-71	1.90E+01	5.67E+00	
699-49-55	7.57E+00	2.82E+00	1.00E-01
699-49-57	1.90E+02	1.38E+02	1.33E+00
699-49-79	4.53E+01	9.67E-01	
699-50-42	<5.00E-01	1.53E+00	
699-50-53	1.73E+01	1.03E+00	8.78E-02
699-51-63	3.40E+00	<9.00E-01	
699-51-75	6.15E-01	7.65E-01	
699-53-47	<5.00E-01	8.80E-01	
699-53-55A	<5.00E-01	1.03E+00	
699-54-42	<5.00E-01	<6.85E-01	
699-54-57	9.33E-01	1.30E+00	
699-55-44	<5.00E-01	1.05E+00	
699-55-50A	5.75E-01	1.68E+00	

a =<7.50E-02

TABLE D-1. Average Concentrations of Nitrate, Tritium and Beta Contamination by Well Number (Continued).

Well Number	Average Concentration		
	Nitrate (NO_3) mg/l	Tritium pCi/ml	Beta pCi/ml
699-55-50(C)	5.60E-01	1.25E+00	
699-55-50(D)	7.37E-01	1.03E+00	
699-55-70	<5.00E-01	8.70E-01	
699-55-76	<5.00E-01		
699-56E-43	<5.00E-01	9.13E-01	
699-59-58	5.55E-01	2.80E+00	
699-60-57	<5.00E-01	1.78E+00	

a =<7.50E-02

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