Chapter 2

Hydrogeology

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1995

Chapter 2: Hydrogeology

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Well Identification and Location Systems

Wells in this report are identified by well log numbers assigned by the Water Resources Department. Each "number" consists of the first four letters of the county in which the well is located and a six-digit number. Wells with more than one well log are assigned the number of the earliest log of record. Wells without logs on file at the Water Resources Department are designated by the letters LUB (Lower Umatilla Basin) and an arbitrary sequence number.

Wells sampled by the Department of Environmental Quality (DEQ) are also identified by a three-character project code (UMA) and a three-digit number. Cross references are made in appendix A.

Well locations in this report are based on the public land survey system. Each location is designated by listing land tracts of descending size (Figure 2.1). For example, the well location 4N/28E-11aab indicates a well within township 4 north, range 28 east (36 square miles), section 11 (1 square mile). The first letter following the section (a) represents the quarter section (160 acres), the second letter (a) the quarter-quarter section (40 acres), and the third letter (b) the quarter-quarter-quarter section (10 acres).

Locations of geographic features are also referenced to the public land survey system but, following convention, are designated by land tracts of increasing size. For example, the notation NW/NE/NE 11-4N/28E indicates a feature in the northwest quarter (10 acres) of the northeast quarter (40 acres) of the northeast quarter (160 acres) of section 11 (1 square mile) in township 4 north, range 28 east (36 square miles).

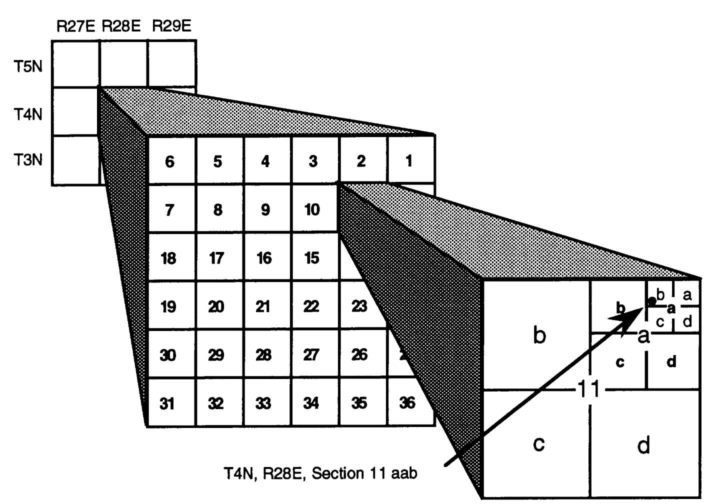


Figure 2.1 Well location system

Abstract

The Lower Umatilla Basin study area encompasses about 550 square miles of northern Morrow and Umatilla counties between Willow Creek, Cold Springs Reservoir, and the Columbia River. The area is drained by the Umatilla River, Butter Creek, and the Columbia River.

The Umatilla Basin is a topographic and structural trough between the Columbia Hills of Washington and the Blue Mountains of Oregon. The Dalles-Umatilla syncline, which forms the axis of the trough, is roughly coincident with the Columbia River between Arlington and Umatilla, Oregon. The basin and surrounding highlands are underlain by a thick sequence of Columbia River Basalt flows which are locally deformed by faults and folds. Up to 250 feet of alluvial sediments overlie the basalt flows near the basin axis.

A shallow unconfined to locally confined aquifer occurs in the alluvial sediments of the Umatilla basin. Multiple confined aquifers occur in the underlying basalt flows. The alluvial aquifer and shallow basalt aquifers are the main sources of domestic water for rural residents of the area. The alluvial aquifer is also a major source of municipal water for the cities of Hermiston, Irrigon, and Boardman and, an important source of irrigation water in local areas. Deeper basalt aquifers are major sources of irrigation water in many areas of the basin.

The principal water-producing zones of the alluvial aquifer occur in sands and gravels deposited by catastrophic floods during the Pleistocene Epoch. Flood sands and gravels occur in broad tracts of varying thickness or as thin beds encased in silts or clays. The main productive areas occur in three east to northeast-trending shallow troughs which are largely filled with coarse sands and gravels. Thin sand and gravel beds also produce moderate quantities of water in areas of the aquifer which are dominated by silt and fine-grained sand.

The available evidence indicates that water readily infiltrates the soils of the basin and travels rapidly through the unsaturated silts, sands, and gravels which overlie the alluvial aquifer. Therefore, the aquifer is highly susceptible to contamination from activities at the land surface.

The principal source of recharge to the alluvial aquifer comes from leaking canals and ditches. Additional recharge comes from applied irrigation water. Irrigation recharge is probably highest in areas irrigated by flooding but also occurs in areas irrigated by center pivots. In local areas, leakage from reservoirs and streams is an important source of recharge. Recharge from precipitation is minimal. The volume of recharge to the alluvial aquifer will decrease over time as irrigation districts and individual farmers implement water conservation measures.

Regional flow in the alluvial aquifer is to the northwest with discharge to the Umatilla and Columbia rivers; however, flow directions vary considerably over space and time. Flow is influenced by the "topography" of the underlying basalt, by seasonal pumping of high-capacity wells, and by seasonal recharge from

leaking canals. Seasonal reversals of flow are documented beneath the southern one-half of the Umatilla Ordnance Depot and may occur elsewhere.

Average flow velocities in the alluvial aquifer may be as low as 0.0001 miles per year (0.002 feet per day) in the silts and silty sands and as high as 0.50 miles per year (8 feet per day) in the sands and gravels. Net displacement of water over a year's time may be considerably less because of seasonal variations in hydraulic gradients and flow directions.

Total pumpage discharge from the alluvial aquifer is estimated between 65,000 and 98,000 acre-feet per year. In the Ordnance area, pumpage has contributed to periodic water-level declines, including a decline which spans from 1986 to 1993. Pumpage near the Columbia River, between Boardman and Umatilla, is buffered by recharge from the river. Groundwater supplies in this area are relatively unlimited but are developed at the expense of the Columbia River. Additional pumpage capacity probably exists in the Hermiston area but excess capacity will likely be diminished by water conservation projects in the Hermiston and Stanfield irrigation districts.

Water-bearing zones within shallow Columbia River basalt flows are limited to thin breccia or fracture zones at the top or base of individual flows. The dense interiors of flows are relatively impermeable and confine groundwater to discrete tabular aquifers. Existing data indicate that permeabilities in the breccia zones are moderately high and storage capacities are low.

The geometry of the shallow basalt aquifers indicates that they are hydraulically connected to the alluvial aquifer and the Columbia River. Recharge is mostly from the alluvial aquifer but some recharge may be induced from the Columbia River by pumping.

Groundwater flow directions in the shallow basalt aquifers are parallel to the regional dip of the basalt flows, which is northerly toward the Columbia River throughout most of the study area. Discharge is to the Columbia River.

Because recharge to the shallow basalt aquifers is from the alluvial aquifer and the Columbia River, water quality in the shallow basalt aquifers is related to quality of water in these sources.

The lack of deep seals in many wells probably allows water from the alluvial aquifer to migrate downward to aquifers in the underlying basalt flows. The commingling of basalt aquifers through open boreholes also provides a pathway by which water can migrate from shallow to deeper basalt aquifers. These pathways may be responsible for some of the contamination that is found in the shallow basalt aquifers.

Chapter 2 : Hydrogeology

Introduction

A shallow unconfined to locally confined aquifer occurs in the alluvial sediments of northern Morrow and Umatilla counties between the cities of Boardman, Umatilla, and Echo. Multiple confined aquifers occur in basalt flows which underlie the sediments. The alluvial aquifer and the upper two or three basalt aquifers are the principal sources of domestic groundwater in the basin. The alluvial aquifer is also the primary source of municipal water for Boardman and a major source for Hermiston and Irrigon. In local areas, the alluvial aquifer is also developed as a source of irrigation water. Deeper basalt aquifers are major sources of irrigation water in the area and serve as important sources of municipal water for Hermiston and Irrigon. The deeper basalt aquifers are the sole source of municipal water for Echo, Stanfield, and Umatilla.

During the 1980s and early 1990s, widespread nitrate contamination was found in wells that produce water from the alluvial aquifer and shallow basalt aquifers. Nitrate levels in many of the wells exceeded state and federal drinking water standards. This report characterizes the hydrogeology of these shallow contaminated aquifers.

Purpose and Scope of Work

The primary purpose of this investigation is to provide a framework for understanding how contaminants enter and travel through shallow aquifers in the Lower Umatilla Basin. This is accomplished by describing the geometry, hydraulic properties, recharge sources, and flow systems of the various aquifers. A secondary purpose of the study is to evaluate groundwater supplies in the shallow aquifers.

Previous Investigations

Geologic field investigations that encompass all or part of the study area include those by Bretz (1925, 1928), Allison (1933), Hogenson (1964), Newcomb (1967), Robison (1971), Walker (1973), and Swanson and others (1981). Site-specific geologic field studies within the study area include those by Portland General

Electric (1973), Shannon and Wilson (1972a, 1972b, 1973a, 1973b, 1973c), Bechtel (1973), and McCall (1975).

Regional geologic reports or compendiums which are pertinent to the Lower Umatilla Basin include Bretz (1925, 1928, 1929, 1969), Bretz and others (1956), Newcomb (1966, 1967, 1970), Baker and Nummendal (1978), Farooqui and others (1981), Waitt (1985), Schuster (1987), and Reidel and Hooper (1989). General overviews of the regional geology are presented by Allen and others (1986) and Orr and others (1992).

A variety of hydrogeologic studies include all or part of the Lower Umatilla Basin. Wagner (1949) summarized the early use of groundwater in Morrow and Umatilla counties and compiled drillers' logs for early wells. Newcomb (1959, 1961) described the general features which control groundwater occurrence in Columbia River Basalt flows. The first comprehensive study of groundwater in the Umatilla Basin was produced by Hogenson (1964), who mapped the general geology, compiled water well data, and summarized groundwater occurrence by geologic unit. Robison (1971) modified and extended Hogenson's geologic map and summarized the hydrology of aquifers within the Columbia River Basalt Group. A recent inventory of wells and water levels are reported by Davies-Smith and others (1983).

The geologic framework of regional aquifers in eastern Oregon and Washington is characterized by Drost and others (1990). A digital model which simulates regional groundwater flow in the Umatilla Plateau and Horse Heaven Hills area of Oregon and Washington is described by Davies-Smith and others (1988).

The Oregon Water Resources Department (WRD) has published several reports on groundwater in selected portions of the Umatilla Basin. Sceva (1966) and McCall (1975) discuss water-level declines in saturated sands and gravels in the vicinity of the Umatilla Ordnance Depot. Artificial recharge of these sediments is described and evaluated by Miller (1985). Additional reports document declining water levels in basalt aquifers near Ordnance (Sceva, 1966; McCall, 1975); in the Butter Creek-Hermiston area (Bartholomew, 1975; Norton and Bartholomew, 1984); in the vicinity of Ella Buttes (Zwart, 1988); and in the Hermiston-Stanfield-Echo area (Zwart, 1990).

Numerous site-specific groundwater studies have been conducted throughout the study area. Most are unpublished reports available on file at the Water Resources Department or at the Department of Environmental Quality (DEQ). A brief list by geographical locality follows.

Carty Reservoir and vicinity (2N/24E and 3N/24E):
- Shannon and Wilson (1972a, 1973a)
- Bechtel (1973)
- Portland General Electric (1993)

Finley Buttes (2N/26E and 3N/26E)
- David J. Newton Associates, Inc. (1990, 1991)
- Finley Buttes Landfill Company (1992)

Boardman/Irrigon area (5N/26E)
- CH2M Hill (1975)
- CH2M Hill (1992a)
- Cascade Earth Sciences (1992a, 1992b, 1993)

Umatilla Ordnance Depot (5N/27E):
- Dawson (1982)
- Century Environmental Sciences (1986)
- Dames & Moore (1992, 1994a, 1994b)

Butter Creek drainage:
- Sweet-Edwards/EMCON (1990)
- EMCON Northwest (1992)
- CH2M Hill (1991, 1992b, 1992c)
- Lamb-Weston (1992)

Umatilla River drainage between Echo and Hermiston:
- Applied Geotechnology, Inc. (1993)
- Sweet, Edwards & Associates (1983, 1985, 1987)
- Cascade Earth Sciences (1992c)
- EMCON Northwest (1992)
- Cascade Earth Sciences (1992d)

Hermiston Airport area:
- Cascade Earth Sciences (1990, 1991)

Cold Springs Reservoir:
- Acree (1988)

Investigative Methods

A large body of geologic and hydrologic information exists concerning the Umatilla Basin. Some of this information is readily available in published reports but much of it resides in scattered unpublished reports and files at various government agencies. Every attempt was made to compile and review as many sources of relevant information as possible. A considerable amount of data from unpublished reports was used to augment data collected during the investigation.

A geologic map for the study area (Plate 2.2) was compiled based on maps by Hogenson (1953, 1964), Robison (1971), Walker (1973), Shannon and Wilson (1973b), and Swanson and others (1981). The map was modified during the investigation based on reconnaissance field mapping and air photo interpretations.

Drill cuttings from 10 water wells were examined to determine the nature of geologic units in the sub-surface and to interpret the descriptions of geologic materials by well drillers. In addition, descriptions on water well logs were systematically compared to descriptions on the geologic drill logs of nearby monitoring wells. This information was used to construct geologic cross sections to show the distribution of geologic units in the subsurface.

Over 700 wells were used as the principal data set for the investigation. Only wells with well logs and reliable locations were included in the set. Approximately 230 of the study wells are monitoring wells with surveyed locations and elevations. Locations for the remaining wells were determined by several methods. Approximately 180 wells were field-located on 7.5-minute topographic maps during the investigation. Another 200 were field-located during earlier WRD investigations. Locations for an additional 30 wells were obtained from 7.5-minute maps in unpublished reports at WRD or DEQ. About 90 well locations were determined by plotting surveyed coordinates from WRD water rights files onto 7.5-minutes maps. Land surface elevations for non-monitoring wells were estimated from contours on 7.5-minute maps.

Locations for surveyed monitoring wells are probably accurate to ±10 feet; elevations are probably accurate to several tenths of a foot. The accuracy of locations for wells which were physically sited during the study is estimated to be ±50 feet; elevation accuracy is estimated to be ±5 feet. The accuracy of locations and elevations for the remaining wells may be less precise.

Approximately 130 field-located wells were selected for periodic water-level measurements. Historical water levels, spanning from 2 to 40 years, were available for about 40 of these wells. Water levels were also compiled for approximately 230 monitoring wells with periods of records ranging from 1 to 10 years. Many of the monitoring wells have been measured monthly or quarterly over the last 3 to 4 years.

Seasonal variations in water levels were documented using reported water levels for monitoring wells. In addition, digital water-level recorders were installed in several wells to monitor seasonal changes in water level caused by irrigation practices, climatic events, and the pumping of wells. Recorder hydrographs were also available for 4 wells on the Umatilla Ordnance Depot. Selected hydrographs are shown in figures throughout the text.

In order to develop a regional picture of groundwater levels at specific times, approximately 120 field-located wells were measured during three 10-day synoptic rounds conducted in February 1991, August 1991, and February 1992 (Appendix 2.B). Reported water levels from monitoring wells were used to augment synoptic measurements if they were made within 2 weeks of the synoptic rounds. The rounds were timed to occur before and near the end of the irrigation season. The February 1991 data set was used to contour the water table for the alluvial aquifer (Plate 2.4).

One aquifer test was conducted to determine the hydraulic properties of the alluvial aquifer (Appendix 2C. The results of other aquifer tests were compiled for comparison.

Plate 2.1 shows the locations of selected wells and illustrates the various kinds of data associated with each well.

Acknowledgements

Many residents in the study area generously provided access to their wells for periodic water-level measurements and displayed great interest in the groundwater resources of the basin. Special thanks go to Don and Jim Key for allowing the author to instrument one of their wells with a continuous recorder and for allowing an aquifer test to be conducted on a nearby well. Additional thanks go to Sam Godwin, W. Bryan Wolfe, and the Oregon Department of Transportation for allowing continuous recorders to be installed in their wells for extended lengths of time.

Jerald Rea of the Port of Morrow, Jeff Lyon of Simplot, Mike Henderson of Lamb-Weston, and Lance Horn of A. E. Staley Manufacturing provided valuable assistance by coordinating well measurement schedules to coincide with synoptic rounds and, by providing well and water-level data to the author. Thanks also go to Don Eppenbach of the City of Irrigon for providing access to city monitoring wells and to Barry Beyeler of the City of Boardman for providing information on the city's Ranney collector and wellhead demonstration project. Particular thanks are given to Dr. Charles Lechner of the Army Environmental Center for providing electronic files of water-level measurements and copies of reports for ongoing investigations at the Umatilla Ordnance Depot.

Generous assistance was provided by many professional colleagues at WRD and DEQ during the course of this study. Doug Woodcock began the original investigation, was responsible for the initial planning, and participated in much of the field work. Sarah Gates, Jan Koehler, and Ken Lite also helped with the field work. The draft report was reviewed by Jerry Grondin, Donn Miller, Ken Lite, Marc Norton, and Doug Woodcock. Special acknowledgement is also given to members of WRD's Geographic Information System Section. Ken Rauscher developed the original programs for preparing digital cross sections and was responsible for the research, design, and layout of many of the preliminary maps. Mike Ciscell prepared many of the final maps and served as a consultant for data analysis and map layout.

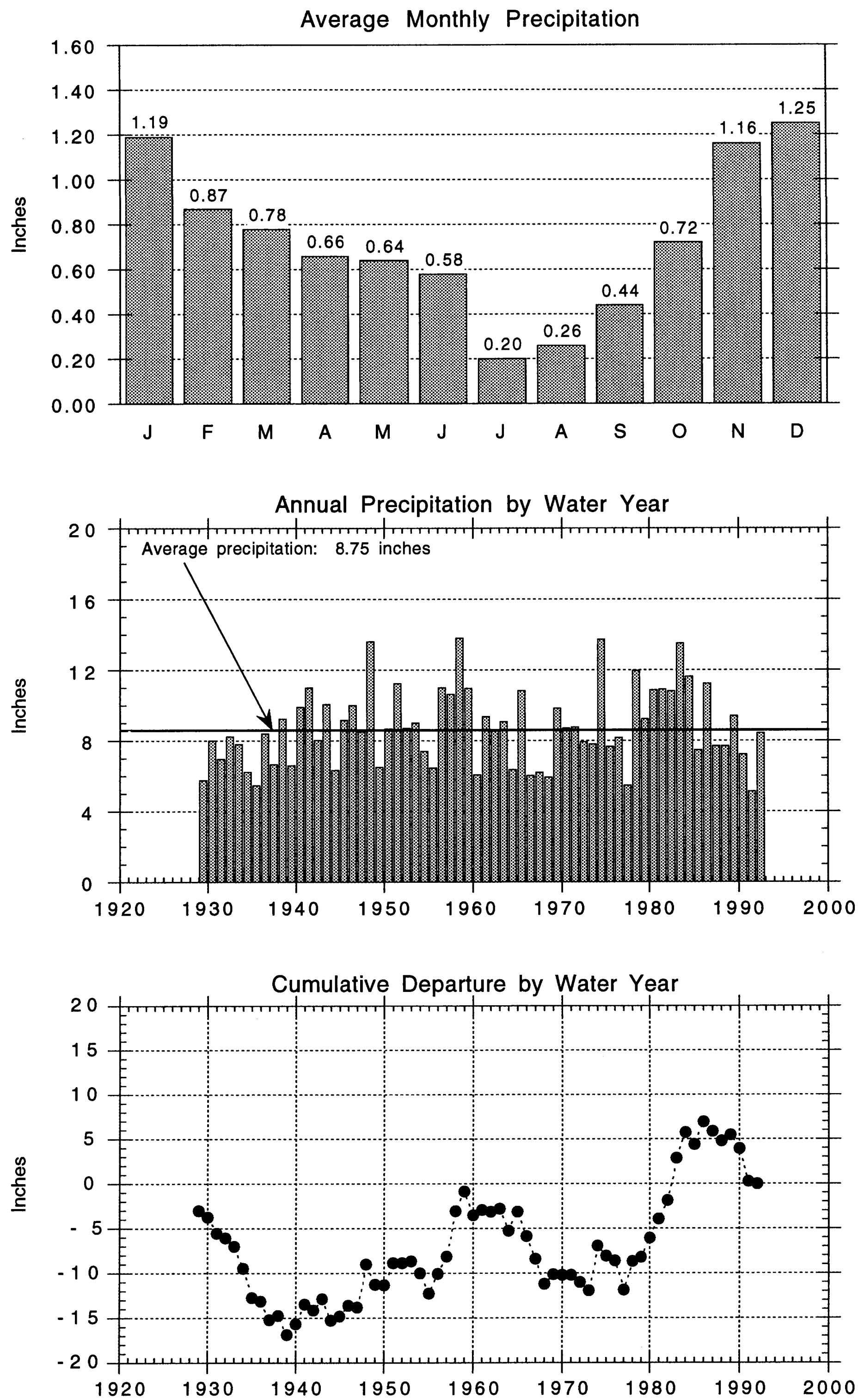


Figure 2.2 Precipitation at the Hermiston airport weather station: monthly, annual, and cumulative departure (1928-1992)

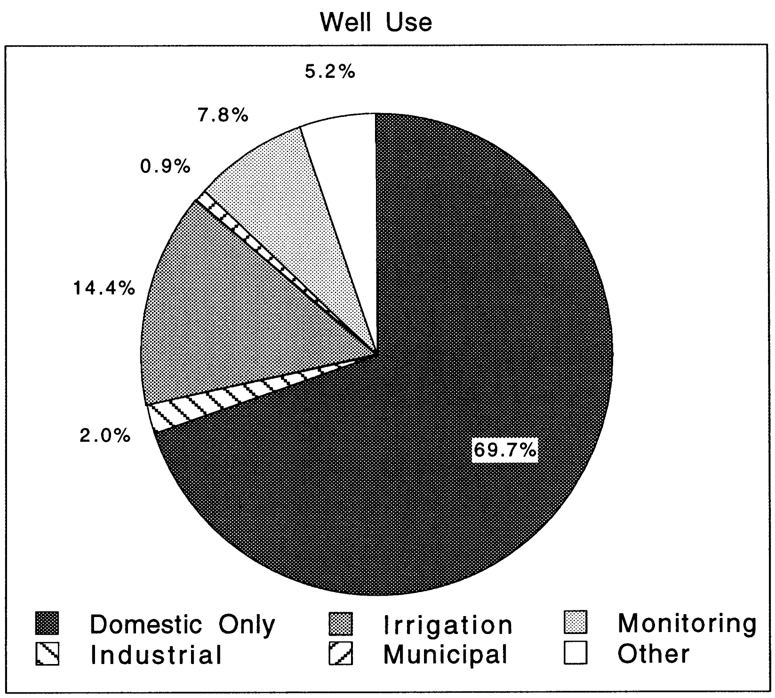
Geography and Climate

The Lower Umatilla Basin study area occupies about 550 square miles of northern Morrow and Umatilla counties between Willow Creek, Cold Springs Reservoir, and the Columbia River (Plate 2.1). The area is part of the Umatilla Lowlands, a portion of the Deschutes-Columbia Plateau physiographic province that is adjacent to the northern foothills of the Blue Mountains (Hogenson, 1964; Orr and others, 1992). The basin is drained by the Umatilla River, Butter Creek, and the Columbia River.

Most of the study area occupies an undulating, northward-sloping plain that lacks an integrated drainage system. Elevations on the plain range from 250 feet near the Columbia River to 750 feet at its southern margin. South of the plain, dissected hills rise to elevations above 1200 feet. Shallow canyons drain the hills but generally do not continue across the plain to the north. Ephemeral streams from the hills generally infiltrate the ground within a short distance of the base of the hills.

The Lower Umatilla Basin has a semiarid climate characterized by hot dry summers and cool moist winters. Annual precipitation varies with elevation and ranges from about 8 inches near the Columbia River to about 10 inches near the southern study boundary (based on data from Johnsgard, 1963).

Average precipitation by water year (October through September) is 8.75 inches at Hermiston, a figure considered typical for most of the study area (Figure 2.2). About 70% of the yearly total occurs during the months of October through March. Most of the total falls as rain but snowfall is significant in some years. Precipitation trends are shown by plotting cumulative departure from the long-term average (Figure 2.2). Rising trends indicate periods of above average precipitation; falling trends indicate periods of below average precipitation. A notable rising trend occurred between 1978 and 1986, followed by a declining trend through 1992.



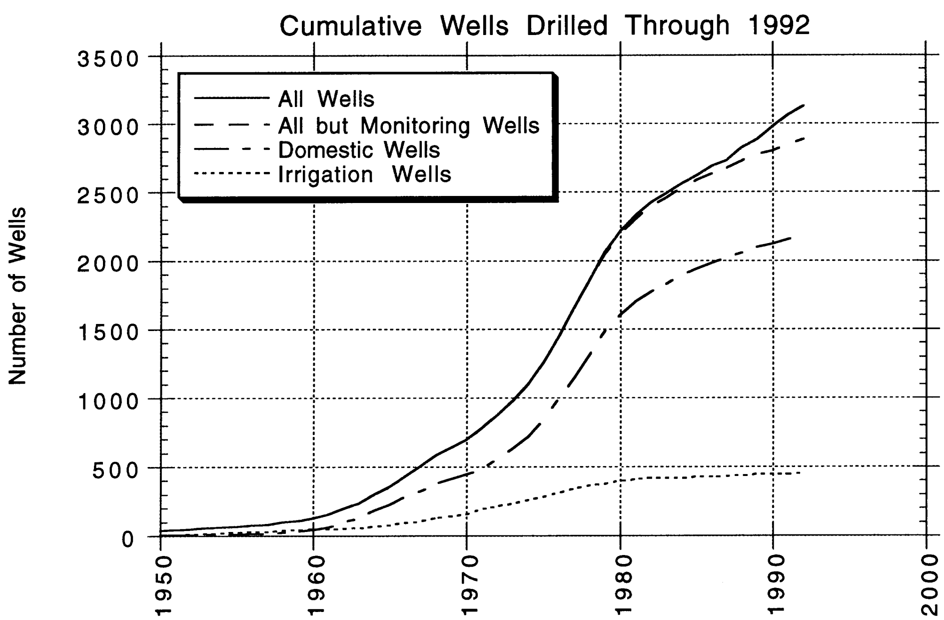


Figure 2.3 Well use and cumulative wells drilled through 1992

Groundwater Development

Well log files at the Water Resources Department indicate that 3130 wells (all aquifers) have been drilled in the study area through the end of 1992. The distribution of wells is shown on Plate 5. Domestic wells account for 70% of the wells in the basin, followed by irrigation wells at 14% (Figure 2.3). Although 2183 domestic well logs are on file, a Department of Environmental Quality survey shows a total of 4375 rural septic systems (Jerry Grondin, DEQ, personal communication). Assuming one domestic well per septic system, this suggests that the state has records for only 50% of the domestic wells in the area.

A cumulative graph of wells drilled over time (Figure 2.3) reflects the history of groundwater development in the study area. Prior to 1960, groundwater use was relatively stable and largely limited to stock, domestic, and municipal wells. Between 1960 and 1980 groundwater was extensively developed as a source for irrigation water. Few irrigation wells have been drilled since 1980 because of water-use restrictions triggered by declining water levels in many aquifers. Use of groundwater for domestic purposes has increased significantly since 1960 and is likely to increase in the future. Changes in the slope of the cumulative curve for domestic wells probably reflect changes in economic conditions and changes in the rate of rural population growth. Concerns about aquifer contamination have resulted in the drilling of several hundred monitoring wells since the early 1980s, including about 125 on the Umatilla Ordnance Depot.

Geologic Unit*						Hydrogeologic Unit
System	**Series**	**Group**	**Formation**	**Age (m.y.)**	**Member or Unit**	**Aquifer or Confining Bed**
Quaternary	Holocene		Surficial Sediments		Wind-blown Silt and Sand	Alluvial Aquifer
Quaternary	Holocene		Holocene Alluvium		Alluvial Flood Plain Sediments	Alluvial Aquifer
Quaternary	Pleistocene		Catastro-phic Flood Deposits	.013 - ?	Fine-grained Sediments / Coarse-grained Sediments	Alluvial Aquifer
Tertiary	Pliocene				*Erosional Unconformity*	Alluvial Aquifer
Tertiary	Pliocene		— ? — ? — Alkali Canyon — ? — ? —		Undifferentiated Sediments	Alluvial Aquifer
Tertiary	Miocene				*Local Erosional Unconformity*	Alluvial Aquifer
Tertiary	Miocene	Columbia River Basalt Group	Saddle Mountains Basalt	10.5	Elephant Mountain Basalt	*Confining Bed*
Tertiary	Miocene	Columbia River Basalt Group	Saddle Mountains Basalt	10.5	Rattlesnake Ridge Interbed†	Basal Elephant Mountain Aquifer
Tertiary	Miocene	Columbia River Basalt Group	Saddle Mountains Basalt	12	Pomona Basalt	*Confining Bed*
Tertiary	Miocene	Columbia River Basalt Group	Saddle Mountains Basalt	12	Selah Interbed†	Basal Pomona Aquifer
Tertiary	Miocene	Columbia River Basalt Group	Saddle Mountains Basalt		Umatilla Basalt	*Confining Bed*
Tertiary	Miocene	Columbia River Basalt Group	Saddle Mountains Basalt		Mabton Interbed†	Basal Umatilla Aquifer
Tertiary	Miocene	Columbia River Basalt Group	Wanapum Basalt	14.5 - 15.6	Undifferentiated Columbia River Basalt	*Confining Bed* / Undifferentiated Columbia River Basalt Aquifers
Tertiary	Miocene	Columbia River Basalt Group	Grande Ronde Basalt	15.6 - 16.5	Undifferentiated Columbia River Basalt	Undifferentiated Columbia River Basalt Aquifers

*Modified from Tolan and others, 1989 †Ellensburg Formation

Figure 2.4 Comparison of geologic and hydrogeologic units

Geologic Framework

The Umatilla Basin is a topographic and structural trough between the Columbia Hills of Washington and the Blue Mountains of Oregon. The axis of the trough is roughly coincident with the Columbia River between Arlington and Umatilla, Oregon. The basin and surrounding highlands are underlain by multiple basalt flows which are locally deformed by faults and folds. Up to 250 feet of sediments overlie the basalt flows near the basin axis.

The Umatilla Basin is a part of the Columbia Plateau, a regional downwarp between the Rocky mountains and the Cascade Range. The basin lies at the southern margin of the Yakima Fold Belt, a portion of the Columbia Plateau characterized by east-west trending anticlinal ridges and synclinal basins (Reidel and others, 1989).

From oldest to youngest, the principal stratigraphic units in the basin are the Columbia River Basalt Group, the Ellensburg Formation, the Alkali Canyon Formation, and Pleistocene catastrophic flood deposits (Figure 2.4). Thin deposits of Holocene Alluvium occur in the lower drainages of the Umatilla River and Butter Creek and a veneer of windblown (aeolian) silt and sand overlies most of the lower portion of the basin. The major structures of the basin (Plate 2.2) are the Dalles-Umatilla Syncline, a structural trough which forms the axis of the basin, and the Service Anticline, a north-south trending fold and fault complex which is aligned with Umatilla, Hermiston, and Emigrant Buttes. The distribution of geologic units and structural features is shown on the geologic map and sections of Plates 2.2 and 2.3.

Stratigraphic Units

Columbia River Basalt Group and Interbedded Ellensburg Formation

Between 17.5 and 6.0 million year ago, large outpourings of fluid basaltic lava flooded the Columbia Plateau. The resulting lava field is collectively known as the Columbia River Basalt Group (Swanson and others, 1975). Most of the lavas were extruded from linear vents in eastern Washington and Oregon, and western Idaho. Many of the eruptions released tremendous volumes of lava over short periods of time. The resulting flows advanced as sheetfloods which obliterated the pre-eruption topography over vast areas. Smaller flows also occurred but were restricted to river drainages and topographic lows. In general, the volume and frequency of eruptions diminished over time. In some instances, the time interval between eruptions was long enough to allow sediments to accumulate in low-lying areas. The resulting sedimentary interbeds are formally assigned to the Ellensburg Formation.

Throughout the eruptive history of the basalts, the central portion of the Columbia Plateau was subsiding and the Blue Mountains were rising (Reidel and others, 1989). In general, this influenced the regional distribution of lavas by preventing younger flows from travelling as far to the south as older flows. Thus, the total thickness of the lava field decreases from north to south. Within the Yakima Fold Belt, the distribution of flows was also influenced by faults and folds which were developing at the same time the basalt flows were being emplaced. The age, volume, and regional distribution of the principal basalt units are presented by Tolan and others (1989) and Reidel, Tolan, and others (1989) and summarized in Orr and others (1992).

Three formations of the Columbia River Basalt Group occur in the Umatilla basin. From oldest to youngest these are the Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Each formation is composed of multiple members and each member consists of one or more individual lava flows. Within the basin, the total thickness of the basalts is probably at least 5000 feet and may exceed 10,000 feet (Davies-Smith and others, 1988). In contrast, the deepest well in the study area (UMAT 5450) penetrates 1275 feet of basalt.

Grande Ronde and Wanapum flows are exposed on Service Buttes, several miles south of the study area. Wanapum flows are also exposed on the western bluffs of the Umatilla River near Echo and immediately east of the study area in Cold Springs Canyon, Despain Gulch, and Stage Gulch (Swanson and others, 1981). Both units occur at depth in the study area and are principally developed as sources of irrigation water. Neither unit is differentiated on the maps and cross sections of this report.

Saddle Mountains Basalt occurs at or near land surface throughout most of the study area. Aquifers within these lavas are common sources of water for domestic wells. Three members occur in the study area, each consisting of a single flow. From oldest to youngest, these are the Umatilla, Pomona, and Elephant Mountain basalts. Sedimentary interbeds are common at the base of these lavas but the distribution of sediments is uneven across the basin. Interbeds were not mapped at the surface but are shown on the geologic sections of Plate 2.3. General features of each member and its associated interbed are summarized below.

Umatilla Member

The Umatilla Member occurs in the study area as a medium-to-dark gray, aphyric (lacking visible crystals) basalt that ranges up to 100 feet thick. The flow is exposed in a narrow strip that parallels the Columbia River from about two miles east of McNary Dam to beyond the eastern boundary of the study area. At Hat Rock State Park, the Umatilla forms the brim of the hat. A twenty-foot thick, porous, brecciated flow top, overlain by Pomona basalt, is exposed at an elevation of 430 feet in an old railroad cut just west of the park (NW/NW 15-5N/29E), adjacent to the Columbia River. The base of the flow is also exposed in the bed of the Columbia River near the park.

The top of the Umatilla flow is also exposed in a limited area at the northern base of Hermiston Butte at an elevation of 460 feet. No other exposures occur within the study area but Swanson and others (1981) map limited exposures in Cold Springs Canyon, about 2 miles east of Cold Springs Reservoir, and on the north side of Despain Gulch, in sections 16 and 17 of 4N/30E. At both localities, the base of the flow occurs at an elevation of about 700 feet.

East of Service Anticline, outcrop patterns of the Umatilla flow, and flows of the immediately underlying Wanapum Basalt, indicate that the southern limit of the Umatilla flow occurs in a northeast-trending zone just north of the city of Echo. A northeast-trending ridge, defined by structure contours on the top of the Columbia River Basalt Group (Plate 2.2), is interpreted as the approximate southern margin of the flow.

No exposures of the Umatilla member occur west of Service Anticline in Oregon, but the flow is exposed at various localities west of the anticline along the Washington side of the Columbia River. This suggests that the formation of the Service Anticline predates the Umatilla flow. Data from the current investigation were insufficient to confirm or deny the subsurface occurrence of the Umatilla Basalt in Oregon west of the anticline. Geologic mapping by Swanson and others (1981) shows that the Umatilla Basalt is breached in the bed of the Columbia River immediately west of the study area.

Selah Interbed

The Selah interbed consists of vitric tuffs (fine glassy volcanic ash) and weakly indurated siltstones and sandstones which accumulated in river channels and flood plains prior to the eruption of the Pomona basalt (Schmincke, 1967; Smith and others, 1989). On drillers' logs, Selah sediments are commonly described as blue or green clay. The Selah interbed does not occur east of the Service Anticline. West of the anticline, the Selah is thin to nonexistent near the southern margin of the study area, but thickens toward the Columbia River. The Selah also thickens dramatically from east to west along the Columbia River. Near the city of Umatilla, the Selah is about 15 feet thick; near Boardman, it is about 150 feet thick.

Pomona Member

The Pomona Member is a light-to-medium gray basalt characterized by slender (6 to 12 inch diameter) undulating columns, sparse phenocrysts (macroscopic crystals) of olivine and plagioclase, and scattered glomerocrysts (clusters of macroscopic crystals) of olivine, plagioclase, and clinopyroxene. Outcrop and subsurface data indicate a maximum thickness of about 150 feet.

The Pomona is widely exposed at land surface east of Service Anticline. East of the city of Umatilla, it crops out in a wide band on both sides of highway 730. At Hat Rock State Park, erosional remnants of the Pomona form the "hat" and "boat" of Hat Rock and Boat Rock. Immediately west of the park, the base of the Pomona is at about 430 feet elevation and its eroded top is at 510 feet elevation. Three miles to the south, the top of the flow is exposed at elevations above 650 feet along the northern shore of Cold Springs Reservoir. In several isolated alluvial valleys immediately southwest of Hat Rock State Park, the Pomona has been completely stripped away by erosion (Plate 2.2 and cross section E-E', Plate 2.3). Outcrop patterns show that the Pomona dips gently to the west along the Columbia River. The base of the flow reaches river level at about 1.5 miles east of McNary Dam.

Umatilla Butte is wholly composed of Pomona basalt. The Pomona also occurs as erosional "islands", surrounded by alluvial sediments, along the crest of the Service Anticline, from Hermiston Buttes to Emigrant Buttes. At Hermiston Butte, the eroded top of the Pomona is at 610 feet elevation and the base is at 480 feet elevation — a total exposed thickness of 130 feet. Immediately north and south of the butte, sediments occur from land surface to depths of 80 feet in an area where the Pomona has been completely removed by erosion. The Pomona has also been removed by erosion in the Umatilla River valley where the valley crosses the Service Anticline.

The southernmost exposure of Pomona Basalt east of Service Anticline occurs at Emigrant Buttes, where the top of the flow is at about 750 feet elevation. Outcrop patterns indicate that the southern margin of the Pomona flow occurs in a northeast-trending zone between Emigrant Buttes and Cold Springs Reservoir. A northeast-trending ridge, defined by structure contours on the top of the Columbia River Basalt (Plate 2.2), is interpreted as the approximate southern margin of the flow north of the Umatilla River.

West of Service Anticline, the upper surface of the Pomona is exposed beneath the southwestern arm of Carty Reservoir. It is also exposed as a north-trending dip slope in the floor of the Umatilla River between Three Mile Dam and the Columbia River. Outcrop relationships indicate that the southern margin of the Pomona Basalt occurs in an east-west zone roughly coincident with the boundary between townships 2N and 3N. The location of this margin (not shown on Plate 2.2) is well documented in the Carty Reservoir area (Shannon and Wilson, Inc., 1972a) but is poorly constrained to the east. Outcrop patterns in Washington indicate that the Pomona is breached in the bed of the Columbia River between Crow Butte Island and the western boundary of the study area (Swanson and others, 1981).

Rattlesnake Ridge Interbed

The Rattlesnake Ridge interbed is a deposit of silt, clay, and vitric tuff that underlies the Elephant Mountain basalt throughout most of the study area. On drillers' logs it is commonly described as blue or green clay. The thickness of the interbed is commonly less than 10 feet but ranges up to 30 feet. Systematic variations in thickness were not observed.

Elephant Mountain Member

The Elephant Mountain Member is a single, dark grey or black, aphyric basalt flow. The flow is widespread west of Service Anticline but is not found to the east. Good exposures occur between Boardman and Willow Creek along the

Columbia River. South of this area, the flow is covered by up to 150 feet of alluvial sediments or wind-blown silts and sands. Near the Columbia River, the Elephant Mountain ranges from 70 to 80 feet thick. Near its southern margin, roughly coincident with the southern boundary of the study area, the flow thins to less than 40 feet thick.

In places, the Elephant Mountain Basalt and the underlying Rattlesnake Ridge interbed are breached by troughs which rest on the upper surface of the Pomona Basalt (Plates 2.2 and 2.3). In most instances, the troughs are filled with Pleistocene catastrophic flood sediments which obscure the underlying basalt flows. Many of the troughs are coincident with stream drainages and appear to be caused by stream erosion after the emplacement of the Elephant Mountain flow, but before the deposition of the flood sediments. Examples occur in the lower Umatilla River valley between Butter Creek and the Columbia River and, in Sixmile Canyon north of Carty Reservoir. Similar erosional troughs are expected where the northern drainages of Juniper Canyon and Sand Hollow are obscured by a cover of catastrophic flood deposits as they exit from the dissected hills to the south. The drainage areas of these valleys are similar in size to the drainage area of Sixmile Canyon. This suggests that pre-modern streams in these drainages also cut into the surface of the Elephant Mountain basalt prior to the deposition of the the flood sediments. However, the occurrence of troughs in these areas could not be confirmed because of the lack of wells.

The Elephant Mountain flow is also breached by an east-west trough which occurs along the southern border of the Umatilla Ordnance Depot (Plate 2.2 and cross section C-C', Plate 2.3). The origin of this feature is obscure, since it is not directly associated with any modern drainage, but its morphology suggests that it is also an erosional feature.

The Columbia River breaches the Elephant Mountain flow in several places along the Dalles-Umatilla Syncline where the base of the flow rises above the level of the river. One breached section occurs between the mouth of the Umatilla River and section 16 of 5N/27E. A second occurs just west of Crow Butte Island.

Alkali Canyon Formation

The Alkali Canyon Formation consists of tuffaceous silts and sands and moderately indurated gravels which were shed from the rising Blue Mountains in late Miocene and Pliocene times (Farooqui and others, 1981; Smith and others, 1989). Within the study area, these deposits have also been mapped as Pliocene fanglomerate (Hogenson, 1964; Robison, 1971) or as the Dalles Formation (Newcomb, 1966; Shannon and Wilson, 1972a).

In the Lower Umatilla Basin, Alkali Canyon sediments form a wedge-shaped deposit that is exposed between elevations of 750 and 1500 feet. The wedge attains a thickness of 250 feet near its northern limit and thins to zero in the south. Thicknesses are generally less than 50 feet to the east of the Service Buttes Anticline and greater than 150 feet to the west of the anticline.

Catastrophic Flood Deposits

During the Pleistocene Epoch, a dam of glacial ice periodically blocked the drainage of the Clark Fork River near Missoula Montana forming a large body of water known as glacial Lake Missoula. Episodic failure of the dam released tremendous volumes of water which swept across western Washington and down the Columbia River drainage basin. These floods are variously referred to as the Spokane floods, the Bretz floods, or the Missoula floods. Estimates of the number of floods range from 8 (Bretz, 1969) to more than 40 (Waitt, 1985). The last flood occurred about 13,000 years ago (Baker, 1978).

The torrent of water released by each flood stripped soil and sediment from the land, scoured the underlying rock surfaces, and deposited extensive tracts of boulders, gravel, sand, and silt. The resulting sediments are informally referred to as catastrophic flood deposits (Farooqui and others, 1981). The sands and gravels of this unit form extensive deposits in the lowlands of the Umatilla Basin and are the principal groundwater-producing zones in the sediments which overlie the Columbia River Basalt Group.

Within the Umatilla Basin, the distribution of flood gravels and scoured basalt surfaces indicates that some of the floods crested at elevations near 750 feet, near the top of Emigrant Buttes (Bretz, 1925; Hogenson, 1964). As flood waters exited the basin near Arlington, the narrow profile at the entrance of the Columbia River Gorge caused a temporary, hydraulic ponding of water. The slackwater conditions allowed clay, silt, and fine sand to settle out in upstream areas. Pebbles and boulders which were embedded in ice rafts were also released as the ice was stranded at shorelines and melted. These fine-grained sediments and their associated erratics are found at elevations up to 1150 feet, the approximate upper limit of ponded water in the basin (Allison, 1933; Hogenson, 1964).

For the purposes of this study, the flood deposits are divided into two assemblages: a predominantly coarse-grained assemblage of boulders, gravels and medium- to coarse-grained sands (Pscfc) and, a predominantly fine-grained assemblage of silts, fine-grained sands, and clays, with interbeds of sand and gravel (Pscff). For brevity, these will also be referred to as coarse-grained flood deposits or fine-grained flood deposits. The assemblages are differentiated on geologic cross sections (Plate 2.3) but were not mapped separately at land surface.

Coarse-grained flood deposits (Pscfc) occur at or near land surface throughout most of the Lower Umatilla Basin at elevations below 750 feet. These sediments are equivalent to the glaciofluviatile deposits of Hogenson (1964), the Older alluvium of Robison (1971), and the fluvioglacial deposits of Walker (1973). Total thickness ranges up to 200 feet. The thickest accumulations occur in three shallow, east- to northeast-trending troughs: one along the Columbia River between Umatilla and Boardman, a second between Hermiston Butte and Hat Rock State Park, and a third which spans the southern part of Umatilla Ordnance Depot. Along the trough axes, coarse-grained sediments rest on a scoured basalt surface or on a floor of fine-grained flood sediments; away from the axes they lap onto basalt highs or the assemblage of predominantly fine-grained sediments. The coarse-grained deposits thin to the north and south as the floor of each trough rises away from its axis. The shape, orientation, and position of the troughs suggest that they were eroded by the Missoula floods and that their coarse-grained fill was deposited by main-channel flood currents.

On water well reports, coarse-grained flood deposits are commonly described as sands, gravels, or boulders. On the geologic logs of monitoring wells they are described as poorly-sorted sands and gravels; where differentiated, gravel clasts are generally reported as basalt and less frequently as quartz.

Exposures of coarse-grained flood deposits can be seen in many quarries in the area. The deposits typically occur as unconsolidated, poorly-sorted, clast-supported gravels with lenticular interbeds of medium- to coarse-grained sand or, as thick, cross-bedded sequences of fine- to coarse-grained sand with lenticular beds of gravel. Pore spaces in the gravel are partly void or filled with fine- to coarse-grained sand. About 70% of the examined gravel clasts are angular fragments of basalt; the remainder are rounded fragments of granitic, metamorphic, and volcanic rock which are not native to the Umatilla Basin. Quarries with good exposures of these deposits are located near Hermiston (NE 7-4N/29E), Umatilla (SW 16-5N/28E), and Irrigon (NW 30-5N/27E, SE 10-4N/26E), and adjacent to the Umatilla Ordnance Depot (SW 26-4N/27E, NE 28-4N/27E, SE 10-4N/26E).

Predominantly fine-grained catastrophic flood deposits (Pscff) occur as silts, fine silty sands, and clays, with interbeds of sand and gravel. These include sediments between elevations of 750 and 1150 feet which were described as pebbly silts by Allison (1933) and mapped as glacial-lake sediments by Hogenson(1964) and Walker (1973). Well reports and drill cuttings show that similar deposits commonly underlie coarse-grained flood deposits in the subsurface below elevations of 750 feet. Water well reports commonly describe the finer fraction of these deposits as brown, tan, or yellow clay, or as claystone, clay and sand, or clay and gravel. On the geologic logs of monitoring wells, they are described as yellow or brown sandy silt, silty sand, clayey silt, or silty clay, and less commonly, as silty sand or silty gravel. Mica is noted at scattered localities. A comparison of geologic drill logs with nearby water well logs suggests that many of the sediments that water well drillers describe as brown or yellow clay are in fact sandy silts or silty fine-grained sands.

Interbeds of fine sand, sand, and gravel are common in the predominantly fine-grained flood deposits. The beds are typically less than 5 feet thick, but aggregate thickness ranges up to 40 feet. In general, the coarse-grained beds cannot be correlated over any distance based on the descriptions on water well logs. Monitoring wells at scattered localities describe the presence of quartz, quartzite, and mica grains within these beds. Examples include a 4-feet thick quartz sand at a depth of 140 feet in UMAT 5365 (4N/28E-6aba) and, a 4-feet thick gravel containing quartzite and mica at a depth of 175 feet in LUB 73 (3N/28E-3cc).

The total thickness of predominantly fine-grained flood deposits ranges up to 200 feet. In general, the fine-grained sediments thicken away from the troughs which contain coarse-grained flood sediments. Thick accumulations of fine-grained flood sediments occur beneath the terrace between Hermiston and Stanfield, beneath the northeastern part of the Umatilla Ordnance Depot, and beneath the lower part of the Butter Creek and Umatilla River drainages.

Silts, sands, and silty sands of the predominantly fine-grained flood deposits are interpreted as slackwater sediments deposited during the ponding phase of the various floods. They are equivalent to the Touchet Beds of the Walla Walla Valley (Flint, 1938). The interbeds of sand and gravel are interpreted as lag sediments, deposited during the main flooding phase, when currents were strong or, during the transition between initial flooding and ponding, when current strength was waning. The interbedding of fine and coarse-grained sediments probably reflects the occurrence of multiple floods of various strengths. Other criteria that would support multiple floods are generally not noted on the logs of water wells or monitoring wells. However, several monitoring well logs report thin beds of red or reddish-brown clay and silt within the fine-grained sediments northeast of the Umatilla Ordnance Depot. These beds may be buried soil horizons which formed between successive floods.

Prior to the late 1960s, most geologists were skeptical about the occurrence and nature of the Missoula floods (Baker, 1978). This has led to some confusion about the relative ages of fine- versus coarse-grained flood sediments in the Lower Umatilla Basin. For example, Allison (1933) believed that his pebbly silts were younger than gravels near the Columbia River that Bretz (1925; 1928) had ascribed to catastrophic floods. Hogenson (1964) reversed this relationship by assigning an early Pleistocene age to his glacial-lake deposits and a late Pleistocene age to his glaciofluviatile deposits. Current knowledge of multiple floods and a better understanding of the hydraulics of the floods indicate that these sediments are equivalent in age, but span a range of times.

Holocene Alluvium

During the last 12,000 years, thin deposits of micaceous silt, sand, and gravel have accumulated in the flood plains of Butter Creek and the Umatilla River. These alluvial sediments are largely composed of reworked loessal soils, reworked catastrophic flood sediments, and basaltic gravels washed from the upper reaches of local stream drainages. In most areas, Holocene sediments overlie Pleistocene catastrophic flood deposits. Upstream from Echo, in the Umatilla River valley, Holocene sediments may rest directly on basalt bedrock. Because of similarities in composition, the subsurface contact between Holocene Alluvium and underlying flood deposits cannot generally be determined with confidence based on the sediment descriptions on well logs.

Surficial Deposits

A windblown deposit of micaceous silt and sand veneers most of the Lower Umatilla Basin. The unit ranges up to 30 feet thick but is typically less than 10 feet thick. Active and stabilized dunes can be observed on undisturbed surfaces but dunes have been obliterated in most irrigated areas. Most of the soils of the basin are formed in this deposit.

Geologic Structures

The Dalles-Umatilla Syncline and the Service Anticline are the principal structures in the Lower Umatilla Basin (Plate 2.2). These features control the orientation of Columbia River basalts and the geometry of the land surface. They have also influenced the pattern of erosion in the basalts and the distribution of sediments overlying the basalts. The lack of deformation in the overlying sediments indicates that structural growth ended prior to the deposition of the sediments.

The Dalles-Umatilla Syncline (Newcomb, 1967) forms a regional topographic low which controls the modern course of the Columbia River between Arlington and Umatilla, Oregon. The syncline is typically mapped as a single fold within the Umatilla Basin but the precise nature of the structure, and the location of its axis, are obscured by a cover of alluvial sediments in most places along the river. Several authors have extended the syncline eastward from Umatilla to Pendleton (Newcomb, 1967; Tolan and Reidel, 1989) but the current investigation indicates that the fold terminates at the Service Anticline, near the Port of Umatilla.

Well correlations on the Oregon limb of the Dalles-Umatilla Syncline indicate that dips are about 50 feet per mile to the north. Outcrop patterns and subsurface correlations indicate that the syncline plunges to the west between Umatilla and Irrigon and to the east between the western boundary of the study area and Boardman (Plate 2.2).

Service Anticline is an alignment of buttes and ridges that extends from Sillusi Butte in Washington to Service Buttes in Oregon. Between Umatilla Butte and Service Buttes, the structure is expressed as a chain of isolated basalt buttes which are surrounded by alluvial sediments. Hogenson (1964) and Shannon & Wilson (1973b) describe minor faults associated with the structure but map it as an anticline along its entire length. Robison (1971) notes that a closed fold is not visible along most of the structure and infers bounding faults on both sides of the buttes along most of the structural trend. Data from the current investigation are not sufficient to resolve the nature of the structure in most places but outcrop and well log data suggest that faulting has produced at least 250 feet of vertical structural relief on the west side of Hermiston Butte (Plate 2.2 and cross section F-F', Plate 2.3). In addition, structure contours define a narrow, north-south trough immediately east of Hermiston Butte that may be a fault or a tightly-folded syncline.

The "topography" of the surface of the Columbia River Basalt Group (Plate 2.2) reflects tectonic deformation (folding and faulting) and erosion. West of Service Anticline the basalt surface has undergone only minor erosion and largely reflects the structural dip of the Elephant Mountain Basalt.

East of Service Anticline, the basalt surface is characterized by several northeast-trending ridges and troughs. The broadest trough, which underlies Hermiston, is a low-amplitude syncline which has been accentuated by erosion during the Missoula floods. Ridges south of the Hermiston trough are interpreted as the southern margins of the Pomona and Umatilla basalts, modified by erosion during the Missoula floods.

Groundwater Occurrence

Groundwater occurrence is influenced by the distribution of geologic units and the variation of permeability and porosity within each unit. These factors affect the ability of water to migrate into the ground and travel through the groundwater system. They also govern how easily groundwater can be extracted by wells.

Water well logs indicate the presence of multiple water-bearing zones in the Lower Umatilla Basin. The principal zones occur in sands and gravels which overlie the Columbia River Basalt Group or in breccia/fracture zones within the Columbia River Basalt flows. The upper two or three basalt flows and the overlying sands and gravels contain the most widely used sources of domestic groundwater. These shallow aquifers are the focus of this report.

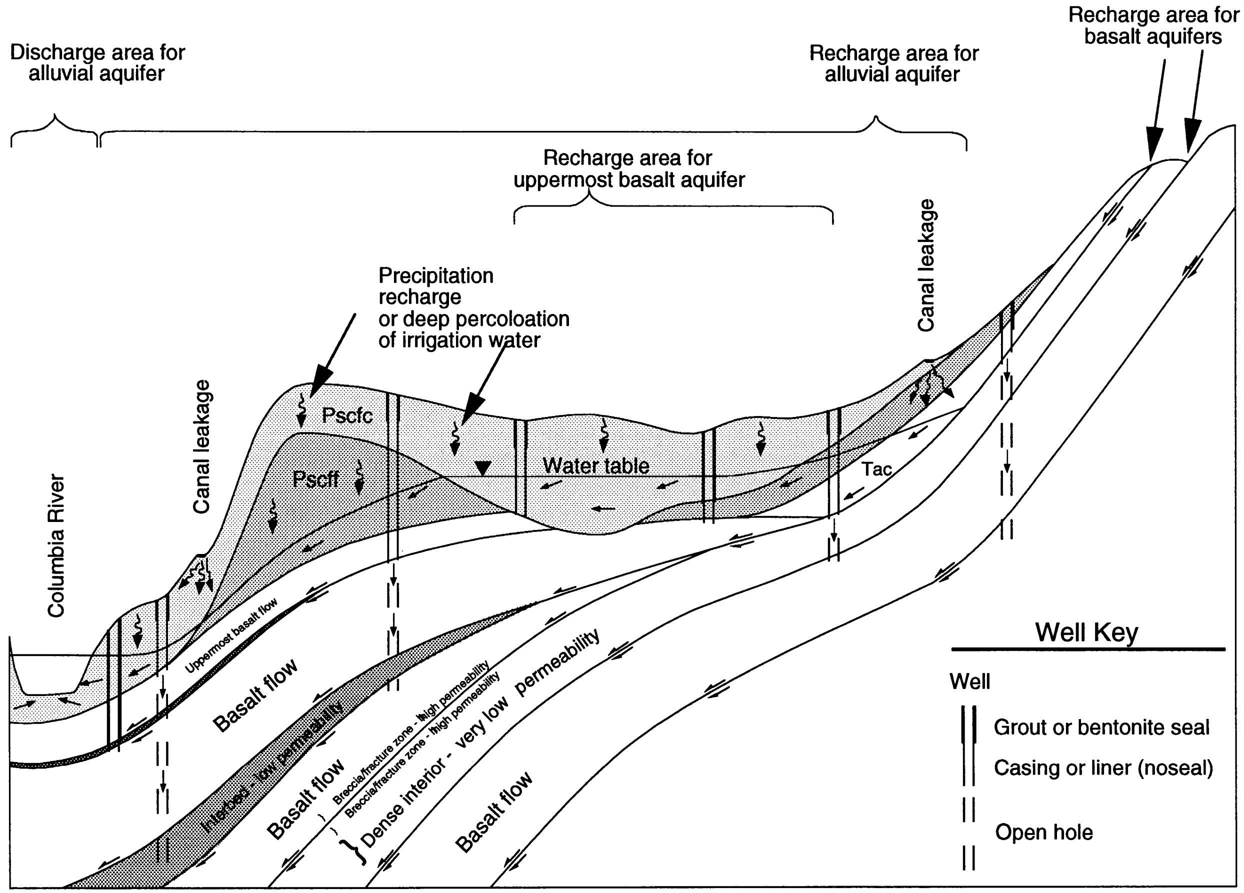
Aquifer Units

For the purpose of this study, four shallow aquifer units are defined on the basis of stratigraphic boundaries. These boundaries segregate groundwater into discrete zones with distinctive water levels and flow paths. From upper to lowermost, these are the alluvial aquifer, the basal Elephant Mountain aquifer, the basal Pomona aquifer, and the basal Umatilla aquifer. The basalt aquifers will alternatively be referred to as the Elephant Mountain aquifer, the Pomona aquifer, and the Umatilla aquifer. The relationship between aquifer units and geologic units is shown is Figure 2.4.

Conceptual Model of the Groundwater Flow System

Figure 2.5 shows a conceptual model of the shallow groundwater flow system in the basin. An understanding of the flow system at any given locality can be gained by referencing the schematic model to the geologic sections and maps on Plates 2.2, 2.3, and 2.4.

Groundwater recharge comes from precipitation, deep percolation of irrigation water (percolation past the root zone), and leakage from canals, streams, and reservoirs. The recharge area for the alluvial aquifer is very broad because porous and permeable sediments overlie the aquifer throughout most of its extent. Recharge areas for the basalt aquifers are narrow because porous and permeable zones in the basalt flows are generally restricted to tabular breccia or fracture zones at the top or base of flows (Figure 2.6). Because the breccias typically constitute less than ten percent of a flow's thickness, their surface area is relatively small where exposed at land surface or beneath a cover of sediments.



Pscfc Coarse-grained catastrophic flood deposits
Pscff Fine-grained catastrophic flood deposits
Tac Alkali Canyon Formation

Figure 2.5 Conceptual model of the shallow groundwater flow system

Groundwater in the shallow aquifers is constantly flowing toward the Columbia and Umatilla rivers where it is discharged from the groundwater system to become stream flow. Discharge from the basalt aquifers to the rivers is probably inefficient except where individual flows are breached in one of the riverbeds. Some alluvial groundwater is also discharged to underlying basalt aquifers where updip margins of lava flows are exposed at the base of the alluvial aquifer.

Water wells impact the groundwater and surface water system in several ways. If annual pumpage exceeds annual recharge, the volume of groundwater in storage will decrease and water levels in an aquifer will drop. Pumpage from wells can also change groundwater flow paths, especially in areas where high-capacity wells are clustered. Wells can also allow water to migrate between aquifers with different hydraulic heads. This mixing, or commingling, of groundwater can occur in the annular space behind ungrouted well casing or in open well bores that penetrate more than one aquifer.

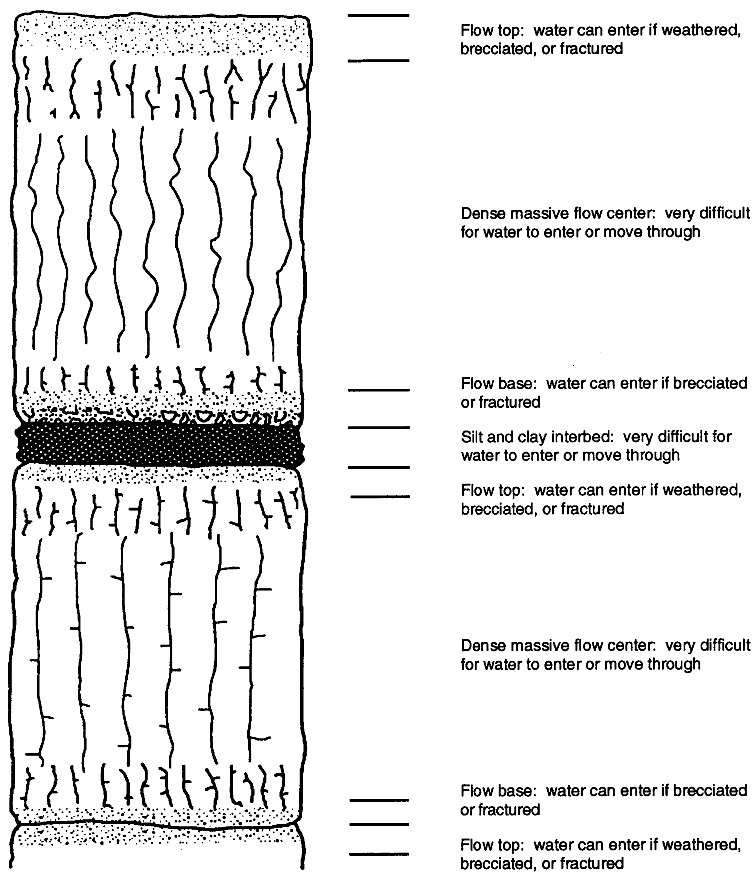


Figure 2.6 Idealized relationship between basalt stratigraphy and groundwater occurrence.

Alluvial Aquifer

The alluvial aquifer includes all saturated sediments which overlie the Columbia River Basalt Group and any saturated breccia/fracture zones at the top of the uppermost basalt flow. Sedimentary units within the aquifer include Holocene Alluvium, Pleistocene catastrophic flood deposits, and the Alkali Canyon Formation (Figure 2.4). The principal water-bearing zones occur in sands and gravels within the flood deposits (Plates 2.3 and 2.4).

The boundaries of the productive aquifer are approximated by the limits of the water-level contours shown on Plate 2.4. Limiting contours correspond to areas where the saturated thickness is generally less than 20 feet or where well yields are insufficient for most consumptive uses. Scattered well logs indicate that thin saturated zones occur at considerable distances beyond the limits of the contours. Most of the productive alluvial groundwater resource occurs within the area between Boardman, Cold Springs Reservoir, and Echo but, an isolated resource occurs in the sediments of Sixmile Canyon between Carty Reservoir and the Columbia River.

The upper surface of the Columbia River Basalt Group defines the approximate base of the alluvial aquifer (Plate 2.2). The subsurface "topography" of this bedrock surface is the primary factor controlling the thickness of the alluvial aquifer. The aquifer thins above local bedrock highs and thickens above bedrock lows. The aquifer also thins to the south and east as the basalt surface rises to higher elevations. The saturated thickness of the aquifer can be estimated at any locality by subtracting the elevation of the basalt surface from the elevation of the water table.

In a general sense, the water-level contours on Plate 2.4 can be thought of as the slope, or gradient, of the water table. In this sense, groundwater flows "downslope", or down gradient, from areas of high to low hydraulic head. Regional water-level highs generally correspond to areas of regional recharge and regional water-level lows correspond to areas of potential discharge. Local water-level mounds indicate areas of local recharge.

Water-Bearing Units

Holocene Alluvium

Holocene Alluvium occurs as a thin veneer of silt, sand, and gravel in the Butter Creek flood plain and in the Umatilla River flood plain upstream of Butter Creek. In most areas these deposits are saturated to within several feet of land surface and water levels are within a few feet of the elevation of adjacent streams.

Catastrophic Flood Deposits

Catastrophic flood deposits are the principal water-bearing unit in the alluvial aquifer (Plates 2.3 and 2.4). Flood sediments include gravels, sands, silts, and clays. Where saturated, the sands and gravels yield moderate to high quantities of water to wells. Silts and silty sands locally yield small quantities of water to wells. Hydraulic properties vary geographically within the flood deposits and correlate to the distribution of coarse-grained versus fine-grained sediments. In general, the permeability of the coarse-grained deposits is much higher than that of the fine-grained deposits. This is reflected by higher well yields and lower hydraulic gradients in the coarse-grained sediments.

Predominantly coarse-grained catastrophic flood deposits (Pscfc) occur as broad tracts of sands and gravels. Extensive saturated deposits occur as lobate areas that are centered on three east to northeast-trending troughs (highlighted in yellow on Plate 2.4). Each area is characterized by a saturated thickness greater than 10 feet, low hydraulic gradients (typically less than 10 feet per mile), and high well yields. Yields in high capacity wells are commonly greater than 1000 gallons per minute and range up to 4000 gallons per minute. Collectively, these areas represent the most productive part of the alluvial aquifer. Saturated coarse-grained flood deposits also occur in Sixmile Canyon and tributary canyons between Carty Reservoir and the Columbia River. Outside of these areas, groundwater occurs in predominantly fine-grained flood sediments (Pscff) or in thin saturated zones within coarse-grained flood sediments.

Predominantly fine-grained catastrophic flood deposits (Pscff) occur as clays, silts, sandy silts, and gravelly silts with thin interbeds of sand and gravel. Silts and silty sands are the predominant sediment type. Where saturated, these deposits are characterized by hydraulic gradients greater than 25 feet per mile and well yields up to 500 gallons per minute. In some areas the sand and gravel interbeds are locally confined by overlying beds of silt or clay. The confining beds and the sand and gravel interbeds are laterally discontinuous; in many cases they cannot be traced for distances greater than one mile. The cumulative thickness of saturated sand and gravel beds is as high as 30 feet but commonly totals less than 5 feet. In some areas, sands and gravels are absent. Productive confined sands occur locally on the terrace between Hermiston and Stanfield, in the Umatilla River valley below Umatilla Meadows, and in the vicinity of Lost Lake (10-3N/27E). Well yields in these areas range up to 500 gallons per minute but are commonly less than 100 gallons per minute. Elsewhere, well yields from the fine-grained deposits are sufficient for domestic purposes only.

The following sections summarize the hydrogeologic characteristics of the flood deposits on a region by region basis.

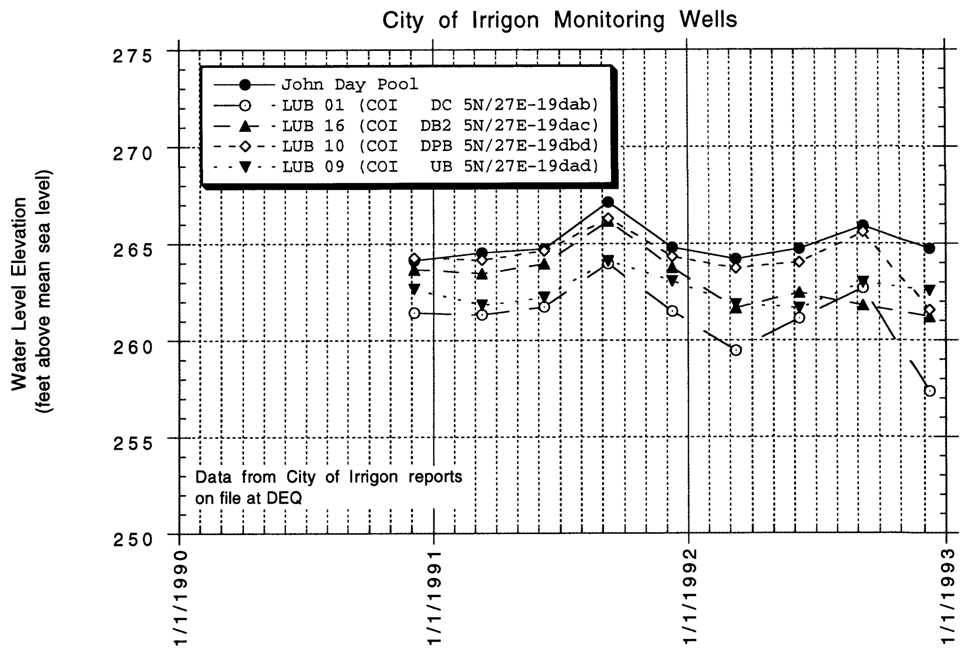
Boardman-Umatilla Area

Coarse-grained catastrophic flood deposits fill the trough of the Dalles-Umatilla syncline along the Columbia River between Boardman and Umatilla. The saturated thickness of these deposits exceeds 40 feet at the river but decreases toless than 10 feet as the surface of the underlying basalt rises to the south (cross sections B-B', C-C', and D-D', Plate 2.3). Groundwater flow is generally to the north with discharge to the Columbia River. Adjacent to the river, groundwater elevations are within several feet of the John Day pool level (average pool elevation, 265 feet). Data from monitoring wells near the Port of Morrow (Cascade Earth Sciences, Ltd., 1993) show that hydraulic gradients are 2 to 4 feet per mile near the river but increase abruptly to 50 feet per mile about 2 miles south of the river (Figure 2.8B). The hinge line at which this change occurs is roughly equivalent to the elevation at which the basalt surface (the base of the alluvial aquifer) rises above the John Day pool level (cross section B-B', Plate 2.3). Although water-level data is sparse elsewhere, the general pattern of water levels, the continuity of the sands and gravels, and the geometry of the underlying basalts suggests that similar conditions occur along the river between Boardman and Umatilla(see cross sections C-C′ and D-D′, Plate 2.3).

Groundwater levels in coarse-grained flood deposits adjacent to the Columbia River are 2 to 4 feet higher in the summer than in the winter (Figure 2.7). These changes correspond to seasonal variation of the John Day pool level. Pool level is typically 267 feet elevation in the summer and 261 feet in the winter (personal communications, Art Fong and Fred Miklancic, U.S. Army Corp of Engineers). Because the hydraulic gradient of the aquifer is very low near the river, rapid rises in pool level may temporarily reverse the gradient near the river and cause river water to flow into the aquifer. Not enough data is available to substantiate such reversals in the study area but reversals have been documented in a similar setting at the Hanford Site in Washington state (Gilmore and others, 1993).

In contrast, monitoring wells in section 1 of 4N/25E, and sections 6 and 7 of 4N/26E, at distances greater than 1 mile from the river, show lower water levels in summer and higher levels in winter (Figure 2.8A). June 1992 water-level contours suggest that these trends are caused by the pumping of a high-capacity well in section 36, 5N/25E, near MORR 696 (Figure 2.8B). Similar effects are expected to the east near a cluster of high-capacity irrigation wells which are located along the boundary between 4N/26E and 5N/26E (Plate 2.6). Pumping impacts in this area are likely to be intensified because of an abrupt decrease in saturated thickness to the south.

After the John Day dam was completed in April of 1968, alluvial groundwater levels rose up to 25 feet in the Boardman area (Robison, 1971; unpublished charts in Oregon Water Resources Department's Groundwater files). Similar rises occurred along the river between Boardman and Umatilla. For example, UMAT 3294 (5N/27E-14dda), halfway between Irrigon and Umatilla and 1300 feet south of the river, had a pre-dam static water-level elevation of 253 feet in February 1966 compared to a post-dam elevation of 266 feet in February 1991.



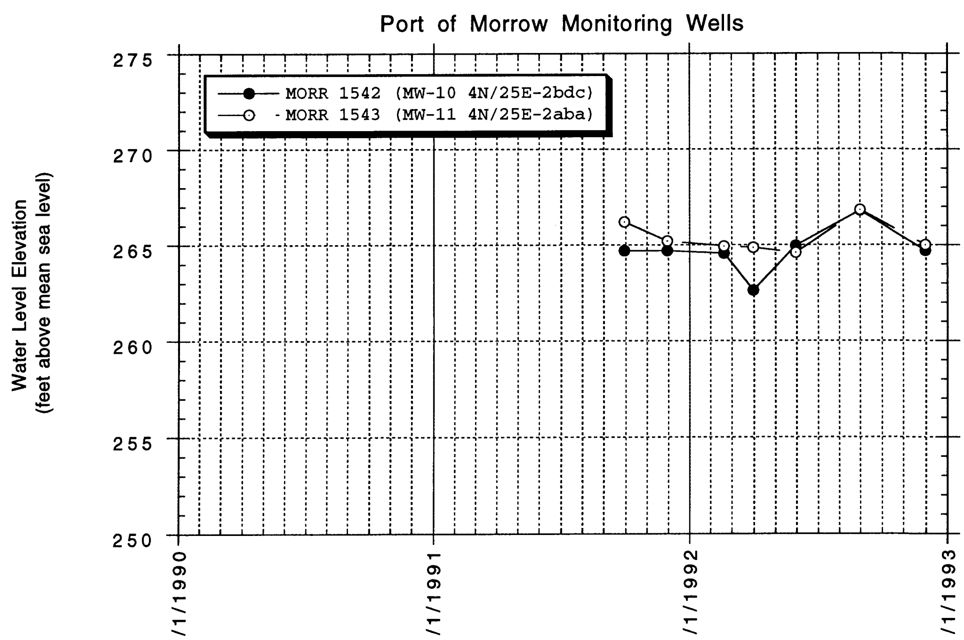
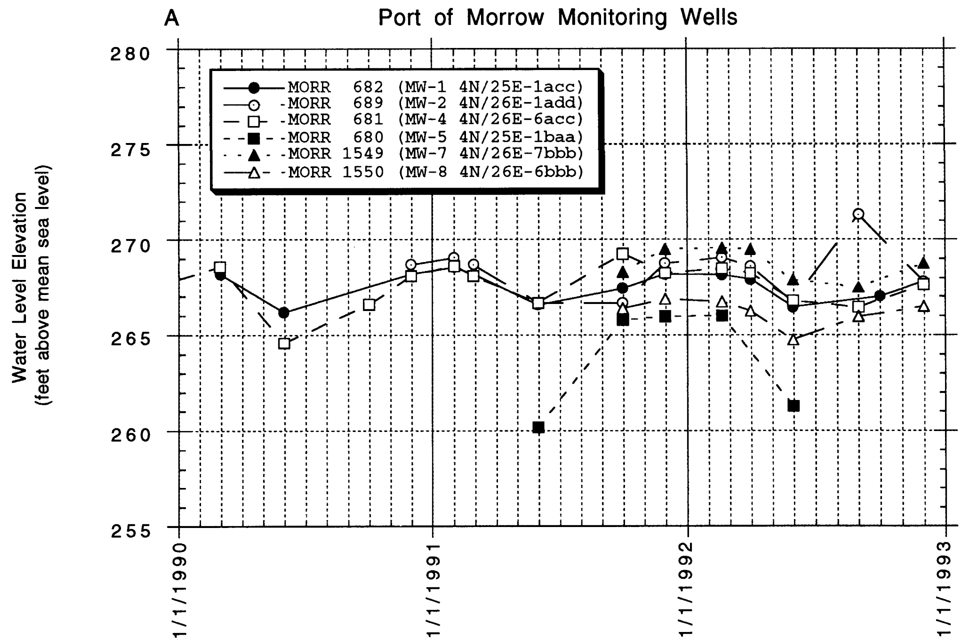


Figure 2.7 Effect of river stage on groundwater levels in coarse-grained flood deposits adjacent to the Columbia River between Irrigon and Boardman



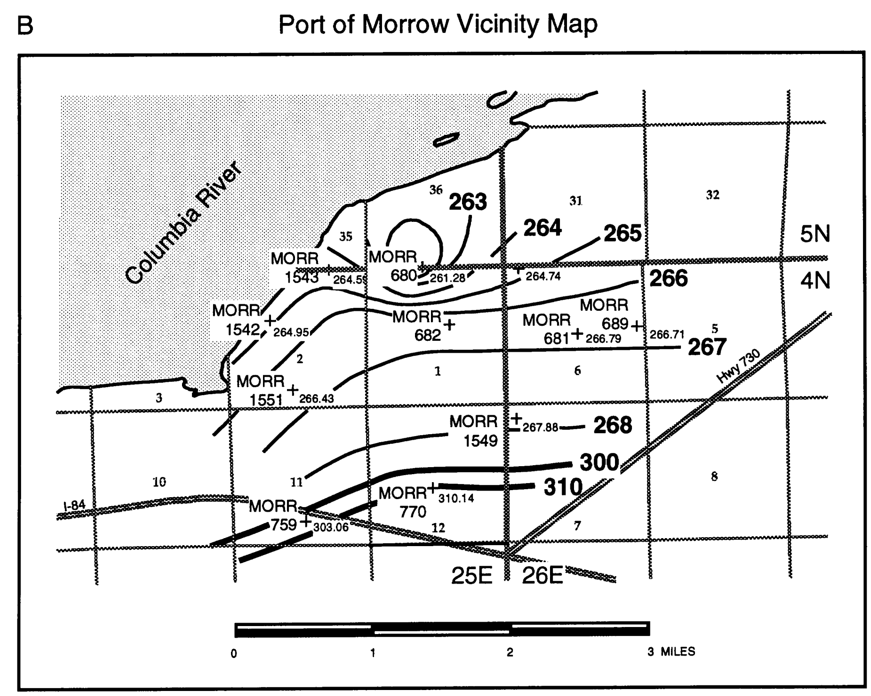


Figure 2.8 Possible effects of pumping on groundwater levels in coarse-grained flood deposits east of the Port of Morrow

Seasonal or long-term lowering of the John Day pool will cause groundwater levels in the alluvial aquifer to decline. The decline will be greatest adjacent to the river and least near the southern margin of the saturated coarse-grained deposits as delineated on Plate 2.4. South of this margin, the base of the alluvial aquifer rises above the level of the John Day pool and saturated thickness decreases dramatically. Saturated thickness in the southern area is unlikely to be impacted by pool changes since it is dependent upon local recharge and groundwater influx from the south. The configuration of the water table at any John Day pool level can be predicted by finding the equivalent line of elevation on the basalt surface. This will be the approximate location of the new hinge line which separates the low-gradient area to the north from the thinly-saturated high-gradient area to the south.

Umatilla Ordnance Depot Area

The nature of the alluvial aquifer in the Ordnance area has been the focus of some controversy. McCall postulated that fine-grained sediments separated saturated gravels into eastern and western areas (his Westland Road and Lost Lake-Depot subareas) with minimal hydraulic connection. McCall also constructed a water table map which inferred that groundwater in both areas flowed northerly, with discharge to the Columbia River. In contrast, Miller (1985) concluded that gravels in the northern two-thirds of both areas were hydraulically connected and that groundwater flow was to the northeast, with discharge to the Umatilla River. Based on a more extensive data set, the current investigation supports Miller's conclusion that the gravels are part of a single hydraulic system but finds that groundwater flow in the area is more complex than proposed by either author (see Plate 2.4).

Predominantly coarse-grained catastrophic flood deposits fill an east-west trough centered on the southern part of the Umatilla Ordnance Depot (see cross sections C-C' and D-D' on Plate 2.3). McCall (1985) and others have informally referred to these sediments as the Ordnance gravels. The saturated portion of the "gravels" (highlighted in yellow on Plate 2.4) is centered on the trough axis and forms an elongate lobe which extends from the western boundary of the Depot to the Umatilla River. Seasonal and long-term hydrographs show that water-level trends are consistent over broad areas within the gravels (Figures 2.9, 2.10, 2.11). These factors indicate that the gravels are part of a single hydraulic unit that responds to the same set of stresses over a broad area.

Saturated thickness in the gravels ranges up to 125 feet near the center of the trough but thins to zero as the underlying contact with predominantly fine-grained flood sediments rises above the water table to the north and south (Plate 2.3, cross sections C-C' and D-D', and Plate 2.4). A similar thinning is inferred to the west but cannot be confirmed due to a lack of well control. In February 1991, groundwater elevations ranged from 495 to 500 feet throughout most of the gravels but varied by less than 1 foot across the southeastern quarter of the Depot (Plate 2.4). Because well-head elevations were not surveyed outside of the Depot, most of the water-level variation in these areas may be due to uncertainties in those elevations. If so, the hydraulic gradient was probably less than 1.5 feet per mile throughout most of the extent of the gravels.

Figure 2.9 shows long-term hydrographs for representative wells completed in coarse-grained flood deposits east and south of the Depot. The major trends are a water-level decline between 1960 and 1978, a rise between 1978 and 1986 and a decline from 1986 to 1993. These trends roughly parallel the historical development of groundwater in the area but, they also correlate to long-term fluctuations in annual rainfall (Figure 2.2) (Miller, 1985). The correlation with rainfall is believed to be indirect since precipitation recharge is considered to be negligible in the area (see section on precipitation recharge below). Irrigation pumpage in the Ordnance area began in the early 1950s, increased slowly through the early 1960s, and accelerated between 1965 and 1976. In 1976, pumpage was stabilized by regulation at about 13,000 acre-feet per year south of the Depot and at about 6000 acre-feet per year east of the Depot. Also, in 1976, the County Line Water Improvement District (CLWID) began artificial recharge of the aquifer via a leaky canal, 2.5 miles in length, located about one mile south of the Depot (Plate 2.4). Recharge from the canal has averaged about 5200 acre-feet per year through 1993. In the mid 1980s, the Westland Irrigation District lined several miles of the A canal and replaced the F canal with pressurized pipes. This has probably resulted in decreased recharge to the gravels and may be responsible for some of the water-level decline between 1986 and 1993 (see the section on canal leakage recharge below).

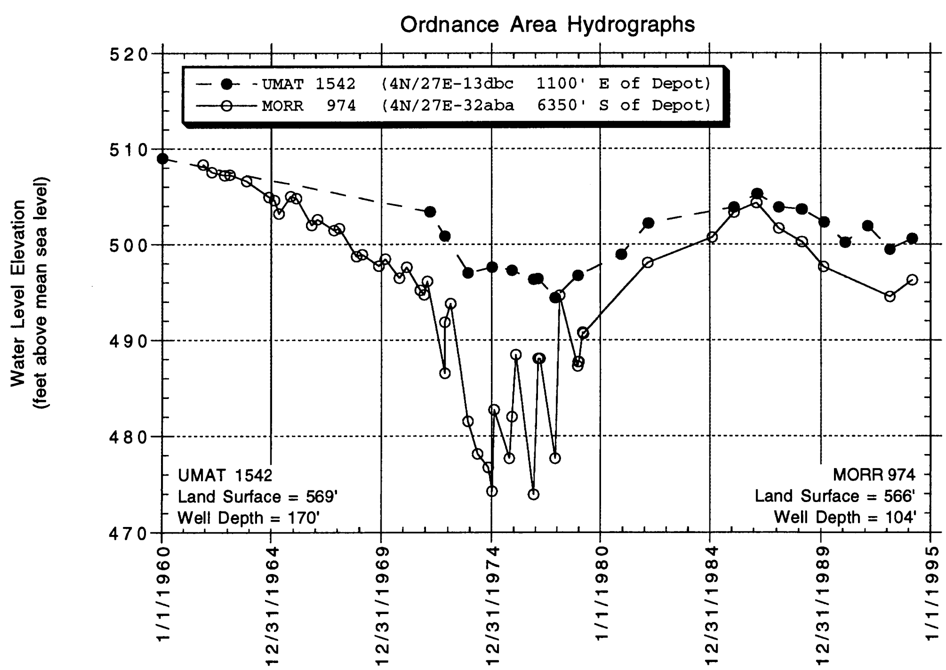


Figure 2.9 Long-term hydrographs of representative wells completed in coarse-grained flood deposits east and south of the Umatilla Ordnance Depot

An example of seasonal water-level fluctuations in the gravels is illustrated by the continuous recorder hydrograph for MORR 963 (Figure 2.10). At the beginning of the irrigation season, water levels fall in response to pumpage from nearby irrigation wells. Near the end of the irrigation season, water levels reach their lowest point. This is followed by a gradual rise which corresponds to a recovery from pumping and possibly some precipitation recharge. A steep rise in water level between early February and late March 1992 corresponds to artificial recharge from the County Line Water Improvement District's recharge canal. The beginning of this rise occurs within several days of the filling of the recharge canal. Similar responses in wells near the canal are noted by Miller (1985).

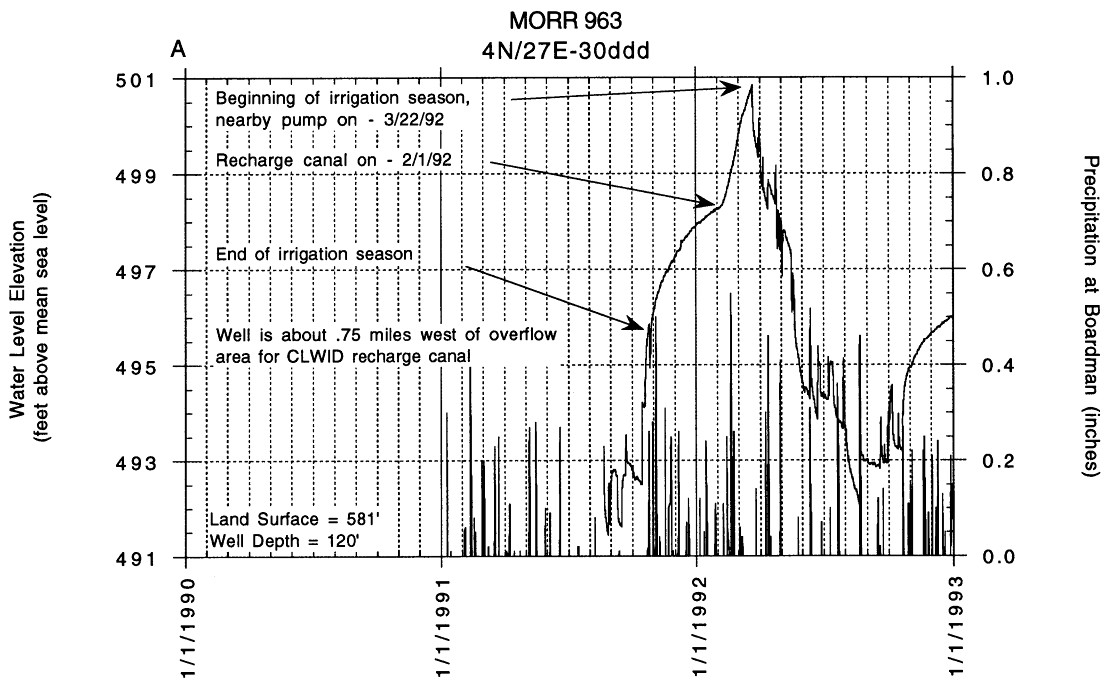
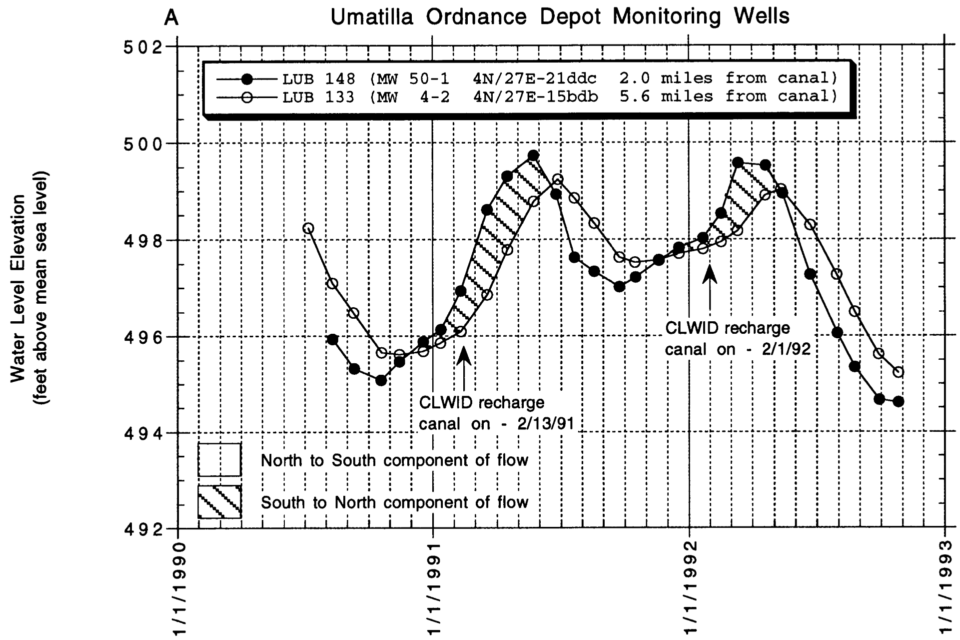
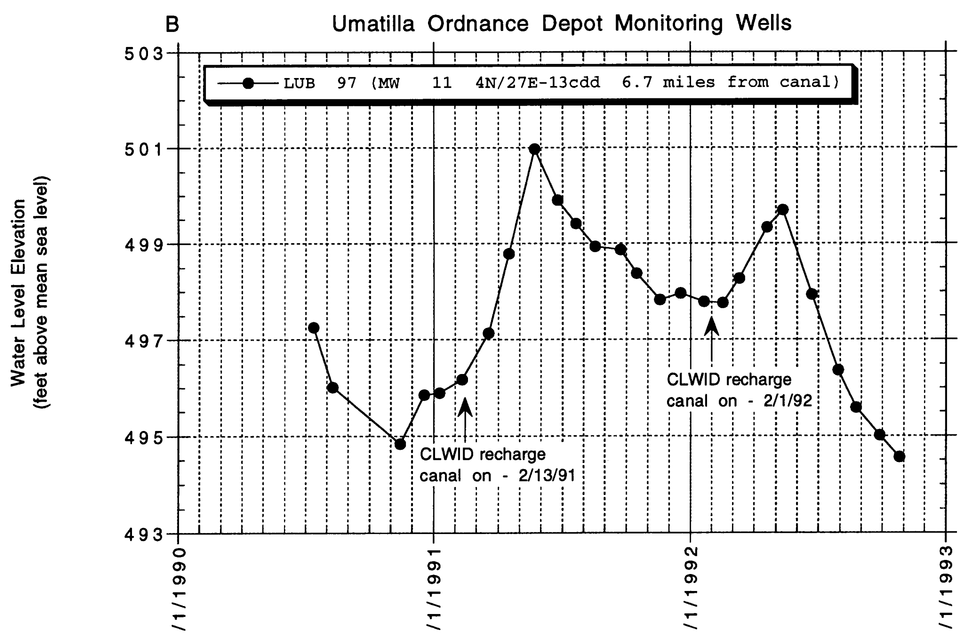


Figure 2.10 Seasonal hydrograph of continuous recorder well completed in coarse-grained flood deposits south of the Umatilla Ordnance Depot

On the Umatilla Ordnance Depot, widely-spaced monitoring wells completed in the gravels display seasonal trends which correspond to those of MORR 963 (Figure 2.11). Seasonal fluctuations have an amplitude of about 5 feet and water level elevations are generally within 2 to 3 feet over a broad area. The timing of the major changes in water level trends is related to the distance from major pumping centers and recharge sources. For example, peaks and troughs occur earlier in the year at wells which are closer to the southern and eastern boundary of the Depot (Figure 2.11), adjacent to areas of major irrigation withdrawals from the alluvial aquifer (Plate 2.6). Similarly, a change from gradual to steep water-level rise in late winter occurs earlier in wells near the southern boundary and correlates to distance from the CLWID recharge canal (Figure 2.11). Continuous recorder hydrographs for Depot wells confirm these patterns in detail for the period from August 1990 through October 1991 (Dames & Moore, Inc., 1992).





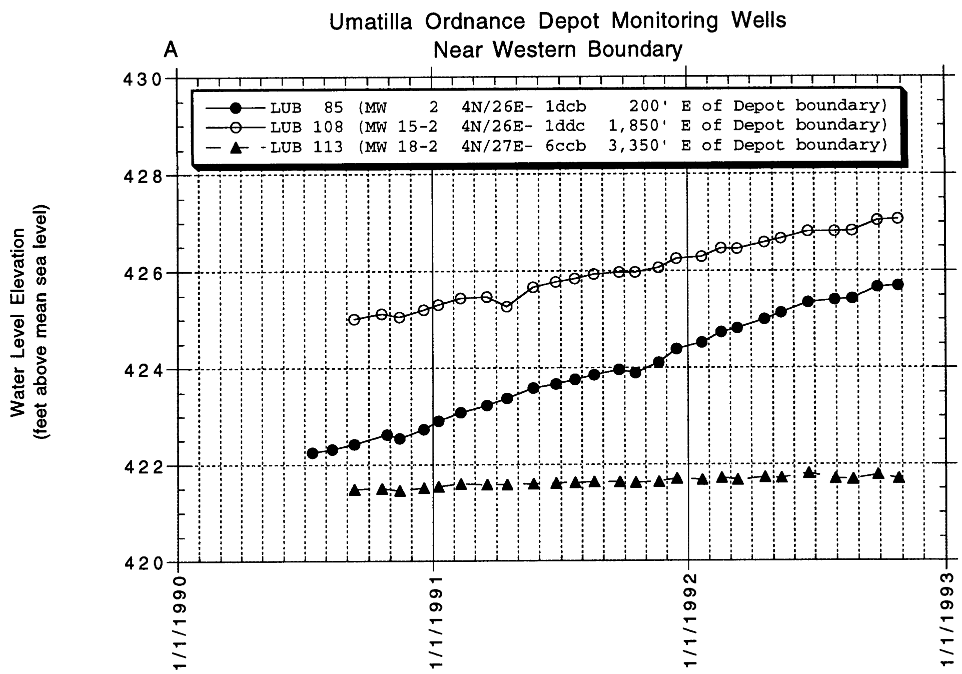
Fiugre 2.11 Seasonal hydrographs of representative wells completed in coarse-grained flood deposits on the Umatilla Ordnance Depot. A, Wells in south-central part of Depot; B, Well near eastern boundary of Depot

Depot monitoring wells completed in fine-grained flood deposits show notably different water-level trends compared to wells completed in coarse-grained flood deposits. Between July of 1990 and October of 1992, most fine-grained wells show annual water-level rises between 0.5 and 3 feet and little or no seasonal fluctuation (Figure 2.12). Annual water level rises are greatest along the eastern and western boundaries and decrease toward the interior of the Depot. One well near the center of the Depot (LUB 130) shows a small annual water-level decline. Along the western boundary of the Depot, these trends produce a bending, or refraction, of the water-level contours which indicates that groundwater is flowing onto the Depot from the southwest (Plate 2.4). Rising groundwater levels in the northeastern part of the Depot correspond to inflow from a groundwater mound which is centered about one-half mile east of the northeast corner of the Depot.

The contrasting seasonal behavior of groundwater in fine-grained versus coarse-grained sediments in the Ordnance area is consistent with a large permeability contrast caused by an abrupt lateral change from channel-filling sands and gravels in the south to slackwater silts and clays in the north. This lateral permeability contrast dampens the seasonal water-level fluctuations which occur within the coarse-grained deposits. The efficiency of this hydraulic boundary as a barrier to flow cannot be determined from the present data.

Investigations on the Depot (Dames & Moore, 1992; Dames & Moore, 1994b) show that flow directions in the coarse-grained flood deposits (their Ordnance Aquifer) fluctuate seasonally in response to off-site pumping and recharge. In general, flow directions are to the east and south in summer and autumn and to the north and west in winter and spring. Additional variation is seen at other times of the year. The rough nature of these seasonal changes can be seen in Figure 2.11A by noting that the relative flow direction between any two wells is reversed when their water level trends cross on a hydrograph.

Water levels on Plate 2.4 indicate that the predominant direction of groundwater flow in the coarse-grained deposits in February 1991 was easterly toward the Umatilla River. Water levels also indicate some northwesterly outflow from the coarse-grained deposits, with discharge to the Columbia River. However, the permeability contrast between the coarse-grained and fine-grained deposits probably restricts the rate and volume of flow to the northwest. Dames & Moore (1994b) suggest that water-level declines in the coarse-grained deposits have decreased past the point where hydraulic heads are sufficient to drive groundwater into the fine-grained sediments to the north (their northern Aquifer). On this basis, they show a narrow groundwater divide separating the finer-grained sediments in the north from the coarse-grained sediments in the south (see their Figures 3-8 to 3-14). It seems unlikely, however, that localized sources of recharge could maintain such a narrow divide over the breadth of the Depot.



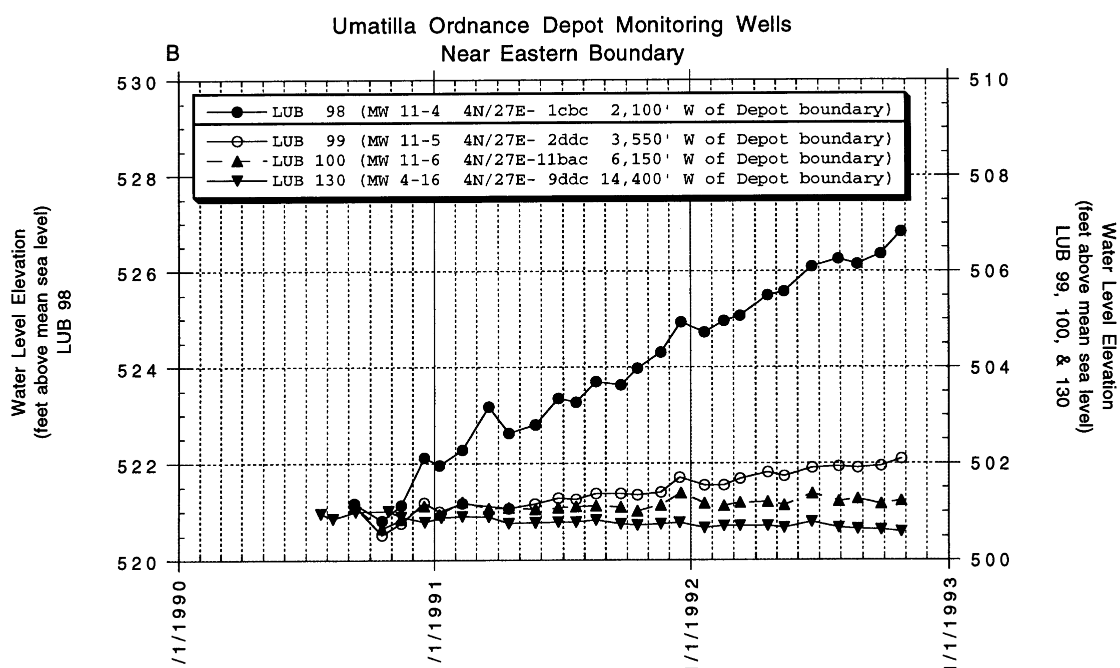


Figure 2.12 Seasonal hydrographs of monitoring wells screened in fine-grained flood deposits on the Umatilla Ordnance Depot. A, Wells near western boundary; B, Wells near eastern boundary

Water levels also indicate that discharge from the gravels to the Umatilla River occurs between Cottonwood Bend and Bridge Road. In this reach, the river penetrates the gravels at elevations coincident with the elevation of the water table (450 to 500 feet). This is consistent with surface water measurements which indicate that this stretch of the river gains water from groundwater discharge (Kreag, 1991). Pumpage discharge that lowers or reverses the hydraulic gradient of the alluvial aquifer toward the river will decrease the rate of discharge to the river. Alternatively, canal leakage will increase the gradient toward the river and increase the rate of discharge to the river.

Contaminant plumes for RDX (Royal Demolition Explosive) and nitrate/nitrite in coarse-grained sediments at the Washout Lagoons area of the Depot (section 15 of 4N/27E) show that contaminants have migrated to the south and southeast from their source at the lagoons (Dames & Moore, 1994b, figures 4-75 to 4-78). This suggests that the net yearly movement of groundwater in that area is to the southeast. This is consistent with discharge to the Umatilla River. Alternatively, most of this contaminant migration may have occurred prior to 1976, when pumping during the irrigation season was not offset by artificial recharge in the winter months.

In summary, flow directions vary seasonally in the coarse-grained flood deposits in the Ordnance area because of a complex interaction between pumpage east and south of the Depot, artificial recharge south of the Depot, and leakage from irrigation canals east and south of the Depot. Some northwesterly flow out of the gravels is likely, but the predominant direction of flow is to the east, with discharge to the Umatilla River.

Hermiston Area

Saturated coarse-grained flood deposits occur in a northeast-trending trough between the city of Hermiston and Hat Rock State Park (highlighted in yellow on Plate 2.4). The trough occupies a shallow syncline (Plate 2.2) which has been modified by erosion during the Missoula floods. Along the central and northern parts of the trough, sands and gravels rest directly on basalt and the saturated thickness is controlled by the elevation of the basalt surface. Along the trough axis, the saturated thickness increases from 40 feet in the east to 100 feet in the west. To the north and east, the saturated zone thins to zero as the surface of the underlying basalt rises gradually above the elevation of the water table. To the south, the saturated zone within the sands and gravels thins abruptly to zero as the contact with underlying fine-grained deposits rises sharply above the elevation of the water table on the terrace south of Hermiston. A similar thinning occurs to the east as the water table drops below the elevation of the contact with fine-grained sediments. In places, the water table intercepts land surface to form shallow ponds and swamps. The most notable examples are in Hermiston between Elm and Jennie Avenues (NW/NE 11-4N/28E) and northeast of Hermiston near the intersection of Diagonal and Locust roads (NW/NE 28-5N/29E). In both localities, land surface elevations are at, or slightly below, 440 feet.

In February 1991, measured groundwater elevations varied between 435 and 445 feet throughout most of the coarse-grained deposits in the Hermiston trough (Plate 2.4). As in the Ordnance area, some of this variation is probably due to uncertainties in land surface elevations at field-located wells. In August 1991, water levels were 1 to 3 feet lower in most wells (Appendix B), presumably in response to irrigation withdrawals during the summer (Plate 2.6). In contrast, August 1991 water levels were 2 to 3 feet higher in wells near the base of the south Hermiston terrace, adjacent to, and downgradient from, the A Line canal (in the northwest portion of 4N/29E and the southwest portion of 5N/29E). High summer groundwater levels in this area are believed to be caused by leakage from the A Line canal and its distributary ditches or, from deep percolation of water from flood-irrigated fields (see the section on groundwater recharge below).

The continuous recorder hydrograph for UMAT 3609 (5N/28E-35ccc) shows a seasonal water-level trend which is believed to be typical for the central part of the Hermiston trough (Figure 2.13). The annual water-level high occurs in winter and the low occurs in late summer. Rising water-levels from September through late winter correlate to decreasing pumpage, increasing rainfall, and decreasing evapotranspiration. Minor water-level rises during the spring and summer months correlate to short episodes of intense rainfall (Figure 2.13).

Local residents report a water table rise of several feet at the beginning of the irrigation season near canals in the northern part of the Hermiston trough. This phenomena was observed by the author in a sump north of Hermiston (NW 25-5N/28E) during several visits in late spring. Measurements in nearby wells were not frequent enough to document similar changes in the subsurface.

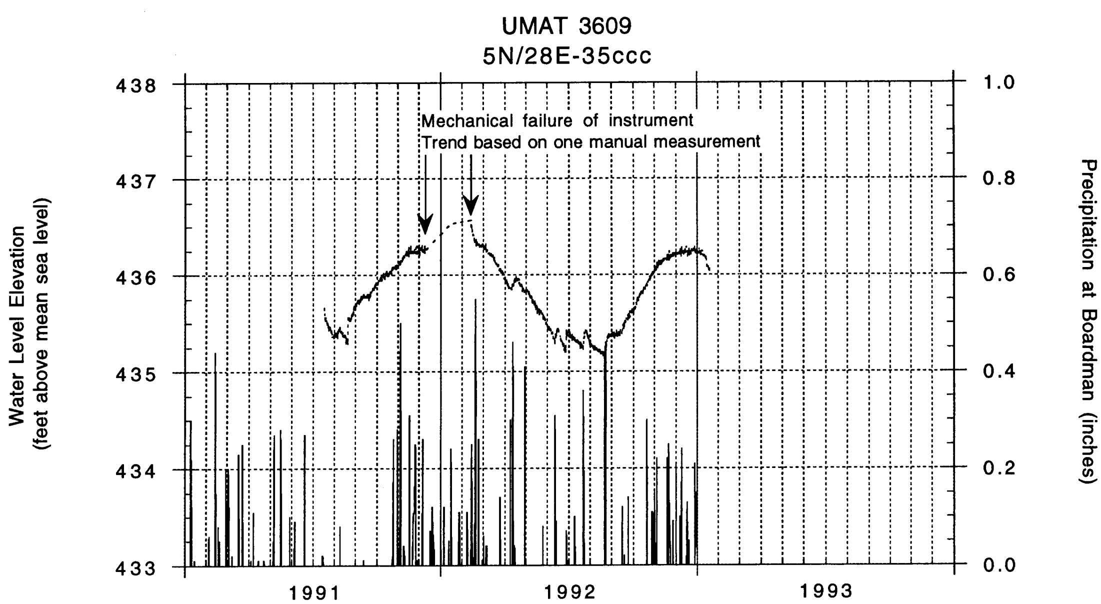


Figure 2.13 Continuous recorder hydrograph for well completed in coarse-grained flood deposits near Hermiston

Because hydraulic gradients are very low and well-head elevations are imprecise, the direction of groundwater flow in the Hermiston trough cannot be directly inferred from the water levels on Plate 2.4. Groundwater flow to the northeast cannot be precluded in the eastern one-third of the trough, an area which is drained to the Columbia River by Cold Springs Wash. Any such flow, however, would be restricted to a very narrow sediment-filled gap in the lower drainage of the wash. Because the land surface and the underlying basalt surface (Plate 2.2) slope gently to the southeast throughout most of the Hermiston trough, the predominant flow direction is inferred to be southwesterly, with discharge to the Umatilla River. Flowpaths in the western part of the trough are restricted to relatively narrow sediment-filled gaps located north and south of Hermiston Butte. Because of the low hydraulic gradients, local or seasonal flow directions may be highly variable, especially in the vicinity of high capacity wells or leaky canals.

Umatilla River Valley

Groundwater in the Umatilla River Valley occurs in undifferentiated catastrophic flood deposits and Holocene Alluvium. Groundwater levels near the river are at, or near, river level. The hydraulic connection between the river and the alluvial aquifer is illustrated by the water-level trends of several monitoring wells completed at the water table near the river (Figure 2.14). Seasonal water-level fluctuations range from 2 to 4 feet and correspond to the stage of the Umatilla River; the highest water levels occur in winter and spring, the lowest levels in summer and autumn. Spikes in June of 1991 correspond to flooding of the Umatilla River several weeks earlier, in late May (EMCON Northwest, 1992).

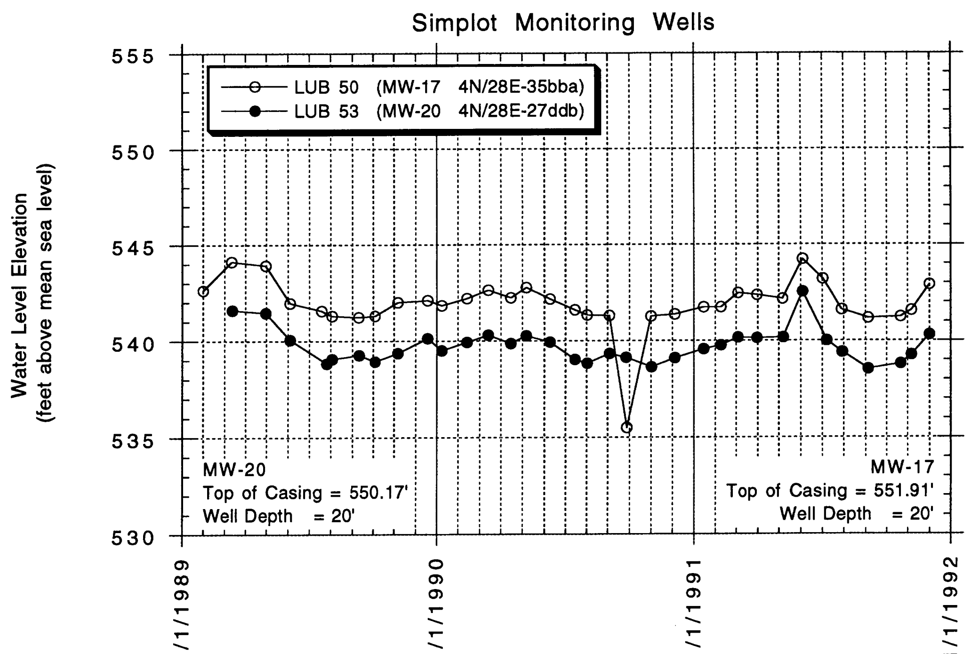


Figure 2.14 Hydrographs of wells completed in shallow unconfined water-bearing zones of the alluvial aquifer in the Umatilla River floodplain

Sixmile Canyon Area

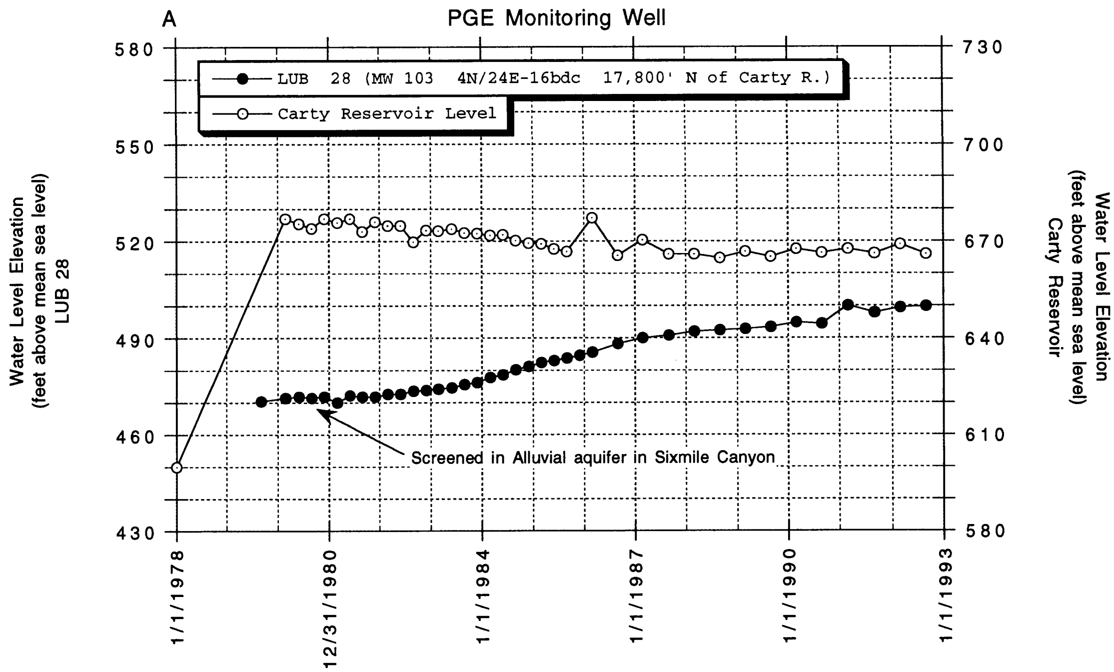
Sixmile Canyon is a narrow gorge which cuts through the Elephant Mountain Basalt between Carty Reservoir and the Columbia River. The canyon contains up to seventy feet of silt, sand, and gravel which rest upon the upper surface of the Pomona Basalt (cross section A-A', Plate 2.3). Saturated thickness within the sediments ranges up to 35 feet. Groundwater flow is to the north with discharge to the Columbia River. The hydraulic gradient averages about 30 feet per mile.

Prior to the filling of Carty Reservoir in 1977, Sixmile Canyon was dry and groundwater was limited to a thin zone at the base of the sediments (Portland General Electric, 1973). The long-term hydrograph for LUB 28 (Figure 2.15A) shows that groundwater levels in the canyon sediments have risen up to 30 feet since the reservoir was filled. Similar rises have occurred in wells completed in the basal Elephant Mountain aquifer in nearby areas (Figure 2.15B). In general, the onset of water-level rise is earlier, and the rate and magnitude of rise is greater, in wells closer to the reservoir. These relationships suggest that the observed rises are caused by leakage from Carty Reservoir and that the affected area has increased over time. Portland General Electric (1992) estimates that reservoir losses to groundwater are about 4000 acre-feet per year. This is equivalent to 10 or 15 percent of the total reservoir capacity.

Rising groundwater levels are also believed to be responsible for the ponds which now occur on the floor of Sixmile Canyon (and its western tributary) in and north of sections 16 and 17 of 3N/24E. The ponds occur in closed depressions, up to 30 feet deep, and were first observed in 1982 (Portland General Electric, 1984; Portland General Electric, 1985). An analysis of air photos and topographic contours (Ella 7.5-minute quadrangle) shows that pond elevations in sections 8 and 17 of 3N/24E were within a few feet of groundwater elevations in LUB 28 (4N/24E-16bdc) in September, 1989.

Although Carty Reservoir is believed to be the main source of recharge water to the alluvial aquifer in Sixmile Canyon, Portland General Electric (1992) presents water quality data that suggests a component of recharge from irrigated lands to the west. Quarterly measurements in LUB 27 (4N/24E-30cda) prior to 1986 indicate that annual water level highs occurred in late winter or early spring and seasonal lows in late summer or early fall. This suggests that seasonal groundwater-level trends in the canyon are not controlled by recharge from irrigation water. Seasonal trends after 1986 are less certain because of a change to semi-annual measurements.

In the areas adjacent to Sixmile Canyon, alluvial groundwater is limited to a thin layer near the top of the Elephant Mountain Basalt. The available data indicates that water levels have not changed notably in these areas since Carty Reservoir was filled.



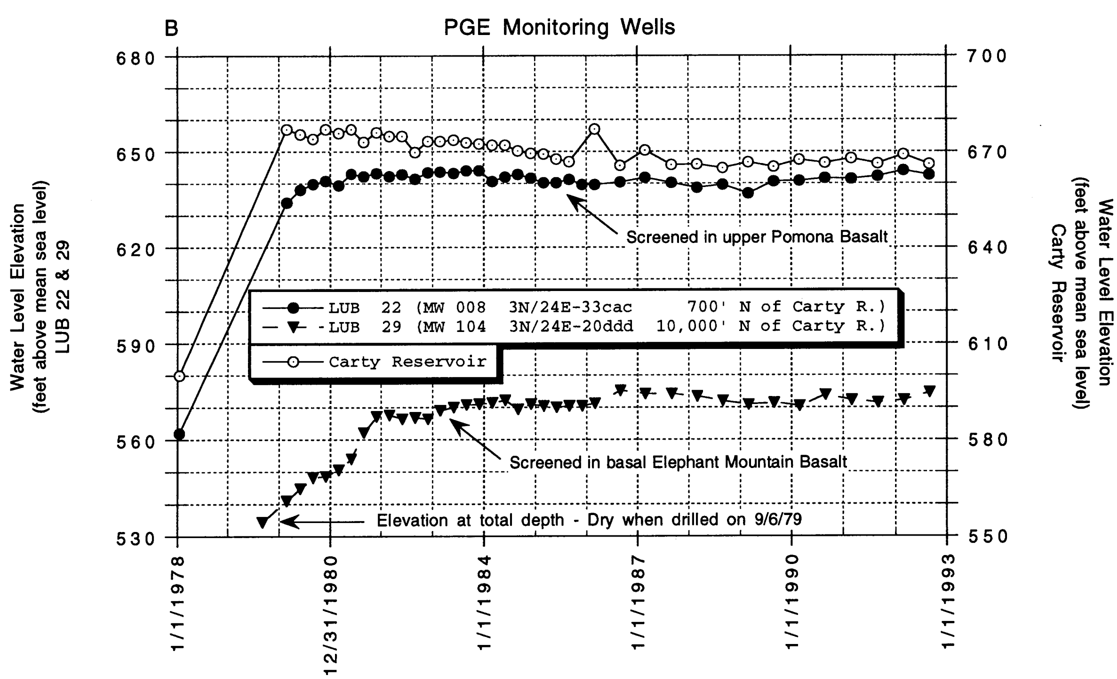


Figure 2.15 Hydrographs of monitoring wells near Sixmile Canyon showing rises in groundwater levels since the filling of Carty Reservoir. A, Alluvial well in Sixmile Canyon; B, Basalt wells west of Sixmile Canyon

Alkali Canyon Formation

The Alkali Canyon Formation is composed of poorly sorted clays, silts, sands, and gravels. The overall permeability of the unit appears to be low and well yields are capable of satisfying domestic needs only. Most of the formation lies above the regional groundwater table but scattered wells indicate the presence of some saturated zones at the base of the unit where it overlies the Columbia River Basalt Group. Beneath Finley Buttes, for example, saturated Alkali Canyon sediments occur several hundred feet below land surface. The saturated thickness ranges up to 40 feet but decreases to zero where local basalt highs rise above the water table (David J. Newton Associates, Inc., 1990).

Breccia/Fracture Zones at the Top of the Columbia River Basalt Group

The upper portions of Columbia River basalt flows are commonly scoriaceous and fractured. The occurrence of these brecciated or fractured zones at the top of the uppermost basalt flow is generally not noted on water well logs but is reported on many monitoring well logs. Reported thicknesses range up to 40 feet. Where overlain by saturated alluvial sediments, the breccia/fracture zones are likely to be hydraulically connected to the sediments, since both are relatively porous and permeable. Conversely, the uppermost breccia/fracture zone is hydraulically isolated from the first underlying basalt aquifer by the dense, relatively impermeable interior of the uppermost basalt flow. On this basis, the uppermost breccia/fracture zone is considered to be part of the alluvial aquifer.

The hydraulic connection between the uppermost breccia/fracture zone and the overlying alluvial sediments is illustrated by the behavior of adjacent monitoring wells completed in these zones at the Umatilla Ordnance Depot (Figure 2.16). One well (LUB 182) is completed exclusively in the uppermost breccia/fracture zone; the second (LUB 165) is screened at the water table in the overlying coarse-grained flood deposits. The hydrographs of both wells are virtually identical, showing the same response to seasonal pumping and recharge stresses that occur in the alluvial aquifer in the Ordnance area. Several pairs of similar wells at the Depot show the same behavior (Dames & Moore, Inc., 1992).

Hydraulic Properties

Table 2.1 shows a summary of hydraulic parameters derived from aquifer tests conducted in water-bearing units of the alluvial aquifer. For comparison, average conductivities from slug tests are also shown for wells on the Umatilla Ordnance Depot. Most of the data was collected from reports on file at the Oregon Water Resources Department. A single aquifer test was conducted in the coarse-grained catastrophic flood deposits during the current investigation; a summary of the test is presented in Appendix 2C.

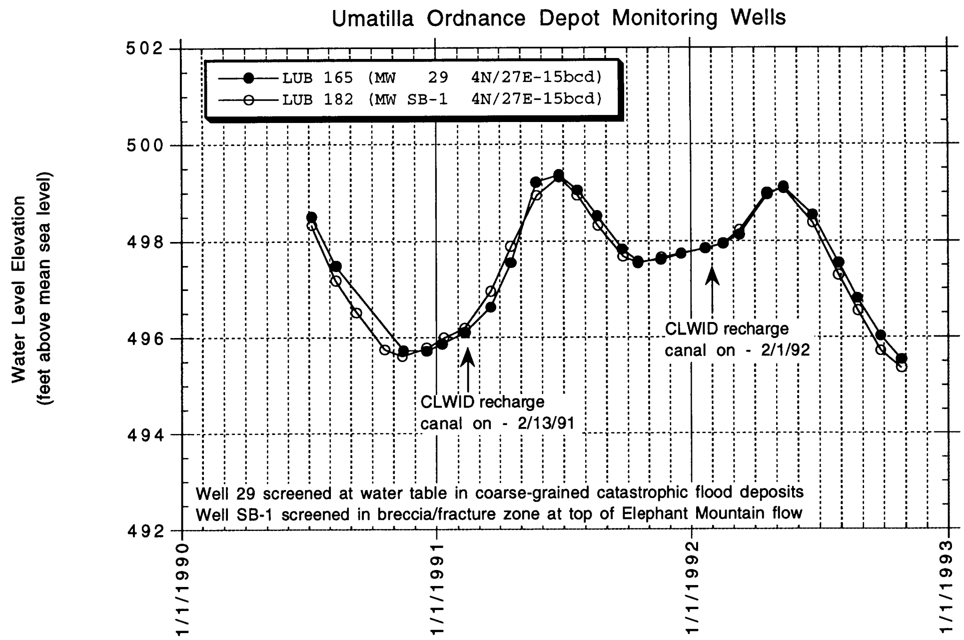


Figure 2.16 Hydrographs of adjacent monitoring wells completed at the water table in coarse-grained flood deposits and in the breccia/fracture zone at the top of the uppermost Columbia River Basalt flow on the Umatilla Ordnance Depot

The data in Table 2.1 show some scatter for hydraulic conductivity values in the alluvial aquifer. This is not unexpected since controlling factors, such as grain size and sorting, are known to vary locally and regionally in the aquifer. Some of the scatter can also be attributed to variations in testing methods and interpretive bias. Although it is beyond the scope of this report to critique the methods and assumptions of each of the tests, a review of the tests indicates that the reported values represent acceptable order-of-magnitude estimates of hydraulic conductivities in the alluvial aquifer.

High well yields and low hydraulic gradients suggest that hydraulic conductivities are high in the coarse-grained flood deposits. The rapid response of wells to artificial recharge and the widespread similarity in well behavior in the Ordnance area also indicate that conductivities are high. Based on these factors, and the data in Table 2.1, hydraulic conductivities for the coarse-grained flood deposits are assumed to be in the range of 1000 to 4000 feet per day. This is consistent with general estimates for clean sands and gravels (Freeze and Cherry, 1979). Storage coefficients for the coarse-grained flood deposits are assumed to range between 0.15 and 0.25.

Table 2.1 Summary of hydraulic parameters for the alluvial aquifer

Unit	Discharge	K gpd/ft*ft	K ft/day	S	Location	Method	Well	Source
Pscfc			2000-5000		Umatilla Ordnance Depot	Aquifer tests		Nick Easterly, Army Corp., personal comm.
Pscfc	>500 gpm	14960	2000	0.2	4N/27E-30	Aquifer test	MORR 683	This report, Appendix C
Pscfc	>500 gpm	9312	1245	0.24	4N/25E-02	Aquifer test	MORR 684	CH2M Hill, 1975
Pscfc	>500 gpm	9267	1239	0.37	5N/26E-27	Aquifer test	MORR 1250	CH2M Hill, 1975
Pscfc	>500 gpm	5131	686	0.21	5N/26E-31	Aquifer test	MORR 1252	CH2M Hill, 1975
Pscfc	<100 gpm	3067 - 13,389	410 - 1790		4N/27E-15bcd	Aquifer test	LUB 124	Dames and Moore, 1994b
Pscfc	<100 gpm	30,765 - 50,490	4113 - 6750		4N/27E-15bcd	Aquifer test	LUB 132	Dames and Moore, 1994b
Pscfc	<100 gpm	7802 - 29,351	1043 - 3924		4N/27E-15cab	Aquifer test	LUB 127	Dames and Moore, 1994b
Pscfc		4376	585		Umatilla Ordnance Depot	Average of multiple slug tests		Dames and Moore, 1994b
Pscff	>500 gpm	667	89 - 178	2.5 E-04	4N/29E-17	Aquifer tests	UMAT 2866	WRD files
Pscff		202	27		Umatilla Ordnance Depot	Average of multiple slug tests		Dames and Moore, 1994b

Pscfc: Coarse-grained catastrophic flood deposits
Pscff: Fine-grained catastrophic flood deposits

Little data is available on the hydraulic parameters of the fine-grained flood deposits. Steep hydraulic gradients and low yields suggest that hydraulic conductivities are low. Two aquifer tests have been conducted for UMAT 2866 (4N/29E-17), which produces from a 20 foot sand encased in "clay". Values from these tests suggest that hydraulic conductivities for the sand beds in the fine-grained deposits may range between 50 and 200 feet per day. Gravel beds are likely to have higher conductivities. Slug tests in fine-grained deposits on the Umatilla Ordnance Depot suggest that conductivities for flood silts and silty sands are less than 50 feet per day. General estimates for the hydraulic conductivities of silts and silty sands range from .001 to 10 feet per day (Freeze and Cherry, 1979).

Hydraulic properties of Holocene sediments are unknown but are expected to be similar to those of the catastrophic flood deposits because of the similarity in the sediments of the two deposits. Hydraulic properties of the Alkali Canyon Formation are also expected to be similar to those of the fine-grained flood deposits.

Recharge

Recharge to groundwater systems occurs when water infiltrates the land surface and percolates through soils and unsaturated materials to reach the water table. Potential sources of recharge include precipitation, canal leakage, stream leakage, reservoir leakage, and deep percolation of applied irrigation water.

Although a comprehensive accounting of recharge is beyond the scope of this project, rough estimates of recharge magnitude can be made for the major sources of potential recharge in the basin. These estimates are subject to large uncertainties and are presented solely to provide a sense of the relative magnitude of recharge from each source.

Soils in the Lower Umatilla Basin are typically sandy loams with moderate to high permeabilities (Johnson and Makinson, 1988). In many areas, these soils overlie coarse sands and gravels which are highly permeable. These conditions promote the rapid downward movement of any excess water that occurs at land surface. An example of rapid seepage in sandy soil was observed by the author in an area south of the Umatilla Ordnance Depot (SE/SE 30-4N/28E) when a one-mile length of 16-inch pipe was drained for repair in late March 1992. About 17,500 gallons of water was discharged from the pipe to a depression on the surface over a period of 1.5 hours (195 gallons per minute). After about 15 minutes of discharge, water began to accumulate in a shallow pond which grew to a maximum area of about 50 by 50 feet. Twenty minutes after discharge ended, all of the water in the pond had infiltrated the ground. This rapid infiltration of water is consistent with the known properties of the soils of the basin.

As will be shown below, the timing of water-level rises in wells near recharge sources indicates that recharge water can travel from the land surface to the water table in a period of time ranging from several days to several months.

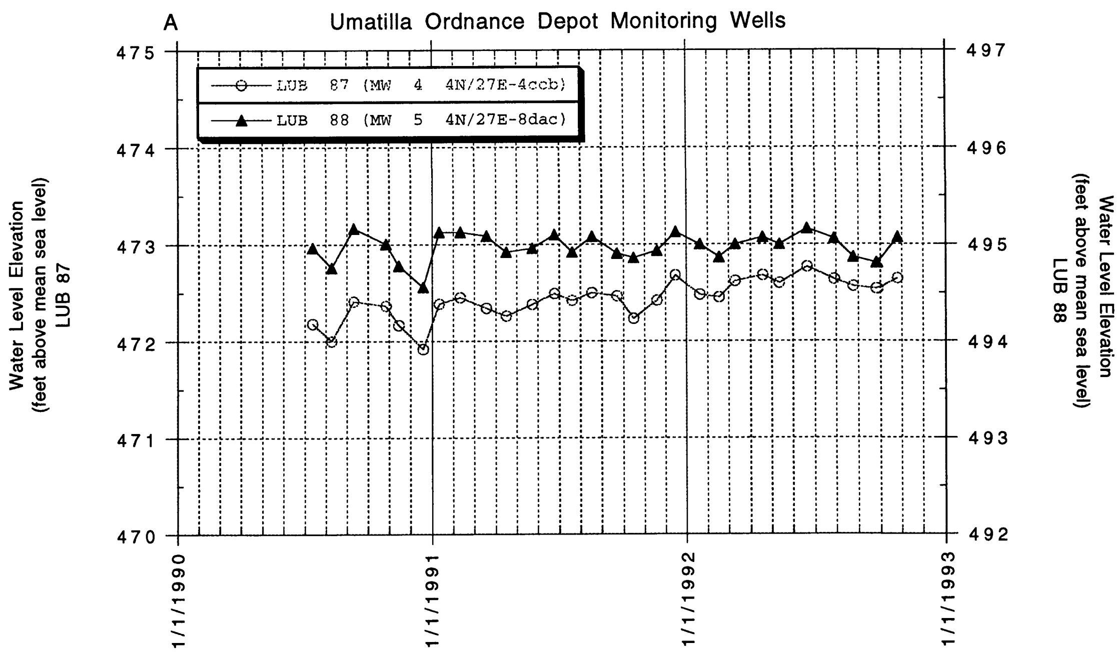
From Precipitation

Average precipitation in the study area ranges from about 8.0 inches per year near the Columbia River to 10.0 inches per year at the southern boundary (Johnsgard, 1963). Much of this precipitation is lost to evaporation and uptake by plants (evapotranspiration). When precipitation exceeds evapotranspiration some of the surplus moisture is lost as runoff and some is used to recharge soil moisture. The remainder is available as groundwater recharge.

A rough estimate of potential recharge from precipitation can be made by calculating an average monthly water balance. At Hermiston, for example, Johnsgaard (1963) estimates that evapotranspiration exceeds precipitation except for the months of November through February; for these months, the average moisture surplus totals 3.4 inches, about 40 percent of the average annual precipitation. This is the maximum potential recharge. Actual recharge will be lower because of losses to runoff and soil moisture buildup. This analysis suggests that most precipitation recharge occurs in the winter months and that the average long-term recharge from precipitation is less than 3 inches per year.

Using a model developed by the U.S. Geological Survey, Davies-Smith and others (1988) estimate that long-term recharge from precipitation is less than 0.2 inches per year in the area covered by the present study. This suggests that 2 inches per year would be a liberal estimate of precipitation recharge.

The behavior of wells completed in the fine-grained flood sediments on the northern part of the Depot also suggests that 2 inches per year is a liberal estimate for recharge from precipitation. As discussed above, water levels in these wells show rises of up to 3 feet per year but, little or no seasonal fluctuations (Figure 2.12). Rises are greatest near the eastern and western boundaries of the Depot and decrease toward the interior. This is consistent with inflow from the east and west. Since precipitation is likely to be uniform across the Depot, the variation in water-level rises cannot be attributed to precipitation recharge. On the other hand, wells near the center of the Depot are the most likely candidates to exhibit the effects of precipitation recharge because they are remote from other potential recharge sources. The best candidates are shown in Figure 2.17. Of these, LUB 88 shows no annual change and LUB 87 shows an annual rise of about 0.25 feet. Month to month trends are similar in both wells and show no obvious correlation to monthly precipitation trends at Boardman. In both wells, minor water-level rises of less than 0.5 feet occur in December or January of some years. This is equivalent to 1.2 inches of precipitation recharge, assuming an aquifer porosity of 20%.



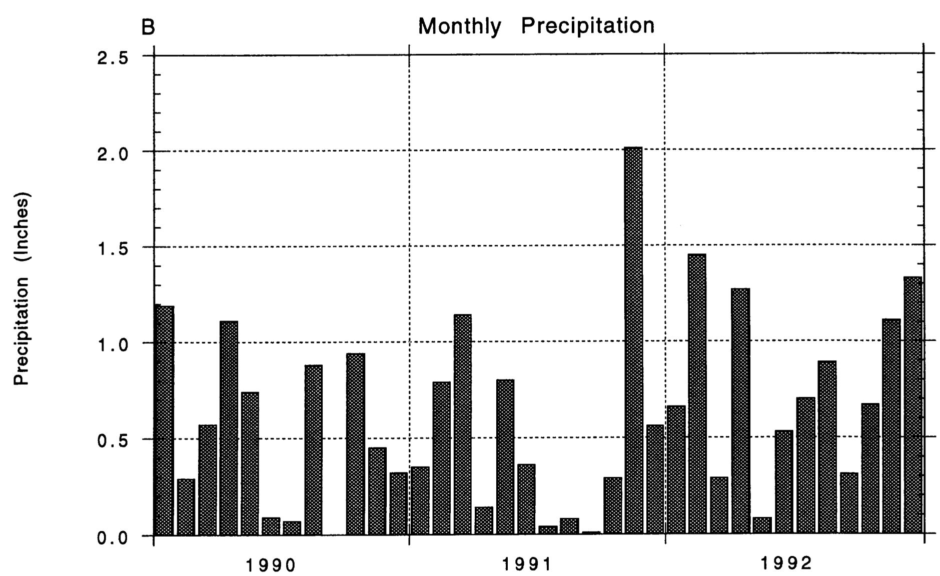


Figure 2.17 Comparison of water-level trends and precipitation in the interior of the Umatilla Ordnance Depot. A, Hydrographs of wells screened in fine-grained flood deposits; B, Monthly precipitation at Boardman

For comparative purposes, it is assumed that the average yearly recharge from precipitation falls within the range of 0.2 to 2 inches per year. This is the equivalent of 400 to 4000 acre-feet of recharge per township per year.

A conventional analysis suggests that precipitation recharge is unlikely outside of the winter months. However, as discussed above, the recorder hydrograph for UMAT 3609 (Figure 2.13) suggests that some precipitation recharge may occur during the spring and summer months. At this well, minor water-level rises in the spring and summer generally occur within two days following rainfalls of 0.3 inches or more. If these rises are caused by precipitation recharge, they indicate rapid rates of infiltration. If the surrounding soils are already near 100% saturation because of irrigation, 0.3 inches of rainfall may be sufficient to drive water downward to the water table.

From Canal Leakage

Approximately 130 miles of primary canals, and an unknown length of secondary canals and ditches, convey water for four irrigation districts in the basin (Plate 2.1). Most of the canals are unlined or have older linings which are reported to be in poor repair. In most areas, the canals traverse well-drained soils which are classified as fine loamy sand with moderate or "rapid" permeabilities (Johnson and Makinson, 1988). Although canal losses are known to be significant, no comprehensive study of losses has been conducted.

The Bureau of Reclamation estimates overall system losses of about 30% for the West Extension District, the only district with a lined major canal (LeAnn Ray, West Extension Irrigation District Manager, personal communication). Losses for the Stanfield and Westlands irrigation districts may be as high as 65% and losses for the Hermiston district may be even higher (Bill Porfily, former manager of Stanfield, Westlands, and Hermiston irrigation districts, personal communication) . These figures include all losses from the headgates to irrigated fields and do not differentiate between canal seepage, evaporation, and deep percolation of applied irrigation water.

The potential for canal leakage is illustrated by the artificial recharge project of the County Line Water Improvement District. The project was constructed in the early 1970s to recharge the alluvial aquifer in the Lost Lake area. The recharge project consists of an unlined canal which is about 2.5 miles long and 20 feet wide (Plates 2.1 and 2.4). A broad area at the western end of the canal is sometimes used as an overflow area and infiltration pond. Water is delivered to the southern end of the recharge canal by a pipeline which diverts water from the Westland High Line Canal near its terminus at Lost Lake. Annual water deliveries to the recharge canal have averaged about 5200 acre-feet per water year through 1993 (WRD files). Evaporation losses are believed to be relatively low because most of the water is delivered in the winter months. Assuming that most of the infiltration occurs through the floor of the canal, the infiltration rate is about 2000 acre-feet per canal mile per year. Assuming an average operating period of 150 days, this is equivalent to about 13 acre-feet per canal mile per day. These estimates are probably high since an unknown amount of water percolates through the infiltration pond at the western end of the canal. As noted above, nearby wells respond to recharge within several days of the filling of the canal. This is consistent with a rapid rate of infiltration.

Evidence for canal leakage can be seen on the hydrographs of various wells in the basin. The best examples are from shallow monitoring wells screened at the water table in the northern part of the Butter Creek floodplain. In this area, the floodplain is bordered and crossed by several canals of the Westland Irrigation District. Hunt Ditch, the southernmost canal, crosses the floodplain in section 8 of 3N/28E, about 2.5 miles south of Interstate 84. Figure 2.18A shows hydrographs for typical monitoring wells located north of the Hunt Ditch crossing. In these wells, water levels rise in the spring, peak in the summer, and fall to annual lows in the winter. Annual fluctuations of 10 to 15 feet across the floodplain suggest a high volume of recharge in the spring and early summer. These patterns do not correlate to precipitation (see Figure 2.17B) or to flow in Butter Creek, which is typically depleted by diversions beginning in May. In wells south of the Hunt Ditch crossing (Figure 2.18B), water-level highs occur earlier in the year, seasonal fluctuations are on the order of 5 feet, and the water table is above the elevation of the ditch (about 615 feet). Since irrigation practices and stream flow do not vary significantly north and south of Hunt Ditch, most of the annual water-level rise in the northern wells can be attributed to seepage losses from Hunt Ditch, the High Line Canal, and the A Canal. Water-level rises in January, February, and March may correspond to seepage loss from Butter Creek or to deep percolation of potato-processing plant effluent water prior to the irrigation season.

The Westland Irrigation District has long suspected substantial losses along a section of the A canal near Cottonwood Bend (Miller, 1985). In this area soils are thin and Pleistocene flood gravels are exposed at or near the surface. Measurements during the summer of 1994 indicate a loss of 7.5 cfs out of a total flow of 50 cfs over a 4 mile section (Carol Bradford, Westland Irrigation District manager, personal communication, 1995). This translates to a loss of 3.7 acre-feet per mile per day or about 550 acre-feet per mile per year, assuming a 150 day operating season.

Comparison values are available for the Umatilla Project Feed Canal. The Feed Canal diverts water from the Umatilla River near Echo and delivers it to Cold Springs Reservoir during the months of November through May. The canal is 24.5 miles long, has no secondary diversions, is unlined, and is gauged at both ends. The average diversion at Echo over 65 years of record is 69,810 acre-feet per water year (Oregon Water Resources Dept., 1988). Gauge readings for the period of December 6, 1993 to March 23, 1994 (107 days), indicate a transmission loss of approximately 13.25% (Pendleton Watermaster Office). This is equivalent to an average loss of about 9250 acre-feet per year or 380 acre-feet per mile per year. Since the canal operates mainly during the winter months, evaporation losses are considered to be small. Assuming that the canal operates for 150 days, seepage losses are about 2.5 acre-feet per mile per day. Similar canals operating in the summer would probably have somewhat higher evaporation losses and lower seepage losses.

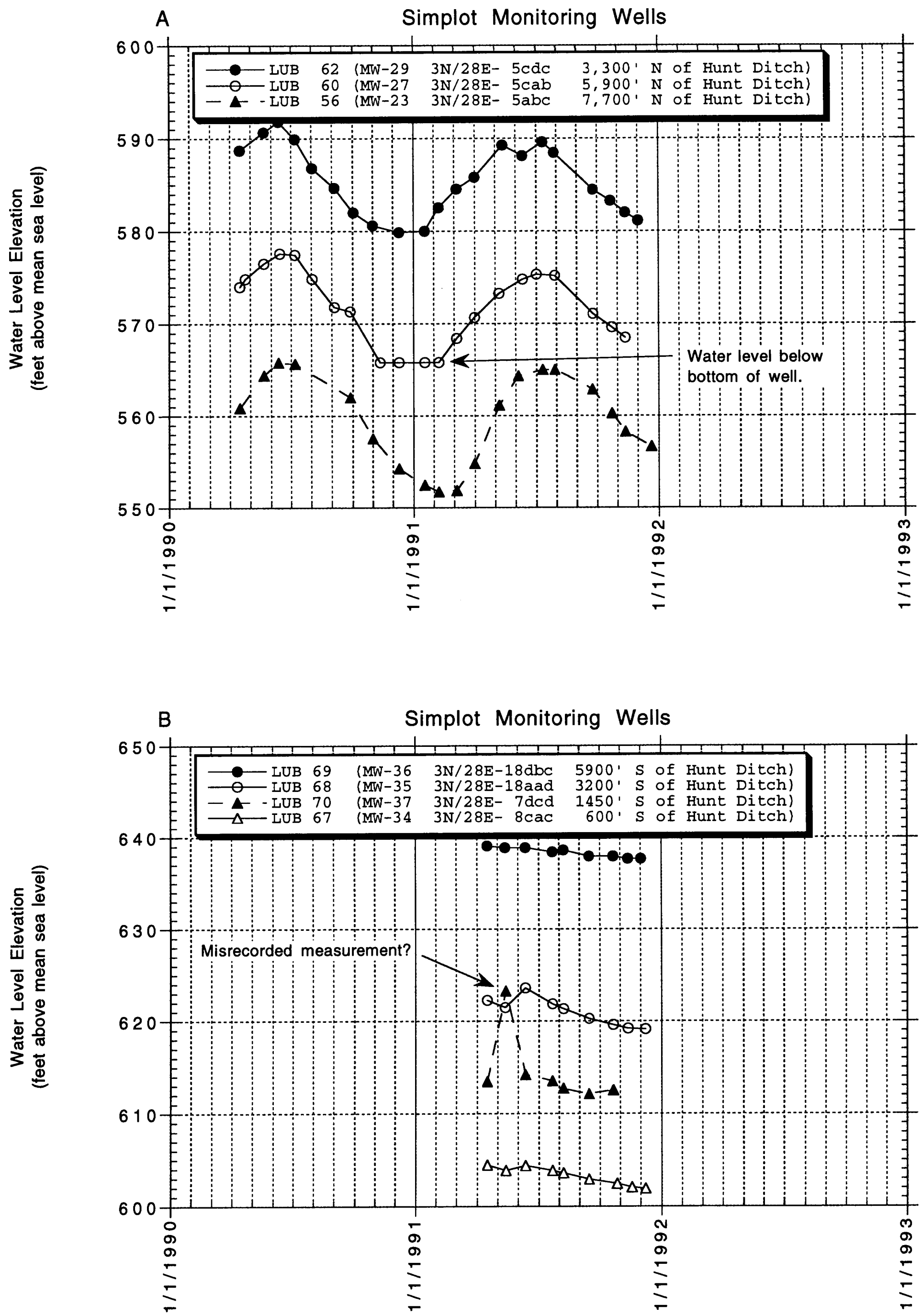


Figure 2.18 Hydrographs of monitoring wells screened in Holocene Alluvium in the Butter Creek floodplain. A, Wells north of Hunt Ditch; B, Wells south of Hunt Ditch

Soil conditions along the Feed Canal are typical for the main delivery canals in the basin. On this basis, seepage rates for the Feed Canal are assumed to be representative for other major canals. Seepage rates for the Westland A canal in the Cottonwood Bend area are assumed to represent an upper limit for losses from typical canals. These assumptions ignore other factors which influence seepage rates, such as canal width and depth and variations in soil permeabilities, but are considered to be reasonable as a first-order approximation of canal losses.

Estimates of yearly canal losses for the main delivery canals in the basin are shown in Table 2.2 The estimates assume a seepage rate of 2.0 acre-feet per mile per day, a rate slightly lower than that of the Feed Canal. The estimates also assume a five-month operating season. This equates to a loss of 300 acre-feet per mile per year. By this account, losses for the four districts total about 40,000 acre-feet per year. Of the total area downslope (downgradient) of canals in these districts, approximately 190 square miles (5.3 townships) are underlain by the alluvial aquifer. This equates to a canal recharge of about 7500 acre-feet per township in the affected areas, the equivalent of about 4 inches of rainfall per year

Table 2.2 Estimates of yearly canal losses for main delivery canals.

Irrigation District	Canal	Avg Yrly Diversion * (acre-ft)	Length** (miles)	Estimated Loss (acre-ft/yr)
Hermiston	U S Feed	69,810	25.0	7500
	A Line	50,000	10.0	3000
	Maxwell	18,680	10.0	3000
Stanfield	Furnish	36,550	30.0	9000
Westland	Westland	63,340	20.0	6000
	A***		8.0	2400
West Extension	West Extension	62,360	27.0	8100
Totals		300,740	130	39,000

* Oregon Department of Water Resources, 1988
** Based on digitized lengths from 1:100,000 scale maps
*** Excludes recently lined sections

As noted above, these estimates do not include an analysis of factors that would cause seepage to vary from place to place. They also ignore losses from lateral canals, ditches, and drains. If we assume that all errors have been on the liberal side for seepage, 150 acre-feet per mile per year (4000 acre-feet per township or 2 inches of rainfall per year) represents a conservative lower limit on canal losses. This is equivalent to a liberal estimate of annual recharge from rainfall. More than likely, recharge from precipitation is lower and recharge from canal seepage is higher.

For comparative purposes, canal losses have been shown in terms of acre-feet per township. All else being equal, however, the effective recharge from canals will vary from place to place because of variations in canal density. In addition, portions of some canals lie within a short distance of the Umatilla River. In these areas, canal losses may only affect a small portion of the aquifer before the water is discharged to the river. A qualitative impression of the canal impacts on the groundwater system can be gained by noting the distribution of canals on Plate 2.4.

Projects which reduce or eliminate canal seepage will impact groundwater recharge. For example, in order to maintain higher flows in the Umatilla River, the Bureau of Reclamation plans to decrease diversions to the Feed Canal and the Furnish Ditch (Phase II of the Columbia Basin Project). Replacement water will be pumped via pipeline from the McNary Pool on the Columbia River to the newly constructed Columbia-Cold Springs Canal. The canal, which is lined, will deliver water to Cold Springs Reservoir and to the lower section of the Furnish Ditch. This may decrease seepage recharge to the alluvial aquifer by up to 10,000 acre-feet per year.

Several irrigation districts are actively seeking funds to reduce seepage losses. The Westland District has already lined several miles of the A canal and replaced the F canal with pressurized pipes. These modifications were made in the late 1980s and may be partly responsible for water-level declines which have occurred since 1986 in the coarse-grained flood deposits of the Ordnance area. Additional conservation measures are likely to be implemented by all of the districts in the future. If discharge remains at historic levels, the overall effect of these conservation measures will be to decrease the amount of groundwater in storage. Conservation measures in the West Extension District are expected to have the least impact because losses are relatively low to begin with and, because the saturated thickness of the aquifer in the area is largely controlled by the elevation of the John Day pool of the Columbia River.

From Stream Leakage

A comparison of stream elevations (7.5-minute topographic maps), water levels in wells, and water table elevations (Plate 2.4) indicates that stream elevations are up to 20 feet higher than adjacent water table elevations in the lower Butter Creek valley north of sections 17 and 18 of 3N/28E and, in the Umatilla River valley between sections 19 and 30 of 4N/28E (Cottonwood Bend) and section 35 of 4N/28E. These relationships indicate that Butter Creek and the Umatilla River lose water to the underlying alluvial aquifer along these reaches. The rate of downward flow cannot be determined on the basis of the available data.

Although several reports infer that the uppermost water-bearing zones in these stream reaches are perched above the water table of the alluvial aquifer, no data is provided to document an underlying unsaturated zone (Sweet, Edwards & Associates, 1987; EMCON Northwest, Inc.). If no unsaturated zone is present, pumpage from nearby alluvial wells may increase the hydraulic gradient between the streams and the aquifer. This will increase the rate of stream leakage and decrease flow in the streams.

From Reservoir Leakage

Cold Springs and Carty reservoirs are the main water-storage facilities in the Lower Umatilla Basin. Cold Springs is located about six miles east of Hermiston and is operated by the Bureau of Reclamation. Carty Reservoir is operated by Portland General Electric (PGE) at its Boardman coal-fired generating plant site, about 12 miles southwest of Boardman. Although Carty Reservoir is west of the main productive part of the alluvial aquifer, leakage is well documented and the reservoir illustrates the potential, as well as the mechanisms, for leakage.

Carty Reservoir provides cooling water for the Boardman Coal-Fired Plant and receives some plant effluent discharge. The reservoir lies behind the escarpment formed by the southern terminus of the Elephant Mountain flow and fills a swale which was probably created by the Missoula floods. The reservoir dam is constructed across the head of Sixmile Canyon at the edge of the escarpment (Plate 2.2 and cross section A-A', Plate 2.3). Reservoir capacity ranges from 26,000 acre-feet at low pool elevation (667 feet) to 38,300 acre-feet at high pool elevation (677 feet). Maximum reservoir depth ranges from 67 to 77 feet. Water to fill and maintain the reservoir is pumped via pipeline from the Columbia River at the mouth of Willow Creek. Prior to the filling of Carty Reservoir in 1977, Sixmile Canyon was dry and groundwater occurred only at the base of the sediments in the canyon (Portland General Electric, 1973). The long-term hydrograph for LUB 28 (Figure 2.15A) shows that groundwater levels in the canyon have risen progressively since the reservoir was filled. Similar rises have occurred in confined aquifers at the base of the Elephant Mountain Basalt and the top of the Pomona Basalt (Figure 2.15B). Portland General Electric (1992) estimates that reservoir losses to groundwater total about 4000 acre-feet per year (11 acre-feet per day), the equivalent of 10 to 15 percent of the total reservoir capacity. The proportion of losses to the sediments versus the basalt flows is unknown.

Seepage to the sediments in Sixmile Canyon may occur beneath the toe of Carty dam or beneath wing dams on the east and west sides of the reservoir. Indirect seepage to the sediments probably occurs through breccia/fracture zones at the base of the Elephant Mountain and the top of the Pomona basalts. These zones, exposed in the floor of the reservoir and beneath sediments in the reservoir and Sixmile Canyon, provide a conduit for transporting groundwater from the reservoir to the alluvial aquifer in Sixmile Canyon (cross section A-A', Plate 2.3). The rapid rise in water levels in the basal part of the Elephant Mountain flow and the upper upper part of the Pomona flow after the filling of Carty Reservoir suggests that these zones are relatively permeable.

Leakage is also documented at Cold Springs Reservoir. Cold Springs was constructed in 1908 to store Umatilla River water for the Hermiston Irrigation District. River water is delivered to the reservoir via the Feed Canal during winter and spring and released through the A Line Canal during the irrigation season. Reservoir capacity is about 50,000 acre-feet and pool elevation varies from about 570 to 623 feet. The minimum pool level occurs at the end of the irrigation season and the maximum level occurs in late spring.

Cold Springs dam is an earthfill embankment constructed across a narrow gorge in Cold Springs Wash near the southern margin of the Pomona Basalt (Plate 2.2 and cross section E-E', Plate 2.3). An adjoining wingdam extends south to the Feed Canal, a distance of about 2000 feet. The northern part of the dam in Cold Springs Wash abuts against the Pomona Basalt, which forms the northern barrier for the reservoir. Along the northern shore, the surface of the basalt lies above elevations of 600 feet except in an erosional saddle on the northwest shore. The Pomona basalt also occurs along the southern dam abutment up to elevations of about 580 feet, just above the outlet level for the A Line Canal. South of Cold Springs Wash, the surface of the Pomona Basalt dips to the south and alluvial sediments form the southwestern bank of the reservoir. At the damsite, Cold Springs Wash cuts through about 100 feet of the Pomona Basalt. About 40 feet of alluvial sediments overlie the basalt in the wash at the base of the dam. The water table in these sediments occurs within several feet of land surface. When the dam was built, the sedimentary fill was removed and the underlying basalt was trenched and filled with a small concrete berm to prevent seepage through the sediments at the base of the wash (Acree, 1988).

Seeps are common along the southern dam abutment and have been reported since the reservoir was first filled (Acree, 1988). Some of these seeps occur in Cold Springs Wash at the southern toe of the dam. Others occur above the A Line Canal at the contact between the Pomona Basalt and the overlying alluvial sediments. About 3500 feet downstream from the dam, a spring occurs in the floor of the wash. The owner of the spring reports (Acree, 1988) that flow is constant throughout the year at a rate of 1000 gallons per minute (4.4 acre-feet per day) but this has not been confirmed by independent measurements.

Piezometers installed by the Bureau of Reclamation (Acree, 1988) indicate that seepage from the reservoir occurs through the alluvial sediments which underlie the southern wing dam but not through the dam itself. Seepage also occurs through breccia/fracture zones at the top of the basalt. Figure 2.19 shows hydraulic heads for a representative pair of piezometers installed in the alluvial sediments and the upper basalt surface beneath the southern wing dam. The piezometers are nested at a single well site. As seen in the figure, a substantial mound of groundwater builds up in the aquifer as the reservoir fills. Nearby piezometers indicate a maximum rise of 20 feet. A vertical component of hydraulic gradient is indicated by lower hydraulic heads at depth. This is consistent with recharge from the reservoir.

The rate of seepage loss from Cold Springs Reservoir to the alluvial aquifer cannot be calculated from the available data. Several years of gauge records document the inflow and outflow of water through canals but a complete water budget would require an analysis of evaporation losses and knowledge of inflow from Despain Gulch and Cold Springs Canyon.

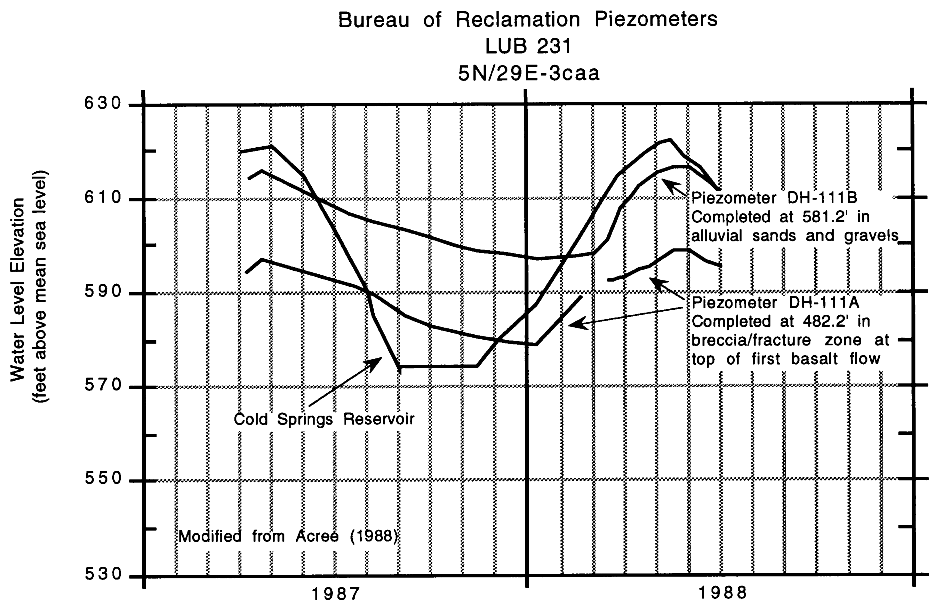


Figure 2.19 Hydrographs of paired piezometers completed near the water table in the alluvial aquifer and in the breccia/fracture zone at the top of the uppermost Columbia River Basalt flow near Cold Springs Dam.

Seepage at Cold Springs Reservoir is controlled by the geometry of the Columbia River Basalt flows. Only minor seepage occurs along the north abutment of the dam (Acree, 1988) which sits directly on the basalt surface in Cold Springs Wash. In addition, piezometers completed in basalt at the base of the dam show little response to changing reservoir levels. These factors suggest that the interior of the Pomona flow is relatively impermeable to the flow of water. Seepage is possible under the southern wing dam because permeable alluvial sediments occur beneath the dam south of Cold Springs Wash (Plate 2.2). The basal elevation of the sediments is controlled by the "topography" of the underlying basalt surface which forms a northeast-trending trough centered about 0.6 miles south of Cold Springs Wash. At the outlet for the A Line Canal, the base of the sediments occurs at an elevation of about 580 feet, 43 feet below the maximum reservoir level. One-quarter mile to the southwest, the base of the sediments drops to an elevation of about 490 feet, 133 feet below the maximum reservoir level. The base remains near this level for another one-half mile to the southeast where the basalt surface begins to rise gradually to the southeast. Throughout this area, the silts, sands, and gravels which overlie the basalt provide a conduit for the flow of water from the reservoir to the alluvial aquifer.

A similar geometry occurs along the northwestern shore of Cold Springs Reservoir where a saddle in the basalt surface drops the base of the alluvial sediments to slightly below 600 feet elevation. Above this elevation, the sediments form the northern bank of the reservoir. These sediments, and the upper brecciated surface of the Pomona flow, form a potential northwesterly pathway for the seepage of water from Cold Springs when the reservoir level rises above 600 feet elevation. No well data is available to confirm seepage along this pathway.

Another potential pathway for seepage from Cold Springs Reservoir is through breccia/fracture zones at the contact between the Pomona Basalt and the underlying Umatilla Basalt. These zones are exposed at the southern margin of the Pomona flow which appears to occur beneath a cover of alluvial sediments in the reservoir (Plate 2.2 and cross section E-E', Plate 2.3). The geometry between the reservoir and the southern margin of the Pomona flow is analogous to that between Carty Reservoir and the southern margin of the Elephant Mountain flow. Although well data is not available to confirm seepage along this pathway, the analogy with Carty Reservoir suggests that seepage is likely to occur.

From Deep Percolation of Irrigation Water

Deep percolation occurs when irrigation water infiltrates beyond the root zone and becomes available for groundwater recharge. The potential for deep percolation exists wherever irrigation water is being applied to the land surface. The occurrence of deep percolation is controlled by factors such as soil permeability, soil moisture content, depth of the root zone, and the rate and timing of water application.

All other factors being equal, the potential for deep percolation is related to the rate at which water is applied to the land surface. Application rates are controlled by the method of irrigation and by the water management strategies of individual irrigators. Within the study area, irrigation methods include the flooding of fields, the use of various sprinkler systems (hand lines, wheel lines, and center pivots), and the use of drip irrigation systems. The relative potential for deep percolation is high for flood irrigation, less for sprinkler irrigation, and very low for drip irrigation.

A survey of irrigation districts indicates that flood-irrigated lands total about 10% of the Stanfield and Westland districts, about 40% of the West Extension district, and as much as 50% of the Hermiston district (Bill Porfily, Carol Bradford, LeAnn Ray, former and current district managers, personal communications). The remaining lands are irrigated by sprinkler systems. Center pivots are common on large plots in the districts and are the dominant sprinkler system used outside of the districts.

Areas of potential deep percolation correspond to irrigated lands which overlie the alluvial aquifer. According to files at the Oregon Water Resources Department, approximately 188,000 acres of irrigated lands are listed on valid water rights in the study area (Plate 2.6). This corresponds reasonably well to an estimate by DEQ (this report) of 180,000 acres of irrigated land based on 1992 LANDSAT photos. Current information is not sufficient to calculate the total contribution of deep percolation to recharge of the alluvial aquifer. However, based on irrigation methods, the relative potential is considered highest within the Hermiston and West Extension irrigation districts, lower in the other districts, and lowest outside of the districts.

Evidence for deep percolation of irrigation water is seen in various places around the basin. Examples are discussed below.

Deep percolation is probably the major source of recharge in the area around the northeast corner of the Umatilla Ordnance Depot. In that area, groundwater occurs in predominantly fine-grained flood deposits dominated by silt and clay, with minor interbeds of sand. Unconfined groundwater occurs in shallow water-bearing zones and confined groundwater occurs in deeper water-bearing zones. Local recharge is indicated by the presence of a groundwater mound (Plate 2.4). A comparison of adjacent wells completed in shallow and deep water-bearing zones shows that water-levels are higher in the shallow zones (Figure 2.20). This indicates a downward component of hydraulic gradient consistent with local recharge. The similarity in the trend and magnitude of water-level changes in these wells suggests that they are responding to the same stresses. Large-capacity pumping wells are not located in the area (Plate 2.6) and the hydrographs do not show any pumping influences. This suggests that recharge is the principal factor controlling water levels in both zones. The rapid increase in water levels in both wells in late February of 1991 suggests that recharge water moves downward relatively rapidly in spite of the predominantly fine-grained nature of the sediments.

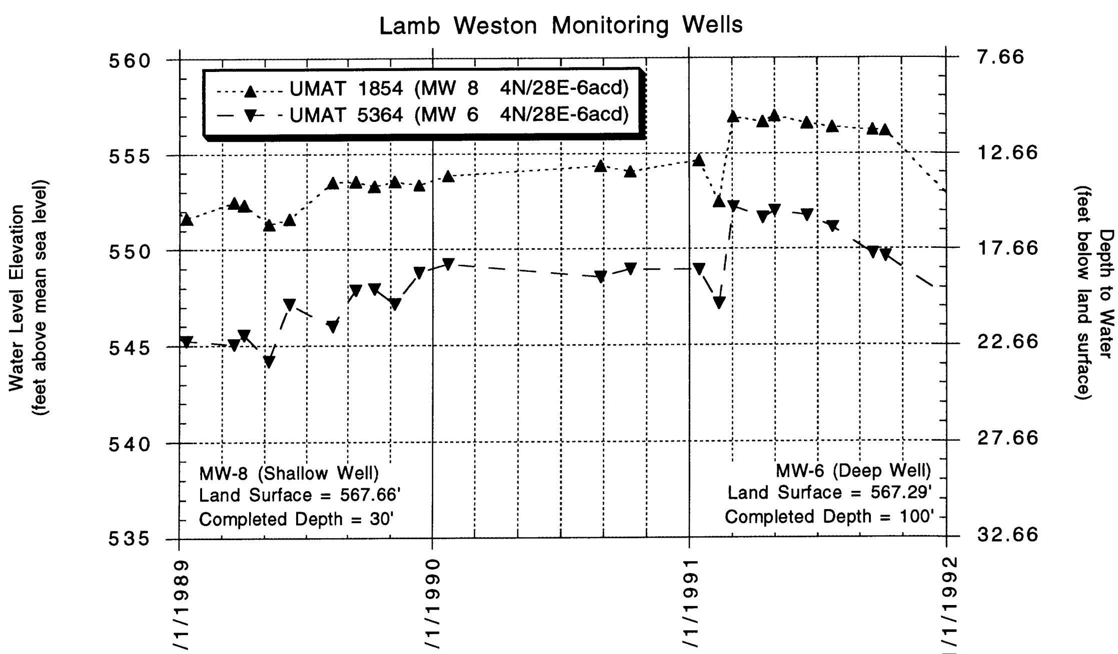
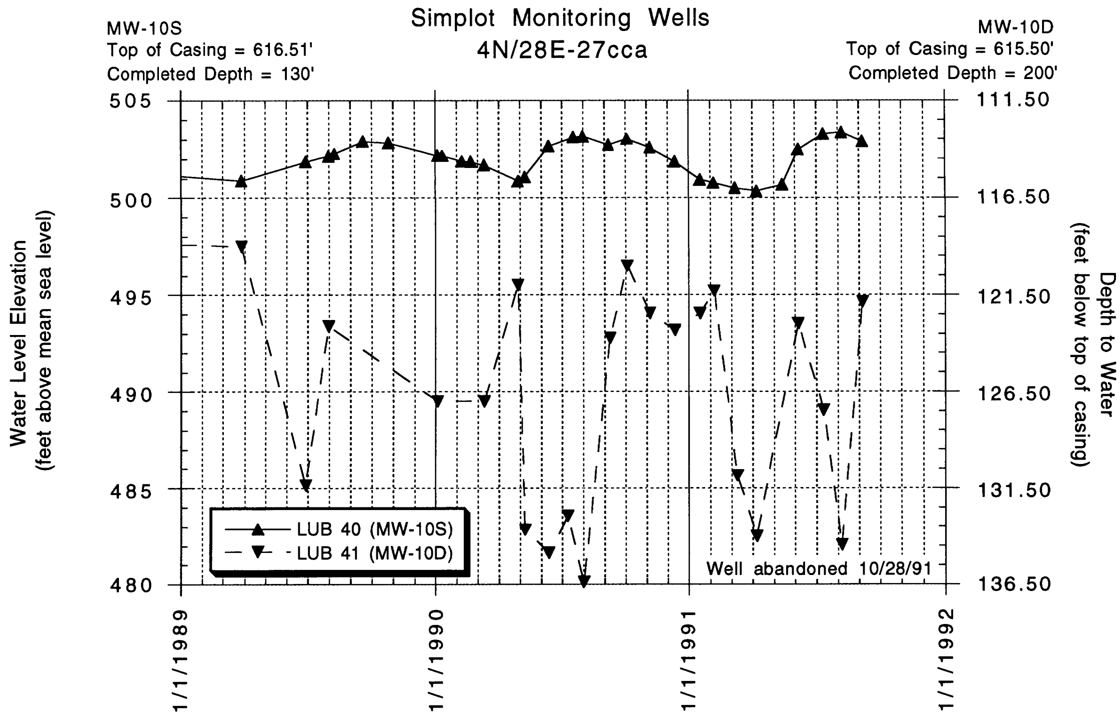


Figure 2.20 Hydrographs of adjacent wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits northeast of the Umatilla Ordnance Depot

Potential recharge sources near the northeastern boundary of the Depot include precipitation, leakage from the Westland A Canal, leakage from an unlined pond in the southeast corner of section 1 of 4N/27E, and deep percolation of irrigation water. As discussed above, hydrographs in the northeastern corner of the Depot (Figure 2.12B) show annual water-level rises that decrease with distance from the eastern boundary of the Depot. This indicates that recharge rates are higher to the east. Since precipitation is likely to be uniform across the area, it can be eliminated as a major recharge source for the mound. Although the Westland A Canal flows through the area on the eastern side of the mound, the elevation of the canal (about 558 feet) is at least 20 feet lower than the highest part of the mound. In addition, this section of the canal is an unlikely recharge source because it was lined in the late 1980s when highway I-82 was built. The pond in the southeast corner of section 1 of 4N/27E lies at an elevation of approximately 600 feet, about 20 feet above the highest part of the mound, but is located about one-half mile south of the center of the mound. At less than 4 acres in size, the pond seems an unlikely source for such widespread recharge effects. This suggests that deep percolation of irrigation water is the principal source of recharge over the mound. Lands immediately overlying the center of the mound have been used for the year-round disposal of waste water (through irrigation sprinklers) from a local food-processing plant since 1972. The applied acreage has increase from about 320 acres in 1972 to about 800 acres at present. Records at DEQ (DEQ Water Quality File 48780) indicate that, until recently, water was applied to these fields at rates greater than needed for crop cultivation. In addition, much of the water was applied in the winter months when evapotranspiration was minimal. These conditions, which are highly favorable for deep percolation, suggest that much of the recharge for the groundwater mound has come from land application of food-processing waste water at this site.

Deep percolation is also a likely source of recharge on the terrace immediately north of the Umatilla River between highway 207 and the Hinkle rail yards (sections 26-28 and 33-34 of 4N/28E). Groundwater in this area occurs in predominantly fine-grained flood deposits. Well logs document a shallow unconfined water-bearing zone separated from one or more deeper confined water-bearing zones by laterally discontinuous beds of silt or clay. Various reports (Sweet, Edwards & Associates, 1983, 1985, 1987; EMCON Northwest, Inc., 1992) refer to the shallow zone as a perched groundwater body but no evidence is presented to document an unsaturated zone at its base. The boring log (WRD files) for LUB 46 (4N/28E-28ddc) indicates that confining beds of gravelly silt and silt between the upper and lower water-bearing zones are saturated throughout.

Figure 2.21 shows hydrographs for wells completed in the shallow unconfined water-bearing zone and the deeper confined water-bearing zones on the terrace north of the Umatilla River. Higher water-levels in the shallow zone indicate a downward component of hydraulic gradient consistent with local recharge. The deeper confined zones show pumping impacts from nearby irrigation and industrial wells (Plate 2.6), most notably in the summer. In contrast, the shallow unconfined zone shows no obvious pumping impacts. Water levels in the shallow zone are highest in summer and autumn and lowest in winter and spring.



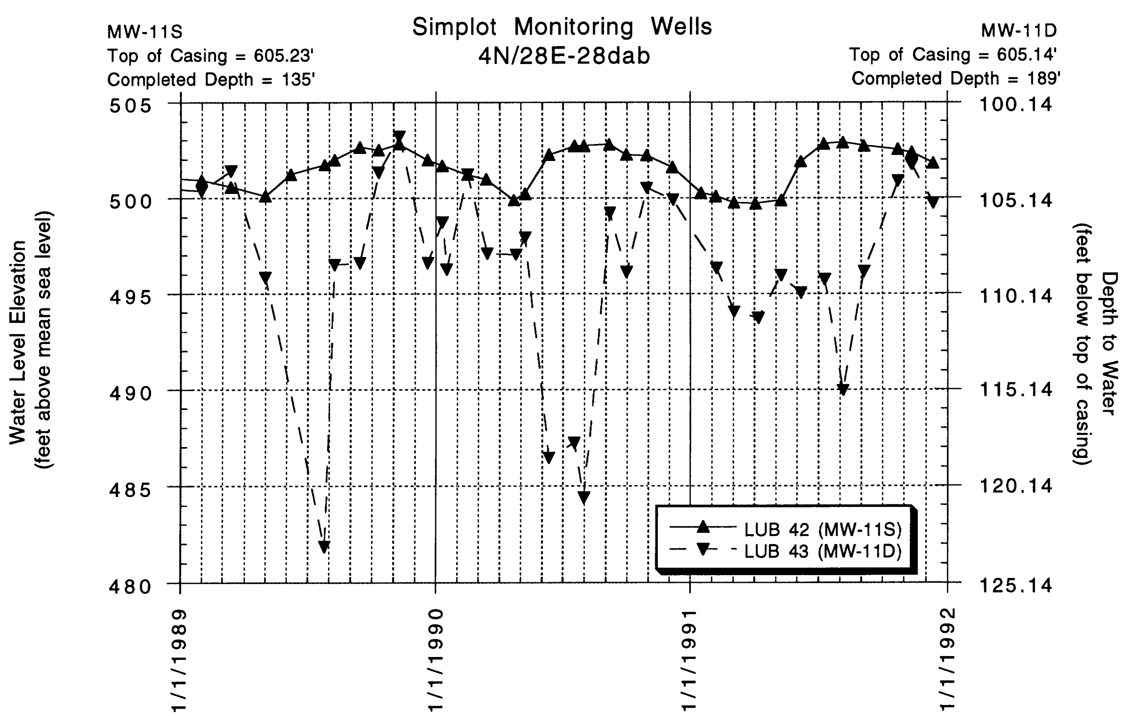


Figure 2.21 Hydrographs of paired wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits on the terrace north of the Umatilla River.

This suggests that the dominant factor controlling water levels is canal leakage or deep percolation of irrigation water. The presence of elevated nitrates in the shallow zone (EMCON Northwest, Inc., 1992) suggests that deep percolation is an important source of recharge but recharge from nearby canals cannot be precluded. The nearest canals include the Maxwell Canal (about one-half mile to the east at and elevation of 529 feet), the Feed Canal (about one mile to the northeast at an elevation of 628 feet), and the A Line Canal (about 1.5 miles to the northwest at an elevation of 555 feet). All three canals occur at higher elevations than the shallow water-bearing zone on the terrace. Apart from pumping effects, water-level trends in the deeper zones are similar to trends in the shallow zone. This suggests that both zones are recharged by the same sources.

Evidence for deep percolation is also seen in the hydrographs of several monitoring wells in section 4 of 3N/28E, between Butter Creek and Emigrant Buttes (Figure 2.22A). Water levels in these wells show seasonal fluctuations that correlate in part to leakage from the nearby Hunt Ditch (compare with Figure 2.18A but note the difference in vertical scale). An additional source of recharge is indicated by the observation that seasonal trends in these wells are superimposed on a rising annual trend ,whereas water-level trends directly associated with canal leakage (Figure 2.18A) are falling over the same time period. The seasonal water-level fluctuations in Figure 2.22A do not correlate to precipitation (Figure 2.22B). In addition, the rising annual trends occur during a period of declining annual rainfall (Figure 2.2). This suggests that deep percolation is the source of the additional recharge. The surrounding acreage is irrigated with effluent water from a food processing plant but the timing and rate of water applications is not known.

The above examples are all associated with lands irrigated with effluent water from food-processing plants. In at least some of these areas, water has been applied at rates which exceeded crop needs and at times outside the irrigation season (DEQ, this report). Because of this, these areas may not be representative of most irrigated lands in the basin. Therefore, evidence of deep percolation on other irrigated lands is presented below.

For example, deep percolation is probably a major source of recharge in the area west and southwest of the Umatilla Ordnance Depot. More than 30,000 acres of land are irrigated by center pivots on these lands in townships 3N/26E and 4N/26E. Lands on the Depot are not irrigated. As discussed above, the bending of contours across the western Depot boundary (Plate 2.4) and the pattern of water-level rises in wells adjacent to the boundary (Figure 2.12A) indicate that groundwater is flowing onto the Depot from the southwest. This indicates that recharge rates are higher on lands west of the Depot. Potential recharge sources in the area are limited to precipitation, leakage from the West Extension canal, and deep percolation of irrigated water. As discussed above, precipitation recharge is expected to be uniform (and low) on or off the Depot. The West Extension canal is an unlikely source of recharge since it lies at a lower elevation (about 390 feet) than most of the affected area of the aquifer. This suggests that deep percolation is the probable cause of higher recharge rates west of the Depot.

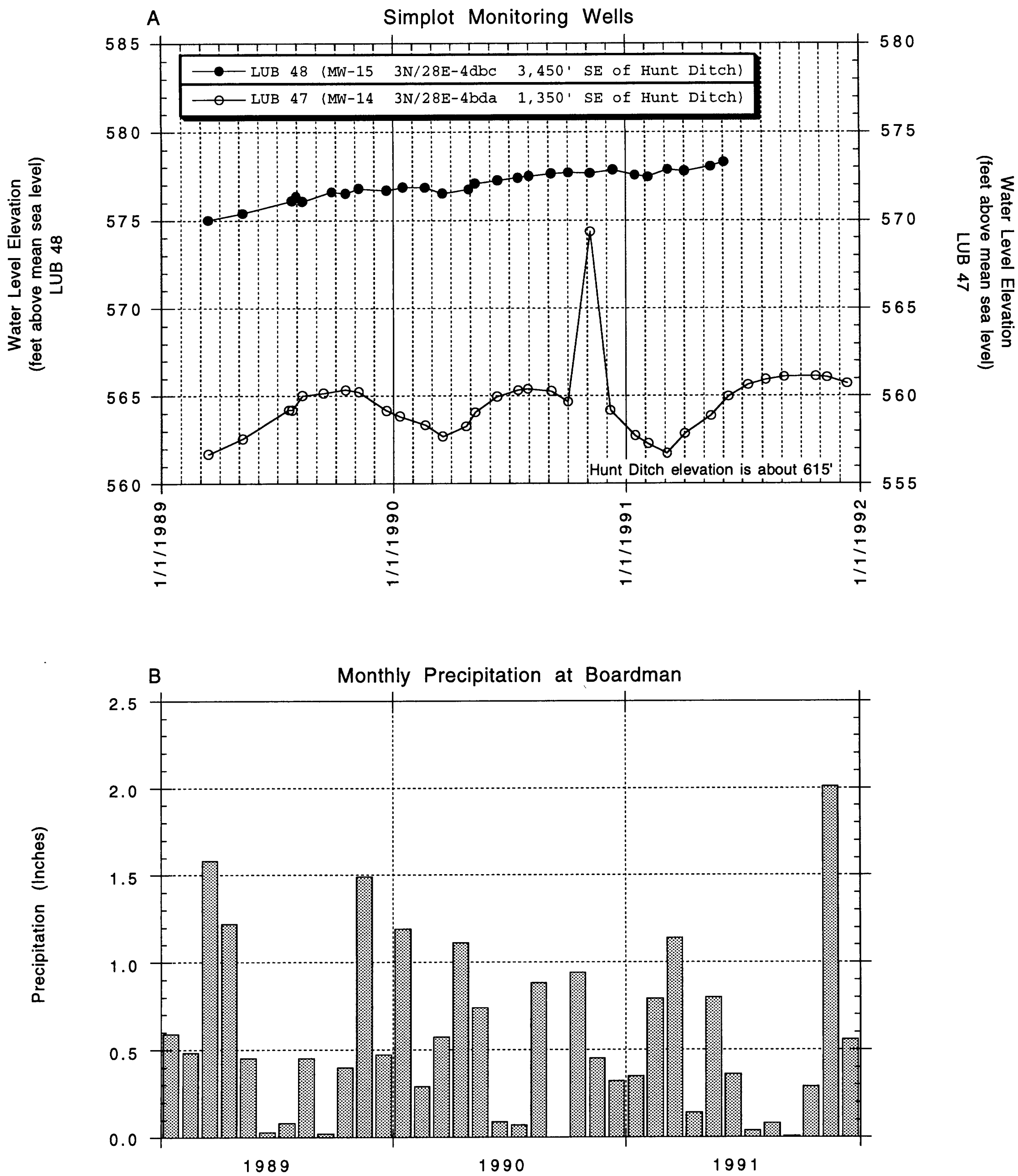


Figure 2.22 Comparison of water-level trends and precipitation in the area between Butter Creek and Emigrant Buttes. A, Hydrographs of wells screened in fine-grained flood deposits; B, Monthly precipitation at Boardman.

Water-level rises at the western boundary of the Depot averaged over 1.5 feet per year between July 1990 and September 1992. The maximum rise was 1.85 feet per year. Because annual water-level rises increase progressively from the interior to the western boundary of the Depot, annual water-level rises west of the Depot are likely to be even higher. This cannot be verified by measurements, however, because of a lack of wells to the west. On this basis, 1.5 feet per year is assumed to be the minimum rise caused by deep percolation recharge. Assuming a porosity of 20% for the alluvial sediments, this is equivalent to about 3.5 inches of recharge per year. Assuming that application rates range from 24 to 36 inches per year (typical rates for low pressure center pivots in the area, Pumphrey and others, 1991), this equates to a deep percolation loss of 10 to 15 percent of the applied water. Not enough data is available to determine if this figure is typical for losses from center pivot systems. Taken as a whole, however, the example suggests that deep percolation is possible even in areas of center pivot irrigation.

The duration of water-level rises on lands west of the Depot is unknown because of a lack of long-term hydrographs, but these lands were originally developed for irrigation in the 1970s. If water-level rises have occurred at a steady rate between 1982 and 1992, the overall rise in the water table would be at least 15 feet. The available data suggests that the water table is now within a few feet of land surface near the West Extension Canal in areas west and northwest of the Depot. If the water-table continues to rise due to deep percolation losses, or if leakage from the canal is substantial during the irrigation season, the water table may intersect the land surface. This is believed to be the cause of ponded water and flooded septic systems which have been reported over the last few years in areas immediately northwest of the Depot. Local residents report that these lands were historically dry but this was not confirmed by independent sources. Additional water-levels from Depot monitoring wells and a survey of the locations and timing of ponding are needed to confirm this mechanism.

Some of the lands west of the Depot are currently being converted from center pivot to drip irrigation systems for the cultivation of poplar trees. The total number of acres to be converted is unknown but the effect may be visible over time in the hydrographs of Depot monitoring wells if large land areas are involved. At present, it is not known if the Depot plans to continue monthly water-level measurements in any or all of its wells.

Evidence for deep percolation in alluvial sediments is also seen in an area irrigated by center pivots immediately west of Carty Reservoir and Sixmile Canyon. In this vicinity, the Elephant Mountain Basalt ranges from 25 to 40 feet thick. The basalt flow is overlain by 5 to 10 feet of alluvial sediments which are in turn capped by 5 to 10 feet of windblown silt and sand (section A-A', Plate 2.3). Prior to the filling of Carty Reservoir in 1977, little or no groundwater was present in the alluvial sediments overlying the Elephant Mountain Basalt or in the breccia/fracture zone at the base of the basalt flow (Portland General Electric, 1992). Hydrographs in Figure 2.23A document water-level trends in these zones in the area northwest of Carty after the reservoir was filled. Two of the wells are screened adjacent to a confined aquifer at the base of the Elephant Mountain Basalt (Figure 2.23B) and display a rising water-level trend that correlates to the filling of the reservoir. The third well (LUB 31) is adjacent to one of the deep wells (LUB 32) and is completed in the sediments which overlie the basalt. Measurements from the shallow well show that a thin layer of groundwater has been present at the base of the sediments since at least 1980, the approximate date at which irrigation of the adjacent lands was first begun. Water levels in the sediments have been relatively constant over time and show no relationship to the filling of the reservoir. This suggests that deep percolation is the source of the groundwater in the alluvium.

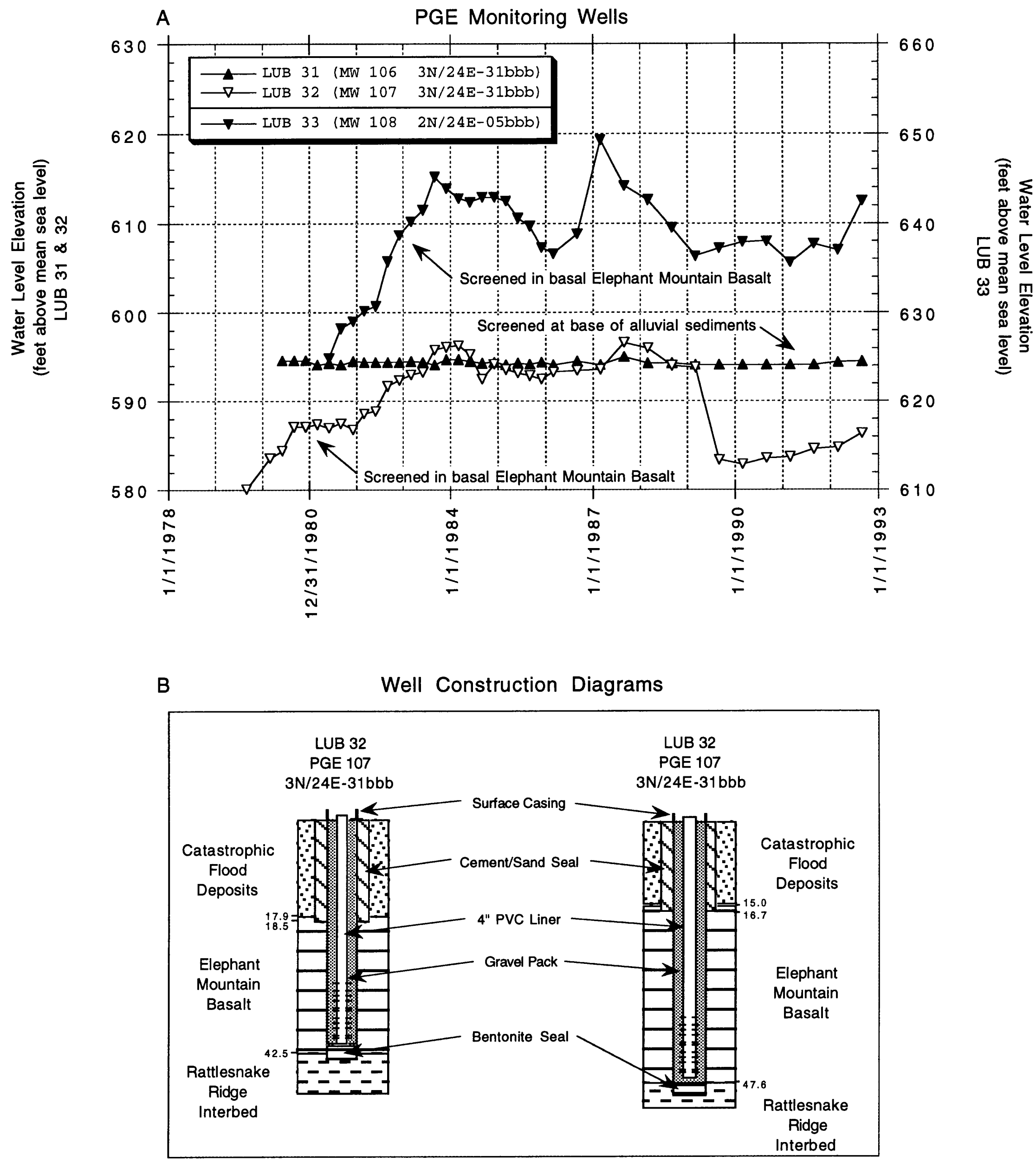


Figure 2.23 Water-level trends and construction details of monitoring wells northwest of Carty Reservoir. A, Hydrographs of alluvial and basalt wells; B, Well construction diagrams of basalt wells.

Although water levels in the deep wells in Figure 2.23A correlate to the filling of Carty Reservoir, the chemistry of groundwater from these wells indicates a component of recharge from agricultural sources (Portland General Electric, 1992). This discrepancy is believed to be caused by well construction features. Both deep wells have a sand/cement seal which extends no more than 5 feet into the top of the Elephant Mountain Basalt (Figure 2.23B). Gravel packs expose the remainder of the basalt to the well bore. This construction is not likely to prevent alluvial groundwater from seeping into the well bore through the breccia/fracture zone at the top of the basalt flow.

This example provides additional evidence that some deep percolation recharge can occur in areas of center pivot irrigation. It also illustrates a mechanism by which alluvial water can migrate into the bores of wells which are nominally completed in basalt aquifers. This is believed to be a common occurrence in many wells in the study area because of well construction practices. The water quality implications of these practices are discussed below in the section on discharge to the shallow basalt aquifers.

Economic factors have encouraged many irrigators in the study area to reduce their per acre water consumption. This has resulted in a gradual shift to sprinkler systems and an increased use of center pivots over time. Recent conservation trends include drip irrigation and the use of sophisticated water-management techniques. Water budgets are now commonly established for individual plots using satellite images, aerial photographs, daily weather data, crop water requirements, and neutron probes. In this manner, water use is adjusted daily to apply only that amount which is optimal for the growth of crops. All of these trends will decrease deep percolation of irrigation water and reduce the amount of recharge to the alluvial aquifer over time.

In summary, evidence for deep percolation of irrigation water is found in various areas of the basin. Percolation recharge may be as great as 15 percent of the applied water in areas irrigated by center pivots. Proportionately higher recharge rates are expected in areas irrigated by wheel lines, hand lines, and flooding of fields. If 2.4 inches per year (a 10 percent loss for 24 inches of applied water) is assumed to be a minimum recharge rate for the 180,000 acres of irrigated lands in the study area, the minimum annual recharge from this source would total about 36,000 acre-feet per year. Over time, the component of recharge from deep percolation is expected to decrease as the use of flood irrigation decreases, as the use of drip irrigation increases, and as water management programs become more common on individual farms.

Flow Directions and Velocities

Interpreted flow directions for the alluvial aquifer are shown on Plate 2.4. As a first approximation, flow was assumed to be perpendicular to the contours, a condition that is strictly true for isotropic aquifers only. In areas where data is sparse, or the contour interval is too coarse, flow directions were determined by analyzing local hydrogeologic factors, as discussed in the earlier sections of this report. The flow patterns on the map reflect conditions in late winter when pumping is at a minimum. Average groundwater flow velocity along a given flow path can be estimated from a modification of Darcy's Law which states that the velocity of groundwater is equal to the hydraulic conductivity times the hydraulic gradient divided by the effective porosity of the aquifer (Freeze and Cherry, 1979).

Table 2.3 shows estimated velocities based on a probable range of hydraulic parameters in the study area. The effective porosity of the coarse-grained deposits was assumed to be equal to the storage coefficient as determined by aquifer tests. A conservative effective porosity of 0.05 was assumed for the fine-grained deposits. Greater values of effective porosity will yield lower velocities.

Table 2.3 Estimated groundwater flow velocities in the alluvial aquifer.

Water-bearing Unit	Hydraulic Conductivity ft/day	Hydraulic Gradient ft/mile	Effective Porosity	Average Linear Velocity		
				ft/day	ft/year	mi/yr
Pscfc	1000	2	0.2	1.8939	691.8	0.1310
	4000	2	0.2	7.5758	2767.0	0.5241
Pscff	0.01	50	0.05	0.0019	0.7	0.0001
	0.1	50	0.05	0.0189	6.9	0.0013
	1	50	0.05	0.1894	69.2	0.0131
	10	50	0.05	1.8939	691.8	0.1310
	100	50	0.2	4.7348	1729.4	0.3275

Assuming a hydraulic gradient of 2 feet per mile (.0004), velocities in the coarse-grained flood deposits are estimated to range from 2 to 8 feet per day or 0.13 to 0.52 miles per year. Assuming a gradient of 50 feet per mile (.0095), velocities in the fine-grained deposits are estimated to range from 0.002 to 2 feet per day or 0.0001 to 0.13 miles per year. Velocities within sand and gravel beds in the fine-grained deposits are likely to fall somewhere in between.

These are rough estimates which are presented only to give a sense of relative flow velocities through the various aquifer materials. A variety of simplifying assumptions underlie the estimates. The actual flow velocity of a given particle of water may vary greatly because of local variations in hydraulic conductivity and porosity. In addition, pumping and recharge can locally alter hydraulic gradients and flow directions during the year, especially in the vicinity of aquifer boundaries. This is well documented in the coarse-grained flood deposits near the Umatilla Ordnance Depot. For example, the above estimates and the flow lines on Plate 2.4 suggest that groundwater will travel from the center of the Depot to the Umatilla River within a period of 10 to 40 years. However, seasonal water-level measurements in Depot wells indicate that flow directions vary by up to 180 degrees during the year, in response to off-site pumping and recharge. The net direction of water movement in this system is difficult to predict but the net displacement of a given particle of water is likely to be much less than the range of 0.13 to 0.52 miles per year. This probably explains why contaminant plumes on the Depot have not migrated far from their source areas.

It is beyond the scope of this study to predict the effects of transient pumping and recharge in any particular area. However, a general idea of the potential impact of these stresses can be gained by comparing the flow patterns on Plate 2.4 with the locations of canals and the density of high-capacity wells which produce from the alluvial aquifer (Plate 2.6).

Discharge

Water exits the alluvial aquifer by discharge to streams, by evapotranspiration from wetlands, by discharge to underlying basalt aquifers, and by withdrawal from wells. Evapotranspiration may be important in areas where the water table is near land surface but is probably a minor source of discharge for the aquifer as a whole. Not enough data is available to determine the rates of discharge to streams and basalt aquifers but it is possible to outline areas where such discharge is likely to occur. Estimates of withdrawals by wells can be made with a fair degree of confidence.

To Streams

As noted above, the Columbia River fully penetrates the alluvial aquifer in most places between Boardman and McNary Dam. Under natural conditions, groundwater flow directions are to the north and the aquifer discharges to the river along this reach.

Water-level contours (Plate 2.4) indicate that the alluvial aquifer discharges to the Umatilla River throughout most of its reach in the study area. An exception occurs between sections 19 and 30 of 4N/28E (Cottonwood Bend) and section 35 of 4N/28E, where the river loses water to the underlying aquifer (see the above section on recharge from streams). An analysis of return flows to the river (Kreag, 1991) suggests that groundwater discharge may be minimal except for a stretch between the Dillon Canal East Drain and Bridge Road (river mile 19.9 to 8.8). Discharge in this stretch of the river is manifested by perennial seeps and springs which occur between Cottonwood Bend and Bridge Road and seasonal springs which occur during the irrigation season near Bridge Road. Measurable spring flow at Minnehaha Springs and Bridge Road ranges from 3.5 cfs (cubic feet per second) in late spring to 12.8 cfs during the summer (Kreag, 1991). This is equivalent to about 7 to 25 acre-feet per day or about 2500 to 9000 acre-feet per year. These are conservative estimates of discharge to the river since additional unmeasurable spring flow and seepage (through the bed of the river) are not accounted for. Kreag (1991) estimates that this unaccounted component of discharge may range from 35 to 60 cfs (about 70 to 120 acre-feet per day) during the summer.

Downstream of Bridge road, the Umatilla river cuts progressively through the alluvial aquifer until it exposes the top of the underlying Pomona flow at Three Mile Dam (Plate 2.2 and cross section F-F', Plate 2.3). This suggests that discharge from the alluvial aquifer is also occurring along this reach of the river. Since springs are not noted in this stretch, discharge must occur by seepage through the bed of the stream.

To Shallow Basalt Aquifers

The potential for discharge to shallow basalt aquifers exists wherever the margins of basalt flows are exposed beneath saturated sediments of the alluvial aquifer. The approximate locations for the principal margins of Saddle Mountains Basalt flows are shown on Plate 2.2 and on the cross sections of Plate 2.3. Margins shown east of Service Anticline are not well constrained but the general relations hold nonetheless. Additional flow margins are likely along the flanks of Service Anticline, between Umatilla Butte and Emigrant Buttes, but could not be mapped with any degree of confidence.

The efficiency of discharge to a basalt aquifer depends upon a variety of factors including the permeability of the sediments, the permeability of the exposed margin of the basalt flow, and the hydraulic head in the sediments and the basalt flows. All else being equal, the potential for discharge to basalt aquifers is likely to be greatest in areas where high permeability sediments overlie flow margins

Not enough data are available to determine rates and volumes of discharge to shallow basalt aquifers, but geometric relationships indicate that the alluvial aquifer is the main source of recharge to the shallow basalt aquifers. This will be discussed in more detail in the section on basalt aquifer recharge.

To Wells

Table 2.4 summarizes well withdrawals from the alluvial aquifer within the study area. The distribution of wells is shown on Plate 5. Total withdrawal is estimated between 65,000 and 98,000 acre-feet per year. Irrigation is the largest category of use and accounts for 51,000 to 85,000 acre-feet of withdrawal per year. Domestic pumpage is relatively insignificant at about 1800 acre-feet per year. Wells for the City of Boardman and the Umatilla Fish Hatchery are not included in the total because much of their water probably comes from the Columbia River by induced infiltration. Boardman uses a collector well with laterals that extend partly beneath the Columbia River. The hatchery also uses several collector wells in addition to four high-capacity wells that are located near the river. Based on water chemistry, CH2M Hill (1992) estimates that 60 to 80 percent of the water produced by Boardman's collector well comes from the Columbia River. The remainder comes from the alluvial aquifer.

Total pumpage in the early 1980s was estimated by Davies-Smith and others (1988) at about 25,000 acre-feet per year for the alluvial aquifer. This estimate is considerably lower than the conservative estimate of 65,000 acre-feet per year shown in Table 2.4. The Davies-Smith total, however, does not include withdrawals from the alluvial aquifer along the Boardman-Umatilla strip. This probably accounts for a significant portion of the difference between the two estimates. A small part of the difference is probably due to the issuance of new permits (mostly for commercial and industrial uses) since 1982. Neither of these factors is likely to account for the majority of the difference. The remaining discrepancy must be due to errors in either or both of the estimates.

Table 2.4 Summary of well withdrawals from the alluvial aquifer.

Category	Discharge acre-ft/yr	Comments
Domestic Wells	1750†	Assumes 500 gallons per day per well
Irrigation - Primary	36,000 - 54000	Assumes 2-3 acre-ft/yr/acre
Irrigation - Supplemental	15,500†† - 31,000	Assumes 1-2 acre-ft/yr/acre
Miscellaneous	9,332	Mostly commercial and industrial use permits
City of Hermiston	1,811	City well #5
City of Irrigon	291	City well #2
Total	64,684 - 98184	
City of Boardman	1,108	Ranney collector adjacent to Columbia River
Umatilla Fish Hatchery	8,881	Wells and collectors adjacent to Columbia River

†Includes all wells less than 200 feet deep
††Includes County Line Water Improvement District recharge permit for 5339 acres

Although many assumptions underlie the above estimates, the figures are presented to provide a general sense of the overall magnitude of well withdrawals in the study area. The methods used for estimating well withdrawals are summarized below.

Withdrawals from domestic wells were estimated by assuming that all wells less than 200 feet deep produce from the alluvial aquifer. This probably overestimates the number of alluvial wells because the depth to basalt is less than 100 feet in some areas. It was also assumed that well logs on file at the Water Resources Department represent only 50% of the actual wells in the study area (see Groundwater Development). It was further assumed that domestic consumption averages 500 gallons per day per well.

Pumpage from irrigation wells was estimated using the Water Rights database at the Water Resources Department. The total number of acres permitted for primary and supplemental irrigation was summed for all wells (and sumps) which produce from the alluvial aquifer. Pumpage was estimated by assuming a duty of 2 to 3 acre-feet per year for primary rights and 1 to 2 acre-feet per year for supplemental rights.

Withdrawals from miscellaneous permitted wells were also estimated using the Water Rights database. Most of the wells in this category are permitted for commercial or manufacturing use and are associated with food-processing facilities. It was assumed that each well was used to the full capacity permitted on the water right. This probably overestimates actual usage.

Pumpage from municipal wells and from wells at the Umatilla Fish Hatchery were obtained from monthly water-use reports on file at the Water Resources Department.

Groundwater Supply

Under natural conditions, the average annual discharge from an aquifer is in equilibrium with the average annual recharge. Under these conditions, the volume of water in storage is constant, and water levels in the aquifer are stable. Artificial recharge or discharge can disrupt this stability and lead to changes in storage. Under favorable conditions, a new equilibrium will be reached and water levels will stabilize at a different level. If artificial discharge is too great, equilibrium may not possible and water levels will decline until the aquifer is depleted.

Although a comprehensive groundwater budget is beyond the scope of the current study, a general evaluation of groundwater supplies in the alluvial aquifer is possible on an area by area basis.

The principal productive areas of the alluvial aquifer occur within three shallow troughs which are filled with coarse-grained flood deposits (Plate 2.4). The limited extent of the coarse-grained sediments limits the effective size of the groundwater resource in each area. However, conditions which affect groundwater supplies also vary in each area.

In the Ordnance area, the saturated coarse-grained deposits are bounded on all sides by predominantly fine-grained sediments. Recharge sources are limited and the aquifer has been extensively developed as a source of irrigation water. Water-level declines between 1960 and 1976 and between 1986 and 1993 (Figure 2.9) indicate that discharge was greater than recharge during these time intervals. If the current imbalance continues, water levels will continue to decline. Additional development of groundwater in this area cannot be sustained unless recharge can be increased to compensate for the new withdrawals.

In the Boardman-Umatilla area, the alluvial aquifer is hydraulically connected to the Columbia River and the river determines the base level of the water table. If river levels are maintained over time, long-term storage will remain stable. Large increases in annual pumpage from the aquifer will induce water to flow from the river into the aquifer. In this sense, groundwater supplies in the Boardman-Umatilla strip are relatively unlimited but are developed at the expense of the Columbia River.

The alluvial groundwater resource in the Hermiston area is similar in size and geometry to that of the Ordnance area. In Hermiston, however, pumpage is lower and the density of canals is higher. The existing data indicate that groundwater levels are stable and that annual recharge is in balance with annual discharge. This suggests that some additional groundwater development can be sustained. Because canal leakage and deep percolation of irrigation water are the principal sources of recharge in the area, future conservation measures by the Hermiston Irrigation District and decreased use of the Feed Canal to deliver water to Cold Springs Reservoir may impact groundwater supplies. This may be compounded by additional pumpage as the population continues to grow in the area. At present, major pumping withdrawals are limited to the City of Hermiston's well #5 (UMAT 1771, 4N/28E-3dba) and a dozen or so high-capacity irrigation wells to the north and northeast of Hermiston (Plate 2.6). In the future, the city plans to use alluvial groundwater from their well #5 to recharge the deeper basalt aquifers during the winter months. It would be prudent to monitor groundwater levels in the alluvial aquifer to determine the nature and extent of changes in groundwater storage, if any, over time.

Groundwater in the alluvial aquifer is also developed from laterally discontinuous sand and gravel beds (within predominantly fine-grained flood deposits) on the terrace between Hermiston and Stanfield. Well logs, water levels, well yields, and aquifer test data indicate local confinement, moderate transmissivities, and low storage capacities. This is reflected in the large pumping drawdowns observed in monitoring wells which are completed in these zones (Figure 2.21). Relatively stable water levels in the area indicate that discharge is currently balanced by recharge.

Groundwater in the Umatilla River Valley is hydraulically connected to the Umatilla River. Groundwater levels adjacent to the river are at, or near, river level. Additional pumpage capacity is available but pumpage will decrease stream flow by decreasing the rate of groundwater discharge to the river or, by inducing water to flow from the river into the aquifer.

Shallow Basalt Aquifers

Water-bearing zones within Columbia River basalts are largely limited to thin breccia or fracture zones at the top or base of individual flows (Figure 2.6). The dense interiors of flows are believed to be relatively impermeable and confine groundwater to discrete tabular aquifers. Data from well logs indicate that productive aquifers do not occur at the top or base of every flow or at all localities of a given flow. This is consistent with exposures in road cuts which show that the thickness of individual breccia zones may vary considerably over short distances. In general, breccias and fracture zones account for less than 10% of the thickness of a flow. Assuming an average porosity of 10%, only about 1% of the total flow volume is available for the storage of groundwater. Because these aquifers are confined, only a fraction of the stored water is available for withdrawal by wells. This is because water is released from confined aquifers by expansion of water and by compression of the framework of the aquifer; neither mechanism is capable of releasing much water. Because of their low storage potential, Columbia River basalt aquifers are particularly vulnerable to overdraft, as evidenced by declining water levels in of many of the deeper basalt aquifers of the Umatilla Basin (Sceva, 1966; McCall, 1975; Bartholomew, 1975; Norton and Bartholomew, 1984; Zwart, 1990).

Three shallow aquifers occur within flows of the Saddle Mountains Basalt. From upper to lowermost, these are the Basal Elephant Mountain aquifer, the Basal Pomona aquifer, and the Basal Umatilla aquifer. Each aquifer unit includes water-bearing zones at the base of the named flow and at the top of the underlying flow (Figure 2.4). Although a thin interbed of silt and clay separates the two water-bearing zones in many areas, in practical terms they form a single aquifer. An exception to this generality occurs west of the Umatilla Ordnance Depot where the Selah interbed thickens to greater than 150 feet and probably effectively isolates the water-bearing zone at the base of the Pomona from the zone at the top of the underlying flow.

As discussed in earlier sections of this report, the geometry of Saddle Mountains Basalt flows is reasonably well defined based on surface exposures and subsurface correlations (Plates 2.2 and 2.3). The regional dip of the flows is to the north, largely controlled by the Dalles-Umatilla Syncline. Each of the flows is breached in downdip areas by the Columbia River, some at more than one locality. Margins of each flow are also exposed in updip areas beneath saturated alluvial sediments. From a geometric perspective, the aquifers in these flows are hydraulically connected to the Columbia River and the alluvial aquifer.

A limited amount of water-level data was collected from wells completed in the shallow basalt aquifers during the course of this investigation. Most of the reported data are from wells which are completed in a single aquifer. Many wells in the basin commingle water from several basalt aquifers. Hydraulic heads in commingling wells represent some combination of the heads of several aquifers and are probably unreliable for determining hydraulic gradients and flow directions. Several generalities can be made from the available dataset.

Water-level elevations in the uppermost basalt aquifer are typically a few feet or a few tens of feet lower than levels in the alluvial aquifer (Plate 2.4). In addition, water-level elevations in the shallow basalt aquifers generally decrease with depth (see Dames and Moore, 1994b for example). Because of this falling-head-with-depth relationship, any interconnections between the shallow aquifers will result in the downward movement of water.

Water-level trends in the basalt aquifers are illustrated by hydrographs of wells completed in the basal Pomona aquifer at the Umatilla Ordnance Depot (Figure 2.24). Seasonal lows occur in the summer in response to pumping withdrawals. Seasonal highs occur in the winter. At this locality, the amplitude of seasonal change is about 10 feet. Seasonal amplitudes at other localities are likely to vary depending upon the density of pumping wells and the cumulative pumping rates. Although the nearest wells which pump water from the basal Pomona aquifer are located several miles to the east, seasonal pumping effects at the Depot are on the order of 10 feet. This suggests that hydraulic conductivities are moderately high and storage capacities are low.

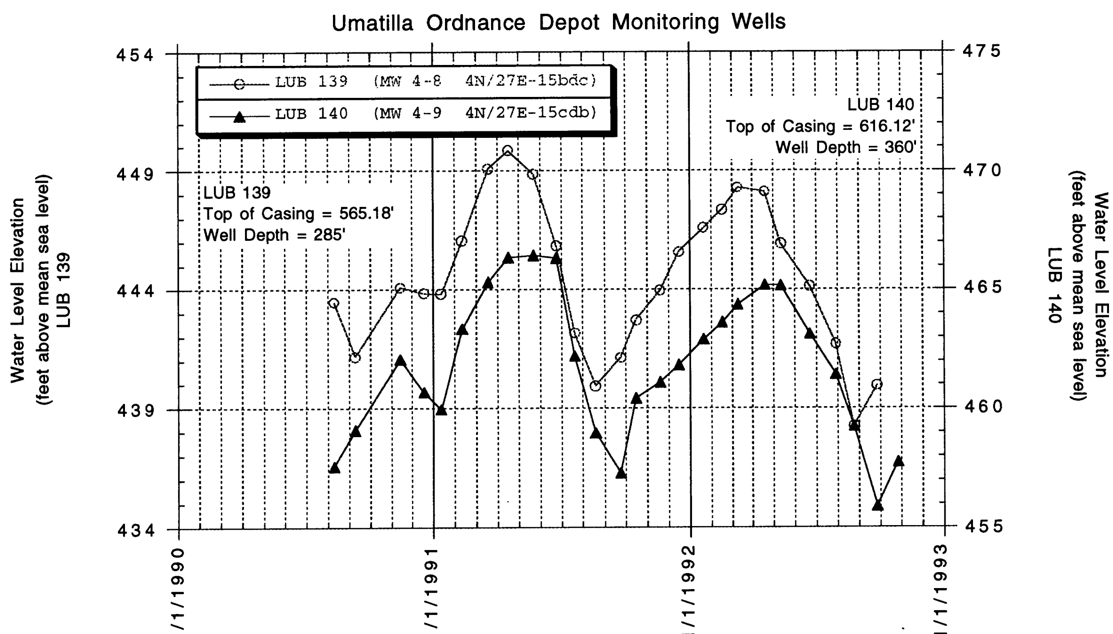


Figure 2.24 Hydrographs of monitoring wells completed in the basal Pomona aquifer on the Umatilla Ordnance Depot.

Aquifer Properties

Reliable values for the hydraulic properties of the shallow basalt aquifers and their associated interbeds are lacking. Aquifer tests were conducted in several wells completed in the basal Pomona aquifer on the Umatilla Ordnance Depot (Dames and Moore, 1992) but a review of the tests suggests that the data was compromised by the pumping of wells adjacent to the Depot. Packer tests and constant-head slug tests in boreholes at Portland General Electric's Boardman coal-fired plant indicate hydraulic conductivities of about 0.06 to 3.0 feet per day for the Elephant Mountain Basalt, 0.0003 to 0.3 feet per day for the brecciated upper portion of the Pomona Basalt, and 0.00003 to 0.003 feet per day for the dense interior of the Pomona Basalt. Tests also indicate hydraulic conductivities of 0.003 to 0.6 feet per day for the Rattlesnake Ridge interbed, and 0.0003 to .003 feet per day for the Selah interbed (Shannon and Wilson, 1972a; 1973a). Packer and slug tests evaluate small disturbed rock or sediment volumes in the immediate vicinity of well bores and may not reflect the bulk permeabilities of these materials under natural conditions. Using specific capacity data, Davies-Smith and others (1988) estimate a permeability of 18 feet per day for water-bearing zones in the Saddle Mountains Basalt. Vertical hydraulic conductivities are estimated to be several orders of magnitude lower. Estimates of storage coefficients for the water-bearing zones in the Saddle Mountains Basalt range as high as .003 (Davies-Smith and others, 1988).

The above data indicate that hydraulic conductivities in the shallow basalt aquifers are comparable to those of the fine-grained sediments in the alluvial aquifer. The rapid rate of water-level rise in the basal Elephant Mountain aquifer after Carty Reservoir was filled suggests that these values may be conservatively low.

Recharge

Because the interiors of the basalt flows are relatively impermeable, effective recharge to the shallow basalt aquifers is probably limited to areas where the margins of the basalt flows are exposed to recharge waters. Recharge rates cannot be determined from the present data but areas where recharge is likely to occur can be established.

From the Alluvial Aquifer

Within the study area, updip margins of the upper two basalt flows generally occur beneath a cover of alluvial sediments (Plates 2.2 and 2.4). Effective recharge to the basalts is probably limited to areas where these sediments are saturated. This is supported by the observation that in areas updip from the Columbia River, saturated portions of the shallow basalt aquifers are generally limited to areas which are overlain by the alluvial aquifer. These factors suggest that most of the recharge to these aquifers comes from groundwater that is discharged from the alluvial aquifer. Therefore, the water quality of the shallow basalt aquifers will be influenced by the water quality of the alluvial aquifer.

From Reservoirs and Streams

The upper surface of the Pomona flow is exposed beneath Carty Reservoir and in the bed of the Umatilla River between Three Mile Dam and the Columbia River. Leakage from Carty Reservoir to the basal Elephant Mountain aquifer (breccia/fracture zones at the base of the Elephant Mountain and the top of the underlying Pomona) is well documented. Leakage from the Umatilla River is highly probable.

Recharge from the Columbia River is also possible wherever the basalt aquifers are breached by the river. However, throughout most of the study area, hydraulic gradients in the basalt aquifers are sloped toward the river. Because of this, recharge from the river is probably limited to areas where well withdrawals are sufficient to locally reverse the gradient near the river.

Recharge from the Columbia River cannot be demonstrated in the study area but is illustrated by an example from several miles to the west, in the vicinity of Arlington. At the western boundary of the study area, the axis of the Dalles-Umatilla syncline leaves the path of the Columbia River and swings to south (Swanson and others, 1981). Because of this, the basalt flows dip to the south between the river and Arlington. After the John Day dam was completed in 1968, water levels in the City of Arlington's municipal well rose about 60 feet over a period of about 12 years (Figure 2.25). Apparently, the rising pool behind the dam inundated a breccia zone in the basalts which was previously above river level. This allowed water to migrate downdip toward Arlington where it was captured by the open (uncased) borehole of the municipal well.

From the Alluvial Aquifer Through Wells

As discussed in earlier sections of this report, some recharge to the shallow basalt aquifers also comes from alluvial groundwater which migrates through the bores of wells which have inadequate seals. A typical domestic supply well in the basalts has an 18 foot seal at the surface and a steel casing which extends from land surface to the top of the uppermost basalt flow (see cross sections on Plate 2.3 for examples). In most instances the casing rests on the basalt surface or penetrates only a few feet into the basalt. The remainder of the well consists of an open hole which penetrates one or more basalt aquifers. The lack of a seal into the dense interior of the first basalt flow may allow water from the alluvial aquifer to migrate into the well bore through breccia or fracture zones which occur at the top of the basalt. The volume of water that enters a borehole through this mechanism will probably vary locally depending on conditions at the surface of the basalt. In most cases, the rate of inflow will probably be low. If the alluvial aquifer is contaminated, a small rate of inflow may only degrade the water in and near the well bore. A large rate of inflow may produce a contaminant plume in the basalt aquifer. If significant inflow occurs through many wells, a large portion of the aquifer may be contaminated. At least one driller has reported some success in cleaning up domestic water wells in the Boardman area by placing a grout seal completely through the first basalt flow. This suggests that, in at least some cases, contamination of the basalt aquifers is limited to the vicinity of the well bore.

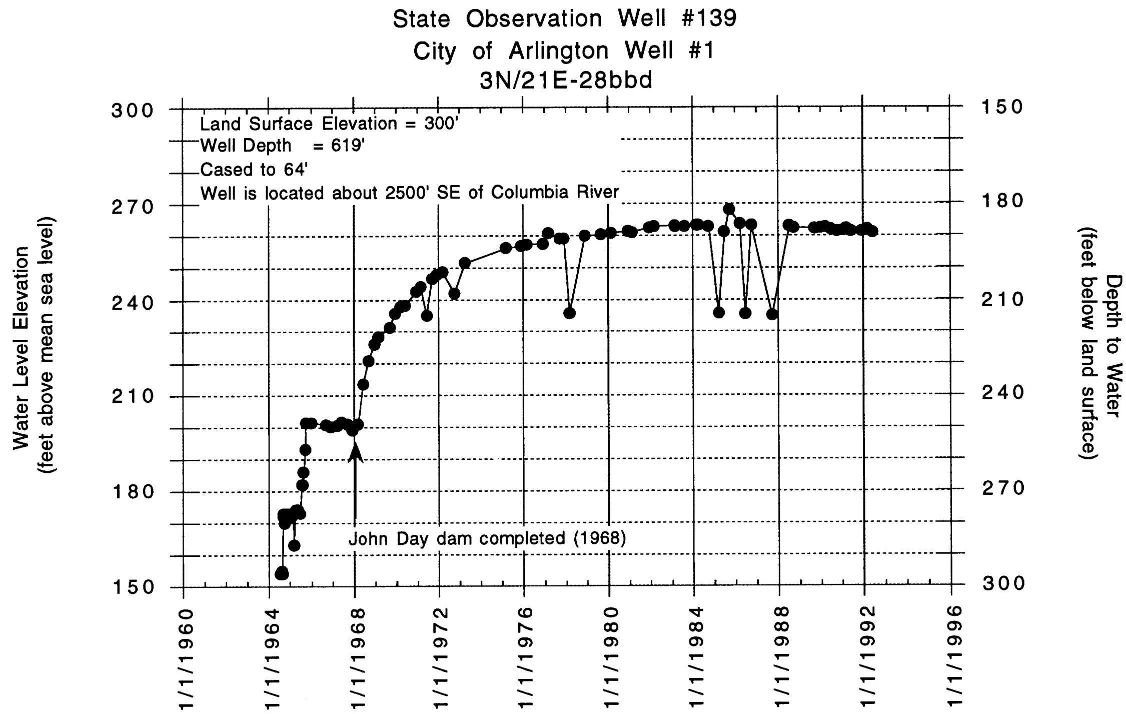


Figure 2.25 Hydrograph of the city of Arlington's municipal well #1 showing a rise in water level associated with the completion of the John Day dam

Flow Directions and Velocities

Although not enough data was collected from each of the shallow basalt aquifers to contour flow directions, the available data indicate that flow is generally parallel to the regional dip of the basalt flows (Plates 2.2 and 2.4). Throughout most of the study area, regional dips are to the north and groundwater flow is toward the Columbia River. Hydraulic gradients appear to range from 25 to 50 feet per mile.

Assuming a hydraulic conductivity of 18 feet per day and an effective porosity of 10%, the average groundwater flow velocity in the shallow basalt aquifers is estimated to range between about 1 and 2 feet per day, or 350 to 700 feet per year. These estimates are subject to considerable uncertainty.

Discharge

Water exits the shallow basalt aquifers by discharge to the Columbia River, by withdrawal from wells, and by discharge through well bores to other basalt aquifers.

Although shallow basalt groundwater flow is toward the Columbia River, effective discharge to the river is probably limited to areas where basalt flows are breached by the river. Because the three shallowest basalt flows are breached at various localities within the study area, efficient hydraulic connections probably exist between the shallow aquifers and the river. However, discharge rates cannot be calculated using available data.

Pumpage discharge from the shallow basalt aquifers was not estimated for the current study but sufficient data are available to make such an estimate.

Many wells in the study are completed in more than one basalt aquifer. Because hydraulic heads are commonly different in the various aquifers, this practice allows groundwater to migrate between aquifers. The magnitude of discharge by this mechanism is unknown but it may be significant in areas of high well density because of the limited storage capacity of the shallow basalt aquifers. The commingling of aquifers in wells also provides a pathway for contaminants to travel between aquifers.

Groundwater Supply

The limited thicknesses and storage capacities of the shallow basalt aquifers suggest that development potential is somewhat limited. Low hydraulic conductivities and storativities also increase the likelihood of interference between wells.

Groundwater supplies in the shallow basalt aquifers are expected to be relatively stable in downdip areas where aquifer elevations are near the level of the Columbia River. Because each of the shallow aquifers is breached by the river, pumpage is likely to be buffered by recharge from the river.

Where aquifer elevations rise above the level of the river, groundwater supplies are more prone to depletion by pumping. The most susceptible areas are likely to be near updip flow margins, especially where the overlying alluvial aquifer is thin or, where the basalts are overlain by predominantly fine-grained sediments with low hydraulic conductivities.

Excessive water-level declines have recently occurred in many wells completed in the shallow basalt aquifers in and around sections 8, 9 and 17 of 4N/28E (Marc Norton, WRD, personal communication). This is an area of rapid development immediately west of Hermiston which has more than 100 wells completed in shallow basalt aquifers. Declines over the past few years have resulted in many well deepenings. In most instances, the upper basalt aquifers have not been sealed off when these wells were deepened. Because hydraulic heads decline with depth in the area, the open wellbores will allow groundwater to migrate from the shallow zones into the deeper zones. This practice is likely to exacerbate water-level declines in wells which have not been deepened. Because the deeper basalt aquifers in the area are also declining because of irrigation pumpage (Norton and Bartholomew, 1984), water supplies from these zones may not be reliable in the future.

In most of the study area, long-term water-level trends are unknown in the shallow basalt aquifers because of a lack of data. However, limited data collected between 1990 and 1993 suggest that water levels are somewhat stable in many areas. For example, two years of record at the Umatilla Ordnance Depot (Figure 2.24) show a decline of about two feet per year in the basal Pomona aquifer (Dames and Moore, 1994b). However, this trend cannot be extrapolated into the future with any degree of confidence.

The proposed lowering of the John Day pool will probably have only a small impact on groundwater supplies in the shallow basalt aquifers within the study area. A drop in pool level will lower the base level at which discharge occurs and cause a small increase in hydraulic gradients within the aquifers. Near the river, water levels may drop the full distance that the pool is lowered, but this will only be a small fraction of the height of the water-column in a well. South of the river, water levels will drop only a fraction of the pool drawdown distance. Alternatively, a steepening of the hydraulic gradient will lead to a greater rate of discharge to the river.

Summary and Conclusions

A shallow unconfined to locally confined aquifer occurs in the alluvial sediments of northern Morrow and Umatilla counties between the cities of Boardman, Umatilla, and Echo. Multiple confined aquifers occur in the Columbia River Basalt flows which underlie the sediments. Shallow groundwater occurs in four discrete aquifers. From upper to lowermost, these are informally identified as the alluvial aquifer, the basal Elephant Mountain aquifer, the basal Pomona aquifer, and the basal Umatilla aquifer.

The principal water-bearing zones in the alluvial aquifer occur in sands and gravels deposited by catastrophic floods during the Pleistocene Epoch. The main productive areas occur in three east to northeast-trending shallow troughs which are largely filled with sands and gravels. Boundaries within each trough limit the size of the groundwater resource.

The available evidence indicates that water readily infiltrate the soils of the basin and travels rapidly through the unsaturated silts, sands, and gravels which overlie the alluvial aquifer. Because of this, the aquifer is highly susceptible to contamination from activities at the land surface.

Canal and ditch leakage are the principal sources of recharge to the alluvial aquifer. Deep percolation is probably an important source of recharge in areas which are irrigated by flooding or with low efficiency sprinkler systems. Some deep percolation also occurs in areas irrigated by center pivot systems. Recharge from reservoirs and streams may be substantial in some areas. Recharge from precipitation may be minimal. Local water-level highs near the northwest corner of the Depot and on the terrace between Hermiston and Stanfield indicate areas of sustained local recharge.

Between the Umatilla Ordnance Depot and Boardman, groundwater flow in the alluvial aquifer is uniformly to the northwest toward the Columbia River. South and east of the Depot, flow directions are more variable and flow is generally toward the Umatilla River. In the area east of the Depot, the topography of the underlying basalt surface is a major factor which controls flow directions. Flow directions are also influenced by the seasonal pumping of high-capacity wells and by pulses of recharge from canals. Average flow velocities may be as low as 0.0001 miles per year (0.002 feet per day) in the silts and silty sands and as high as 0.50 miles per year (8 feet per day) in the sands and gravels. Net displacement of water over a year's time may be considerably less because of seasonal variations in hydraulic gradients and flow directions.

Substantial quantities of groundwater are discharged from the alluvial aquifer by wells. In the Ordnance area, pumpage and other discharge has exceeded recharge since 1986 and groundwater levels are declining several feet per year. Pumpage discharge between Boardman and Umatilla is buffered by recharge from the Columbia River. Groundwater supplies in this area are relatively unlimited but are developed at the expense of the Columbia River. Pumpage in the Hermiston area is currently less than annual recharge but the capacity for additional development is unknown.

The shallow basalt aquifers of the basin are hydraulically connected to the alluvial aquifer and the Columbia River. Recharge is mostly from the alluvial aquifer but some recharge may be induced from the Columbia River by wells near the river. Therefore, water quality in the shallow basalts is affected by the quality of water in these sources.

The lack of deep seals in many wells probably allows water from the alluvial aquifer to migrate downward to aquifers in the underlying basalt flows. The commingling of basalt aquifers through open boreholes also provides a pathway by which water can migrate from shallow to deeper basalt aquifers. These pathways may be responsible for some of the contamination that is found in the shallow basalt aquifers.