**Hydrogeology Along the Southern
Boundary of the Hanford Site Between
the Yakima and Columbia Rivers, Washington**

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Preface

This report was originally published in May 1993 as a thesis for the degree of Master of Science with a major in hydrology through the University of Idaho. Research for the report was conducted between June 1989 and May 1990. The report contains valuable information on the hydrogeology along the southern boundary of the Hanford Site; therefore, the Ground-Water Surveillance Project agreed to publish it as a Pacific Northwest Laboratory technical report.

Because the report was published in 1993, references are made to activities, organizations, and/or previous investigations that were pertinent at the time, but may no longer be applicable, or have since been updated. Hence, the report remains essentially as it was originally written.

Summary

The 1100 and 3000 Areas are located along the southern boundary of the U.S. Department of Energy's (DOE) Hanford Site, near the city of Richland, Washington. Hazardous wastes have been discharged to the ground within the 1100 and 3000 Areas, and the city of Richland is considering annexing all or a portion of these areas.

The purpose of this study was to describe the hydrogeologic framework along the southern boundary of the Hanford Site as a basis for the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Superfund Amendments and Reauthorization Act (SARA) of 1986 investigations and potential annexation by the city of Richland. The general objective was to characterize the unconfined ground-water flow system between the Columbia and Yakima rivers in support of future hazardous waste site investigations and ground-water and land-use management. Study activities were coordinated through the Hanford contractors to complement ongoing CERCLA/SARA investigations in the study area.

The 1100 and 3000 Areas and the adjacent lands are underlain by the Saddle Mountains Basalt Formation and sediments of the Ringold Formation and Hanford formation. An unconfined aquifer occurs within the Ringold and Hanford sediments. The North Richland well field, which serves as the secondary water-supply system for the city of Richland, taps the unconfined aquifer. Several of the disposal sites within the 1100 and 3000 Areas and other nearby industries are hydraulically upgradient of the well field.

The unconfined ground-water flow system between the Yakima and Columbia rivers was characterized in this study using site hydrogeology and spatial and temporal distribution of hydraulic head within the aquifer. An inventory of existing wells was made and water-level measurements were taken for a period of 1 year. Study results show that ground water in the unconfined aquifer flows generally west to east toward the Columbia River. Currently, the net recharge pumped to the North Richland well field has the most significant impact on water levels and hydraulic gradients for the unconfined aquifer; flow is altered by a ground-water mound beneath the well field. No impacts are evident at this time from farming west of the 1100 Area or farming and lawn irrigation in the 3000 Area. Ground-water levels near the Columbia River are influenced by fluctuations in river elevation.

Additional data needs for future hazardous waste site investigations and Richland corporate annexation of the 1100 and 3000 Areas have been identified. These needs are focused in four areas: 1) well maintenance and rehabilitation, 2) hydrogeologic characterization, 3) ground-water monitoring, and 4) ground-water management.

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1.0 Introduction

U.S. Department of Energy (DOE) operations at the Hanford Site, located in southeastern Washington, have generated large volumes of hazardous and radioactive wastes since 1944. Some of the hazardous wastes were discharged to the ground in the 1100 and 3000 Areas, near the city of Richland. The specific waste types and quantities are unknown; however, they probably include battery acid, antifreeze, hydraulic fluids, waste oils, solvents, degreasers, paints, and paint thinners.

Disposal sites within the 1100 and 3000 Areas are regulated by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. This law requires hydrogeologic investigation, risk assessment, and cleanup of inactive hazardous waste disposal sites.

The city of Richland is considering annexing all or a portion of the 1100 and 3000 Areas. In addition, several of the disposal sites are hydraulically upgradient of the North Richland well field, which serves as the secondary water-supply system for the city of Richland. This water-supply system consists of a settling basin and two recharge basins adjacent to pumping wells completed in the unconfined aquifer. Water from the Columbia River is pumped into the settling basin, discharged through a flow divider into the recharge basins, allowed to infiltrate, and then pumped from the wells for use. Historical data indicate that operation of this system has a significant impact on water levels and hydraulic gradients in the area.^(a)

Additional sites or features in the vicinity of the 1100 and 3000 Areas that may affect the ground-water quantity and/or quality include:

- city of Richland landfill
- Horn Rapids landfill
- Siemens Power Corp. facilities for producing commercial nuclear fuel
- Lamb-Weston Inc. potato processing plant
- Irrigated agricultural fields and lawns
- Yakima and Columbia rivers.

Collection, analysis, and documentation of hydrogeologic data near the 1100 and 3000 Areas are necessary to provide a basis for CERCLA/SARA investigations and ground-water and land-use management. Information on the unconfined aquifer is important in understanding ground-water flow and contaminant transport characteristics. Limited research has been conducted in these areas to define the distribution and concentrations of selected wastes in soil samples and the ground water.

The purpose of this study was to describe the hydrogeologic framework along the southern boundary of the Hanford Site as a basis for CERCLA/SARA investigations and Richland corporate annexation. The general objective was to characterize the unconfined ground-water flow system

(a) Freshley, M. D., M. P. Bergeron, and N. J. Aimo. 1989. Ground-Water Modeling Investigation of North Richland Well Field and the 1100 Area, Letter Report. Pacific Northwest Laboratory, Richland, Washington.

between the Yakima and Columbia rivers in support of future hazardous waste site investigations and ground-water and land-use management. The specific objectives were to

- collect and review existing hydrogeologic data for the study area and establish a water-level monitoring network
- describe the regional and study area hydrogeology
- develop a hydrogeologic conceptual model of the unconfined ground-water flow system beneath the study area, based on available data
- describe the flow characteristics of the unconfined aquifer based on the spatial and temporal distribution of hydraulic head within the aquifer
- use the results of this study to delineate additional data needs in support of future Remedial Investigation/Feasibility Studies (RI/FS), Fate and Transport modeling, Baseline Risk Assessments (BRA), and ground-water and land-use management.

These activities were coordinated through the Hanford contractors to complement ongoing CERCLA/SARA investigations in the study area.

1.1 Background

The study area is located along the southern boundary of the Hanford Site in southeastern Washington (Figure 1.1) and covers approximately 25 mi² with a primary focus on the sediments overlying the basalt bedrock. The study area is bounded to the west and east by the Yakima and Columbia rivers, respectively (Figure 1.2). The northern boundary parallels Horn Rapids Road, and the southern boundary is near the city of Richland. The study area varies in elevation from approximately 515 ft above mean sea level (msl) near the city of Richland landfill to 340 ft above msl along the Columbia River.

1.2 Geographic Setting

The Hanford Site overlies the central Pasco Basin within the Columbia Basin physiographic subprovince of the Columbia Intermontane Province. The Hanford Site covers approximately 560 mi² and is used for reactor and fuel processing operations and waste storage and disposal. The adjacent lands to the north, west, and east are primarily range and agricultural lands. The Tri-Cities (Richland, Kennewick, and Pasco) constitute the nearest population center and are located southeast of the Site.

The Hanford Site is bounded to the north, west, and southwest by several structural anticlinal ridges (Figure 1.3). These large basaltic ridges trend to the east and southeast. The Site is bounded to the east by the Columbia River and to the south by the Yakima River and city of Richland. Elevations vary from approximately 3580 ft above msl on Rattlesnake Mountain at the southwestern border of the Site to 340 ft above msl along the Columbia River within the study area.

The Hanford Site is located in the rain shadow formed by the Cascade Mountains. Precipitation on the Site averages 6.25 in. annually (Stone et al. 1983). More than 40% of this precipitation occurs from November to January, and approximately 38% occurs as snow from December to February.

S9304073.10

Figure 1.1 Generalized Location Map of the Study Area

Prevailing winds at the Hanford Site are west-northwest and northwest year around. The Cascade Mountains serve as a source of cold air drainage and cause topographic wind channeling. Average hourly wind speeds in July vary from 5 to 13 mph, whereas the average hourly wind speed in January is 6 mph.

Temperature variations at the Hanford Site reflect the proximity to the Cascade Mountains. Colder temperatures occur in the winter and warmer temperatures in the summer than would occur without the mountains. Winter minima range from -27 to 22° F and summer maxima from 100 to 115° F (Stone et al. 1983).

Figure 1.2 Map of the Study Area, June 1989

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Figure 1.3 Structural Geology of the Pasco Basin (modified from DOE 1988a)

1.3 Previous Investigations

Numerous geologic and hydrogeologic reports and papers are published on the Columbia Intermontane Province, Columbia Basin subprovince, Pasco Basin, and Hanford Site. Research most relevant to this study is discussed below.

DOE (1988a,b) provided a comprehensive description of the hydrogeologic setting for the Columbia Intermontane Province. This report was submitted as part of the process for siting a nuclear waste repository at the Hanford Site under the Basalt Waste Isolation Project.

Newcomb et al. (1972) described the general geologic and hydrologic conditions at the Hanford Site. Stratigraphic relations, direction and rate of ground-water movement, natural and artificial effects on the water table, aquifer coefficients, and contaminant migration were presented.

Brown (1979) presented an overview of the Pasco Basin suprabasalt hydrogeology for areas adjacent to the Hanford Site. Lithostratigraphic units, hydraulic properties, and flow characteristics of the unconfined aquifer were discussed. Transmissivity values were tabulated for over 200 wells.

Lindberg and Bond (1979) assessed the ground-water flow and transport system beneath the 300 Area, located northeast of the study area. Ground-water flow directions, natural and artificial effects on the water table, water chemistry data, and numerical modeling results were presented.

Schalla et al. (1988) contains information on the Hazardous Waste Ground-Water Monitoring Compliance Program for the 300 Area Process Trenches. This document is a compilation of preliminary results including hydrogeologic characterization, ground-water monitoring, geochemistry, and numerical modeling. The process trenches are regulated by the Resource Conservation and Recovery Act (RCRA) of 1976 as amended by the Hazardous and Solid Waste Amendments of 1984.

Fecht and Lillie (1982) and McGhan (1989) provided lithologic logs and construction data, respectively, for several wells within the study area. Hard copy borehole and geophysical logs are maintained by Pacific Northwest Laboratory (PNL). Several logs are available in PNL's Hanford Ground-Water Data Base (HGWDB).

Bryce (1989) outlined the well installation and ground-water sampling plan for five monitoring wells in the 1100 Area. Bryce and Goodwin (1989) contains data collected during installation and initial sampling of the five wells including geologic and geophysical logs, survey data, and sample analyses.

DOE (1990b,c) documented the findings of the Phase I Remedial Investigation for the 1100-EM-1 Operable Unit. The findings included operational history, physical characteristics, nature and extent of contamination, and risk assessment for the unit. This unit is one of four 1100 Area operable units regulated by CERCLA/SARA.

ICF Northwest (1987) investigated and tested the North Richland well field and recharge basins. Borehole logs, hydraulic testing data, infiltration rates, and operational strategies were evaluated. Recommendations were made to reduce operational costs. Numerical modeling was used to determine the impact of the well field and recharge basins on ground-water flow in the 1100 Area. Simulation results indicated recharge to this system has a significant impact on hydraulic gradients and flow directions.^(a)

J-U-B Engineers Inc. (1982) briefly discussed the hydrogeology near the Siemens Power Corp. facilities. Unit thicknesses, water-table maps, aquifer coefficients, and ground-water flow rates were given.

(a) Freshley, M. D., M. P. Bergeron, and N. J. Aimo. 1989. Ground-Water Modeling Investigation of North Richland Well Field and the 1100 Area, Letter Report. Pacific Northwest Laboratory, Richland, Washington.

1.4 Method of Study

This study was conducted in four phases: 1) collection and review of existing hydrogeologic data, 2) establishment of a water-level monitoring network, 3) data analysis, and 4) interpretation of results.

Existing hydrogeologic data document general stratigraphic relations between geologic formations for several areas within and adjacent to the Hanford Site. Limited information on the unconfined ground-water flow system in the 1100 and 3000 Areas is available, but until now has not been compiled, analyzed, and published. Hydraulic head and soil and water chemistry data have been collected before this study.

A well network was established to characterize the hydrogeology and monitor water levels in the unconfined aquifer. Field activities included installation and maintenance of continuous water-level recorders, water-level measurements, and natural gamma and borehole television logging. Field activities were conducted between June 1989 and May 1990. Data analysis included defining the distribution of hydrogeologic units in the study area, developing a hydrogeologic conceptual model for the unconfined aquifer, and describing the spatial and temporal distribution of hydraulic head within the aquifer. Study results are used to delineate additional data needs in support of future hazardous waste site investigations and ground-water and land-use management.

Chapter 2.0 of this report contains information on the regional hydrogeology of the Pasco Basin; Chapter 3.0 describes the study area hydrogeology; Chapter 4.0 discusses the spatial and temporal distribution of hydraulic head including details on the water-level monitoring network, anthropogenic impacts to the water table, and the interrelationship with the Yakima and Columbia rivers; Chapters 5.0, 6.0, and 7.0 discuss results, conclusions, and additional data needs, respectively. The references cited throughout the text are presented in detail in Chapter 8.0. Four appendixes at the back of the report provide supporting data in the form of diagrams, tables, maps, and graphs. Five plates are included in the pocket.

2.0 Regional Hydrogeology

This chapter provides information on the hydrogeology of the Pasco Basin as a preface to describing the study area hydrogeology. Summaries of the principal geologic and hydrologic units and the primary surface and ground-water features within the Pasco Basin are presented.

2.1 Geology of the Pasco Basin

The principal geologic units within the Pasco Basin are, in ascending stratigraphic order, 1) Columbia River Basalt Group with interbeds of the Ellensburg Formation, 2) Ringold Formation, 3) Plio-Pleistocene sediments, and 4) Hanford formation (informal name). Locally, Pleistocene/Holocene alluvium, colluvium, and eolian deposits veneer the surface. A generalized geologic cross section through the central Pasco Basin is shown in Figure 2.1. Figure 2.2 summarizes the Pasco Basin stratigraphy.

2.1.1 Columbia River Basalt Group

Tholeiitic flood basalts of the Columbia River Basalt Group form the bedrock of the Pasco Basin. This Miocene basalt sequence was formed between 17 and 6 million years before present (mybp) (DOE 1988a) when large volumes of lava erupted from fissures in eastern Washington, western Idaho, and north-central and northeastern Oregon. The basalts cover more than 63,000 mi² with an estimated volume of 40,800 mi³. They may be as much as 11,450 ft thick beneath the Pasco Basin (DOE 1988a). The Columbia River Basalt Group is subdivided into five formations: Imnaha, Picture Gorge, Grande Ronde, Wanapum, and Saddle Mountains Basalts. The Grande Ronde, Wanapum, and Saddle Mountains Basalts are present in the Pasco Basin.

Miocene and locally Pliocene, epiclastic and volcanoclastic sediments of the Ellensburg Formation are intercalated between flows of the Columbia River Basalt Group. Areal extensive units include the Vantage, Mabton, Cold Creek, Selah, and Rattlesnake Ridge interbeds. These units are restricted primarily to the Wanapum and Saddle Mountains Basalts within the Pasco Basin.

2.1.2 Ringold Formation

The Columbia River Basalt Group is overlain by late Miocene to Pliocene sediments of the Ringold Formation. These sediments were deposited between 8.5 and 3.7 mybp (DOE 1988a) by the ancestral Columbia and Snake rivers in a fluvial-lacustrine environment, reaching a maximum thickness of more than 1200 ft (Newcomb et al. 1972).

The Ringold Formation has generally been classified into three stratigraphic section types within the Pasco Basin. However, considerable variation in sediment types can occur, and lithofacies may not correlate across the entire basin. Section type I, located in the central Pasco Basin, is subdivided into four lithofacies: 1) basal sand and gravel unit, 2) lower clay, silt, and sand unit, 3) middle sand and gravel or conglomerate unit, and 4) upper clay, silt, and sand unit. These lithofacies represent mainstream deposits. Section type II consists of overbank-floodplain clay, silt, and sand with minor gravel lenses and is found north and east of Gable Mountain. Section type III is a fan conglomerate,

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Figure 2.1 Generalized Geologic Cross Section Through the Central Pasco Basin (modified from Last et al. 1989)

Period	Epoch	Group	Subgroup	Formation	K-Ar Age Years x 10 ⁶	Member or Sequence	Geologic Mapping Symbol	Sediment Stratigraphy or Basalt Flows
TERTIARY	Pleistocene/ Holocene					Surficial Units	Qf Qd Qa, Qaf Qld Qt Qco	Loess Sand Dunes Alluvium and Alluvial Fans Landslides Talus Colluvium
							Qh/Qhp	
	Pliocene			Ringold			Trs Trc Trls Trq	Plio-Pleistocene Sediments Upper Ringold Middle Ringold Lower Ringold Basal Ringold
								Fanglomerate
	Miocene	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	8.5	Ice Harbor Member	Ti { Tig Tim Tib	Goose Island Flow Martindale Flow Basin City Flow
						Elephant Mountain Member	Tem { Tem ₂ Tem ₁	Levey Interbed Upper Elephant Mountain Flow Lower Elephant Mountain Flow
					12.0	Pomona Member	Tp { Tp ₂ Tp ₁	Rattlesnake Ridge Interbed Upper Pomona Flow Lower Pomona Flow
						Esquatzel Member	Te { Te ₂ Te ₁	Selah Interbed Upper Gable Mountain Gable Mountain Interbed Lower Gable Mountain Flow
					13.6	Asotin Member	Ta	Cold Creek Interbed Huntzinger Flow
						Wilbur Creek Member	Tw	Wahluke Flow
						Umatilla Member	Tu { Tu _s Tu _u	Siliusi Flow Umatilla Flow
						Priest Rapids Member	Tpr { Tpr ₁ Tpr _r	Mabton Interbed Lolo Flow Rosalia Flows
				Wanapum Basalt	14.5	Roza Member	Tr { Tr ₂ Tr ₁	Quincy Interbed Upper Roza Flow Lower Roza Flow
						Frenchman Springs Member	Tf { Tf ₂ Tf ₁	Squaw Creek Interbed Aphyric Flows Phyric Flows
			Grande Ronde Basalt	15.6	Sentinel Bluffs Sequence	Tsb		Vantage Interbed Undifferentiated Flows Rocky Coulee Flow Unnamed flow Cohasset Flow Undifferentiated Flows McCoy Canyon Flow Intermediate-Mg Flow
								Low-Mg Flow Above Umtanum Umtanum Flow
				16.1	Schwana Sequence	Ts		High-Mg Flows Below Umtanum Very High-Mg Flow At Least 30 Low-Mg Flows

SS406061.1

Figure 2.2 Pasco Basin Stratigraphy (modified from DOE 1984)

composed of talus, colluvium, and sidestream deposits that occur along the flanks of the anticlinal ridges and interfinger with the central basin deposits. Distribution of these section types is shown in Figure 2.3.

Figure 2.3 Distribution of Ringold Formation Section Types Within the Pasco Basin (modified from DOE 1988a)

2.1.3 Plio-Pleistocene Sediments

The late Pliocene to early Pleistocene is characterized by erosion of the uppermost Ringold Formation within the Pasco Basin. Localized deposition of the Plio-Pleistocene unit and early "Palouse" soil followed. Relatively high caliche content is found in the Plio-Pleistocene unit, and the early "Palouse" soil is thought to be an early Pleistocene loess. The Plio-Pleistocene sediments were probably deposited as reworked Ringold sediments.

2.1.4 Hanford Formation

The Hanford formation lies unconformably on the eroded surface of the Ringold Formation, Plio-Pleistocene sediments, and locally, Columbia River Basalt Group. The Hanford formation consists of catastrophic flood sediments that were deposited during the rapid draining of glacial Lake Missoula in western Montana and northern Idaho. Massive volumes of water spilled abruptly across eastern and central Washington scouring the land surface, locally eroding into the Ringold Formation, upper basalt flows, and interbeds. Thick sequences of glaciofluvial sediments were deposited by several episodes of Pleistocene flooding, with the last major flood sequence dated about 13,000 years before present (Myers and Price 1979).

The Hanford formation has locally been divided into two lithofacies, termed the "Pasco Gravels facies" and the "Touchet Beds facies." The Pasco Gravels facies is composed of poorly sorted gravels and coarse sand indicative of a high-energy depositional environment. The Touchet Beds facies consists of rhythmically bedded sequences of graded silt, sand, and minor gravel lenses. These sediments are limited to areas where slack-water conditions existed.

Eolian sediments, including loess and active and stabilized sand dunes, locally veneer the surface of the Pasco Basin. Alluvium and colluvium occur along major river and stream courses and beneath moderate to high relief areas, respectively.

2.2 Hydrology of the Pasco Basin

The Pasco Basin contains several natural and artificial surface-water bodies, numerous semi-confined to confined aquifers, and an unconfined aquifer. The following discussion focuses on streamflow characteristics and ground-water occurrence, recharge, and discharge.

2.2.1 Surface Water

The primary surface-water feature within the Pasco Basin is the Columbia River and its major tributaries, the Yakima, Snake, and Walla Walla rivers. Cold Creek and its tributary, Dry Creek, are ephemeral streams draining areas along the western part of the basin. West Lake, located southwest of Gable Mountain, is the only natural lake. Artificial ponds and ditches are present on the Hanford Site and are generally associated with nuclear fuel reprocessing and waste disposal activities. Figure 2.4 shows the major surface-water features within the Pasco Basin.

The Columbia River enters the Pasco Basin at Sentinel Gap and exits at Wallula Gap. Flow along the Hanford reach averages 120,000 cubic feet per second (cfs) and is controlled by Priest Rapids Dam (DOE 1988b). River elevations range from 486 ft above msl near Sentinel Gap to 340 ft above msl near Wallula Gap. Several multipurpose water resource projects are located along this reach, including Hanford Site intakes for onsite use and irrigation outfalls for the Columbia Basin Irrigation Project. The Columbia River contributes 67% of the outflow from the Pasco Basin, the Snake River contributes 30%, the Yakima River contributes 2%, and the Walla Walla River contributes less than 1% (DOE 1988b).

2.2.2 Ground Water

Ground water within the Pasco Basin occurs under confined to unconfined conditions. Four principal hydrologic units have been identified in this multiaquifer system: 1) Grande Ronde Basalt, 2) Wanapum Basalt, 3) Saddle Mountains Basalt, and 4) Ringold and Hanford sediments. Figure 2.5 is a generalized hydrologic cross section through the central Pasco Basin.

2.2.2.1 Semiconfined to Confined Aquifers

Several semiconfined to confined aquifers are contained within the basalt flow tops, flow bottoms, and sedimentary interbeds of the Grande Ronde, Wanapum, and Saddle Mountains Basalts. Dense basalt flow interiors act as aquicludes and clay interbeds form aquitards between these aquifers.

Figure 2.4 Major Surface-Water Features Within the Pasco Basin (modified from DOE 1988b)

Precipitation infiltration and interbasin runoff along the margins of the Pasco Basin locally recharge the semiconfined to confined aquifers. Additional recharge occurs outside the basin where the Grande Ronde and Wanapum Basalts crop out. Discharge from these aquifers occurs to the overlying unconfined aquifer and the Columbia River.

The potential for hydraulic connection between the uppermost confined and unconfined aquifers has been documented south of Gable Mountain extending to the 200 East Area (Graham et al. 1984). In this region, postglacial flood waters and the ancestral Columbia River eroded portions of the Elephant Mountain Basalt Member separating the two aquifers.

2.2.2.2 Unconfined Aquifer

The unconfined aquifer is the uppermost regionally extensive aquifer. It is contained within the fluvial-lacustrine sediments of the Ringold Formation and the glaciofluvial gravels and sands of the Hanford formation. Depth to water ranges from less than 1 ft near the Yakima and Columbia rivers,

to over 350 ft near the center of the Hanford Site. The aquifer is approximately 500 ft thick west of the 200 West Area (Last et al. 1989). The basalt surface, and locally, the lower clay, silt, and sand unit of the Ringold Formation, form the aquifer base. Areal hydraulic conductivity, transmissivity, and specific yield estimates for the unconfined aquifer are shown in Table 2.1.

Sources of natural recharge to the unconfined aquifer are rainfall and runoff from bordering elevations, ephemeral stream infiltration, and river water along influent reaches of the Yakima and Columbia rivers. Artificial recharge occurs from waste-water disposal on the Hanford Site and agricultural irrigation. Figure 2.6 shows water-table elevations beneath the Site for June 1989. Ground water flows primarily from recharge areas in the west, eastward to discharge areas along the Columbia River. Flow is altered locally by ground-water mounds beneath the 200 Areas.

Figure 2.5 Generalized Hydrologic Cross Section Through the Central Pasco Basin (modified from DOE 1990b)

Table 2.1 Hydraulic Property Estimates for the Unconfined Aquifer Within the Pasco Basin
(modified from Gephart et al. 1979)

Hydrogeologic Unit	Hydraulic Conductivity (ft/day)
Hanford formation	500-20,000
Undifferentiated Hanford formation and middle Ringold unit	100-7,000
Middle Ringold unit	20-600
Lower Ringold unit	0.11-10
Area	Transmissivity (ft ² /day)
North of Gable Butte and Gable Mountain	4,000-25,000
Paleochannels along flanks of Gable Butte and Gable Mountain	40,000-600,000
Other areas on the Hanford Site	2,000-40,000
Area	Storage Coefficients
Throughout the unconfined aquifer	0.01-0.1

Figure 2.6 Hanford Site Water-Table Elevations, June 1989 (Newcomer et al. 1990)

3.0 Study Area Hydrogeology

This chapter provides information on the study area hydrogeology. An inventory of existing wells and descriptions of the principal lithofacies and hydrofacies are presented. A hydrogeologic conceptual model for the unconfined ground-water flow system was developed based on these descriptions.

3.1 Existing Well Inventory

Existing wells within the study area from which hydrogeologic information was obtained include Hanford Site monitoring wells, city of Richland monitoring and production wells, agricultural irrigation wells, private monitoring and water-supply wells, and a hand-dug farm well. These well locations are shown in Figure 3.1. Well construction and lithologic diagrams are contained in Appendix A. Well completion data and recommended maintenance for several wells are summarized in Table 3.1.

Additional monitoring wells were drilled concurrent with and after this study as part of the RI/FS for the 1100-EM-1 Operable Unit. Information on most of these wells is discussed in DOE (1990b). Drilling logs (water well reports) for other wells within and adjacent to the study area are available from Westinghouse Hanford Company (WHC), Siemens Power Corp., Washington Department of Ecology, city of Richland, and local drilling companies.

3.1.1 Monitoring Wells

The Hanford Site monitoring wells used in this study are prefixed by 699- (Table 3.1 and Figure 3.1) and were drilled from 1944 to 1988. Detailed information on the Hanford well numbering system is contained in McGhan (1989). These wells were drilled to monitor ground-water contamination resulting from Hanford Site activities. Generally, the wells drilled before 1986 are constructed of perforated carbon steel casing or carbon steel casing and stainless steel screen. Wells drilled after 1985 are constructed of stainless steel casing and screen. Of the 20 Hanford Site monitoring wells, 5 each are constructed of perforated carbon steel casing, carbon steel casing and stainless steel screen, and stainless steel casing and screen; 3 wells are open bottom completions; and 2 have unknown completions (Table 3.1).

Wells 699-S23-26 and 699-S24-19 were initially drilled as water-supply wells and later incorporated into the Hanford Site monitoring network. Well 699-S28-E0 supplies water to the Hanford Patrol Training Academy, and well 699-S51-2 supplies water to the city of West Richland. Well 699-S36-E12A is used to supplement the PNL irrigation intake at the Port of Benton (D.R. Schielke, PNL, personal communication, 1990).

Other monitoring wells within the study area include those designated TW14 through TW18, owned by Siemens Power Corp., and EC-1 and Landfill Wells #1 through #4, owned by the city of Richland (Figure 3.1). Wells TW14 through TW18 monitor ground water adjacent to the Siemens Power Corp. process lagoons. Two of these wells are constructed of slotted polyvinyl chloride (PVC) casing; 1 is constructed of carbon steel casing and stainless steel screen; and 2 are open bottom completions (Table 3.1). Well EC-1 is an open bottom PVC well (Table 3.1) installed to monitor

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Figure 3.1 Wells Used to Provide Hydrogeologic Data for the Study Area

Table 3.1 Completion Data for the Study Area Wells

Well Number	Plant, Richland Coordinates		Casing Elev. (ft)	M.P. Elev. (ft)	Land Surface Elev. (ft)	Casing Diam. (in)	Construction Materials		Depth to Btm. (ft)	W-L Depth # (ft)	Depth of Screened Interval (ft)	Comp. Date	Recommended Maintenance
3000-F (3099-47-18B)	RN 47120	RE 17686	374.95		372.97	17	C	PC	71	33.65	24-72	8/48	
699-S30-E15A	PS 30257	PE 14838	400.14		397.67	6	CS	SS	78	58.64	58-78	10/71	
699-S32-E13A			390.46		388.67	8	CS	SS	75	43.18	50-70	9/79	
699-S31-E13			394.06		392.29	8	CS	SS	72	47.11	50-68	10/79	
699-S32-E13B			394.72		392.69	8	CS	SS	74	47.18	50-70	10/79	
699-S29-E12	PS 29392	PE 12065	387.96		383.71	6	CS	PCS, SS	79	41.95	37-59, 59-79	11/71	
TW17			379.45		377.45	3	PVC	PVC	34	26.11	24-28, 33-37	1982	Cleanout/Develop
TW16			376.73		375.41	6	CS	SS	33	23.43	33-38	1982	Cleanout/Develop
TW18			377.34		375.57	3	PVC	PVC	34	24.04	24-28, 33-37	1982	Cleanout/Develop
TW15			370.60		368.88	6	CS		24	17.26			Cleanout/Develop, Borehole TV
TW14			370.21		368.48	6	CS		22	16.83			Cleanout/Develop, Borehole TV
699-S31-1	PS 30600	PW 725	460.00		458.09	8	CS	PCS	142	84.33	93-103	1/51	Hydraulic Testing
699-S31-1P	PS 30600	PW 725	460.00		458.09	4	CS	OH	228	80.49	221-228	1/51	Hydraulic Testing
699-S23-26	PS 22675	PW 26349	424.70		418.32	12	CS		11	10.13		6/44	
EC-1			361.11	362.57	362.45	10	PVC	OB	8	7.10	OB		Resurvey
W-1			359.78		358.87	8	CS	PCS	18	7.09	5-30	1/83	Cleanout/Develop
W-3			358.88		355.63	6	CS	PCS	24	5.99	5-29	1/83	Cleanout/Develop
W-4			361.50		360.00	8	CS	PCS?	30	5.07	PCS?	1989	Survey, Borehole TV Log
W-5			361.82	361.97	360.00	14	CS	PCS?	67	6.23	PCS?	4/89	Survey, Borehole TV Log
W-6			361.70		360.00	10	CS	PCS	32	5.92	17-27	5/89	Survey
Saint			361.17	360.87	360.00	8	CS	SS	47	15.04	43-53	7/76	Resurvey
1100-2 (1199-34-13)	RN 34026	RE 13203	394.78		392.03	8	CS	PCS	75	41.63	45-90	3/48	Cleanout/Develop
699-S43-E12	PS 43060	PE 11986	405.60		402.33	4	SS	SS	58	51.39	42-58	10/88	
699-S41-E13A	PS 41004	PE 12811	410.56		407.21	4	SS	SS	63	55.69	47-63	10/88	
699-S41-E13B	PS 40970	PE 12813	410.10		406.75	4	SS	SS	87	55.22	77-87	10/88	
699-S37-E14	PS 39745	PE 13980	408.28		404.88	4	SS	SS	63	54.61	44-63	10/88	
3000-D1 (1199-41-13C)	RN 41030	RE 13259	405.98		404.51	20	CS		74	51.64		3/44	
699-S36-E12B	PS 36182	PE 12350	399.07		397.44	8	CS	OB	72	45.25	OB	10/79	
699-S36-E13B	PS 36195	PE 12846	399.63		397.76	8	CS	OB	81	45.76	OB	10/79	
699-S36-E13A			399.30		398.34	8	CS	SS	72	45.70	52-72	9/79	
F-2 (3099-45-16)	RN 45108	RE 16386	408.04	408.09	406.87	36	C	OB	65	60.07	OB		Resurvey

Notes:

M.P. = Measuring Point

W-L = Water Level

RN = Richland North

RE = Richland East

PS = Plant South

PE = Plant East

PW = Plant West

C = Concrete

PC = Perforated Concrete

CS = Carbon Steel

PCS = Perforated Carbon Steel

SS = Stainless Steel

PVC = Polyvinyl Chloride

OB = Open Bottom

OH = Open Hole

Piezometer 699-S31-1P is Located in Well 699-S31-1

* = Approximate Number

= Measured Below Top of Casing or Measuring Point in October 1989

Table 3.1 (cont'd)

Well Number	Plant, Richland Coordinates		Casing Elev. (ft)	M.P. Elev. (ft)	Land Surface Elev. (ft)	Casing Diam. (in)	Construction Materials Casing Screen		Depth to Btm. (ft)	W-L Depth # (ft)	Depth of Screened Interval (ft)	Comp. Date	Recommended Maintenance
699-S30-E14	PS 30380	PE 14497	401.39		399.81	1.50	CS	OH	2053	5.42	1,973-2,053	1970	
699-S28-E0	PS 28072	PE 189	448.45		444.45	8	CS	PCS, OH	226		90-180, 223-236	5/81	Hydraulic Testing
699-S24-19	PS 23965	PW 18974	427.83		426.83	6	CS	PCS, OH	79	20.04	20-27, 35-42, 68-89	9/49	Hydraulic Testing
W-2			360.15		359.15	6	CS	PCS	30	4*	5-30	1/83	Cleanout/Develop
699-S40-E14	PS 39745	PE 13927	402.85		399.34	4	SS	SS	60	47.95	34-60	10/88	
699-S36-E12A	PS 35667	PE 12353	398.64		397.64	8	CS		102	50*		10/79	Resurvey, Borehole TV Log
ORV #1 (699-ORV-1)			474.00		472.00	8	CS	OH, PCS	386	77*	217-386	11/82	Survey, Hydraulic Testing
ORV #2 (699-ORV-2)			457.00		455.00	10	CS	PCS	485	80*	330-465	6/85	Survey, Hydraulic Testing
Landfill (699-LANDFILL)			484.00		482.00	8	CS	OH	312	105*	248-312	12/77	Survey, Hydraulic Testing
Landfill #1			487.10		484.00	2	SS	SS	136	106*	110-120, 125-136	5/87	
Landfill #2			467.40		464.10	2	SS	SS	120	90*	95-105, 110-120	5/87	
Landfill #3			479.10		475.70	2	SS	SS	130	101*	105-115, 120-130	5/87	
Landfill #4			460.00		456.70	2	SS	SS	110	81*	85-95, 100-110	5/87	
699-S51-2	PS 50876	PW 2488	387.16		386.00	16	CS	PCS, OH	572		77-79, 173-572	1/57	Hydraulic Testing
Rackley			391.00		390.00	8	CS	SS	41	9*	36-41	5/87	
Rigby			386.00		385.00	8	CS	SS	38	9*	33-38	5/87	
Lamb-Weston Inc.			370.00		370.00	10	CS	SS	53	20*	33-53	9/73	Survey
Huisingh			361.00		360.00	6	CS	SS	55	29*	45-55	7/80	
1100-D (1199-34-15B)			367.75	368.24	367.75	20	CS	PCS	86	15.90	42-78		Resurvey
3000-D5 (3099-42-16)	RN 41572	RE 16180	407.63	408.12	407.50	12	CS	PCS	131	54.91	55-125	10/44	Resurvey
3000-A (1199-40-15)	RN 40088	RE 15442	395.45	396.18	395.00	20	CS	PCS	81	41.16	47-82	4/48	Resurvey
3000-B (1199-40-16B)	RN 40087	RE 15977	391.66	392.27	390.00	20	CS	PCS	90	37.96	47-84	5/48	Resurvey
3000-H (1199-40-16C)	RN 39600	RE 15950	381.00		380.00	20	CS	PCS	56	26.68	26-51		Resurvey
3000-C (1199-39-16D)	RN 39300	RE 15945	371.17	371.82	370.30	20	CS	PCS	64	16.60	31-61	5/48	Resurvey
3000-K (1199-38-16)	RN 38300	RE 15800	366.00		365.40	20	CS	PCS	57	12.19	16-51		Resurvey
3000-N (1199-37-16)	RN 37450	RE 15700	363.40		361.00	24	CS	SS	40	9.47	24-40	11/61	Resurvey
3000-L (1199-39-16E)	RN 38900	RE 15500	398.00		397.00	20	CS	PCS	83	42.87	56-81		Resurvey
3000-D (1199-39-16C)	RN 39097	RE 15621	385.77	387.22	385.30	20	CS	PCS	75	31.76	41-71	5/48	Resurvey
3000-J (1199-39-15)	RN 39300	RE 15400	393.00		392.00	20	CS	PCS	71	38.29	45-70		Resurvey
3000-G (1199-41-15)	RN 40767	RE 15184	399.07		397.51	20	C		73	44.34		10/49	Resurvey
1100-8 (1199-34-15A)	RN 33750	RE 14700	371.00		369.00	10	CS	PCS	120		24-27, 44-95, 96-120	9/48	Resurvey

Notes:

M.P. = Measuring Point

W-L = Water Level

RN = Richland North

RE = Richland East

PS = Plant South

PE = Plant East

PW = Plant West

C = Concrete

PC = Perforated Concrete

CS = Carbon Steel

PCS = Perforated Carbon Steel

SS = Stainless Steel

PVC = Polyvinyl Chloride

OB = Open Bottom

OH = Open Hole

Piezometer 699-S31-1P is Located in Well 699-S31-1

* = Approximate Number

= Measured Below Top of Casing or Measuring Point in October 1989

water-level fluctuations resulting from agricultural irrigation (S. Arlt, city of Richland, personal communication, 1989). Landfill Wells #1 through #4 were drilled per regulatory requirement in May 1987 and monitor ground water beneath the city of Richland landfill. These wells are constructed of stainless steel casing and screen (Table 3.1).

3.1.2 Production Wells

Wells prefixed by 1100- and 3000- (Figure 3.1) are city of Richland production wells. Corresponding Hanford well numbers are given in parentheses (Table 3.1). Most of these wells were drilled in the 1940s and are constructed of perforated carbon steel casing (Table 3.1). Wells located in the North Richland well field are pumped as part of the secondary water-supply system for the city of Richland. Wells ORV #1, ORV #2, and the Landfill Well supply water to the city of Richland off-road vehicle park and landfill, respectively.

3.1.3 Agricultural Irrigation Wells

Wells W-4 through W-6 (Figure 3.1) were drilled in 1989 to supply water for agricultural irrigation. These wells are constructed of perforated carbon steel casing (Table 3.1) and were pumped by the Agricultural Engineering and Development Company (AEDC) to irrigate a half circle (approximately 250 acres) of potatoes west of the 1100 Area during the 1989 growing season (Figure 3.2). The farming was expanded to eight full circles (approximately 4000 acres) of potatoes before the 1990 growing season (Figure 3.3), and irrigation water was drawn from the AEDC intake at the Port of Benton. Wells W-4 through W-6 currently are used to supplement the river intake.

3.1.4 Other Wells

Wells W-1 through W-3 (Figure 3.1) are constructed of perforated carbon steel casing (Table 3.1). These wells were drilled in 1983 to determine if sufficient ground-water quantities existed at shallow depths to irrigate the planned Horn Rapids Triangle golf course.

The remaining wells in Figure 3.1 are private water-supply wells and a hand-dug farm well. The private water-supply wells are constructed of carbon steel casing and stainless steel screen (Table 3.1). Information on these wells was provided by the city of Richland and Onwego Drilling Company Inc. The hand-dug farm well (F-2) is constructed of concrete casing with an open-bottom completion (Table 3.1). A borehole television camera was used to help gather information on this well.

3.2 Geology of the Study Area

This section focuses on the principal lithofacies, occurrence, and thicknesses of the geologic formations beneath the study area. Lithofacies interpretation was based primarily on geologic sample descriptions, including texture, sorting, gross mineralogy, color, and consolidation. Natural gamma, neutron, and density logs were used qualitatively to indicate relative differences in lithology. Geologic, top of basalt contour, structural cross section, and stratigraphic correlation maps from Myers and Price (1979) were also used as input in the interpretation. Hydrogeologic data were obtained from the 61 wells shown in Figure 3.1. Well construction and lithologic diagrams for these wells are contained in Appendix A.

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Figure 3.2 Potato Farming, 1989 Growing Season

Figure 3.3 Potato Farming, 1990 Growing Season

Five geologic formations, the Grande Ronde, Wanapum, and Saddle Mountains Basalts, and sediments of the Ringold Formation and Hanford formation, have been identified beneath the study area. Figure 3.4 is a generalized geologic column showing the order, principal lithofacies, and average elevation of the upper Saddle Mountains Basalt and Ringold Formations, and Hanford formation. The Grande Ronde and Wanapum Basalts are not considered further in this study. Table 3.2 lists formation depths, elevations, and thicknesses. General characteristics of each formation including texture, sorting, mineralogy, color, consolidation, and occurrence are given in Table 3.3. Figure 3.5 shows the location of five cross sections, parallel and perpendicular to ground-water flow. The cross sections are included as Plates 1 through 5. A detailed discussion of each formation follows. References to depth are given in feet below land surface (bls) with elevation in feet above msl in parentheses.

3.2.1 Saddle Mountains Basalt Formation

The Saddle Mountains Basalt Formation was encountered in eight wells at depths ranging from 52 to 248 ft bls (375 to 191 ft above msl) (Table 3.2). Geologic samples were characterized as fractured to dense gray and black basalt mixed with clay and sand. Structural cross section and stratigraphic correlation maps (Myers and Price 1979) show that the Ice Harbor Member (Ti) is the uppermost basalt throughout the study area. Drilling logs indicate the member ranges from 75 to 108 ft thick (Table 3.2). The Ice Harbor Member crops out south of the Yakima River horn (Plates 1 through 3 and Figure 3.6).

The Levey Interbed (Tel), described as a tuffaceous sandstone to gray-green and blue clay, was noted in three wells below the Ice Harbor Member. Gray dense basalt from the Elephant Mountain Member (Tem) was noted below the Levey Interbed. The Elephant Mountain Member also crops out south of the Yakima River horn (Plates 1 through 3 and Figure 3.6).

Myers and Price (1979) reported that the Ice Harbor and Elephant Mountain Members erupted from fissures in southeastern Washington and adjacent Oregon and Idaho. The members erupted between 10.5 and 6 mybp near the end of the Columbia River Basalt volcanism. Plates 1 through 3 and Figure 3.6 show that the basalt surface dips to the east and southeast between the Horn Rapids Structure (anticline) and Pasco Syncline. Myers and Price (1979) concluded that basalt compression and uplift occurred from mid-Miocene to early Pliocene (15 to 5 mybp). Newcomb et al. (1972) suggested that in some areas, the lower Ringold sediments were deposited contemporaneously with basalt deformation. Relatively thinner accumulations of the overlying sediment along the Horn Rapids Structure and thicker accumulations near the Pasco Syncline (Plates 1 through 3) support these conclusions.

3.2.2 Ringold and Hanford Formations

The Saddle Mountains Basalt Formation is overlain by fluvial and overbank-floodplain sediments of the Ringold Formation and glaciofluvial sediments of the Hanford formation. These sediments exhibit varied texture, sorting, and consolidation within and between lithofacies. Gross mineralogy, sorting, and color distinctions typically used to delineate the contact between the Ringold Formation and Hanford formation are not evident or are inconsistent in the drilling logs and HGWDB. The formations may be interstratified or have gradational contacts beneath the study area. The uppermost Ringold sediments were probably eroded and redeposited with the Hanford sediments by the ancestral

Figure 3.4 Generalized Geologic Column for the Study Area (after Liikala 1988; Compton 1967)

Table 3.2 Formation Depths, Elevations, and Thicknesses Beneath the Study Area

Well Number	Land Surface Elev. (ft)	SS Thick. (ft)	SG Depth (ft)	SG Elev. (ft)	SG Thick. (ft)	V-L Depth # (ft)	V-L Elev. (ft)	H/R Depth (ft)	H/R Elev. (ft)	GS/SC Depth (ft)	GS/SC Elev. (ft)	GS/SC Thick. (ft)	SC Depth (ft)	SC Elev. (ft)	SC Thick. (ft)	Ti Depth (ft)	Ti Elev. (ft)	Ti Thick. (ft)	Tel Depth (ft)	Tel Elev. (ft)	Tel Thick. (ft)	Tem Depth (ft)	Tem Elev. (ft)
3000-F (3099-47-18B)	372.97	8	8	364.97	33	33.65	341.30			41	331.97												
699-S30-E15A	397.67			397.67		58.64	341.50	45	352.67														
699-S32-E13A	388.67	4	4	384.67	71	43.18	347.28	52	336.67	75	313.67												
699-S31-E13	392.29	5	5	387.29	65	47.11	346.95			70	322.29												
699-S32-E13B	392.69	5	5	387.69	63	47.18	347.54			68	324.69												
699-S29-E12	383.71			383.71		41.95	346.01	45	338.71														
TW17	377.45	5*	5*	372.45		26.11	353.34	18	359.45														
TW16	375.41	5*	5*	370.41	38	23.43	353.30	18	357.41	43	332.41												
TW18	375.57	5*	5*	370.57		24.04	353.30	18	357.57														
TW15	368.88					17.26	353.34																
TW14	368.48					16.83	353.38																
699-S31-1	458.09	21	21	437.09		84.33	375.67	128	330.09														
699-S31-1P	458.09	21	21	437.09	164	80.49	379.51	128	330.09				185	273.09	36	221	237.09						
699-S23-26	418.32	3.75	3.75	414.57	25	10.13	414.57	29	389.32	29	389.32												
EC-1	362.45					7.10	355.47																
W-1	358.87	5	5	353.87	24	7.09	352.69			29	329.87												
W-3	355.63	2.74	2.74	352.89		5.99	352.89																
W-4	360.00					5.07	356.43																
W-5	360.00			360.00	34	6.23	355.74			34	326.00												
W-6	360.00	2	2	358.00	30	5.92	355.78			32	328.00												
Saint	360.00	7	7	353.00		15.04	345.83	49	311.00														
1100-2 (1199-34-13)	392.03	26	26	363.03	49	41.63	353.15	50	339.03	78	314.03												
699-S43-E12	402.33			402.33		51.39	354.21	50	352.33														
699-S41-E13A	407.21			407.21		55.69	354.87	50	357.21														
699-S41-E13B	406.75			406.75	90	55.22	354.88	50	356.75	90	316.75												
699-S37-E14	404.88			404.88		54.61	353.67	50	354.88														
3000-D1 (1199-41-13C)	404.51	5	5	399.51	79	51.64	354.34	66	338.51	84	320.51												
699-S36-E12B	397.44			397.44	82	45.25	353.82			82	315.44												
699-S36-E13B	397.76			397.76	75	45.76	353.87	52	345.76	75	322.76												
699-S36-E13A	398.34			398.34		45.70	353.60	58	340.34														
F-2 (3099-45-16)	406.87					60.07	347.97																
Average	398	27	27	386	65	34	357	56	344	65	325	53	142	293	37	191	250	91	285	129	46	331	83

Notes:

SS = Silty Sand Lithofacies

SG = Sandy Gravel Lithofacies

V-L = Water Level

H/R = Hanford formation/Ringold Formation Contact

GS/SC = Gravelly Sand to Silty Clay Lithofacies

SC = Silty Clay Lithofacies

Ti = Ice Harbor Member

Tel = Ellensburg Formation

Tem = Elephant Mountain Member

Piezometer 699-S31-1P is Located in Well 699-S31-1

* = Approximate Number

= Measured Below Top of Casing or Measuring Point in October 1989

Table 3.2 (cont'd)

Well Number	Land Surface Elev. (ft)	SS Thick. (ft)	SG Depth (ft)	SG Elev. (ft)	SG Thick. (ft)	W-L Depth # (ft)	W-L Elev. (ft)	H/R Depth (ft)	H/R Elev. (ft)	GS/SC Depth (ft)	GS/SC Elev. (ft)	GS/SC Thick. (ft)	SC Depth (ft)	SC Elev. (ft)	SC Thick. (ft)	Ti Depth (ft)	Ti Elev. (ft)	Ti Thick. (ft)	Tel Depth (ft)	Tel Elev. (ft)	Tel Thick. (ft)	Tem Depth (ft)	Tem Elev. (ft)
699-S30-E14	399.81	2	2	397.81	88	5.42	395.97			90	309.81	73	163	236.81	46	209	190.81	75	284	115.81	39	323	76.88
699-S28-E0	444.45	75	75	369.45	112			101	343.45				187	257.45	36	223	221.45						
699-S24-19	426.83			426.83	31	20.04	407.79	31	395.83	31	395.83	20	51	375.83	1	52	374.83						
W-2	359.15	3	3	356.15	25	4*	355*			28	331.15												
699-S40-E14	399.34			399.34		47.95	354.90	52	347.34														
699-S36-E12A	397.64			397.64	76	50*	348*	76	321.64														
ORV #1 (699-ORV-1)	472.00	75	75	397.00	83	77*	395*	75	397.00				158	314.00	42	200	272.00						
ORV #2 (699-ORV-2)	455.00	60	60	395.00	100	80*	375*						160	295.00	40	200	255.00	90	290	165.00	40	330	125.00
Landfill (699-LANDFILL)	482.00	86	86	396.00	116	105*	379*			202	280.00	46	248	234.00									
Landfill #1	484.00	99	99	385.00		106*	378*																
Landfill #2	464.10	68	68	396.10		90*	374*																
Landfill #3	475.70	92	92	383.70		101*	375*																
Landfill #4	456.70	56	56	400.70		81*	375*																
699-S51-2	386.00	8	8	378.00	50								125	261.00	48	173	213.00	108	281	105.00	59	340	46
Rackley	390.00	9*	9*	381.00	41	9*	381*	58	328.00	58	328.00	67	50	340.00									
Rigby	385.00			385.00		9*	376*																
Lamb-Weston Inc.	370.00	8	8	362.00	53	20*	350*			61	309.00												
Huisingsh	360.00			360.00	56	29*	331*	37	323.00	56	304.00												
1100-D (1199-34-15B)	367.75			367.75		15.90	352.34																
3000-D5 (3099-42-16)	407.50	2	2	405.50		54.91	353.21	83	324.50														
3000-A (1199-40-15)	395.00			395.00	85	41.16	355.02	66	329.00	85	310.00												
3000-B (1199-40-16B)	390.00			390.00	82	37.96	354.31	73	317.00	82	308.00												
3000-H (1199-40-16C)	380.00	15	15	365.00		26.68	354.32																
3000-C (1199-39-16D)	370.30			370.30	59	16.60	355.22	56	314.30	59	311.30												
3000-K (1199-38-16)	365.40	3	3	362.40	47	12.19	353.81			50	315.40												
3000-N (1199-37-16)	361.00			361.00	41	9.47	353.93			41	320.00												
3000-L (1199-39-16E)	397.00			397.00		42.87	355.13																
3000-D (1199-39-16C)	385.30			385.30		31.76	355.46	67	318.30														
3000-J (1199-39-15)	392.00			392.00		38.29	354.71																
3000-G (1199-41-15)	397.51			397.51	74	44.34	354.73	49	348.51	74	323.51												
1100-8 (1199-34-15A)	369.00			369.00				27	342.00														
Average	398	27	27	386	65	34	357	56	344	60	325	53	142	293	37	191	250	91	285	129	46	331	83

Notes:

SS - Silty Sand Lithofacies

SG - Sandy Gravel Lithofacies

W-L - Water Level

H/R - Hanford formation/Ringold Formation Contact

GS/SC - Gravelly Sand to Silty Clay Lithofacies

SC - Silty Clay Lithofacies

Ti - Ice Harbor Member

Tel - Ellensburg Formation

Tem - Elephant Mountain Member

Piezometer 699-S31-1P is Located in Well 699-S31-1

* - Approximate Number

- Measured Below Top of Casing or Measuring Point in October 1989

Table 3.3 General Characteristics of the Geologic Formations Beneath the Study Area

Formation	Lithofacies/ Member	Texture	Sorting	Mineralogy	Color	Consolidation	Occurrence
Hanford	Silty Sand (SS)	Silt, Very Fine to Coarse Sand	Well	Quartzose, Basaltic	Brown, Black, Gray	Unconsolidated	Present east of Yakima River near well 699-S24-19 to Columbia River along northern boundary of study area. Discontinuous south and east of Stevens Drive/Horn Rapids Road intersection and along Yakima River floodplain. Variable thickness (2-99 ft).
Hanford/Ringold	Sandy Gravel (SG)	Gravel, Sand, Silt	Poor	Basaltic, Metamorphic, Quartzose	Black, Brown	Unconsolidated to Cemented	Present throughout entire study area. Crops out south and east of Stevens Drive/Horn Rapids Road intersection to southern end of study area. Variable thickness (24-164 ft).
Ringold	Gravelly Sand to Silty Clay (GS/SC)	Clay, Silt, Sand, Gravel	Poor	Quartzose, Basaltic, Metamorphic	Brown, Black, Blue, Green, Yellow	Consolidated, Locally Cemented	Present east of Siemens Power Corp. and Tri-Cities Enterprise Center to Columbia River. Discontinuous along Yakima River floodplain. Absent in north central portion of study area. Variable thickness (20-73 ft).
Ringold	Silty Clay (SC)	Clay, Silt	Well	Quartzose	Yellow, Brown, Blue	Consolidated	Present throughout most of study area. Variable thickness (1-48 ft).
Saddle Mountains Basalt	Ice Harbor (Ti)	Basalt, Clay, Sand		Basaltic	Gray, Black	Fractured to Dense	Present throughout entire study area. Crops out south of Yakima River horn. Well logs supplemented by geologic, top of basalt contour, structural cross section, and stratigraphic correlation maps.
Ellensburg	Levey Interbed (Tel)	Tuffaceous Sandstone, Clay			Gray, Blue, Green		Noted in wells 699-S30-E14, ORV #2, and 699-S51-2.
Saddle Mountains Basalt	Elephant Mountain (Tem)	Basalt		Basaltic	Gray	Dense	Noted in wells 699-S30-E14, ORV #2, and 699-S51-2. Crops out south of Yakima River horn.

Figure 3.5 Locations of the Study Area Cross Sections

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Figure 3.6 Top of Basalt Map for the Study Area (modified from Myers and Price 1979)

Columbia and Snake rivers and postglacial flooding. Future hydrogeologic investigations should include laboratory tests for bulk mineralogy and geochemistry to help delineate this contact.

For this study, the Ringold and Hanford sediments have been subdivided into four principal lithofacies. They are, in ascending order, 1) silty clay lithofacies (SC), 2) gravelly sand to silty clay lithofacies (GS/SC), 3) sandy gravel lithofacies (SG), and 4) silty sand lithofacies (SS). Predominant textural composition of these lithofacies is delineated in Figure 3.4 by clay/silt (C/S), sand (S), gravel (G), and cobble/boulder (C/B). Lindsey and Gaylord (1990) and Bjornstad (1990) suggested the use of lithofacies as the most accurate method for describing lithologic heterogeneities in fluvial depositional environments.

Delineation of these lithofacies was based on geologic sample descriptions from various sources and qualitative interpretation of geophysical logs. A small number of wells exist over a large study area. Both horizontal and vertical changes in sediment characteristics probably occur over short distances. The descriptions and occurrences of the lithofacies may require refinement as additional data are collected in future hydrogeologic investigations. Advanced borehole geophysical tools (e.g., commercial vendor sondes) should be run in several wells to provide more quantitative data on the properties of the suprabasalt sediments.

3.2.2.1 Silty Clay Lithofacies

The silty clay lithofacies occurs in nine wells ranging from 50 to 202 ft bls (376 to 237 ft above msl) (Table 3.2 and Figure 3.7). These sediments consist of well-sorted clay and silt with minor amounts of sand and weathered basalt fragments, suggesting low-energy deposition in an overbank-floodplain environment. The sediments are further characterized as quartzose and consolidated with variable colors, including yellow, brown, and blue. Geophysical logs show relatively higher natural gamma (higher clay content) and lower neutron neutron (higher porosity) and gamma gamma (lower density) counts in these sediments.

The silty clay lithofacies is present throughout most of the study area, ranging from 1 to 48 ft thick (Table 3.2). The thickness appears to be relatively constant from the center of the study area eastward as the sediments slope about the same rate as the basalt surface (Plates 1 through 3 and Figure 3.7). The silty clay lithofacies probably correlates to the fine-grained Ringold sequence beneath the 300 Area described in DOE (1990a), the lower silt and clay of the Ringold Formation beneath the 300 Area in Lindberg and Bond (1979), and the lower Ringold unit beneath the 300 Area in (Schalla et al. 1988). Newcomb et al. (1972) noted blue clays in the lowest part of the Ringold Formation beneath the Richland area.

3.2.2.2 Gravelly Sand to Silty Clay Lithofacies

The silty clay lithofacies is overlain, in part, by a poorly sorted mixture of clay, silt, sand, and gravel. These sediments comprise the gravelly sand to silty clay lithofacies. This lithofacies contains several discontinuous sequences of fining upward sediments with a distinct silty clay lens forming the top. Webster and Crosby (1982) described fining upward cycles within the Ringold Formation elsewhere on the Hanford Site.

The sediments within the gravelly sand to silty clay lithofacies consist of quartzose, basaltic, and metamorphic grains. Color changes are common, including brown, black, blue, green, and yellow.

Figure 3.7 Top of Silty Clay Lithofacies Map

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Drilling logs indicate the sediments are consolidated and locally cemented. Relatively higher natural gamma counts (higher clay content) were noted near the top of the lithofacies. Texture and sorting suggest several episodes of fluvial and slack-water deposition.

The gravelly sand to silty clay lithofacies occurs in 27 wells at depths of 28 to 90 ft bls (396 to 304 ft above msl) (Table 3.2 and Figure 3.8) and ranges in thickness from 20 to 73 ft (Table 3.2). The sediments are present primarily in the eastern part of the study area and discontinuous along the Yakima River floodplain (Plates 1 through 5 and Figure 3.8). Future hydrogeologic investigations within the study area should include test holes between the city of Richland landfill and 1100 Area to further characterize the distribution of these sediments.

The silty clay lens at the top of the gravelly sand to silty clay lithofacies appears to be an erosional unconformity with peak elevations east of George Washington Way and west of Stevens Drive (Figure 3.8). Thickness of the silty clay lens ranges from 8 ft in well 699-S32-E13B to 45 ft in well W-5. The silty clay lens correlates to the uppermost fine-grained Ringold Formation facies beneath the 1100-EM-1 Operable Unit described in DOE (1990b). DOE (1990b) also noted an ash layer east of the Horn Rapids landfill (Figure 1.2), which is laterally continuous with the uppermost fine-grained Ringold Formation facies. The ash layer is interpreted to be originally an airfall deposit of limited extent, transported to its present location by the ancestral Yakima River.

3.2.2.3 Sandy Gravel Lithofacies

The sandy gravel lithofacies is present throughout the entire study area. The sandy gravel lithofacies overlies the silty clay lithofacies in the western part of the study area and the gravelly sand to silty clay lithofacies in the eastern part of the study area. The sediments crop out south and east of the Stevens Drive/Horn Rapids Road intersection to the southern end of the study area (Plates 1 through 5 and Figure 3.9).

The sandy gravel lithofacies was partially or fully penetrated in all 61 wells at depths ranging from land surface to 99 ft bls (437 to 353 ft above msl) (Table 3.2 and Figure 3.9). Thickness of the lithofacies varies between 24 and 164 ft (Table 3.2), with the thickest accumulation in piezometer 699-S31-1P. The sediments are poorly sorted, consisting of fine to coarse gravel with a sand and silt matrix. The gravels consist mainly of basalt with some metamorphic and quartzose clasts. The sands and silts consist of black and brown basaltic and quartzose grains. The sediments range from unconsolidated to cemented. Backfill materials from construction activities are found locally at or near the surface and are generally indistinguishable from the in situ gravels and sands. Texture and sorting suggest high-energy deposition, resulting from both fluvial and glaciofluvial processes.

The sandy gravel lithofacies correlates to the coarse-grained Ringold Formation facies and Hanford formation beneath the 1100-EM-1 Operable Unit described in DOE (1990b). These sediments also appear to correlate to the coarse-grained Ringold sequence and Hanford formation beneath the 300 Area in DOE (1990a) and the middle Ringold unit and Hanford formation beneath the 300 Area in (Schalla et al. 1988).

3.2.2.4 Silty Sand Lithofacies

The silty sand lithofacies is the uppermost lithofacies in the study area except where the sandy gravel lithofacies crops out (Plates 1 through 5 and Figure 3.9). The silty sand lithofacies was

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Figure 3.8 Top of Gravelly Sand to Silty Clay Lithofacies Map

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Figure 3.9 Top of Sandy Gravel Lithofacies Map

probably removed during construction activities in these areas. The silty sand lithofacies consists of unconsolidated and well-sorted silt and very fine to coarse sand. The grains are described as both quartzose and basaltic and brown, black, and gray. Minor gravel lenses are noted in wells ORV #1, ORV #2, the Landfill Well, and 699-S31-1 (Plates 1, 2, and 4). The sediments range in thickness from 2 to 99 ft (Table 3.2), with the thickest accumulation near the city of Richland landfill (Figure 1.2).

The silty sand lithofacies was probably derived from two sources. The coarse-grained sands and minor gravel lenses probably represent a transitional facies between the flood deposits of the Pasco Gravels facies and the slack-water deposits of the Touchet Beds facies. The silt and fine sands, evident in the form of northeast-trending sand dunes, are probably eolian deposits derived from reworked Hanford sediments. The silt and fine sands correlate to the surficial deposits at the 1100-EM-1 Operable Unit described in DOE (1990b) and the eolian deposits at the 300 Area in DOE (1990a), Lindberg and Bond (1979), and Schalla et al. (1988).

3.3 Hydrology of the Study Area

Several natural and artificial surface-water bodies, a confined aquifer, and an unconfined aquifer are present within the study area. This discussion focuses on the surface-water types, locations, and uses, and ground-water occurrence, recharge, and discharge.

3.3.1 Surface Water

The primary surface-water features within the study area are the Yakima and Columbia rivers (Figure 1.2). The Yakima River bounds the study area to the west from approximately State Highway 24 to State Highway 224. The Columbia River forms the eastern boundary from approximately Horn Rapids Road to Saint Street. Flows along these reaches are controlled primarily by the Horn Rapids irrigation diversion dam in the Yakima River and Priest Rapids and McNary hydroelectric dams in the Columbia River.

Surface runoff to the Yakima and Columbia rivers within the study area contributes little to total gaged flows (DOE 1988b). Low-intensity precipitation events combined with high evapotranspiration rates and soil infiltration capacities are insufficient to generate runoff. Seeps have been documented within the study area along the Columbia River shoreline (McCormack and Carlile 1984). The seeps flow intermittently, primarily as a result of fluctuating river levels.

The Columbia River is used as a source for drinking water, agricultural and lawn irrigation, and recreational activities. The city of Richland pumping station at Snyder Street supplies the municipal water-treatment plant and North Richland well field. Irrigation intakes include the AEDC and PNL at the Port of Benton and Washington State University Tri-Cities at Sprout Road. The Yakima River is used for irrigation and recreational activities.

Ponded water is present in low-lying areas of the Yakima River floodplain (Figure 1.2). Ponded water was also noted near wells W-1 through W-6 (Figure 3.1) from February through April 1990, when ground-water levels rose above land surface. Ground water also discharges year-round to several drainage ditches south of the study area in the city of Richland.

Artificial surface-water features within the study area include the settling and recharge basins within the North Richland well field, Siemens Power Corp. process lagoons, and Horn Rapids ditch, which diverts water from the Yakima River at Horn Rapids Dam (Figure 1.2).

3.3.2 Ground Water

Both confined and unconfined aquifers occur beneath the study area. For this study, four principal hydrofacies have been identified. Hydrofacies are defined here as laterally continuous units of hydrologic significance. Hydrologic significance is indicated by a change in water level with depth and/or a hydraulic conductivity contrast between units. No hydrochemical data are available from this study. The hydrofacies are, in ascending order, 1) a confined aquifer (CA) within the Ice Harbor Member, 2) an aquitard (A) formed by the silty clay lithofacies, 3) the unconfined aquifer (UA) within the gravelly sand to silty clay and sandy gravel lithofacies, and 4) the unsaturated sediments (US) within the sandy gravel and silty sand lithofacies. Figure 3.10 is a generalized hydrofacies diagram showing the average water-level elevations available for the study area. Table 3.4 lists hydrofacies depths, elevations, and thicknesses. Hydraulic property estimates for hydrologic units within and adjacent to the study area are available from several sources. These estimates are shown in Table 3.5.

Interpretation of these hydrofacies was based on geologic sample descriptions, primarily texture, sorting, and consolidation. Natural gamma, neutron, and density logs were used qualitatively to indicate relative differences in hydraulic conductivity and porosity. Hydraulic head measurements were used to calculate horizontal and vertical gradients. However, as mentioned previously, only a few wells exist over a large study area. Most of these wells are completed in the unconfined aquifer. Changes in sediment characteristics probably occur over short distances resulting in heterogeneous and anisotropic conditions. Refinement of the hydrofacies descriptions and occurrences may be required as new hydrogeologic data become available. As additional monitoring wells are completed at discrete intervals, water levels should be measured concurrently across the study area. A flow net should be constructed to analyze the hydraulic heads within and between hydrofacies.

3.3.2.1 Confined Aquifer

A confined aquifer occurs within the Ice Harbor Member of the Saddle Mountains Basalt Formation and is monitored in two of the eight wells penetrating basalt. Drilling logs describe the aquifer as water-bearing, black, porous, or vesicular basalt with some sand. Aquifer thickness ranges from 1 to 22 ft (Table 3.4); however, the lateral continuity of the confined aquifer is unknown. The distribution and continuity of the aquifer should be further characterized to better understand ground-water flow and contaminant transport. Schalla et al. (1988) noted an uppermost confined aquifer beneath the 300 Area within the Ice Harbor Member and basal Ringold unit with horizontal hydraulic conductivities of 2 to 260 ft/day and transmissivities of 60 to 1300 ft²/day (Table 3.5).

Local recharge to the confined aquifer probably occurs near the Yakima River horn where the Ice Harbor Member crops out adjacent to the Yakima River (Plates 1 through 3 and Figure 3.6). Increasing hydraulic head with depth was noted in drilling logs for well ORV #1 (Figure 3.1). Schalla et al. (1988) reported hydraulic heads for the uppermost confined aquifer beneath the 300 Area approximately 20 to 35 ft higher than the unconfined aquifer, resulting in an upward hydraulic gradient of 0.15 to 0.27 ft/ft. Discharge occurs to the unconfined aquifer and Columbia River.

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Figure 3.10 Generalized Hydrofacies Diagram for the Study Area

Table 3.4 Hydrofacies Depths, Elevations, and Thicknesses Beneath the Study Area

Well Number	Land Surface Elev. (ft)	US Thick. (ft)	W-L Depth # (ft)	W-L Elev. (ft)	UA Thick. (ft)	SCL Depth (ft)	SCL Elev. (ft)	SCL Thick. (ft)	A Depth (ft)	A Elev. (ft)	A Thick. (ft)	CA Depth (ft)	CA Elev. (ft)	CA Thick. (ft)
3000-F (3099-47-18B)	372.97	32	33.65	341.30		41	331.97	15						
699-S30-E15A	397.67	56	58.64	341.50										
699-S32-E13A	388.67	41	43.18	347.28		75	313.67	11						
699-S31-E13	392.29	45	47.11	346.95		70	322.29	12						
699-S32-E13B	392.69	45	47.18	347.54		68	324.69	8						
699-S29-E12	383.71	38	41.95	346.01										
TW17	377.45	24	26.11	353.34										
TW16	375.41	22	23.43	353.30		43	332.41							
TW18	375.57	22	24.04	353.30										
TW15	368.88	16	17.26	353.34										
TW14	368.48	15	16.83	353.38										
699-S31-1	458.09	82	84.33	375.67										
699-S31-1P	458.09	82	80.49	379.51	103				185	273.09	36	221	237.09	
699-S23-26	418.32	4	10.13	414.57		29	389.32							
EC-1	362.45	7	7.10	355.47										
W-1	358.87	6	7.09	352.69		29	329.87							
W-3	355.63	3	5.99	352.89										
W-4	360.00	4	5.07	356.43										
W-5	360.00	4	6.23	355.74		34	326.00	45						
W-6	360.00	4	5.92	355.78		32	328.00							
Saint	360.00	14	15.04	345.83										
1100-2 (1199-34-13)	392.03	36	41.63	353.15		78	314.03	11						
699-S43-E12	402.33	48	51.39	354.21										
699-S41-E13A	407.21	52	55.69	354.87										
699-S41-E13B	406.75	52	55.22	354.88		90	316.75							
699-S37-E14	404.88	51	54.61	353.67										
3000-D1 (1199-41-13C)	404.51	50	51.64	354.34		84	320.51							
699-S36-E12B	397.44	44	45.25	353.82		82	315.44	17						
699-S36-E13B	397.76	44	45.76	353.87		75	322.76	15						
699-S36-E13A	398.34	45	45.70	353.60										
F-2 (3099-45-16)	406.87	59	60.07	347.97										
Average	398	33	34	357		59	325	17	142	293	37	191	250	9

Notes:

US = Unsaturated Sediments

W-L = Water Level

UA = Unconfined Aquifer

SCL = Silty Clay Lens at the Top of the Gravelly Sand to Silty Clay Lithofacies

A = Aquitard

CA = Confined Aquifer

Piezometer 699-S31-1P is Located in Well 699-S31-1

* = Approximate Number

= Measured Below Top of Casing or Measuring Point in October 1989

Table 3.4 (cont'd)

Well Number	Land Surface Elev. (ft)	US Thick. (ft)	W-L Depth # (ft)	W-L Elev. (ft)	UA Thick. (ft)	SCL Depth (ft)	SCL Elev. (ft)	SCL Thick. (ft)	A Depth (ft)	A Elev. (ft)	A Thick. (ft)	CA Depth (ft)	CA Elev. (ft)	CA Thick. (ft)
699-S30-E14	399.81	58*	5.42	395.97	105*	90	309.81	30	163	236.81	46	209	190.81	
699-S28-E0	444.45								187	257.45	36	223	221.45	11
699-S24-19	426.83	29*	20.04	407.79	22*	31	395.83	5	51	375.83	1	52	374.83	1
W-2	359.15	4*	4*	355*		28	331.15							
699-S40-E14	399.34	44	47.95	354.90										
699-S36-E12A	397.64	50*	50*	348*										
ORV #1 (699-ORV-1)	472.00	108*	77*	364*	50*				158	314.00	42	200	272.00	22
ORV #2 (699-ORV-2)	455.00		80*						160	295.00	40	200	255.00	
Landfill (699-LANDFIL)	482.00		105*						202	280.00	46	248	234.00	3
Landfill #1	484.00	106*	106*	378*										
Landfill #2	464.10	90*	90*	374*										
Landfill #3	475.70	101*	101*	375*										
Landfill #4	456.70	81*	81*	375*										
699-S51-2	386.00					58	328.00	17	125	261.00	48	173	213.00	8
Rackley	390.00	9*	9*	381*	41*				50	340.00				
Rigby	385.00	9*	9*	376*										
Lamb-Weston Inc.	370.00	20*	20*	350*		61	309.00							
Huisingsh	360.00	29*	29*	331*		56	304.00							
1100-D (1199-34-15B)	367.75	15	15.90	352.34										
3000-D5 (3099-42-16)	407.50	54	54.91	353.21										
3000-A (1199-40-15)	395.00	40	41.16	355.02		85	310.00							
3000-B (1199-40-16B)	390.00	36	37.96	354.31		82	308.00							
3000-H (1199-40-16C)	380.00	26	26.68	355.22										
3000-C (1199-39-16D)	370.30	15	16.60	355.22		59	311.30							
3000-K (1199-38-16)	365.40	12	12.19	353.81		50	315.40							
3000-N (1199-37-16)	361.00	7	9.47	353.93		41	320.00							
3000-L (1199-39-16E)	397.00	42	42.87	355.13										
3000-D (1199-39-16C)	385.30	30	31.76	355.46										
3000-J (1199-39-15)	392.00	37	38.29	354.71										
3000-G (1199-41-15)	397.51	43	44.34	354.73		74	323.51							
1100-8 (1199-34-15A)	369.00													
Average	398	33	34	357		59	325	17	142	293	37	191	250	9

Notes:

US = Unsaturated Sediments

W-L = Water Level

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A = Aquitard

CA = Confined Aquifer

Piezometer 699-S31-1P is Located in Well 699-S31-1

* = Approximate Number

= Measured Below Top of Casing or Measuring Point in October 1989

Table 3.5 Hydraulic Property Estimates Within and Adjacent to the Study Area

Hydrologic Unit	Area	Horizontal Hydraulic Conductivity (ft/day)	Vertical Hydraulic Conductivity (ft/day)	Transmissivity (ft ² /day)	Storativity or Specific Yield	Source
Uppermost Confined Aquifer	300 Area	2-260		60-1,300		Schalla et al. (1988)
Lower Aquitard	1100-EM-1 Operable Unit	0.001				DOE (1990b)
Upper Confined Aquifer	1100-EM-1 Operable Unit	0.3 and 1				DOE (1990b)
Upper Aquitard	1100-EM-1 Operable Unit		0.00009-0.1			DOE (1990b)
Unconfined Aquifer*	1100 and 3000 Areas	10-3,100		940-114,000		Bierschenk (1959)
	600 Area	90		2,700		Bierschenk (1959)
	300 Area	30-4,400		2,800-201,000		Bierschenk (1959)
	Richland-West Richland			5,900		Brown (1979)
	1100-EM-1 Operable Unit	2-140				DOE (1990b)
	North Richland Well Field			86,000	0.1	ICF Northwest (1987)
	Siemens Power Corp.	520				J-U-B Engineers Inc. (1982)
	300 Area			15,000-625,000		Lindberg and Bond (1979)
	3000 Area			19,500-144,400		Newcomb et al. (1972)
	300 Area	1.9-50,000		100-1,000,000		Schalla et al. (1988)
	300 Area	2400		160,000	0.1	Tillson et al. (1969)

Note:

* = Undifferentiated Ringold Formation and Hanford formation

Hydraulic head data collected in this study for both wells monitoring the confined aquifer (piezometer 699-S31-1P and well 699-S24-19) are questionable. Drilling logs indicate potential hydraulic connection between the confined and unconfined aquifers. Annular seals between the aquifers are not evident in the logs. Potential hydraulic connection is also noted for five of the six other wells penetrating basalt. Hydraulic testing should be done at these wells to assess these potential connections.

3.3.2.2 Aquitard

An aquitard is formed by the silty clay lithofacies overlying the Ice Harbor Member. The aquitard ranges in thickness from 1 to 48 ft (Table 3.4) and appears to be laterally continuous within and beyond the study area, extending north to the 300 Area and south to the city of Richland. Beneath the 1100-EM-1 Operable Unit, DOE (1990b) reported a silt layer overlying the basalt with estimated horizontal hydraulic conductivity of 0.001 ft/day (Table 3.5). Geophysical logs show relatively higher natural gamma (higher clay content) and lower neutron neutron (higher porosity) and gamma gamma (lower density) counts in these sediments.

3.3.2.3 Unconfined Aquifer

The unconfined aquifer is the uppermost areally extensive aquifer beneath the study area and is contained within the gravelly sand to silty clay and sandy gravel lithofacies. The unconfined aquifer is laterally continuous within the Ringold Formation and Hanford formation beneath the Hanford Site. Fifty six of the 61 wells used in this study are completed in the unconfined aquifer. Depth to water ranges from near land surface in wells W-1 through W-6 to approximately 100 ft in the city of Richland landfill wells (Figure 3.1). Perched water is found locally in north Richland during the summer irrigation season (J.R. Raymond, PNL, personal communication, 1990).

Thickness of the unconfined aquifer is varied, ranging from approximately 22 to 105 ft (Table 3.4). The minimum thickness occurs in well 699-S24-19, where the basalt has been uplifted and the overlying sediments are generally thinner (Plate 1 and Figure 3.6). Thickness increases to a maximum in the central part of the study area in piezometer 699-S31-1P and again in the northeastern part of the study area in well 699-S30-E14. Ground-water mounding occurs beneath the settling and recharge basins within the North Richland well field.

The base of the unconfined aquifer is formed, at least in part, by the aquitard overlying the Ice Harbor Member. The silty clay lens at the top of the gravelly sand to silty clay lithofacies may divide the aquifer into two parts in the eastern part of the study area. The silty clay lens ranges from 8 to 45 ft thick (Table 3.4 and Figure 3.11). The surface of the silty clay lens appears to be an erosional unconformity (Figure 3.8) and discontinuities may occur. The silty clay lens may also cause local semiconfined to confined conditions within the unconfined aquifer. DOE (1990b) noted a silt aquitard of similar thickness (4 to 33 ft) beneath the 1100-EM-1 Operable Unit that correlates to the silty clay lens. Vertical hydraulic conductivities for this aquitard range from 0.00009 to 0.1 ft/day (Table 3.5). DOE (1990b) further noted an upper confined aquifer beneath the silt aquitard with horizontal hydraulic conductivities of 0.3 and 1 ft/day (Table 3.5). A hydraulic head in the upper confined aquifer approximately 6 ft higher than the unconfined aquifer was measured near the Horn Rapids landfill (Figure 1.2). This results in an upward hydraulic gradient of 0.36 ft/ft.

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Figure 3.11 Isopach Map for the Silty Clay Lens

No water-level data are available from this study to evaluate the hydrologic significance of the silty clay lens. Recent water-level measurements in the HGWDB from well 699-S41-E13C, adjacent to wells 699-S41-E13A and 699-S41-E13B (Figure 3.1), indicate a downward hydraulic gradient near these wells. The silty clay lens appears to be locally significant enough to produce hydraulic head differences. The unconfined aquifer probably acts as a heterogeneous hydrofacies on a small scale over a short time and a homogeneous hydrofacies on a large scale over a long time. The distribution and continuity of the silty clay lens should be further characterized as it may have a marked effect on ground-water flow and contaminant transport in the unconfined aquifer.

Hydraulic property estimates for the unconfined aquifer within and adjacent to the study area are available from several sources, including Bierschenk (1959), Brown (1979), DOE (1990b), ICF Northwest (1987), J-U-B Engineers Inc. (1982), Lindberg and Bond (1979), Newcomb et al. (1972), Schalla et al. (1988), and Tillson et al. (1969). A summary of these estimates is provided in Table 3.5. The hydraulic conductivity and transmissivity values range over several orders of magnitude, probably as a result of aquifer heterogeneity, well design and construction, and/or aquifer test methods.

Local sources of natural recharge to the unconfined aquifer are river water along influent reaches of the Yakima River and precipitation infiltration. Significant artificial recharge occurs from the settling and recharge basins within the North Richland well field. Additional recharge occurs from agricultural, lawn, and waste-water irrigation (Figure 1.2). Discharge occurs primarily to the Columbia River. Lesser discharge occurs to production wells in the North Richland well field, agricultural irrigation wells, monitoring wells, and private wells in north Richland. Figure 3.12 shows water-level elevations for the unconfined aquifer in July 1989. This month was chosen because a complete set of water-level data exists for all of the monitoring wells. Ground water flows generally from west to east. Detailed information on the spatial and temporal distribution of hydraulic head in the unconfined aquifer is provided in Chapter 4.0.

3.3.2.4 Unsaturated Sediments

The unsaturated sediments consist of the upper part of the sandy gravel lithofacies and all of the silty sand lithofacies. The unsaturated sediments range from 3 to 108 ft thick (Table 3.4 and Figure 3.13). The thinnest accumulation occurs in wells W-1 through W-6, where the water table is near land surface. The unsaturated sediments are also thin immediately downgradient of the settling and recharge basins within the North Richland well field. The unsaturated sediments are thickest beneath the city of Richland landfill.

The unsaturated sediments correspond to the vadose zone beneath the 1100-EM-1 Operable Unit described in DOE (1990b). DOE (1990b) reported moisture contents ranging from 1.09 to 7.28% in this zone.

3.4 Hydrogeologic Conceptual Model of the Unconfined Ground-Water Flow System

The remainder of this study focuses on ground-water flow characteristics within the unconfined aquifer beneath the study area. Analysis of existing hydrogeologic data has resulted in the development of the following conceptual model for the unconfined aquifer.

Figure 3.12 Study Area Water-Level Elevations, July 1989

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Figure 3.13 Isopach Map for the Unsaturated Sediments

The hydrogeology of the unconfined aquifer beneath the study area is very complex. Sediments of the Ringold Formation and Hanford formation, which constitute the aquifer, were derived from both fluvial and glaciofluvial processes. Depositional environments ranged from high to low energy. The fluvial sediments were deposited by the ancestral Columbia and Snake rivers. These river courses varied significantly over time, changing as the Columbia River Basalts continued to be uplifted. Sediments range from main stream to overbank-floodplain deposits. The glaciofluvial sediments were deposited by catastrophic floods. Floods eroded portions of the underlying sediments and redeposited them with the flood sediments. These sediments range from massive flood to slack-water deposits.

The depositional history of the Ringold and Hanford sediments has resulted in an unconfined aquifer that is both heterogeneous and anisotropic. The unconfined aquifer occurs within the gravelly sand to silty clay and sandy gravel lithofacies. Aquifer thickness and undoubtedly, hydraulic properties, are varied. The silty clay lithofacies serves as the aquifer bottom in the western part of the study area. In the eastern part of the study area, the silty clay lens at the top of the gravelly sand to silty clay lithofacies may divide the aquifer into two parts. Local semiconfined to confined conditions within the unconfined aquifer may be caused by the silty clay lens. The unconfined aquifer probably acts as a heterogeneous hydrofacies on a small scale over a short time and a homogeneous hydrofacies on a large scale over a long time. Ground water flows generally west to east, from the Yakima River to the Columbia River. The aquifer is recharged by the Yakima River and discharges to the Columbia River.

4.0 Hydraulic Head Distribution

This chapter describes the flow characteristics of the unconfined aquifer beneath the study area based on the spatial and temporal distribution of hydraulic head within the aquifer. A description of the water-level monitoring network is provided. The operations and impacts of the North Richland well field and agricultural, lawn, and waste-water irrigation are discussed as well as the interrelationship with the Yakima and Columbia rivers.

4.1 Description of the Water-Level Monitoring Network

The water-level monitoring network for this study included 46 wells and two gaging stations on the Columbia River. Wells were selected based on their completion interval (primarily within the unconfined aquifer) and whether routine access to the well site was permitted. Well completion distribution is shown in Table 4.1. Water-level data were collected using electric/steel tapes, continuous water-level recorders, and transducers and data loggers. Additional river-elevation and North Richland well field data were collected from the city of Richland at the municipal water-treatment plant on Saint Street.

Water-level data were collected from June 1989 to May 1990. Measurement frequencies varied with collection method and included continuous, every half hour, every 6 hours, weekly, monthly, and biannually. The monthly measurements shown in Table 4.2 and other frequencies where appropriate, were used for analysis and interpretation. The complete water-level data set is contained in Appendix B. Figure 4.1 shows the locations and collection methods for the network.

4.1.1 Electric/Steel Tapes

Thirty nine of the 46 wells in the water-level monitoring network were measured using electric/steel tapes (Figure 4.1). All 39 of these wells are completed in the unconfined aquifer (Table 4.1). An electric tape was used initially to measure the approximate depth to water with steel tape measurements used thereafter.

Hydraulic heads in the monitoring, agricultural irrigation, and other wells were measured on a weekly basis from June to August 1989 and monthly from September 1989 to May 1990, except for the wells completed in basalt. Heads in these wells were measured infrequently during the year because of the focus on the unconfined aquifer. Hydraulic heads in the production wells were measured on a monthly basis from June 1989 to January 1990. Field data including date, procedure, measuring device, initials, well number, time, held value, cut value, depth to water, casing elevation, water-level elevation, and comments were recorded in a bound notebook and transferred to computer spreadsheets for analysis and interpretation. The water levels were measured per PNL technical procedure WL-1, "Water-Level Measurement Procedure" (PNL 1989). The steel tapes are calibrated on an annual basis per PNL technical procedure WL-2, "Procedure for Standardizing Steel Tapes" (PNL 1989).

Table 4.1 Completion Distribution for the Water-Level Monitoring Network

UA Top	UA Above SCL	UA Fully Penetrating Above SCL	UA Open Bottom Above SCL	UA Partially Penetrating Below SCL	Basalt Completion
699-S30-E15A	TW16	699-S32-E13A	EC-1	3000-F	699-S31-1P (CA)
TW17	W-6	699-S31-E13	699-S36-E13B	699-S36-E12B	699-S30-E14
TW18	Saint	699-S32-E13B	F-2	W-5?	699-S24-19 (CA)
699-S31-1	699-S41-E13B	699-S29-E12	699-S23-26?		
699-S43-E12	1100-D	W-1	3000-D1?		
699-S41-E13A	3000-C	W-3			
699-S37-E14	3000-N	1100-2			
699-S36-E13A	3000-L	699-S24-19			
699-S40-E14	W-4?	3000-D5			
TW15?		3000-A			
TW14?		3000-B			
HRD?		3000-H			
		3000-K			
		3000-D			
		3000-J			
		3000-G?			
12	9	16	5	3	3

Notes:

UA = Unconfined Aquifer

SCL = Silty Clay Lens

CA = Confined Aquifer

? = Unsure

Piezometer 699-S31-1P is Located in Well 699-S31-1

HRD = Hand Dug Well Near Horn Rapids Dam

Table 4.2 Monthly Water-Level Measurements Used for Analysis and Interpretation

Well Number	Casing Elev. (ft)	M.P. Elev. (ft)	Land Surface Elev. (ft)	June 1989 Elev. (ft)	June 1989 Depth (ft)	July 1989 Elev. (ft)	July 1989 Depth (ft)	Aug. 1989 Elev. (ft)	Aug. 1989 Depth (ft)	Sept. 1989 Elev. (ft)	Sept. 1989 Depth (ft)	Oct. 1989 Elev. (ft)	Oct. 1989 Depth (ft)	Nov. 1989 Elev. (ft)	Nov. 1989 Depth (ft)	Dec. 1989 Elev. (ft)	Dec. 1989 Depth (ft)	Jan. 1990 Elev. (ft)	Jan. 1990 Depth (ft)	Feb. 1990 Elev. (ft)	Feb. 1990 Depth (ft)	Mar. 1990 Elev. (ft)	Mar. 1990 Depth (ft)	Apr. 1990 Elev. (ft)	Apr. 1990 Depth (ft)	May 1990 Elev. (ft)	May 1990 Depth (ft)
3000-F (3099-47-18B)	374.95		372.97			34.90	340.05	34.82	340.13	33.41	341.54	33.22	341.73	33.78	341.17	32.26	342.69	32.64	342.31	31.56	343.39	31.50	343.45	32.29	342.66	31.59	343.36
699-S30-E15A	400.14		397.67	58.41	341.73	59.98	340.16	59.45	340.69	58.61	341.53	59.33	341.81	58.76	341.38	57.58	342.56	57.57	342.57	56.33	343.81	56.93	343.21	57.79	342.35	56.92	343.22
699-S32-E13A	390.46		388.67	43.55	346.91	43.57	346.89	43.24	347.22	43.35	347.11	43.40	347.06	44.06	346.40	44.22	346.24	44.10	346.36	44.32	346.14	44.45	346.01	44.49	345.97	43.95	346.51
699-S31-E13	394.06		392.29	47.48	346.58	47.53	346.53	47.19	346.87	47.29	346.77	47.33	346.73	47.93	346.13	48.12	345.94	48.00	346.06	48.14	345.92	48.31	345.75	48.36	345.70	47.83	346.23
699-S32-E13B	394.72		392.69	47.64	347.08	47.56	347.16	47.24	347.48	47.36	347.36	47.39	347.33	48.03	346.69	48.22	346.50	48.15	346.57	48.34	346.38	48.44	346.28	48.50	346.22	48.00	346.72
699-S29-E12	387.96		383.71	42.06	345.90	42.13	345.83	42.08	345.88	42.05	345.91	41.98	345.98	42.24	345.72	42.39	345.57	42.32	345.64	42.28	345.68	42.36	345.60	42.36	345.60	42.14	345.82
TW17	379.45		377.45			26.37	353.08	26.28	353.17	26.20	353.25	26.04	353.41	26.02	353.43	26.05	353.40	26.03	353.42	26.03	353.42	26.08	353.37	26.15	353.30	26.18	353.27
TW16	376.73		375.41			23.68	353.05	23.59	353.14	23.51	353.22	23.38	353.35	23.34	353.39	23.37	353.36	23.35	353.38	23.36	353.37	23.41	353.32	23.46	353.27	23.48	353.25
TW18	377.34		375.57			24.29	353.05	24.20	353.14	24.13	353.21	23.99	353.35	23.95	353.39	23.98	353.36	23.95	353.39	23.95	353.39	24.01	353.33	24.07	353.27	24.09	353.25
TW15	370.60		368.88			17.50	353.10	17.41	353.19	17.34	353.26	17.21	353.39	17.17	353.43	17.20	353.40	17.19	353.41	17.18	353.42	17.23	353.37	17.29	353.31	17.32	353.28
TW14	370.21		368.48			17.08	353.13	16.99	353.22	16.92	353.29	16.78	353.43	16.75	353.46	16.77	353.44	16.75	353.46	16.76	353.45	16.82	353.39	16.87	353.34	16.89	353.32
699-S31-1	460.00		458.09	84.34	375.66	84.34	375.66	84.32	375.68	84.31	375.69	84.39	375.61	84.29	375.71	84.32	375.68	84.28	375.72	84.28	375.72	84.27	375.73	84.22	375.78	84.20	375.80
699-S31-1P	460.00		458.09	83.12	376.88	84.24	375.76	84.33	375.67	84.41	375.59																
699-S23-26	424.70		418.32			10.43	414.27	10.43	414.27	10.25	414.45	9.88	414.82	9.66	415.04	9.67	415.03	9.22	415.48	9.20	415.50	9.03	415.67	8.10	416.60	9.65	415.05
EC-1	361.11	362.57	362.45			6.82	355.75	7.20	355.37	7.33	355.24	6.94	355.63	6.58	355.99	6.07	356.50	5.60	356.97	5.27	357.30	5.44	357.13	5.74	356.83	6.34	356.23
W-1	359.78		358.87			13.03	346.75	16.05	343.73	7.97	351.81	6.85	352.93	5.68	354.10	5.47	354.31	5.25	354.53	5.19	354.59	5.19	354.59	5.68	354.10	6.24	353.54
W-3	358.88		355.63			10.00	348.88	9.90	348.98	6.69	352.19	5.77	353.11	4.78	354.10	4.56	354.32	4.36	354.52	4.28	354.60	4.34	354.54	4.71	354.17	5.23	353.65
W-4	361.50		360.00							5.95	355.55	4.82	356.68	3.65	357.85	3.45	358.05	3.22	358.28	3.16	358.34	3.26	358.24	3.68	357.82	4.24	357.26
W-5	361.82	361.97	360.00			6.23	355.74							6.23	355.74												
W-6	361.70		360.00					7.68	354.02	6.72	354.98	5.78	355.92	5.09	356.61	4.95	356.75	4.76	356.94	4.83	356.87	5.02	356.68	5.44	356.26	5.87	355.83
Saint	361.17	360.87	360.00			15.82	345.05	15.43	345.44	14.90	345.97	14.98	345.89	15.17	345.70	14.95	345.92	14.94	345.93	14.66	346.21	14.95	345.92	14.95	345.92	14.86	346.01
1100-2 (1199-34-13)	394.78		392.03	42.48	352.30	41.95	352.83	41.62	353.16	41.49	353.29	41.72	353.06	41.96	352.82	42.20	352.58	42.28	352.50	42.53	352.25	42.73	352.05	42.95	351.83	42.90	351.88
699-S43-E12	405.60		402.33	52.00	353.60	51.58	354.02	51.28	354.32	51.20	354.40	51.48	354.12	51.69	353.91	51.54	354.06	51.60	354.00	52.04	353.56	52.35	353.25	52.62	352.98	52.52	353.08
699-S41-E13A	410.56		407.21	54.78	355.78	54.66	355.90	53.80	356.76	55.24	355.32	55.84	354.72	57.02	353.54	55.13	355.43	56.49	354.07	57.82	352.74	58.42	352.14	57.83	352.73	57.46	353.10
699-S41-E13B	410.10		406.75	54.29	355.81	54.17	355.93	53.31	356.79	54.76	355.34	55.37	354.73	56.58	353.52	54.63	355.47	56.02	354.08	57.38	352.72	57.98	352.12	57.35	352.75	57.00	353.10
699-S37-E14	408.28		404.88	53.88	354.40	53.74	354.54	53.10	355.18	54.16	354.12	54.74	353.54	55.65	352.63	54.93	353.35	55.71	352.37	56.83	351.45	57.42	350.86	57.02	351.26	56.62	351.66
3000-D1 (1199-41-13C)	405.98		404.51	50.88	355.10	50.70	355.28	50.13	355.85	51.14	354.84	51.79	354.19	52.45	353.53	51.54	354.44	52.49	353.49	53.82	352.16	54.32	351.66	53.99	351.99	53.45	352.53
699-S36-E12B	399.07		397.44	44.78	354.29	44.54	354.53	44.08	354.99	44.71	354.36	45.40	353.67	46.38	352.69	45.60	353.47	46.21	352.86	47.38	351.69	48.10	350.97	47.97	351.10	47.06	352.01
699-S36-E13B	399.63		397.76	45.50	354.13	45.11	354.52	44.48	355.15	45.19	354.44	45.96	353.67	46.94	352.69	46.47	353.16	46.58	353.05	47.92	351.71	48.64	350.99	48.72	350.91	47.65	351.98
699-S36-E13A	399.30		398.34	45.26	354.04	45.02	354.28	44.53	354.77	45.26	354.04	45.85	353.45	46.74	352.56	46.07	353.23	46.68	352.62	47.75	351.55	48.40	350.90	48.33	350.97	47.43	351.87
F-2 (3099-45-16)	408.04	408.09	406.87	60.16	347.93	60.34	347.75	59.87	348.22	59.94	348.15	60.20	347.89	61.07	347.02	60.86	347.23	60.85	347.24	61.26	346.83	61.97	346.12	62.07	346.02	61.24	346.85
699-S30-E14	401.39		399.81			5.42	395.97																				
699-S24-19	427.83		426.83					20.04	407.79																		
699-S40-E14	402.85		399.34	45.85	357.00	45.78	357.07	44.99	357.86	46.67	356.18	47.95	354.90	48.98	353.87	46.55	356.30	47.94	354.91								
1100-D (1199-34-15B)	367.75	368.24	367.75	16.72	351.52	16.00	352.24	15.61	352.63	15.60	352.64	15.90	352.34	16.13	352.11	16.69	351.55	16.85	351.39								
3000-D5 (3099-42-16)	407.63	408.12	407.50			54.30	353.82	53.53	354.59	54.45	353.67	54.91	353.21	56.13	351.99	55.84	352.28	56.01	352.11								
3000-A (1199-40-15)	395.45	396.18	395.00	39.25	356.93	39.32	356.86	38.46	357.72	40.10	356.08	41.16	355.02	42.30	353.88	39.96	356.22	41.17	355.01								
3000-B (1199-40-16B)	391.66	392.27	390.00	35.93	356.34	35.95	356.32	35.15	357.12	37.02	355.25	37.96	354.31	39.23	353.04	37.84	354.43	38.25	354.02								
3000-H (1199-40-16C)	381.00		380.00	24.12	356.88	24.14	356.86	23.27	357.73	25.41	355.59	26.68	354.32	27.88	353.12	26.92	354.08	26.53	354.47								
3000-C (1199-39-16D)	371.17	371.82	370.30	13.77	358.05	13.73	358.09	12.85	358.97	15.09	356.73	16.60	355.22	17.80	354.02	15.42	356.40	16.22	355.60								
3000-K (1199-38-16)	366.00		365.40	12.16	353.84	11.28	354.72	9.21	356.79	10.96	355.04	12.19	353.81	13.48	352.52	12.12	353.88	12.55	353.45								
3000-N (1199-37-16)	363.40		361.00	9.30	354.10	8.45	354.95	7.15	356.25	8.57	354.83	9.47	353.93	10.83	352.57	10.22	353.18	10.82	352.58								
3000-L (1199-39-16E)	398.00		397.00	41.30	356.70	41.03	356.97	39.93	358.07	41.71	356.29	42.87	355.13	44.17	353.83	42.02	355.98	43.05	354.95								
3000-D (1199-39-16C)	385.77	387.22	385.30	29.20	358.02	29.25	357.97	28.26	358.96	30.20	357.02	31.76	355.46	32.93	354.29	30.28	356.94	31.60	355.62								
3000-J (1199-39-15)	393.00		392.00	35.6

S9203107.4

Figure 4.1 Water-Level Monitoring Network for the Study Area

4.1.2 Continuous Water-Level Recorders

Six of the 46 wells in the water-level monitoring network were measured using continuous water-level recorders (Figure 4.1). Five of these six wells were selected based on the following criteria: 1) the wells are completed in the unconfined aquifer (Table 4.1), 2) the casing diameters are sufficient to accept 6-in. floats, and 3) the wells are located adjacent to a waste disposal site, agricultural field, or the Columbia River. Well 3000-D1 was initially monitored as part of an ongoing Hanford Site project. Stevens Type F recorders were installed per manufacturer's instructions on the wells. Table 4.3 lists the well number, recorder serial number, clock type, drum and clock gears, and starting and ending dates.

Five of the six wells were set up with drum gears of 1 ft per revolution. Well 3000-F was set up with drum gears of 5 ft per revolution because of its proximity to the Columbia River (Figure 4.1). The recorder charts were changed on a weekly basis from June to August 1989 and monthly from September 1989 to May 1990. The well number, clock type, feet per revolution, date, time, measuring device, initials, and starting and ending depths to water were recorded on the chart. The starting and ending depths to water were measured using a steel tape per PNL technical procedure WL-1, "Water-Level Measurement Procedure" (PNL 1989). The recorders were cleaned, oiled, and the batteries replaced monthly. Field data including date, well number, time, held value, cut value, depth to water, casing elevation, measuring point elevation, water-level elevation, comments, procedure, measuring device, and initials were recorded in a bound notebook. The recorder charts were digitized, with the 1200 hrs reading for each day transferred to computer spreadsheet for analysis and interpretation.

4.1.3 Transducers and Data Loggers

One of the 46 wells in the water-level monitoring network and 1 Columbia River gaging station were measured using transducers and data loggers (Figure 4.1). These devices were installed initially as part of other ongoing Hanford Site projects.

A Keller 10-psi transducer and Terra 8D data logger were installed in well 699-S40-E14 in November 1988. The transducer and data logger were set up to monitor fluctuations in the unconfined aquifer adjacent to the North Richland well field. Well 699-S40-E14 is located immediately west of the well field (Figure 4.1). Historical data indicate that operation of the well field has a significant impact on water levels and hydraulic gradients in this area.^(a)

Hydraulic head measurements during this study were recorded every half hour from June 1, 1989, to January 26, 1990, and then every 6 hours through May 31, 1990. The data were downloaded monthly to a computer in the field. Steel tape measurements were used to calibrate the transducer and data logger for instrument drift after downloading. Rechargeable batteries were installed every month. Field data including date, well number, depth to water, time, measuring device, filename, comments, and initials were recorded in a bound notebook. The field data were converted to ascii files and transferred to computer spreadsheet. The actual and daily average water-level elevations were used for analysis and interpretation.

(a) Freshley, M. D., M. P. Bergeron, and N. J. Aimo. 1989. Ground-Water Modeling Investigation of North Richland Well Field and the 1100 Area, Letter Report. Pacific Northwest Laboratory, Richland, Washington.

Table 4.3 Continuous Water-Level Recorder Inventory

Well Number	Recorder Serial Number	Clock Type	Drum Gears	Clock Gears	Starting Date	Ending Date
3000-F	99994-81	PNL Wind Up	110/33	128/16	06-26-89	10-05-89
	J-024400	UI Battery		128/16	10-05-89	05-17-90
EC-1	92654-79	PNL Wind Up	84/56	128/16	07-13-89	08-22-89
	B-9580	WHC Battery		128/16	08-22-89	05-17-90
1100-2	99993-81	PNL Battery	84/56	96/48	06-14-89	08-16-89
				128/16	08-16-89	05-17-90
3000-D1	92655-79	PNL Wind Up	84/56	128/16	06-21-89	09-09-89
	J-024391	UI Battery		128/16	09-09-89	02-23-90
	130510	UI QMT		N/A	03-03-90	05-17-90
699-S36-E13A	99995-81	PNL Battery	84/56	96/48	06-26-89	08-16-89
				128/16	08-16-89	05-17-90
F-2	92653-79	PNL Battery	84/56	96/48	06-14-89	08-16-89
				128/16	08-16-89	05-17-90

Notes:

PNL = Pacific Northwest Laboratory

UI = University of Idaho

WHC = Westinghouse Hanford Company

QMT = Quartz Multispeed Timer

A Keller 10-psi transducer and Terra 8D data logger were also installed at the Surface Water Monitoring Station (SWS-1) adjacent to the 300 Area (Figure 4.1). The transducer and data logger were set up to monitor fluctuations in the Columbia River downgradient from the 300 Area Process Trenches.

River-elevation measurements were recorded every half hour. Data were collected for this study from June 1, 1989, through May 31, 1990. The data were downloaded monthly to a computer in the field. Staff-gage measurements were used to calibrate the transducer and data logger for instrument drift after downloading. Rechargeable batteries were installed every month. Field data including date, station number, river elevation, time, filename, comments, and initials were recorded in a bound notebook. The field data were converted to ascii files and transferred to computer spreadsheet. The actual, daily average, and 10-day average river elevations were used for analysis and interpretation.

4.1.4 Other Water-Level Data

Other water-level data collected for this study include Columbia River elevations at the city of Richland pumping station on Snyder Street (Figure 4.1). Daily staff-gage readings were recorded in a monthly Richland Water System Report. Data were collected for the period June 1, 1989, to May 31, 1990. These reports also provided the daily and monthly volumes of recharge and production water pumped to and from the North Richland well field, respectively. The well field serves as the secondary water-supply system for the city of Richland.

4.2 Hydraulic Head Distribution

The spatial and temporal distribution of hydraulic head in the unconfined aquifer is based on hydraulic head measurements from the water-level monitoring network described above. The analysis and interpretation of these measurements focuses on ground-water flow directions, horizontal and vertical hydraulic gradients, and well and river hydrographs. Water-level elevations for July 1989 are shown in Figure 3.12. This month was chosen because a complete set of water-level data exists for all of the monitoring wells. Water-level elevation maps for June 1989 and August 1989 through May 1990 are included in Appendix C. Figure 4.2 shows hydrographs for selected wells and the Columbia River at SWS-1. Hydrographs for the remaining wells, in both collective (for adjacent wells) and individual format, and the city of Richland pumping station at Snyder Street are contained in Appendix D.

4.2.1 Spatial Distribution of Hydraulic Head

Ground water in the unconfined aquifer beneath the study area flows generally west to east toward the Columbia River year around (Figure 3.12 and Appendix C). This flow direction is altered locally by the ground-water mound beneath the North Richland well field and to a lesser extent by pumping from wells W-4 through W-6. The ground-water mound results from the net recharge (volume of recharge minus production water) pumped to the well field. The impacts of this mound are evident across the eastern part of the study area. Ground-water flow is directed to the northeast and southeast of the well field.

A cone of depression forms near wells W-4 through W-6 when these wells are pumped to irrigate the potatoes west of the 1100 Area (Figure 3.12 and Appendix C). The cone of depression extends outward approximately 0.25 mi and is noted to the southwest in well EC-1.

Ground-water levels near the Columbia River are influenced by fluctuations in the river elevation. Responses to these fluctuations are most pronounced along the river shore near well 3000-F and can be seen at least 1500 ft inland in the northeastern part of the study area. The fluctuations are dampened significantly to the south, within approximately 500 ft of the river, near the Saint Well.

Ground-water levels in the north central part of the study area appear to reflect natural conditions. No influence from human activities is evident at this time.

Figure 4.2 Hydrographs for Selected Wells Across the Study Area

Horizontal hydraulic gradients for the unconfined aquifer were calculated and generally reflect the eastward sloping topography of the study area. The monthly and average gradients for three west to east transects, using hydraulic head data from wells 699-S23-26, 3000-F, 699-S37-E14, and the Saint Well, are shown in Table 4.4. The hydraulic gradients range from approximately 6 to 8 ft/mi and are consistent between the three transects over time.

No data from this study are available on the vertical hydraulic gradients between the unconfined and confined aquifers. Gradient calculations were attempted using hydraulic head data from well 699-S31-1 and piezometer 699-S31-1P, and a hand-dug well (HRD) completed in the unconfined aquifer near Horn Rapids Dam and well 699-S24-19 (Figure 4.1). The gradients indicate no vertical flow in these areas, probably as a result of poor well construction. Drilling logs for well 699-S31-1 and piezometer 699-S31-1P, and well 699-S24-19 indicate potential hydraulic connections between the unconfined and confined aquifers. Annular seals between the two hydrofacies are not evident in the logs, so the resultant heads probably are combined. Hydraulic testing should be done in well 699-S31-1 and piezometer 699-S31-1P, and well 699-S24-19 to assess these potential connections.

Vertical hydraulic gradients were calculated within the unconfined aquifer in the eastern part of the study area. Hydraulic head measurements from wells 699-S41-E13A and 699-S41-E13B (Figure 4.1) indicate no vertical flow in this area. Well 699-S41-E13A is completed at the top of the unconfined aquifer (Table 4.1). Well 699-S41-E13B is completed just above the silty clay lens at the top of the gravelly sand to silty clay lithofacies. Both wells are located within the ground-water mound beneath the North Richland well field, where a downward gradient would be expected. However, these wells are located approximately 25 ft apart and monitor intervals with a vertical displacement of only 30 ft.

No wells in the water-level monitoring network are completed in the silty clay lens or aquitard overlying the Ice Harbor Member. Two wells, drilled concurrent with this study as part of the RI/FS for the 1100-EM-1 Operable Unit, are completed below the silty clay lens. However, the limited and varied information on the vertical hydraulic gradients from this study, DOE (1990b), and Schalla et al. (1988) accentuates the need for further characterization. The vertical distribution of hydraulic head between the unconfined and confined aquifers and across the silty clay lens is necessary to better understand ground-water recharge and discharge areas, flow directions, and contaminant transport among these aquifers.

4.2.2 Temporal Distribution of Hydraulic Head

The temporal distribution of hydraulic head in the unconfined aquifer can be divided into several distinct periods. The frequency and length of these periods vary with location. In the eastern part of the study area, 27 wells in the water-level monitoring network respond to the net recharge pumped to the North Richland well field. Hydrographs for these wells generally peak in August to October 1989 and reach lows in November 1989 and April 1990 (Figure 4.2 and Appendix D).

Wells EC-1, W-1, and W-3, located in the southcentral part of the study area, respond to the seasonal pumping of wells W-4 through W-6. Hydrographs for these six wells show a drawdown period from June to August 1989, followed by a recovery period from August to December 1989 (Figure 4.2 and Appendix D). The recovery period appears to be enhanced by seasonal recharge as

Table 4.4 Horizontal Hydraulic Gradients for the Unconfined Aquifer Beneath the Study Area

Month	Year	Horizontal Hydraulic Gradient • (ft/mi)	Horizontal Hydraulic Gradient # (ft/mi)	Horizontal Hydraulic Gradient @ (ft/mi)	Average Gradient (ft/mi)
June	1989				
July	1989	8.4	6.9	6.9	7.4
August	1989	8.4	6.8	6.9	7.4
September	1989	8.3	6.9	6.8	7.3
October	1989	8.3	7.0	6.8	7.4
November	1989	8.4	7.1	6.9	7.4
December	1989	8.2	7.0	6.8	7.4
January	1990	8.3	7.1	6.8	7.4
February	1990	8.2	7.2	6.8	7.4
March	1990	8.2	7.3	6.8	7.4
April	1990	8.4	7.2	6.8	7.5
May	1990	8.1	7.2	6.8	7.4

Notes:

- = Horizontal Hydraulic Gradient Between Wells 699-S23-26 and 3000-F
- # = Horizontal Hydraulic Gradient Between Wells 699-S23-26 and 699-S37-E14
- @ = Horizontal Hydraulic Gradient Between Wells 699-S23-26 and Saint

water levels continue to rise until the beginning of the 1990 growing season. Ground water was noted above land surface from February to April 1990 near these wells. The water levels begin to decline again as the wells are used to supplement the AEDC intake at the Port of Benton.

Water-level data for wells EC-1, W-1, and W-3 through W-6 (Appendix D) indicate a horizontal gradient between wells W-4 through W-6 during the recovery period. This gradient is probably an artifact of the casing elevations being estimated from the Richland quadrangle, Washington map (USGS 1978). Horizontal and vertical control for wells W-4 through W-6 should be resurveyed to provide more accurate lithofacies, hydrofacies, and water-level elevations.

Wells 3000-F, 699-S30-E15A, and the Saint Well, located near the Columbia River, respond to fluctuations in the river level. Hydrographs for these wells and the river are lowest in July 1989 and peak in April to May 1990 (Figure 4.2 and Appendix D). The amplitude of the peak in the river hydrograph for the city of Richland pumping station at Snyder Street is somewhat lower than at SWS-1. This probably reflects the differences in data collection methods. The data at SWS-1 were collected every half hour using a transducer and data logger. Daily staff-gage readings were recorded at the pumping station. The hydrograph for well 699-S23-26 shows a similar profile to the wells near the Columbia River but indicates a response to elevation changes in the Yakima River.

Water levels in well 699-S31-1, located in the northcentral part of the study area, reflect ground-water flow conditions away from recharge or discharge areas. The hydrograph for this well is relatively flat, varying less than 0.2 ft during the entire data collection period (Figure 4.2 and Appendix D). Hydrographs for wells TW14 through TW18 have less than 0.4 ft of change. The slight increase in water-level elevation from August 1989 to January 1990 may be a distant effect of the North Richland well field or related to activities at the Siemens Power Corp. process lagoons (Figure 1.2).

4.3 Operations and Impacts of the North Richland Well Field

The North Richland well field serves as the secondary water-supply system for the city of Richland. This water-supply system consists of a settling basin and two recharge basins located adjacent to 12 production wells completed in the unconfined aquifer. Columbia River water is pumped from the city of Richland pumping station at Snyder Street into the south end of the settling basin. The water infiltrates or flows through a weir at the north end of the basin into a flow divider and is discharged to the recharge basins. The water infiltrates from the recharge basins and is then pumped from the adjacent production wells using line shaft turbine pumps. The production water is treated by a central chlorinator system before being dispensed to city lines for use.

The settling and recharge basins are wide, shallow depressions, designed to enhance infiltration. ICF Northwest (1987) recommended lining the basins with sand, repairing the dike between the recharge basins, and relocating the largest pumps to the wells with the highest yield to improve production of this system. The sediments beneath the basins act as a natural filter to remove the turbidity from the Columbia River water. The river water also serves to reduce the hardness of the ground water.

Since the time of construction of the city of Richland municipal water-treatment plant until 1987, volumes ranging from zero to 16 million gallons per day (mgd) have been pumped to the settling basin (ICF Northwest 1987). From November 1988 to May 1990, an average volume of 7.0 mgd was pumped to the settling basin. The North Richland well field is operated year-round with peak usage occurring during the summer irrigation months and again in December and January, when the water-treatment plant is shut down for annual maintenance. Figure 4.3 shows the monthly total volume of recharge and production water pumped to and from the well field, respectively, during this study. The ratio of recharge to production water varied from 2:1 to 11:1 with an average ratio of 4:1. The monthly average net recharge for this period was 134.9 million gallons (mg). Historical data indicate that the ratio has ranged from 2:1 to 4:1.^(a) Reasons for this operational history are unknown. The current strategy used by the city of Richland is based, in a large part, on mitigating the potential for any ground-water contamination to migrate from upgradient disposal sites within the 1100-EM-1 Operable Unit to the well field. During periods of high net recharge, a mound develops causing

(a) Freshley, M. D., M. P. Bergeron, and N. J. Aimo. 1989. Ground-Water Modeling Investigation of North Richland Well Field and the 1100 Area, Letter Report. Pacific Northwest Laboratory, Richland, Washington.

Recharge vs. Production June 1989 - May 1990

S9208029.3

Figure 4.3 Recharge and Production Volumes for June 1989 to May 1990

ground-water flow to be diverted around the well field.^(a) No net recharge produces a small localized mound, but ground water from the 1100 Area can move toward the well field.

Currently, the net recharge pumped to the well field has the most significant impact on water levels and hydraulic gradients for the unconfined aquifer beneath the study area. Twenty seven, and possibly 32, of the 46 wells in the water-level monitoring network respond to this recharge. Two north-south hydrologic cross sections, with hydrographs for several wells located within and adjacent to the well field, are shown in Figures 4.4 and 4.5. The hydrographs in these figures have similar profiles to that of Figure 4.3 for at least a mile to the north and south of the well field. Figure 4.6 shows the net water-level changes that occurred in each well and the Columbia River between July 1989 and January 1990. This period was chosen because a complete set of monthly water-level data exists for all 46 wells in the monitoring network. Wells affected by the net recharge to the well field showed a net water-level decrease. The magnitude of change in these wells varied from approximately 2.5 to less than 1 ft and generally decreased with increased distance from the well field. Responses were noted farther to the north and south than west and east. Water-level responses to the west and east probably are dampened by the horizontal hydraulic gradient.

Horizontal hydraulic gradients were calculated for three west to east transects at or near the well field, using hydraulic head data from wells 3000-D1, 3000-D5, 699-S40-E14, 3000-H, 699-S41-E13A, and 3000-K. The monthly and average gradients for June 1989 through January 1990 are shown in Table 4.5. The gradients range from less than 1 to approximately 11 ft/mi and vary significantly with the net recharge pumped to the well field. Generally, the steepest gradients occurred in June and December where high monthly net recharge was preceded by low monthly net recharge. A reverse gradient occurred in August 1989 between wells 699-S41-E13A and 3000-K as a result of three successive months of high net recharge. Gradients were not calculated for February through May 1990 because water levels were not measured in wells 3000-D5, 3000-H, and 3000-K during these months. Overall, the net recharge to the North Richland well field probably has increased water levels in the unconfined aquifer significantly within and adjacent to the well field and will continue to do so under the current operational strategy. This effect may eventually become a concern near wells 3000-N, 3000-K, and 3000-C, where the minimum depth to water during this study ranged from approximately 5 to 11 ft bls (Figure 4.7). Monitoring of water-level elevations and ground-water quality should continue in this area to assess the long-term effects of the net recharge.

4.4 Operations and Impacts of the Agricultural, Residential-Lawn, and Waste-Water Irrigation

Agricultural, residential-lawn, and waste-water irrigation occurs at several locations within and adjacent to the study area (Figure 1.2). Table 4.6 lists the estimated monthly maximum volumes of irrigation applied. The estimated volumes are based primarily on total pumping capacities for each

(a) Freshley, M. D., M. P. Bergeron, and N. J. Aimo. 1989. Ground-Water Modeling Investigation of North Richland Well Field and the 1100 Area, Letter Report. Pacific Northwest Laboratory, Richland, Washington.

S9304073.8

Figure 4.4 Hydrologic Cross Section A-A' to the North of the Well Field

Figure 4.5 Hydrologic Cross Section B-B' to the South of the Well Field

Figure 4.6 Net Water-Level Changes Between July 1989 and January 1990

Table 4.5 Horizontal Hydraulic Gradients for the Unconfined Aquifer Near the North Richland Well Field

Month	Year	Horizontal Hydraulic Gradient * (ft/mi)	Horizontal Hydraulic Gradient # (ft/mi)	Horizontal Hydraulic Gradient @ (ft/mi)	Average Gradient (ft/mi)
June	1989		0.6	5.9	3.2
July	1989	2.2	1.0	3.6	2.3
August	1989	1.9	0.6	-0.1	0.8
September	1989	1.7	3.0	0.8	1.8
October	1989	1.5	2.9	2.8	2.4
November	1989	2.3	3.8	3.1	3.0
December	1989	3.2	11.1	4.7	6.3
January	1990	2.1	2.2	1.9	2.0

Notes:

* = Horizontal Hydraulic Gradient Between Wells 3000-D1 and 3000-D5

= Horizontal Hydraulic Gradient Between Wells 699-S40-E14 and 3000-H

@ = Horizontal Hydraulic Gradient Between Wells 699-S41-E13A and 3000-K

system. The actual volumes may vary significantly depending on local requirements/conditions. The two most significant locations are the farming west of the 1100 Area and the farming and PNL lawn irrigation in the 3000 Area.

4.4.1 Farming West of the 1100 Area

The AEDC has leased much of the land east of the city of Richland landfill and west of the 1100 Area, informally known as the Horn Rapids Triangle. The lease runs for 20 years with an option to buy. A half circle (approximately 250 acres) of potatoes was irrigated in 1989 (Figure 3.2). Wells W-4 through W-6 (Figure 4.1) were pumped continuously during the growing season (as conditions permitted) at combined rate of approximately 500 gpm to irrigate the half circle (T. Wiser, AEDC, personal communication, 1989). This rate results in an estimated monthly maximum volume of 21.6 mg (Table 4.6). However, the pumps in wells W-4 and W-6 became sand locked several times.

S9203107.16

Figure 4.7 Minimum Depth to Water Below Land Surface for June 1989 to May 1990

Table 4.6 Estimated Monthly Maximum Volumes of Irrigation Applied

Type	Location	User	Source	Estimated Monthly Maximum Volume (mg)	Reference
Potato (1/2 Circle)	West of 1100 Area	AEDC	Ground Water from Wells W-4 through W-6	22	T. Wiser, AEDC, Personal Communication, 1989
Potato (8 Circles)	West of 1100 Area	AEDC	Columbia River Intake @ the Port of Benton, Ground Water from Wells W-4 through W-6	238	T. Wiser, AEDC, Personal Communication, 1990
Potato (16 Circles)	West of 1100 Area	AEDC	Columbia River Intake @ the Port of Benton, Ground Water from Wells W-4 through W-6	238	Observation
Alfalfa, PNL Lawn	PNL Property	AEDC, PNL	Columbia River Intake @ the Port of Benton, Ground Water from Well 699-S36-E12A	130	D.R. Schielke, PNL, Personal Communication, 1990
Residential Lawn	North Richland	City Residents	City Lines, Private Wells	60	(a)
Waste-Water	Lamb-Weston Inc. Property	Lamb-Weston Inc.	City Lines	6	(a)

Notes:

mg = Million Gallons

(a) Thorne, P. D., and D. A. Myers. 1982. North Richland Drainage Problem. Letter Report. Pacific Northwest Laboratory, Richland, Washington.

The farming was expanded to eight full circles (approximately 4000 acres) of potatoes before the 1990 growing season (Figure 3.3) and 16 full circles (approximately 7500 acres) of potatoes before the 1991 growing season (Figure 4.8). Irrigation water is drawn primarily from the Columbia River at the Port of Benton, where the AEDC installed five 1000-gpm capacity, line shaft turbine pumps. The water is pumped through a 36-in. line and distributed using two pumping stations, 50 and 150 hp, located south of Siemens Power Corp. Wells W-4 through W-6 are pumped intermittently to supplement the river intake and lower water levels near these wells. Pumping both systems at full capacity would result in an estimated monthly maximum volume of 238 mg (Table 4.6). This volume is approximately 75% greater than the monthly average net recharge to the North Richland well field. The actual total pumping rate and volume of water applied are unknown (T. Wiser, AEDC, personal communication, 1990). However, the rate and volume are known to vary with soil conditions, crop type and growth, temperature, wind velocity, and precipitation.

The cone of depression, which forms when wells W-4 through W-6 are pumped for irrigation, is of limited extent. Drawdowns were noted only in wells EC-1, W-1, and W-3 through W-6 and ranged from 1 up to at least 11 ft. No other impacts from the farming west of the 1100 Area are evident on water levels and hydraulic gradients for the unconfined aquifer beneath the study area at this time. This lack of impact may be the result of several factors, including 1) the water-level data from this study were collected during the initial farming operations and are too preliminary to assess any impacts, 2) the pumping rates and volume of water applied are significantly less than capacity, 3) an insufficient number of monitoring wells exist in key locations to assess any impacts, 4) the irrigation occurs over a large area, 5) the irrigation is seasonal, 6) the irrigation is masked by or combined with the impacts from the North Richland well field (Figure 4.6), and/or 7) most of the water applied evapotranspires with little drainage below the root zone.

In the long term, irrigation of the fields west of the 1100 Area probably will contribute to changes in water levels in the unconfined aquifer beneath the study area. Potatoes require a relatively large amount of moisture. Precipitation for this area averages less than 7 in. annually. The crops are planted in the well-sorted silt and very fine to coarse sand of the silty sand lithofacies. These sediments are relatively porous and have high infiltration capacities. The silty sand lithofacies becomes increasingly thinner east of the city of Richland landfill and reaches a minimum in wells W-1 through W-6. Irrigation water will recharge the unconfined aquifer much faster where the water table is nearer land surface (Figure 4.7). Potatoes also require the application of nitrate for fertilization and diquat or sulfuric acid to kill the vines before harvesting. Monitoring of water-level elevations and ground-water quality west of the 1100 Area should continue to assess the long-term effects of the farming on the unconfined aquifer.

4.4.2 3000 Area Farming and PNL Lawn Irrigation

The farming and PNL lawn irrigation in the 3000 Area is another significant location of irrigation within the study area. The AEDC has leased the land surrounding the main PNL complex from PNL to grow alfalfa. This crop was chosen because of its ability to grow in the poorly sorted gravels and sands of the sandy gravel lithofacies. The PNL complex is landscaped with lawns, shrubs, and trees. Irrigation water is drawn primarily from the Columbia River at the Port of Benton, where three 1000-gpm capacity, line shaft turbine pumps have been installed. Well 699-S36-E12A (Figure 3.1) is equipped with a 500-gpm capacity, 40 hp, submersible pump and is used to supplement the PNL intake during peak irrigation periods. The pump raises the pressure on the southern part this irrigation system

S9201008.2

Figure 4.8 Potato Farming, 1991 Growing Season

(D.R. Schielke, PNL, personal communication, 1990). At full capacity, the estimated monthly maximum volume of irrigation for this system is 130 mg (Table 4.6). The actual rate and volume of irrigation applied are unknown; however, the alfalfa is irrigated continuously during the growing season, except during the four to five harvests.

No impacts are evident on water levels and hydraulic gradients for the unconfined aquifer beneath the study area from the 3000 Area farming and PNL lawn irrigation. Water levels in wells F-2, 699-S32-E13A, 699-S31-E13, 699-S32-E13B, 699-S36-E12B, 699-S36-E13B, and 699-S36-E13A, which surround the farming and lawn irrigation, respond to the net recharge pumped to the North Richland well field. A local cone of depression may form near well 699-S36-E12A during pumping; however, no responses are noted in wells within 500 ft. Possible explanations for these observations are that 1) the pumping rates and volume of water applied are significantly less than capacity, 2) the farming and lawn irrigation are seasonal, 3) the farming and lawn irrigation are masked by or combined with the impacts from the North Richland well field (Figure 4.6), 4) the alfalfa and lawn uptake are a significant portion of the irrigation applied, 5) any recharge is retained in the unsaturated sediments as the minimum depth to water in this area is approximately 45 to 60 ft bls (Figure 4.7), and/or 6) the unconfined aquifer is relatively more transmissive in this area and any recharge rapidly dissipates or is discharged to the nearby Columbia River.

In general, the alfalfa farming and PNL lawn irrigation probably will continue to contribute little, if any, to changes in water levels in the unconfined aquifer beneath the study area. The farming and lawn irrigation have been operated consistently for several years. Additionally, PNL has plans for further expansion of facilities on the leased land.

4.4.3 Residential-Lawn and Waste-Water Irrigation

Lesser amounts of irrigation are applied to residential areas within north Richland and the Lamb-Weston Inc. property (Figure 1.2). This irrigation includes lawn, shrub, and tree irrigation in the residential areas and waste-water irrigation on the Lamb-Weston Inc. property. City lines are the primary water source for these irrigation systems although some residents use private wells for lawn irrigation.

Seasonally high ground-water levels and drainage problems in North Richland were investigated for the city.^(a) High Yakima and Columbia river levels and residential-lawn, and to a lesser extent, waste-water irrigation were cited as contributing factors to these problems. Ground water was noted less than 1 ft bls in May 1982, approximately 1 mi south of the study area. Monthly maximum volumes of irrigation were estimated at 60 mg in the residential areas and 6 mg on the Lamb-Weston Inc. property.^(a) These numbers probably have increased significantly with the continued development of North Richland and the expansion of Lamb-Weston Inc. operations. A perforated drain pipe was installed to mitigate the high ground-water levels and drainage problems; however, the problems have recurred (S. Arlt, city of Richland, personal communication, 1990). Similar problems probably will occur elsewhere in North Richland where the ground water is shallow, especially if combined with the

(a) Thorne, P. D., and D. A. Myers. 1982. North Richland Drainage Problem, Letter Report. Pacific Northwest Laboratory, Richland, Washington.

net recharge from the North Richland well field. Routine monitoring of water-level elevations should be initiated to assess the long-term effects of the residential-lawn and waste-water irrigation.

4.5 Interrelationship with the Yakima and Columbia Rivers

The Yakima and Columbia rivers have significant influence on ground-water flow in the unconfined aquifer beneath the study area. The aquifer is recharged along influent reaches of the Yakima River; ground water flows generally eastward, discharging to the Columbia River. River flows along these reaches are controlled primarily by the Horn Rapids irrigation diversion dam on the Yakima River, and Priest Rapids and McNary hydroelectric dams on the Columbia River. Flows adjacent to the study area average 3300 cfs in the Yakima River and 120,000 cfs in the Columbia River. During this study, flows averaged 2500 and 102,500 cfs in the two rivers, respectively. Fluctuations in the river elevations affect the horizontal hydraulic gradients in the aquifer near the rivers. Near the Yakima River, increases in river elevation locally steepen the hydraulic gradients in the aquifer, whereas decreases flatten the gradients locally. In contrast, near the Columbia River, increases in elevation decrease the hydraulic gradients and cause water levels in the aquifer to rise, whereas decreases in elevation steepen the gradients.

Annual fluctuations in the Yakima River are thought to be less than 3 ft based on the hydrograph for well 699-S23-26 (Appendix D). This well is located approximately 80 ft from the river. Well 699-S23-26 had a net water-level increase of 1.21 ft (Figure 4.6). The minimum depth to water was 2.84 ft bls (Figure 4.7). Overbank flooding may occur during peak runoff years; however, this should not be a major concern given the remoteness of the area.

The Columbia River fluctuates up to 5 ft per day. Well 3000-F is located approximately 180 ft from the river and fluctuates up to 3.5 ft per day. Between July 1989 and January 1990, net water-level increases of approximately 1 to 2.5 ft were noted in wells responding to the Columbia River, with the higher magnitude changes occurring closer to the river (Figure 4.6). Hydrographs for wells 3000-F and 699-S30-E15A exhibit similar profiles to the Columbia River at SWS-1 (Figure 4.2 and Appendix D). Net water-level increases in these wells were 2.26 and 2.41 ft, respectively. The hydrograph for the Saint Well has a somewhat similar profile; however, the river-level fluctuations appear to be dampened significantly. This well is located approximately 500 ft from the river but the water level varied less than 1 ft. Possible reasons for this profile include 1) north-south channeling of the Ringold and Hanford sediments near the river (Brown 1979) has formed an erosional boundary between the well and river, 2) a hydraulic conductivity contrast occurs within the sandy gravel lithofacies between the well and river, 3) the unconfined aquifer is much thicker near the Saint Well than wells 3000-F and 699-S30-E15A, and/or 4) water levels in the Saint Well may be influenced by elevation changes in the McNary pool [Lake Wallula extends upriver as far as the city of Richland (USGS 1978)], whereas wells 3000-F and 699-S30-E15A reflect control by Priest Rapids Dam. The minimum depth to water for wells 3000-F, 699-S30-E15A, and the Saint Well ranges from approximately 14 to 55 ft bls (Figure 4.7).

Sufficient data have been gathered in this study to further analyze the unconfined aquifer/Columbia River interrelationship. The similarity of changes in timing and magnitude with distance from the river should be analyzed to determine the hydraulic diffusivity (i.e., transmissivity/storativity) for the aquifer

between well 3000-F and the river at SWS-1. Short- (i.e., several days) and long-term (i.e., several months) fluctuations should be compared. Similar analyses could be done on the unconfined aquifer/ Yakima River interrelationship by correlating continuous water-level data from well 699-S23-26 with river elevation data from the U.S. Geological Survey gaging station at Kiona, Washington.

5.0 Discussion of Results and Additional Data Needs for CERCLA/SARA Investigations and Richland Corporate Annexation

This chapter summarizes the results of this study of the unconfined ground-water flow system between the Yakima and Columbia rivers. The results are used to delineate additional data needs in support of future CERCLA/SARA investigations and Richland Corporate annexation of the 1100 and 3000 Areas.

5.1 Discussion of Results

The hydrogeology of the unconfined aquifer beneath the study area is very complex. The Ringold Formation and Hanford formation sediments, which form the hydrogeologic framework of the unconfined aquifer, were derived from both fluvial and glaciofluvial processes. These processes have resulted in an aquifer that is both heterogeneous and anisotropic.

The unconfined aquifer is contained within the gravelly sand to silty clay and sandy gravel lithofacies. These sediments vary in occurrence, distribution, texture, and sorting across the study area. The unconfined aquifer exhibits varied thickness, and undoubtedly, varied hydraulic properties. The silty clay lithofacies serves as the aquifer bottom in the western part of the study area. In the eastern part of the study area, the silty clay lens at the top of the gravelly sand to silty clay lithofacies may divide the aquifer into two parts, causing local semiconfined to confined conditions within the unconfined aquifer. The unconfined aquifer probably acts as a heterogeneous hydrofacies on a small scale over a short time and a homogeneous hydrofacies on a large scale over a long time.

Ground water in the unconfined aquifer flows generally west to east beneath the study area. The aquifer is recharged by the Yakima River and discharges to the Columbia River. Flow is altered locally by the ground-water mound beneath the North Richland well field and to a lesser extent by pumping from wells W-4 through W-6. Ground-water levels near the Columbia River are influenced by fluctuations in the river elevation. Responses to fluctuations can be seen at least 1500 ft inland in the northeastern part of the study area. Levels in the north central part of the study area appear to reflect natural conditions.

Currently, the net recharge pumped to the North Richland well field has the most significant impact on water levels and hydraulic gradients for the unconfined aquifer beneath the study area. The net recharge probably has increased water levels in the aquifer significantly over the past several years and will continue to do so under the current operational strategy. With the exception of the cone of depression that forms near wells W-1 through W-6, no other impacts from the farming west of the 1100 Area are evident at this time. In the long term, the irrigation probably will contribute to changes in water levels in the unconfined aquifer. No impacts are evident from the 3000 Area farming and PNL lawn irrigation. In general, the farming and PNL lawn irrigation probably will continue to contribute little, if any, to changes in water levels in the unconfined aquifer. A local cone of depression may form near well 699-S36-E12A during pumping.

Previously estimated monthly maximum volumes of residential-lawn and waste-water irrigation probably have increased significantly with the continued development of North Richland and the expansion of Lamb-Weston Inc. operations. Seasonally high ground-water levels and drainage problems resulting from this irrigation probably will occur elsewhere in North Richland where the ground water is shallow, especially if combined with the net recharge from the well field.

5.2 CERCLA/SARA Investigations

Hazardous wastes have been discharged to the ground in the 1100 and 3000 Areas. These disposal sites are contained within the 1100-EM-1 Operable Unit, which is regulated by CERCLA/SARA. The results of this study can be used to delineate additional data needs in support of future CERCLA/SARA activities at the 1100-EM-1 Operable Unit. The additional data needs are focused in three areas: 1) well maintenance and rehabilitation, 2) hydrogeologic characterization, and 3) ground-water monitoring. Following through with these activities will provide a more quantitative data set for use in the RI/FS, Fate and Transport modeling, and the BRA and reduce costs by maximizing use of existing structures.

5.2.1 Well Maintenance and Rehabilitation

Inconsistencies exist between the drilling logs and the WELL DATA files in the HGWDB. These inconsistencies should be corrected to help prevent misinterpretation of well construction details. Several wells should be surveyed (resurveyed) for horizontal and vertical control to provide more accurate lithofacies, hydrofacies, and water-level elevations. These wells include EC-1, W-4, W-5, W-6, the Saint Well, F-2, ORV #1, ORV #2, the Landfill Well, the Lamb-Weston Inc. Well, 1100-D, 3000-D5, 3000-A, 3000-B, 3000-H, 3000-C, 3000-K, 3000-N, 3000-L, 3000-D, 3000-J, 3000-G, and 1100-8.

A borehole television camera should be used to help gather completion information on wells TW15, TW14, W-4, W-5, and 699-S36-E12A. Hydraulic testing should be done in wells 699-S31-1 and piezometer 699-S31-1P, 699-S28-E0, 699-S24-19, ORV #1, ORV #2, the Landfill Well, and 699-S51-2 to assess the potential connections between the confined and unconfined aquifers.

Wells TW14 through TW18, W-1 through W-3, and 1100-2 should be cleaned out and developed to provide more accurate and representative water-level elevations and ground-water samples, respectively. Several other wells should be rehabilitated to improve construction and provide more accurate and representative ground-water samples. These wells include 699-S23-26, EC-1, 1100-2, 699-S36-E12B, 699-S36-E13B, 3000-G, and possibly 3000-D1.

5.2.2 Hydrogeologic Characterization

A catalog of borehole lithologic logs (after Fecht and Lillie 1982) and a catalog of borehole geophysical logs (after Blair et al. 1981) from the study area should be published to summarize existing hydrogeologic data. Inconsistencies between the drilling logs and the GEODAT DATA files in the HGWDB should be corrected to help prevent misinterpretation of the hydrogeology.

Future hydrogeologic investigations within and adjacent to the study area should include laboratory tests for bulk mineralogy and geochemistry to help delineate the contact between the Ringold Formation and Hanford formation. Future investigations should also include test holes between the city of Richland landfill and 1100 Area to further characterize the distribution of the gravelly sand to silty clay lithofacies. Advanced borehole geophysical tools (e.g., commercial vendor sondes) should be run in several wells to provide more quantitative data on the properties of the suprabasalt sediments.

The distribution and continuity of the confined aquifer should be further characterized to better understand ground-water flow and contaminant transport in this aquifer. The distribution and continuity of the silty clay lens at the top of the gravelly sand to silty clay lithofacies should also be further characterized as it may have a marked effect on ground-water flow and contaminant transport in the unconfined aquifer. The vertical distribution of hydraulic head between the unconfined and confined aquifers and across the silty clay lens should be further characterized to better understand ground-water recharge and discharge areas, flow directions, and contaminant transport among these aquifers. As additional monitoring wells are drilled within the study area, water levels should be measured concurrently across the study area to construct a flow net.

The unconfined aquifer/Columbia River interrelationship beneath the study area should be further analyzed to determine the hydraulic diffusivity for the aquifer between well 3000-F and the river at SWS-1. Short- and long-term fluctuations should be compared. Similar analyses could be done on the unconfined aquifer/Yakima River interrelationship by correlating continuous water-level data from well 699-S23-26 with river elevation data from the U.S. Geological Survey gaging station at Kiona, Washington.

Sufficient data have been gathered herein to construct a ground-water flow model for the unconfined aquifer near the North Richland well field. The physical configuration of the aquifer including location, areal extent, thickness, and location of surface water features have been presented. Hydraulic property estimates are contained in Table 3.6. Water-level elevation maps have been constructed for the period June 1989 to May 1990 (Figure 3.12 and Appendix C). Production and recharge volumes for the North Richland well field and estimated irrigation volumes are available in Appendix B and Table 3.11, respectively. The model should be used to simulate regional changes in hydraulic head caused by the well field and farming west of the 1100 Area.

5.2.3 Ground-Water Monitoring

Wells within the study area selected for routine water-level monitoring and ground-water sampling should be added to the PNL and WHC well maintenance programs. Monitoring of water-level elevations and ground-water quality in and adjacent to the North Richland well field should continue to assess the long-term effects of the net recharge to the well field on the unconfined aquifer. Monitoring of water-level elevations and ground-water quality west of the 1100 Area should also continue to assess the long-term effects of the farming on the aquifer. Routine monitoring of water-level elevations should be initiated to assess the long-term effects of the residential-lawn and waste-water irrigation on the unconfined aquifer.

5.3 Richland Corporate Annexation

The city of Richland is considering annexing all or a portion of the 1100 and 3000 Areas to within its corporate boundary. These areas and the surrounding land have been designated as the "Tri-Cities Science and Technology Park" and are zoned for non-DOE industrial development. A number of these developments probably will be located hydraulically upgradient of the North Richland well field, given the current availability of land.

Several of the disposal sites within the 1100-EM-1 Operable Unit are also hydraulically upgradient of the well field. Additional sites or features in the vicinity of the 1100 and 3000 Areas that may affect the ground-water quantity and/or quality include 1) city of Richland landfill, 2) Horn Rapids landfill, 3) Siemens Power Corp. facilities for producing commercial nuclear fuel, 4) Lamb-Weston Inc. potato processing plant, and 5) irrigated agricultural fields and lawns.

The potential ground-water quantity and/or quality impacts to the North Richland well field from the planned development of the Tri-Cities Science and Technology Park and existing sites may be very significant. A ground-water management plan should be developed for the city of Richland to address these potential problems. The plan should also address issues such as management potential, artificial recharge, and conjunctive use of ground-water and surface water. The plan should be a cooperative effort between the city of Richland and DOE and its contractors. Other contributors/reviewers may include Siemens Power Corp., AEDC, and Lamb-Weston Inc. The plan should be modeled after successful existing ground-water management plans (e.g., Pullman-Moscow, and some communities in Colorado). The plan would serve as a proactive management/development tool for the city of Richland.

6.0 Conclusions

The conclusions from this study are as follows.

1. The study area is underlain by the Saddle Mountains Basalt Formation with interbeds of the Ellensburg Formation and sediments of the Ringold Formation and Hanford formation. Four principal lithofacies were identified within the Ringold and Hanford sediments. They are, in ascending order, silty clay lithofacies, gravelly sand to silty clay lithofacies, sandy gravel lithofacies, and silty sand lithofacies. The descriptions and occurrences of the lithofacies may require refinement as additional data are collected in future hydrogeologic investigations.
2. Ground water beneath the study area occurs as both confined and unconfined aquifers. Four principal hydrofacies have been identified in this study. They are, in ascending order, a confined aquifer within the Ice Harbor Member, an aquitard formed by the silty clay lithofacies, the unconfined aquifer within the gravelly sand to silty clay and sandy gravel lithofacies, and the unsaturated sediments. Refinement of the hydrofacies descriptions and occurrences may be required as additional hydrogeologic data become available.
3. No water-level data are available from this study to evaluate the hydrologic significance of the silty clay lens at the top of the gravelly sand to silty clay lithofacies. Recent water-level measurements in the HGWDB from well 699-S41-E13C, adjacent to wells 699-S41-E13A and 699-S41-E13B, indicate a downward hydraulic gradient near these wells. The silty clay lens appears to be locally significant enough to produce hydraulic head differences. The unconfined aquifer probably acts as a heterogeneous hydrofacies on a small scale over a short time and a homogeneous hydrofacies on a large scale over a long time.
4. Ground water in the unconfined aquifer flows generally from west to east beneath the study area. The aquifer is recharged along influent reaches of the Yakima River and discharges to the Columbia River. Flow is altered locally by the ground-water mound beneath the North Richland well field and to a lesser extent, by pumping from wells W-4 through W-6. Ground-water levels near the Columbia River are influenced by fluctuations in the river elevation. Levels in the north central part of the study area appear to reflect natural conditions.
5. Currently, the net recharge pumped to the North Richland well field has the most significant impact on water levels and hydraulic gradients for the unconfined aquifer beneath the study area. Twenty seven, and possibly 32, of the 46 wells in the water-level monitoring network respond to this recharge.
6. The net recharge pumped to the North Richland well field probably has increased water levels in the unconfined aquifer beneath the study area significantly over the past several years and will continue to do so under the current operational strategy. This may eventually become a concern near wells 3000-N, 3000-K, and 3000-C.

7. With the exception of the cone of depression that forms near wells W-1 through W-6, no other impacts from the farming west of the 1100 Area are evident on water levels and hydraulic gradients for the unconfined aquifer beneath the study area at this time. In the long term, the irrigation probably will contribute to changes in water levels in the unconfined aquifer.
8. No impacts are evident on water levels and hydraulic gradients for the unconfined aquifer beneath the study area from the 3000 Area farming and PNL lawn irrigation. In general, the farming and PNL lawn irrigation probably will continue to contribute little, if any, to changes in water levels in the unconfined aquifer. A local cone of depression may form near well 699-S36-E12A during pumping.
9. Previously estimated monthly maximum volumes of residential-lawn and waste-water irrigation probably have increased significantly with the continued development of North Richland and the expansion of Lamb-Weston Inc. operations. Seasonally high ground-water levels and drainage problems resulting from this irrigation probably will occur elsewhere in North Richland where the ground water is shallow, especially if combined with the net recharge from the North Richland well field.
10. Fluctuations in the Yakima and Columbia rivers have significant influence on water levels and hydraulic gradients in the unconfined aquifer beneath the study area. Responses to fluctuations in the Columbia River can be seen at least 1500 ft inland in the northeastern part of the study area.

7.0 Additional Data Needs

The additional data needs identified in this study are as follows.

1. A catalog of borehole lithologic logs from the study area should be published to summarize existing hydrogeologic data.
2. A catalog of borehole geophysical logs from the study area should be published to summarize existing hydrogeologic data.
3. Inconsistencies between the drilling logs and GEODAT DATA and WELL DATA files in the HGWDB should be corrected to help prevent misinterpretation.
4. Wells EC-1, W-4, W-5, W-6, the Saint Well, F-2, ORV #1, ORV #2, the Landfill Well, the Lamb-Weston Inc. Well, 1100-D, 3000-D5, 3000-A, 3000-B, 3000-H, 3000-C, 3000-K, 3000-N, 3000-L, 3000-D, 3000-J, 3000-G, and 1100-8 should be surveyed (resurveyed) for horizontal and vertical control to provide more accurate lithofacies, hydrofacies, and water-level elevations.
5. A borehole television camera should be used to help gather completion information on wells TW15, TW14, W-4, W-5, and 699-S36-E12A.
6. Future hydrogeologic investigations within and adjacent to the study area should include laboratory tests for bulk mineralogy and geochemistry to help delineate the contact between the Ringold Formation and Hanford formation.
7. Advanced borehole geophysical tools (e.g., commercial vendor sondes) should be run in several wells to provide more quantitative data on the properties of the suprabasalt sediments beneath the study area.
8. Future hydrogeologic investigations within the study area should include test holes between the city of Richland landfill and 1100 Area to further characterize the distribution of the gravelly sand to silty clay lithofacies.
9. As additional monitoring wells are drilled within the study area, water levels should be measured concurrently across the study area to construct a flow net.
10. The distribution and continuity of the confined aquifer should be further characterized to better understand ground-water flow and contaminant transport in this aquifer.
11. Hydraulic testing should be done in wells 699-S31-1 and piezometer 699-S31-1P, 699-S28-E0, 699-S24-19, ORV #1, ORV #2, the Landfill Well, and 699-S51-2 to assess the potential connections between the confined and unconfined aquifers.
12. The distribution and continuity of the silty clay lens at the top of the gravelly sand to silty clay lithofacies should be further characterized as it may have a marked effect on ground-water flow and contaminant transport in the unconfined aquifer.

13. Wells TW14 through TW18, W-1 through W-3, and 1100-2 should be cleaned out and developed to provide more accurate and representative water-level elevations and ground-water samples, respectively.
14. Wells within the study area selected for routine water-level monitoring and ground-water sampling should be added to the PNL and WHC well-maintenance programs.
15. The vertical distribution of hydraulic head between the unconfined and confined aquifers and across the silty clay lens at the top of the gravelly sand to silty clay lithofacies should be further characterized to better understand ground-water recharge and discharge areas, flow directions, and contaminant transport among these aquifers.
16. Monitoring of water-level elevations and ground-water quality in and adjacent to the North Richland well field should continue to assess the long-term effects of the net recharge to the well field on the unconfined aquifer.
17. Monitoring of water-level elevations and ground-water quality west of the 1100 Area should continue to assess the long-term effects of the farming on the unconfined aquifer.
18. Routine monitoring of water-level elevations should be initiated in the southern and southwestern parts of the study area to assess the long-term effects of the residential-lawn and waste-water irrigation on the unconfined aquifer.
19. The unconfined aquifer/Columbia River interrelationship beneath the study area should be further analyzed to determine the hydraulic diffusivity for the aquifer between well 3000-F and the river at SWS-1. Short- and long-term fluctuations should be compared. Similar analyses could be done on the unconfined aquifer/Yakima River interrelationship by correlating continuous water-level data from well 699-S23-26 with river elevation data from the U.S. Geological Survey gaging station at Kiona, Washington.
20. A ground-water flow model for the unconfined aquifer near the North Richland well field should be constructed using the data gathered herein. The model should be used to simulate regional changes in hydraulic head caused by the well field and farming west of the 1100 Area.
21. Wells 699-S23-26, EC-1, 1100-2, 699-S36-E12B, 699-S36-E13B, 3000-G, and possibly 3000-D1 should be rehabilitated to improve construction and provide more accurate and representative ground-water samples.
22. A ground-water management plan should be developed for the city of Richland to address potential ground-water quantity and/or quality problems resulting from existing sites and the planned development of the Tri-Cities Science and Technology Park. The plan should also address issues such as management potential, artificial recharge, and conjunctive use of ground-water and surface water. The plan should be a cooperative effort between the city of Richland and DOE and its contractors. Other contributors/reviewers may include Siemens Power Corp., AEDC, and Lamb-Weston Inc. The plan should be modeled after successful existing ground-water management plans (e.g., Pullman-Moscow, and some communities in Colorado). The plan would serve as a proactive management/development tool for the city of Richland.

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Appendix A

Well Construction and Lithologic Diagrams

WELL NUMBER 3000-F (3099-47-18B)

Well Completed 8/48

S9007059.2

WELL NUMBER 699-S30-E15A

Well Completed 10/71

S9007059.1

WELL NUMBER 699-S32-E13A

Well Completed 9/79

SS007059

WELL NUMBER 699-S31-E13

Well Completed 10/79

SS007059.5

WELL NUMBER 699-S32-E13B

Well Completed 10/79

SS9007059.11

WELL NUMBER 699-S29-E12

Well Completed 11/71

59007059 3

WELL NUMBER TW17

Well Completed 1982

S3007059.6

WELL NUMBER TW16

Well Completed 1982

S9007059.7

WELL NUMBER TW18

S9007059.3

WELL NUMBER TW15

35007059.10

WELL NUMBER TW14

S9007059.25

59007059 3

WELL NUMBER 699-S23-26

Well Completed 3/44

S9007059.23

WELL NUMBER EC-1

56007059.27

WELL NUMBER W-1

WELL NUMBER W-3

Well Completed 1/83

S9007359.67

WELL NUMBER W-4

Well Completed 1989

55007055 29

WELL NUMBER W-5

35007053-40

S5007059 #2

WELL NUMBER 1100-2 (1199-34-13)

59007059.53

WELL NUMBER 699-S43-E12

Well Completed 10/88

S9007059.39

WELL NUMBER 699-S41-E13A

S9007059.38

WELL NUMBER 699-S41-E13B

S9007059.37

WELL NUMBER 699-S37-E14

SS007059 12

WELL NUMBER 3000-D1 (1199-41-13C)

S9007059.13

WELL NUMBER 699-S36-E12B

Well Completed 10/79

S9007059 14

WELL NUMBER 699-S36-E13B

Well Completed 10/79

S9007059.15

WELL NUMBER 699-S36-E13A

Well Completed 9/79

S9007059.17

WELL NUMBER F-2 (3099-45-16)

S5007059.16

WELL NUMBER 699-S30-E14

S9007059 21

WELL NUMBER 699-S28-E0

S9007059.12

WELL NUMBER 699-S24-19

S9007059.23

WELL NUMBER W-2

Well Completed 1/83

S9007059 24

WELL NUMBER 699-S40-E14

Well Completed 10/88

S9007059 25

WELL NUMBER 699-S36-E12A

Well Completed 10/79

S9007059 31

WELL NUMBER ORV #1 (699-ORV-1)

S9007059 41

WELL NUMBER ORV #2 (699-ORV-2)

Well Completed 6/85

S9007059 32

LANDFILL WELL (699-LANDFILL)

Well Completed 5/87

S9007059 33

LANDFILL WELL #2

Well Completed 5/87

S9007059.42

Well Completed 5/87

S9007059.43

LANDFILL WELL #4

Well Completed 5/87

S9007059.44

WELL NUMBER 699-S51-2

Well Completed 1/57

S9007059 35

RACKLEY WELL

Well Completed 5/87

S9007059 45

RIGBY WELL

Well Completed 5/87

SS007059 34

LAMB - WESTON INC. WELL

Well Completed 9/73

SS007059-49

HUISINGH WELL

Well Completed 7/80

S9007059 48

WELL NUMBER 1100-D (1199-34-15B)

S9007059 47

WELL NUMBER 3000-D5 (3099-42-16)

Well Completed 10/44

S9007059 56

WELL NUMBER 3000-A (1199-40-15)

Well Completed 4/48

S5007059.57

WELL NUMBER 3000-B (1199-40-16B)

S9007059 58

WELL NUMBER 3000-H (1199-40-16C)

35007059.59

WELL NUMBER 3000-C (1199-39-16D)

WELL NUMBER 3000-K (1199-38-16)

S9007059.66

WELL NUMBER 3000-N (1199-37-16)

Well Completed 11/61

S9007059.68

WELL NUMBER 3000-L (1199-39-16E)

S9007059.61

WELL NUMBER 3000-D (1199-39-16C)

Well Completed 5/48

S9007059 62

WELL NUMBER 3000-J (1199-39-15)

S5007059 63

WELL NUMBER 3000-G (1199-41-15)

Well Completed 10/49

S9007059.50

WELL NUMBER 1100-8 (1199-34-15A)

Well Completed 9/48

S9007059 64

Appendix B

Water-Level Data

Electric/Steel Tape Wells

699-S30-E15A

Date	W-L Elev. (ft)
06/15/89	344.17
06/21/89	341.73
06/27/89	341.15
07/05/89	340.57
07/11/89	340.79
07/18/89	340.16
07/25/89	341.20
08/01/89	340.98
08/08/89	341.08
08/16/89	340.69
09/07/89	341.53
10/06/89	341.50
10/20/89	341.81
11/25/89	341.38
12/28/89	342.56
01/22/90	342.57
02/22/90	343.81
03/22/90	343.21
04/18/90	342.35
05/17/90	343.22

699-S31-E13

Date	W-L Elev. (ft)
06/15/89	346.47
06/21/89	346.58
06/27/89	346.53
07/05/89	346.62
07/11/89	346.61
07/18/89	346.53
07/25/89	346.44
08/01/89	346.57
08/08/89	346.71
08/16/89	346.87
09/07/89	346.77
10/06/89	346.95
10/20/89	346.73
11/25/89	346.13
12/28/89	345.94
01/22/90	346.06
02/22/90	345.92
03/22/90	345.75
04/18/90	345.70
05/17/90	346.23

699-S29-E12

Date	W-L Elev. (ft)
06/21/89	345.90
06/27/89	345.89
07/05/89	345.87
07/11/89	345.86
07/18/89	345.83
07/25/89	345.78
08/01/89	345.76
08/08/89	345.80
08/16/89	345.88
09/07/89	345.91
10/06/89	346.01
10/20/89	345.98
11/25/89	345.72
12/28/89	345.57
01/22/90	345.64
02/22/90	345.68
03/22/90	345.60
04/18/90	345.60
05/17/90	345.82

699-S32-E13A

Date	W-L Elev. (ft)
06/15/89	346.79
06/21/89	346.91
06/27/89	346.89
07/05/89	346.98
07/11/89	346.87
07/18/89	346.89
07/25/89	346.80
08/01/89	346.94
08/08/89	347.10
08/16/89	347.22
09/07/89	347.11
10/06/89	347.28
10/20/89	347.06
11/25/89	346.40
12/28/89	346.24
01/22/90	346.36
02/22/90	346.14
03/22/90	346.01
04/18/90	345.97
05/17/90	346.51

699-S32-E13B

Date	W-L Elev. (ft)
06/15/89	346.90
06/21/89	347.08
06/27/89	347.16
07/05/89	347.24
07/11/89	347.24
07/18/89	347.16
07/25/89	347.08
08/01/89	347.20
08/08/89	347.34
08/16/89	347.48
09/07/89	347.36
10/06/89	347.54
10/20/89	347.33
11/25/89	346.69
12/28/89	346.50
01/22/90	346.57
02/22/90	346.38
03/22/90	346.28
04/18/90	346.22
05/17/90	346.72

TW17

Date	W-L Elev. (ft)
07/11/89	353.07
07/18/89	353.08
07/25/89	353.10
08/01/89	353.12
08/08/89	353.15
08/16/89	353.17
09/07/89	353.25
10/06/89	353.34
10/21/89	353.41
11/25/89	353.43
12/28/89	353.40
01/22/90	353.42
02/22/90	353.42
03/22/90	353.37
04/18/90	353.30
05/17/90	353.27

TW16

Date	W-L Elev. (ft)
07/11/89	353.04
07/18/89	353.05
07/25/89	353.07
08/01/89	353.09
08/08/89	353.11
08/16/89	353.14
09/07/89	353.22
10/06/89	353.30
10/21/89	353.35
11/25/89	353.39
12/28/89	353.36
01/22/90	353.38
02/22/90	353.37
03/22/90	353.32
04/18/90	353.27
05/17/90	353.25

TW15

Date	W-L Elev. (ft)
07/11/89	353.09
07/18/89	353.10
07/25/89	353.12
08/01/89	353.13
08/08/89	353.15
08/16/89	353.19
09/07/89	353.26
10/06/89	353.34
10/21/89	353.39
11/25/89	353.43
12/28/89	353.40
01/22/90	353.41
02/22/90	353.42
03/22/90	353.37
04/18/90	353.31
05/17/90	353.28

699-S31-1

Date	W-L Elev. (ft)
06/21/89	375.66
06/27/89	375.67
07/05/89	375.66
07/11/89	375.66
07/18/89	375.66
07/25/89	375.68
08/01/89	375.69
08/08/89	375.70
08/17/89	375.68
09/07/89	375.69
10/06/89	375.67
10/21/89	375.61
11/25/89	375.71
12/28/89	375.68
01/22/90	375.72
02/22/90	375.72
03/22/90	375.73
04/18/90	375.78
05/17/90	375.80

TW18

Date	W-L Elev. (ft)
07/11/89	353.04
07/18/89	353.05
07/25/89	353.06
08/01/89	353.08
08/08/89	353.11
08/16/89	353.14
09/07/89	353.21
10/06/89	353.30
10/21/89	353.35
11/25/89	353.39
12/28/89	353.36
01/22/90	353.39
02/22/90	353.39
03/22/90	353.33
04/18/90	353.27
05/17/90	353.25

TW14

Date	W-L Elev. (ft)
07/11/89	353.11
07/18/89	353.13
07/25/89	353.15
08/01/89	353.17
08/08/89	353.18
08/16/89	353.22
09/07/89	353.29
10/06/89	353.38
10/21/89	353.43
11/25/89	353.46
12/28/89	353.44
01/22/90	353.46
02/22/90	353.45
03/22/90	353.39
04/18/90	353.34
05/17/90	353.32

699-S23-26

Date	W-L Elev. (ft)
06/27/89	414.44
07/05/89	414.47
07/11/89	414.34
07/18/89	414.27
07/25/89	414.22
08/01/89	414.18
08/08/89	414.17
08/17/89	414.27
09/07/89	414.45
10/06/89	414.57
10/21/89	414.82
11/25/89	415.04
12/28/89	415.03
01/22/90	415.48
02/22/90	415.50
03/22/90	415.67
04/18/90	416.60
05/17/90	415.05

W-1

Date	W-L Elev. (ft)
07/05/89	351.54
07/11/89	351.50
07/18/89	346.75
07/25/89	343.42
08/01/89	343.39
08/08/89	343.39
08/17/89	343.73
08/22/89	350.69
09/08/89	351.81
10/06/89	352.69
10/21/89	352.93
11/25/89	354.10
12/28/89	354.31
01/22/90	354.53
02/22/90	354.59
03/22/90	354.59
04/18/90	354.10
05/17/90	353.54

W-4

Date	W-L Elev. (ft)
07/05/89	355.34
07/11/89	355.29
09/08/89	355.55
10/06/89	356.43
10/21/89	356.68
11/25/89	357.85
12/28/89	358.05
01/22/90	358.28
02/22/90	358.34
03/22/90	358.24
04/18/90	357.82
05/17/90	357.26

W-6

Date	W-L Elev. (ft)
07/25/89	353.72
08/01/89	353.76
08/08/89	353.82
08/17/89	354.02
08/22/89	354.33
09/08/89	354.98
10/06/89	355.78
10/21/89	355.92
11/25/89	356.61
12/28/89	356.75
01/22/90	356.94
02/22/90	356.87
03/22/90	356.68
04/18/90	356.26
05/17/90	355.83

W-3

Date	W-L Elev. (ft)
07/05/89	351.80
07/11/89	351.74
07/18/89	348.88
07/25/89	348.62
08/01/89	348.54
08/08/89	348.54
08/17/89	348.98
08/22/89	351.14
09/08/89	352.19
10/06/89	352.89
10/21/89	353.11
11/25/89	354.10
12/28/89	354.32
01/22/90	354.52
02/22/90	354.60
03/22/90	354.54
04/18/90	354.17
05/17/90	353.65

W-5

Date	W-L Elev. (ft)
11/25/89	355.74
03/22/90	355.79
05/17/90	355.19

Saint

Date	W-L Elev. (ft)
07/11/89	345.05
07/18/89	345.05
07/25/89	345.36
08/01/89	345.49
08/08/89	345.58
08/17/89	345.44
09/08/89	345.97
10/06/89	345.83
10/21/89	345.89
11/25/89	345.70
12/28/89	345.92
01/24/90	345.93
02/23/90	346.21
03/22/90	345.92
04/18/90	345.92
05/17/90	346.01

699-S43-E12

Date	W-L Elev. (ft)
06/21/89	353.60
07/13/89	353.96
07/18/89	354.02
07/25/89	354.06
08/01/89	354.11
08/08/89	354.20
08/17/89	354.32
09/08/89	354.40
10/06/89	354.21
10/22/89	354.12
11/25/89	353.91
12/28/89	354.06
01/24/90	354.00
02/23/90	353.56
03/22/90	353.25
04/18/90	352.98
05/17/90	353.08

699-S41-E13B

Date	W-L Elev. (ft)
06/21/89	355.81
07/13/89	355.94
07/18/89	355.93
07/25/89	355.89
08/01/89	356.12
08/08/89	356.21
08/17/89	356.79
09/08/89	355.34
10/06/89	354.88
10/18/89	354.73
11/13/89	353.52
01/02/90	355.47
01/22/90	354.08
02/23/90	352.72
03/22/90	352.12
04/18/90	352.75
05/17/90	353.10

699-S36-E12B

Date	W-L Elev. (ft)
06/15/89	354.03
06/21/89	354.29
06/27/89	354.43
07/05/89	354.59
07/11/89	354.61
07/18/89	354.53
07/26/89	354.50
08/01/89	354.58
08/08/89	354.73
08/17/89	354.99
09/08/89	354.36
10/06/89	353.82
10/22/89	353.67
11/25/89	352.69
12/28/89	353.47
01/24/90	352.86
02/23/90	351.69
03/22/90	350.97
04/18/90	351.10
05/17/90	352.01

699-S41-E13A

Date	W-L Elev. (ft)
06/21/89	355.78
07/13/89	355.91
07/18/89	355.90
07/25/89	355.86
08/01/89	356.09
08/08/89	356.17
08/17/89	356.76
09/08/89	355.32
10/06/89	354.87
10/18/89	354.72
11/13/89	353.54
01/02/90	355.43
01/22/90	354.07
02/23/90	352.74
03/22/90	352.14
04/18/90	352.73
05/17/90	353.10

699-S37-E14

Date	W-L Elev. (ft)
06/21/89	354.40
07/13/89	354.61
07/18/89	354.54
07/25/89	354.54
08/01/89	354.72
08/08/89	354.85
08/17/89	355.18
09/08/89	354.12
10/06/89	353.67
10/22/89	353.54
11/25/89	352.63
12/28/89	353.35
01/24/90	352.57
02/23/90	351.45
03/22/90	350.86
04/18/90	351.26
05/17/90	351.66

699-S36-E13B

Date	W-L Elev. (ft)
06/14/89	354.01
06/21/89	354.13
06/26/89	354.31
06/27/89	354.36
07/05/89	354.51
07/11/89	354.51
07/18/89	354.52
07/26/89	354.49
08/01/89	354.49
08/08/89	354.54
08/17/89	355.15
09/08/89	354.44
10/06/89	353.87
10/22/89	353.67
11/25/89	352.69
12/28/89	353.16
01/24/90	353.05
02/23/90	351.71
03/22/90	350.99
04/18/90	350.91
05/17/90	351.98

Continuous Water-Level Recorder Wells

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
June	1	1989		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26		34.73	340.22
	27		33.50	341.45
	28		33.90	341.05
	29		33.74	341.21
	30			

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
July	1	1989		
	2			
	3			
	4		34.39	340.56
	5		34.86	340.09
	6		34.23	340.72
	7		33.93	341.02
	8		33.78	341.17
	9		34.39	340.56
	10		34.79	340.16
	11		34.15	340.80
	12		33.65	341.30
	13		34.34	340.61
	14		34.38	340.57
	15		35.05	339.90
	16		35.64	339.31
	17		35.63	339.32
	18		34.90	340.05
	19		34.89	340.06
	20		34.38	340.57
	21		34.27	340.68
	22		33.71	341.24
	23		34.28	340.67
	24		34.25	340.70
	25		33.48	341.47
	26		33.15	341.80
	27		33.67	341.28
	28		33.92	341.03
	29		33.45	341.50
	30		33.92	341.03
	31		34.38	340.57

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
August	1	1989	34.24	340.71
	2		34.79	340.16
	3		35.24	339.71
	4		34.27	340.68
	5		33.63	341.32
	6		34.13	340.82
	7		34.22	340.73
	8		33.75	341.20
	9		33.68	341.27
	10		33.78	341.17
	11		34.10	340.85
	12		34.10	340.85
	13		34.34	340.61
	14		34.53	340.42
	15			
	16		34.82	340.13
	17		34.69	340.26
	18		33.79	341.16
	19		33.82	341.13
	20		34.27	340.68
	21		33.95	341.00
	22		34.77	340.18
	23		35.21	339.74
	24		35.10	339.85
	25		34.64	340.31
	26		34.69	340.26
	27		35.05	339.90
	28		35.22	339.73
	29		34.56	340.39
	30		34.44	340.51
	31		33.62	341.33

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
September	1	1989	33.91	341.04
	2		33.96	340.99
	3		34.41	340.54
	4		34.53	340.42
	5		34.51	340.44
	6		33.72	341.23
	7		33.41	341.54
	8		33.71	341.24
	9		33.99	340.96
	10		34.52	340.43
	11		34.82	340.13
	12		34.62	340.33
	13		34.28	340.67
	14		33.95	341.00
	15		33.96	340.99
	16		34.06	340.89
	17		34.41	340.54
	18		34.87	340.08
	19		34.18	340.77
	20		33.58	341.37
	21		33.73	341.22
	22		34.01	340.94
	23		33.55	341.40
	24		34.18	340.77
	25		34.74	340.21
	26		33.93	341.02
	27		33.74	341.21
	28		33.63	341.32
	29		33.69	341.26
	30		33.83	341.12

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
October	1	1989	34.58	340.37
	2		34.42	340.53
	3		33.56	341.39
	4		33.12	341.83
	5		33.65	341.30
	6		34.10	340.85
	7		33.46	341.49
	8		33.75	341.20
	9		34.72	340.23
	10		33.80	341.15
	11		33.58	341.37
	12		32.99	341.96
	13		32.78	342.17
	14		33.20	341.75
	15		34.05	340.90
	16		34.13	340.82
	17		33.38	341.57
	18		33.20	341.75
	19		33.10	341.85
	20		33.22	341.73
	21		32.98	341.97
	22		33.45	341.50
	23		33.74	341.21
	24		34.17	340.78
	25		33.90	341.05
	26		33.65	341.30
	27		33.43	341.52
	28		33.39	341.56
	29		33.24	341.71
	30		33.67	341.28
	31		33.72	341.23

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
November	1	1989	33.52	341.43
	2		33.25	341.70
	3		33.51	341.44
	4		33.50	341.45
	5		33.10	341.85
	6		33.38	341.57
	7		33.00	341.95
	8		32.37	342.58
	9		32.37	342.58
	10		32.40	342.55
	11		32.52	342.43
	12		32.69	342.26
	13		32.84	342.11
	14		32.60	342.35
	15		32.04	342.91
	16		31.73	343.22
	17		32.10	342.85
	18		32.19	342.76
	19		32.38	342.57
	20		32.90	342.05
	21		32.67	342.28
	22			
	23			
	24		34.17	340.78
	25		33.78	341.17
	26		33.37	341.58
	27		33.28	341.67
	28		32.91	342.04
	29		32.46	342.49
	30		32.09	342.86

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
December	1	1989	32.80	342.15
	2		33.03	341.92
	3		33.30	341.65
	4		33.73	341.22
	5		34.08	340.87
	6		33.82	341.13
	7		32.68	342.27
	8		32.28	342.67
	9		32.48	342.47
	10		33.03	341.92
	11		32.47	342.48
	12		32.40	342.55
	13		32.74	342.21
	14		32.36	342.59
	15		32.25	342.70
	16		32.82	342.13
	17		32.51	342.44
	18		32.90	342.05
	19		32.50	342.45
	20		32.14	342.81
	21		32.11	342.84
	22		32.64	342.31
	23		32.64	342.31
	24		33.14	341.81
	25		33.51	341.44
	26		33.83	341.12
	27		32.52	342.43
	28		32.26	342.69
	29		32.00	342.95
	30		32.65	342.30
	31		32.45	342.50

Month	Date	Year	3000-F (3099-47-18B)	
			Depth (ft)	Elev. (ft)
January	1	1990	32.98	341.97
	2		32.86	342.09
	3		32.68	342.27
	4		31.64	343.31
	5		31.62	343.33
	6		32.23	342.72
	7		32.62	342.33
	8		32.94	342.01
	9		32.74	342.21
	10		31.80	343.15
	11		31.56	343.39
	12		32.32	342.63
	13		32.34	342.61
	14		32.82	342.13
	15		33.14	341.81
	16		32.49	342.46
	17		32.29	342.66
	18		32.51	342.44
	19		32.64	342.31
	20		32.72	342.23
	21		32.34	342.61
	22		32.64	342.31
	23		32.69	342.26
	24		32.23	342.72
	25			
	26			
	27			
	28			
	29			
	30			
	31			

3000-F (3099-47-18B)				
Month	Date	Year	Depth (ft)	Elev. (ft)
February	1	1990		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22		31.56	343.39
	23		32.04	342.91
	24		32.37	342.58
	25		32.29	342.66
	26		32.23	342.72
	27		32.39	342.56
	28		32.42	342.53

3000-F (3099-47-18B)				
Month	Date	Year	Depth (ft)	Elev. (ft)
March	1	1990	32.00	342.95
	2		31.40	343.55
	3		32.24	342.71
	4		32.23	342.72
	5		32.75	342.20
	6		32.28	342.67
	7		32.19	342.76
	8		32.20	342.75
	9		31.22	343.73
	10		30.93	344.02
	11		32.12	342.83
	12		32.20	342.75
	13		32.33	342.62
	14		32.74	342.21
	15		32.79	342.16
	16		32.26	342.69
	17		31.81	343.14
	18		32.00	342.95
	19		32.08	342.87
	20		32.45	342.50
	21		32.27	342.68
	22		31.50	343.45
	23		31.35	343.60
	24		31.06	343.89
	25		31.18	343.77
	26		31.37	343.58
	27		31.73	343.22
	28		31.46	343.49
	29		30.72	344.23
	30		32.10	342.85
	31		32.92	342.03

3000-F (3099-47-18B)				
Month	Date	Year	Depth (ft)	Elev. (ft)
April	1	1990	33.01	341.94
	2		32.05	342.90
	3		30.22	344.73
	4		31.07	343.88
	5		32.03	342.92
	6		32.34	342.61
	7		32.30	342.65
	8		31.14	343.81
	9		32.20	342.75
	10		31.92	343.03
	11		31.77	343.18
	12		31.82	343.13
	13		32.13	342.82
	14		31.99	342.96
	15		32.96	341.99
	16		33.73	341.22
	17		33.12	341.83
	18		32.29	342.66
	19		32.01	342.94
	20		31.52	343.43
	21		31.85	343.10
	22		32.78	342.17
	23		33.33	341.62
	24		31.45	343.50
	25		31.98	342.97
	26		30.02	344.93
	27		30.55	344.40
	28		31.90	343.05
	29		32.58	342.37
	30		33.45	341.50

3000-F (3099-47-18B)				
Month	Date	Year	Depth (ft)	Elev. (ft)
May	1	1990	32.29	342.66
	2		32.36	342.59
	3		30.85	344.10
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17		31.59	343.36
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
June	1	1989		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
July	1	1989		
	2			
	3			
	4			
	5		7.49	356.22
	6			
	7			
	8			
	9			
	10			
	11		7.69	356.02
	12			
	13		7.79	355.92
	14		7.83	355.88
	15		7.87	355.84
	16		7.90	355.81
	17		7.94	355.77
	18		7.96	355.75
	19		7.99	355.72
	20			
	21		6.71	355.86
	22		6.75	355.82
	23		6.78	355.79
	24		6.81	355.76
	25		6.84	355.73
	26		6.86	355.71
	27		6.89	355.68
	28		6.91	355.66
	29		6.94	355.63
	30		6.96	355.61
	31		6.98	355.59

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
August	1	1989	7.00	355.57
	2		7.02	355.55
	3		7.04	355.53
	4		7.06	355.51
	5		7.08	355.49
	6		7.10	355.47
	7		7.11	355.46
	8		7.12	355.45
	9		7.13	355.44
	10		7.14	355.43
	11		7.15	355.42
	12		7.16	355.41
	13			
	14			
	15			
	16		7.20	355.37
	17			
	18			
	19			
	20			
	21			
	22		7.27	355.30
	23		7.27	355.30
	24		7.28	355.29
	25		7.28	355.29
	26		7.29	355.28
	27		7.30	355.27
	28		7.30	355.27
	29		7.30	355.27
	30		7.30	355.27
	31		7.31	355.26

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
September	1	1989	7.31	355.26
	2		7.32	355.25
	3		7.33	355.24
	4		7.33	355.24
	5		7.33	355.24
	6		7.33	355.24
	7		7.33	355.24
	8		7.33	355.24
	9		7.34	355.23
	10		7.35	355.22
	11		7.35	355.22
	12		7.36	355.21
	13		7.36	355.21
	14		7.36	355.21
	15		7.37	355.20
	16		7.37	355.20
	17		7.35	355.22
	18		7.33	355.24
	19		7.30	355.27
	20		7.27	355.30
	21		7.25	355.32
	22		7.24	355.33
	23		7.22	355.35
	24		7.20	355.37
	25		7.19	355.38
	26		7.18	355.39
	27		7.17	355.40
	28		7.17	355.40
	29		7.17	355.40
	30		7.17	355.40

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
October	1	1989	7.17	355.40
	2		7.16	355.41
	3		7.15	355.42
	4		7.13	355.44
	5		7.10	355.47
	6		7.09	355.48
	7		7.07	355.50
	8		7.05	355.52
	9		7.04	355.53
	10		7.02	355.55
	11		7.01	355.56
	12		7.01	355.56
	13		7.00	355.57
	14		7.00	355.57
	15		6.99	355.58
	16		6.99	355.58
	17		6.99	355.58
	18		6.97	355.60
	19		6.97	355.60
	20		6.96	355.61
	21		6.94	355.63
	22		6.93	355.64
	23		6.92	355.65
	24		6.90	355.67
	25		6.89	355.68
	26		6.87	355.70
	27		6.86	355.71
	28		6.85	355.72
	29		6.83	355.74
	30		6.82	355.75
	31		6.81	355.76

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
November	1	1989	6.80	355.77
	2		6.79	355.78
	3		6.78	355.79
	4		6.78	355.79
	5		6.78	355.79
	6		6.77	355.80
	7		6.77	355.80
	8		6.76	355.81
	9		6.76	355.81
	10		6.75	355.82
	11		6.75	355.82
	12		6.74	355.83
	13		6.74	355.83
	14		6.74	355.83
	15		6.73	355.84
	16		6.72	355.85
	17		6.72	355.85
	18		6.70	355.87
	19		6.69	355.88
	20		6.67	355.90
	21		6.66	355.91
	22		6.65	355.92
	23		6.63	355.94
	24		6.60	355.97
	25		6.58	355.99
	26		6.56	356.01
	27		6.54	356.03
	28		6.52	356.05
	29		6.49	356.08
	30		6.47	356.10

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
December	1	1989	6.45	356.12
	2		6.43	356.14
	3		6.42	356.15
	4		6.40	356.17
	5		6.40	356.17
	6		6.39	356.18
	7		6.38	356.19
	8		6.36	356.21
	9		6.35	356.22
	10		6.35	356.22
	11		6.35	356.22
	12		6.35	356.22
	13		6.35	356.22
	14		6.35	356.22
	15		6.35	356.22
	16		6.35	356.22
	17		6.35	356.22
	18		6.34	356.23
	19		6.33	356.24
	20		6.32	356.25
	21		6.31	356.26
	22		6.30	356.27
	23		6.27	356.30
	24		6.25	356.32
	25		6.20	356.37
	26		6.15	356.42
	27		6.10	356.47
	28		6.07	356.50
	29		6.04	356.53
	30		6.01	356.56
	31		5.97	356.60

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
January	1	1990	5.93	356.64
	2		5.91	356.66
	3		5.89	356.68
	4		5.88	356.69
	5		5.87	356.70
	6		5.86	356.71
	7		5.84	356.73
	8		5.81	356.76
	9		5.80	356.77
	10		5.77	356.80
	11		5.74	356.83
	12		5.71	356.86
	13		5.69	356.88
	14		5.68	356.89
	15		5.66	356.91
	16		5.65	356.92
	17		5.64	356.93
	18		5.63	356.94
	19		5.62	356.95
	20		5.62	356.95
	21		5.61	356.96
	22		5.60	356.97
	23		5.59	356.98
	24		5.58	356.99
	25		5.56	357.01
	26		5.54	357.03
	27		5.50	357.07
	28		5.46	357.11
	29		5.43	357.14
	30		5.39	357.18
	31		5.36	357.21

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
February	1	1990	5.33	357.24
	2		5.31	357.26
	3		5.29	357.28
	4		5.28	357.29
	5		5.27	357.30
	6		5.26	357.31
	7		5.25	357.32
	8		5.24	357.33
	9		5.24	357.33
	10		5.25	357.32
	11		5.25	357.32
	12		5.25	357.32
	13		5.27	357.30
	14		5.28	357.29
	15		5.26	357.31
	16		5.28	357.29
	17		5.30	357.27
	18		5.32	357.25
	19		5.30	357.27
	20		5.27	357.30
	21		5.28	357.29
	22		5.27	357.30
	23		5.28	357.29
	24		5.29	357.28
	25		5.29	357.28
	26		5.30	357.27
	27		5.30	357.27
	28		5.28	357.29

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
March	1	1990	5.27	357.30
	2		5.27	357.30
	3		5.27	357.30
	4		5.28	357.29
	5		5.30	357.27
	6		5.31	357.26
	7		5.28	357.29
	8		5.28	357.29
	9		5.27	357.30
	10		5.26	357.31
	11		5.26	357.31
	12		5.28	357.29
	13		5.29	357.28
	14		5.31	357.26
	15		5.32	357.25
	16		5.33	357.24
	17		5.35	357.22
	18		5.36	357.21
	19		5.38	357.19
	20		5.40	357.17
	21		5.42	357.15
	22		5.44	357.13
	23		5.47	357.10
	24		5.48	357.09
	25		5.49	357.08
	26		5.51	357.06
	27		5.52	357.05
	28		5.53	357.04
	29		5.54	357.03
	30		5.55	357.02
	31		5.56	357.01

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
April	1	1990	5.57	357.00
	2		5.58	356.99
	3		5.59	356.98
	4		5.60	356.97
	5		5.61	356.96
	6		5.62	356.95
	7		5.62	356.95
	8		5.64	356.93
	9		5.64	356.93
	10		5.64	356.93
	11		5.65	356.92
	12		5.67	356.90
	13		5.68	356.89
	14		5.69	356.88
	15		5.70	356.87
	16		5.70	356.87
	17		5.72	356.85
	18		5.74	356.83
	19		5.76	356.81
	20		5.78	356.79
	21		5.80	356.77
	22		5.81	356.76
	23		5.83	356.74
	24		5.85	356.72
	25		5.86	356.71
	26		5.89	356.68
	27		5.90	356.67
	28		5.92	356.65
	29		5.94	356.63
	30		5.96	356.61

Month	Date	Year	EC-1	
			Depth (ft)	Elev. (ft)
May	1	1990	5.98	356.59
	2		5.99	356.58
	3		6.02	356.55
	4		6.04	356.53
	5		6.07	356.50
	6		6.10	356.47
	7		6.11	356.46
	8		6.14	356.43
	9		6.16	356.41
	10		6.18	356.39
	11		6.21	356.36
	12		6.24	356.33
	13		6.26	356.31
	14		6.28	356.29
	15		6.30	356.27
	16		6.31	356.26
	17		6.34	356.23
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
June	1	1989		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14		42.64	352.14
	15		42.62	352.16
	16		42.60	352.18
	17		42.58	352.20
	18		42.55	352.23
	19		42.52	352.26
	20		42.51	352.27
	21		42.48	352.30
	22		42.45	352.33
	23		42.43	352.35
	24		42.41	352.37
	25		42.39	352.39
	26		42.36	352.42
	27		42.34	352.44
	28		42.33	352.45
	29		42.30	352.48
	30		42.28	352.50

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
July	1	1989	42.26	352.52
	2		42.24	352.54
	3		42.22	352.56
	4		42.22	352.56
	5		42.20	352.58
	6		42.18	352.60
	7		42.15	352.63
	8		42.14	352.64
	9		42.11	352.67
	10		42.10	352.68
	11		42.07	352.71
	12		42.05	352.73
	13		42.04	352.74
	14		42.01	352.77
	15		42.00	352.78
	16		41.98	352.80
	17		41.96	352.82
	18		41.95	352.83
	19		41.93	352.85
	20		41.92	352.86
	21		41.91	352.87
	22		41.89	352.89
	23		41.87	352.91
	24		41.86	352.92
	25		41.85	352.93
	26		41.84	352.94
	27		41.82	352.96
	28		41.81	352.97
	29		41.79	352.99
	30		41.78	353.00
	31		41.76	353.02

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
August	1	1989	41.75	353.03
	2		41.72	353.06
	3		41.71	353.07
	4		41.70	353.08
	5		41.69	353.09
	6			
	7			
	8		41.69	353.09
	9		41.68	353.10
	10		41.67	353.11
	11		41.67	353.11
	12		41.66	353.12
	13		41.65	353.13
	14		41.64	353.14
	15		41.63	353.15
	16		41.62	353.16
	17		41.62	353.16
	18		41.61	353.17
	19		41.61	353.17
	20		41.60	353.18
	21		41.59	353.19
	22		41.57	353.21
	23		41.56	353.22
	24		41.55	353.23
	25		41.54	353.24
	26		41.53	353.25
	27		41.53	353.25
	28		41.52	353.26
	29		41.51	353.27
	30		41.50	353.28
	31		41.50	353.28

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
September	1	1989	41.50	353.28
	2		41.50	353.28
	3		41.50	353.28
	4		41.49	353.29
	5		41.50	353.28
	6		41.49	353.29
	7		41.49	353.29
	8		41.49	353.29
	9		41.50	353.28
	10		41.50	353.28
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
October	1	1989		
	2			
	3			
	4			
	5			
	6		41.63	353.15
	7		41.63	353.15
	8		41.64	353.14
	9		41.64	353.14
	10		41.63	353.15
	11		41.66	353.12
	12		41.66	353.12
	13		41.67	353.11
	14		41.68	353.10
	15		41.68	353.10
	16		41.69	353.09
	17		41.70	353.08
	18		41.70	353.08
	19		41.69	353.09
	20		41.69	353.09
	21		41.70	353.08
	22		41.72	353.06
	23		41.71	353.07
	24		41.73	353.05
	25		41.73	353.05
	26		41.73	353.05
	27		41.74	353.04
	28		41.75	353.03
	29		41.75	353.03
	30		41.74	353.04
	31		41.76	353.02

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
November	1	1989	41.76	353.02
	2		41.76	353.02
	3		41.75	353.03
	4		41.77	353.01
	5		41.77	353.01
	6		41.77	353.01
	7		41.80	352.98
	8		41.79	352.99
	9		41.80	352.98
	10		41.80	352.98
	11		41.81	352.97
	12		41.83	352.95
	13		41.84	352.94
	14		41.86	352.92
	15		41.86	352.92
	16		41.87	352.91
	17		41.88	352.90
	18		41.89	352.89
	19		41.90	352.88
	20		41.91	352.87
	21		41.93	352.85
	22		41.93	352.85
	23		41.94	352.84
	24		41.95	352.83
	25		41.96	352.82
	26		41.98	352.80
	27		42.01	352.77
	28		42.01	352.77
	29		42.03	352.75
	30		42.04	352.74

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
December	1	1989	42.05	352.73
	2		42.05	352.73
	3		42.06	352.72
	4		42.06	352.72
	5		42.08	352.70
	6		42.09	352.69
	7		42.09	352.69
	8		42.10	352.68
	9		42.12	352.66
	10		42.13	352.65
	11		42.12	352.66
	12		42.13	352.65
	13		42.14	352.64
	14		42.14	352.64
	15		42.15	352.63
	16		42.15	352.63
	17		42.16	352.62
	18		42.16	352.62
	19		42.17	352.61
	20		42.17	352.61
	21		42.18	352.60
	22		42.19	352.59
	23		42.20	352.58
	24		42.19	352.59
	25		42.19	352.59
	26		42.18	352.60
	27		42.18	352.60
	28		42.20	352.58
	29		42.20	352.58
	30		42.20	352.58
	31		42.19	352.59

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
January	1	1990	42.19	352.59
	2		42.21	352.57
	3		42.21	352.57
	4		42.21	352.57
	5		42.20	352.58
	6		42.20	352.58
	7		42.20	352.58
	8		42.22	352.56
	9		42.20	352.58
	10		42.23	352.55
	11		42.22	352.56
	12		42.20	352.58
	13		42.21	352.57
	14		42.23	352.55
	15		42.22	352.56
	16		42.23	352.55
	17		42.24	352.54
	18		42.24	352.54
	19		42.25	352.53
	20		42.25	352.53
	21		42.24	352.54
	22		42.25	352.53
	23		42.27	352.51
	24		42.28	352.50
	25		42.27	352.51
	26		42.30	352.48
	27		42.29	352.49
	28		42.28	352.50
	29		42.30	352.48
	30		42.31	352.47
	31		42.32	352.46

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
February	1	1990	42.33	352.45
	2		42.34	352.44
	3		42.34	352.44
	4		42.36	352.42
	5		42.36	352.42
	6		42.37	352.41
	7		42.36	352.42
	8		42.39	352.39
	9		42.40	352.38
	10		42.42	352.36
	11		42.42	352.36
	12		42.42	352.36
	13		42.45	352.33
	14		42.45	352.33
	15		42.44	352.34
	16		42.46	352.32
	17		42.48	352.30
	18		42.50	352.28
	19		42.50	352.28
	20		42.51	352.27
	21		42.52	352.26
	22		42.52	352.26
	23		42.53	352.25
	24		42.53	352.25
	25		42.54	352.24
	26		42.55	352.23
	27		42.56	352.22
	28		42.56	352.22

1100-2 (1199-34-13)				
Month	Date	Year	Depth (ft)	Elev. (ft)
March	1	1990	42.57	352.21
	2		42.57	352.21
	3		42.58	352.20
	4		42.58	352.20
	5		42.60	352.18
	6		42.61	352.17
	7		42.61	352.17
	8		42.62	352.16
	9		42.62	352.16
	10		42.63	352.15
	11		42.65	352.13
	12		42.66	352.12
	13		42.67	352.11
	14		42.68	352.10
	15		42.69	352.09
	16		42.69	352.09
	17		42.70	352.08
	18		42.70	352.08
	19		42.71	352.07
	20		42.72	352.06
	21		42.73	352.05
	22		42.73	352.05
	23		42.75	352.03
	24		42.75	352.03
	25		42.75	352.03
	26		42.76	352.02
	27		42.77	352.01
	28		42.78	352.00
	29		42.79	351.99
	30		42.79	351.99
	31		42.81	351.97

Month	Date	Year	1100-2 (1199-34-13)	
			Depth (ft)	Elev. (ft)
April	1	1990	42.82	351.96
	2		42.83	351.95
	3		42.84	351.94
	4		42.85	351.93
	5		42.85	351.93
	6		42.86	351.92
	7		42.87	351.91
	8		42.89	351.89
	9		42.90	351.88
	10		42.90	351.88
	11		42.91	351.87
	12		42.92	351.86
	13		42.92	351.86
	14		42.93	351.85
	15		42.93	351.85
	16		42.94	351.84
	17		42.95	351.83
	18		42.95	351.83
	19		42.96	351.82
	20		42.96	351.82
	21		42.96	351.82
	22		42.96	351.82
	23		42.97	351.81
	24		42.97	351.81
	25		42.96	351.82
	26		42.97	351.81
	27		42.96	351.82
	28		42.96	351.82
	29		42.97	351.81
	30		42.98	351.80

Month	Date	Year	1100-2 (1199-34-13)	
			Depth (ft)	Elev. (ft)
May	1	1990	42.96	351.82
	2		42.96	351.82
	3		42.98	351.80
	4		42.97	351.81
	5		42.95	351.83
	6		42.95	351.83
	7		42.94	351.84
	8		42.95	351.83
	9		42.93	351.85
	10		42.93	351.85
	11		42.92	351.86
	12		42.92	351.86
	13		42.91	351.87
	14		42.91	351.87
	15		42.91	351.87
	16		42.90	351.88
	17		42.90	351.88
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
June	1	1989		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21		50.88	355.10
	22		50.85	355.13
	23		50.84	355.14
	24		50.83	355.15
	25		50.80	355.18
	26		50.77	355.21
	27		50.71	355.27
	28		50.69	355.29
	29		50.68	355.30
	30		50.68	355.30

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
July	1	1989	50.68	355.30
	2		50.63	355.35
	3		50.61	355.37
	4		50.64	355.34
	5		50.67	355.31
	6		50.69	355.29
	7		50.70	355.28
	8		50.72	355.26
	9		50.70	355.28
	10		50.67	355.31
	11		50.64	355.34
	12		50.63	355.35
	13		50.65	355.33
	14		50.67	355.31
	15		50.77	355.21
	16		50.82	355.16
	17		50.74	355.24
	18		50.70	355.28
	19		50.71	355.27
	20		50.75	355.23
	21		50.80	355.18
	22		50.81	355.17
	23		50.77	355.21
	24		50.74	355.24
	25		50.72	355.26
	26		50.73	355.25
	27		50.75	355.23
	28		50.74	355.24
	29		50.72	355.26
	30		50.68	355.30
	31		50.64	355.34

Month	Date	Year	3000-D1 (1199-41-13C)	
			Depth (ft)	Elev. (ft)
August	1	1989	50.61	355.37
	2		50.57	355.41
	3		50.53	355.45
	4		50.55	355.43
	5		50.55	355.43
	6		50.52	355.46
	7		50.50	355.48
	8		50.48	355.50
	9		50.50	355.48
	10		50.42	355.56
	11		50.37	355.61
	12		50.35	355.63
	13		50.31	355.67
	14		50.27	355.71
	15		50.24	355.74
	16		50.16	355.82
	17		50.13	355.85
	18		50.11	355.87
	19		50.08	355.90
	20		50.07	355.91
	21		50.03	355.95
	22		50.00	355.98
	23		50.10	355.88
	24		50.24	355.74
	25		50.36	355.62
	26		50.44	355.54
	27		50.50	355.48
	28		50.52	355.46
	29		50.51	355.47
	30		50.57	355.41
	31		50.63	355.35

Month	Date	Year	3000-D1 (1199-41-13C)	
			Depth (ft)	Elev. (ft)
September	1	1989	50.70	355.28
	2		50.80	355.18
	3		50.88	355.10
	4		50.97	355.01
	5		50.98	355.00
	6		51.04	354.94
	7		51.10	354.88
	8		51.14	354.84
	9		51.20	354.78
	10		51.25	354.73
	11		51.23	354.75
	12		51.16	354.82
	13		51.16	354.82
	14		51.18	354.80
	15		51.21	354.77
	16		51.23	354.75
	17		51.27	354.71
	18		51.28	354.70
	19		51.18	354.80
	20		51.15	354.83
	21		51.22	354.76
	22		51.32	354.66
	23		51.41	354.57
	24		51.49	354.49
	25		51.46	354.52
	26		51.37	354.61
	27		51.39	354.59
	28		51.45	354.53
	29		51.50	354.48
	30		51.57	354.41

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
October	1	1989	51.66	354.32
	2			
	3			
	4			
	5			
	6		51.64	354.34
	7		51.66	354.32
	8		51.67	354.31
	9		51.66	354.32
	10		51.58	354.40
	11		51.57	354.41
	12		51.59	354.39
	13		51.65	354.33
	14		51.72	354.26
	15		51.77	354.21
	16		51.75	354.23
	17		51.70	354.28
	18		51.74	354.24
	19		51.75	354.23
	20		51.75	354.23
	21		51.77	354.21
	22		51.79	354.19
	23		51.75	354.23
	24		51.65	354.33
	25		51.66	354.32
	26		51.72	354.26
	27		51.77	354.21
	28		51.84	354.14
	29		51.90	354.08
	30		51.96	354.02
	31		51.95	354.03

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
November	1	1989	52.02	353.96
	2		52.05	353.93
	3		52.10	353.88
	4		52.20	353.78
	5		52.29	353.69
	6		52.36	353.62
	7		52.28	353.70
	8		52.28	353.70
	9		52.36	353.62
	10		52.46	353.52
	11		52.57	353.41
	12		52.69	353.29
	13		52.82	353.16
	14		52.77	353.21
	15		52.80	353.18
	16		52.87	353.11
	17		52.95	353.03
	18		52.97	353.01
	19		52.98	353.00
	20		52.92	353.06
	21		52.76	353.22
	22		52.76	353.22
	23		52.65	353.33
	24		52.54	353.44
	25		52.45	353.53
	26		52.33	353.65
	27		52.25	353.73
	28		52.20	353.78
	29		52.22	353.76
	30		52.43	353.55

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
December	1	1989	52.63	353.35
	2		52.57	353.41
	3		52.44	353.54
	4		52.31	353.67
	5		52.22	353.76
	6		52.14	353.84
	7		52.07	353.91
	8		52.02	353.96
	9		51.98	354.00
	10		51.94	354.04
	11		51.90	354.08
	12		51.87	354.11
	13		51.88	354.10
	14		51.90	354.08
	15		51.88	354.10
	16		51.85	354.13
	17		51.81	354.17
	18		51.80	354.18
	19		51.77	354.21
	20		51.74	354.24
	21		51.72	354.26
	22		51.70	354.28
	23		51.68	354.30
	24		51.65	354.33
	25		51.63	354.35
	26		51.58	354.40
	27		51.55	354.43
	28		51.54	354.44
	29		51.54	354.44
	30		51.53	354.45
	31		51.52	354.46

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
January	1	1990	51.48	354.50
	2		51.45	354.53
	3		51.41	354.57
	4		51.39	354.59
	5		51.39	354.59
	6		51.37	354.61
	7		51.35	354.63
	8		51.34	354.64
	9		51.32	354.66
	10		51.35	354.63
	11		51.33	354.65
	12		51.31	354.67
	13		51.36	354.62
	14		51.60	354.38
	15		51.93	354.05
	16		52.15	353.83
	17		52.21	353.77
	18		52.20	353.78
	19		52.33	353.65
	20		52.45	353.53
	21		52.53	353.45
	22		52.44	353.54
	23		52.40	353.58
	24		52.49	353.49
	25		52.55	353.43
	26		52.69	353.29
	27		52.81	353.17
	28		52.93	353.05
	29		53.05	352.93
	30		53.08	352.90
	31		53.15	352.83

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
February	1	1990	53.24	352.74
	2		52.35	353.63
	3		53.44	352.54
	4		53.54	352.44
	5		53.60	352.38
	6		53.53	352.45
	7		53.49	352.49
	8		53.52	352.46
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22			
	23		53.82	352.16
	24			
	25			
	26			
	27			
	28			

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
March	1	1990		
	2			
	3		53.99	351.99
	4		54.02	351.96
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22		54.32	351.66
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
April	1	1990		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18		53.99	351.99
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			

3000-D1 (1199-41-13C)				
Month	Date	Year	Depth (ft)	Elev. (ft)
May	1	1990		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17		53.45	352.53
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
June	1	1989		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16		45.44	353.86
	17			
	18			
	19			
	20			
	21		45.26	354.04
	22			
	23			
	24			
	25			
	26		45.14	354.16
	27		45.12	354.18
	28		45.08	354.22
	29		45.05	354.25
	30		45.04	354.26

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
July	1	1989	45.04	354.26
	2		45.02	354.28
	3		44.98	354.32
	4		44.96	354.34
	5		44.97	354.33
	6		44.98	354.32
	7		44.98	354.32
	8		45.00	354.30
	9		44.98	354.32
	10		44.96	354.34
	11		44.94	354.36
	12		44.93	354.37
	13		44.95	354.35
	14		44.96	354.34
	15		45.02	354.28
	16		45.07	354.23
	17		45.07	354.23
	18		45.02	354.28
	19		45.02	354.28
	20		45.05	354.25
	21		45.08	354.22
	22		45.10	354.20
	23		45.10	354.20
	24		45.09	354.21
	25		45.05	354.25
	26		45.02	354.28
	27		45.05	354.25
	28		45.04	354.26
	29		45.03	354.27
	30		45.02	354.28
	31		44.98	354.32

Month	Date	Year	699-S36-E13A	
			Depth (ft)	Elev. (ft)
August	1	1989	44.95	354.35
	2		44.93	354.37
	3		44.89	354.41
	4		44.88	354.42
	5		44.88	354.42
	6		44.88	354.42
	7		44.85	354.45
	8		44.81	354.49
	9		44.81	354.49
	10		44.91	354.39
	11		44.80	354.50
	12		44.75	354.55
	13		44.72	354.58
	14		44.68	354.62
	15		44.64	354.66
	16		44.55	354.75
	17		44.53	354.77
	18		44.50	354.80
	19		44.48	354.82
	20		44.46	354.84
	21		44.43	354.87
	22		44.38	354.92
	23		44.40	354.90
	24		44.47	354.83
	25		44.55	354.75
	26		44.62	354.68
	27		44.66	354.64
	28		44.70	354.60
	29		44.68	354.62
	30		44.71	354.59
	31		44.77	354.53

Month	Date	Year	699-S36-E13A	
			Depth (ft)	Elev. (ft)
September	1	1989	44.81	354.49
	2		44.89	354.41
	3		44.95	354.35
	4		45.01	354.29
	5		45.04	354.26
	6		45.07	354.23
	7		45.11	354.19
	8		45.26	354.04
	9		45.30	354.00
	10		45.35	353.95
	11		45.38	353.92
	12		45.36	353.94
	13		45.36	353.94
	14		45.36	353.94
	15		45.37	353.93
	16		45.39	353.91
	17		45.41	353.89
	18		45.42	353.88
	19		45.36	353.94
	20		45.33	353.97
	21		45.34	353.96
	22		45.41	353.89
	23		45.46	353.84
	24		45.51	353.79
	25		45.51	353.79
	26		45.47	353.83
	27		45.46	353.84
	28		45.48	353.82
	29		45.51	353.79
	30		45.55	353.75

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
October	1	1989	45.62	353.68
	2		45.70	353.60
	3		45.69	353.61
	4		45.68	353.62
	5		45.68	353.62
	6		45.70	353.60
	7		45.72	353.58
	8		45.73	353.57
	9		45.74	353.56
	10		45.69	353.61
	11		45.69	353.61
	12		45.70	353.60
	13		45.73	353.57
	14		45.77	353.53
	15		45.81	353.49
	16		45.82	353.48
	17		45.79	353.51
	18		45.79	353.51
	19		45.82	353.48
	20		45.82	353.48
	21		45.83	353.47
	22		45.85	353.45
	23		45.84	353.46
	24		45.82	353.48
	25		45.82	353.48
	26		45.85	353.45
	27		45.88	353.42
	28		45.93	353.37
	29		45.99	353.31
	30		46.03	353.27
	31		46.06	353.24

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
November	1	1989	46.11	353.19
	2		46.14	353.16
	3		46.18	353.12
	4		46.23	353.07
	5		46.30	353.00
	6		46.36	352.94
	7		46.37	352.93
	8		46.37	352.93
	9		46.41	352.89
	10		46.47	352.83
	11		46.55	352.75
	12		46.63	352.67
	13		46.73	352.57
	14		46.77	352.53
	15		46.78	352.52
	16		46.82	352.48
	17		46.89	352.41
	18		46.91	352.39
	19		46.91	352.39
	20		46.91	352.39
	21		46.90	352.40
	22		46.89	352.41
	23		46.85	352.45
	24		46.80	352.50
	25		46.74	352.56
	26		46.68	352.62
	27		46.62	352.68
	28		46.58	352.72
	29		46.56	352.74
	30		46.63	352.67

Month	Date	Year	699-S36-E13A	
			Depth (ft)	Elev. (ft)
December	1	1989	46.77	352.53
	2		46.79	352.51
	3		46.74	352.56
	4		46.67	352.63
	5		46.61	352.69
	6		46.56	352.74
	7		46.50	352.80
	8		46.46	352.84
	9		46.44	352.86
	10		46.40	352.90
	11		46.36	352.94
	12		46.33	352.97
	13		46.32	352.98
	14		46.32	352.98
	15		46.31	352.99
	16		46.29	353.01
	17		46.27	353.03
	18		46.26	353.04
	19		46.23	353.07
	20		46.21	353.09
	21		46.19	353.11
	22		46.18	353.12
	23		46.16	353.14
	24		46.15	353.15
	25		46.14	353.16
	26		46.11	353.19
	27		46.08	353.22
	28		46.07	353.23
	29		46.06	353.24
	30		46.05	353.25
	31		46.04	353.26

Month	Date	Year	699-S36-E13A	
			Depth (ft)	Elev. (ft)
January	1	1990	46.01	353.29
	2		46.00	353.30
	3		45.97	353.33
	4		45.94	353.36
	5		45.93	353.37
	6		45.92	353.38
	7		45.89	353.41
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22			
	23			
	24		46.68	352.62
	25		46.71	352.59
	26		46.79	352.51
	27		46.87	352.43
	28		46.96	352.34
	29		47.05	352.25
	30		47.10	352.20
	31		47.16	352.14

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
February	1	1990	47.21	352.09
	2		47.30	352.00
	3		47.37	351.93
	4		47.46	351.84
	5		47.53	351.77
	6		47.55	351.75
	7		47.53	351.77
	8		47.53	351.77
	9		47.58	351.72
	10		47.63	351.67
	11		47.68	351.62
	12		47.73	351.57
	13		47.70	351.60
	14		47.67	351.63
	15		47.65	351.65
	16		47.69	351.61
	17		47.75	351.55
	18		47.80	351.50
	19		47.83	351.47
	20		47.79	351.51
	21		47.75	351.55
	22		47.74	351.56
	23		47.75	351.55
	24		47.78	351.52
	25		47.83	351.47
	26		47.90	351.40
	27		47.90	351.40
	28		47.89	351.41

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
March	1	1990	47.88	351.42
	2		47.99	351.31
	3		48.18	351.12
	4		48.29	351.01
	5		48.38	350.92
	6		48.41	350.89
	7		48.37	350.93
	8		48.33	350.97
	9		48.38	350.92
	10		48.44	350.86
	11		48.50	350.80
	12		48.55	350.75
	13		48.49	350.81
	14		48.43	350.87
	15		48.40	350.90
	16		48.43	350.87
	17		48.58	350.72
	18		48.63	350.67
	19		48.63	350.67
	20		48.59	350.71
	21		48.51	350.79
	22		48.40	350.90
	23		48.40	350.90
	24		48.41	350.89
	25		48.42	350.88
	26		48.45	350.85
	27		48.71	350.59
	28		48.77	350.53
	29		48.84	350.46
	30		48.91	350.39
	31		48.81	350.49

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
April	1	1990	48.80	350.50
	2		48.81	350.49
	3		48.82	350.48
	4		48.97	350.33
	5		49.08	350.22
	6		49.14	350.16
	7		49.19	350.11
	8		49.19	350.11
	9		49.01	350.29
	10		48.82	350.48
	11		48.72	350.58
	12		48.58	350.72
	13		48.48	350.82
	14		48.40	350.90
	15		48.34	350.96
	16		48.42	350.88
	17		48.40	350.90
	18		48.33	350.97
	19		48.33	350.97
	20		48.29	351.01
	21		48.15	351.15
	22		48.09	351.21
	23		48.02	351.28
	24		47.87	351.43
	25		47.75	351.55
	26		47.71	351.59
	27		47.66	351.64
	28		47.61	351.69
	29		47.58	351.72
	30		47.54	351.76

699-S36-E13A				
Month	Date	Year	Depth (ft)	Elev. (ft)
May	1	1990	47.43	351.87
	2		47.34	351.96
	3		47.31	351.99
	4		47.28	352.02
	5		47.30	352.00
	6		47.36	351.94
	7		47.40	351.90
	8		47.32	351.98
	9		47.26	352.04
	10		47.27	352.03
	11		47.32	351.98
	12		47.40	351.90
	13		47.46	351.84
	14		47.49	351.81
	15		47.41	351.89
	16		47.39	351.91
	17		47.43	351.87
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

F-2 (3099-45-16)									
Month	Date	Year	Depth (ft)	Elev. (ft)					
June	1	1989							
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								
	11								
	12								
	13								
	14		60.17	347.92					
	15		60.11	347.98					
	16		60.05	348.04					
	17		60.06	348.03					
	18		60.11	347.98					
	19		60.17	347.92					
	20		60.21	347.88					
	21		60.16	347.93					
	22		60.17	347.92					
	23		60.20	347.89					
	24		60.23	347.86					
	25		60.25	347.84					
	26		60.27	347.82					
	27		60.27	347.82					
	28		60.25	347.84					
	29		60.24	347.85					
	30		60.22	347.87					

F-2 (3099-45-16)									
Month	Date	Year	Depth (ft)	Elev. (ft)					
July	1	1989	60.22	347.87					
	2		60.23	347.86					
	3		60.23	347.86					
	4		60.24	347.85					
	5		60.24	347.85					
	6		60.25	347.84					
	7		60.22	347.87					
	8		60.20	347.89					
	9		60.19	347.90					
	10		60.20	347.89					
	11		60.19	347.90					
	12		60.18	347.91					
	13		60.17	347.92					
	14		60.17	347.92					
	15		60.20	347.89					
	16		60.25	347.84					
	17		60.30	347.79					
	18		60.34	347.75					
	19		60.36	347.73					
	20		60.36	347.73					
	21		60.37	347.72					
	22		60.35	347.74					
	23		60.33	347.76					
	24		60.32	347.77					
	25		60.30	347.79					
	26		60.27	347.82					
	27		60.24	347.85					
	28		60.22	347.87					
	29		60.20	347.89					
	30		60.17	347.92					
	31		60.15	347.94					

F-2
(3099-45-16)

Month	Date	Year	Depth (ft)	Elev. (ft)
August	1	1989	60.14	347.95
	2		60.14	347.95
	3		60.15	347.94
	4		60.15	347.94
	5		60.12	347.97
	6		60.08	348.01
	7		60.05	348.04
	8		60.02	348.07
	9		60.00	348.09
	10		59.97	348.12
	11		59.94	348.15
	12		59.91	348.18
	13		59.90	348.19
	14		59.88	348.21
	15		59.88	348.21
	16		59.87	348.22
	17		59.87	348.22
	18		59.85	348.24
	19		59.81	348.28
	20		59.78	348.31
	21		59.76	348.33
	22		59.74	348.35
	23		59.74	348.35
	24		59.75	348.34
	25		59.76	348.33
	26		59.78	348.31
	27		59.80	348.29
	28		59.83	348.26
	29		59.84	348.25
	30		59.85	348.24
	31		59.84	348.25

F-2
(3099-45-16)

Month	Date	Year	Depth (ft)	Elev. (ft)
September	1	1989	59.82	348.27
	2		59.83	348.26
	3		59.85	348.24
	4		59.87	348.22
	5		59.90	348.19
	6		59.93	348.16
	7		59.93	348.16
	8		59.94	348.15
	9		59.96	348.13
	10		59.98	348.11
	11		60.01	348.08
	12		60.04	348.05
	13		60.07	348.02
	14		60.08	348.01
	15		60.09	348.00
	16		60.07	348.02
	17		60.07	348.02
	18		60.08	348.01
	19		60.08	348.01
	20		60.06	348.03
	21		60.02	348.07
	22		59.99	348.10
	23		59.98	348.11
	24		59.98	348.11
	25		60.00	348.09
	26		60.02	348.07
	27		60.02	348.07
	28		60.02	348.07
	29		60.00	348.09
	30		59.99	348.10

Month	Date	Year	F-2 (3099-45-16)	
			Depth (ft)	Elev. (ft)
October	1	1989	60.02	348.07
	2		60.06	348.03
	3		60.08	348.01
	4		60.08	348.01
	5		60.06	348.03
	6		60.07	348.02
	7		60.09	348.00
	8		60.10	347.99
	9		60.12	347.97
	10		60.15	347.94
	11		60.17	347.92
	12		60.17	347.92
	13		60.14	347.95
	14		60.11	347.98
	15		60.13	347.96
	16		60.17	347.92
	17		60.20	347.89
	18		60.21	347.88
	19		60.21	347.88
	20		60.19	347.90
	21		60.19	347.90
	22		60.20	347.89
	23		60.21	347.88
	24		60.25	347.84
	25		60.28	347.81
	26		60.31	347.78
	27		60.34	347.75
	28		60.37	347.72
	29		60.39	347.70
	30		60.40	347.69
	31		60.44	347.65

Month	Date	Year	F-2 (3099-45-16)	
			Depth (ft)	Elev. (ft)
November	1	1989	60.48	347.61
	2		60.51	347.58
	3		60.53	347.56
	4		60.56	347.53
	5		60.59	347.50
	6		60.62	347.47
	7		60.65	347.44
	8		60.66	347.43
	9		60.65	347.44
	10		60.65	347.44
	11		60.65	347.44
	12		60.67	347.42
	13		60.70	347.39
	14		60.73	347.36
	15		60.77	347.32
	16		60.77	347.32
	17		60.78	347.31
	18		60.79	347.30
	19		60.81	347.28
	20		60.84	347.25
	21		60.89	347.20
	22		60.91	347.18
	23		60.95	347.14
	24		61.02	347.07
	25		61.07	347.02
	26		61.12	346.97
	27		61.15	346.94
	28		61.17	346.92
	29		61.15	346.94
	30		61.12	346.97

Month	Date	Year	F-2 (3099-45-16)	
			Depth (ft)	Elev. (ft)
December	1	1989	61.09	347.00
	2		61.11	346.98
	3		61.14	346.95
	4		61.17	346.92
	5		61.20	346.89
	6		61.23	346.86
	7		61.24	346.85
	8		61.21	346.88
	9		61.16	346.93
	10		61.11	346.98
	11		61.09	347.00
	12		61.05	347.04
	13		61.02	347.07
	14		60.99	347.10
	15		60.97	347.12
	16		60.94	347.15
	17		60.91	347.18
	18		60.91	347.18
	19		60.92	347.17
	20		60.90	347.19
	21		60.88	347.21
	22		60.84	347.25
	23		60.83	347.26
	24		60.82	347.27
	25		60.84	347.25
	26		60.87	347.22
	27		60.88	347.21
	28		60.86	347.23
	29		60.82	347.27
	30		60.79	347.30
	31		60.77	347.32

Month	Date	Year	F-2 (3099-45-16)	
			Depth (ft)	Elev. (ft)
January	1	1990	60.76	347.33
	2		60.77	347.32
	3		60.77	347.32
	4		60.75	347.34
	5		60.71	347.38
	6		60.67	347.42
	7		60.65	347.44
	8		60.64	347.45
	9		60.63	347.46
	10		60.63	347.46
	11		60.58	347.51
	12		60.53	347.56
	13		60.51	347.58
	14		60.51	347.58
	15		60.54	347.55
	16		60.59	347.50
	17		60.63	347.46
	18		60.65	347.44
	19		60.68	347.41
	20		60.72	347.37
	21		60.75	347.34
	22		60.78	347.31
	23		60.83	347.26
	24		60.85	347.24
	25		60.84	347.25
	26		60.85	347.24
	27		60.85	347.24
	28		60.85	347.24
	29		60.86	347.23
	30		60.89	347.20
	31		60.94	347.15

F-2 (3099-45-16)				
Month	Date	Year	Depth (ft)	Elev. (ft)
February	1	1990	60.97	347.12
	2		60.97	347.12
	3		61.00	347.09
	4		61.04	347.05
	5		61.09	347.00
	6		61.15	346.94
	7		61.23	346.86
	8		61.26	346.83
	9		61.22	346.87
	10		61.19	346.90
	11		61.22	346.87
	12		61.27	346.82
	13		61.32	346.77
	14		61.35	346.74
	15		61.37	346.72
	16		61.34	346.75
	17		61.28	346.81
	18		61.25	346.84
	19		61.29	346.80
	20		61.31	346.78
	21		61.30	346.79
	22		61.26	346.83
	23		61.26	346.83
	24		61.31	346.78
	25		61.36	346.73
	26		61.40	346.69
	27		61.45	346.64
	28		61.49	346.60

F-2 (3099-45-16)				
Month	Date	Year	Depth (ft)	Elev. (ft)
March	1	1990	61.54	346.55
	2		61.55	346.54
	3		61.56	346.53
	4		61.58	346.51
	5		61.61	346.48
	6		61.65	346.44
	7		61.69	346.40
	8		61.71	346.38
	9		61.73	346.36
	10		61.71	346.38
	11		61.69	346.40
	12		61.72	346.37
	13		61.75	346.34
	14		61.78	346.31
	15		61.82	346.27
	16		61.86	346.23
	17		61.89	346.20
	18		61.91	346.18
	19		61.92	346.17
	20		61.93	346.16
	21		61.96	346.13
	22		61.97	346.12
	23		61.97	346.12
	24		61.93	346.16
	25		61.89	346.20
	26		61.85	346.24
	27		61.83	346.26
	28		61.83	346.26
	29		61.81	346.28
	30		61.77	346.32
	31		61.78	346.31

Month	Date	Year	F-2 (3099-45-16)	
			Depth (ft)	Elev. (ft)
April	1	1990	61.86	346.23
	2		61.95	346.14
	3		61.99	346.10
	4		61.92	346.17
	5		61.88	346.21
	6		61.91	346.18
	7		61.97	346.12
	8		62.01	346.08
	9		61.99	346.10
	10		62.01	346.08
	11		62.03	346.06
	12		62.02	346.07
	13		62.00	346.09
	14		62.00	346.09
	15		61.98	346.11
	16		62.00	346.09
	17		62.03	346.06
	18		62.07	346.02
	19		62.07	346.02
	20		62.04	346.05
	21		61.98	346.11
	22		61.94	346.15
	23		61.95	346.14
	24		61.96	346.13
	25		61.90	346.19
	26		61.84	346.25
	27		61.70	346.39
	28		61.57	346.52
	29		61.50	346.59
	30		61.48	346.61

Month	Date	Year	F-2 (3099-45-16)	
			Depth (ft)	Elev. (ft)
May	1	1990	61.52	346.57
	2		61.50	346.59
	3		61.48	346.61
	4		61.41	346.68
	5		61.26	346.83
	6		61.14	346.95
	7		61.06	347.03
	8		61.02	347.07
	9		60.94	347.15
	10		60.86	347.23
	11		60.86	347.23
	12		60.92	347.17
	13		61.01	347.08
	14		61.10	346.99
	15		61.18	346.91
	16		61.22	346.87
	17		61.24	346.85
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

Well 699-S40-E14

Month	Day	Year	Average W-L Elev. (ft)
June	1	1989	357.19
	2		357.17
	3		356.83
	4		356.81
	5		356.67
	6		356.62
	7		356.69
	8		356.63
	9		356.64
	10		356.71
	11		356.66
	12		356.64
	13		356.74
	14		356.78
	15		356.94
	16		357.09
	17		357.03
	18		356.75
	19		356.78
	20		356.81
	21		356.92
	22		356.99
	23		356.94
	24		357.00
	25		357.00
	26		357.28
	27		357.18
	28		357.07
	29		357.00
	30		356.93

Month	Day	Year	Average W-L Elev. (ft)
July	1	1989	357.09
	2		357.29
	3		356.94
	4		356.83
	5		356.72
	6		356.68
	7		356.64
	8		356.59
	9		356.75
	10		356.81
	11		356.76
	12		356.67
	13		356.62
	14		356.18
	15		356.17
	16		356.45
	17		356.87
	18		356.74
	19		356.59
	20		356.51
	21		356.46
	22		356.58
	23		356.69
	24		356.80
	25		356.63
	26		356.58
	27		356.70
	28		356.63
	29		356.78
	30		356.90
	31		356.96

Month	Day	Year	Average W-L Elev. (ft)
August	1	1989	357.07
	2		357.35
	3		357.07
	4		356.94
	5		357.10
	6		357.11
	7		357.18
	8		357.04
	9		357.24
	10		357.57
	11		357.41
	12		357.52
	13		357.56
	14		357.52
	15		357.62
	16		357.77
	17		357.81
	18		357.84
	19		357.80
	20		357.82
	21		358.09
	22		357.16
	23		356.56
	24		356.28
	25		356.20
	26		356.17
	27		356.12
	28		356.69
	29		356.27
	30		356.03
	31		355.95

Month	Day	Year	Average W-L Elev. (ft)
September	1	1989	355.61
	2		355.51
	3		355.35
	4		355.87
	5		355.48
	6		355.34
	7		355.15
	8		355.07
	9		354.99
	10		355.19
	11		355.72
	12		355.49
	13		355.35
	14		355.25
	15		355.15
	16		355.11
	17		355.13
	18		355.91
	19		355.96
	20		355.67
	21		355.21
	22		355.01
	23		354.82
	24		355.08
	25		355.74
	26		355.41
	27		355.16
	28		354.95
	29		
	30		

Month	Day	Year	Average W-L Elev. (ft)
October	1	1989	
	2		
	3		
	4		
	5		
	6		355.17
	7		355.15
	8		355.21
	9		355.71
	10		355.48
	11		355.40
	12		355.23
	13		354.97
	14		354.93
	15		354.88
	16		355.50
	17		355.19
	18		354.92
	19		354.96
	20		354.95
	21		354.92
	22		354.97
	23		355.68
	24		355.31
	25		355.03
	26		354.91
	27		354.79
	28		354.55
	29		354.46
	30		354.77
	31		354.44

Month	Day	Year	Average W-L Elev. (ft)
November	1	1989	354.49
	2		354.32
	3		354.03
	4		353.77
	5		353.67
	6		354.45
	7		354.32
	8		353.90
	9		353.55
	10		353.32
	11		353.11
	12		352.84
	13		353.65
	14		353.79
	15		353.40
	16		353.25
	17		353.30
	18		353.43
	19		353.61
	20		354.60
	21		354.21
	22		354.70
	23		355.18
	24		355.55
	25		355.77
	26		355.84
	27		355.69
	28		355.32
	29		354.27
	30		353.61

Month	Day	Year	Average W-L Elev. (ft)
December	1	1989	354.67
	2		355.43
	3		355.76
	4		355.87
	5		355.92
	6		356.01
	7		356.02
	8		356.03
	9		356.10
	10		356.14
	11		356.11
	12		356.02
	13		355.67
	14		355.87
	15		355.99
	16		356.05
	17		355.95
	18		356.05
	19		356.15
	20		356.24
	21		356.32
	22		356.34
	23		356.34
	24		356.34
	25		356.52
	26		356.53
	27		356.50
	28		356.40
	29		356.39
	30		356.37
	31		356.49

Month	Day	Year	Average W-L Elev. (ft)
January	1	1990	
	2		
	3		
	4		
	5		
	6		
	7		
	8		
	9		
	10		
	11		
	12		
	13		
	14		
	15		
	16		
	17		
	18		
	19		
	20		
	21		353.38
	22		
	23		
	24		
	25		
	26		353.26
	27		353.07
	28		353.05
	29		353.23
	30		353.08
	31		352.85

B.45

Month	Day	Year	Average W-L Elev. (ft)
February	1	1990	352.52
	2		352.43
	3		352.32
	4		352.48
	5		353.14
	6		
	7		
	8		353.17
	9		352.99
	10		352.73
	11		352.45
	12		352.27
	13		352.26
	14		353.15
	15		353.33
	16		353.00
	17		352.71
	18		352.43
	19		352.20
	20		352.20
	21		353.10
	22		
	23		
	24		353.28
	25		353.13
	26		352.80
	27		352.45
	28		352.20

Month	Day	Year	Average W-L Elev. (ft)
March	1	1990	352.00
	2		352.14
	3		352.88
	4		352.71
	5		352.43
	6		352.12
	7		351.90
	8		351.71
	9		351.92
	10		352.67
	11		
	12		
	13		352.61
	14		352.40
	15		352.07
	16		351.78
	17		351.58
	18		351.47
	19		352.22
	20		352.51
	21		352.28
	22		351.98
	23		351.67
	24		351.48
	25		351.25
	26		351.75
	27		
	28		
	29		352.20
	30		352.03
	31		351.86

Month	Day	Year	Average W-L Elev. (ft)
April	1	1990	351.61
	2		351.36
	3		351.19
	4		351.12
	5		350.98
	6		350.79
	7		350.75
	8		350.68
	9		350.62
	10		350.54
	11		350.39
	12		350.38
	13		
	14		
	15		350.23
	16		350.28
	17		350.27
	18		350.24
	19		350.40
	20		351.13
	21		352.70
	22		352.56
	23		352.34
	24		352.28
	25		352.21
	26		352.17
	27		352.47
	28		353.47
	29		
	30		

Month	Day	Year	Average W-L Elev. (ft)
May	1	1990	353.00
	2		352.87
	3		352.62
	4		352.47
	5		352.44
	6		352.51
	7		353.59
	8		354.01
	9		353.41
	10		353.23
	11		353.27
	12		353.32
	13		353.32
	14		353.77
	15		354.34
	16		
	17		
	18		353.99
	19		353.64
	20		353.54
	21		353.16
	22		352.96
	23		352.92
	24		353.96
	25		353.65
	26		353.10
	27		352.82
	28		352.49
	29		352.43
	30		352.61
	31		353.73

Columbia River at SWS-1

Ave. River 10-Day				Ave. River 10-Day			
Elev. Ave.				Elev. Ave.			
(ft)				(ft)			
Month	Day	Year		Month	Day	Year	
June	1	1989		July	1	1989	
	2		343.42		2		340.29
	3		343.82		3		339.99
	4		343.80		4		339.50
	5		343.37		5		340.32
	6		343.01		6		339.79
	7		343.72		7		340.75
	8		344.30		8		340.99
	9		344.66		9		340.66
	10		344.92		10		339.97
	11		344.62		11		339.99
	12		343.62		12		340.57
	13		343.47		13		341.33
	14		343.26		14		340.28
	15		344.81		15		339.94
	16		344.69		16		339.21
	17		341.67		17		338.52
	18		340.32		18		339.02
	19		339.87		19		339.70
	20		340.34		20		340.16
	21		341.78		21		340.61
	22		340.98		22		340.72
	23		340.66		23		341.10
	24		340.58		24		340.40
	25		340.22		25		340.58
	26		339.48		26		341.38
	27		340.24		27		341.72
	28		341.85		28		340.93
	29		340.77		29		340.90
	30		341.24		30		341.29
			340.55		31		340.70
			340.65				340.00
							340.89

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
August	1	1989	340.09	
	2		339.49	
	3		339.47	
	4		341.06	
	5		341.24	
	6		340.37	
	7		340.24	
	8		340.94	
	9		340.98	
	10		340.77	340.46
	11		340.51	
	12		340.49	
	13		340.15	
	14		339.80	
	15		340.02	
	16		339.68	
	17		340.11	
	18		341.06	
	19		340.84	
	20		340.34	340.30
	21		340.28	
	22		339.52	
	23		339.03	
	24		339.44	
	25		339.95	
	26		339.71	
	27		339.30	
	28		339.37	
	29		340.56	
	30		340.72	
	31		341.34	339.92

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
September	1	1989	340.97	
	2		340.76	
	3		340.17	
	4		340.30	
	5		340.12	
	6		341.72	
	7		341.17	
	8		340.75	
	9		340.77	
	10		339.93	340.67
	11		339.85	
	12		339.93	
	13		340.43	
	14		340.59	
	15		340.91	
	16		340.59	
	17		340.10	
	18		339.75	
	19		340.89	
	20		341.28	340.43
	21		341.04	
	22		340.61	
	23		341.35	
	24		340.32	
	25		339.82	
	26		340.81	
	27		340.86	
	28		341.10	
	29		341.21	
	30		340.55	340.76

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
October	1	1989	339.93	
	2		340.25	
	3		341.69	
	4		341.80	
	5		341.26	
	6		340.38	
	7		341.05	
	8		340.51	
	9		339.65	
	10		341.01	340.75
	11		341.51	
	12		342.02	
	13		342.24	
	14		340.83	
	15		340.21	
	16		340.20	
	17		341.28	
	18		341.32	
	19		341.26	
	20		341.33	341.23
	21		341.39	
	22		340.81	
	23		340.52	
	24		340.07	
	25		340.57	
	26		341.06	
	27		341.13	
	28		341.24	
	29		341.42	
	30		340.65	
	31		340.79	340.90

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
November	1	1989	341.24	
	2		341.43	
	3		341.00	
	4		341.24	
	5		341.77	
	6		341.25	
	7		342.26	
	8		342.75	
	9		342.49	
	10		342.41	341.80
	11		342.10	
	12		341.97	
	13		341.82	
	14		342.21	
	15		343.11	
	16		342.97	
	17		342.68	
	18		342.57	
	19		342.08	
	20		342.38	342.40
	21		342.39	
	22		341.18	
	23		341.33	
	24		340.87	
	25		341.22	
	26		341.69	
	27		341.86	
	28		342.31	
	29		342.87	
	30		343.24	341.89

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
December	1	1989	341.93	
	2		342.37	
	3		341.30	
	4		341.22	
	5		340.86	
	6		341.34	
	7		342.93	
	8		343.17	
	9		342.98	
	10		342.06	342.02
	11		342.83	
	12		342.81	
	13		342.57	
	14		343.02	
	15		343.04	
	16		342.60	
	17		342.17	
	18		342.02	
	19		342.99	
	20		343.17	342.73
	21		343.15	
	22		342.63	
	23		342.43	
	24		341.47	
	25		341.33	
	26		341.29	
	27		342.80	
	28		343.22	
	29		343.13	
	30		342.06	
	31		342.55	342.37

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
January	1	1990		
	2		341.92	
	3		342.71	
	4		343.66	
	5		343.51	
	6		342.66	
	7		342.44	
	8		341.98	
	9		342.61	
	10		343.84	342.86
	11		343.35	
	12		342.49	
	13		342.98	
	14		341.86	
	15		342.12	
	16		342.63	342.62
	17			
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30			
	31			

B.51

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
February	1	1990		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
March	1	1990		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
	17			
	18			
	19			
	20			
	21			
	22			
	23			
	24			
	25			
	26			
	27			
	28			
	29			
	30		342.85	
	31		342.25	342.47

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
April	1	1990	342.34	
	2		343.72	
	3		345.83	
	4		344.84	
	5		343.56	
	6		343.13	
	7		343.28	
	8		345.09	
	9		343.21	
	10		343.89	343.89
	11		343.97	
	12		343.83	
	13		343.43	
	14		343.61	
	15		342.37	
	16		341.38	
	17		342.22	
	18		343.20	
	19		343.23	
	20		344.07	343.14
	21		343.43	
	22		342.23	
	23		341.95	
	24		344.50	
	25		343.83	
	26		346.13	
	27		345.09	
	28		343.61	
	29		342.67	
	30		341.30	343.38

Month	Day	Year	Ave. River Elev. (ft)	10-Day Ave. (ft)
May	1	1990	343.51	
	2		343.17	
	3		345.17	
	4		346.10	
	5		345.35	
	6		344.70	
	7		344.53	
	8		345.92	
	9		345.56	
	10		343.54	344.76
	11		342.37	
	12		341.18	
	13		341.96	
	14		342.50	
	15		343.07	
	16		343.50	
	17		343.77	
	18		344.26	
	19		344.22	
	20		342.58	342.95
	21		342.04	
	22		343.90	
	23		344.28	
	24		344.19	
	25		344.02	
	26		342.41	
	27		342.40	
	28		343.28	
	29		342.96	
	30		345.40	343.42
	31			

Columbia River at Snyder Street

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
June	1	1989	343.6	341.6
	2		342.2	
	3		341.5	
	4		341.3	
	5		340.7	
	6		341.3	
	7		341.4	
	8		341.4	
	9		341.6	
	10		341.4	340.7
	11		341.6	
	12		340.2	
	13		341.4	
	14		342.0	
	15		341.6	
	16		340.4	
	17		340.9	
	18		339.5	
	19		339.0	
	20		340.4	339.6
	21		340.3	
	22		339.8	
	23		339.0	
	24		339.5	
	25		339.5	
	26		339.7	
	27		340.0	
	28		339.4	
	29		339.7	
	30		339.0	

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
July	1	1989	339.2	339.0
	2		339.2	
	3		339.0	
	4		338.8	
	5		338.1	
	6		339.0	
	7		339.9	
	8		339.5	
	9		338.6	
	10		338.6	338.7
	11		339.5	
	12		339.3	
	13		339.5	
	14		339.6	
	15		338.6	
	16		337.5	
	17		338.0	
	18		338.0	
	19		338.2	
	20		338.6	340.3
	21		339.0	
	22		339.5	
	23		338.8	
	24		339.6	
	25		341.2	
	26		340.2	
	27		340.6	
	28		341.0	
	29		340.8	
	30		341.4	
	31		339.4	

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
August	1	1989	339.2	
	2		338.7	
	3		338.0	
	4		339.4	
	5		339.4	
	6		338.1	
	7		339.0	
	8		340.9	
	9		340.5	
	10		340.3	339.4
	11		339.2	
	12		340.6	
	13		340.8	
	14		339.5	
	15		339.0	
	16		338.4	
	17		338.5	
	18		340.0	
	19		340.4	
	20		340.1	339.7
	21		339.8	
	22		340.0	
	23		339.7	
	24		339.7	
	25		339.7	
	26		339.8	
	27		338.8	
	28		338.6	
	29		339.7	
	30		339.7	
	31		340.0	339.6

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
September	1	1989	341.2	
	2		341.6	
	3		340.8	
	4		339.4	
	5		340.6	
	6		340.4	
	7		339.2	
	8		339.6	
	9		340.1	
	10		338.8	340.2
	11		340.2	
	12			
	13			
	14			
	15			
	16		341.0	
	17		339.4	
	18		340.8	
	19		340.6	
	20		341.4	340.6
	21		341.8	
	22		341.6	
	23		341.8	
	24		340.6	
	25		341.4	
	26		341.8	
	27		340.0	
	28		339.8	
	29		339.8	
	30		339.6	340.8

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
October	1	1989	339.0	
	2		339.0	
	3		339.0	
	4		339.6	
	5		340.5	
	6		341.0	
	7		339.6	
	8		340.1	
	9		340.1	
	10		339.8	339.8
	11		339.8	
	12		340.4	
	13		341.2	
	14		341.4	
	15		341.0	
	16		342.9	
	17		342.4	
	18		341.2	
	19		341.3	
	20		341.5	341.3
	21		340.7	
	22		340.3	
	23		339.7	
	24		339.3	
	25		339.7	
	26		339.9	
	27		340.1	
	28		340.7	
	29		340.9	
	30		339.2	
	31		339.3	339.9

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
November	1	1989	340.7	
	2		340.3	
	3		341.4	
	4		340.5	
	5		341.8	
	6		340.9	
	7		341.0	
	8		342.1	
	9		342.6	
	10		342.9	341.4
	11		342.9	
	12		342.4	
	13		342.8	
	14		339.0	
	15		343.0	
	16		343.3	
	17		342.4	
	18		342.9	
	19		343.0	
	20		343.0	342.5
	21		340.7	
	22		340.9	
	23		340.2	
	24		339.8	
	25		339.2	
	26		339.1	
	27		339.1	
	28		340.1	
	29		340.1	
	30		340.4	340.0

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
December	1	1989	342.9	
	2		339.3	
	3		339.7	
	4		339.0	
	5		338.6	
	6		340.1	
	7		341.0	
	8		341.4	
	9		341.6	
	10		341.0	340.5
	11		341.1	
	12		342.0	
	13		341.0	
	14		340.6	
	15		340.6	
	16		340.0	
	17		340.0	
	18		340.5	
	19		340.9	
	20		340.8	340.8
	21		340.8	
	22		340.4	
	23		339.2	
	24		340.0	
	25		339.2	
	26		340.0	
	27		339.2	
	28		339.4	
	29		340.0	
	30		341.0	
	31		341.3	340.0

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
January	1	1990	339.1	
	2		339.6	
	3		339.8	
	4		339.9	
	5		339.2	
	6		339.2	
	7		339.3	
	8		340.0	
	9		340.7	
	10		339.6	339.6
	11		339.6	
	12		339.0	
	13		341.1	
	14		340.6	
	15		340.3	
	16		340.2	
	17		340.6	
	18		340.7	
	19		339.9	
	20		339.3	340.1
	21		340.5	
	22		340.4	
	23		340.6	
	24		340.2	
	25		339.2	
	26		340.0	
	27		341.7	
	28		341.9	
	29		341.0	
	30		341.0	
	31		340.7	340.7

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
February	1	1990	340.0	
	2		340.6	
	3		341.0	
	4		340.5	
	5		340.6	
	6		340.5	
	7		341.2	
	8		342.5	
	9		342.8	
	10		341.6	341.1
	11		341.0	
	12		341.5	
	13		341.2	
	14		341.0	
	15		342.7	
	16		342.9	
	17		343.0	
	18		343.0	
	19		341.0	
	20		341.2	341.9
	21		341.6	
	22		341.6	
	23		342.0	
	24		340.7	
	25		341.0	
	26		341.1	
	27		341.4	
	28		341.1	341.3

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
March	1	1990	341.8	
	2		341.8	
	3		341.5	
	4		341.0	
	5		340.8	
	6		342.0	
	7		341.0	
	8		340.8	
	9		341.0	
	10		340.7	341.2
	11		341.2	
	12		341.8	
	13		342.0	
	14		341.0	
	15		341.6	
	16		341.2	
	17		341.0	
	18		340.4	
	19		340.0	
	20		340.7	341.1
	21		341.2	
	22		341.6	
	23		342.4	
	24		342.1	
	25		342.2	
	26		342.4	
	27		342.2	
	28		341.4	

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
April	1	1990	340.0	
	2		341.5	
	3		343.0	
	4		342.8	
	5		341.0	
	6		341.2	
	7		340.5	
	8		342.2	
	9		342.6	
	10		342.0	341.7
	11		340.5	
	12		341.6	
	13		342.8	
	14		340.2	
	15		339.2	
	16		339.4	
	17		339.2	
	18		341.8	
	19		341.4	
	20		341.6	340.8
	21		340.8	
	22		339.9	
	23		339.6	
	24		340.8	
	25		340.4	
	26		340.0	
	27		340.4	
	28		341.0	
	29		341.0	
	30		340.8	340.5

Month	Day	Year	River Elev. (ft)	10-Day Ave. (ft)
May	1	1990	340.5	
	2		341.5	
	3		342.5	
	4		342.2	
	5		343.2	
	6		343.0	
	7		342.6	
	8		343.2	
	9		343.0	
	10		342.0	342.4
	11		342.2	
	12		338.5	
	13		339.0	
	14		339.2	
	15		341.0	
	16		341.2	
	17		341.1	
	18		341.6	
	19		341.2	
	20		341.8	340.7
	21		341.9	
	22		342.0	
	23		342.0	
	24		342.4	
	25		342.2	
	26		341.5	
	27		342.0	
	28		342.0	
	29		342.5	
	30		341.8	
	31		342.0	342.0

Average Daily Recharge and Production at the North Richland Well Field

Month	Year	Daily Ave. Total Recharge (mg)	Daily Ave. Total Production (mg)	Ratio Recharge: Production
November	1988	2.8	0.81	3.5
December	1988	13.1	5.67	2.3
January	1989	9.8	4.30	2.3
February	1989	6.9	3.18	2.2
March	1989	1.2	0.57	2.1
April	1989	2.9	0.56	5.1
May	1989	8.4	2.50	3.3
June	1989	12.8	6.27	2.0
July	1989	11.8	5.74	2.1
August	1989	10.1	3.34	3.0
September	1989	5.3	1.3	4.1
October	1989	5.5	0.91	6.0
November	1989	6.2	2.14	2.9
December	1989	13.8	6.40	2.2
January	1990	7.5	4.19	1.8
February	1990	2.4	0.22	10.7
March	1990	1.7	0.24	7.3
April	1990	4.9	0.78	6.3
May	1990	5.3	2.79	1.9
Total		132.3	51.91	
Average		7.0	2.7	3.7
Ave. (August through November 1989)		6.8	1.9	4.0

Average Monthly Recharge and Production at the North Richland Well Field

Month	Year	Total Recharge (mg)	Total Production (mg)	Net Recharge (mg)	Ratio Recharge: Production
November	1988	34.5	24.4	60.1	3.5
December	1988	407.0	175.3	231.2	2.3
January	1989	304.0	133.4	170.6	2.3
February	1989	192.0	89.0	103.0	2.2
March	1989	36.3	17.7	18.6	2.1
April	1989	85.9	16.7	69.2	5.1
May	1989	251.0	54.9	196.1	4.6
June	1989	383.9	188.2	195.7	2.0
July	1989	367.0	178.0	189.0	2.1
August	1989	313.1	103.5	209.6	3.0
September	1989	160.1	38.0	122.1	4.2
October	1989	159.3	29.3	141.0	6.0
November	1989	135.3	64.1	121.7	2.9
December	1989	426.7	198.3	228.4	2.2
January	1990	231.0	129.9	101.1	1.8
February	1990	66.1	6.2	59.9	10.7
March	1990	54.0	7.4	46.6	7.3
April	1990	148.3	23.4	124.9	6.3
May	1990	165.4	36.5	78.9	1.9
Average		212.2	82.3	129.9	3.3
Ave. (June 1989 through May 1990)		222.6	37.7	134.9	4.2
Ave. (May through August 1989)		328.8	131.2	197.6	2.9
Ave. (September through November 1989)		171.7	43.5	128.3	4.4

Appendix C

**Water-Elevation Maps for June 1989
and August 1989 Through May 1990**

S9203107.11

S9203107.3

S9203107.5

S9203107.8

S9203107.15

Appendix D

Hydrographs for the Water-Level Monitoring Network

WATER-LEVEL ELEVATIONS

June 1989 - May 1990

— 3000-F Date + 530-E15A

WELL 3000-F (3099-47-18B)

June 1989 - May 1990

WELL 699-S30-E15A

June 1989 - May 1990

WATER-LEVEL ELEVATIONS

June 1989 - May 1990

WELL 699-S32-E13A

June 1989 - May 1990

WELL 699-S31-E13

June 1989 - May 1990

D.7

WELL 699-S29-E12

June 1989 - May 1990

WELL TW17 June 1989 -- May 1990

June 1989 - May 1990

June 1989 - May 1990

June 1989 - May 1990

WELL TW15 June 1989 - May 1990

D.14

June 1989 - May 1990

WELL 699-S23-26

June 1989 - May 1990

D.17

WATER-LEVEL ELEVATIONS

June 1989 - May 1990

WELL EC-1

June 1989 - May 1990

WELL W-1

June 1989 - May 1990

D.20

(ft above 1983 datum)

WELL W-5 June 1989 - May 1990

WELL W-6 June 1989 - May 1990

SAINT WELL

June 1989 - May 1990

WELL 1100-2 (1199-34-13)

June 1989 - May 1990

WATER-LEVEL ELEVATIONS

June 1989 - May 1990

D.27

WELL 699-S41-E13A

June 1989 - May 1990

D.29

Water Level (ft. above msl)

WELL 699-S41-E13B

June 1989 - May 1990

WELL 699-S37-E14

June 1989 - May 1990

WATER-LEVEL ELEVATIONS

June 1989 - May 1990

WELL 3000-D1 (1199-41-13C)

June 1989 - May 1990

WELL 699-S36-E12B

June 1989 - May 1990

WELL 699-S36-E13B

June 1989 - May 1990

D.35

WELL F-2 (3099-45-16)

June 1989 - May 1990

WELL 699-S40-E14

June 1989 - May 1990

WATER-LEVEL ELEVATIONS

June 1989 - January 1990

WELL 1100-D (1199-34-15B)

June 1989 - January 1990

WELL 3000-D5 (3099-42-16)

June 1989 - January 1990

WELL 3000-A (1199-40-15)

June 1989 - January 1990

WELL 3000-B (1199-40-16B)

June 1989 - January 1990

WATER-LEVEL ELEVATIONS

June 1989 - January 1990

WELL 3000-H (1199-40-16C)

June 1989 - January 1990

WELL 3000-C (1199-39-16D)

June 1989 - January 1990

Water Level Elevation (ft. above msl)

WELL 3000-K (1199-38-16)

June 1989 - January 1990

WELL 3000-N (1199-37-16)

June 1989 - January 1990

WATER-LEVEL ELEVATIONS

June 1989 - January 1990

WELL 3000-L (1199-39-16E)

June 1989 - January 1990

WELL 3000-D (1199-39-16C)

June 1989 - January 1990

WELL 3000-J (1199-39-15)

June 1989 - January 1990

WELL 3000-G (1199-41-15)

June 1989 - January 1990

COLUMBIA RIVER @ SWS-1

June 1989 - May 1990

COLUMBIA RIVER @ SNYDER STREET

June 1989 - May 1990

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Plate 1 - Geologic Cross Section A-A'

Plate 2 - Geologic Cross Section B-B'

Plate 3 - Geologic Cross Section C-C'

Plate 4 - Geologic Cross Section D-D'

Plate 5 - Geologic Cross Section E-E'

Plate 1

Saddle Mountains Basalt Formation
with Interbeds of the Ellensburg
Formation (Ti, Tem, and Tel)

Plate 4

Silty Sand
Lithofacies (SS)

and

Yakima River

699-S51-2

Sandy Gravel
Lithofacies (SG)

Gravelly Sand
to Silty Clay
Lithofacies (GS/SC)

Silty Clay
Lithofacies (SC)

Basalt

Saddle Mountains Basalt Formation
with Interbeds of the Ellensburg
Formation (Ti, Tem, and Tel)

Alternating Layers
of Porous and
Hard Basalt

2. Contact Lines

Stratigraphic ————
Major Facies - - - - -
Minor Facies - - - - -
(Queried Where Inferred)

3. Elevation Datum-Mean Sea Level

4. Water Level ▼10/89 ▼ ▼8/89
 Measured Projected Basalt
 Water Water Water
 Level Level Level

5. Well Completion

Well Screen ||| Perforations | Open Hole |

Gray Hard
Basalt

Gray-Green
Clay

699-S30-E15A

3000-F (3099-47-18B)