EXECUTIVE SUMMARY:

Lower Umatilla Basin Groundwater Investigation

A Groundwater Contamination Problem

In the Lower Umatilla Basin, local activities--such as irrigated agriculture, food processing, livestock operations, domestic sewage and military activities--have contributed to the degradation of area groundwater. The Oregon Department of Environmental Quality (DEQ) declared the Lower Umatilla Basin a "Groundwater Management Area" in 1990 when groundwater sampling during the mid-1980s found high nitrate concentrations in local groundwater.

The Oregon Groundwater Protection Act of 1989 requires Groundwater Management Areas to address confirmed contamination with nonpoint sources once the contaminant concentrations reach certain levels. Nitrate levels above 10 mg/L triggered the series of steps outlined by the legislation.

Nitrate concentrations in Lower Umatilla Basin groundwater exceed 10 and 20 milligrams per liter (mg/L) in many areas. These levels are of greatest concern for infants (less than six months of age), who may develop a blood disorder from ingesting excessive nitrates.

Addressing the Contamination

Five state agencies began coordinating a groundwater quality investigation in July 1990. State natural resource agencies, coordinated by the Oregon Strategic Water Management Group, appointed two local committees to review the investigation results and co-develop an Action Plan. A citizen committee and a technical advisory committee appointed to the Lower Umatilla Basin Groundwater Management Area began meeting in February 1991.

Nitrate contamination of groundwater within the Lower Umatilla Basin has been confirmed and investigated by these agencies:

- Oregon Department of Environmental Quality
- Oregon Water Resources Department
- Oregon Health Division
- Oregon Department of Agriculture
- Oregon State University

The investigation's findings, presented in the Investigative Overview and three technical chapters, are designed to assist in decisions that will address the groundwater contamination problem.

The local committees will co-develop an Action Plan for reducing the area-wide groundwater contamination to below 7 mg/L, the current trigger level. The state agencies will also co-develop the Action Plan, which must be approved by the Strategic Water Management Group.

The Action Plan will need to consider a number of complex factors that make the Lower Umatilla Basin's groundwater vulnerable to contamination. Given enough added moisture, basin soils allow contaminants to reach groundwater within months. Once in the groundwater, nitrate moves slowly, possibly taking decades to be discharged from the groundwater system. Clearly, the Action Plan won't be able to address the groundwater contamination with a "quick fix" solution.

A Thorough Investigation

Area of Investigation

The 550-square-mile investigation site is located in northern Morrow and Umatilla Counties between Willow Creek, Cold Springs Reservoir and the Columbia River. Affected communities include Boardman, Echo, Hermiston, Irrigon, Stanfield and Umatilla. Most of the area occupies a plain that gently slopes toward the Columbia River. The semi-arid area receives about 8 to 10 inches of annual precipitation.

Land Uses

A number of activities in the Lower Umatilla Basin have the potential to contribute nitrate to groundwater.

Irrigated agriculture, which has expanded to nearly 180,000 acres, is the dominant land use in the basin. Estimates indicate that irrigated agriculture releases the most nitrogen to the basin's land surface. Other studies conducted in the basin indicate some nitrogen escapes beyond the root zone at some irrigated fields, even under conservative management strategies.

Food processing facilities in the basin have expanded quickly since the 1970s to meet the economic demand for processed foods, particularly potato products. Wastewater management at food processing facilities has undergone successive adjustments to protect groundwater. Nutrient-rich food processing wastewater is land applied. A first, crop needs, acreage and growing seasons received inadequate consideration. Efforts to protect groundwater by better managing wastewater continues.

Animal feeding operations, particularly those with large numbers of animals confined to a small area, have the potential to release nitrogen to groundwater. The amount of animal waste stockpiled, stored and land applied has varied greatly from year to year, with some waste management problems noted.

Domestic sewage sludge and wastewater, when stored in lagoons or disposed of on or beneath the ground, can contribute nitrates to groundwater. Nitrate from domestic sewage is a concern mainly in areas with a high density of on-site systems.

Extensive military activities, involving metals, nitrogen, explosives and chemicals, have occurred over 180 square miles. Cleanup is the current focus of the military sites, with nitrate and other contaminants a concern at the U.S. Army Umatilla Depot.

Landfills and other disposal sites, particularly those without liners, could contribute nitrogen to groundwater. Electricity producers, facilities handling hazardous waste, area accidents or spills and groundwater recharge projects, were investigated and found to contribute little or no nitrogen.

Natural sources of nitrogen were also investigated. Background levels and a federal study support the finding that the natural contribution is very low.

The Scientific Approach

This investigation set out to determine which activities are responsible for the nitrate contamination.

To understand the distribution and source of nitrate contaminated groundwater in the Lower Umatilla Basin, various state agencies and area facilities participated in four types of groundwater sampling.

- Reconnaissance sampling (1990-1991) improved on existing data and dictated additional sampling locations.
- Bimonthly sampling of the same 35 to 40 wells from 1991 to 1994 offered a view of seasonal and long-term trends.
- Synoptic water level measurements and sampling provided basin-wide results for an understanding of groundwater flow paths and nitrate concentrations.
- Nitrogen-isotope sampling verified and improved on nitrate source information gathered in the other sampling.

The sampling results were evaluated through statistics, chemical constituent maps, graphs, computer modeling, and nitrogen isotopic analyses.

Sampling Results

State agencies collected nearly 850 groundwater samples from 252 sites in the Lower Umatilla Basin study area between June 1990 and March 1993. The sampling results for nitrate could almost be divided into thirds, with about 30 percent containing nitrate concentrations exceeding 10 mg/L, 26 percent less than 2 mg/L, and the remainder somewhere between 2 and 10 mg/L.

The groundwater samples were analyzed for a variety of other constituents to help identify contamination sources. A few samples contained agricultural or industrial chemicals. Eighty-five percent of the project's groundwater samples had sodium exceeding 20 mg/L, the concentration at which individuals on a physician-prescribed sodium-restricted diet should notify their doctors.

Graphs showed a basin-wide relationship between nitrate and total dissolved solids (TDS). Analysis indicate multiple land uses affect groundwater throughout the basin.

Evaluating chemical constituent relationships helped distinguish between potential sources. For example, the influence of septic systems could be distinguished from other potential sources based on potassium-bromide-chloride relationships, while food processors may be distinguished based on magnesium and bromide.

The Role of Geology

In the Lower Umatilla Basin, basalt lavas have been folded into a prominent trough between Arlington and Hermiston. Up to 250 feet of alluvial sediments have been deposited in this trough, mostly by catastrophic floods that swept down the Columbia River during the ice age.

The alluvial aquifer and the two or three upper basalt aquifers serve as the main sources of drinking water. The cities of Hermiston, Irrigon and Boardman draw water from the alluvial aquifer. Irrigation water is pumped from both the alluvial aquifer and the deeper basalt aquifers.

Soils in the alluvial aquifers allow rapid downward movement from excess water on land. Recharge to the alluvial aquifer comes primarily from canals, streams and reservoirs, with some deep percolation of irrigation water (varying with the irrigation practices) and very little from precipitation.

The aquifers generally discharge to the Umatilla and Columbia Rivers. Water in the alluvial and shallow basalt aquifers seem to be connected, based upon hydrogeological and groundwater chemistry evidence. Inadequate well construction allows additional mixing of alluvial and basalt groundwater.

Average groundwater flow velocities in the basin range from 0.0001 miles per year in silts to 0.5 miles per year in sands and gravels. Well pumping and recharge from surface water can affect groundwater movement, altering both the speed and the direction of the flow.

Travel time to groundwater appears short: one to eighteen months with sufficient moisture. The longer travel times were found mostly at sites with fine sediments and wells exceeding 100 feet in depth. Peak nitrate concentrations in the area generally occur from September through June. This possibly represents travel times to groundwater or deep percolation during the non-growing season. The influence of less moisture, crop uptake and evaporation may inhibit deep percolation during the summer months.

Nitrate Sources

Data analysis indicates no single source is responsible for the nitrate contamination in the basin. Nitrate can be attributed to commercial fertilizers, land application of food processing waste water, livestock waste, and lagoons at the U.S. Army Depot. Septic systems were found to influence nitrate in groundwater at lower concentrations, with some exceptions. Natural nitrogen sources are considered small.

This project identified nitrate contamination sources by considering groundwater chemistry, contamination distribution, land use activity distribution and estimated nitrogen use by each local land activity.

Threemile and Sixmile Canyon

This area yielded the highest total dissolved solids levels in the project samples and reported nitrate levels reached 70 mg/L. Analyses identify livestock waste and irrigated agriculture as sources of nitrate contamination. The source of nitrate at PGE's Ash Disposal area, while not from PGE activities, has not been resolved.

Boardman to West Umatilla

The highest nitrate concentrations in project samples came from this area. Project sampling detected nitrate exceeding 70 mg/L in the irrigated crop area between Irrigon and the Port of Morrow. The U.S. Army Depot reported nitrate exceeding 100 mg/L at several sites.

The Depot's explosive washout lagoon area caused the high nitrate concentrations in that area. A Depot source appears responsible for elevated nitrate in the Depot's active landfill area. Nitrate south of the Depot was linked to animal waste and crop irrigation. Nitrate along the west boundary of the Depot was linked to irrigated agriculture. Nitrate north of the Depot appears related to irrigation activity and septic systems.

High nitrates found in groundwater from alluvial and basalt wells south of Boardman are related to irrigated agriculture, livestock waste and septic systems. Nitrate concentrations exceeding 10 mg/L in alluvial groundwater at the Port of Morrow's and Lamb Weston's wastewater land application sites relates to these activities.

Butter Creek to Umatilla

Reported nitrate concentrations reached as high as 100 mg/L in this area. Peak elevated nitrate concentrations were found at the confluence of Butter Creek and the Umatilla River. Past food processing wastewater practices are responsible for elevated nitrates at land application sites. Septic systems affect the groundwater west of the Umatilla River and north of Interstate 84. Livestock and irrigated agriculture also contribute to the elevated nitrate concentrations.

Umatilla to Hat Rock and Echo Meadows Area

Nitrate concentrations did not exceed 31 mg/L and were below 10 mg/L in the Hermiston, Echo, Umatilla Meadows and Hat Rock areas. Nitrate levels for Hermiston's numerous unsewered homes were below 5 mg/L, possibly because of significant canal dilution.

Developing A Solution

Widespread groundwater contamination exists in the Lower Umatilla Basin. Groundwater supplies drinking water to the communities of Boardman, Hermiston, Irrigon, Stanfield, Echo and Umatilla and many rural residents.

Groundwater contamination occurs when water (or another liquid) and nitrate (or another contaminant) exceed what can be removed by vegetation or evaporation. Soil capacity is a factor in preventing deep percolation. Lower Umatilla Basin soils allow nitrate to migrate to groundwater when excess water is available to transport the contaminants.

A wide range of activities introduce water and nutrients to the basin's land surface. The Lower Umatilla Basin Groundwater Management Area Citizen and Technical Committees have the opportunity to address the nitrate sources through the Action Plan.

Steps have already been taken toward preventing nitrate contamination. Some irrigated crop fields already time water and nitrogen application to crop needs.

Food processors have gradually improved their land application techniques for wastewater. The Action Plan can consider if those efforts are sufficient.

Past practices may continue to contribute nitrate to groundwater if too much nitrate is stored in the vadose zone (the zone between groundwater and the land surface). This investigation did not thoroughly explore nitrate in the vadose zone. The committees will need to address the evaluation of different activities for their nitrate contribution to the vadose zone.

The Action Plan may also need to address land uses changes within the Lower Umatilla Basin. For example, septic systems could become a more significant source of nitrate if canal water is no longer available to dilute groundwater in high density areas of individual on-site systems.

Groundwater protection will benefit all Lower Umatilla Basin residents. The challenge lies in coordinating change among diverse land uses for long-term results.

Hydrogeology

Climate

The Lower Umatilla Basin has a semiarid climate with hot dry summers and cool moist winters. Annual precipitation varies with elevation and ranges from about 8 inches near the river to about 10 inches near the southern boundary of the groundwater management area. At Hermiston, the average precipitation by water year (October through September) is 8.75 inches (Figure 1.1). About 70% of the annual total falls during the months of October through March. Most of the total falls as rain but snowfall is significant in some years.

Geologic Setting

Large areas of eastern Washington and northeastern Oregon are underlain by a thick sequence of basalt lavas which are collectively known as the Columbia River Basalt Group. In the Umatilla Basin, the lavas have been folded into a prominent east-west trough (the Dalles-Umatilla Syncline) which is roughly coincident with the Columbia River between Arlington and Hermiston. Up to 250 feet of alluvial sediments have accumulated in the trough. Some of the sediments (the Alkali Canyon Formation) were deposited by streams which drained the Blue Mountains to the south but most were deposited by catastrophic floods which swept down the Columbia River drainage during the Pleistocene Epoch (ice age).

Since the end of the Pleistocene (about 12,000 years ago), thin deposits of micaceous silt, sand, and gravel have accumulated in portions of the Butter Creek and Umatilla River drainages. These modern alluvial deposits (Holocene Alluvium) are less than 30 feet thick and are largely composed of reworked catastrophic flood sediments.

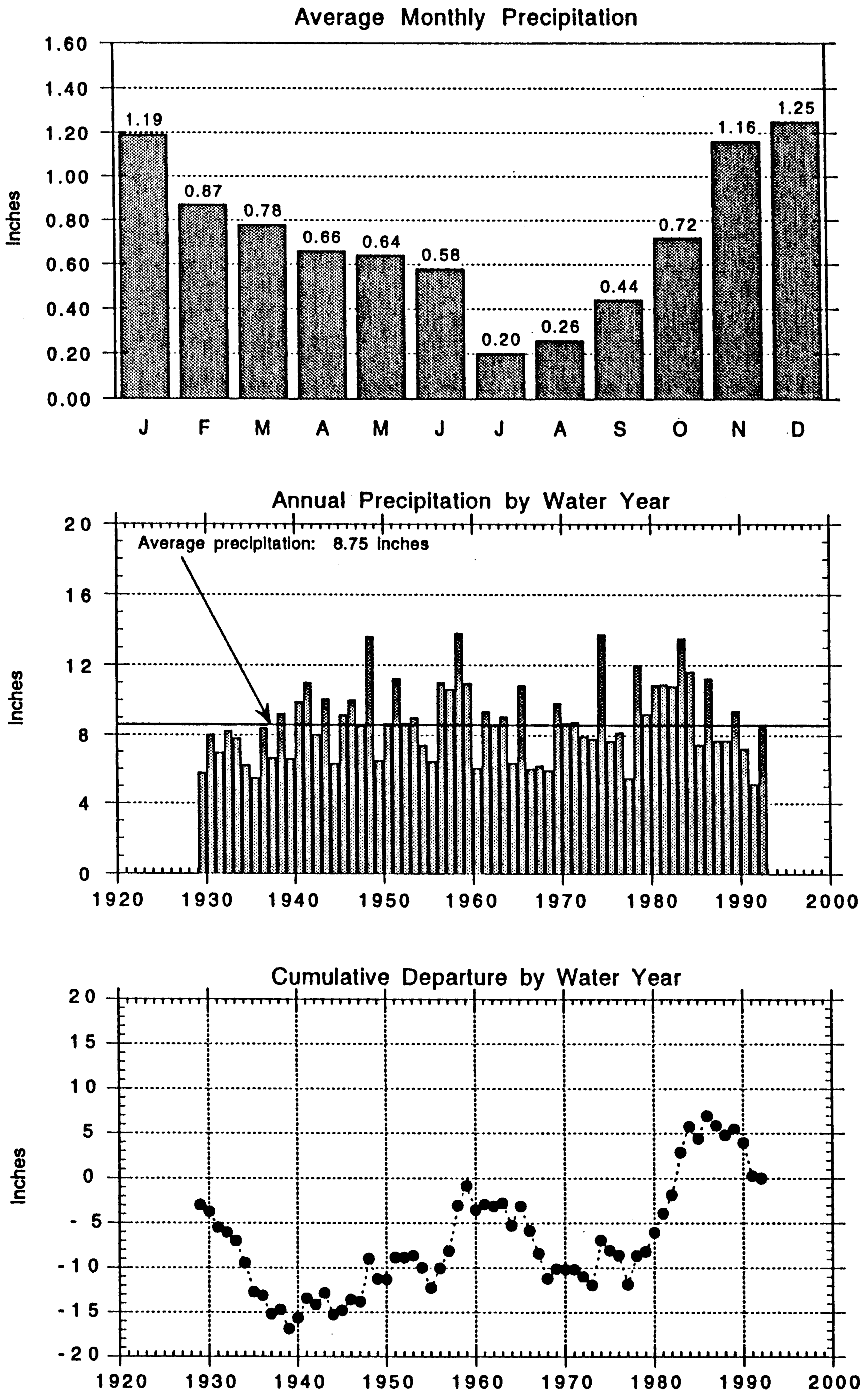


Figure 1.1 Precipitation at the Hermiston airport weather station: average monthly, annual, and cummulative departure (1928-1992).

Groundwater Flow System

The principal aquifers of the Lower Umatilla Basin occur in alluvial sands and gravels which overlie the Columbia River Basalt Group and in porous breccia zones within the basalt flows. 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 a source of irrigation water for local farms and, a source of municipal water for the cities of Hermiston, Irrigon, and Boardman. Deeper basalt aquifers are a major source of irrigation water in the basin. The shallow aquifers are the focus of this report.

Figure 1.2 shows a conceptual model of the shallow groundwater system in the basin. 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 breccia zones in the basalts are generally restricted to the top or bottom of flows (Figure 1.3). Because the breccias typically constitute less than ten percent of a flow's thickness, their exposed surface area is relatively small where the flow margin is exposed at land surface or beneath a cover of sediments.

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 discharged to underlying basalt aquifers where updip margins of lava flows are exposed at the base of the alluvial aquifer. Large volumes of groundwater are discharged from the shallow aquifers by wells. Groundwater can also migrate between aquifers in well bores that are open to more than one aquifer or in the annular space behind ungrouted casing.

Alluvial Aquifer

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

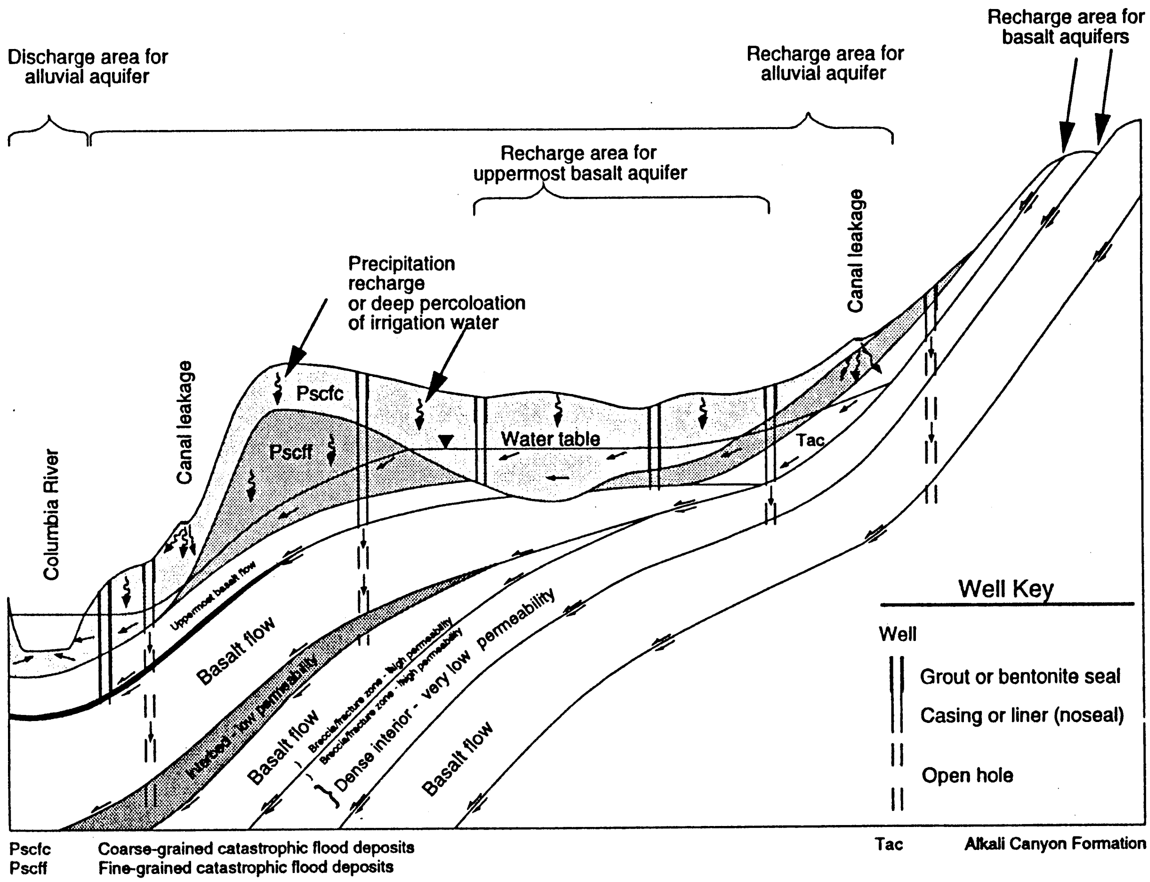


Figure 1.2 Conceptual model of the shallow groundwater flow system

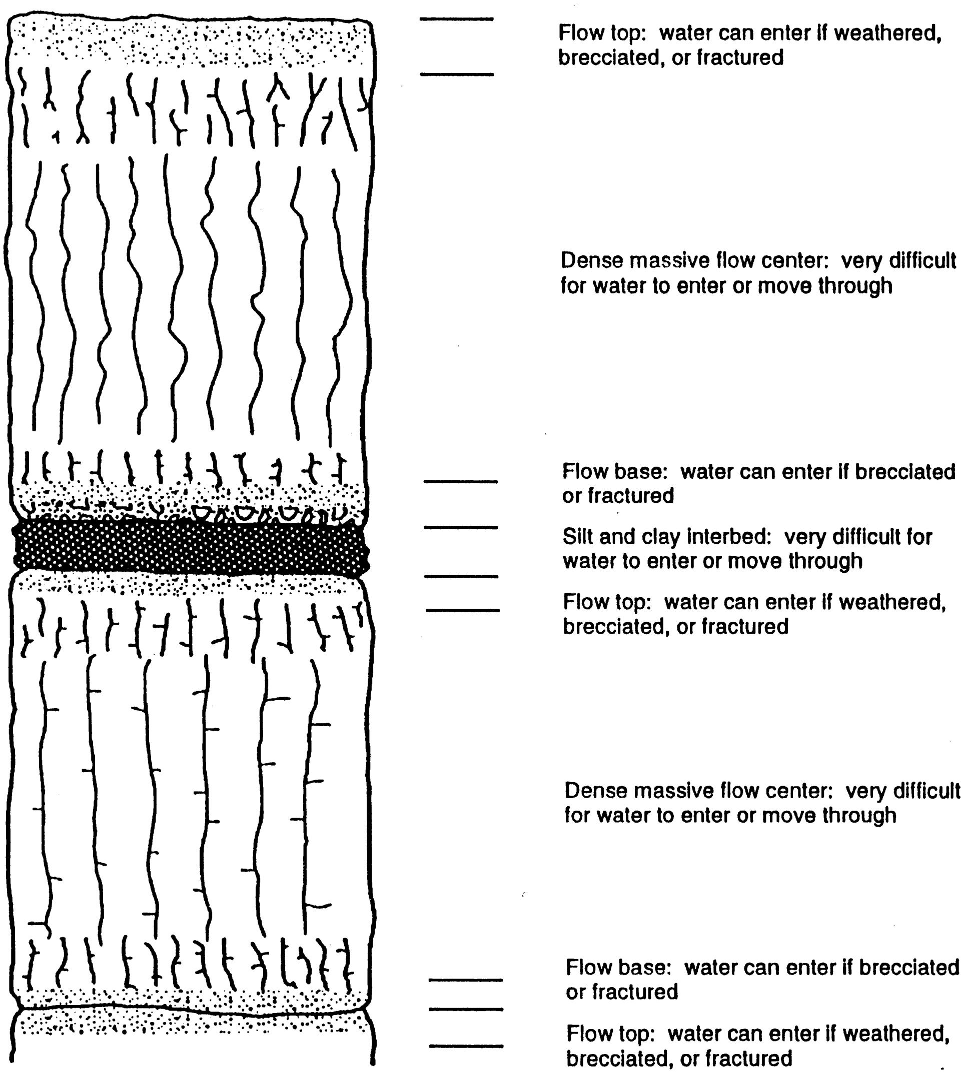


Figure 1.3 Idealized relationship between basalt stratigraphy and groundwater occurrence.

The boundaries of the productive aquifer are approximated by the limits of the water level contours shown on Plate 2.4. The boundaries 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 groundwater resource occurs in 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 the basalt bedrock is the primary factor which controls 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.

Aquifer Properties

Hydraulic properties vary geographically within the alluvial aquifer and correlate to the distribution of coarse-grained versus fine-grained sediments. Broad areas of contrasting properties can be differentiated within the catastrophic flood deposits.

Predominantly coarse-grained flood deposits occur as broad tracts of sands and gravels (Pscfc on Plate 2.3). The thickest accumulations occur in three shallow east- to northeast-trending troughs between Boardman and Cold Springs Reservoir. The saturated portions of these sediments (the principal areas are highlighted in yellow on Plate 4) are characterized by low hydraulic gradients (typically less than 10 feet per mile) and high well yields (up to 4000 gallons per minute). Aquifer tests indicate hydraulic conductivities between 1000 and 4000 feet per day.

Predominantly fine-grained flood deposits occur as silty sands, silts, and clays with interbeds of sand and gravel (Pscff on Plate 2.3). Saturated portions are characterized by steep hydraulic gradients (typically 25 to 50 feet per mile) and low to moderate well yields. Where sand and gravel beds are absent, the silts and silty sands are capable of supplying domestic needs only. Where sand and gravel beds are common, wells are capable of yielding up to 250 gallons per minute. Limited data suggest that hydraulic conductivities are less than 50 feet per day in the silts but may be as high as 200 feet per day in the sand and gravel interbeds.

Recharge

Soils in the Lower Umatilla Basin are typically sandy loams with moderate to high permeabilities. 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. The timing of water-level rises in wells near recharge sources indicates that recharge water travels from the land surface to the water table in several days to several months.

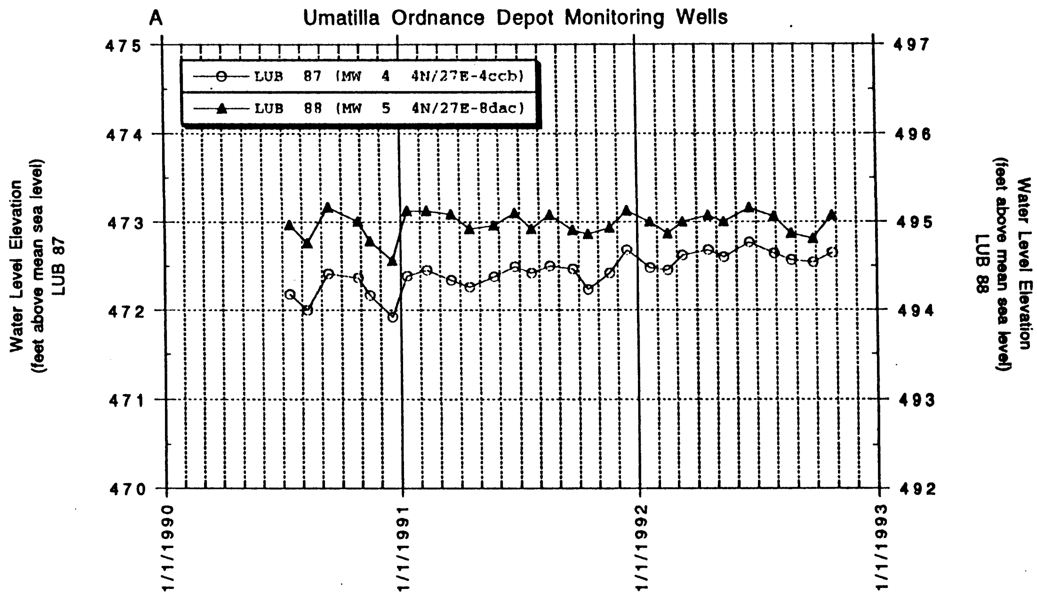
Although a comprehensive accounting of recharge is beyond the scope of this project, rough estimates of recharge magnitude can be made for the major potential recharge sources in the basin. These estimates are subject to large uncertainties and are presented solely to provide a sense of the relative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

Precipitation

Estimates of recharge from precipitation range from 0.2 inches to 2 inches per year (see chapter 2). This is the equivalent of 400 to 4000 acre-feet of recharge per township per year. The conservative estimate is consistent with the behavior of wells near the center of the Umatilla Ordnance Depot, an area remote from other sources of recharge. These wells show flat long-term water-level profiles with no obvious correlation to monthly precipitation trends (Figure 1.4).

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. Most of the canals are unlined or have older linings which are reported to be in poor repair. The available data suggests that losses from primary canals may range from 2.5 acre-feet per mile per day to 3.7 acre-feet per mile per day. Assuming an average seepage rate of 2.0 acre-feet per mile and a five month operating season, the annual loss for the main delivery canals in the basin is estimated at about 40,000 acre-feet per year (Table 1.1). This estimate does not include losses from lateral canals, ditches, and drains.



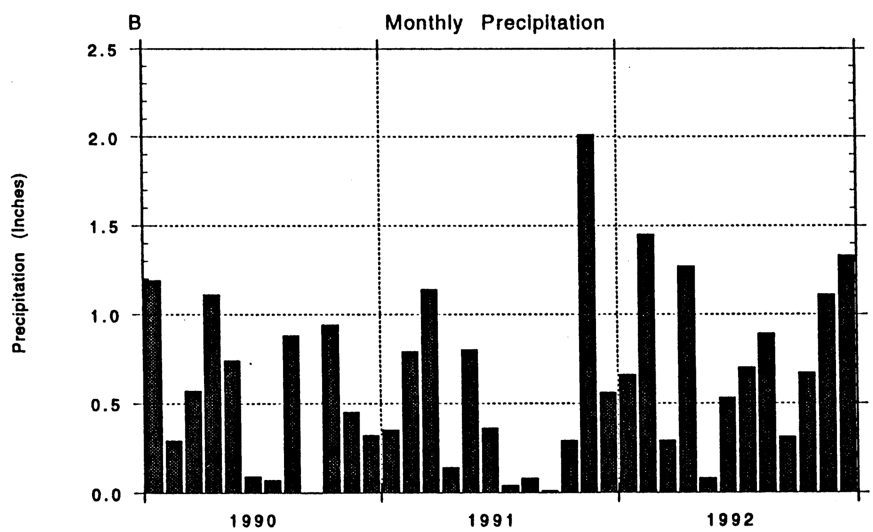


Figure 1.4 Comparison of water-level trends and precipitation in the interior of the Umatilla Ordnance Depot. A, Hydrographs of wells screened in fine-grained flood deposits; B Monthly precipitation at Boardman.

Table 1.1 Estimate 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

Deep Percolation

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. Factors which control the occurrence of deep percolation include soil permeability, soil moisture content, plant uptake rates, depth of the root zone, and the rate and timing of water application. The rate and timing of water application is controlled by the method of irrigation and by the water management strategies of individual irrigators. All else being equal, the relative potential for deep percolation is high for flood irrigation, less for sprinkler irrigation, and low for drip irrigation. Flood irrigation is still common in the West Extension and Hermiston irrigation districts but rare in the Stanfield and Westland districts. Elsewhere in the districts, hand lines and wheel line systems are common. Center pivots are the dominant sprinkler system used outside of the districts.

Evidence for deep percolation can be seen on the hydrographs (plots of water level versus time) of wells northeast of the Umatilla Ordnance Depot and on the terrace north of the Umatilla River (Figures 1.5 and 1.6). Seasonal water-level rises during the summer and the absence of other potential recharge sources at these localities indicate that applied irrigation water is the most likely source of recharge. Evidence for deep percolation is also seen in the hydrographs of several wells between Butter Creek and Emigrant Buttes. These wells show rising water-level trends during a period of declining annual rainfall (Figure 1.7). All three of these localities are irrigated with effluent water from food processing plants.

Data from the western boundary of the Umatilla Ordnance Depot indicate that deep percolation can also occur in areas irrigated by center pivot systems. Lands west and southwest of the Depot are irrigated by center pivots whereas lands on the Depot are not irrigated. Wells near the boundary show annual water-level rises that range between 0.5 and 2 feet but little or no seasonal fluctuation (Figure 1.8A). Annual rises are greatest near the boundary and decrease toward the interior of the Depot. These trends produce a bending of water-level contours which is coincident with the boundary (Plate 2.4). These phenomena indicate that recharge rates are greater on lands west of the Depot and that groundwater is flowing onto the Depot from the southwest. The only apparent source of recharge that can account for these trends is deep percolation on the irrigated lands. In addition, the coincidence of these trends with a cultural boundary suggests that the underlying cause is cultural.

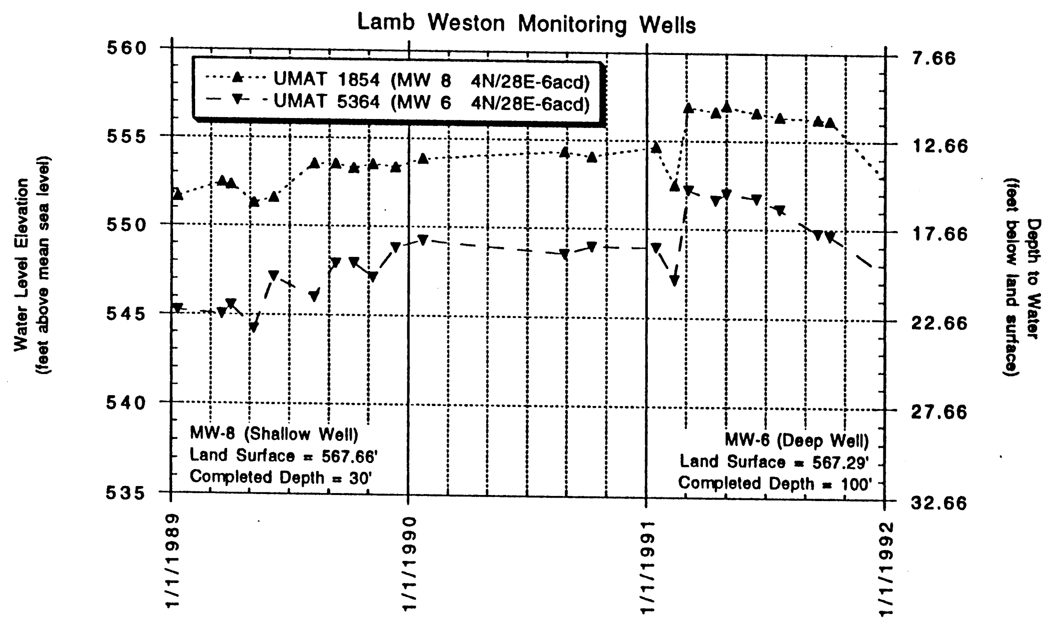
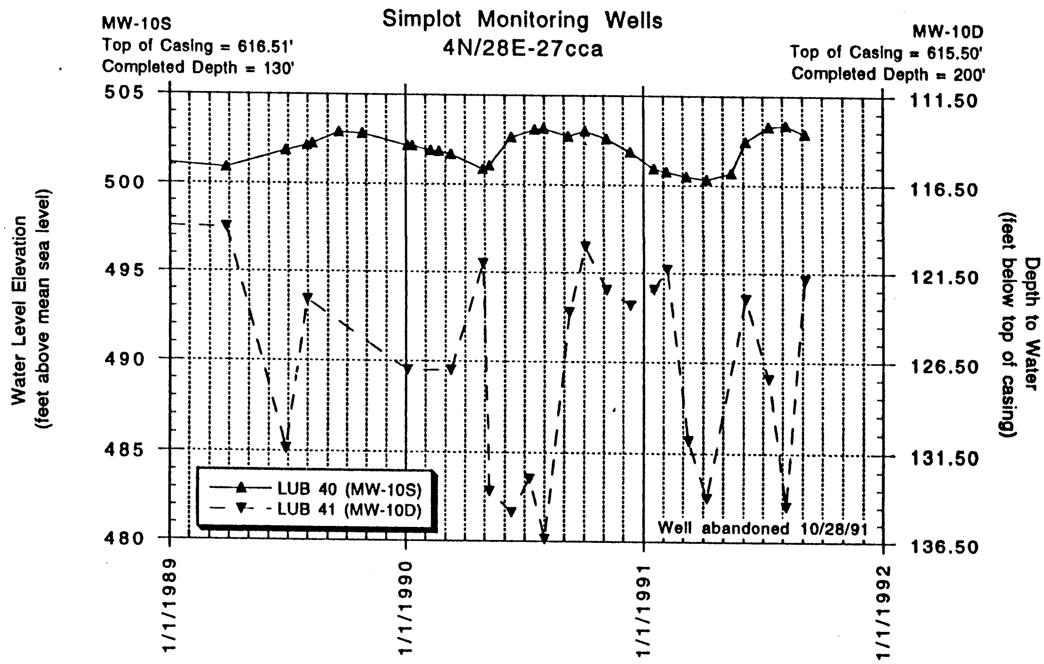


Figure 1.5 Hydrographs of adjacent wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits northeast of the Umatilla Ordnance Depot.



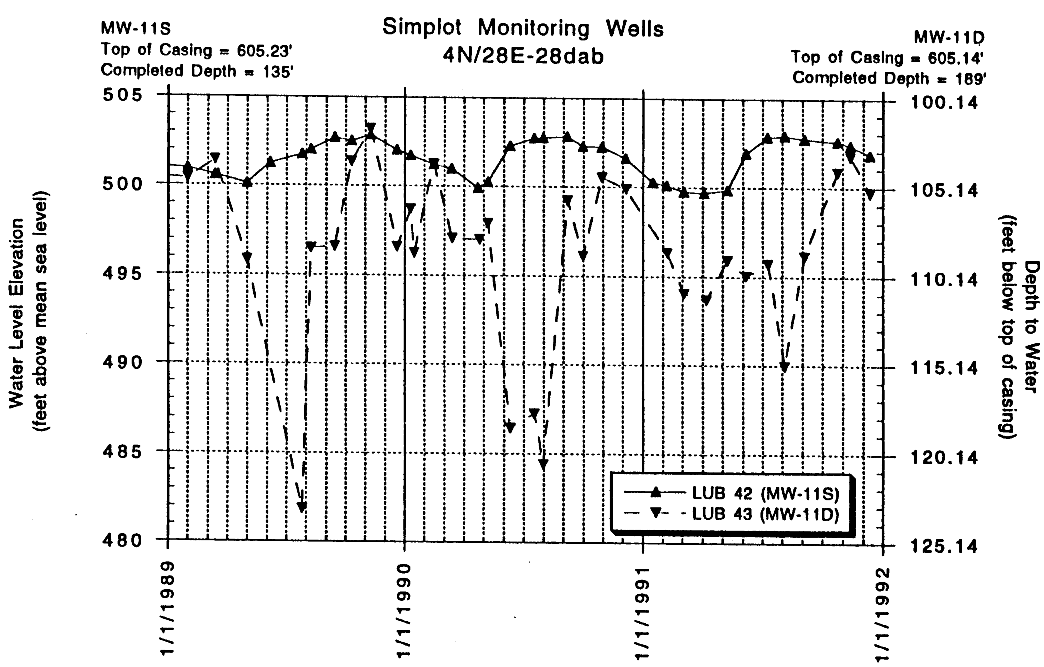


Figure 1.6 Hydrographs of paired wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits on the terrace north of the Umatilla River.

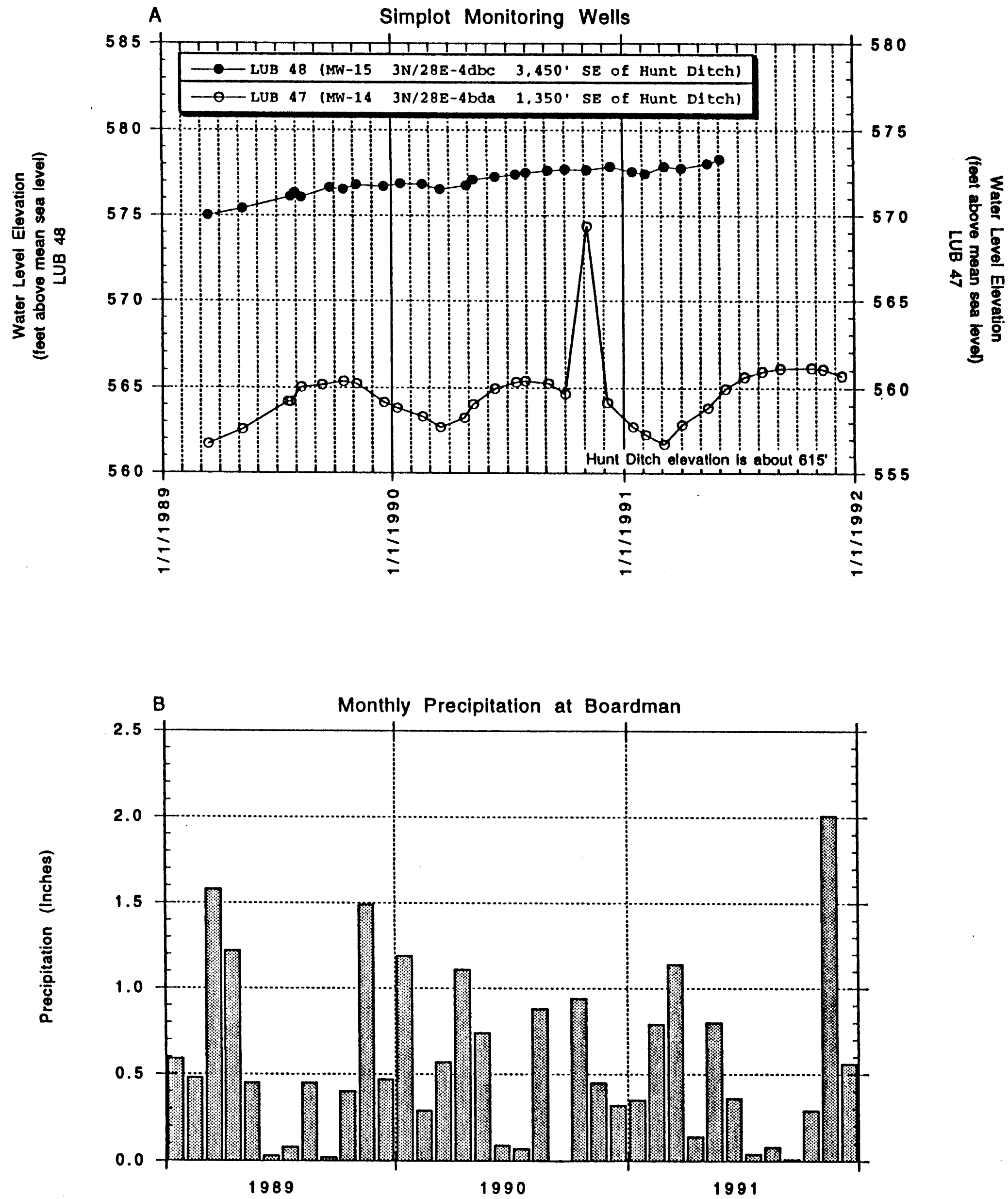
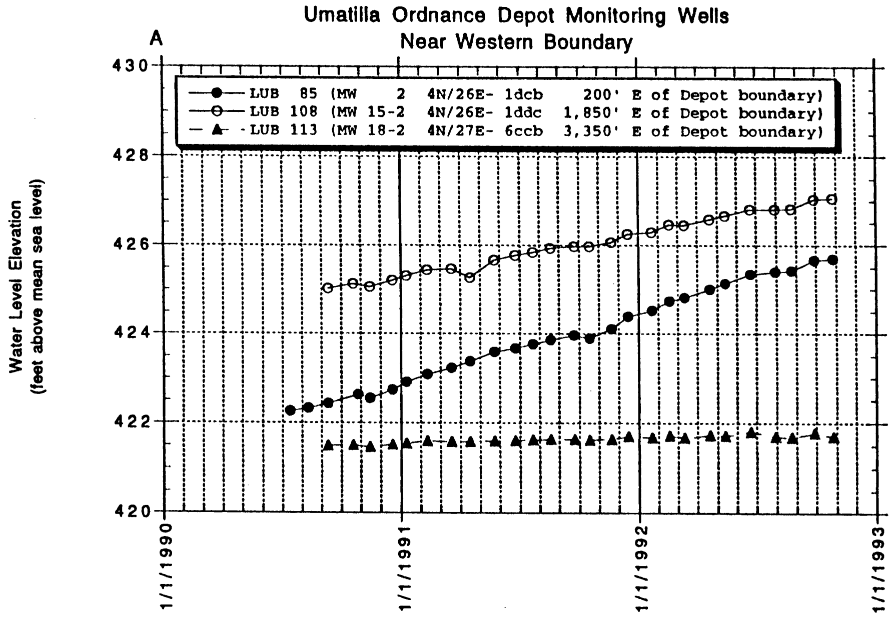


Figure 1.7 Comparison of water-level trends and precipitation in the area between Butter Creek and Emigrant Buttes. A, Hydrographs of wells screened in fine-grained flood deposits; B Monthly precipitation at Boardman.



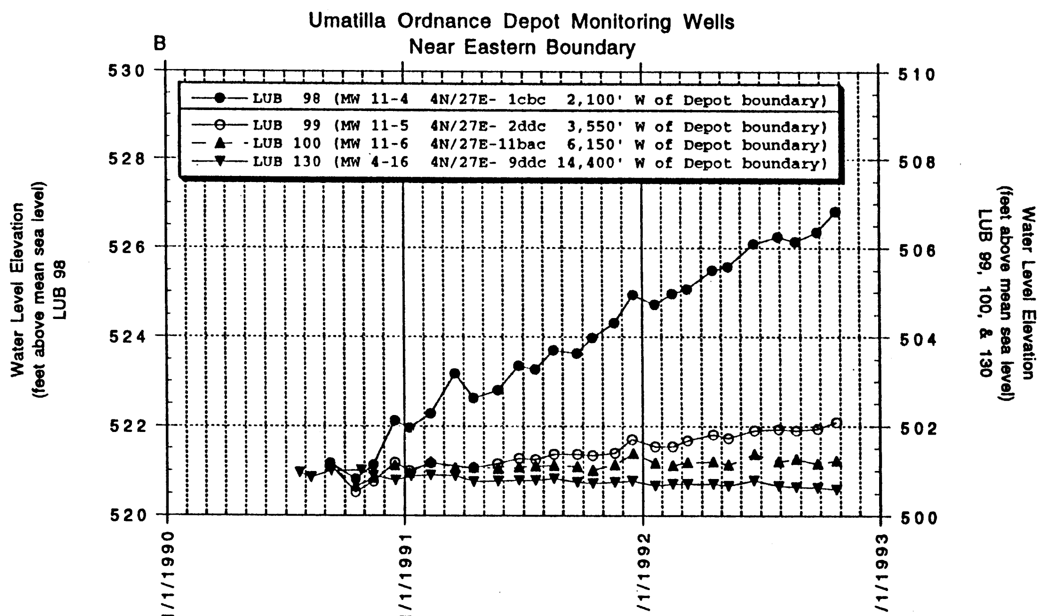


Figure 1.8 Seasonal hydrographs of monitoring wells screened in fine-grained flood deposits on the Umatilla Ordnance Depot. A, Wells near western boundary; B, Wells near eastern boundary.

The available evidence suggests that deep percolation recharge west of the Depot is responsible for groundwater-level rises of about 1.5 feet per year (see chapter 2). Assuming a porosity of 20%, this is equivalent to about 3.6 inches of recharge per year. Assuming an application rate of 36 inches of water per year, this equates to a deep percolation loss of about 10%.

Approximately 180,000 acres of land are irrigated in the Lower Umatilla Basin Groundwater Management area. Percolation recharge of 0.3 inches per year may be typical in areas irrigated by center pivots. Proportionately higher rates are expected in areas irrigated by wheel lines, hand lines, or flooding. If the minimum deep percolation recharge in the basin is assumed to be 2.4 inches per year, the minimum annual recharge from this source would total about 36,000 acre-feet per year.

Reservoir Leakage

Carty and Cold Springs reservoirs are the main water-storage facilities in the Lower Umatilla Basin. Carty Reservoir provides cooling water for Portland General Electric's Boardman Coal-Fired Plant and serves as a sink for some plant effluent. Cold Springs Reservoir is used by the Bureau of Reclamation to store Umatilla River water for the Hermiston Irrigation District. The maximum capacity of Carty Reservoir is 38,300 acre-feet. Cold Springs has a capacity of about 50,000 acre-feet.

Monitoring well hydrographs document leakage to groundwater at both reservoirs (see chapter 2). Wells near Carty indicate that reservoir water recharges the alluvial aquifer in Sixmile Canyon and the uppermost basalt aquifer (Basal Elephant Mountain Aquifer) in a broad area to the north of the reservoir. Prior to the filling of Carty reservoir, saturation in both aquifers was negligible. Wells near Cold Springs Reservoir indicate that the alluvial aquifer is recharged by seepage through the sediments which underlie the southern wing dam.

Leakage from Carty Reservoir to groundwater is estimated by Portland General Electric at about 4000 acre-feet per year, the equivalent of 10% of the total reservoir capacity. Leakage at Cold Springs Reservoir has not been quantified.

Stream Leakage

The potential for recharge from streams exists wherever stream elevations are above the water table. These conditions occur along the Umatilla River between the western part of Umatilla Meadows and Cottonwood Bend. The rate of leakage along this stretch is unknown.

Summary

The available data indicate that canal losses are a major source of recharge to the alluvial aquifer. Basin-wide recharge from deep percolation may be substantial but recharge rates probably vary widely depending upon irrigation practices. Recharge from reservoirs and streams may be significant but is of limited extent. Recharge from precipitation is probably negligible. Projects which reduce or eliminate canal leakage, reservoir leakage, or deep percolation of irrigation water will adversely impact groundwater supplies.

Flow Directions and Velocities

Water-level contours and interpreted flow directions for the alluvial aquifer are shown on Plate 2.4. These features reflect conditions in late winter when pumping withdrawals are minimum.

In a general sense, water-level contours 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 water levels. 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.

Between the Umatilla Ordnance Depot and Boardman, groundwater flow 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. Radial flow patterns centered near the northeast corner of the Depot and on the terrace between Hermiston and Stanfield indicate areas of local recharge. In much of the area east of the Depot, the topography of the basalt surface controls groundwater flow directions. For example, between Emigrant Buttes and Umatilla Butte, groundwater flow is restricted to east-west pathways between bedrock (basalt) highs along the Service Anticline.

Average groundwater flow velocity along a given flow path can be estimated by multiplying the hydraulic gradient (slope of the water table) times the hydraulic conductivity and dividing by the effective porosity of the aquifer. Based on a probable range of parameter values encountered in the study area (Table 1.2) groundwater 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. Velocities in the fine-grained flood deposits are estimated to range from 0.0002 to 2 feet per day or 0.0001 to 0.13 miles per year.

Table 1.2 Estimated 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

These rough estimates are presented only to give the reader a sense of relative flow velocities through the various aquifer materials. Actual flow velocities 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 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.

Discharge

Water exits the alluvial aquifer by discharge to streams, discharge to underlying basalt aquifers, and withdrawal from wells. Not enough data is available to determine discharge rates to streams and basalt aquifers but it is possible to outline areas where such discharge is likely to occur.

To Streams

Regional discharge from the alluvial aquifer is to the Columbia and Umatilla rivers. Between Boardman and McNary Dam, the Columbia River fully penetrates the alluvial aquifer. Under natural conditions, groundwater flow in this reach is to the north and the aquifer discharges to the river.

Well hydrographs and water table contours indicate that the alluvial aquifer discharges to the Umatilla River between Echo and the Columbia River except for the stretch between Umatilla Meadows and Cottonwood Bend, as noted in the above section on stream recharge. North 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. This geometry indicates that most of the alluvial groundwater that is funnelled down the Umatilla drainage must be discharged to the river in areas south of Three Mile Dam. Between Cottonwood Bend and Bridge Road, discharge to the Umatilla River is manifested by perennial seeps and springs. Measurable spring flows at Minnehaha and Bridge Road range from 3 to 5 cfs in the winter months, the equivalent of 2200 to 3650 acre-feet per year. Additional seepage is likely in the bed and banks of the river.

To Shallow Basalt Aquifers

The potential for discharge to shallow basalt aquifers exists wherever the updip margins of basalt flows are exposed beneath saturated sediments of the alluvial aquifer. All else being equal, discharge is likely to be greatest in areas where high permeability sediments overlie flow margins.

Updip flow margins are common in the study area for the upper two or three basalt flows (Saddle Mountains Basalt). Approximate locations for the principal margins are shown on Plates 2.2 and 2.3. Areas of potential discharge can be determined by comparing the location of flow margins with mapped features of the alluvial aquifer on Plate 2.4.

Additional discharge to basalt aquifers occurs where inadequate well construction provides a conduit between the alluvial aquifer and basalt aquifers. Many basalt wells in the basin do not have a seal which extends into the dense interior of the first basalt flow. Under these conditions, groundwater from the alluvial aquifer can migrate into the well bore through breccia zones at the top of the basalt flow. The volume of water that enters a borehole this way will probably vary depending on local conditions at the surface of the basalt. If the Alluvial aquifer is contaminated, a small rate of inflow may degrade only the water in and near the well bore. A large rate of inflow may produce a contaminant plume in the basalt aquifers tapped by the well. One driller has reported some success in cleaning up domestic water wells in the Boardman area by placing a grout seal completely through the dense interior of the first basalt flow. This suggests that, in some cases, contamination of the basalt aquifers is limited to the vicinity of the well bore.

To Wells

Table 1.3 summarizes well withdrawals from the alluvial aquifer. Total withdrawal is estimated between 65,000 and 98,000 acre-feet per year. Irrigation accounts for 80 to 90% of the total yearly withdrawal.

Groundwater Supply

Under natural conditions, the average annual discharge from an aquifer is in equilibrium with the average annual recharge, 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 (and storage) will decline until the aquifer is depleted.

Table 1.3 Summary of well withdrawals from the alluvial aquifer.

Category	Discharge acre-ft/yr			Comments
Domestic Wells	1750*		1,750	Assumes 500 gallons per day per well
Irrigation - Primary	36,000	-	54,000	Assumes 2-3 acre-ft/yr/acre
Irrigation - Supplemental	15,500**	-	31,000	Assumes 1-2 acre-ft/yr/acre
Miscellaneous	9,332		9,332	Mostly commercial and industrial use permits
City of Hermiston	1,811		1,811	City well #5
City of Irrigon	291		291	City well #2
Total	64,684	-	98,184	
City of Boardman	1,108		1,108	Ranney collector adjacent to Columbia River
Umatilla Fish Hatchery	8,881		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

The principal productive areas of the alluvial aquifer occur within three shallow troughs that are filled with coarse-grained flood deposits (Plate 2.4). Groundwater supply conditions vary in each of the troughs.

In the Ordnance trough, water-level declines indicate that discharge exceeded recharge between 1960 and 1976 and between 1986 and 1993. If this imbalance continues, water levels will continue to decline.

In the Boardman-Umatilla trough 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 Hermiston trough is similar in size to the Ordnance trough but has a greater density of canals and a lower volume of well discharge. The existing data indicate that groundwater levels are stable and that annual recharge is in balance with annual discharge. Additional pumping capacity is probably available in this area but future conservation measures by the Hermiston Irrigation District and decreased use of the Feed Canal to deliver water to Cold Springs Reservoir may adversely impact groundwater supplies.

Shallow Basalt Aquifers

Water-bearing zones in the Columbia River basalts are largely 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.

Three shallow aquifers occur within flows of the Saddle Mountains Basalt (the youngest flows of the Columbia River Basalt Group). Each aquifer includes water-bearing zones at the base of a flow and water-bearing zones at the top of the underlying flow. A thin interbed of silt and clay separates the two zones in many areas.

Aquifer Properties

Estimates of hydraulic conductivities for the shallow basalt aquifers range up to 18 feet per day. Estimates of storativity range up to .003. These values are considerably less than their counterparts for the productive parts of the alluvial aquifer.

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 updip margins of the basalt flows are exposed to recharge waters. Recharge rates cannot be determined from the present data but recharge locales and the relative contributions of the various sources can be established.

Within the study area, updip margins of the upper two basalt flows generally occur beneath a cover of alluvial sediments. 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.

The updip margin of the uppermost basalt flow is also 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 uppermost basalt aquifer is well documented. Leakage from the Umatilla River is highly probable.

As discussed above, some recharge to the shallow basalt aquifers also comes from alluvial groundwater which migrates through the bores of wells which are inadequately sealed.

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. 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. Pumpage discharge was not estimated for the current study.

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. Discharge rates cannot be calculated using available data.

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 causes groundwater to migrate between the aquifers. The magnitude of discharge by this mechanism is unknown but 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

In general, breccia and fracture zones account for less than 10% of the thickness of a Columbia River Basalt flow. Assuming an average porosity of 10%, this equates to a storage capacity of about 1% of the total flow volume. Because of this low capacity for storage, Columbia River basalt aquifers are particularly vulnerable to overdraft, a common condition in many of the deeper basalt aquifers of the Umatilla Basin. Low hydraulic conductivities and storativities in the basalt aquifers also increase the likelihood of interference between wells. These factors and the limited extent of the shallow basalt flows suggest that the development potential of the shallow basalt aquifers is somewhat limited.

Water levels in the shallow basalt aquifers appear to be stable in most parts of the study area, but excessive pumpage may be causing some declines in a small area between Hermiston and the Umatilla Ordnance Depot. Declines may be exacerbated when wells are deepened without sealing off the upper aquifer, a common practice in the area.