Hydrogeology, Groundwater Chemistry and Land Uses in the Lower Umatilla Basin Groundwater Management Area

Northern Morrow and Umatilla Counties
Oregon

(Final Review Draft)

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Table of Contents

Acknowledgements

Well Identification and Location Systems

Executive Summary: Lower Umatilla Basin Groundwater Investigation

Chapter 1: Investigative Overview

Chapter 2: Hydrogeology

Chapter 3: Land Use and Nitrogen Loading

Chapter 4: Groundwater Chemistry

References

Appendices

Chapter 1 Appendices

Appendix 1A: State Agency Groundwater Sampling Selected 1984 to 1987 Data

Appendix 1B: Lower Umatilla Basin Groundwater Management Area Citizens Committee

Appendix 1C: Lower Umatilla Basin Groundwater Management Area Technical Advisory Committee

Chapter 2 Appendices

Appendix 2A: Inventory of Project Wells

Appendix 2B: Synoptic Water Level Data

Appendix 2C: Summary of Aquifer Test for MORR 963

Chapter 3 Appendices

Appendix 3A:	Nitrogen in Soil Background Discussion and General Soil Characteristics for the Lower Umatilla Basin
Appendix 3B:	Irrigated Agriculture: Nitrogen Possibly Applied and Possibly Leached
Appendix 3C:	Food Processing Industry: Land Application
Appendix 3D:	Livestock: Nitrogen Produced and Land Applied
Appendix 3E:	Municipal Sewage Treatment Facilities: Land Application and Infiltration
Appendix 3F:	Large On-Site Sewage Systems: Infiltration
Appendix 3G:	Individual On-Site Sewage Systems: Infiltration
Appendix 3H:	U.S. Army Umatilla Depot Activity: Chronologic History, Remedial Investigation Sites, Sites with Soil and/or Groundwater Contamination
Appendix 3I:	Umatilla Butte Landfill: Chronologic History, Wastes Disposed
Appendix 3J:	Union Pacific Railroad: Accidents Reported to DEQ
Appendix 3K:	Accidents and Spills within the Lower Umatilla Basin Reported to DEQ
Appendix 3L:	Hazardous Waste Handlers within the Lower Umatilla Basin
Appendix 3M:	Underground Storage Tanks within the Lower Umatilla Basin

Chapter 4 Appendices

Appendix 4A:	Groundwater Chemistry Background Discussion
Appendix 4B:	Nitrogen Isotopes Background Discussion

Appendix 4C: Groundwater and Surface Water Sampling Sites

Appendix 4D: Reconnaissance Groundwater Sampling Plan

Appendix 4E: Bimonthly Groundwater Sampling Plan

Appendix 4F: Project Sampling Data: Selected Inorganic Constituents (July 1990 - March 1993)

Appendix 4G: Project Groundwater Sampling Data: Detected Pesticides and Volatile Organic Compounds (July 1990 - December 1994)

Appendix 4H: Constituent vs Constituent Graphical Analysis

Plates

Chapter 2 Plates

Plate 2.1 Well Locations and Place Names

Plate 2.2 Geologic Map Showing Structure Contours on Top of the Columbia River Basalt Group

Plate 2.3 Geologic Cross Sections

Plate 2.4 Water Level Contours of the Alluvial Aquifer, February 1991

Plate 2.5 Well Density

Plate 2.6 Irrigated Acreage and Permitted Alluvial Aquifer Wells

Chapter 3 Plates

Plate 3.1: Generalized Agriculture Areas

Plate 3.2: General Industry, Food Processing Facilities, and Landfills

Plate 3.3: Livestock Operations

Plate 3.4: Sewage Treatment Facilities

Plate 3.5: Density of Homes and Facilities Using Septic Drainfields

Plate 3.6: Military Facilities

Plate 3.7: Reported Accidents, Spills, and Leaks

Chapter 4 Plates

Plate 4.1: Groundwater Chemistry Sampling Sites

Plate 4.2: Nitrate + Nitrite-Nitrogen Concentration Distribution in Alluvial Groundwater

Plate 4.3: Maximum Nitrate + Nitrite-Nitrogen Concentrations Detected

Plate 4.4: Total Dissolved Solids Concentration Distribution in Alluvial Groundwater

Plate 4.5: Maximum Total Dissolved Solids Concentrations Detected

Plate 4.6: Maximum Total Arsenic Concentrations Detected

Plate 4.7: Maximum Total Sodium Concentrations Detected

Plate 4.8: Maximum Chloride Concentrations Detected

Plate 4.9: Maximum Total Phosphate Concentrations Detected

Plate 4.10: Maximum Boron Concentrations Detected

Plate 4.11: Maximum Bromide Concentrations Detected

Plate 4.12: Maximum Total Vanadium Concentrations Detected

Plate 4.13: Volatile Organic Compounds and Agricultural Pesticides Detected

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Well Identification and Location Systems

Wells are identified in this report by the well log ID assigned by the Water Resources Department. The ID consists of the first four letters of the county and a six-digit sequentially number. Wells with more than one well log were assigned the ID of the earliest well log of record. Wells without well logs on file are designated by the letters LUB (Lower Umatilla Basin).

Wells sampled by the Department of Environmental Quality are also identified by a three-character project code (UMA) and a sequential number. Cross references are made in the appendices of this report.

Well locations in this report are based on the rectangular system used for the subdivision of public land. Each location is designated by listing land tracts of descending size as shown in Figure 4.1. For example, the well location 4N/28E-20aab indicates a well located within township 4 north, range 28 east (36 square miles), section 20 (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 based on the public land survey system but, following convention, are designated by land tracts of increasing size. For example, the notation NW/NE/NE 20-4N/28E indicates a feature located in the northwest quarter (10 acres) of the northeast quarter (40 acres) of the northeast quarter (160 acres) of section 20 in township 4 north, range 28 east.

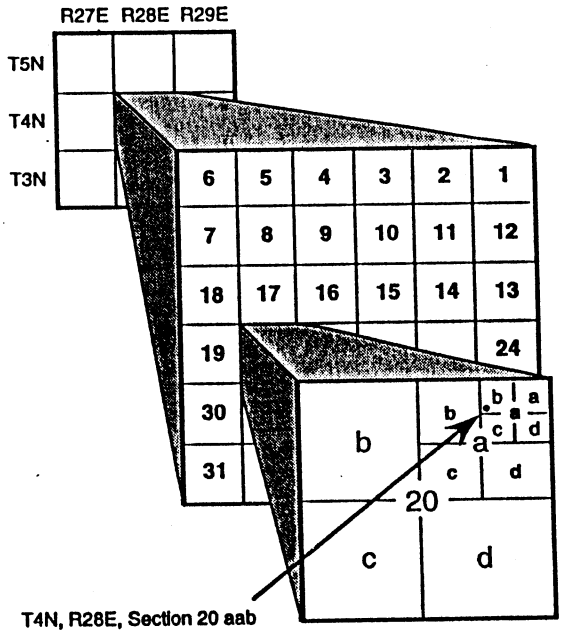


Figure 1 Well location system

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.

Chapter 1

Investigative Overview

Hydrogeology, Groundwater Chemistry and Land Uses in the Lower Umatilla Basin Groundwater Management Area

Northern Morrow and Umatilla Counties
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Chapter 1: Investigative Overview

Table of Contents

Introduction 1
Groundwater Management Area Declaration 1
Oregon Groundwater Protection Act 2
Groundwater Management Area Process 2
Implementation in the Lower Umatilla Basin 3
Potential Health Effects of Nitrate 3
Technical Investigation Conducted 4
Location 4
Technical Investigation Questions 5
Technical Report Supports Action Plan 5
Cooperative Interagency Effort 6
Oregon Water Resources Department 6
Oregon Department of Environmental Quality 6
Oregon Health Division 6
Oregon Department of Agriculture 6
Oregon State University 6

Hydrogeology 7
Climate 7
Geologic Setting 7
Groundwater Flow System 9
Alluvial Aquifer 9
Aquifer Properties 12
Recharge 13
Precipitation 13
Canal Leakage 13
Deep Percolation 16
Reservoir Leakage 21
Stream Leakage 21
Summary 22
Flow Directions and Velocities 22
Discharge 24
To Streams 24
To Shallow Basalt Aquifers 25
To Wells 25
Shallow Basalt Aquifers 27
Aquifer Properties 27
Recharge 28

Flow Directions and Velocities 28
Discharge 29
Groundwater Supply 29

Land Use and Nitrogen Loading 30
Land Use History 30
Before 1945 30
1945-1960s 31
1960s-1970s 31
1970s-1980s 32
Early 1990s 32
Nitrogen Loading 33
Loading Relationship to Groundwater Contamination 33
Local Soils 33
Nitrogen Loading Summary 35
Irrigated Agriculture 35
Food Processing 35
Livestock 35
Domestic Sewage 36
Military Activities 36
Other Land Uses 36
Natural Sources 36
Irrigated Agriculture 37
Background 37
Basin History 37
Irrigated Agriculture Nitrogen Loading 40
Food Processing 41
Basin History 41
Food Processing Nitrogen Loading 41
Livestock 43
Background 43
Basin History 43
Livestock Nitrogen Loading 44
Domestic Sewage (municipal and on-site) 45
Background 45
Basin History: Municipal 45
Basin History: On-site 45
Domestic Sewage Nitrogen Loading: Municipal 46
Domestic Sewage Nitrogen Loading: On-site 46
Military Activities 50
Basin History 50
Military Activities Nitrogen Loading 50
Other Loading Sources 51
Solid Waste 51
Electricity Generation 52
Union Pacific Railroad 52

Pendleton Grain Growers 52
Groundwater Recharge 52
Accidents and Spills 53
Hazardous Waste 53
Underground Storage Tanks 53
Natural Occurrence 53

Groundwater Quality 54
A Focus On Nitrate 54
Sampling and Analyses 55
Introduction 55
Groundwater Sampling Conducted 56
Reconnaissance Sampling 56
Bimonthly Sampling 56
Synoptic Sampling 56
Nitrogen-Isotope Analysis 57
Data Analyses Conducted 57
General Statistics 57
Chemical Constituent Maps 57
Graphical Analyses 58
Groundwater Flow Path 58
Computer Modeling Groundwater Chemistry Variations 59
Nitrogen Isotope Analyses 59
Data Analysis Results 59
Introduction 59
Constituents 60
Nitrate 60
Nitrate Sources for Threemile and Sixmile Canyon Area . . 61
Nitrate Sources for Boardman to west Umatilla 61
Nitrate Sources for Butter Creek to Umatilla 62
Nitrate Sources For Umatilla to Hat Rock to Echo Meadows 63
Total Dissolved Solids 63
Arsenic 63
Sodium 64
Chloride 64
Phosphate, Boron, and Bromide 64
Vanadium 64
Volatile Organic Compounds and Pesticides 65
Graphical Observations and Interpretations 65
Basin-wide Correlations 65
Evaporation and Mixing Influences 67
Piper Trilinear Graph and Schoeller Diagram Results 67
Nitrate Versus Time 68
Influence of Multiple Nitrate Sources 68
Groundwater Flow Path Results 71

Groundwater Chemistry Model Results 71

Evaluation of Canal Leakage 73
The Evaluation of Water-Mineral and Evaporation Influences 73
Evaluation of Food Processing Wastewater Influence 75
Nitrogen Isotopic Analysis Results 75
Evaluation of Denitrification 76
Evaluation of Hydraulic Flushing 76
Alluvial-basalt Groundwater Interconnection 77
Nitrate Travel Time 78
Land Surface to Groundwater 78
Travel Time in Groundwater 80

Investigative Overview Summary 81
Hydrogeology 82
Land Use and Nitrogen Loading 83
Nitrogen Loading 84
Irrigated Agriculture 84
Food Processing 84
Livestock 84
Domestic Sewage 85
Other Potential Sources 85
Groundwater Quality 86
Nitrate 86
Other Influences 87

Chapter 1: Investigative Overview

Summary of Figures and Tables

Figure 1.1 Precipitation at the Hermiston airport weather station: average monthly, annual, and cummulative departure (1928-1992). 8

Figure 1.2 Conceptual model of the shallow groundwater flow system 10

Figure 1.3 Idealized relationship between basalt stratigraphy and groundwater occurrence. 11

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. 14

Table 1.1 Estimate of yearly canal losses for main delivery canals. 15

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. 17

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. 18

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. 19

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. 20

Table 1.2 Estimated flow velocities in the alluvial aquifer 23

Table 1.3 Summary of well withdrawals from the alluvial aquifer. 26

Table 1.4 Assessed risk of groundwater contamination from potential nitrate leaching of local soil. 34

Table 1.5 Total irrigated crop agriculture acreage estimates for the Lower Umatilla Basin. 39

Table 1.6 The average annual nitrogen budget for intensively managed Lower Umatilla Basin crops 40

Table 1.7 Approximate food processing industry total land application area and total nitrogen loading in the Lower Umatilla Basin for selected periods. 42

Figure 1.9 Approximate operational period for basin livestock commodities. 43

Table 1.8 Estimated nitrogen loading in the Lower Umatilla Basin by municipal sewage treatment facilities during 1992-1993. 47

Table 1.9 Estimated nitrogen loading estimate in the Lower Umatilla Basin by selected large on-site sewage treatment systems. 48

Table 1.10 Estimated annual total nitrate-nitrogen loading from domestic septic systems in the Lower Umatilla Basin. 49

Figure 1.10 Nitrate+nitrite-nitrogen versus total dissolved solids and sulfate in Lower Umatilla Basin groundwater. 66

Figure 1.11 Total dissolved solids versus nitrate+nitrite-nitrogen for groundwater sampled near potential nitrate sources (septic tank influences graph within a limited area). 70

Figure 1.12 Variation of calcium, chloride, and nitrate+nitrite-nitrogen along the Butter Creek flow path. 72

Figure 1.13 An example of similar nitrate concentration and groundwater elevation fluctuations in the Lower Umatilla Basin. 79

Chapter 1: Investigative Overview

Introduction

Groundwater Management Area Declaration

The Oregon Department of Environmental Quality (DEQ) established the Lower Umatilla Basin as a Groundwater Management Area (GWMA) in 1990, based upon high nitrate-nitrogen concentrations in groundwater samples.

To be declared a Groundwater Management Area, a location must have confirmed groundwater contamination from multiple widespread sources (nonpoint source activities) at concentrations that meet or exceed specified trigger levels. The trigger level for nitrate-nitrogen in 1990 was 10 mg/L.

Local groundwater samples collected and analyzed for pesticides and other chemicals between 1984 and 1987 confirmed high nitrate concentrations in basin groundwater was common. Nitrate-nitrogen was detected in the Boardman, Irrigon and Umatilla vicinities. Potential nitrate sources included irrigated agriculture, food processing, livestock, domestic sewage and military activities.

Pesticides were detected in samples from four wells (Appendix 1A). Of the 25 wells sampled for nitrate, 11 wells contained concentrations greater than the 10 milligrams per liter (mg/L) nitrate-nitrogen public water supply drinking water standard. Concentrations as high as 80 mg/L nitrate-nitrogen were detected. These results confirmed point source facility monitoring, domestic well testing, public water supplies, and city of Hermiston data, all of which indicated high nitrate concentrations existed in area groundwater.

The 1990 GWMA declaration triggered specific steps outlined in the Oregon Groundwater Protection Act of 1989 (HB3515). An interagency groundwater quality investigation began in July 1990. The Oregon Strategic Water Management Group (SWMG) appointed local citizens to a Lower Umatilla Basin Groundwater Management Area Citizen Committee and a Technical Advisory Committee on November 21, 1990.

Oregon Groundwater Protection Act

The 1989 Oregon legislature passed the Groundwater Protection Act (HB3515) to prevent contamination of Oregon's groundwater resource while striving to conserve, restore, and maintain the high quality of Oregon's groundwater resource for present and future uses. The Act requires a series of activities to address contamination. Those activities include:

- protecting all Oregon groundwater for existing and future beneficial uses;
- conducting public education, research, and demonstration projects;
- identifying and characterizing all Oregon groundwater;
- establishing best practicable management practices to prevent groundwater contamination; and
- establishing areas of concern or groundwater management areas where area-wide groundwater contamination is related to nonpoint sources.

The Act requires implementing those activities by interagency cooperation under the direction of the Oregon Strategic Water Management Group (SWMG).

Groundwater Management Area Process

When a groundwater management area is declared, the Groundwater Protection Act requires SWMG to designate a lead state agency, assign responsibilities to other state agencies, and appoint a local groundwater management committee within 90 days of the declaration. Then, the agencies and the local committee co-develop a draft Action Plan for SWMG approval which will reduce existing groundwater contamination and prevent future contamination.

Implementation in the Lower Umatilla Basin

DEQ currently serves as the lead state agency for the Lower Umatilla Basin Groundwater Management Area (GWMA). State agencies cooperating in the Lower Umatilla Basin GWMA process include:

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

SWMG could shift the lead agency role for agricultural water quality management activities to the Oregon Department of Agriculture (ODA) under Oregon Senate Bill 1010. The 1993 Oregon legislature passed SB 1010 which authorizes the ODA to develop and implement water quality management plans in agricultural and rural areas when such a plan is required by state or federal law. A mandatory, rather than voluntary GWMA Action Plan could trigger the shift. ODA Senate Bill 1010 activities in a groundwater management area are subject to SWMG coordination.

SWMG appointed a local 20-member Citizen Committee and a 10-member Technical Advisory Committee to serve the Citizen Committee on November 21, 1990. Committee members are listed in Appendix 1B and 1C. Both committee memberships represent a variety of local interests. The Action Plan will be developed based upon this report after submitting it to the Citizen Committee and state agencies.

Potential Health Effects of Nitrate

The United States Environmental Protection Agency (USEPA) set a 10 mg/L maximum contaminant level (MCL) for nitrate-nitrogen in public water supplies (Oregon Health Division, 1990). Nitrate levels above 10 mg/L nitrate-nitrogen may represent a serious health concern for infants and pregnant or nursing women.

Adults receive more nitrate exposure from food. Infants, however, receive the greatest exposure from drinking water because most of their food is in liquid form. Nitrate can interfere with the ability of the blood to carry oxygen to vital tissues of the body in infants of six months old or younger. The result is called methemoglobinemia, or "blue baby syndrome." Pregnant women may be less able to tolerate nitrate, and nitrate in the milk of nursing mothers may affect infants directly. These persons should not consume water containing more than 10 mg/L nitrate directly, added to food products, or beverages (especially in baby formula). Other domestic use of this water supply is acceptable, including washing or bathing. (Oregon Health Division, 1990).

The 10 mg/L standard of nitrate-nitrogen in public water supplies has been devised to protect a select group of sensitive persons (infants, and pregnant and nursing women). Available health information suggests that non-sensitive persons, including health adults and children older than six months in age, can consume water containing up to 20 mg/L of nitrate-nitrogen without experiencing adverse health effects. At nitrate levels above 20 mg/L, the Oregon Health Division recommends alternate water supplies be used by all persons (Oregon Health Division, 1990).

It has been suggested in preliminary studies that excessive nitrate ingestion may be linked to gastric cancer (Magee and Barnes, 1967, Bogovski, 1972, National Academy of Sciences, 1977, 1980, Ginocchio, 1984). An EPA review of studies investigating the carcinogenicity of nitrate and nitrite found the results inadequate and inconclusive (U.S.E.P.A., 1985, 1989).

Technical Investigation Conducted

Location

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. Basin communities include Boardman, Echo, Hermiston, Irrigon, Stanfield, and Umatilla. The area is drained by the Umatilla River, Butter Creek and the Columbia River. Most of the study area occupies an undulating plain that slopes gently to the north.

Technical Investigation Questions

The technical investigation addressed the following questions.

- Where is Lower Umatilla Basin groundwater found and what are its sources?
- Where and how does local groundwater flow?
- Does groundwater in different aquifers interconnect?
- Which current and historic basin land uses potentially contaminate groundwater?
- What is the relative contaminant loading from each source?
- What chemical constituents contaminate groundwater?
- Where does groundwater contamination occur?
- How does groundwater contamination and chemistry vary within an area and over time?
- How does groundwater contamination and chemistry relate to the local hydrogeology and land uses?
- What are the likely groundwater contamination sources?

Identifying the basin's nitrate sources and understanding the groundwater chemistry was complicated by the hydrogeology, varied land uses, and natural water chemistry. An intensive analysis helped to determine likely nitrate sources by investigating the complex and inconsistent relationship between nitrate and other constituents.

This overview summarizes the technical investigation. More details about the investigation can be found in Chapters Two, Three and Four.

Technical Report Supports Action Plan Development

The 1989 Groundwater Protection Act requires state agencies and the local Groundwater Management Area Committee to develop an Action Plan. That plan must include identification of sources and practices contributing to the local groundwater contamination, and consideration of alternatives and recommended actions needed to reduce the groundwater contamination below the trigger levels.

The committee members and state agencies will use this report to explore and identify actions that will successfully reduce groundwater contamination in the basin. This report describes the Lower Umatilla Basin groundwater flow system and quality. It also identifies the nature and the likely sources of groundwater contamination.

Cooperative Interagency Effort

Oregon Water Resources Department

The Oregon Water Resources Department (WRD) characterized groundwater occurrence and flow (hydrogeology) within the alluvial aquifer system and shallow basalt aquifers of the Lower Umatilla Basin.

Oregon Department of Environmental Quality

The Oregon Department of Environmental Quality (DEQ) characterized groundwater quality, land uses, and potential contamination sources of the Lower Umatilla Basin. DEQ's activity included conducting laboratory analyses of inorganic constituents and volatile organic compounds.

Oregon Health Division

The Oregon Health Division (OHD) provided well owners information regarding water analyses and potential health impacts. OHD also analyzed and interpreted how groundwater chemistry relates to contamination sources versus other influences of the Lower Umatilla Basin.

Oregon Department of Agriculture

The Oregon Department of Agriculture (ODA) conducted primary laboratory analyses for pesticides, provided grants for local agricultural research, and provided review, comments and guidance for projects.

Oregon State University

Oregon State University (OSU) conducted agricultural assessments, agricultural field research, and confirmation laboratory analyses for pesticides for the Lower Umatilla Basin. OSU also provided review, comments and guidance related to local agriculture.

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.

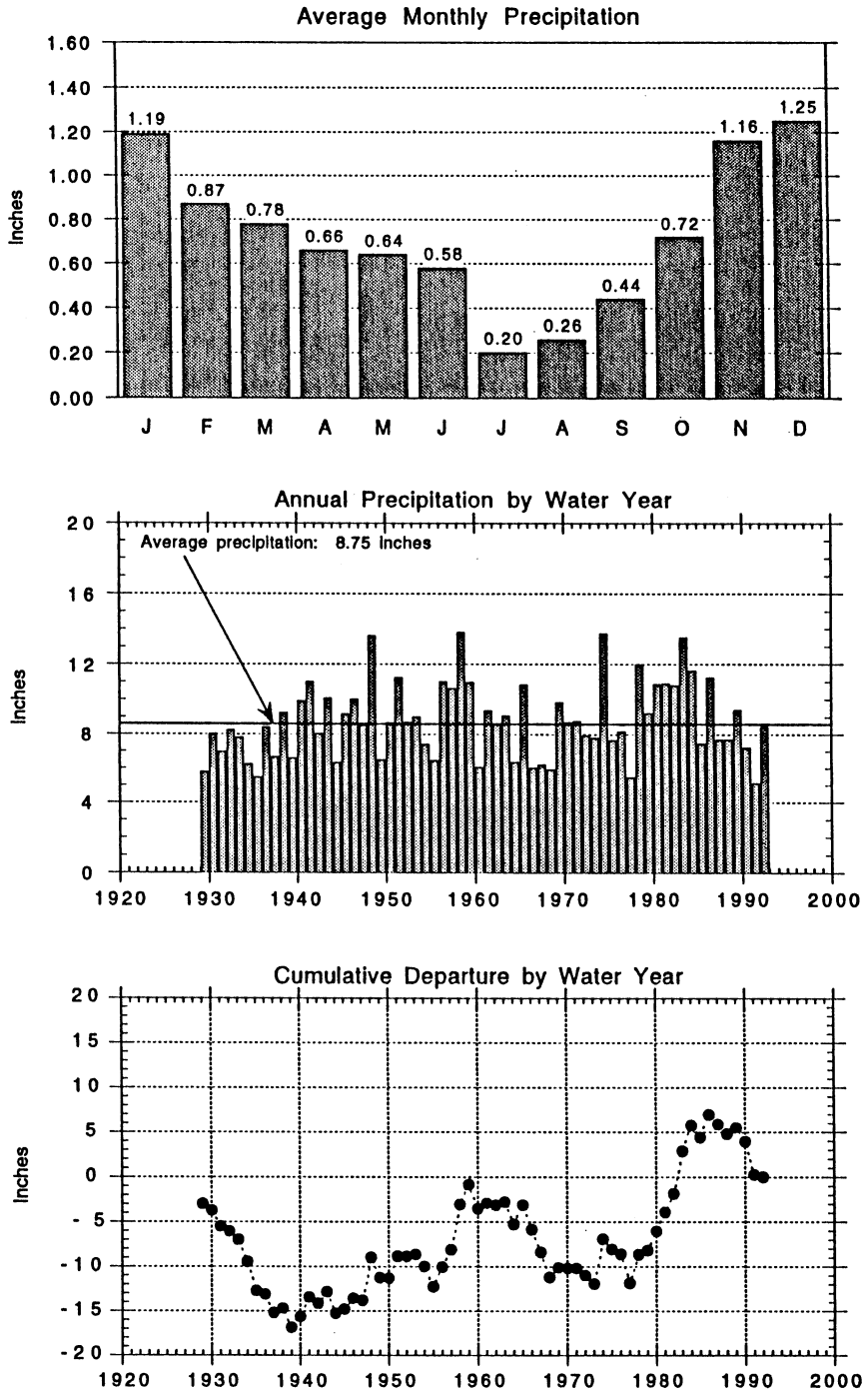


Figure 1.1 Precipitation at the Hermiston airport weather station: average monthly, annual, and cummulative departure (1928-1992).

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).

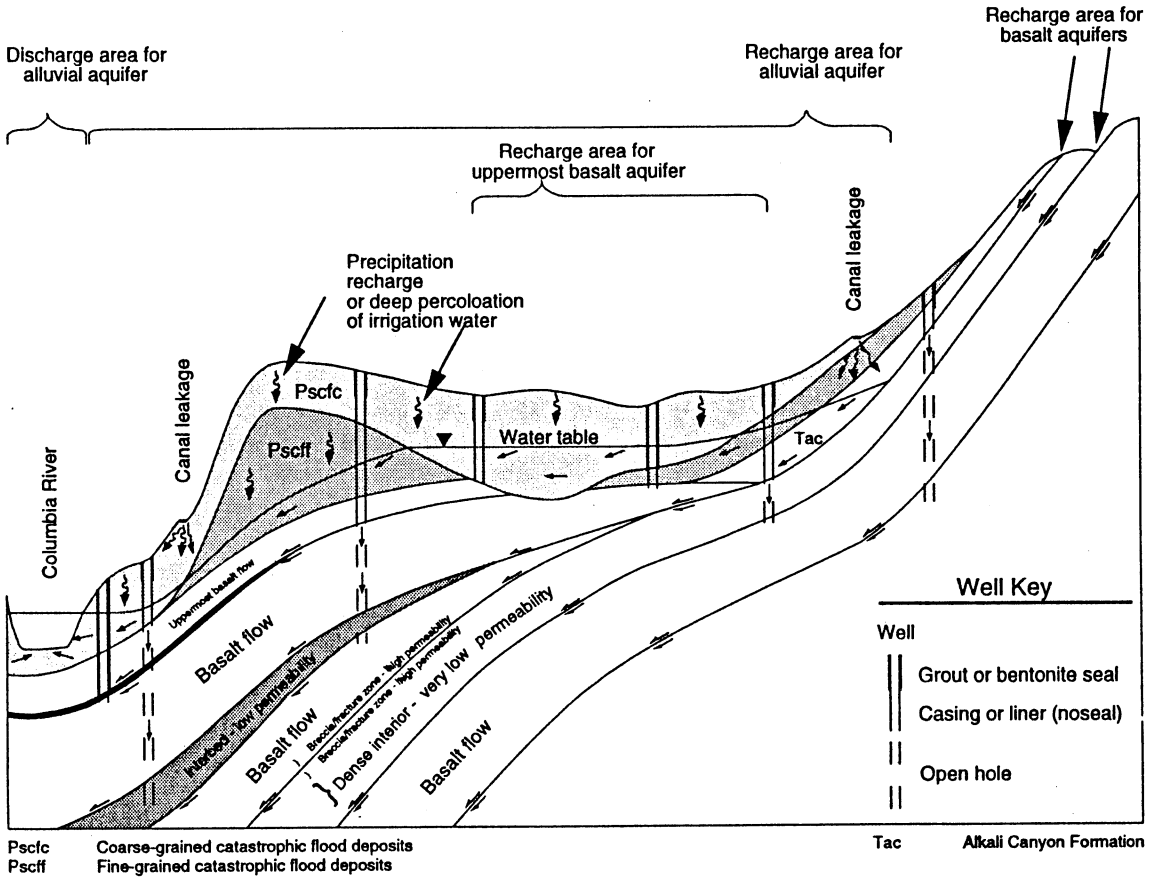


Figure 1.2 Conceptual model of the shallow groundwater flow system

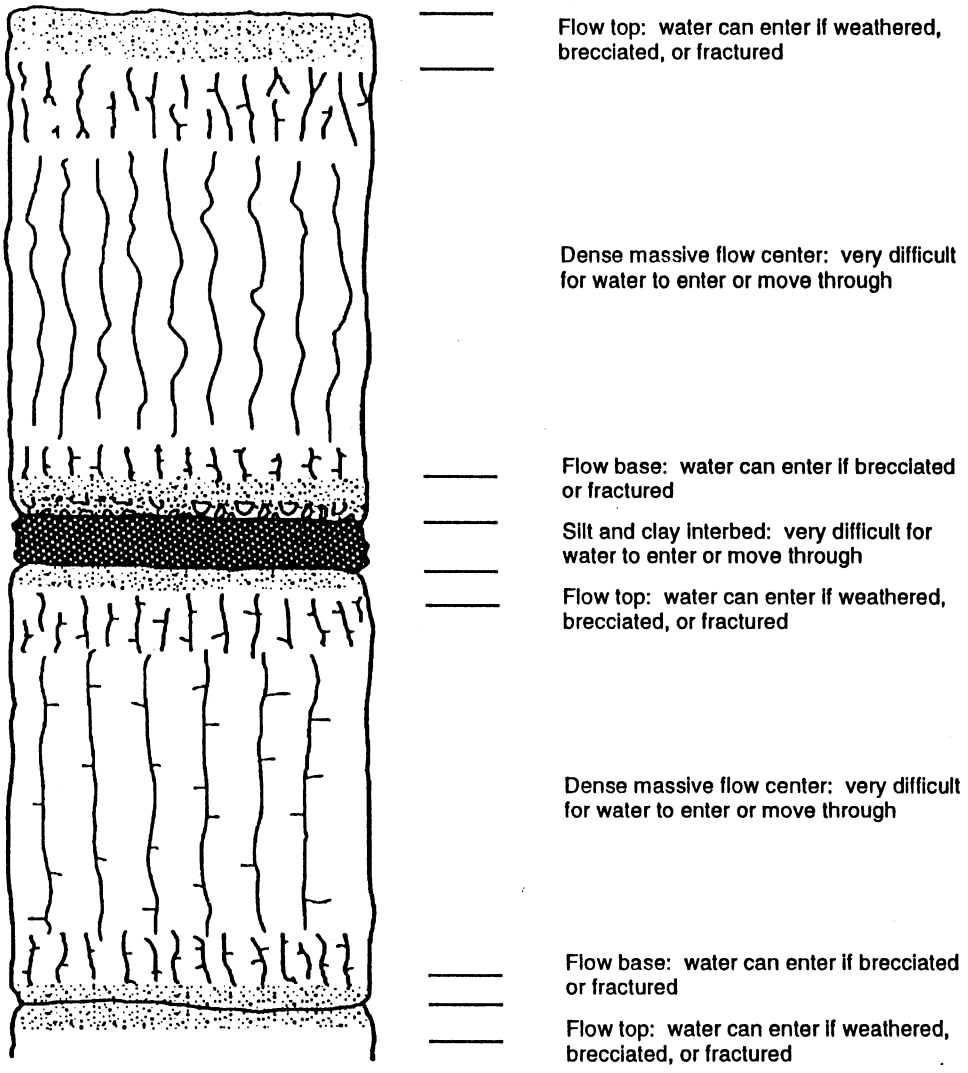


Figure 1.3 Idealized relationship between basalt stratigraphy and groundwater occurrence.

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.

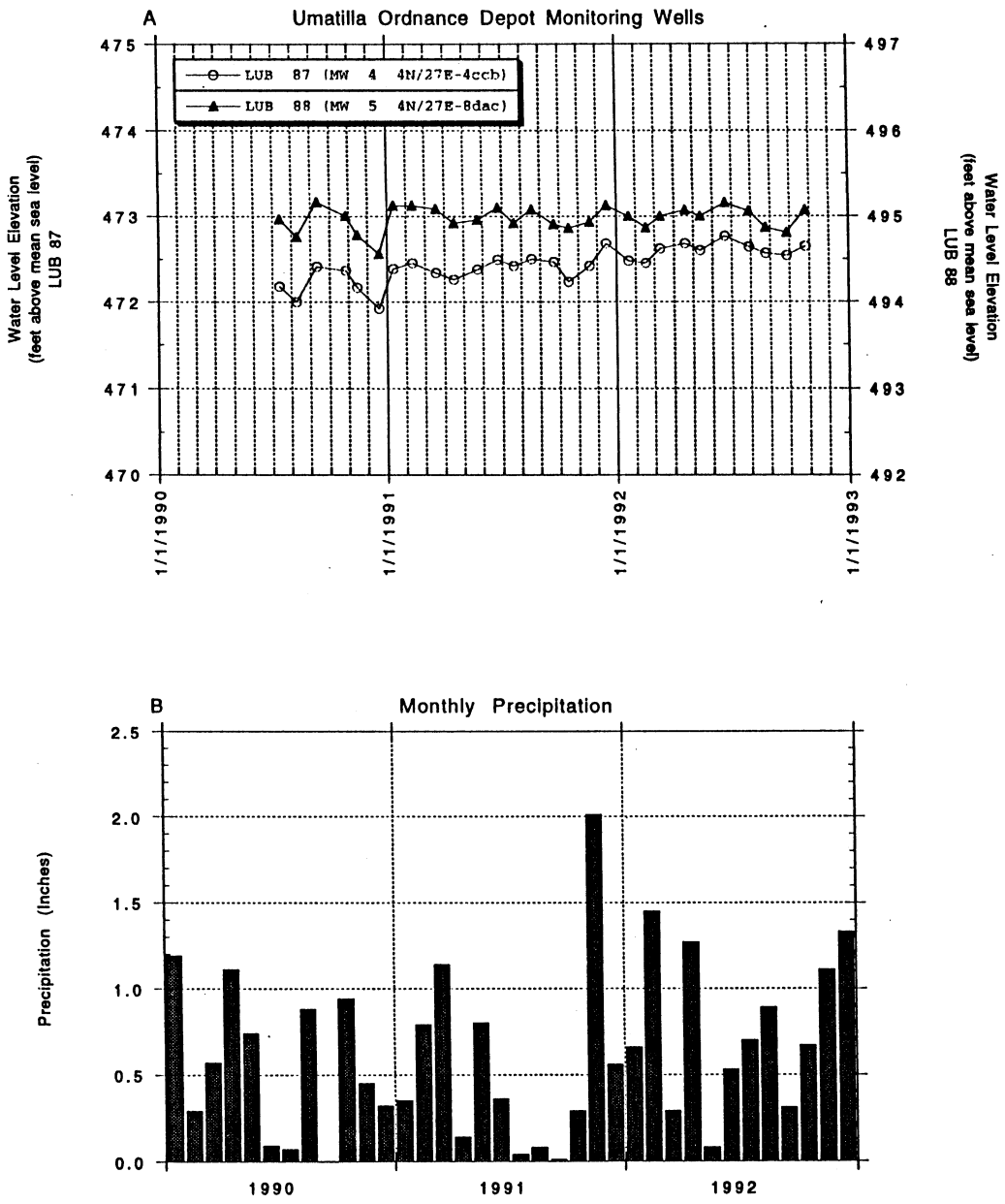


Figure 1.4 Comparison of water-level trends and precipitation in the interior of the Umatilla Ordnance Depot. A, Hydrographs of wells screened in fine-grained flood deposits; B Monthly precipitation at Boardman.

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.

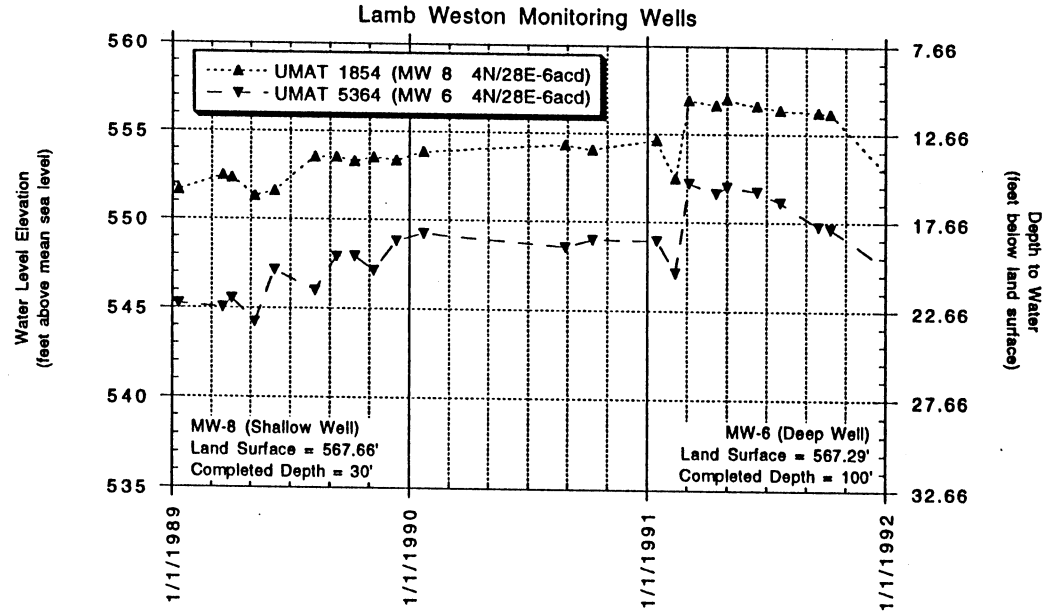


Figure 1.5 Hydrographs of adjacent wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits northeast of the Umatilla Ordnance Depot.

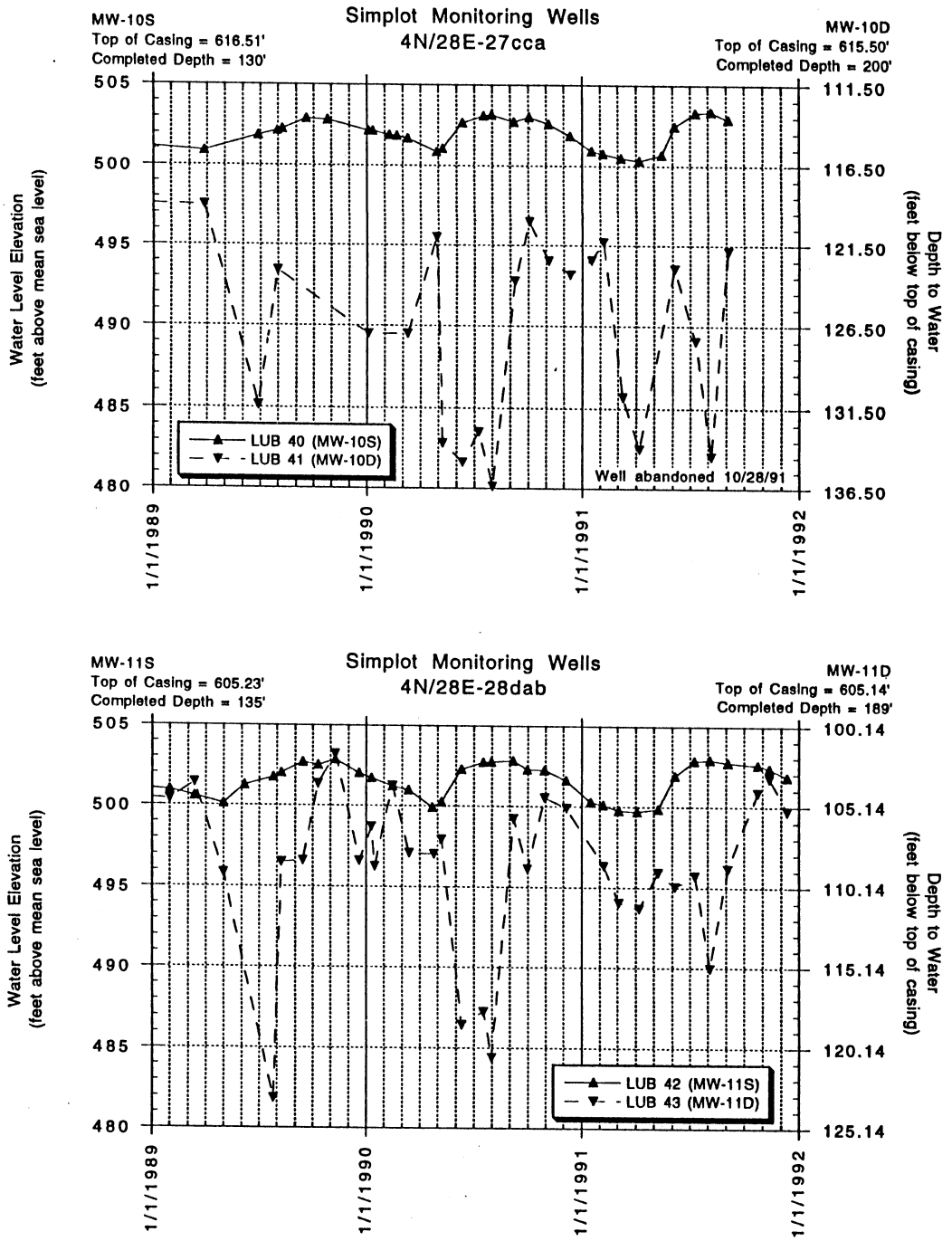


Figure 1.6 Hydrographs of paired wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits on the terrace north of the Umatilla River.

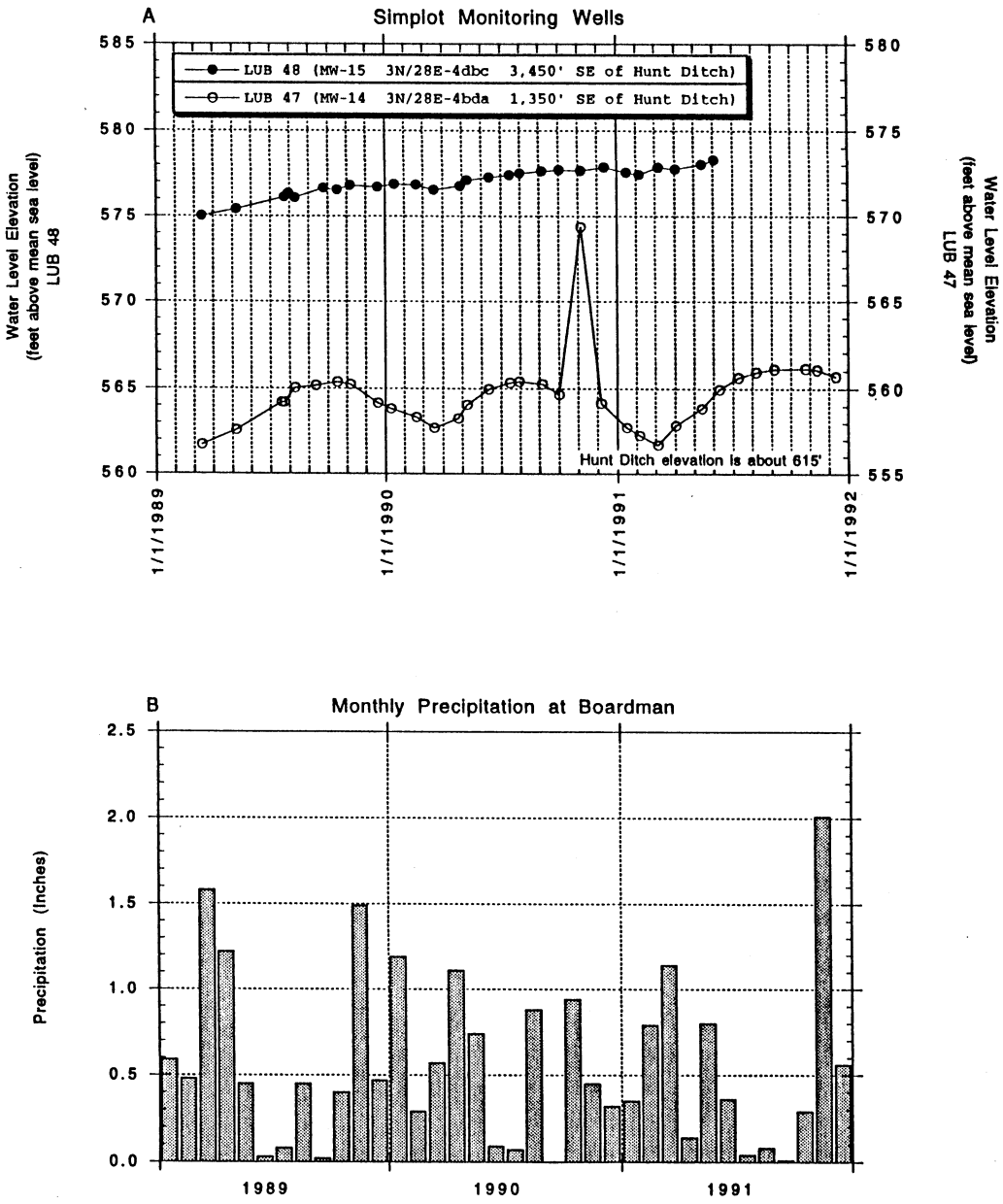


Figure 1.7 Comparison of water-level trends and precipitation in the area between Butter Creek and Emigrant Buttes. A, Hydrographs of wells screened in fine-grained flood deposits; B Monthly precipitation at Boardman.

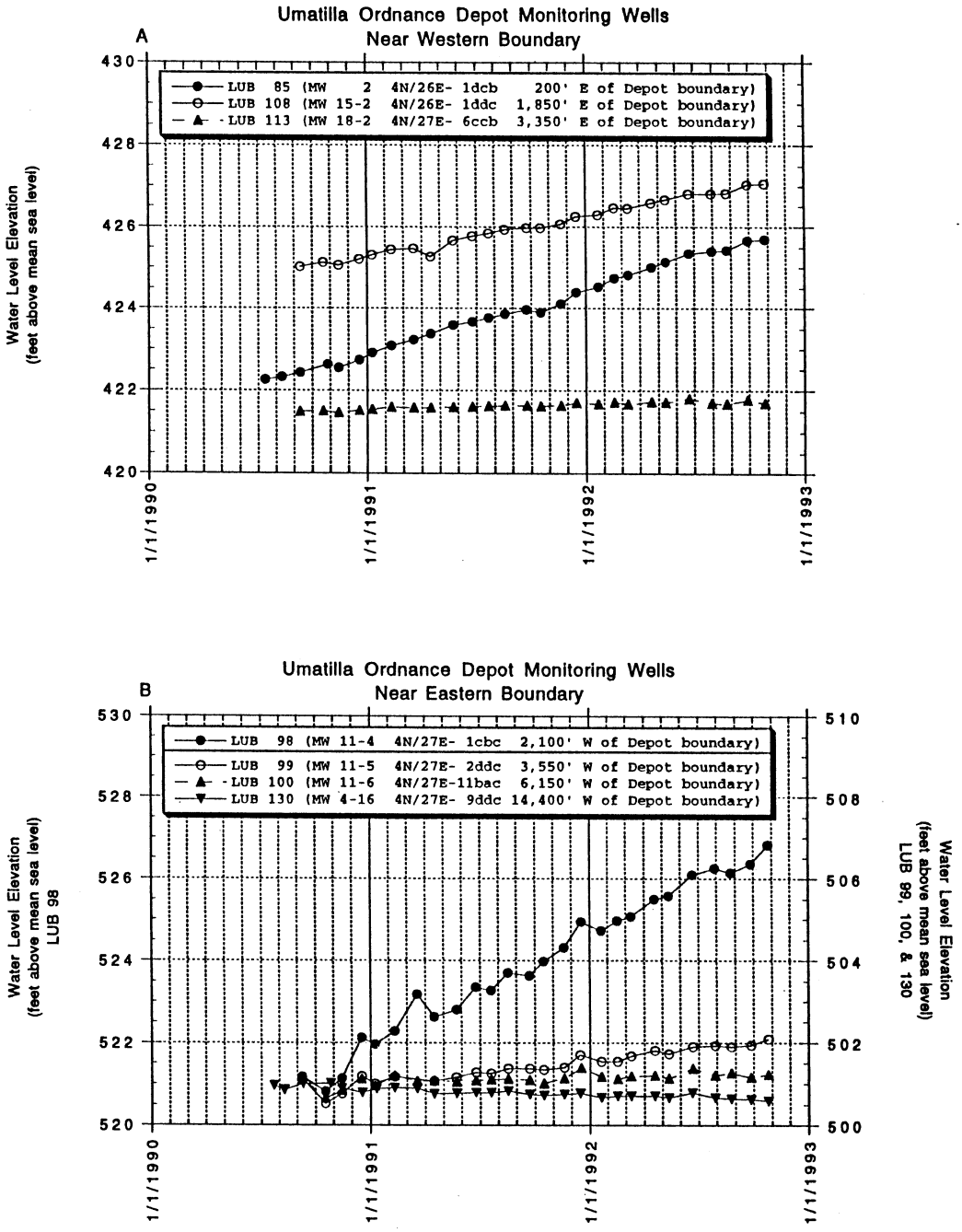


Figure 1.8 Seasonal hydrographs of monitoring wells screened in fine-grained flood deposits on the Umatilla Ordnance Depot. A, Wells near western boundary; B, Wells near eastern boundary.

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.

Land Use and Nitrogen Loading

Land Use History

Diversity, growth and an evolution to intensive use best describe land use in the Lower Umatilla Basin. A wide variety of land uses were considered as potential sources of groundwater contamination. Both recent and historical uses were investigated. A summary of basin land use history and practices follows.

Before 1945

Lower Umatilla Basin activities before 1945 centered around agriculture. Early basin settlers raised livestock and produced limited crops on small farms. Local farmers organized ditch companies and irrigation districts. Shortly after 1900, the West Extension, Hermiston, Stanfield, and Westland districts existed, and U.S. Bureau of Reclamation began constructing the Umatilla Project for irrigation water. Wheat farming expanded when many dryland acres were developed into irrigated wheat farms after water became available. Flood irrigation was the standard method used at the time.

By the 1920s, Umatilla River water for summer irrigation was fully appropriated. Although the Lower Umatilla Basin had large wheat producing areas, alfalfa remained the major crop. Some grains, vegetables and fruit were also grown. Dairy, sheep and poultry became important commodities. Livestock manure was used as a soil amendment and nutrient source for local crops.

Development of local irrigation water sources resumed after the 1920s. Groundwater development began as a limited irrigation source during the 1930s and 1940s. Drought conditions during the 1930s prompted U.S. Government incentives for well drilling. McKay Creek water was also allocated for irrigation during this critical water period. Despite these water developments, limited agricultural land development occurred during the 1930s and 1940s due to the full appropriation of Umatilla River water.

Early in the 1940s, the basin became a site for military activities related to World War II. The U.S. War Department used 150 square miles for a precision bombing range. The U.S. Army established the 31-square-mile Umatilla Depot to store munitions.

1945-1960s

After World War II ended, military activity continued. The military continued to practice at the bombing range. Army activity included ammunition maintenance, renovation and demolition. Explosive washout wastewater was discharged into two lagoons. The Army began storing missile fuels and chemical agents.

Basin farmers introduced many changes after World War II. Farmers began using commercial fertilizers and introduced sprinkler irrigation. Small acreage farmers began rotating crops of alfalfa, wheat and field corn. Other crops included peas, beans, carrots and fruits. Livestock businesses included a strong dairy industry, large poultry farms and hog operations.

Sewage treatment expanded beyond individual on-site systems as cities began operating municipal sewage treatment facilities.

1960s-1970s

With increasing population growth, residents started to manage disposal of solid waste and domestic sewage. Separate unlined landfills served the Army and local residents. Municipal sewage treatment plants were introduced in some cities.

After the 1950s, beef cattle operations grew in importance while dairy and hog operations declined. At least two large poultry facilities remained active until the late 1960s.

The Basin experienced an irrigation expansion "boom." During the 1960s and 1970s, more irrigation and more efficient use of irrigation water accompanied this boom. Wheeled and center pivot irrigation systems were introduced to the basin. Columbia River water became available via pumping and lift stations. Groundwater (including water from basalt aquifers) became available for irrigation. Corporate farming increased as did the conversion of undeveloped dryland to irrigated cropland. Dryland wheat farming yielded to irrigated wheat and row crops during this period. Watermelon production began on a large-scale.

Economics and limited water eventually slowed the boom. In some areas, groundwater use exceeded groundwater recharge, prompting the Oregon Water Resources Department to restrict or reduce groundwater use to sustainable levels by declaring Critical Groundwater Areas within the basin.

1970s-1980s

The basin served as a major regional wheat producer and expanded into intensive potato production. An increased demand for potatoes and use of center pivot irrigation facilitated the potato production expansion. Irrigation scheduling for efficient water management was introduced to the basin during this period. Potato production used more fertilizer and pesticide per acre and in total quantity than other basin crops.

Large-scale potato processing for fast food and other uses settled near Boardman and Hermiston. These facilities generated large volumes of nutrient rich wastewater, which was land applied to limited acreages.

The Depot and the former bombing range were investigated for contamination from past military use, with some cleanups initiated. The Army applied for a permit to incinerate chemical agents stored at the Depot.

Early 1990s

Total irrigated crop acreage in the Lower Umatilla Basin reached approximately 180,000 acres (281 square miles) by 1992. Of this total acreage, about half produced irrigated wheat and potatoes. Center pivots--which were also used for fertilizer applications--irrigated nearly 90 percent of the total irrigated area (IRZ Consulting, 1993). Many of the farms using center pivots employed some form of irrigation scheduling service (IRZ Consulting, 1993).

About 11 percent (20,000 acres) of the total irrigated area was gravity irrigated. Soils--sands and coarse silt loams--at these sites permit rapid infiltration and make efficient water distribution in the fields difficult.

Irrigated agriculture in the Lower Umatilla Basin continues to change. At least two large farms have been purchased to grow poplar trees for paper production. Drip irrigation has begun at some of these farms.

Land application of domestic sewage, sludge and food processing waste has required careful management. All land application sites must comply with environmental regulations for meeting agronomic rates of crops. Food processors have increased land application acreages.

Cleanup of the various military sites continue, with the Depot's explosives washout lagoon and the incineration of stored chemicals being the key concerns.

Nitrogen Loading

Loading Relationship to Groundwater Contamination

The Lower Umatilla Basin's soil conditions and hydrogeological properties make local groundwater very vulnerable to contamination from many different land uses. For example, this project and/or other investigations have detected nitrate, metals, organic compounds, pesticides, and explosives contaminating groundwater. As land uses continue to expand and evolve, other contaminants may potentially leach through basin soils and contaminate groundwater.

This investigation focused on nitrate, which exceeded levels that triggered state action. Project sampling confirmed extensive areas of the basin have nitrate-nitrogen groundwater concentrations near or exceeding the U.S.E.P.A. drinking water standard of 10 mg/L (see Plates 4.2 and 4.3).

The potential for a land use to contaminate groundwater with nitrate or another constituent relates to loading. Groundwater contamination can occur whenever water (or another liquid) and nitrate (or another contaminant) is released and exceeds or bypasses:

- removal by crops or other vegetation
- removal by evaporation
- soil capacity to prevent deep percolation

Management can reduce or prevent nitrate or other contaminant loss to groundwater. This investigation reviewed the nitrogen loading history for all of the basin's land uses. The following discussion and estimates come from available information.

Local Soils

Soil surveys for the Umatilla and Morrow Counties indicate that basin soils consist of well-drained, fine sandy, and sandy loams. The soils are low in clay and nutrients, contain little organic matter, with a pH range from 6.5 to 7.8 in near surface soil and up to 9.0 in deeper soil. The soil permeability rates from moderate to high, and the available water holding capacity ranges from approximately 0.7 to 3 inches of water per foot of soil.

This investigation assessed nitrate contamination risks of Lower Umatilla Basin soils by using the Oregon Water Quality Decision Aid publication (Oregon State University Extension, 1993). The assessment considered local soil characteristics, available moisture, and the depth of groundwater. Nitrate leaching from basin soils and contaminating groundwater rated primarily as a moderate to high risk with sufficient moisture, and a low to very low risk under dryland conditions. Table 1.4 presents the assessed risk for groundwater contamination from local soils.

Table 1.4 Assessed risk of groundwater contamination from potential nitrate leaching of local soil.

Soil	Leaching Potential		Groundwater Contamination Risk	
	Dryland	Irrigated	Dryland	Irrigated
Adkins WET	Very Low	High	Very Low	High
Koehler	Very Low	High	Low	High
Pedigo	Very Low	Moderate	Very Low	Moderate
Powder	Very Low	Moderate	Very Low	Moderate
Quincy	Very Low	High	Low	Very High
Quinton	Very Low	High	High to Very High	
Sagehill	Very Low	Low to Moderate	Low	Low to Moderate
Shano	Very Low	Low	Low	Low
Winchester	Very Low	High	Low	Very High

Extracted from Oregon Water Quality Decision Aid, H. Huddleston, and others (1993) and used in Oregon HOME*A*SYST, Worksheet #10, Site Evaluation, Oregon State University Extension Service (1993).

Nitrogen Loading Summary

Irrigated Agriculture

Nitrogen fertilizer has been identified as a major source of groundwater nitrate contamination in many areas of the U.S., including the Burbank-Wallula, Washington and Northern Malheur County, Oregon areas. By the early 1980s, nitrate leaching was identified as a problem in most sandy soils. Researchers found nitrate leaching to groundwater depends upon the amount of nitrogen applied, and the method, amount and timing of irrigation. Investigators also found precipitation contributes to residual nitrate leaching from crop soils during the non-growing season.

Irrigated agriculture is the dominant land use in the basin with approximately 180,000 acres (51 percent of the project area) under cultivation in 1992. Information about irrigated agriculture's nitrogen use is limited. Estimates range between a minimum of 7 million pounds of nitrogen used per year since 1975 (141,243 acres, 50 lbs per acre) to 20.5 million pounds of nitrogen used in 1990 (132,500 acres). Any estimate within this range indicates irrigated agriculture releases the most nitrogen to the basin's land surface. Potential nitrate leaching to groundwater depends upon fertilizer and water management.

Food Processing

Nitrogen loading information exists for nutrient and salt-rich food processing wastewater. The local industry has annually produced more than one million pounds of nitrogen since the early 1980s. The potential for nitrate leaching to groundwater depends upon nutrient and water management at the land application sites and possible seepage at wastewater ponds/lagoons.

The industry's waste management has improved, with generally no more year-round land application, expanded application acreage and decreased application rates at those sites. The use of lined storage ponds/lagoons has increased.

Livestock

Nitrogen information for basin animal waste is limited and land application area varied. Project analysis indicates livestock at two large beef, one large hog and one dairy operation, on average, annually produced more than 3.4 million pounds of nitrogen during the 1980s. Assuming nitrogen losses during storage, nitrogen available for land application may have been reduced, probably exceeding 780,000 pounds per year. The potential for nitrate leaching to groundwater depends upon nutrient and water management at land application sites and possible seepage at lagoons, stockpiles and animal pens.

Domestic Sewage

Nitrogen loading information for domestic sewage exists. A high potential for nitrate leaching exists at most large on-site systems and individual systems using drainfields. Most local municipal systems discharge to surface water and/or land apply treated waste. The City of Irrigon's system directly discharges to the subsurface through infiltration beds. Municipal sludge is imported from Portland's metropolitan area and land applied. The potential for nitrate leaching to groundwater depends upon nutrient and water management at land application sites and possible seepage at lagoons.

Military Activities

Nitrogen loading information related to military activity in the basin is limited. Significant loading to groundwater apparently occurred at the U.S. Army Umatilla Depot Activity Washout Lagoons. Approximately 85 million gallons of explosives washout water discharged to the lagoons (0.09 acres total) from the mid-1950s to the mid-1960s, but project information is insufficient for estimating the amount of nitrogen in the washout water. The Depot's unlined landfill received an undetermined amount of nitrogen in dried sewage sludge.

Other Land Uses

Other land uses investigated for nitrogen loading included environmental cleanup sites, accidents, underground storage tanks, landfills, electricity generation, and groundwater recharge. Nitrogen loading information is limited. Except for a landfill, these land uses contribute little or no nitrogen.

Natural Sources

Natural nitrogen loading sources include igneous rocks, lightning, decomposing organic matter and nitrogen fixation by bacteria. Available information was not sufficient to determine local loading from these sources. However, loading is considered small relative to other basin sources. Upgradient groundwater samples with low nitrogen concentrations and USGS statewide groundwater quality statistics support this assumption.

Irrigated Agriculture

Background

Existing literature identifies nitrogen fertilizer as a major source of groundwater nitrate contamination in the U.S. including Burbank-Wallula, Washington (Spalding and others, 1982) and northern Malheur County (Malheur County Groundwater Management Committee, 1991). By the early 1990s, nitrate leaching was identified as a problem in most irrigated sandy soils (Lembke and Thorne, 1980; Watts and Martin, 1981).

Research shows nitrate leaching to groundwater correlates to the amount of nitrogen applied, and the method, amount and timing of irrigation. Spalding and Kitchen (1988) found increasing the amount of applied nitrogen fertilizer beyond 100 pounds per acre correlated to an increased amount of extractable nitrate in the unsaturated zone sampled 6 to 60 feet below irrigated farm land. Hergert (1986) noted that matching nitrogen fertilizer rates more closely to crop yield requirements could substantially reduce nitrate leaching from sprinkler irrigated sandy soil to groundwater. McNeal (1976) and Wendt (1976) found irrigation methods using less water (sprinkler versus furrow and subirrigation versus furrow and sprinkler) caused less nitrate leaching. Watts and Martin (1981) noted irrigation scheduling minimized deep percolation and nitrate leaching. They concluded that irrigation based upon soil moisture requirements or evapotranspiration was the most practical water management method for controlling nitrate leaching.

Research also found precipitation leaching residual nitrate from crop soils during the non-growing season (Hergert, 1986; Detroy and others, 1988, 1990).

Basin History

Irrigated agriculture entered the Lower Umatilla Basin before the 1920s when local farmers organized ditch companies and irrigation districts, and the U.S. Bureau of Reclamation constructed the Umatilla Project (Kopecz, 1994). Many dryland acres developed into irrigated wheat farms after water became available. Flood and furrow irrigation were the standard methods used (Fitch, 1994).

Total irrigated agriculture acreage in the basin apparently increased from approximately 85,500 acres (134 square miles) in 1965 to nearly 180,000 acres (281 square miles) by 1992 (Table 1.5) due to available water, technologic improvements, and market demands (Kopecz, 1994; Pumphrey, 1994). About half of the total acreage produced irrigated wheat and potatoes. Other irrigated crops included field corn, watermelon, alfalfa hay and pasture (Anderson, 1993; Fitch, 1994). Center pivots irrigated nearly 90 percent of the total irrigated area, and they were also used for fertilizer applications. Many farms using these center pivots employed some form of irrigation scheduling service (IRZ Consulting, 1993).

Table 1.5 Total irrigated crop agriculture acreage estimates for the Lower Umatilla Basin.

Period	OWRD Primary Irrigation Water Rights[a] (total acres)	Adjusted OWRD Primary Irrigation Water Rights[b] (total acres)	LANDSAT Photo/GIS Derived (total acres)
1986 - 1992	260,255	233,695	179,880[d]
1976 - 1985	251,556	224,996	171,181[e]
1966 - 1975	200,178	195,058	141,243[f]
1956 - 1965	85,488	85,488[c]	85,488

[a]: Values presented in this column are from the Oregon Water Resources Department Water Rights Database. The values are for primary irrigation water rights, and they reflect the total acreage at the end of each period. These values include acreages yet to be developed.

[b]: Values in this column were derived by using the values in the first column and subtracting undeveloped acreages readily observed on a LANDSAT photograph.

[c]: Undeveloped acreage was not easily identified on the LANDSAT photograph. So, no adjustment of total acres was made.

[d]: This value was derived with the aid of OSU Experiment Station and Morrow County ASCS staff. Irrigated areas by crop were outlined on a LANDSAT photo. The outline was transferred to a map. The map was reviewed and corrected. Then, the map was entered into an electronic Geographic Information System (GIS). The GIS provided the acreage for each crop category. These acreages were totalled yielding the number shown.

[e]: This number was derived by: (179,880) - (233,695 - 224,996) = 171,181

[f]: This number was derived by: (171,181) - (224,996 - 195,058) = 141,243

Irrigated Agriculture Nitrogen Loading

An average annual nitrogen budget for selected crops grown in the Lower Umatilla Basin is presented in Table 1.6. The budget indicates residual nitrogen may remain in the soil after the growing season. That nitrogen could leach beyond the crop root zone. A review of IRZ Consulting (1993) and del Nero (1994) indicate nitrogen does penetrate beyond the root zone at some irrigated crop fields within the basin. However, IRZ Consulting (1993) observed no significant leaching below the root zone in the basin where good irrigation and soil fertility management (water and nitrogen applications timed and limited to actual crop need) was practiced.

Table 1.6 The average annual nitrogen budget for intensively managed Lower Umatilla Basin crops.

	ALFALFA (HAY)	FIELD CORN, GRAIN	PASTURE	POTATO-TUBERS	WATER-MELONS	WINTER WHEAT (GRAIN)
YIELD	6.5 T	185 Bu	3 T	480 cwt	16 T	123 Bu
N REQUIRED, LB/A	360	190	190	295		190
N APPLIED/PRESENT:						
N IN CROP RESIDUE, LB/A	40	60	30	90		60
N APPLIED, LBS/A	25	280	110	350	140	195
N RELEASED FROM SOIL, LB/A	300	60	40	80	80	75
N AVAILABLE, LB/A	365	400	180	520	220	330
N OUTPUT:						
DE-NITRIFICATION, LB/A	0	25	0	40	10	10
RESIDUE, LB/A	0	50	0	10		50
N REMOVED, LBS/A	320	130	160	205	130	130
N REMAINING IN PROFILE, LB/A	45	195	20	265	80	140

From "Lower Umatilla Basin Water Management Area Crop Production Practices and Groundwater Quality, May 1991; and individual contact with L. Fitch, OSU Hermiston Ag. Research and Extension Ctr, and V. Pumphrey, Retired Professor, OSU.

Nitrogen applied to irrigated crops in the basin--alfalfa, corn potatoes, pasture, watermelons and wheat--in the basin may have exceeded 20.5 million pounds total during the 1990 growing season (project analysis of Pumphrey and others, 1991). Nitrogen lost to deep percolation may have exceeded one million pounds assuming a five percent loss to deep percolation. Assuming a five percent loss appears conservative given Ritter (1989) and Vitosh (1991). They indicate nitrogen loss to deep percolation at agricultural fields in the United States can range from one to 50 percent depending upon the amount of nitrogen applied, the time of application, soil texture, and the amount and timing of water applied.

Food Processing

Basin History

Basin food processing activity before 1970 consisted of slaughterhouses, a cooperative cannery, potato fresh pack sheds and one specialty potato processor (Fitch, 1994; Kopecz, 1994). Slaughterhouse and cannery wastewater discharged to city sewers (Kopecz, 1994). The potato sheds produced little or no wastewater (Fitch, 1994).

Large-scale potato processing for fast food and other uses entered the region east of Boardman and south of Hermiston, during the 1970s. It expanded to dominate all local food processing activities. The processing plants generate large volumes of nutrient and/or salt rich wastewater daily. The wastewater is land applied and sometimes stored in ponds.

Food Processing Nitrogen Loading

Originally, the food processing facilities land applied their wastewater to limited acreages, during all seasons, and at amounts exceeding crop needs. This initial land application approach caused some local nitrate groundwater contamination. Today, facilities are expanding their land application areas, building or expanding wastewater storage, and scheduling wastewater application to meet crop nutrient and water needs. These changes are designed to reduce nitrate loading to groundwater by food processors.

Estimated land application area and nitrogen loading for all individual food processing facilities are presented in Table 1.7 and in Appendix 3C.

The total wastewater land application acreage has expanded from nearly 825 acres in 1977 to nearly 7,500 by 1992. Nitrogen land application rates generally decreased after 1991. The rates ranged from 14 to 2,500 pounds per acre per year from the 1970s through 1991. Since 1991, the application rates have ranged from 3 to nearly 680 pounds per acre per year. The decrease coincided with the land application area expansion. Leaching to deep percolation was not determined.

The process wastewater also contains salt which crops do not use. Salt application rates currently range in excess of 3,000 to nearly 30,000 pounds per acre per year at some sites (Appendix 3C).

Table 1.7 Approximate food processing industry total land application area and total nitrogen loading in the Lower Umatilla Basin for selected periods.

Period	Total Acreage (acres)	Total Nitrogen or TKN Loaded[a] (total pounds/yr)	Average Nitrogen or TKN Loading Rate (pounds/acre-yr)
1977	824	-	-
1981 - 1984	2,097	>1,074,361[b]	>512[b]
1985 - 1989	2,805	2,506,446	894
1991 - 1992	7,492	1,591,898	212

Values in this table were derived from Appendix 3C.

[a] Values in this column should be considered approximate values only

[b] These values are missing nitrogen loading by Port of Morrow.

Livestock

Background

Stewart and others (1967), Spalding and Fulton (1988), and other investigators have documented U.S. groundwater contamination from livestock waste. This includes the Burbank-Wallula area in Washington (Spalding and others, 1982). Nitrogen is the primary livestock waste component that contaminates groundwater (Goldberg, 1989). The potential for groundwater contamination depends upon waste management at livestock yards, waste ponds, and/or land application sites.

Basin History

Livestock production in the basin has occurred since approximately 1900 (Kopecz, 1994, Reed-no date). Figure 1.9 shows the production periods for sheep, turkeys, chickens, hogs, dairies and beef cattle. This production has contributed to the local economy and provided valuable crop nutrients.

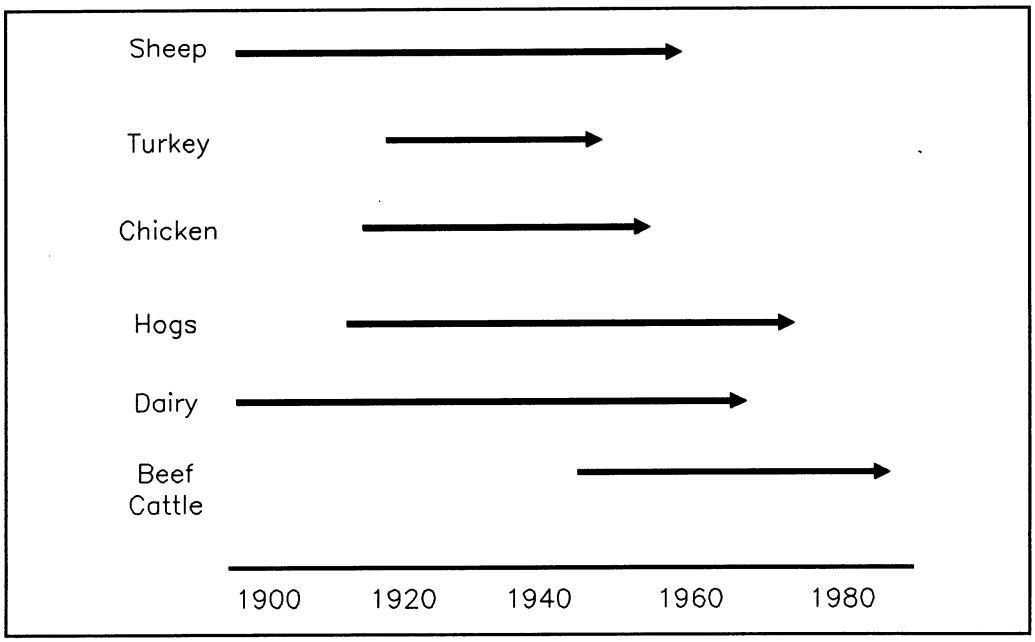


Figure 1.9 Approximate operational period for basin livestock commodities. (Source: Fitch, 1994, Pumphrey, 1994, and Kopecz, 1994).

Basin residents have valued and used livestock manure since early settlements. Very little, if any, commercial fertilizer was applied to crops from 1910 to 1930 (Kopecz, 1994). Instead, manure additions to the soil provided necessary crop nutrients and improved the soil tilth, water holding capacity, and resistance to wind erosion. Alfalfa was also used to provide some nutrients and to build up the soil (Tisdale, 1975). Manure use for Lower Umatilla Basin crop fertilization declined after World War II when the local dairy industry declined and produced less manure. The local cattle beef industry sustains continued manure use in the Lower Umatilla Basin.

Livestock Nitrogen Loading

Information necessary to calculate basin nitrogen loading from livestock waste is very limited. Some 1980s information exists for two large beef cattle operations, one large hog operation, and one dairy. Waste management at these facilities include waste removal from confined animal areas, waste storage in unlined ponds or stockpiles and land application. The amount of waste stockpiled, stored in ponds, sold and land applied varied by year. Calculations indicate that manure from basin livestock probably produced more than 3.4 million pounds of total nitrogen per year during the 1980s. However, nitrogen losses during storage possibly decreased the total nitrogen available for land application to around 780,000 pounds per year.

The total animal waste land application acreage varied during the 1980s, while the amount of waste and total nitrogen remained relatively constant. The total acreage apparently exceeded 1,350 acres some years and 14,350 acres other years. The actual acreage utilized each year was not obtained.

Actual nitrogen land application rates were not determined due to insufficient information. However, limited data from three facilities indicates annual nitrogen application of livestock waste possibly exceeded 15 to 78 pounds per acre. Consultants for one of these facilities recommended applying 300 to 450 pounds per acre. That same facility occasionally stockpiled waste at a 10-acre site in the years that land application acreage was unavailable. Nitrogen annually stockpiled possibly exceeded 35,000 pounds per acre.

Nitrogen leaching to deep percolation from land application, pond, stockpile, and animal yard sites was not determined due to insufficient information.

Domestic Sewage (municipal and on-site)

Background

Domestic sewage facilities include municipal, large on-site and individual on-site systems. Wastewater and sludge management at these facilities can include treatment, discharge to surface water, storage in ponds, land application, burial, or subsurface discharge through infiltration beds, sandfilters, drainfields or disposal wells.

Groundwater contamination from on-site systems has been documented. Oregon examples include mid-Multnomah County, Santa Clara/River Road, Clatsop Plains, La Pine and Irrigon.

Basin History: Municipal

Boardman, Echo, Hermiston, Irrigon, Stanfield, and Umatilla currently operate municipal sewage treatment facilities within the basin (DEQ Water Quality Files 9104, 26200, 38212, 42490, 84405, and 90659). Permits allow four facilities to discharge treated waste to the Umatilla or Columbia Rivers. Two facilities use sewage lagoons. Five facilities land apply sludge solids and/or sewage wastewater. One facility discharges collected septic tank effluent to the subsurface via infiltration beds.

City of Portland and Washington County, Oregon ship sewage sludge to the basin for land application at irrigated and non-irrigated sites. This activity began in the late 1980s and early 1990s (DEQ files 70725 and 90770).

Basin History: On-site

Six large on-site sewage systems operate in the basin. Facilities on file with the DEQ Water Quality Division are:

- Oregon Department of Transportation Stanfield Rest Areas (file 105049)
- Oregon Department of Transportation Boardman Rest Areas (file 64710)
- Hinkle Hotel (file 100132)
- Shady Rest Mobile Home Park (file 103745)
- Vista Park Mobile Home Park (file 100128)
- the U.S. Army Umatilla Depot Activity (file 91000)

Most of these facilities discharge domestic sewage water to drainfields and remove sludge for off-site treatment. The Boardman Rest Area uses evaporative lagoons. Army Depot sewage sludge was buried at the Depot's Active Landfill site until late 1993. Other large on-site facilities probably exist in the basin.

About 4,375 homes, mobile homes, businesses, public buildings, churches and other facility units outside of community sewer service areas in the basin are assumed to use individual on-site systems. This project identified these units from Morrow and Umatilla County Planning Offices tax lot records. The highest density of units are found near Hermiston, Boardman, and Irrigon.

Domestic Sewage Nitrogen Loading: Municipal

The total acreage available to land apply treated municipal waste in the Lower Umatilla Basin was once less than 400 acres. Land applied sludge from Portland and Washington County expanded that acreage to more than 2,700 acres by 1993. Historic and recent average annual land application rates for nitrogen at different sites ranged from none applied to nearly 215 pounds per acre.

Some municipal sewage wastewater deep percolation has occurred in the basin. The City of Irrigon currently discharges sewage wastewater to the subsurface via infiltration beds within a 2-acre area. The average nitrogen loading from the infiltration beds to the subsurface apparently increased from about 2,200 pounds per acre in 1990 to about 4,500 pounds per acre in 1992 (Table 1.8, Appendix 3E). The City of Echo sewage treatment lagoons reportedly lost 85 percent of the lagoon influent to subsurface seepage from 1976 until 1985 repairs. The average 1983 nitrogen loading from the lagoons was 195 pounds per acre (Appendix 3E).

Domestic Sewage Nitrogen Loading: On-site

Contamination from large or individual on-site systems are generally limited to localized areas near the systems. The large on-site systems identified by this investigation primarily discharge wastewater to the subsurface via drainfields or bottomless sand filters. One facility also uses dry wells. Deep percolation of nitrate-nitrogen from these systems appears to annually exceed 4,700 pounds over an area exceeding 10 acres (Table 1.9).

This investigation assumed all individual units are active and use individual on-site systems which discharge directly to the subsurface via drainfields. Deep percolation of nitrate-nitrogen from these systems may annually exceed 113,000 pounds for the entire basin (Table 1.10, Appendix 3G).

Table 1.8 Estimated nitrogen loading in the Lower Umatilla Basin by municipal sewage treatment facilities during 1992-1993.

Facility	Loading Area	Acres	Constituent	Units	Estimated Loading		
					Max	Min	Average
City of Boardman[a] (1993)	Poplar trees	10	Nitrogen	pounds/acre-year	-	-	69
City of Echo[b]	Sludge land application area	54.5?	Nitrogen	Pounds/acre-year	0	0	0
City of Hermiston (1992)	Poplar trees and Wadekamper Ranch	161	Nitrogen	pounds/acre-year	139	6	22
City of Irrigon (1992)	Infiltration beds	2	Nitrogen	pounds/acre-year	-	-	4,550[c]
City of Stanfield (1993)	Sludge land application area	48	Nitrogen	pounds/acre-year	-	-	16
City of Umatilla (1992)	Current sludge land application area	7.7[d]	Nitrogen	pounds/acre-year	-	-	212
City of Portland (1992)	Madison Ranch	1809	Nitrogen	pound/acre-year	-	-	75
Unified Sewerage Agency (1993)	Madison Ranch	630	Nitrogen	pounds/acre-year	-	-	-[e]

See Appendix 3E for estimated nitrogen loading tables for individual facilities.

[a] City of Boardman land applied wastewater to 40 acres of alfalfa from 1986 - 1990. No land application occurred in 1991 or 1992.

[b] From 1976 to July 1985, the City of Echo lagoons lost approximately 85 percent of the influent to subsurface seepage.

[c] This value reflects nitrogen leaving the infiltration bed to the subsurface after nitrogen reduction/losses in the beds.

[d] Historic sludge land application area was an 80 acre site.

[e] Land application began in September 1993.

Sources: DEQ files: 26200, 42490
DEQ Northwest Regional Office Staff
DEQ Pendleton Office Staff
SCM Consultants, Inc (1990)
Beyeler (1993)
Richwine (1994)

Table 1.9 Estimated nitrogen loading estimate in the Lower Umatilla Basin by selected large on-site sewage treatment systems.

Year	Facility	Acres	Constituent	Units	Estimated Loading		
					Max	Min	Average
1978 - Present	Hinkle Railroad Inn (drainfield)	2.41	Nitrate-N	pounds/acre-year	551[a]	-	-
1993[b]	OR Dept of Transportation Boardman Rest Area (land application area)	5	Nitrogen	Pounds/acre	-	-	60
1993	OR Dept of Transportation Stanfield Rest Area West Bound (drainfield)	0.17	Nitrate-N	pounds total	-	-	244
1993	OR Dept of Transportation Stanfield Rest Area East Bound (drainfield)	0.17	Nitrate-N	pounds total	-	-	244
1991	Shady Rest Mobile Home Park (bottomless sand filter)	0.19	Nitrate-N	pounds total	-	-	441
1990	US Army Umatilla Depot Activity Administration Area (drainfield)	0.23	Nitrate-N	pounds total	-	-	2,483
1986	Vista Park Mobile Home Park (drainfield)	4.13	Nitrate-N	pound/acre	-	-	752

See Appendix 3F for estimated nitrogen loading tables for individual facilities.

[a] Value is based on the maximum discharge allowed by WPCF permit number 100195

[b] The only land application event since the facility began operating in 1977.

Facilities operating with drainfield values came from using available discharge flow information and by using a 40 mg/l nitrate-nitrogen concentration for drainfield effluent percolating by groundwater. The 40 mg/l nitrate-nitrogen concentration came from EPA (1980) and DEQ (Ronayne et al., 1982) literature as well as recent work conducted by DEQ employee Henning Larson.

Sources: DEQ files: 100132, 105049, 103745, 91000, 100128
DEQ Pendleton Office Staff
Bochsler and Hansen (1990)
Joleen Odens (1994)

Table 1.10 Estimated annual total nitrate-nitrogen loading from domestic septic systems in the Lower Umatilla Basin.

Units	Units Counted[a]	Estimated Annual Nitrate Loading[b] (pounds/year)
Homes/Mobile Homes	4,015	103,846
Public Places (Churches, Schools, Parks, Public Buildings)	40	1,035[c]
Work Places (Business, Shop/Industry)	320	8,277[c]
Grand Total	4,375	113,157[d]

[a] Units outside of sewer services areas identified from Morrow and Umatilla County Records. Some units may not be occupied. Other units may be serviced by large on-site systems.

[b] Estimate calculations used 25•8,644 pounds of nitrate per year per unit. This value was derived from using an average 213.3 gallon per day wastewater discharge rate for households/small businesses and 40 mg/l average nitrate concentration in septic tank effluent percolating to groundwater. The wastewater discharge rate for households/small businesses was calculated from Lower Umatilla Basin sewage treatment facility data. The 40 mg/L average nitrate concentration was derived from EPA (1980) and DEQ (Ronayne et al., 1982) literature as well as recent work conducted by DEQ employee Henning Larsen.

[c] The total amount of nitrate loading for these units may be larger than the estimates shown. The total population served by these units was not determined form the sources reviewed. However, some of these units may be inactive, out buildings without toilet facilities, or units with an alternate sewage treatment system.

[d] The column total differs from the number shown by 1 pound/year due to errors introduced by rounding numbers to a whole number.

Military Activities

Basin History

The U.S. Army Umatilla Depot Activity was established in 1941 and currently occupies 30.8 square miles north of Interstate 84 between Boardman and Hermiston (Dawson and others, 1982). Groundwater contamination exists beneath portions of the Depot. Constituents include metals, nitrate, explosives, and organic chemicals (Dawson and others, 1982, Ritchie and others, 1992, Mahannah and others, 1993, Machacek and others, 1993, Woodland and others, 1993, and Bowen and others, 1993).

Military Activities Nitrogen Loading

Historic and current Depot sites potentially contributing nitrate to groundwater include the Explosive Washout Lagoons, the Ammunition Demolition Area, the Administration Area sewage treatment facility, and the Active Landfill.

- About 85 million gallons of explosive washout water was discharged to the 0.09 total acres of the unlined Explosive Washout Lagoons from the mid 1950s to the mid 1960s. This activity contaminated groundwater with nitrate and other constituents (Dawson and others, 1982, Ritchie and others, 1992, Bowen and others, 1993).

- Deep percolation of nitrate-nitrogen at the Depot's sewage treatment facility from 1985 through 1990 possibly exceeded 2,450 pounds annually at a 0.23 acre site (Appendix 3H).

- Dried sewage sludge was disposed of at the 10-acre unlined Active Landfill (former gravel pit) until 1993 (Ritchie and others, 1992, Golder and Associates, Inc., 1992, Dana, 1995). Project information was insufficient to estimate nitrogen loading. Other investigators attributed nitrate in the vicinity's groundwater to an offsite source and possibly the landfill (Ritchie and others, 1992).

- Project information was insufficient to estimate nitrogen loading at the 20 sites within the 1,750 acre Ammunition Demolition Area. Although nitrogen amounts are unknown, other investigators concluded that activity within the area did not and will not contaminate groundwater (Dawson and others, 1982, Ritchie and others, 1992, Mahannah and others, 1993).

Other Loading Sources

A variety of additional land uses were investigated and found to be contributing very little or no nitrogen to area groundwater.

Solid Waste

Historic and current basin landfill activity includes Finley Buttes, Umatilla Buttes, U.S. Army Depot sites, trenches at the former Boardman Air Force Range, and possibly other sites. A review of DEQ Solid Waste Disposal Facility Permit files and facility reports indicate the use of liners to prevent deep percolation of leachate occurs at the Finley Butte landfill only.

Some landfills may or did receive waste containing nitrogen:

- Currently, each load disposed at the Finley Buttes and Umatilla Buttes landfills can contain up to 25 gallons of free liquid including non-digested sewage sludge and septic tank pumpings (DEQ Solid Waste Disposal Facility Permit File Numbers 394 and 143). Liners at Finley Buttes should prevent deep percolation. Project information was not sufficient to calculate nitrogen loading, if any, from Umatilla Buttes landfill.

- Septic tank pumpage was disposed of at three ponds near the current Umatilla Buttes landfill entrance from 1974 to 1983 (Advanced Sciences, Inc., 1992). Pumpage disposed in 1977 contained nearly 230 pounds Total Kjeldahl Nitrogen (organic nitrogen) only. Information was insufficient to calculate deep percolation of nitrogen, if any.

- The U.S. Army disposed of dried sludge at the Depot's Active Landfill (see military activities).

- Sewage runoff was observed in one disposal trench at the former Boardman Air Force Range (DEQ Environmental Cleanup File 1030). Information was not sufficient to calculate pounds of nitrogen or deep percolation, if any.

Electricity Generation

Electricity production is expanding in the Lower Umatilla Basin. Local production began with the construction of McNary hydroelectric dam near Umatilla in 1956 (Stephenson, 1994). The Portland General Electric (PGE) built a coal fired plant southwest of Boardman in 1980 (Carter, 1987). Since 1990, three natural gas electric co-generation facilities have been proposed for the basin (Barlow and Tipton, 1993, CH2MHill, 1992, IDA-West Energy Company, 1993).

Available information indicates possible loading from existing or proposed facilities is limited to salt and other constituents besides nitrogen. PGE has reported elevated nitrate concentrations in groundwater sampled in the vicinity of the coal fired plant. PGE attributes the contamination to nearby agriculture (Carter, 1987, 1988, 1989, 1990).

Union Pacific Railroad

By 1960, the Union Pacific Railroad Company consolidated three railroad terminals and began servicing diesel locomotives at the Hinkle site (DEQ Water Quality File 90860). Historic and current potential loading at the site primarily involves oil or diesel except for domestic sewage and grain washed out of railcars.

Pendleton Grain Growers

About three acres of Pendleton Grain Growers, Incorporated - Stanfield became an environmental cleanup site after a 1988 fire involving 10,000 pounds of agricultural pesticides and 600,000 pounds of various fertilizers. Pesticides were detected in soil 30 to 40 feet below an evaporative pond. Nitrate exceeding 10 mg/L in nearby groundwater was attributed to a neighboring cattle feedlot (DEQ Environmental Cleanup File 639, Gilles, 1993). Project information was not sufficient to estimate nitrogen loading at this site.

Groundwater Recharge

Lower Umatilla Basin groundwater recharge projects include the existing County Line Groundwater Recharge Project, the tentative City of Hermiston Groundwater Recharge Demonstration Project, and the proposed Echo Junction Aquifer Storage and Recovery Project. These projects seek to alleviate existing groundwater supply problems. Existing or potential nitrogen loading from these projects appear minor.

Accidents and Spills

Numerous accidents and spills reported to DEQ have occurred in the Lower Umatilla Basin since the late 1970s (Appendix 3K, Plate 3.7). Only a few involved nitrogen. These include several sewage overflows onto land and 1,000 gallons of fertilizer spilled along Powerline Road near Hermiston. Project information was not sufficient to estimate nitrogen loading from these incidents, but they appear small.

Hazardous Waste

No nitrogen or other constituent loading related to hazardous chemicals or waste handled or generated by some facilities in the Lower Umatilla Basin should be occurring.

Underground Storage Tanks

This projects expects no nitrogen loading related to underground storage tanks. However, some Umatilla Basin underground storage tanks have reportedly released petroleum products (DEQ Underground Storage Tank Cleanup List).

Natural Occurrence

Nitrogen from igneous rock, lightning, decomposing organic matter, and nitrogen fixation by bacteria can enter water (Davis and DeWeist, 1966, Hem 1985, Waring, 1949). Project information was not sufficient to estimate nitrogen loading from natural sources. However, low nitrogen concentrations detected in project groundwater samples collected at upgradient sites and statewide groundwater quality statistics by the U.S. Geological Survey (Miller and Gonthier, 1984) suggest nitrogen loading from natural sources is very low.

Groundwater Quality

A Focus On Nitrate

The Lower Umatilla Basin groundwater investigation focused on nitrate. However, the chemical analysis also tested for many other substances or constituents, which served the investigation in two ways. First, the analysis helped determine whether other constituents contaminated groundwater. Secondly, the relationship between the other constituents and nitrates were explored to provide a better understanding of the sources and fate of nitrate.

Nearly one-third of the project's groundwater sampling sites yielded samples with nitrate concentrations exceeding the 10 mg/L drinking water standards. Areas with nitrate concentrations greater than 10 mg/L are not evenly distributed. Higher nitrate concentrations in groundwater occur in or near the vicinities of Threemile and Sixmile Canyons, Boardman, Irrigon, the U.S. Army Umatilla Depot, County Line Road, and the Butter Creek-Umatilla River confluence. Samples with the highest concentrations came from an area between the Port of Morrow and Irrigon.

Data analyses indicate multiple sources are responsible for the nitrate contamination in the Lower Umatilla Basin. Sources that formerly and/or currently contributed nitrate, either alone or in combination, include:

- irrigated agriculture (including center pivots),
- food processing wastewater,
- livestock operations,
- domestic sewage, and
- military activities.

Nitrogen loading from these sources can occur in several ways:

- land application of chemicals or waste
- use of unlined ponds or lagoons, and
- use of drainfields or infiltration beds

Data analyses also provided information about nitrate travel times. It appears that nitrate leaching through soil can reach groundwater within one to nineteen months, given sufficient moisture. Once in groundwater, nitrate transport appears slow in portions of the basin. Natural groundwater flushing of nitrate may require decades. Flat gradients and well pumping or canal recharge contribute to a slow-moving flow, causing temporary flow reversals

This investigation used four types of sampling, a variety of laboratory chemical analyses, and a variety of data analyses to make these conclusions. The following discussion presents the science conducted and the conclusions obtained.

Sampling and Analyses

Introduction

The groundwater chemistry phase of the Lower Umatilla Basin Groundwater Management Area technical investigation included multiple groundwater sampling, laboratory analyses, and data analyses. The groundwater sampling included reconnaissance, bimonthly, synoptic, and sampling for nitrogen-isotopic analysis, with each type serving a different purpose.

Laboratories at Oregon Department of Environmental Quality, Oregon Department of Agriculture, Oregon State University Department of Agricultural Chemistry, and Boston University (nitrogen isotope) chemically analyzed the groundwater samples. Laboratory availability, the type of laboratory services offered, and project resources determined which laboratories were used.

Project analyses included using general statistics, some groundwater chemistry computer modeling, the evaluation of nitrogen-isotopes, and many maps and graphs to understand the prevalence, distribution, sources and fate of nitrate in local groundwater.

Groundwater Sampling Conducted

Reconnaissance Sampling

Characterizing Lower Umatilla Basin groundwater quality began with reconnaissance groundwater sampling conducted from July 1990 through October 1991. Oregon Department of Environmental Quality (DEQ) staff collected 206 reconnaissance samples. The DEQ, Oregon Department of Agriculture, and Oregon State University Department of Agricultural Chemistry laboratories conducted the chemical analyses.

The sampling effort provided a basic understanding about the nature, extent and concentration range of local groundwater contamination in the basin. That understanding directed decisions about subsequent groundwater sampling, laboratory analyses, and data analyses.

The reconnaissance sampling indicated area-wide nitrate contamination, elevated levels of total dissolved solids and scattered pesticide/industrial chemical detection within the designated investigation area.

Bimonthly Sampling

Ongoing bimonthly groundwater sampling at a specific group of 35 to 40 basin wells began in October 1991. The sampling effort provides information about seasonal and long term nitrate and other constituent concentration trends at different locations and along selected groundwater flow paths. These trends help determine any contamination concentration changes and any contaminant movement. They also help identify seasonal versus constant influences and sources.

The sampling occurs January, March, May, July, September, and November. The DEQ and Oregon Department of Agriculture laboratories conduct most of these chemical analyses.

Synoptic Sampling

Synoptic sampling, a single sampling event in June and July 1992, provided sufficient concurrent data for basin-wide analyses. Basin sampling occurred at 207 wells (179 with alluvial groundwater, 28 with basalt groundwater), 26 surface water locations, and one drain.

The concurrent data helped characterize the basin-wide distribution of nitrate and total dissolved solids in alluvial groundwater; characterize the relationship between nitrate, other constituents and contamination sources; identify various nitrate sources contaminating basin areas; and understand the fate of contaminants along additional alluvial groundwater flow paths. The data distinguished between the influences of dilution, mixing, evaporation and water-rock reactions in groundwater chemistry. It also helped to understand the relationship between groundwater in the alluvial and basalt water-bearing zones.

Collecting the synoptic samples was a cooperative effort between state agencies and eight local facilities. DEQ laboratory staff conducted the synoptic sampling chemical analyses which included nutrients (nitrate), major ions, and metals.

Nitrogen-Isotope Analysis

Sampling for nitrogen-isotopic analyses occurred during three 1993 and 1994 sampling events at approximately 20 wells, 3 lysimeters, and a food processing wastewater surge pond. Repeat sampling at many of these sites provided data to verify or improve the identification of nitrate sources and processes influencing Lower Umatilla Basin groundwater. The Boston University Stable Isotope Laboratory conducted the nitrogen-isotopic chemical analysis.

Data Analyses Conducted

General Statistics

Limited statistical analyses were conducted to identify the percent of sampling sites and samples having constituent concentrations within specific ranges. This was useful for defining the groundwater contamination problem in the Lower Umatilla Basin. It was not useful for characterizing the fate of the groundwater contamination or identifying the contamination sources.

Chemical Constituent Maps

Maximum concentration constituent maps and concentration contour maps were produced and analyzed (Plates 4.2 through 4.13). The maps show the concentration distribution of selected chemical constituents across the basin. That concentration distribution was compared to the distribution of current and historic land uses in the basin to identify groundwater contamination sources and other influences on the groundwater chemistry.

Nine maximum concentration maps were produced for nine chemical constituents: nitrate+nitrite-nitrogen, total dissolved solids (TDS), sodium, arsenic, chloride, phosphate, bromide, boron, and vanadium. These constituents were selected for different purposes. Nitrate is the focus of this investigation. TDS became a concern during the land use review and constituent loading assessment phases of this investigation. Arsenic and sodium were detected in Lower Umatilla Basin groundwater samples at concentrations that could pose health concerns. Phosphate, chloride, bromide, boron and vanadium were included to help identify nitrate sources contaminating local groundwater.

Two chemical concentration contour maps were produced for nitrate+nitrite-nitrogen and total dissolved solids (TDS) in alluvial groundwater during June-July 1992 using synoptic sampling data. These maps show distribution of high versus low nitrate and TDS concentrations in the basin's alluvial groundwater. They show that TDS concentration distribution variations appear related to different nitrate sources and other basin groundwater chemistry influences.

Graphical Analyses

Graphical methods were used to analyze the Lower Umatilla Basin groundwater and surface water chemistry data. The methods included a variety of x-y graphs, Piper trilinear graphs and Schoeller Diagrams. The x-y graphs show the relationship between a component, like constituent concentration or groundwater elevations plotted along a vertical axis and another component, such as time, location or another constituent plotted along the horizontal axis. Piper trilinear graphs and Schoeller Diagrams show the relationship between multiple constituents. The graphs were reviewed to identify processes and nitrate sources influencing the basin's groundwater.

Groundwater Flow Path

Several flow path analyses were conducted to better understand the human and natural influences affecting the basin's groundwater chemistry. Flowpath analyses investigate the chemical changes groundwater experiences from natural and human influences as it moves from an upgradient area to a downgradient location.

Basin-wide correlation between nitrate and other constituents is generally poor except for TDS and conductivity. This indicates the combination of influences affecting the groundwater chemistry varies across the basin. By focusing on smaller areas or flow paths, constituent correlations improved which helped project investigators identify local groundwater chemistry influences.

Computer Modeling Groundwater Chemistry Variations

This investigation used NETPATH (Plummer and others, 1991) and PHREEQE (Parkhurst and others, 1980) groundwater chemistry computer models for data analyses. NETPATH calculates the geochemical mass-balance between groundwater at the beginning and end of a groundwater flow path. PHREEQE calculates geochemical reactions. The computer models were selectively used to understand and distinguish between natural and human influences upon Lower Umatilla Basin groundwater.

Nitrogen Isotope Analyses

During 1993 and 1994, nitrogen isotope groundwater samples were collected. The nitrogen isotopic compositions of Lower Umatilla Basin groundwater were to supplement other nitrogen source identification data analyses.

Samples were collected from private wells in the Butter Creek drainage, and other wells in the area of the Depot's explosive washout lagoon, wells near areas of application of food processing wastewater, near past and present animal lots, and near irrigated agriculture where commercial fertilizers are applied.

Data Analysis Results

Introduction

Understanding the distribution, source, and fate of nitrate contaminated groundwater is the primary purpose of the Lower Umatilla Basin groundwater technical investigation. The complexity of natural processes, land uses, groundwater flow, and groundwater chemistry in the basin made using various data analyses necessary to achieve that understanding.

Groundwater contains many dissolved chemical constituents related to natural and/or human influences. Distinguishing between various natural and/or human influences on the groundwater chemistry requires a careful analyses of groundwater chemistry and the hydrogeologic environment. Understanding unique chemical constituent proportions and correlations helped identify groundwater contamination sources. Understanding the natural chemical changes aided the understanding of groundwater occurrence and flow in an area.

Constituents

Nitrate

Nearly 31 percent of the project sampling sites had groundwater nitrate+nitrite-nitrogen concentrations greater than the current 10 mg/L standard for drinking water. The percent of samples and sites with concentrations exceeding 10 mg/L is greatest for groundwater from alluvial sediments. The greatest concentrations detected in groundwater sampled from alluvial sediments and basalt water-bearing zones were 76 mg/L and 64 mg/L respectively.

Conversely, approximately 26 percent of the sampling sites had groundwater nitrate+nitrite-nitrogen concentrations less than 2 mg/L.

Areas of high and low nitrate+nitrite-nitrogen concentrations are not uniformly distributed across the basin (Plates 4.2 and 4.3). Areas where nitrate+nitrite-nitrogen concentrations in project groundwater samples exceed 10 mg/L include:

- Threemile and Sixmile Canyons;
- Boardman;
- between the U.S. Navy Bombing Range, U.S. Army Umatilla Depot Activity, Irrigon, and the wildlife refuge (the highest concentration area);
- between Irrigon and Umatilla;
- the northeast corner of the Army Depot;
- the central area of the Army Depot;
- between the Army Depot and Lost Lake;
- the general Butter Creek and Umatilla River confluence area;
- between Interstate 82 and the Umatilla River; and
- between Stanfield Loop Road and Diagonal Road near the Cold Springs Reservoir.

Sources responsible for nigher nitrate concentrations across the basin appear to vary by location. Past and/or current general sources include:

- Irrigated agriculture, including center pivots;
- Food processing wastewater land application;
- Livestock operations;
- U.S. Army Umatilla Depot Activity;
- Sewage waste from municipal infiltration beds, large on-site systems, and areas with concentrated individual septic systems.

Dilution from canals or surface water appears to reduce nitrate concentrations along the Columbia River, near the High Line Canal, Carty Reservoir and Lost Lake. Significant mixing between Umatilla River water and groundwater appears to occur north of Interstate 84 and east of the Umatilla River.

Types of Nitrogen

Nitrogen converts into different components of the nitrogen cycle. These components are, in order of decreasing oxidation state, nitrate, nitrite, ammonia and organic nitrogen. References to Total Kjeldahl nitrogen considers the sum of organic nitrogen and ammonia nitrogen.

Nitrate Sources for Threemile and Sixmile Canyon Area

Historic and current land uses within Threemile and Sixmile Canyons include the Air Force Bombing Range, the PGE plant, a large beef cattle feedlot, and a large farm which has used feedlot animal waste to fertilized crops.

Project and facility alluvial groundwater sampling at the J.R. Simplot Feedlot and PGE's monitoring wells detected elevated nitrate, total Kjeldahl nitrogen (TKN) and ammonia concentrations. The elevated TKN and ammonia values suggest nitrogen conversion to nitrate is locally incomplete and they strongly indicate an animal waste or another organic nitrogen source influences local groundwater. Commercial fertilizer may also be a contamination source. Higher nitrate concentrations in basalt groundwater indicate a connection exists between water in the alluvial sediments and the shallow basalt water-bearing zones in the Taggares Farm vicinity and PGE's ash disposal area. Lower concentrations within the Carty Reservoir vicinity suggests the reservoir dilutes nearby groundwater.

Nitrate Sources for Boardman to west Umatilla

Historic and current land uses within this area include two municipalities, the Navy Bombing Range, the Army Depot, irrigated agriculture, livestock operations, food processing, municipal and on-site sewage systems, and landfills. Sources of nitrate contaminating groundwater varies across the area.

Elevated nitrate concentrations south of Boardman appear primarily related to irrigated agriculture, with some local contamination at relative lower concentrations from animal operations and septic systems.

- Wastewater land application appears responsible for elevated nitrate concentrations at the Port of Morrow and Lamb-Weston sites east of Boardman and northeast of the Army Depot, respectively.
- Irrigated crops appear responsible for elevated nitrate between the Port of Morrow and Irrigon, and along the Army Depot's western boundary.
- Irrigation related activity and septic systems appear responsible for elevated concentrations north of the Depot.
- Animal operations and irrigated agriculture appear primarily responsible for nitrate in groundwater south of the Depot.
- Elevated groundwater nitrate concentrations detected in the US Army Depot active landfill area appears to be a Depot source, possibly dried domestic sludge disposed at the landfill.
- Historic activity at the Army Depot's explosive washout lagoons is responsible for elevated groundwater nitrate concentrations in that vicinity.
- Elevated nitrate concentrations were detected in some basalt groundwater samples indicating a route exists for nitrate to travel to some basalt water-bearing zones.

Nitrate Sources for Butter Creek to Umatilla

Historic and current land uses within this area include food processing, livestock, municipal and on-site sewage systems, and a landfill. Sources contaminating groundwater with nitrate vary.

- Food processing wastewater appears primarily responsible for elevated nitrate concentrations at the Butter Creek-Umatilla River confluence vicinity and outside the northeast corner of the U.S. Army Depot.
- Animal waste appears to be the primary source of elevated nitrate in alluvial groundwater sampled near C&B Livestock. Concentrations decrease downgradient. Canal leakage may be responsible for some of that decrease.
- Irrigated agriculture appears responsible for some elevated nitrate concentrations detected in groundwater sampled northwest of C&B Livestock.
- Septic systems appear to be an important influence upon the groundwater chemistry in the area north of Interstate 84 and west of the Umatilla River where project sampling detected some elevated nitrate concentrations.

Nitrate Sources For Umatilla to Hat Rock to Echo Meadows

Historic and current land uses within this area included four municipalities, irrigated crops, livestock, food processing, domestic sewage, and a railroad yard.

Irrigated crop activity appears primarily responsible for groundwater nitrate concentrations exceeding 10 mg/L with septic systems additionally responsible in some areas. Sources responsible for groundwater nitrate concentrations below 10 mg/L include septic systems, animal waste, irrigated crop activity, and wastewater land application. Dilution from canal leakage appears to be an important influence in the area.

Total Dissolved Solids

Total Dissolved Solids (TDS) became a concern during the land use review and constituent loading assessment phases of this investigation. More than 25 percent of the project groundwater sampling sites had TDS concentrations greater than the current 500 mg/L secondary (aesthetic) drinking water standard. The percent of sampling sites with maximum concentrations exceeding 500 mg/L is greatest for groundwater from alluvial sediments. The greatest concentration detected in groundwater sampled from alluvial sediments and basalt water-bearing zones was 1200 mg/L and 1600 mg/L respectively.

Areas of high and low TDS concentrations are not uniformly distributed across the Lower Umatilla Basin (Plates 4.4 and 4.5). Locations of high and low TDS concentration areas are similar to the high and low nitrate+nitrite-nitrogen concentration areas with some exceptions. The exceptions appear related to the nitrate sources. Two areas with the highest TDS concentrations are located along Six Mile Canyon and between Boardman and Irrigon. Dilution appears responsible for lower TDS concentration along the Columbia River, northwest of Lost Lake, Carty Reservoir, within Hermiston basin, the terrace south of Hermiston and the Echo and Umatilla Meadows area.

Arsenic

Arsenic in groundwater can pose a health risk. Plate 4.6 shows the maximum concentrations detected across the basin by project sampling. Only four alluvial groundwater sampling sites had total arsenic concentrations exceeding the current 0.05 mg/L drinking water standard. The four sites are dispersed: the northwest corner of the U.S. Army Umatilla Depot Activity; the east side of the Depot; east of the Depot's northeast corner; and west of Stanfield.

Sodium

Natural water commonly contains low levels of sodium. Sources include human activity and natural processes. Elevated sodium concentrations in groundwater can pose a health risk to persons on a physician prescribed sodium restricted diet.

Nearly 85 percent of all project sampling sites had total sodium concentrations in groundwater greater than the 20 mg/L currently recommended for persons with a physician prescribed sodium restricted diet. Plate 4.7 shows the maximum concentrations detected in basin groundwater by project sampling. The highest concentrations detected in groundwater from alluvial sediments versus basalt water-bearing zones was 300 mg/L and 140 mg/L respectively. However, basalt water-bearing zones had the highest average maximum concentration.

Chloride

Natural water commonly contains chloride. Sources include human activity and natural processes. Plate 4.8 shows the distribution of maximum chloride concentration detected by project sampling. Only one project sampling site had chloride in groundwater exceeding the current secondary (aesthetic) drinking water standard (250 mg/L). That site obtains groundwater from basalt.

Phosphate, Boron, and Bromide

The occurrence and relative proportion of phosphate, boron, and bromide to other chemical constituents in groundwater can occasionally help identify nitrate sources. Plates 4.9, 4.10 and 4.11 show the maximum concentrations detected in the basin by project sampling. Lower phosphate concentrations were often found in or near irrigated crop areas.

Vanadium

Vanadium concentrations in Lower Umatilla Basin groundwater are an unusual curiosity (Plate 4.12). Typically vanadium concentrations in groundwater rarely exceeds 0.01 mg/L (Hem, 1985). However, average maximum concentrations in basin groundwater from basalt water-bearing zones and alluvial sediments, respectively, are 0.02 mg/L and 0.04 mg/L. The maximum concentration detected was 2 mg/L in groundwater from alluvial sediments.

Volatile Organic Compounds and Pesticides

Volatile organic compounds (VOC) or pesticides from human activity were infrequently detected in Lower Umatilla Basin groundwater (see Plate 4.13). Most groundwater samples containing VOCs and/or pesticides came from alluvial sediments. Project sampling detected only one compound, ethylene dibromide (EDB), at concentrations exceeding current drinking water standards. Project sampling also detected 1,1,2,2 tetrachloroethylene (1 site), chloroform (4 sites), toluene (1 site), atrazine (6 sites) and dacthal acid (4 sites).

Graphical Observations and Interpretations

State agency staff conducted graphical analyses of Lower Umatilla Basin sampling data to identify the chemical and physical processes influencing the groundwater chemistry variations observed in the basin. alluvial groundwater data and basalt water-bearing zone groundwater data were analyzed separately, because the groundwater came from different hydrogeologic units.

Basin-wide Correlations

Correlations suggest a common influence. Total dissolved solids (TDS) and electrical conductivity best correlate with nitrate+nitrite-nitrogen concentrations basin-wide. A poor correlation generally exists between nitrate+nitrite-nitrogen and other chemical constituents. These poor correlations basin-wide indicate significantly different basin groundwater chemistry histories may exist, as represented by the various constituents that accompany nitrate in groundwater.

Figure 1.10 shows nitrate+nitrite-nitrogen versus TDS and sulfate for all project groundwater samples. The change from scatter below 1/mg/L nitrate+nitrite-nitrogen to correlation above 1 mg/L suggests the dominating chemical influence upon local groundwater possibly changes from natural processes to human activity.

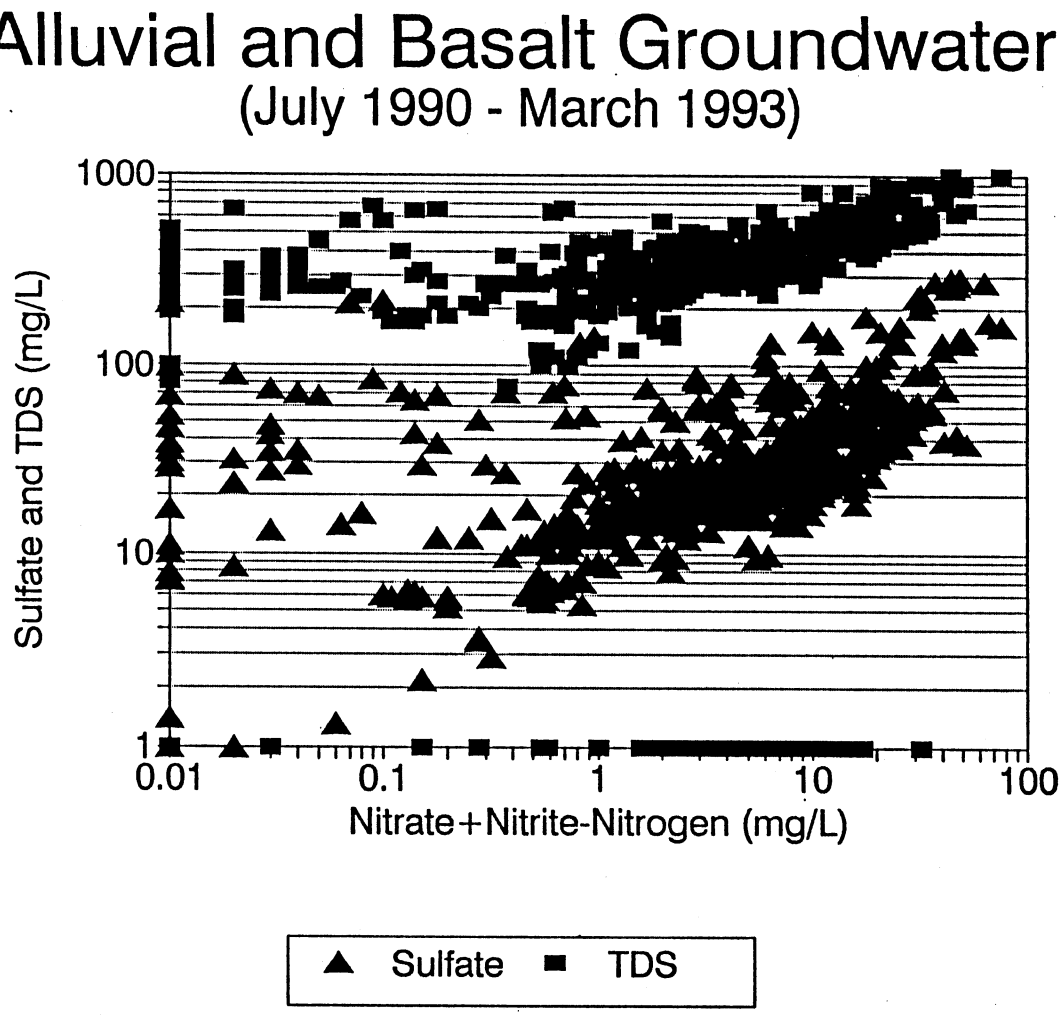


Figure 1.10 Nitrate+nitrite-nitrogen versus total dissolved solids and sulfate in Lower Umatilla Basin groundwater.

Evaporation and Mixing Influences

An understanding of the basin's evaporation and mixing influences helped determine any effects they may have on the basin's groundwater chemistry, and better identified the sources of contamination.

Evaporation appears to influence groundwater associated with many wells in the basin. However, the data graphed are often displaced from the evaporation line toward chemical compositions representing potential nitrate sources. Constituent versus constituent graphs indicate evaporation and mixing influences the alluvial groundwater chemistry in the Lower Umatilla Basin. Chloride versus potassium graph along an approximate evaporation trend that begins with a dilute source such as the Columbia or Umatilla Rivers.

The Umatilla River may be receiving nitrate and TDS from groundwater or runoff. Groundwater in some basalt water-bearing zones appear hydraulically connected to alluvial groundwater. In chloride versus nitrate+nitrite-nitrogen graphical analyses, the alluvial groundwater samples show evaporation evidence. However, nitrate concentrations greater than expected for simple evaporation of a source are consistent with a model of water mixing with nitrate enriched waters.

Piper Trilinear Graph and Schoeller Diagram Results

Groundwater samples related to specific nitrate sources did not graph uniquely on these diagrams. However, the diagrams did assist efforts to link some groundwater samples indirectly to nitrate sources.

Most groundwater samples plotted as mixed-cation\bicarbonate dominated and calcium\bicarbonate dominated water on the Piper trilinear diagrams. Chloride and sulfate proportion variations observed on the trilinear graphs often correlated to groundwater nitrate+nitrite-nitrogen concentration variations over time and by location. Occasionally, calcium proportions correlated similarly or inversely to nitrate+nitrite-nitrogen concentrations.

Many major ion concentrations in Lower Umatilla Basin groundwater sampled often correlated to nitrate+nitrite-nitrogen concentration variations over time and by location. This relationship appeared on Schoeller diagrams as similar line patterns shifting up, down, or superimposing when nitrate+nitrite-nitrogen concentration increased, decreased, or remained unchanged, respectively. Detectable phosphate concentrations often correlated inversely to groundwater nitrate+nitrite-nitrogen concentration variations over time and by location on these diagrams.

Nitrate Versus Time

Nitrate concentrations commonly fluctuate in Lower Umatilla Basin groundwater with some exceptions. The nitrate concentration peaks generally occurred during the non-growing season. The peaks occurred less frequently during the mid-summer months. Other constituents often had concentration peaks during fall, winter, and spring months also.

The concentration peaks occurring primarily during fall, winter, and spring may relate to one or more influences. It may relate to the time needed for nitrogen, other constituents, and water applied at land surface to travel to groundwater. It may also relate to when nitrogen, other constituents, and water can most easily escape to groundwater.

Relatively steady nitrate+nitrite-nitrogen concentrations over time were observed for groundwater samples from some wells. Steady nitrate+nitrite-nitrogen concentrations above 1 mg/L appear related to a constant source like septic systems or nitrate accumulating in areas where limited groundwater movement occurs.

Comparing constituent concentration versus time graphs did not distinguish different sources and processes.

Influence of Multiple Nitrate Sources

Constituent versus constituent graphs helped characterize the influence of some nitrate sources upon Lower Umatilla Basin groundwater. June-July 1992 data for groundwater sampled at wells within or near areas with septic systems, animal feedlots, food processing wastewater land application, and irrigated agriculture were graphed. The rationale for this analysis is that nitrate generally travels in water percolating from the surface to groundwater. That water will contain other constituents that reflect its source and the chemical modifications that occurred during its history. Therefore, the water percolating downward carrying nitrate from a specific land use, may have an identifiable chemical signatures.

The relationship between total dissolved solids (TDS) and nitrate+nitrite-nitrogen concentrations was graphically analyzed (Figure 1.11). The constituent concentrations correlated well for each land use represented, which means multiple sources contribute nitrate and TDS to basin groundwater. The amount of nitrate and TDS contributed by each land use activity varies. For example, groundwater sampled in areas associated with irrigated agriculture, animal feedlots, and food processing wastewater land application had a wide nitrate+nitrite-nitrogen and TDS concentration range. Conversely, the concentration range in groundwater sampled in areas associated with septic systems was much more limited. The concentrations were generally for less than 15 mg/L for nitrate+nitrite-nitrogen concentrations and less than 500 mg/L for TDS.

Analysis of potassium versus bromide and chloride versus potassium yielded three findings. First, groundwater influenced by septic systems has lower chloride concentrations than other sources in addition to having lower TDS and nitrate concentrations. Second, the influence of food processing wastewater upon groundwater chemistry is significantly different from the influence of other sources in terms of bromide to potassium and chloride to potassium relations. Third and most importantly, each potential source groups into separate fields on the graphs, regardless of their location (e.g., the septic systems field represents both Hermiston and Irrigon). These graphs are useful for identifying land uses potentially influencing basin groundwater.

The influence of individual food processing wastewater sources were distinguished on magnesium versus sulfate and calcium graphs. The chemistry differences may relate to the source water used, human activity unique to the facility operation, or geochemical processes unique to the land application area.

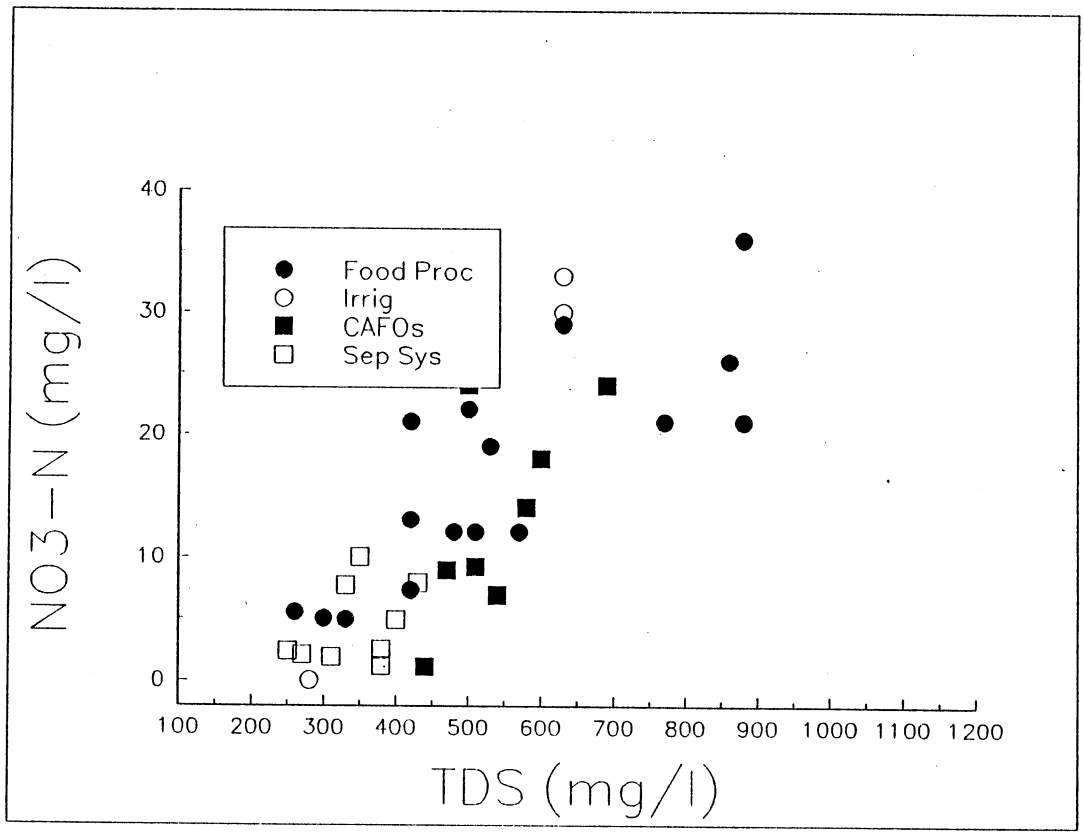


Figure 1.11 Total dissolved solids versus nitrate+nitrite-nitrogen for groundwater sampled near potential nitrate sources (septic tank influences graph within a limited area).

Note: Nitrate+nitrite-nitrogen and TDS share a generally positive correlation for all activities.

Groundwater Flow Path Results

A Butter Creek flow path and a composite flow path through the U.S. Army Umatilla Depot were analyzed. The analyses provided these conclusions.

- Multiple influences affect the groundwater chemistry along each groundwater flow path, including influences unrelated to nitrate.
- More than one source contributes nitrate to groundwater along each groundwater flow path.
- Nitrate relates better to calcium and chloride than sodium and sulfate along each groundwater flow path.
- Constituent concentrations in groundwater along the Butter Creek flow path do not progressively increase downgradient. This would be expected from chemical influences limited to progressive water rock reactions or non-point source loading. Instead, stationary groundwater chemistry anomalies or irregularities exist along the flow paths.
- Analysis of the Butter Creek flow path data revealed a stationary concentration peak for nitrate+nitrite-nitrogen and other constituents along the flow path (Figure 1.12). The stationary peak implies that there is no tendency for concentrations to migrate downgradient with time. The data analyzed suggests that the source of the dissolved constituents and elevated nitrate is local, and with some seasonal variations.

Groundwater Chemistry Model Results

This investigation used NETPATH to assess and refine interpretations of natural and human influences on groundwater chemistry along selected groundwater flow paths. The following results from individual NETPATH analyses apply to the Lower Umatilla Basin in general.

- Cyclic evaporation-dissolution may be occurring in the vadose (unsaturated) zone, contributing to elevated TDS in groundwater.
- Water from canal leakage influences the local groundwater chemistry.
- Mixing of deeper alluvial groundwater with infiltrating water primarily explains the alluvial groundwater chemical composition observed.

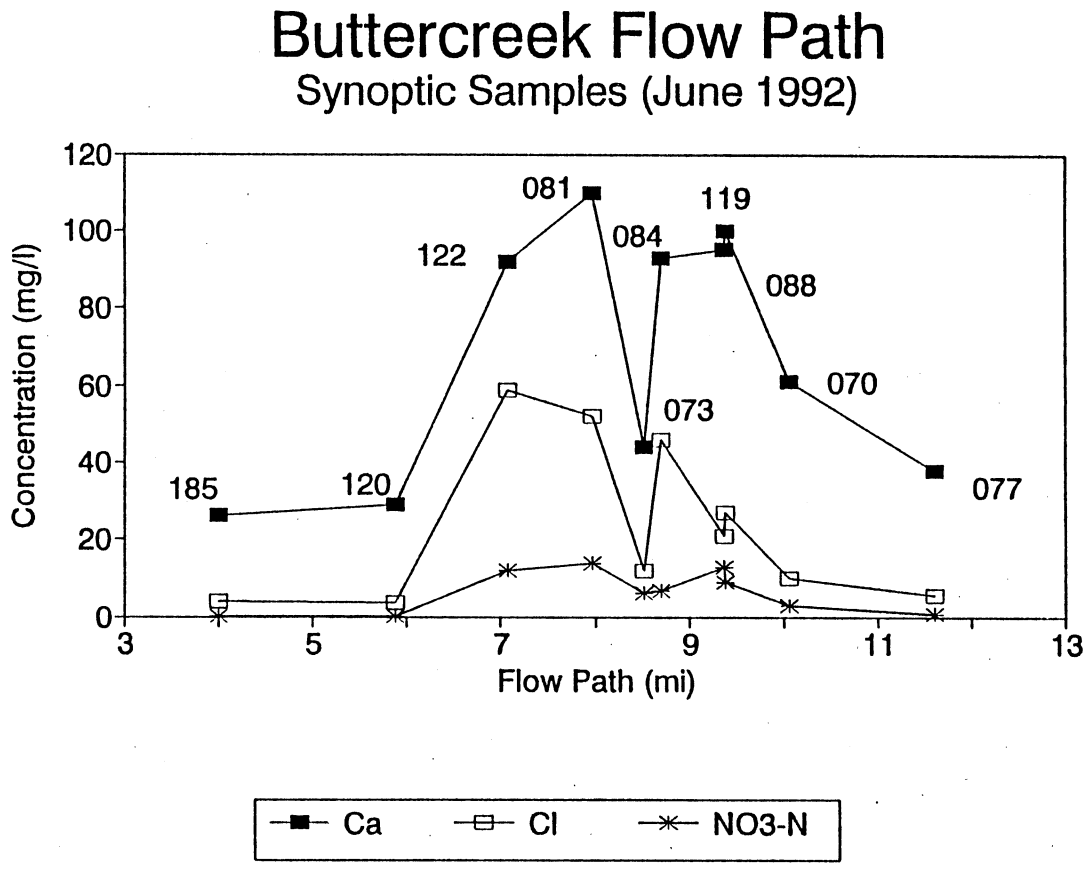


Figure 1.12 Variation of calcium, chloride, and nitrate+nitrite-nitrogen along the Butter Creek flow path.

Evaluation of Canal Leakage

Project analysis used the NETPATH groundwater chemistry computer model to evaluate the influence of canal leakage upon nitrate concentrations in groundwater flowing into the Hermiston basin from upgradient sites south of Hermiston.

The model scenario allowed upgradient groundwater to mix with canal water while undergoing water-mineral reactions. The model solutions indicate that locally, canal water significantly affects the groundwater chemistry diluting nitrate as it moves downgradient.

The modeling results indicate that the percentage of groundwater recharge from canal water in the immediate downgradient vicinity of the canals may exceed 95 percent of the groundwater. This suggests canal leakage is the principle source of recharge to shallow water-bearing zones supplying some domestic wells.

The Evaluation of Water-Mineral and Evaporation Influences

The groundwater chemistry computer model program NETPATH was used to evaluate the chemical relationship between groundwater and the aquifer material along the Butter Creek flow path.

The aquifer material is glaciofluvial in origin, consisting largely of basaltic fragments varying in size from small boulders to sand. Volcanic glass, clay minerals and secondary minerals such as calcite, are common constituents.

Groundwater undergoes minor changes along a flow path as a result of water-rock mineral reactions typical of a groundwater basalt system.

To recognize the various sources of nitrate loading that may have affected groundwater compositions in the Lower Umatilla Basin area, the investigation considered the natural water-mineral reactions within the saturated zone.

Computer modeling with NETPATH indicated that the bulk of the compositional variation could be accounted for by groundwater interaction with basalt glass and clay minerals, with less contribution from the secondary minerals gypsum (or mirabilite), calcite and dolomite.

This investigation used PHREEQE to assess the likelihood that constituent concentrations in some basalt groundwater samples are or are not a result of natural water-rock reactions. The results suggest an external calcium source influences some basalt groundwater through hydraulic connection with alluvial groundwater.

Two scenarios were explored. One scenario had "unimpacted" basalt groundwater dissolve calcium bearing basalt minerals (plagioclase and clinopyroxene). The other scenario had the same groundwater dissolve basaltic glass with a chemical composition described by Allan and Strope (1983). The results from both scenarios indicate obtaining the observed calcium concentrations from natural water-rock reactions is unlikely. To test the application of NETPATH to groundwater, wells immediately upgradient and downgradient of a single Simplot irrigation circle (field 1A) were chosen. The results indicate that shallow groundwater, presumably originating as water applied within the irrigation circle, has impacted deeper regional groundwater.

A possible origin of the higher TDS shallow groundwater is cyclic evaporation-dissolution, where repeated application-evaporation of wastewater leads to the precipitation of dissolved salts in the soil and vadose zone. Subsequent "flushing" of this zone with more dilute waters leads to dissolution of those phases and leaching of the components downward.

The results from both scenarios indicate calcium in groundwater influenced by natural water-rock reactions only will reach saturation with calcite and dolomite at concentrations much lower than observed in groundwater samples collected. Reaching saturation should limit the calcium concentration in the groundwater. The basalt glass scenario result indicates potassium and phosphate concentrations in groundwater should exceed 60 mg/l and 25 mg/L respectfully if water-basalt glass reactions were responsible for the calcium concentrations observed. These elevated potassium and phosphate concentrations were not observed in Lower Umatilla Basin basalt groundwater samples collected.

In summary, these analyses support the hypothesis that evaporation and ambient groundwater mixing with water infiltrating from various nitrate sources influences the alluvial groundwater chemistry.

Evaluation of Food Processing Wastewater Influence

An abrupt increase in TDS was detected in groundwater along the Butter Creek flow path between two closely spaced domestic wells during the June-July 1992 project synoptic sampling (Figure 1.12). The chemical evolution of groundwater between those wells was modeled by NETPATH as a mixing model. The shallow groundwater at a nearby food processor monitoring well was mixed with groundwater from the upgradient domestic well. It is significant that the overall chemistry pattern for the impacted downgradient well closely resembles the chemistry pattern of shallow unconfined groundwater at the nearby food processing monitoring well. Because of the shallow groundwater chemistry at the monitoring well reflects the infiltration of food processing wastewater, it is logical to extend that conclusion to the downgradient site as well.

Nitrogen Isotopic Analysis Results

Stable nitrogen isotopes, reported as "delta values" or parts per thousand, behave predictably, making them useful indicators of geochemical or biochemical processes. Significant differences in nitrogen isotopic composition (delta ^{15}N) were observed between some alluvial groundwater in the basin. The delta ^{15}N valves for individual groundwater showed minor differences over time for most of the repeat samples collected.

Evaluation of Nitrate Sources

Nitrogen isotopic analysis of the nitrogen isotopic identified some nitrate sources in the following areas:

- An organic waste influence is clearly evident from the delta ^{15}N values for groundwater sampled from a well (UMA 258) located within an established food processing land application area north of the Umatilla River and east of the Butter Creek Highway.

- A commercial fertilizer influence is clearly evident from the delta ^{15}N values for groundwater sampled from three irrigation wells located north of Highway 730 between Boardman and Irrigon. The delta ^{15}N values remained constant over time despite nitrate+nitrite-nitrogen concentration fluctuations. That indicates the nitrogen source remains uniform and hydraulic flushing of nitrate is very slow. The delta ^{15}N values for the eastern wells are higher. That indicates an additional nitrate source influence is possible.

- The influence of animal waste appears evident from the delta ^{15}N values related to groundwater sampled from a well (UMA 133) located along County Line Road approximately 2 miles south of Interstate 84. Historic and current animal waste sources are located nearby.

- Delta ^{15}N values related to groundwater sampled from wells near the U.S. Army Umatilla Depot Activity explosive washout lagoons indicates most of the nitrate in the groundwater came from explosive contaminants.

- Delta ^{15}N values related to other groundwater samples collected were not diagnostic of a single nitrogen source. Instead, the values indicate mixed nitrogen influences.

Evaluation of Denitrification

Denitrification is a natural process converting dissolved nitrate into nitrogen gas. Denitrification was recognized in groundwater from a single monitoring well (UMA 258) on the Simplot property. The combination of high organic matter and shallow water tables provide for an adequate reducing environment.

Current isotopic data indicates no area-wide denitrification occurs within the Lower Umatilla Basin. This finding does not preclude denitrification occurring locally in flood plain deposits next to existing drainages in appropriate conditions.

Evaluation of Hydraulic Flushing

The nitrogen isotopic sampling results provide evidence of low groundwater flow velocities in the basin. Analysis of groundwater samples collected over a 13-month period at Boardman-Irrigon area irrigation wells showed nitrate concentrations in groundwater varied between well sites, but varied little over time at individual well sites. Analysis also showed no significant isotopic variation over time in samples collected from individual wells. These results support hydrogeologic conclusions that a large volume of very slow moving groundwater underlies the Boardman-Irrigon area.

The low groundwater flow velocities in the Hermiston, Umatilla Ordnance Depot, and Boardman-Irrigon areas leads to an important conclusion. The process of natural hydraulic flushing of the existing nitrate from the groundwater in these areas will be slow. Therefore, the implementation of any practices to reduce future nitrate loading may not have an immediate impact on the observed nitrate concentrations in groundwater in these areas.

Alluvial-basalt Groundwater Interconnection

Observations suggest groundwater in some basalt water-bearing zones originally comes from shallow alluvial groundwater affected by surface activities. A positive correlation exists between total dissolved solids (TDS) versus calcium with the highest calcium concentration approximately 150 mg/L. Analysis using groundwater chemistry computer modeling indicates achieving the higher calcium concentrations through natural water-rock reactions rather than an external process is unlikely.

Review of other constituent versus constituent graphs also indicate an external source affects the groundwater chemistry in some basalt water-bearing zones. The chloride concentrations reach values exceeding 220 mg/L. The chloride probably did not come from the basalt, suggesting alluvial and some basalt groundwater are related.

In terms of TDS and nitrate+nitrite-nitrogen, it is apparent that the trend defined by some basalt groundwater is very similar to that exhibited by alluvial groundwater (Figure 1.13). That groundwater sampled from the basalt well graphed similar to alluvial groundwater is important. No basalt mineral can serve as the chloride source. Additionally, potassium concentrations in basalt minerals are very low. The conformance indicates alluvial groundwater and groundwater in the water-bearing zones experienced the same processes such as evaporation. Locally, they appear to be hydraulically connected.

Samples collected from Lower Umatilla Basin basalt water-bearing zones graph in a manner that suggests alluvial and some basalt groundwater experienced the same influences such as evaporation. This indicates a hydraulic connection exists between alluvial groundwater and some basalt water-bearing zones.

Information presented in the hydrogeology chapter support alluvial groundwater directly entering some basalt water-bearing zones. Saturated alluvial sediments directly contact some basalt water-bearing zones in some areas. Additionally, some wells are constructed improperly. These wells may provide a direct conduit from the alluvial aquifer to one or more basalt-water bearing zones below.

Nitrate Travel Time

Land Surface to Groundwater

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

Evidence of rapid nitrate travel to groundwater includes constituent concentrations correlating to groundwater elevation at some sites. Figure 1.13 is an example. Most of these correlations related to sampling sites where groundwater came primarily from coarse-grained or flood plain alluvial sediments and constructed well depths ranging from 19 to 110 feet. The correlations suggest constituent loading at these sites relates to local groundwater recharge, and the travel time to groundwater is relatively short for conditions existing during the compared times.

Constituent concentrations and groundwater elevations appeared to not correlate or correlate inversely at other sites. Possible explanations for the inverse correlations were explored.

The relationship between groundwater elevations and well screen or open interval elevations were explored as a possible explanation for the apparently opposite correlations observed. Analysis suggests the influence of groundwater elevations relative to well construction fails to apply in the Lower Umatilla Basin.

Time lags were explored as a possible explanation for apparently opposite and no correlation observed between groundwater elevation and constituent concentration graphs.

A time lag became suspected when several groundwater elevation and constituent concentration graphs related to the same site had uniquely similar fluctuations that occurred at different times. The graphs correlated similarly when the graphs were shifted to superimpose the uniquely similar fluctuations. Other apparently opposite or no correlation graph sets also correlated similarly when a time lag shift was considered. Graph sets with observed time lags primarily related to sampling sites where groundwater came from fine grained sediments and constructed well depths exceeded 100 feet. Observed time lags for nitrate ranged from 0 to 18 months. Analysis indicates the nitrate time lags may change significantly when sufficient water is available.

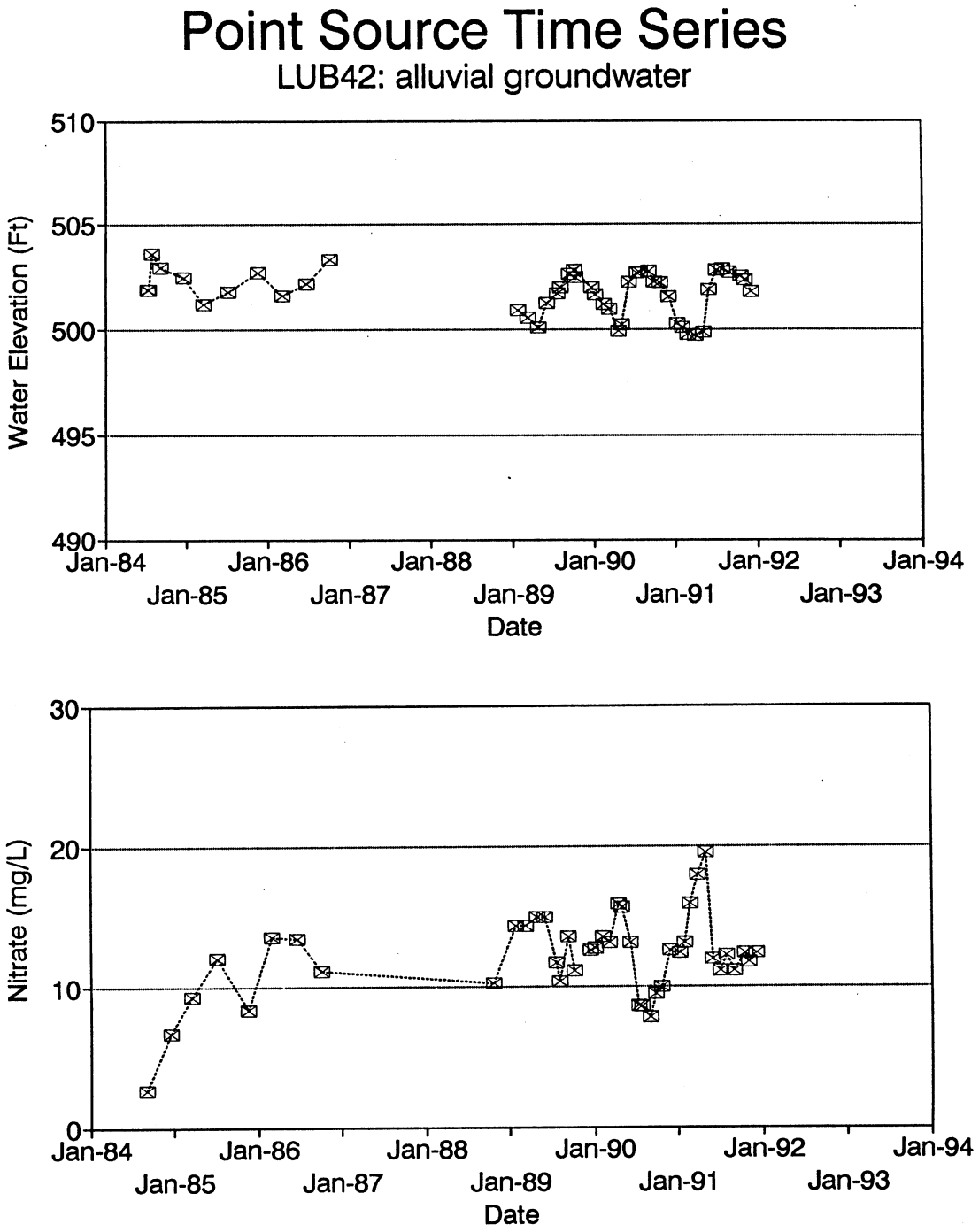


Figure 1.13 An example of similar nitrate concentration and groundwater elevation fluctuations in the Lower Umatilla Basin.

The very similar and time lag related groundwater elevation versus constituent concentration correlations have very important implications for the Lower Umatilla Basin. The correlations indicate nitrate may move to groundwater more quickly than the years and decades previously estimated by other investigators.

Travel Time in Groundwater

Nitrate transport in groundwater depends upon groundwater flow. Hydrogeologic analyses indicate groundwater flow in the alluvial aquifer may vary between less than one foot (silts and silty sands) to one-half of a mile (sands and gravels) per year. Seasonal variations can make flow considerably less.

Flat gradients in coarse-grained deposits create a slow-moving flow that can sometimes be reversed by well pumping or canal recharge. A well-documented example of slow and reversed groundwater travel can be found near the Umatilla Ordnance Depot. Estimated flows indicate that groundwater from the center of the Depot should travel to the Umatilla River within 10 to 40 years. However, seasonal water-level measurements in Depot wells indicate that flow directions can vary by up to 180 degrees during the year due to off-site pumping and recharge.

Nitrogen isotopic analyses also indicate low groundwater flow velocities exist in the basin. No significant isotopic variation over time were observed in samples collected from individual wells in the Boardman-Irrigon area. That indicates a large volume of very slow moving groundwater underlies the area.

A review of Plate 4.2 provides additional evidence of slow groundwater nitrate transport in portions of the basin. For example, elevated nitrate+nitrite-nitrogen in the middle of the U.S. Army depot appears related to the Depot's explosive washout activity which ended by the mid-1960s. Nitrate from the washout lagoons appears to have moved less than four miles (possibly less than 0.5 miles) over three to four decades.

Investigative Overview Summary

The Oregon Department of Environmental Quality (DEQ) established the Lower Umatilla Basin as a Groundwater Management Area in 1990, based upon high nitrate-nitrogen concentrations in groundwater samples.

Nitrate concentrations in Lower Umatilla Basin groundwater exceed 10 mg/L and 20 mg/L in many areas. These levels cause the greatest concern for infants less than six months of age, who are at risk of developing "blue baby syndrome" or methoglobinemia.

An interagency groundwater quality investigation to identify the sources of nitrate-nitrogen began in July 1990. The 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.

Most of the study area occupies an undulating plain that slopes gently to the north. The Lower Umatilla Basin can be considered semi-arid, with hot dry summers and cool moist winters. Annual precipitation varies between 8-10 inches.

Groundwater quality problems exist within the Lower Umatilla Basin Groundwater Management Area (GWMA). Nitrate, total dissolved solids, arsenic, and sodium concentrations exceed the drinking water standard or recommended limit at different locations. Atrazine, ethylene dibromide (EDB), dacthal/dacthal metabolites, chloroform, and toluene have been detected in some groundwater samples. Explosives, chemicals, nitrate, semi-volatile compounds and metals have been detected in U.S Army Umatilla Depot Activity area groundwater samples collected and analyzed by Depot consultants.

Identifying the sources of these contaminants required sophisticated data analyses. The hydrogeology, varied land uses, and natural chemistry complicated an understanding of the basin's groundwater chemistry/quality. Nitrate, the focus of the investigation, is associated with a variety of Lower Umatilla Basin land uses. An intensive analysis investigating the complex and inconsistent relationship between nitrate and other constituents helped to determine likely sources.

Hydrogeology

Aquifers contain and transmit water moving from recharge to discharge areas.

A shallow unconfined to semiconfined aquifer occurs in the alluvial sediments between the cities of Boardman, Umatilla and Echo. Multiple confined aquifers occur in the underlying basalt flows. The alluvial aquifer and shallow basalt aquifers are the main source 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. In localized areas, alluvial groundwater is also an important source of irrigation water.

The available evidence indicates that water readily infiltrates basin soils, traveling 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 of irrigation water is also an important recharge source, especially in areas which are irrigated by flooding or with low efficiency sprinkler systems. Deep percolation also occurs in areas exclusively irrigated by center pivots. In localized areas, leakage from reservoirs and streams provides an important source of recharge. Recharge from precipitation is minimal. Water conservation measures, such as liner improvements for canals, by irrigation districts and individual farmers will reduce the volume of recharge over time.

Flow directions in the alluvial aquifer are highly variable and are constrained by the "topography" of the underlying basalt surface. Flow directions are also influenced by the seasonal pumping of high-capacity wells and by seasonal leakage 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.

The geometry of the shallow basalt aquifers and limited water level data indicate that most recharge to the basalts comes from the Columbia River and the alluvial aquifer. Therefore, water quality in the shallow basalt aquifers will be related to the quality of recharge water from these sources.

Substantial quantities of groundwater are discharged from the alluvial aquifer by wells. In the Ordnance area, pumpage has exceeded recharge since 1986 and groundwater levels are declining. Pumpage discharge between Boardman and Umatilla is buffered by recharge from the Columbia River. Groundwater supplies in this area 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 lack of deep seals in many wells probably allows water from the alluvial aquifer to migrate downward to aquifers in the underlying basalts. The commingling of basalt aquifers through open bore holes provides a pathway by which water and contaminants can easily migrate from shallow to deeper aquifers.

Land Use and Nitrogen Loading

The Lower Umatilla Basin's soil conditions and hydrogeological properties make local groundwater very vulnerable to contamination from many different land uses. For example, the project and/or other investigations have detected nitrate, metals, organic compounds, and explosives contaminating local groundwater. As land uses continue to expand and evolve, other potential contaminants may leach through basin soils as easily as nitrate. Project sampling confirmed extensive areas of nitrate-nitrogen groundwater concentrations near or exceeding the U.S. E.P.A. drinking water limit of 10 mg/L.

This investigation focused on nitrate. The potential for a land use to contaminate groundwater with nitrate or another constituent relates to loading. Groundwater contamination can occur whenever water (or another liquid) and nitrate (or another contaminant) released exceeds or bypasses:

- removal by crops or other vegetation;
- removal by evaporation; and
- soil capacity to prevent deep percolation.

Nitrogen Loading

Irrigated Agriculture

Irrigated agriculture is the dominant land use in the basin. In 1992, it appears to have used nearly 180,000 acres or 51 percent of the total study area. A review of other studies conducted in the basin indicate some nitrogen escapes beyond the root zone at some irrigated crop fields even under conservative management strategies.

An OSU study estimated more than 20.5 million pounds of nitrogen were applied to 1990 crops. Using a more conservative figure of 7 million pounds per year since 1975 (141,243 acres, 50 pounds nitrogen per acre), the total nitrogen loss to groundwater may exceed 350,000 pounds annually.

Food Processing

Large-scale potato processing, for fast food and other uses, generates large volumes of nutrient and salt-rich wastewater. Since the early 1980s, the food processing industry has produced at least one million pounds of nitrogen per year.

Efforts to better manage food processing wastewater land application are in progress. Food processors expanded land application acreage from about 825 acres in 1977 to nearly 7,500 acres by 1992. At the same time they decreased the amount of nitrogen (pounds per acre) annually applied to those sites. Year-round land application has generally ended, and the use of lined wastewater ponds has increased.

Livestock

Livestock at two large beef operations, one large hog operation and one dairy probably produced more than 3.4 million pounds of total nitrogen annually during the 1980s. If stored, the total nitrogen available for land application may have exceeded 780,000 pounds or animal waste per year . The amount of waste stockpiled, sold and land applied (possibly more than 14,000 acres at times) varied from year to year.

Information has been insufficient for determining livestock nitrogen loading for the 1990s.

Domestic Sewage

Nitrate from domestic sewage is a concern mainly in areas with a high density of on-site systems.

Land application of domestic sewage from municipal systems has expanded in the last decade. By 1993, municipal land application appears to have expanded from applying less than 7,000 pounds of nitrogen annually to less than 400 acres to applying more than 140,000 pounds annually to more than 2,700 acres. Municipal sludge imported from the City of Portland and Washington County, Oregon sewage sludge is primarily responsible for the expansion.

One municipal sewage system and most on-site sewage systems discharge sewage wastewater directly to the subsurface. The City of Irrigon apparently released 9,100 pounds of nitrogen directly to the subsurface through two acres of infiltration beds in 1993. Six large on-site systems appear to release at least 4,700 pounds of nitrogen per year to about ten acres. About 4,300 individual on-site systems may release about 113,000 pounds of nitrogen per year.

Other Potential Sources

Two Lower Umatilla Basin environmental cleanup sites, the US Army Depot and the Pendleton Grain Growers, involved nitrogen. Significant loading occurred at the U.S. Army Umatilla Depot Activity Washout Lagoons. Approximately 85 million gallons of explosives washout water discharged to the lagoons (0.09 acres total) from the mid-1950s to the mid-1960s. Project information was insufficient to estimate nitrogen loading at these sites.

Some nitrogen loading is linked to two solid waste disposal facilities in the Lower Umatilla Basin. Less than 250 pounds per year of septic tank pumpage was disposed in three lagoons/ponds near the current Umatilla Butte Landfill entrance from 1974 to 1983. The US Army disposed of dried sludge from the Umatilla Depot Activity sewage treatment facility within a 10-acre Depot landfill since the early 1980s until late 1993. Project information was not sufficient to estimate loading at the Depot landfill, but other investigators identified the landfill as possibly contributing to local groundwater nitrate contamination.

Available information indicates possible loading from existing or proposed electricity generation facilities appears limited to salt and constituents other than nitrogen. PGE has reported elevated nitrate in groundwater sampled in the vicinity of their coal fired plant, and attributes the contamination to nearby agriculture.

Nitrogen loading from existing or proposed groundwater recharge projects appears minor.

No nitrogen or other constituent loading should be occurring in the Lower Umatilla Basin related to hazardous waste/substance handling or generation.

No nitrogen loading associated with underground storage tanks in the Lower Umatilla Basin is suspected. Some tanks have reportedly released petroleum products.

Groundwater Quality

The Lower Umatilla Basin investigation focused on nitrate. However, chemical analyses also tested for many other substances or constituents, which served the investigation in order to determine whether other constituents contaminated groundwater and explore the relationship between the other constituents and nitrates.

Nitrate

Nearly one-third of the project's groundwater sampling sites yielded samples with nitrate concentrations exceeding the 10 mg/L drinking water standard. Areas with nitrate concentrations greater than 10 mg/L are not evenly distributed. Higher nitrate concentrations in groundwater occur in or near the vicinities of Threemile and Sixmile Canyons, Boardman, Irrigon, the U.S. Army Umatilla Depot, County Line Road, and the Butter Creek-Umatilla River confluence.

The project sampling detected the highest concentrations between the Port of Morrow and Irrigon, with concentrations as high as 76 mg/L. Local facilities have reported groundwater nitrate concentrations greater than 100 mg/L.

Data analysis indicate multiple sources are responsible for the nitrate contamination in the basin's groundwater. Sources that formerly and/or currently contribute nitrate, either alone or in combination, include irrigated agriculture (including center pivots), livestock operations, food processing wastewater land application, unlined wastewater lagoons, sewage systems using drainfields or infiltration beds and military activities.

Data analyses also provided information about nitrate travel times. It appears that nitrate leaching through the soil can reach groundwater in one to eighteen months, given sufficient moisture for transport. Once in groundwater, nitrate transport appears slow in portions of the basin. Natural groundwater flushing of nitrate may require decades. Flat gradients and well pumping or canal recharge can temporarily reverse flows.

Other Influences

Data analyses indicate not all influences affecting the groundwater chemistry in the basin contribute nitrate. These influences include cyclic evaporation and dissolution in the vadose (unsaturated) zone, canal leakage causing dilution, and a minor influence from water-rock interactions. Analyses also indicate a hydraulic connection exists between alluvial groundwater and basalt water bearing zones.

Support for Groundwater Quality Conclusions

Support for these conclusions came from sampling which included reconnaissance, bimonthly, and synoptic activities, and sampling for nitrogen isotopic analysis. Laboratory activities included analyzing samples for nitrate, other nutrients, major ions, metals, other inorganic constituents, volatile organic compounds, pesticides, and nitrogen isotopic composition.

Data analysis activities included using general statistics, chemical constituent distribution maps, multiple graphical analyses, groundwater chemistry computer modeling for selected areas, and stable nitrogen isotope interpretations.

Chapter 2

Hydrogeology

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Oregon Water Resources Department

1995

Chapter 2: Hydrogeology

Table of Contents

Well Identification and Location Systems vii

Abstract ix

Introduction 1
- Purpose and Scope of Work 1
- Previous Investigations 1
- Investigative Methods 3
- Acknowledgements 5

Geography and Climate 7

Groundwater Development 9

Geologic Framework 11
- Stratigraphic Units 11
  - Columbia River Basalt Group and Interbedded Ellensburg Formation 11
    - Umatilla Member 12
    - Selah Interbed 13
    - Pomona Member 13
    - Rattlesnake Ridge Interbed 14
    - Elephant Mountain Member 14
  - Alkali Canyon Formation 15
  - Catastrophic Flood Deposits 16
  - Holocene Alluvium 18
  - Surficial Deposits 19
- Geologic Structures 19

Groundwater Occurrence 21
- Aquifer Units 21
- Conceptual Model of the Flow System 21

Alluvial Aquifer 25
- Water-Bearing Units 25
  - Holocene Alluvium 25
  - Catastrophic Flood Deposits 26
    - Boardman-Umatilla Area 27
    - Umatilla Ordnance Depot Area 30
    - Hermiston Area 36
    - Umatilla River Valley 38
    - Sixmile Canyon Area 39
  - Alkali Canyon Formation 41
  - Breccia/Fracture Zones at the Top of the Columbia River Basalt Group 41
- Hydraulic Properties 41

Recharge 44
From Precipitation 45
From Canal Leakage 46
From Stream Leakage 51
From Reservoir Leakage 52
From Deep Percolation of Irrigation Water 55
Flow Directions and Velocities 63
Discharge 65
To Streams 65
To Shallow Basalt Aquifers 66
To Wells 67
Groundwater Supply 68

Shallow Basalt Aquifers 71
Aquifer Properties 73
Recharge 73
From the Alluvial Aquifer 73
From Reservoirs and Streams 74
From the Alluvial Aquifer Through Wells 74
Flow Directions and Velocities 75
Discharge 76
Groundwater Supply 76

Summary and Conclusions 79

Chapter 2: Hydrogeology

Illustrations

Figures

2.1 Well location system vii
2.2 Precipitation at the Hermiston airport weather station: monthly, annual, and cumulative departure (1928-1992) 6
2.3 Well use and cumulative wells drilled through 1992 8
2.4 Comparison of geologic and hydrogeologic units 10
2.5 Conceptual model of the shallow groundwater flow system 22
2.6 Idealized relationship between basalt stratigraphy and groundwater occurrence 23
2.7 Effect of river stage on groundwater levels in coarse-grained flood deposits adjacent to the Columbia River between Irrigon and Boardman 28
2.8 Possible effects of pumping on groundwater levels in coarse-grained flood deposits east of the Port of Morrow 29
2.9 Long-term hydrographs of representative wells completed in coarse-grained flood deposits east and south of the Umatilla Ordnance Depot 31
2.10 Seasonal hydrograph of continuous recorder well completed in coarse-grained flood deposits south of the Umatilla Ordnance Depot 32
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 33
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 35
2.13 Continuous recorder hydrograph for well completed in coarse-grained flood deposits near Hermiston 37
2.14 Hydrographs of wells completed in shallow unconfined water-bearing zones of the alluvial aquifer in the Umatilla River floodplain 38
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 40
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 42
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 46
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 49
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 54

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 56
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 58
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 60
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 62
2.24 Hydrographs of monitoring wells completed in the basal Pomona aquifer on the Umatilla Ordnance Depot 72
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 75

Tables

2.1 Summary of hydraulic parameters for the alluvial aquifer 43
2.3 Estimates of yearly canal losses for main delivery canals 50
2.3 Estimated groundwater flow velocities in the alluvial aquifer 64
2.4 Summary of well withdrawals from the alluvial aquifer 67

Plates (in pocket)

2.1 Well locations and place names
2.2 Geologic map showing structure contours on top of the Columbia River Basalt Group
2.3 Geologic cross sections
2.4 Water-level contours of the alluvial aquifer, February 1991
2.5 Well density
2.6 Irrigated acreage and permitted alluvial aquifer wells.

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).

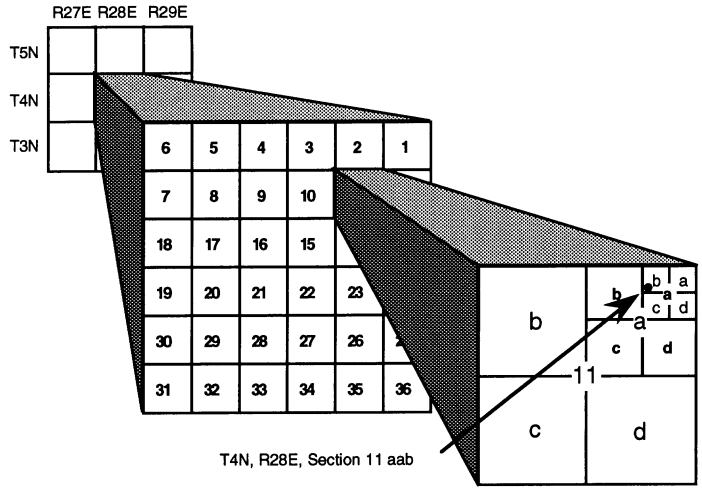


Figure 2.1 Well location system

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.

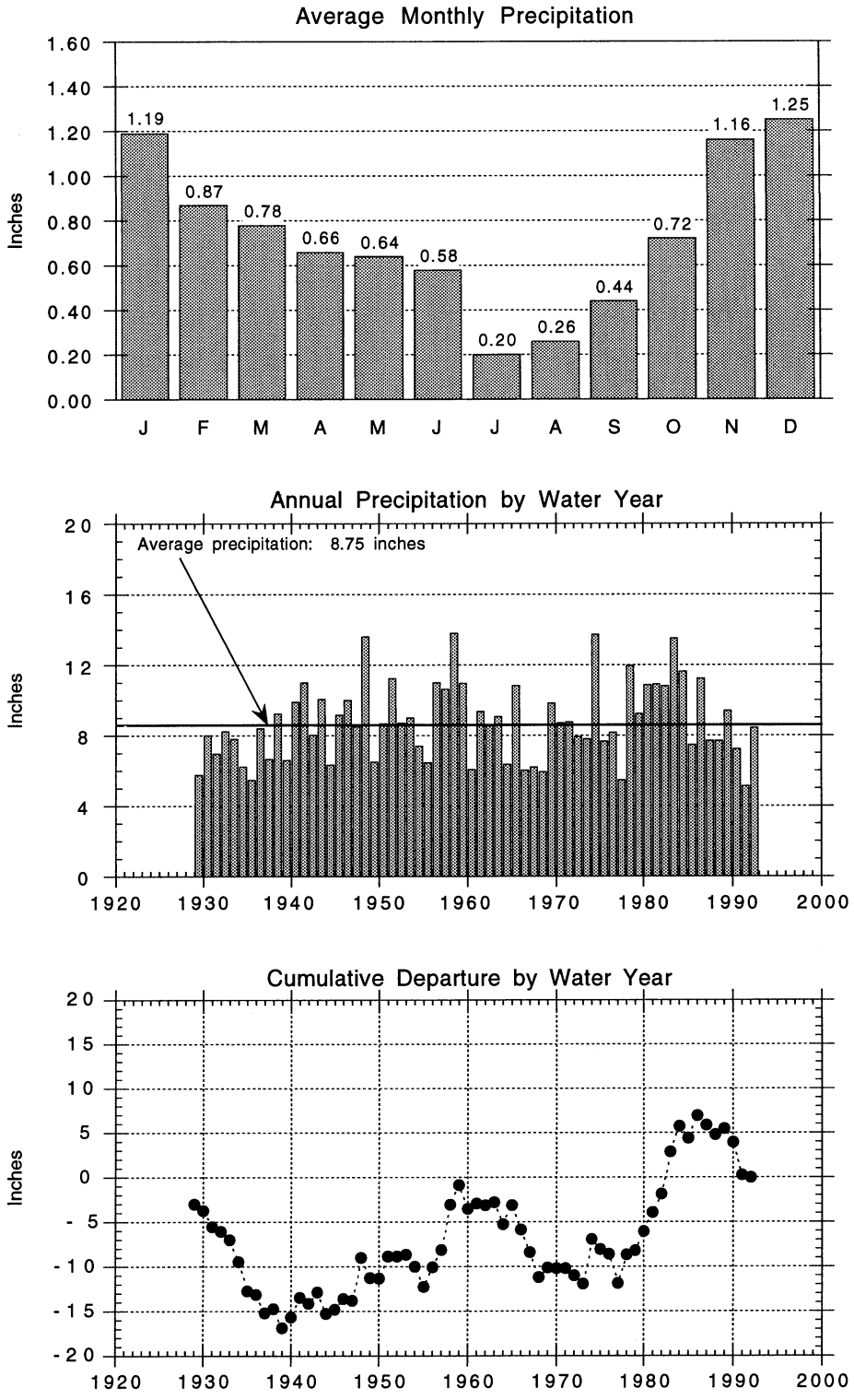


Figure 2.2 Precipitation at the Hermiston airport weather station: monthly, annual, and cumulative departure (1928-1992)

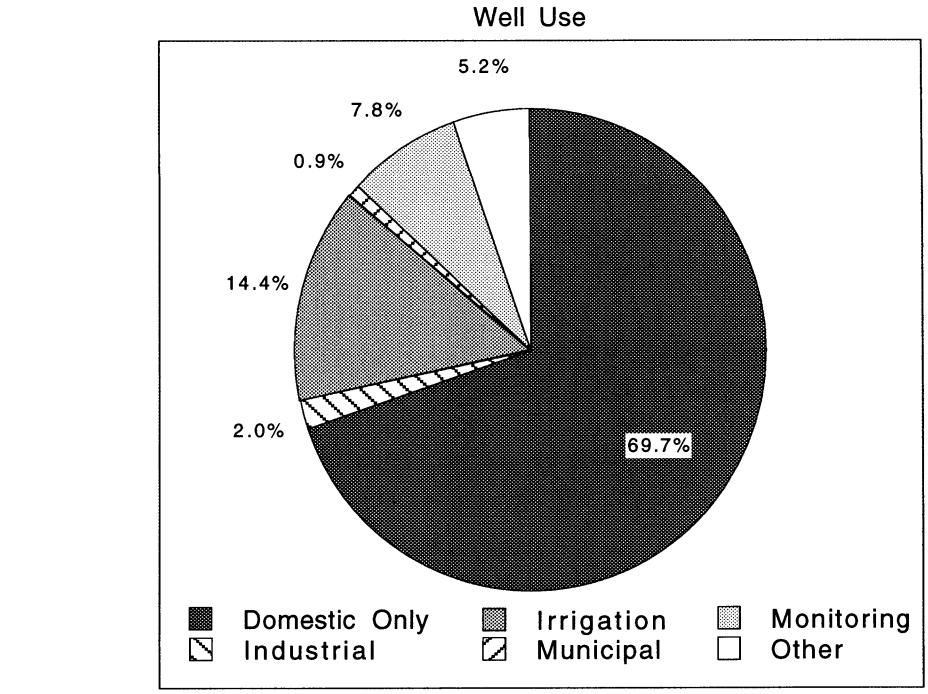
Geography and Climate

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.



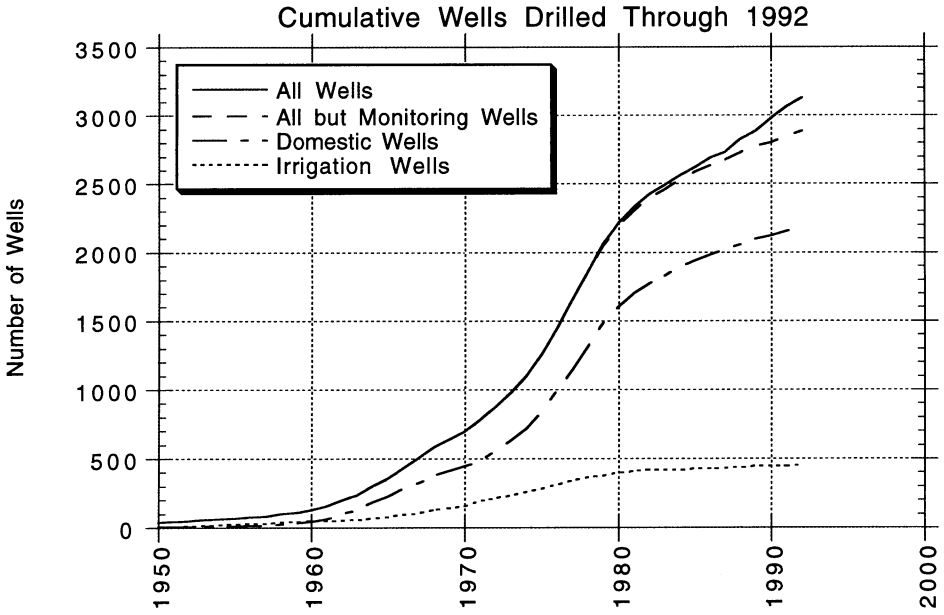
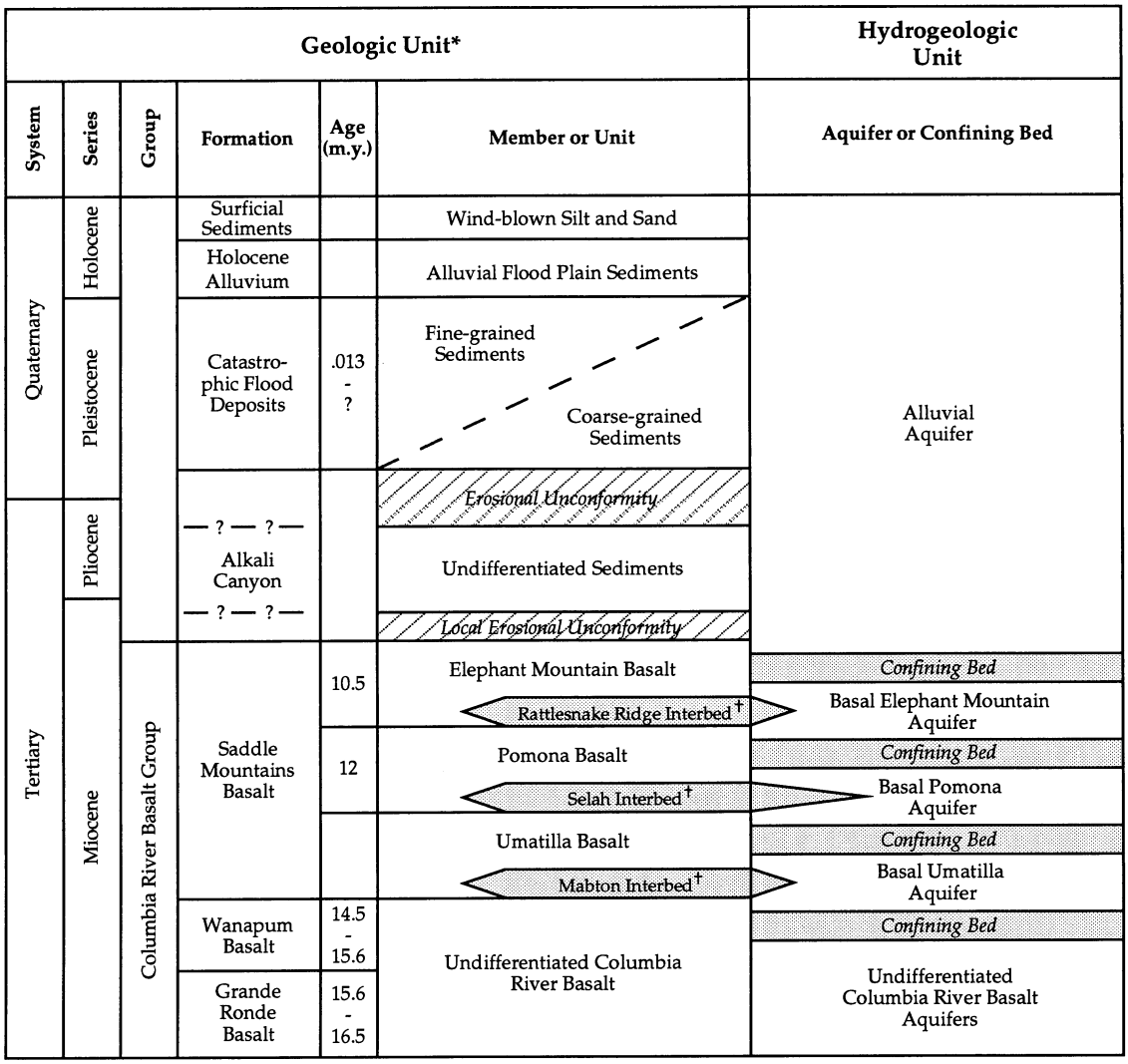


Figure 2.3 Well use and cumulative wells drilled through 1992

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.



*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.

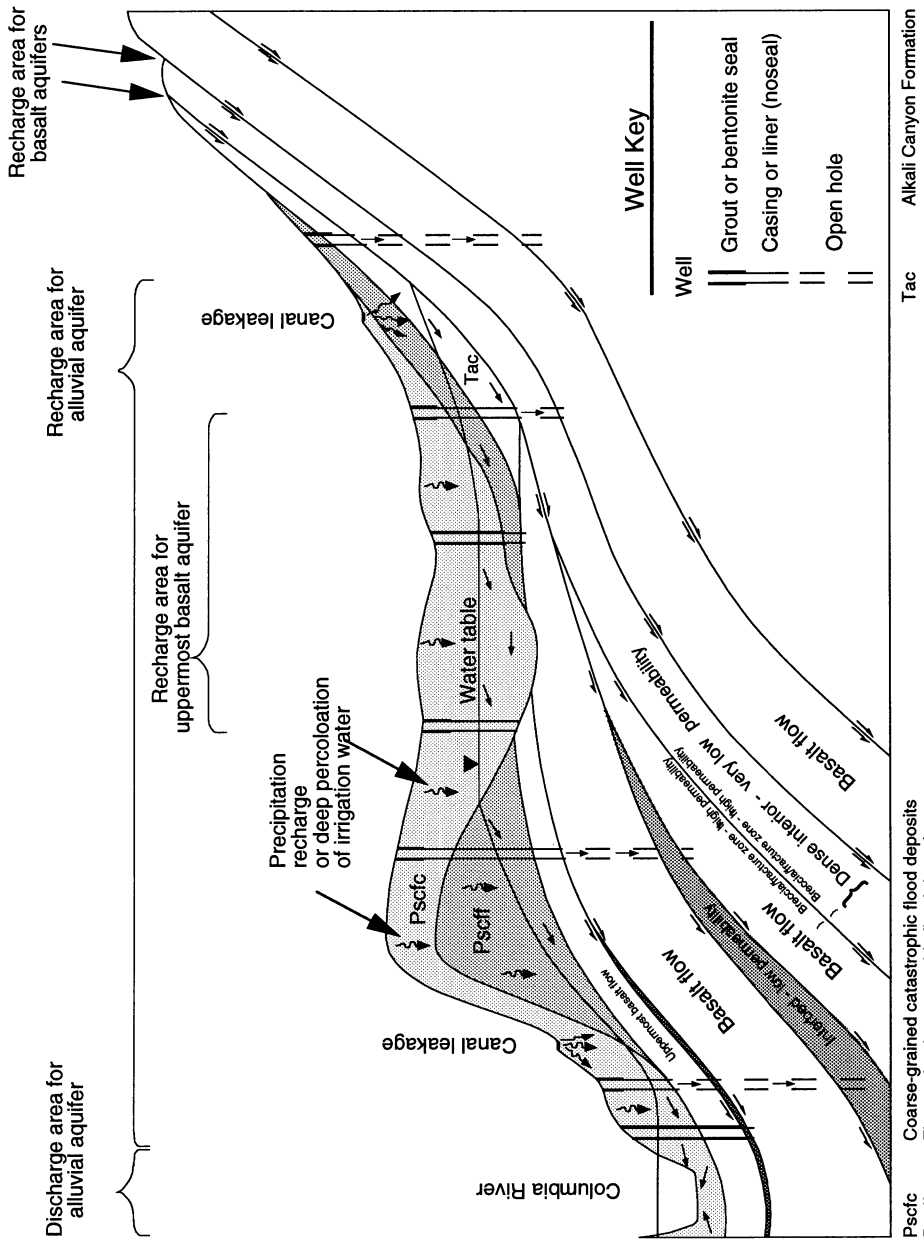


Figure 2.5 Conceptual model of the shallow groundwater flow system

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.

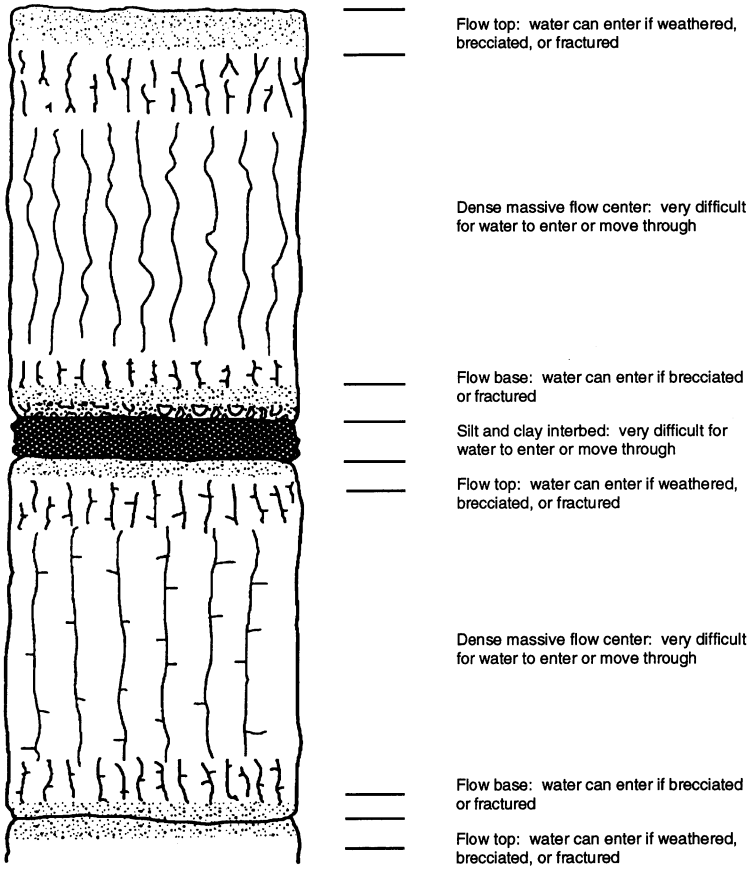


Figure 2.6 Idealized relationship between basalt stratigraphy and groundwater occurrence.

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.

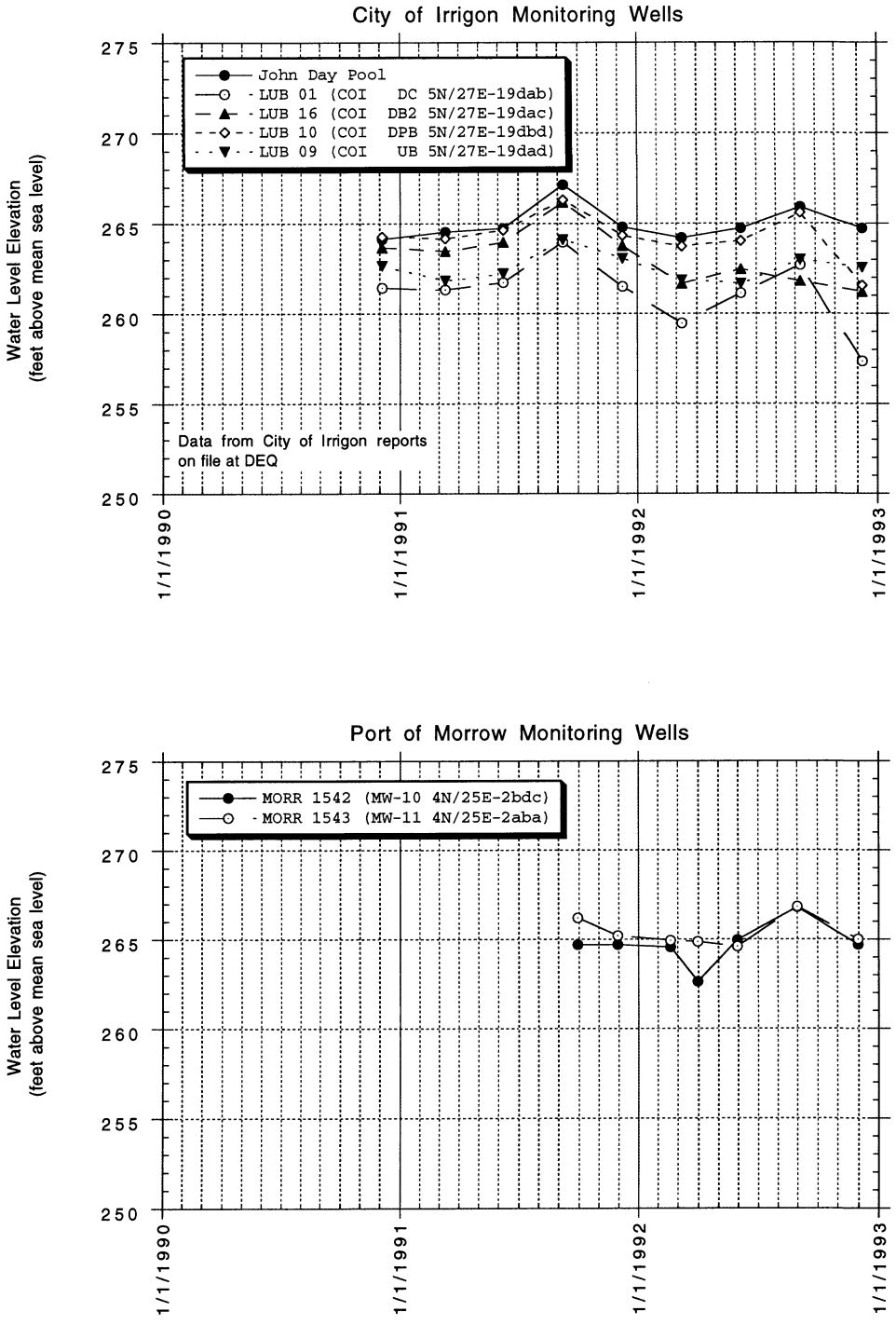


Figure 2.7 Effect of river stage on groundwater levels in coarse-grained flood deposits adjacent to the Columbia River between Irrigon and Boardman

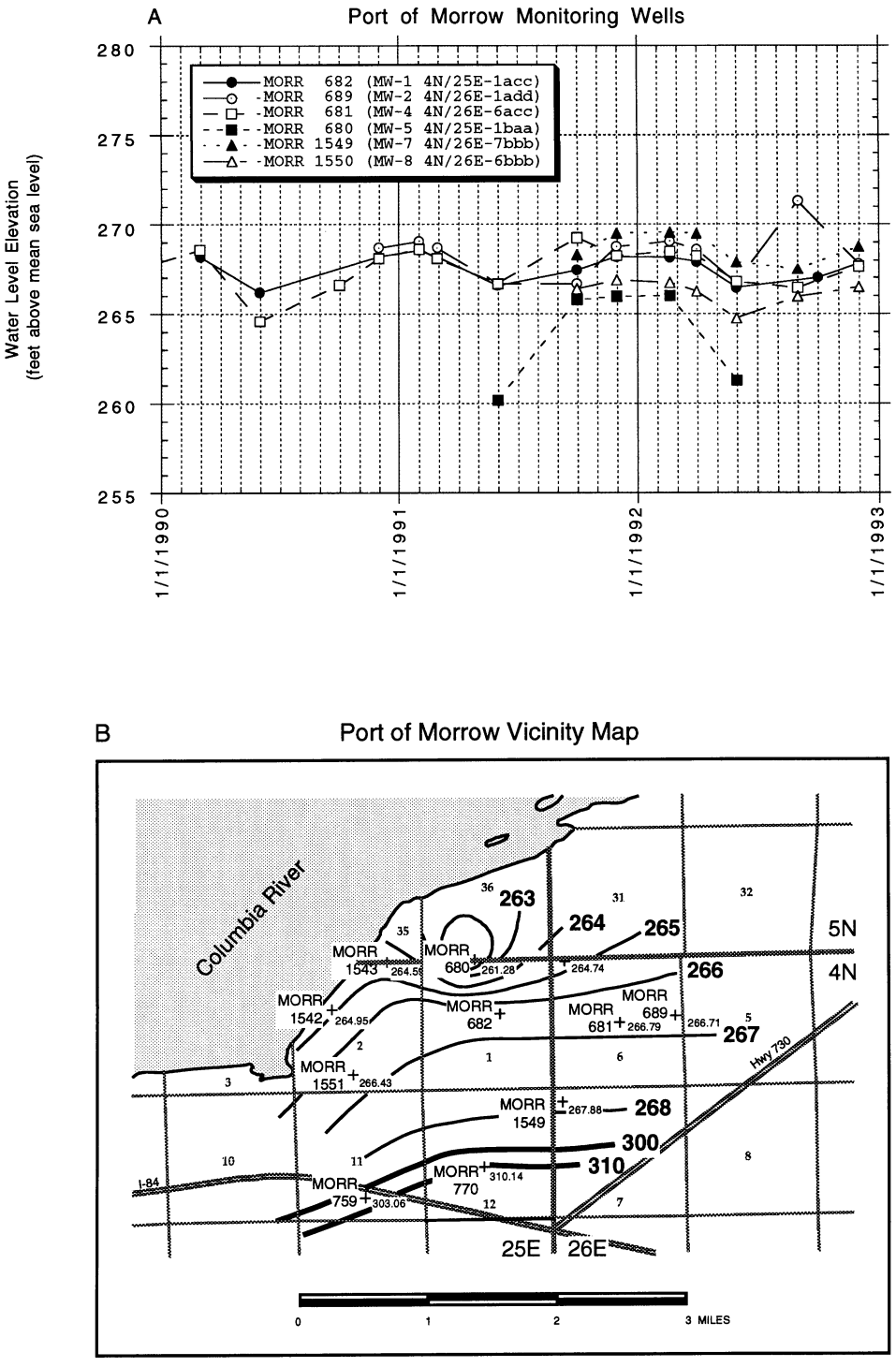


Figure 2.8 Possible effects of pumping on groundwater levels in coarse-grained flood deposits east of the Port of Morrow

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).

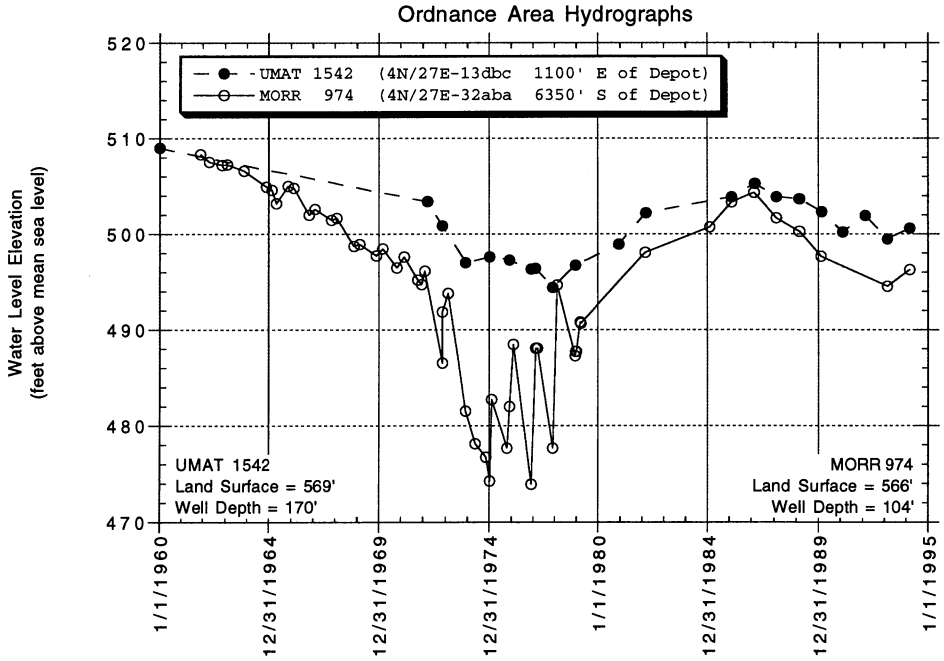


Figure 2.9 Long-term hydrographs of representative wells completed in coarse-grained flood deposits east and south of the Umatilla Ordnance Depot

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).

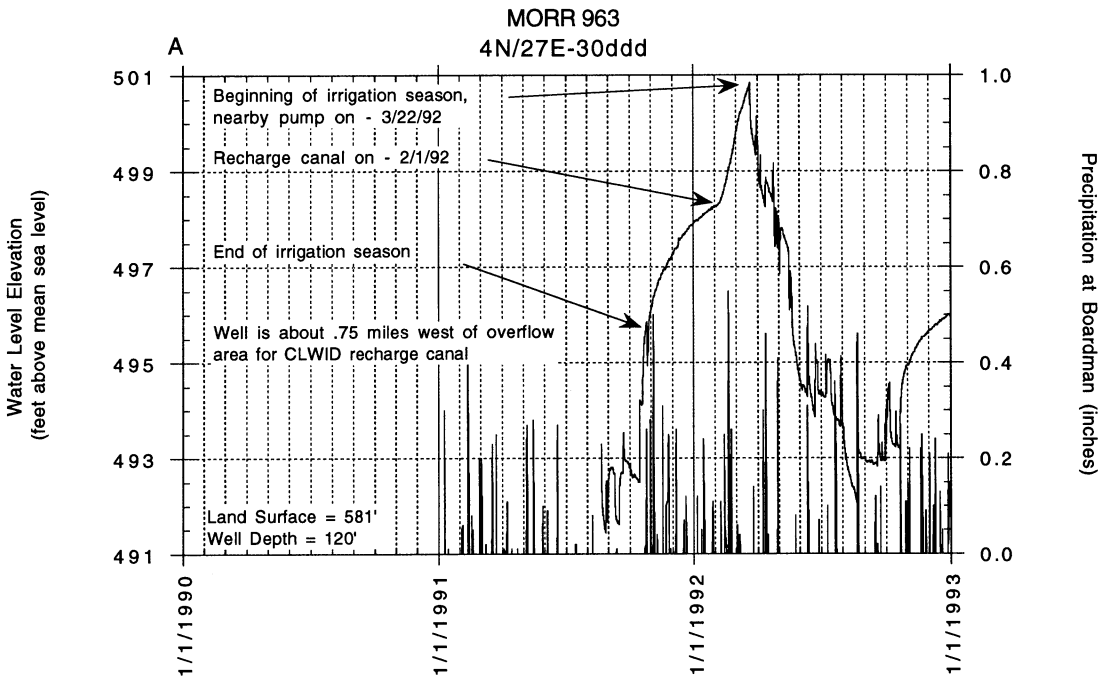
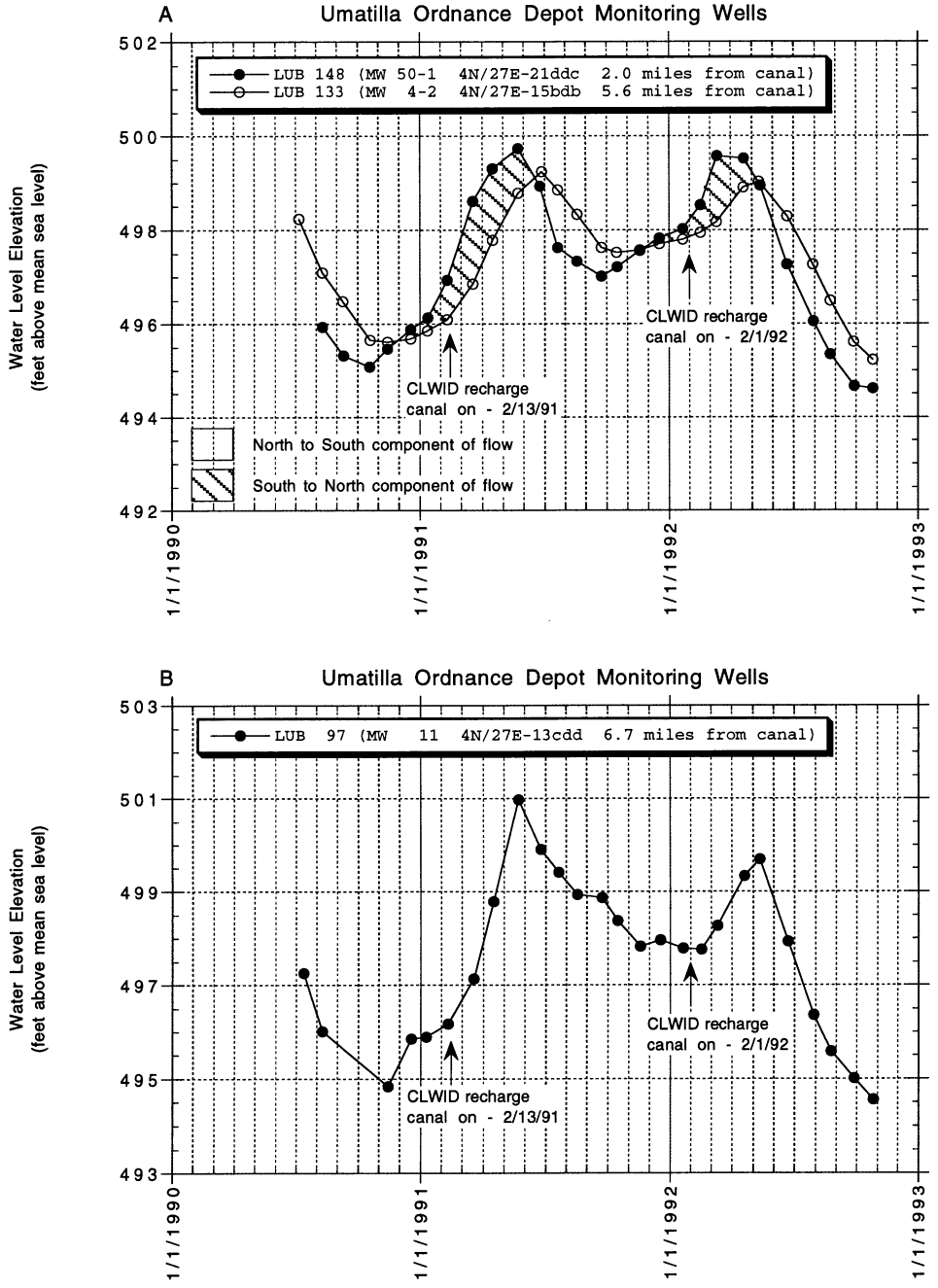


Figure 2.10 Seasonal hydrograph of continuous recorder well completed in coarse-grained flood deposits south of the Umatilla Ordnance Depot

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.

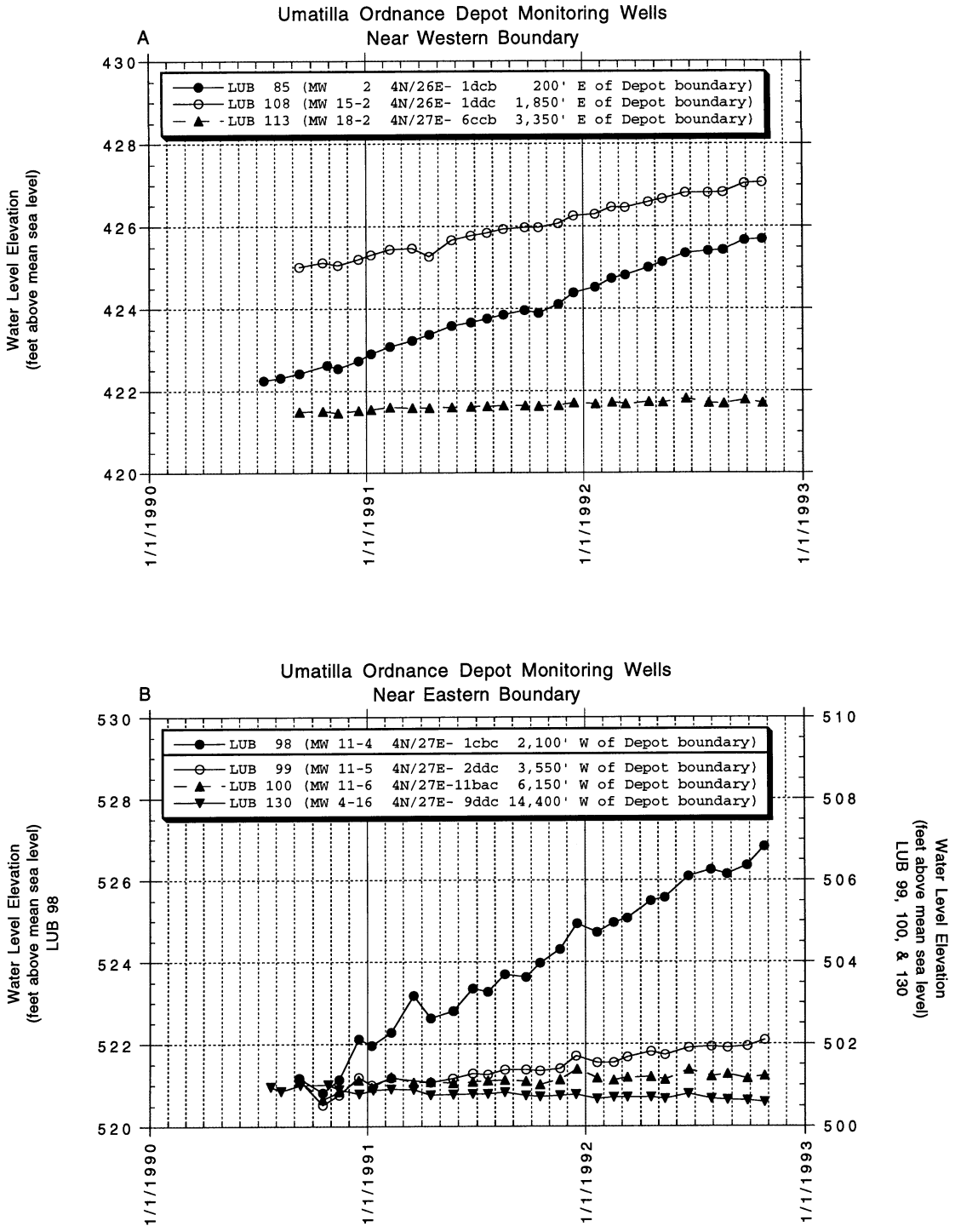


Figure 2.12 Seasonal hydrographs of monitoring wells screened in fine-grained flood deposits on the Umatilla Ordnance Depot. A, Wells near western boundary; B, Wells near eastern boundary

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.

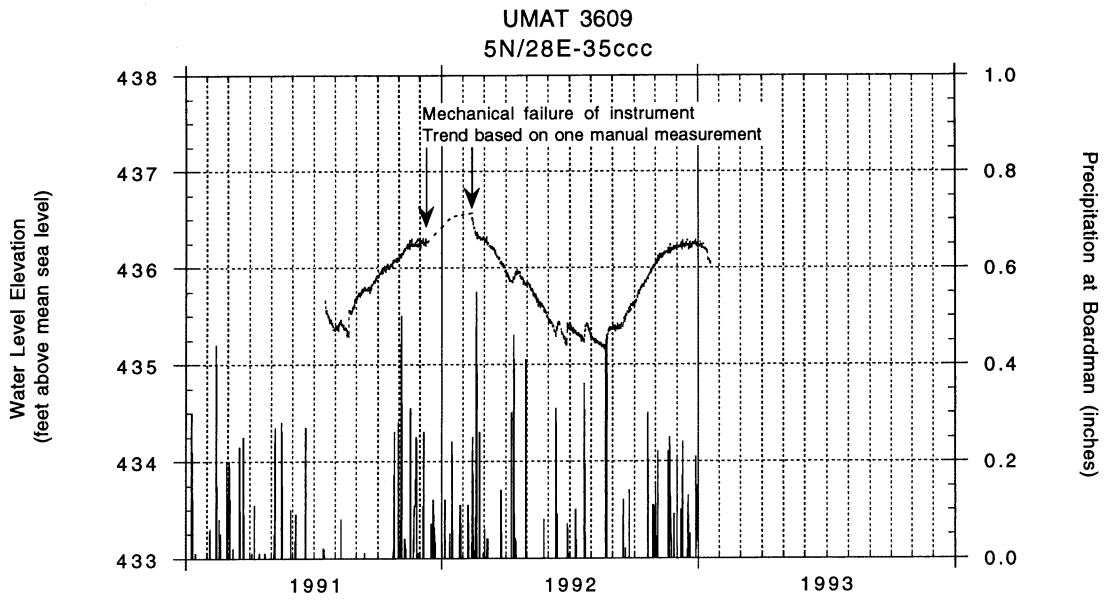


Figure 2.13 Continuous recorder hydrograph for well completed in coarse-grained flood deposits near Hermiston

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).

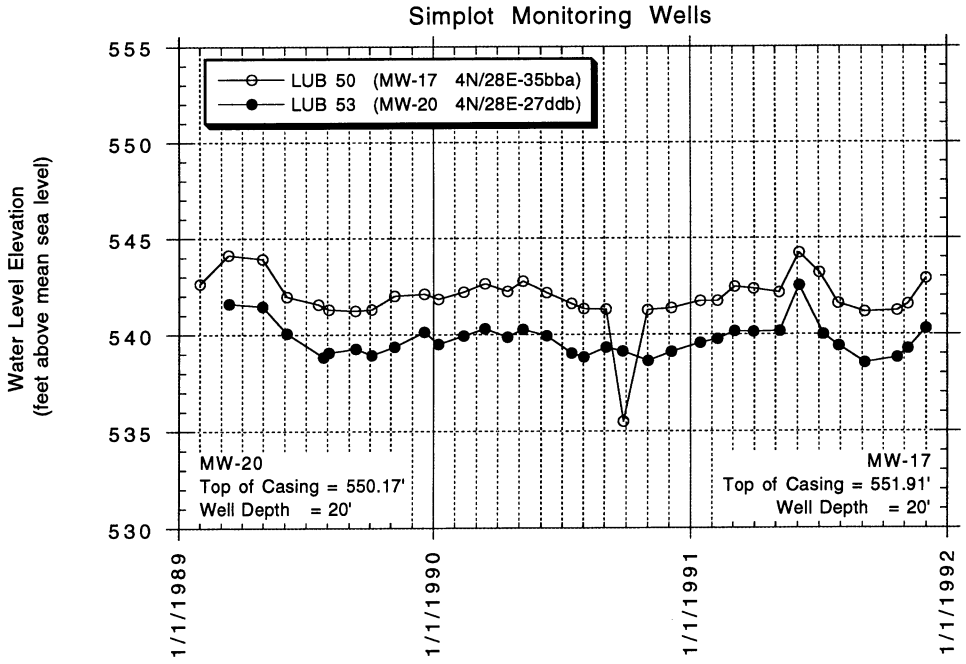


Figure 2.14 Hydrographs of wells completed in shallow unconfined water-bearing zones of the alluvial aquifer in the Umatilla River floodplain

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.

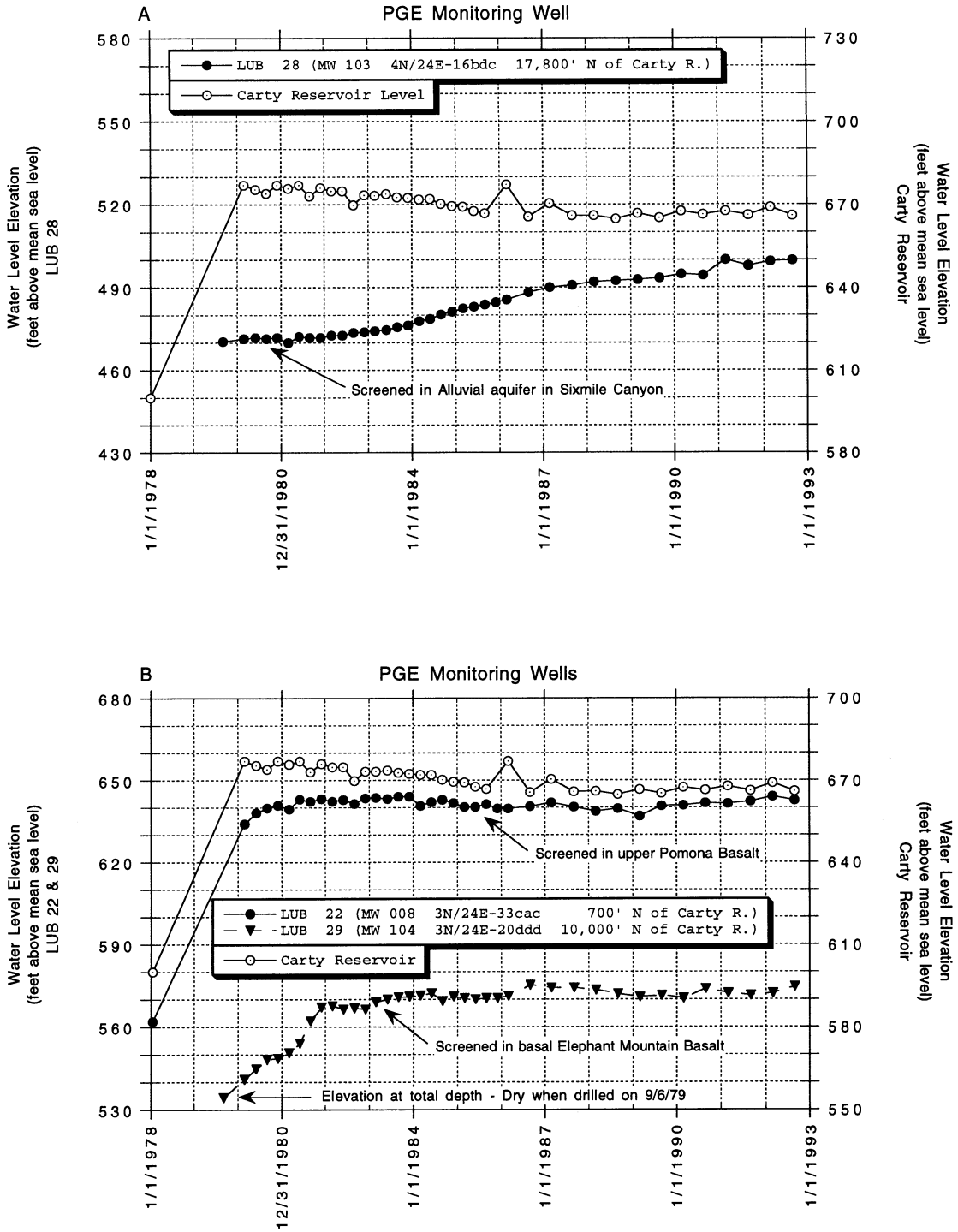


Figure 2.15 Hydrographs of monitoring wells near Sixmile Canyon showing rises in groundwater levels since the filling of Carty Reservoir. A, Alluvial well in Sixmile Canyon; B, Basalt wells west of Sixmile Canyon

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.

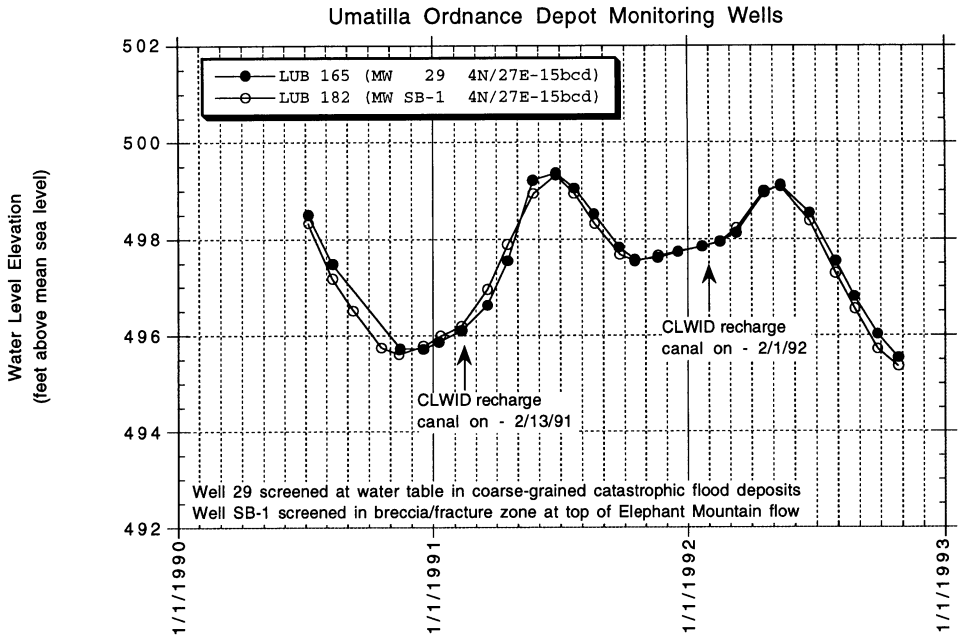


Figure 2.16 Hydrographs of adjacent monitoring wells completed at the water table in coarse-grained flood deposits and in the breccia/fracture zone at the top of the uppermost Columbia River Basalt flow on the Umatilla Ordnance Depot

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%.

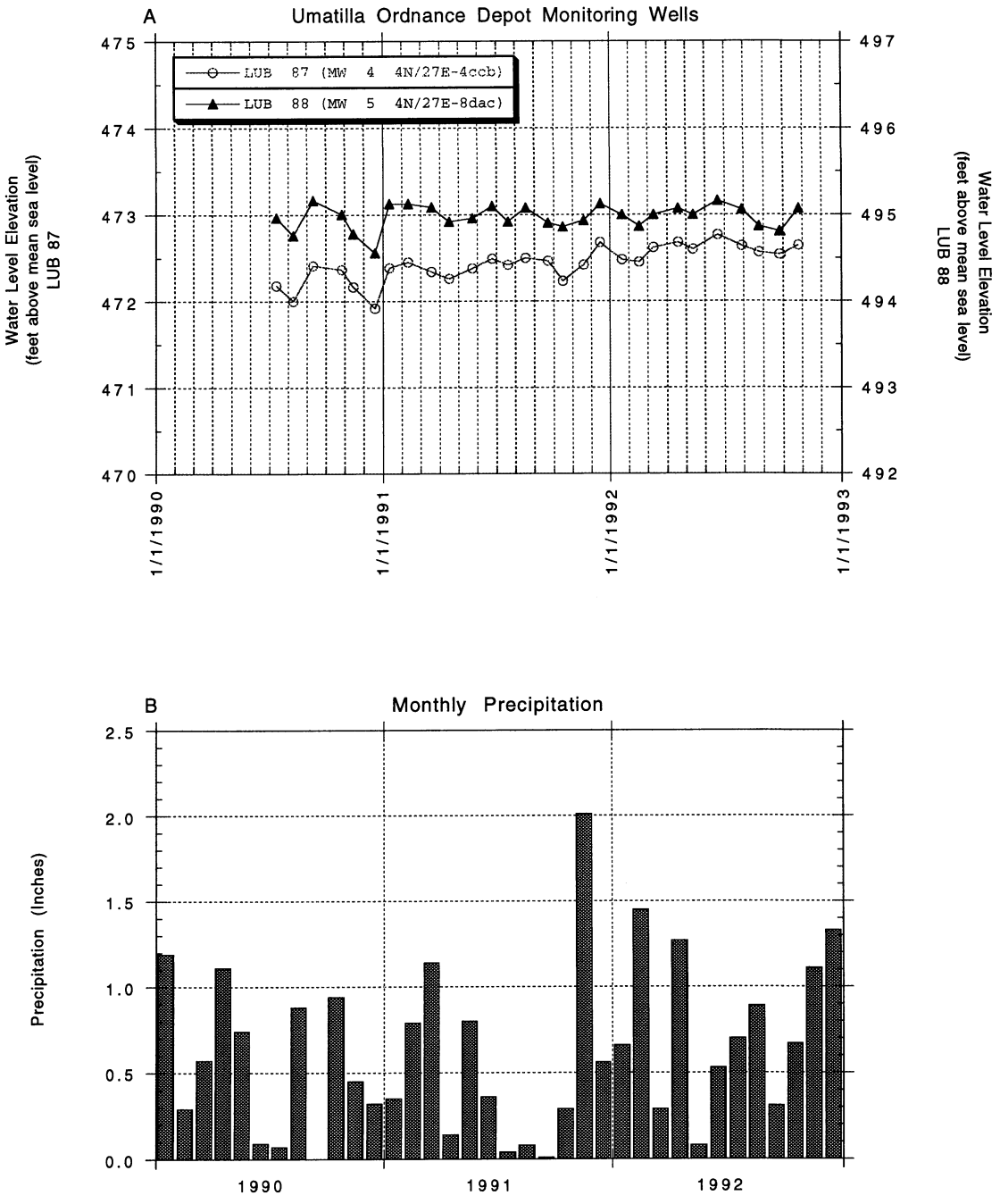


Figure 2.17 Comparison of water-level trends and precipitation in the interior of the Umatilla Ordnance Depot. A, Hydrographs of wells screened in fine-grained flood deposits; B, Monthly precipitation at Boardman

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.

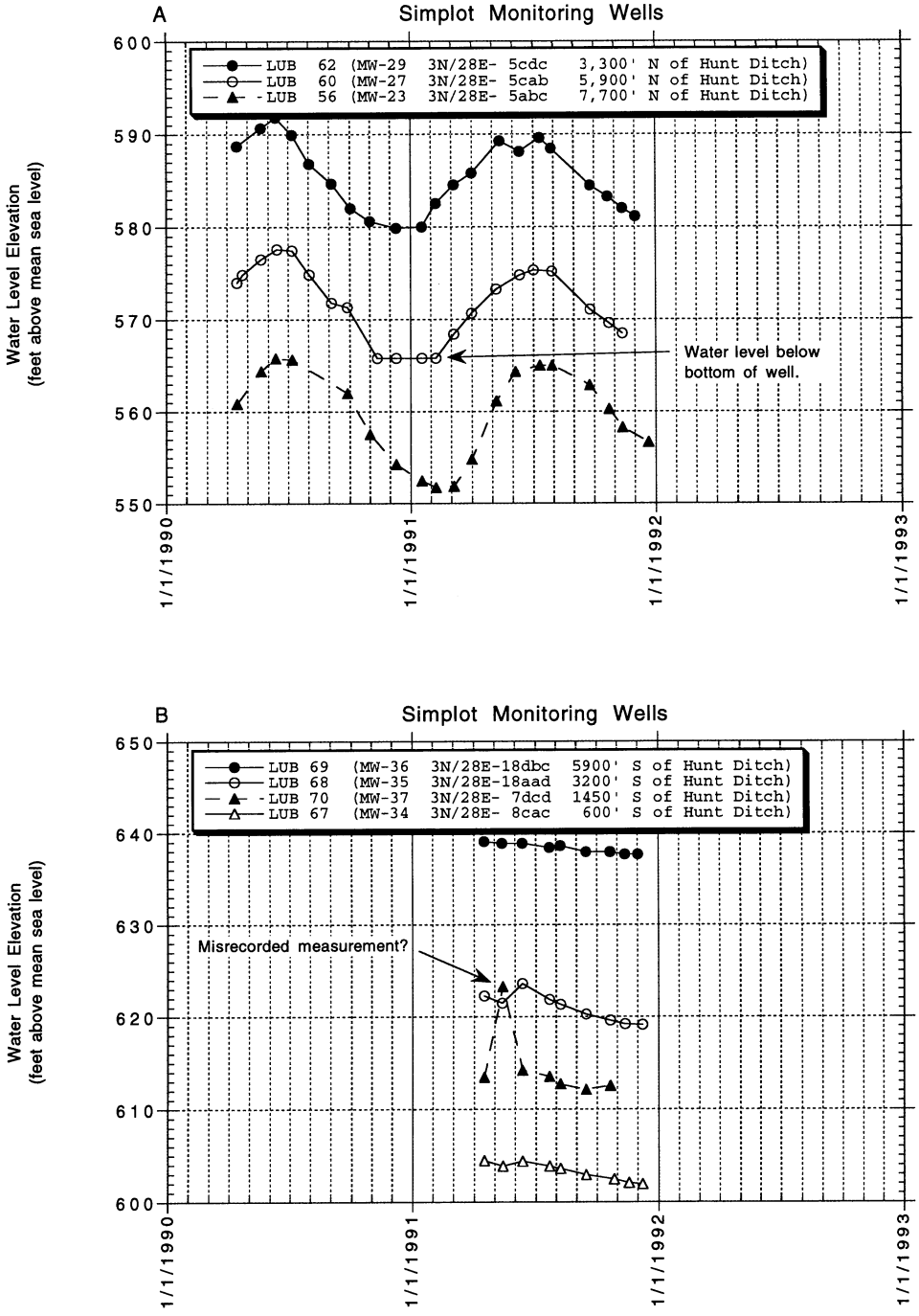


Figure 2.18 Hydrographs of monitoring wells screened in Holocene Alluvium in the Butter Creek floodplain. A, Wells north of Hunt Ditch; B, Wells south of Hunt Ditch

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	US 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.

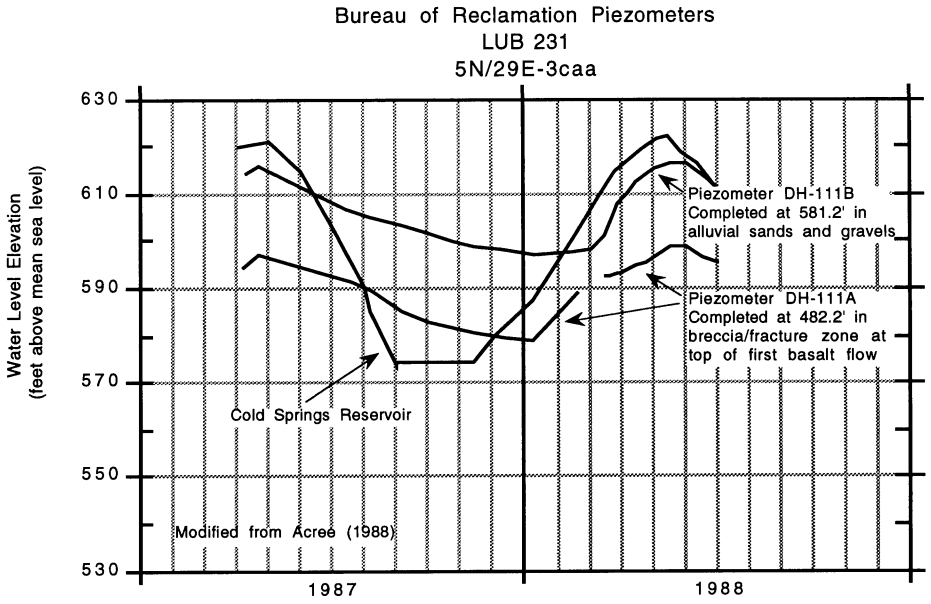


Figure 2.19 Hydrographs of paired piezometers completed near the water table in the alluvial aquifer and in the breccia/fracture zone at the top of the uppermost Columbia River Basalt flow near Cold Springs Dam.

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.

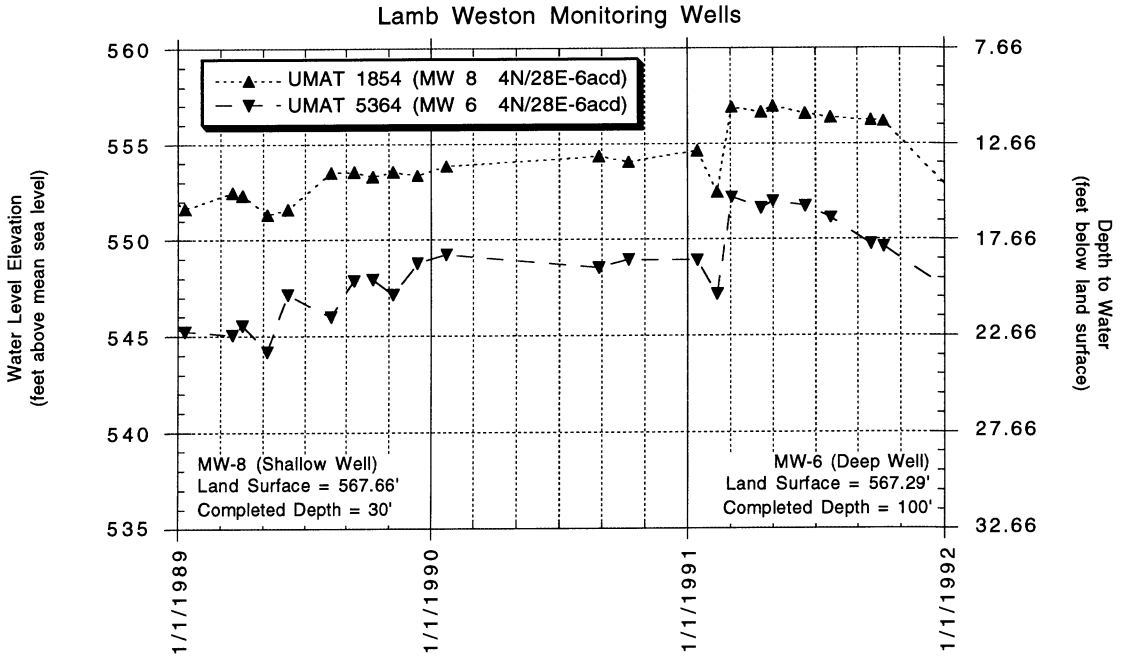


Figure 2.20 Hydrographs of adjacent wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits northeast of the Umatilla Ordnance Depot

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.

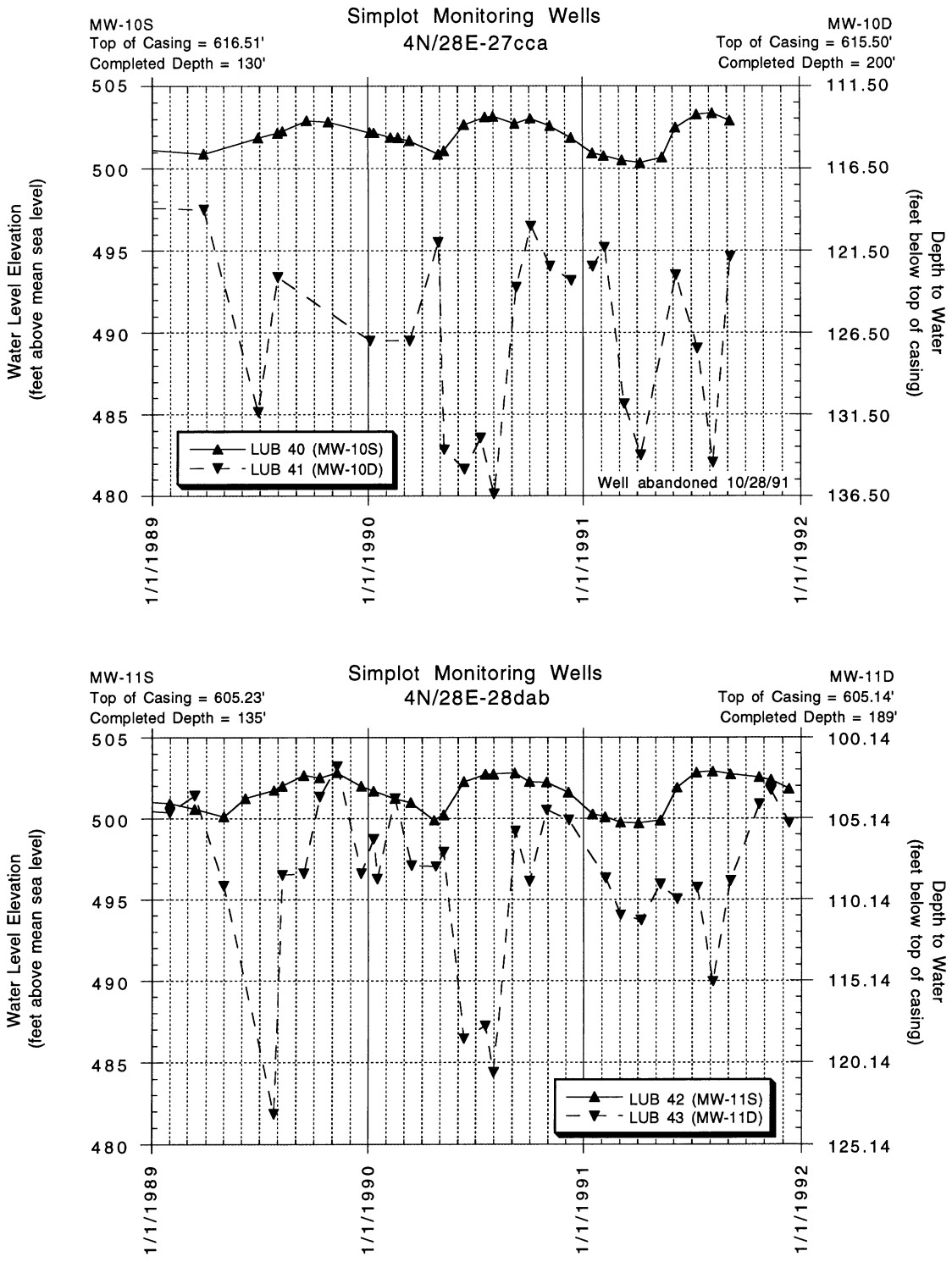


Figure 2.21 Hydrographs of paired wells completed in shallow unconfined and deeper confined water-bearing zones within fine-grained catastrophic flood deposits on the terrace north of the Umatilla River.

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.

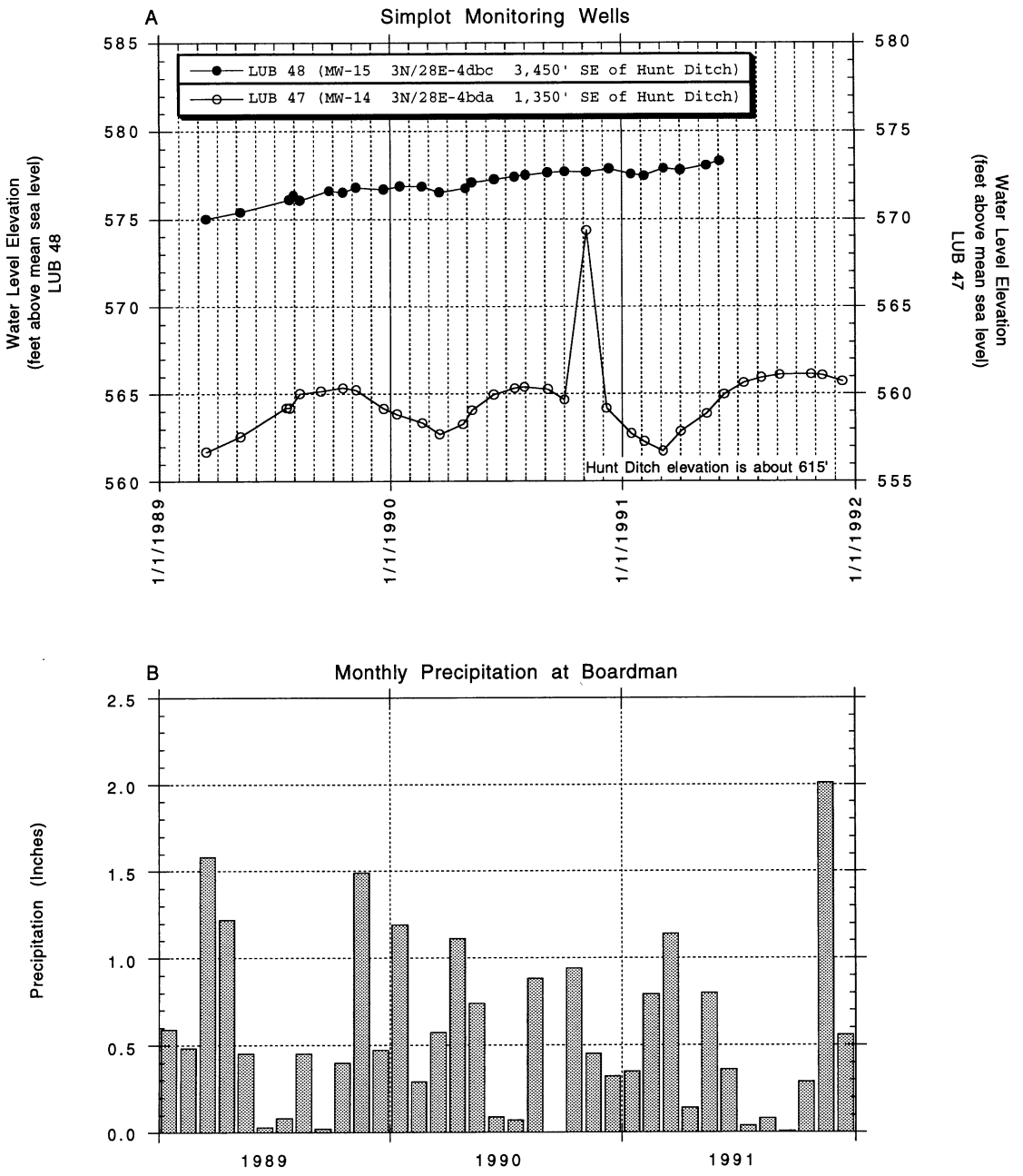


Figure 2.22 Comparison of water-level trends and precipitation in the area between Butter Creek and Emigrant Buttes. A, Hydrographs of wells screened in fine-grained flood deposits; B, Monthly precipitation at Boardman.

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.

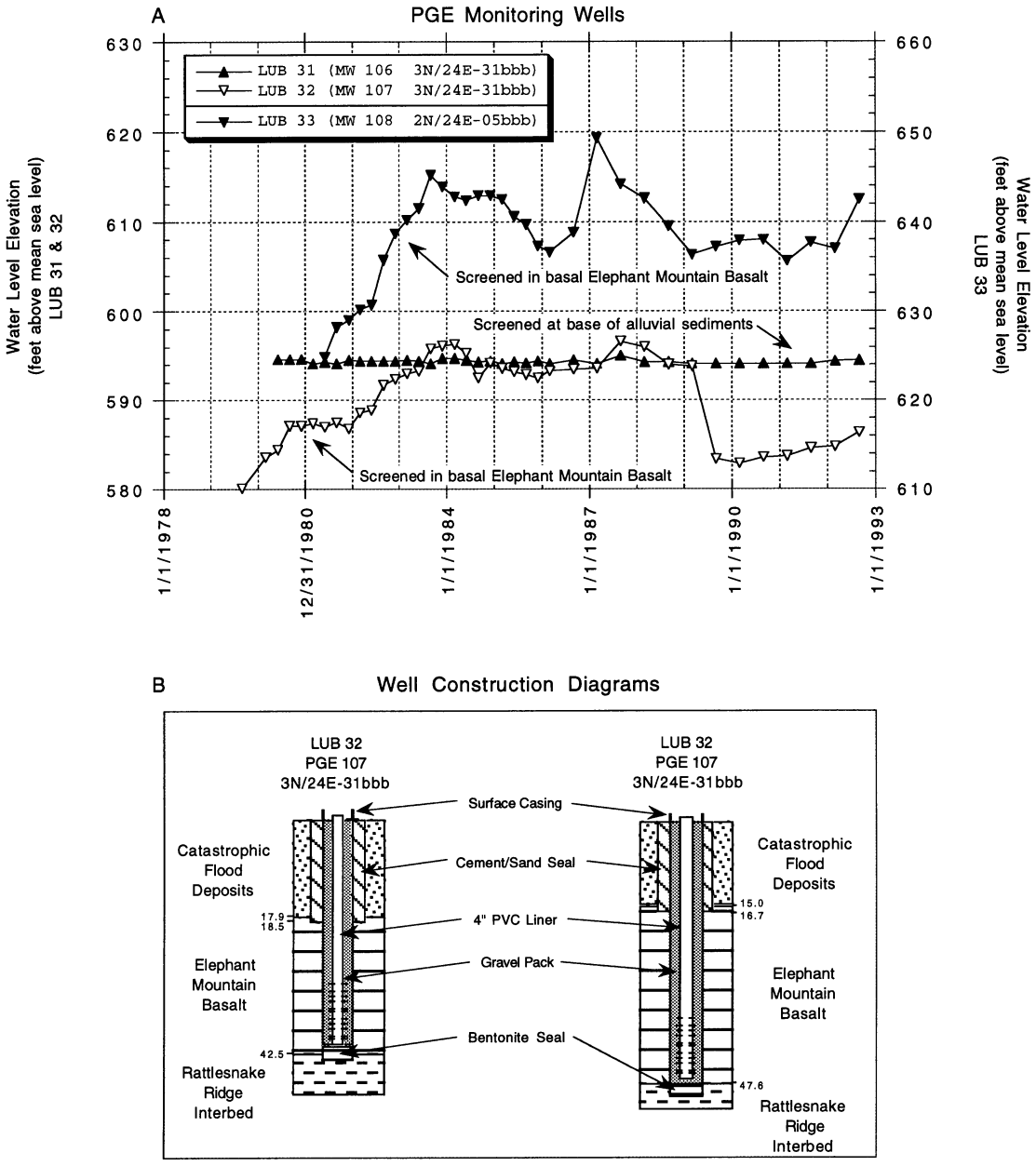


Figure 2.23 Water-level trends and construction details of monitoring wells northwest of Carty Reservoir. A, Hydrographs of alluvial and basalt wells; B, Well construction diagrams of basalt wells.

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 Velocity ft/day	Linear Velocity ft/year	Velocity 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.

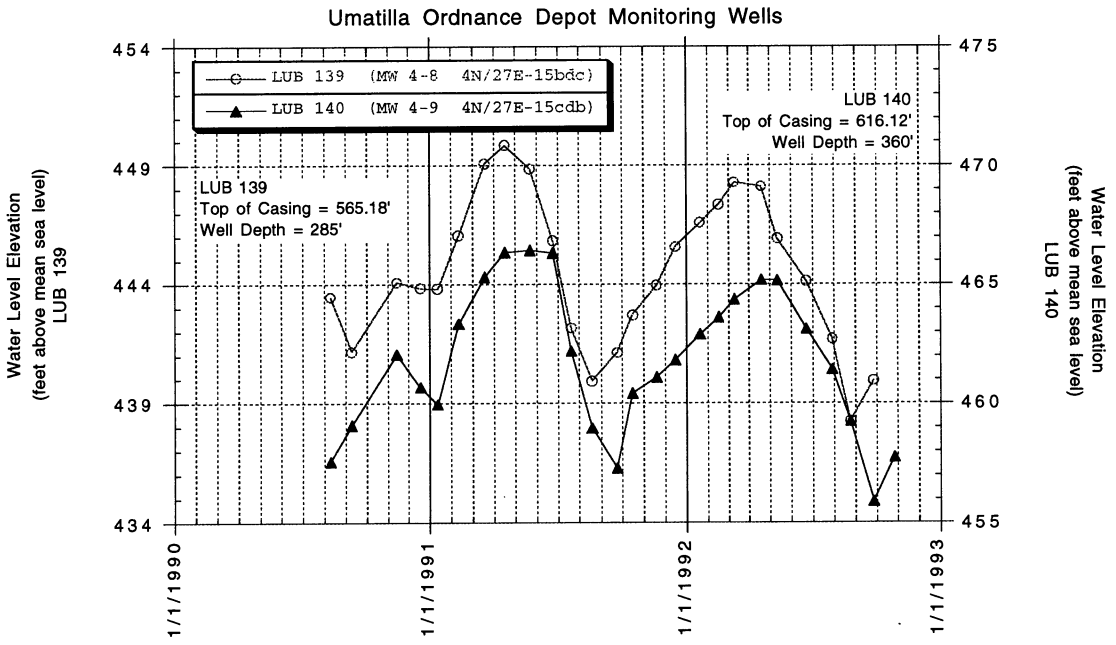


Figure 2.24 Hydrographs of monitoring wells completed in the basal Pomona aquifer on the Umatilla Ordnance Depot.

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.

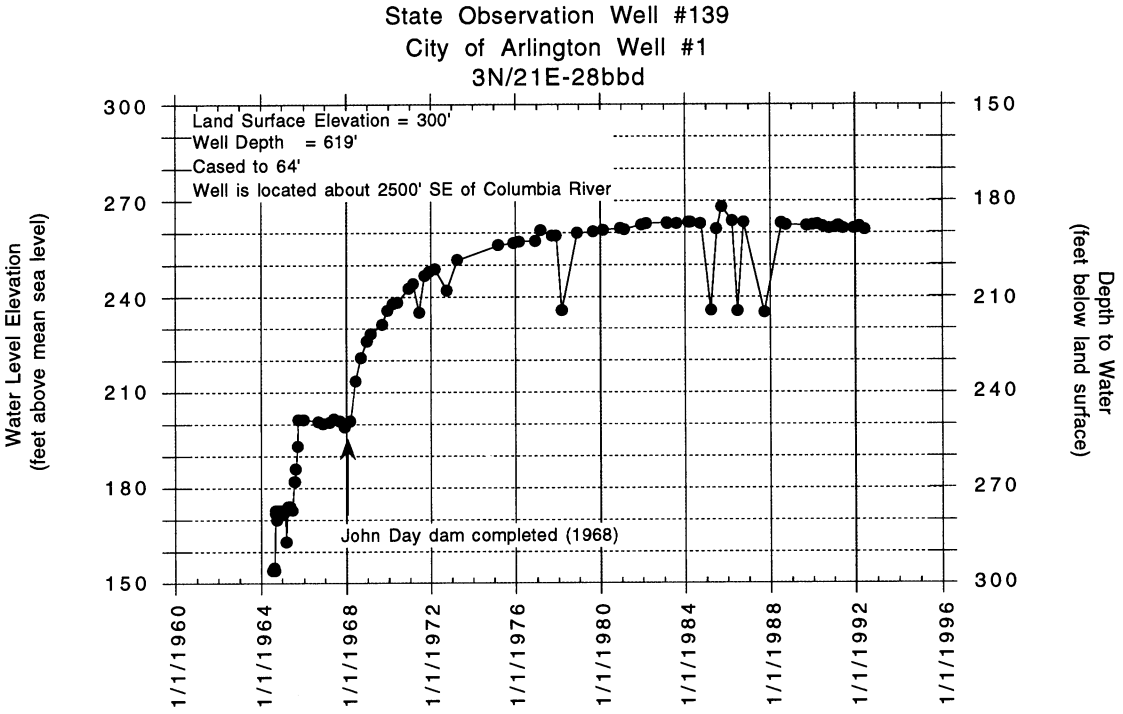


Figure 2.25 Hydrograph of the city of Arlington's municipal well #1 showing a rise in water level associated with the completion of the John Day dam

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.

Chapter 3

Land Use and Nitrogen Loading

in the
Lower Umatilla Basin Groundwater Management Area

Northern Morrow and Umatilla Counties
Oregon

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1995

Chapter 3: Land Use and Nitrogen Loading

Table of Contents

Abstract 1

Introduction 2
- Background 2
- Local Soils 2
- Loading Relationship to Groundwater Contamination 4

Local Land Uses and the Potential for Groundwater Contamination 6
- Irrigated Agriculture 6
  - Introduction 6
  - Irrigated Agriculture: A Groundwater Contamination Source 8
    - National Contamination 8
    - Regional Contamination 8
  - Irrigated Agriculture: Factors Affecting Nitrate Leaching 8
    - Investigation Concern about Pesticides 10
  - Irrigated Agriculture: Local History 10
    - Before 1945 10
    - 1945-1960s 12
    - 1960s-1970s 12
    - 1970s-1980s 12
    - 1990s 13
  - Irrigated Agriculture: Local Nitrogen Use and Potential Loading 14
- Food Processing 17
  - Introduction 17
  - Food Processing Wastewater: A Local Groundwater Contamination Source 17
  - Food Processing Wastewater: Management 18
  - Food Processing History 19
    - Before 1945 19
    - 1945-1960s 19
    - 1970s-1980s 20
    - 1990s 20
  - Food Processing Nitrogen Loading 20
- Livestock 22
  - Introduction 22
  - Livestock Waste: A Groundwater Contamination Source 22

Managing Livestock Waste . . . 23
Livestock History . . . 24
Before 1945 . . . 24
1945-1960s . . . 25
1960-1980s . . . 25
1990s . . . 25
Livestock Waste Nitrogen Loading . . . 26
Domestic Sewage . . . 27
Introduction . . . 27
Municipal Domestic Sewage: A Groundwater Contamination Source . . . 28
On-Site Domestic Sewage: A Groundwater Contamination Concern . . . 28
Municipal Domestic Sewage: Waste Management . . . 29
On-Site Domestic Sewage: Waste Management . . . 30
Domestic Sewage History . . . 30
Before 1970 . . . 30
1970s-1980s . . . 31
1990s . . . 32
Domestic Sewage Nitrogen Loading: Municipal . . . 33
Domestic Sewage Nitrogen Loading: On-Site . . . 33
Military Sites . . . 37
Introduction . . . 37
Military Waste: A Groundwater Contamination Source . . . 38
Managing Military Waste . . . 39
Military Site History . . . 39
1940s . . . 40
1950s-1960s . . . 40
1970s-1980s . . . 41
1990s . . . 41
Military Waste Nitrogen Loading . . . 42
Solid Waste Disposal . . . 43
Potential for Groundwater Contamination from Landfills . . . 43
Solid Waste History . . . 43
1950s-1980s . . . 44
1990s . . . 44
Potential Nitrogen Loading of Solid Waste . . . 45
Electricity Generation . . . 46
Electricity Generation History . . . 46
Before 1990s . . . 46
1990s and Future . . . 47
Potential Nitrogen Loading of Electrical Generation . . . 48
Union Pacific Railroad . . . 48
Union Pacific Railroad History . . . 48
Before 1970s . . . 48
1970s-1990s . . . 49
Potential Nitrogen Loading from Union Pacific Railroad . . . 49
Pendleton Grain Growers, Incorporated - Stanfield . . . 49

PGG History 50
PGG Potential Nitrogen Loading 50
Groundwater Recharge Projects 51
Concern for Groundwater Contamination from Recharge Projects 51
History 51
1970s-1990s 51
Future 52
Potential Nitrogen Loading from Groundwater Recharge 52
Miscellaneous Potential Sources 53
Reported Accidents/Spills 53
Hazardous Waste/Substance Handlers 53
Underground Storage Tanks 54
Natural Nitrogen Sources 54

Summary 55
Irrigated Agriculture 55
Food Processing 56
Livestock 57
Domestic Sewage 57
Military Sites 58
Solid Waste 59
Electricity Generating Facilities 60
Union Pacific Railroad 60
Pendleton Grain Growers, Inc. 60
Groundwater Recharge Projects 61
Miscellaneous Potential Sources 61
Reported Accidents and Spills 61
Hazardous Waste/Substance Handlers 61
Underground Storage Tanks 61
Natural Sources 61

Chapter 3: Land Use and Nitrogen Loading

Summary of Tables and Figures

Table 3.1 Assessed risk of nitrate-nitrogen leaching from Lower Umatilla Basin soils and contaminating groundwater given local soil characteristics. 4

Table 3.2 Practices and nitrogen related to basin land uses. 5

Table 3.3 Total irrigated agriculture acreage estimates for the Lower Umatilla Basin. 7

Table 3.4 Nitrate-nitrogen measured in the unsaturated zone beneath farmlands. . . . 9

Table 3.5 Chronological overview of the major agricultural events in the Lower Umatilla Basin. 11

Table 3.6 Amount of irrigation water used and fertilizer nitrogen applied to Lower Umatilla Basin irrigated agriculture in 1990: comparison between irrigation types. 14

Table 3.7 The average annual nitrogen budget for intensively managed Lower Umatilla Basin crops. 16

Table 3.8 Approximate food processing industry total land application area and total nitrogen loading in the Lower Umatilla Basin for selected periods. 21

Table 3.9 Nutrients in livestock manure at the time of land application. 23

Figure 3.1 Approximate Operational Period for Several Livestock Commodities in the Lower Umatilla Basin. 26

Table 3.10 Estimated nitrogen loading in the Lower Umatilla Basin by municipal sewage treatment facilities during 1992-1993. 34

Table 3.11 Estimated nitrogen loading in the Lower Umatilla Basin by selected large on-site sewage treatment systems. 35

Table 3.12 Estimated annual total nitrate-nitrogen loading from domestic septic systems in the Lower Umatilla Basin. 36

CHAPTER 3: LAND USE AND LOADING

Abstract

Lower Umatilla Basin groundwater is very vulnerable to contamination from many different land uses given the basin's soil conditions and hydrogeologic properties. The potential for a land use to contaminate groundwater with nitrate-nitrogen or another constituent relates to loading. Groundwater contamination can occur whenever water (or another liquid) and nitrate (or another contaminant) released exceeds or bypasses:

- removal by crops or other vegetation;
- removal by evaporation; and
- soil capacity to prevent deep percolation.

Nitrate-nitrogen contamination is the most widespread groundwater contamination problem in the basin, but it is not the only problem. This investigation focused on nitrate nitrogen. It explored how much nitrogen each land use releases to the environment, and how much may percolate to deep groundwater. Investigated activities include:

- irrigated agriculture,
- food processing,
- livestock,
- domestic sewage systems,
- military activities,
- solid waste disposal sites,
- electricity generation,
- groundwater recharge projects,
- underground storage tanks,
- hazardous waste handlers, and
- accidents.

Project review found the greatest potential for historic and/or current nitrate loading to groundwater related to irrigated agriculture, food processing, livestock operations, domestic sewage systems, and military activity. A much lower nitrate loading potential exists for the other activities.

Nearly all of the investigated activities could potentially contaminate groundwater with other constituents, in addition to nitrate. Many of the investigated activities are intermixed, occurring in some of the same locations. Future activities also present a concern. Any new contaminants loading by population growth, agriculture, or industrial activities could affect groundwater quality.

Introduction

Background

The land uses within the approximately 550-square-mile Lower Umatilla Basin Groundwater Management Area are best described as diverse, changing and growing.

Water availability, new technology and economic fluctuations have greatly influenced agricultural activities. Food processing and other industries have located and expanded in the area. Military activities, including munition storage, maintenance, destruction and target bombing practices, have occurred in large areas within the basin. Many hazardous and solid waste sites as well as environmental cleanup and accident sites are also located in the groundwater management area.

Population has grown, especially in the Hermiston and Boardman areas. As a result, private wells and septic systems service many residents who live outside city boundaries and their service areas.

All of these activities occurred in a basin where soil conditions and hydrogeologic conditions make groundwater very vulnerable to contamination.

Local Soils

Soil characteristics and chemical behavior in the environment are important influences to consider when assessing groundwater contamination risks. Appendix 3A presents a general discussion about the behavior of nitrogen in the environment (the nitrogen cycle) and soil influences upon nitrogen transport. Additional information about groundwater contamination risks related to Oregon soils and selected chemicals include Kerle and others (1994a, 1994b) and Huddleston (1994). Oregon State University Extension Service maintains the relevant information in soil sensitivity and pesticide properties databases (Vogue, 1994).

Soil surveys for Umatilla and Morrow Counties indicate that basin soils consist of well-drained, fine sandy, and sandy loams (USDA/SCS, 1976, 1988). The soils are low in clay and nutrients and contain little organic matter. Soil pH typically ranges from 6.5 to 7.8 in near surface soil and up to 9.0 in deeper soil. The soil permeability rates from moderate to high permeability, and the available water holding capacity ranges between approximately 0.7 to 3 inches of water per foot of soil (see Appendix 3A).

With sufficient moisture, nitrate-nitrogen leaching in Lower Umatilla Basin soils becomes a moderate to high risk for contaminating groundwater. Under dryland conditions however, the risk of leaching nitrate-nitrogen from basin soils and contaminating groundwater drops to low and very low.

This investigation assessed nitrate-nitrogen groundwater contamination risks of Lower Umatilla Basin soils by using the Oregon Water Quality Decision Aid publication (State University Extension, 1993). The assessment considered local soil characteristics, available moisture, and the depth of groundwater. Nitrate leaching from basin soils to contaminate groundwater rated primarily as a moderate to high risk with sufficient moisture, and a low to very low risk under dryland conditions (Table 3.1).

Table 3.1 Assessed risk of nitrate-nitrogen leaching from Lower Umatilla Basin soils and contaminating groundwater given local soil characteristics.

Soil	Leaching Potential		Groundwater Contamination Risk	
	Dryland	Irrigated	Dryland	Irrigated
Adkins WET	Very Low	High	Very Low	High
Koehler	Very Low	High	Low	High
Pedigo	Very Low	Moderate	Very Low	Moderate
Powder	Very Low	Moderate	Very Low	Moderate
Quincy	Very Low	High	Low	Very High
Quinton	Very Low	High	High to Very High	
Sagehill	Very Low	Low to Moderate	Low	Low to Moderate
Shano	Very Low	Low	Low	Low
Winchester	Very Low	High	Low	Very High

Extracted from Oregon Water Quality Decision Aid, H. Huddleston and others (1993) and used in Oregon HOME*A*SYST, Worksheet #10, Site Evaluation, Oregon State University Extension Service (1993).

Loading Relationship to Groundwater Contamination

The Lower Umatilla Basin's soil conditions and hydrogeological properties make local groundwater vulnerable to contamination from many different land uses. As land uses continue to expand and evolve, other contaminants may potentially leach through basin soils to contaminate groundwater.

This investigation focused on nitrate-nitrogen. Groundwater sampling confirmed that extensive basin areas have nitrate groundwater concentrations near or exceeding the U.S.E.P.A. drinking water standard of 10 mg/L (Plates 4.2 and 4.3).

The potential for a land use to contaminate groundwater with nitrate-nitrogen or other constituents relates to loading. Loading refers to the quantity of water and concentration of nitrate being released to the land.

Groundwater contamination can occur whenever water (or another liquid) and nitrate-nitrogen (or another contaminant) is released and exceeds or bypasses:

- removal by crops or other vegetation
- removal by evaporation
- soil capacity to prevent deep percolation

Good management practices can reduce or prevent the loss of nitrate or other contaminants to groundwater. This investigation reviewed the history of nitrogen released to the environment by different land uses in the basin and how much may percolate to deep groundwater. Table 3.2 provides a summary of local land use practices and nitrogen released.

Table 3.2 Practices and nitrogen related to basin land uses.

	Practices				**Nitrogen**
Activity or Land Use	*Land Application*	*Ponds or Lagoons*	*Solid Waste*	*Infiltration*	
Irrigated Agriculture	Yes				> 20.5 million lbs. applied to crops in 1990 (limited information)
Livestock	Yes	Yes	Yes		> 3.4 million lbs./yr produced in 1980s > 780,000 lbs. land applied some years (limited information)
Food Processing	Yes	Yes			More than 1 million lbs./yr produced since early 1980s
Sewage Treatment	Yes	Yes		Yes	> 140,000 lbs. municipal land applied 1993 9,100 lbs. municipal infiltration beds 1993 4,700 lbs./yr. large on-site system 113,000 lbs./yr. septic systems
Military		Yes	Yes		85 million gallons of explosive washout water to unlined ponds in 1950s-1960s, causing contamination (nitrogen content unknown)
Industrial	Yes	Yes	Yes		Little or none (limited information)
Landfills		Yes	Yes		Insufficient information, possible impact/loading from Depot landfill.
Underground Storage Tanks				Yes	Little or none
Accidents	Yes			Yes	Little or none

Local Land Uses and the Potential for Groundwater Contamination

Irrigated Agriculture

Introduction

Since the 1920s, irrigated agriculture has expanded and changed in the Lower Umatilla Basin. Total available irrigated agriculture acreages in the basin increased from approximately 85,500 acres (134 square miles) in 1965 to nearly 180,000 acres (281 square miles) by 1992 (Table 3.3). Low rainfall and low soil fertility have created the need to irrigate and fertilize most basin crops.

The combination of nutrients (nitrate, phosphorus, etc.) and water applied in irrigated agriculture creates the potential for those nutrients to leach to groundwater. Results from this investigation's evaluation of groundwater chemistry analyses links some of the basin's highest nitrate-nitrogen concentrations to irrigated agriculture.

Any contamination from the approximate 180,000 acres of crops grown in the basin is considered to come from a "nonpoint source." Since the impacts of irrigated agriculture to the environment are dispersed, they are subject to less regulation and monitoring than point sources which interact with the environment at readily identifiable locations. As a result, this investigation found little existing information about nitrogen and other chemical use and fate in the Lower Umatilla Basin related to irrigated agriculture.

Table 3.3 Total irrigated agriculture acreage estimates for the Lower Umatilla Basin.

Period	OWRD Primary Irrigation Water Rights[a] (total acres)	Adjusted OWRD Primary Irrigation Water Rights[b] (total acres)	LANDSAT Photo/GIS Derived (total acres)
1986 - 1992	260,255	233,695	179,880[d]
1976 - 1985	251,556	224,996	171,181[e]
1966 - 1975	200,178	195,058	141,243[f]
1956 - 1965	85,488	85,488[c]	85,488[c]

[a]: Values presented in this column are from the Oregon Water Resources Department Water Rights Database. The values are for primary irrigation water rights, and they reflect the total acreage at the end of each period. These values include acreages yet to be developed.

[b]: Values in this column were derived by using the values in the first column and subtracting undeveloped acreages readily observed on a LANDSAT photograph.

[c]: Undeveloped acreage was not easily identified on the LANDSAT photograph. So, no adjustment of total acres was made.

[d]: This value was derived with the aid of OSU Experiment Station and Morrow County ASCS staff. Irrigated areas by crop were outlined on a LANDSAT photo. The outline was transferred to a map. The map was reviewed and corrected. Then, the map was entered into an electronic Geographic Information System (GIS). The GIS provided the acreage for each crop category. These acreages were totalled yielding the number shown.

[e]: This number was derived by: (179,880) - (233,695 - 224,996) = 171,181 and assumed a constant percentage difference between rates in column 2.

[f]: This number was derived by: (171,181) - (224,996 - 195,058) = 141,243 and assumed a constant percentage difference between rates in column 2.

Irrigated Agriculture: A Groundwater Contamination Source

National Contamination

Groundwater contamination by agricultural chemicals from nonpoint agricultural sources in the United States has been documented. The literature includes Saffigna and Keeney (1977), Spalding and others (1978), Exner and Spalding (1979, 1990), Gormly and Spalding (1979), Hallberg and Hoyer (1982), Spalding and others (1982), Detroy and Kuzniar (1988), Detroy and others (1988), Detroy and others (1990), and the Malheur County Groundwater Management Committee (1991). Most of the groundwater contamination in these studies occurred in cultivated areas underlain by well-drained soils with groundwater five to 30 feet below ground surface (Spalding and Kitchen, 1988).

Regional Contamination

Irrigated agriculture was identified as the primary source of the contamination in Northern Malheur County, Oregon (Malheur County Groundwater Management Committee, 1991). Reconnaissance groundwater sampling in 1985 found nitrate+nitrite-nitrogen concentrations exceeding the 10 mg/L drinking water standard in 34 percent of 107 samples. The maximum concentration found was 49 mg/L. The pre-emergent herbicide, dacthal di-acid, was found in 67 percent of 81 samples analyzed. Subsequent sampling found similar results.

Spalding and others (1982) used nitrogen isotopes to identify sources of nitrate-nitrogen groundwater contamination for the Burbank-Wallula, Washington area, northeast of the Lower Umatilla Basin. They identified a variety of land uses as contributors to the groundwater contamination. However, nitrogen fertilizers and mineralized soil nitrogen from cultivated fields were identified as the dominant contamination source.

Irrigated Agriculture: Factors Affecting Nitrate Leaching

By the early 1980s, nitrate leaching was identified as a problem in most irrigated sandy soils by Lembke and Thorn (1980), Watts and Martin (1981), and others. Research about factors influencing nitrate leaching from irrigated crop soils includes Viets and Hageman (1971), Wendt (1976), McNeal (1976), Letey and others (1978, 1979), Hergert (1986), Spalding and Kitchen (1988), Kalkhoff and others (1992), and others.

Existing research indicates that the method, amount, and timing of irrigation affects nitrate-nitrogen leaching. Watts and Martin (1981) noted irrigation scheduling minimized deep percolation and nitrate-nitrogen leaching. They concluded that irrigation based upon soil moisture requirements or evapotranspiration was the most practical water management method for controlling nitrate-nitrogen leaching.

Research shows nitrogen fertilizer amounts applied to crops also affect nitrate-nitrogen leaching. Spalding and Kitchen (1988) found increased amounts of applied nitrogen fertilizer beyond 100 pounds per acre correlated to increased amounts of extractable nitrate-nitrogen in the unsaturated zone sampled 6 to 60 feet below irrigated farm land (Table 3.4). Hergert (1986) noted that matching nitrogen fertilizer rates more closely to crop yield requirements could substantially reduce nitrate-nitrogen leaching from sprinkler irrigated sandy soil to groundwater.

Table 3.4 Nitrate-nitrogen measured in the unsaturated zone beneath farmlands.

Nitrogen Applied to Farmland (lbs/acre/year)	Nitrate-Nitrogen Measurements for the Unsaturated Zone Between 6 and 60 Feet Beneath the Farmlands		Calculated Nitrate-Nitrogen Concentration in the Top 25 Feet of Groundwater If All the Nitrate-Flushes From the Unsaturated Zone and Mixes Completely With the Top 25 Feet of Groundwater (mg/L)
	Total Nitrate-Nitrogen (lbs/acre)	Average Nitrate-Nitrogen in the Pore Water (ug/L)	
0	131	4.04 $\pm$ 2.4	7.7
100	154	3.77 $\pm$ 0.9	8.9
200	270	7.30 $\pm$ 1.9	16.0
300	721	19.40 $\pm$ 13.0	42.0
400	1,260	35.10 $\pm$ 16.4	74.0
Source: Spalding and Kitchen (1988)			

A review of IRZ Consulting (1993), Hergert (1986), and Letey and others (1978, 1979) indicates both nitrogen application and irrigation need proper management to prevent nitrate-nitrogen leaching below the crop root zone. For example, IRZ Consulting (1993) observed no significant leaching of nitrate below the root zone where good irrigation and soil fertility management was practiced in the Lower Umatilla Basin. Letey and others (1978, 1979) found a weakened correlation between nitrate leached from commercial farm soils and fertilizer applied when fertilizer and water application were considered separately.

Precipitation also contributes to residual nitrate-nitrogen leaching from crop soils during the non-growing season (Hergert, 1986, Detroy and others, 1988, 1990).

Investigation Concern about Pesticides

Although this investigation focuses on nitrate-nitrogen contamination, pesticides are also a concern. Some pesticides have been detected in groundwater from a few basin locations (Appendix 4G). Dacthal was detected recently. It may become a greater problem. Dacthal di-acid was found in 67 percent of 81 samples analyzed in northern Malheur County, Oregon in a study conducted in the late 1980s.

Irrigated Agriculture: Local History

The following discussion is primarily a summary of personal communications with A. Youse, R. Kopecz, L. Fitch, B. Warkenton, F.V. Pumphrey, and D. Wysocki as well as information found in Pumphrey and others (1991) and IRZ Consulting (1993). Table 3.5 provides a chronological overview.

Before 1945

Early Lower Umatilla Basin settlers raised livestock and produced limited crops. Local farmers organized ditch companies and irrigation districts. Shortly after 1900, the West Extension, Hermiston, Stanfield, and Westland districts existed, and the U.S. Bureau of Reclamation began constructing the Umatilla Project. Many dryland acres were converted to irrigated crops after water became available. Flood and furrow irrigation were the standard methods used during this period. By the 1920s, available Umatilla River water for summer irrigation was fully appropriated. Livestock manure was used as a soil amendment and nutrient source for crops (Kopecz, 1994).

Table 3.5 Chronological overview of the major agricultural events in the Lower Umatilla Basin.

Period	Irrigation	Agricultural Production	Location	Water
1910-1919	Dry-land agriculture. Early irrigation methods (no land leveling, flood), farms next to Umatilla river	Small acreage farms until wheat prices stimulate cultivation of sub-marginal lands. Producers grow mostly alfalfa, grains, vegetables, fruits. Dairy and sheep industry begins (1915's) with manure as fertilizer.	NW Umatilla/ NE Morrow Counties	
1920-1939	Dry and irrigated agriculture. More demand for irrigation technology and water supplies. Some well drilling for irrigation uses occurred. The Umatilla River fully appropriated.	Large areas under wheat production. Alfalfa continues as the major crop, with water shortages limiting to two or three cuttings. Cuttings increased when additional water was obtained (from McKay creek). Turkey and chicken became important commodities.	Northern Morrow/ Western Umatilla Counties. With water, Umatilla, Stanfield, Echo and Boardman flourish.	With the Reclamation Act of 1905, BLM forms the Umatilla Project with water districts set for the West Extension, Hermiston, Stanfield and Westland. Small farms in LUB consolidated. Many farmstead wells are abandoned or used for stock only, reverting to grazing (Post-world war I).
1940-1959	Groundwater as a source for irrigation began. 1930's Drought: Incentives for well-drilling.	LUB agriculture diversifies to include large poultry farms and many crops that require irrigation. Sprinkler irrigation begins. Irrigated alfalfa, wheat and field corn were grown in rotation on small acreage (80 A). Other crops included peas, beans, carrots and fruits. Intensive commercial fertilizer use begins soon after World War II. Fertilizer industry expands. Dairy industry is strong		
1960-1979	Groundwater uses include industrial, domestic and municipal. Potato processing plants begin. Columbia river diversion for irrigation occurs (John Day and McNary's Dams construction began).	Early center pivots first in late 1960's. Potato as a high value crop is welcome in LUB. Potato production becomes significant. Large scale watermelon production begins. Fruit trees and other cash crops are grown. Nitrogen fertilizer on the rise. Dairy industry declines.		High groundwater withdrawals prompted the declaration of critical groundwater areas: Ordnance (gravel and basalt), Butter Creek and Stage Gulch.
1980-1989	Efficient water-management, irrigation scheduling is introduced.	Nitrogen fertilization increases more than irrigation in the past 40 years as producers use available technology. Potato production increases to meet high demand. The area is a major wheat producer region in the West US. Center pivot irrigation use at its peak.	Stanfield becomes a center of potato production.	Nitrates in domestic wells first detected in 1984 (Oregon Health Division sampling).
1990s	Center pivot technology continues to be refined. Water shortage issues affecting agriculture arise.	BMP's practices are to be adopted to improve and protect the groundwater quality of LUB. Center pivot technology continues to be refined. Potato continues to be a high value crop.	Center pivots expand throughout LUB	DEQ declared LUB a Groundwater Management Area based on nitrate levels in groundwater. The LUB GWMA local citizen committee looks at potential contributors: N-fertilizer, food processing, animal and industrial waste, domestic septic systems

Source: Personal communication (A. Youse, ODA; R. Kopecz, L. Fitch, B. Warkenton, F.V. Pumphrey, D. Wysocki, OSU; J. Anderson, Morrow Co. N.R.C.S.); IRZ Consulting, 1993; Pumphrey and others, 1991

Lower Umatilla Basin groundwater development began as a limited source of irrigation water during the 1930s and 1940s. Drought conditions during the 1930s prompted U.S. Government incentives for well drilling. Water from McKay Creek was also allocated for irrigation during this critical water period. Despite these water developments, drought and full appropriation of Umatilla River water limited agricultural land development during this time.

1945-1960s

After World War II, intensive commercial fertilizer use and sprinkler irrigation began. Small acreage farmers began rotating crops of alfalfa, wheat and field corn. Other crops included peas, beans, carrots and fruits.

1960s-1970s

The basin experienced an irrigation expansion "boom" during the 1960s and 1970s. The use of nitrogen fertilizer become more intensified during the irrigation expansion. Along with more irrigation, the use of water become more efficient. Wheeled and center pivot irrigation systems were introduced in the basin. Columbia River water became available via pumping and lift stations. Groundwater (including basalt aquifers) was developed for irrigation. Corporate farming began and dryland farms were converted to irrigated wheat and row crops.

Economics and limited water--both from groundwater and surface water--eventually slowed the boom. In some areas, groundwater use exceeded groundwater recharge, prompting the Oregon Water Resources Department to restrict or reduce groundwater use by declaring Critical Groundwater Areas within the basin.

1970s-1980s

The basin continued as a major regional wheat producer. The introduction of center pivot technology coincided with a new demand for potatoes. Intensive potato production in the Lower Umatilla basin increased, using more nitrogen fertilizer and pesticide per acre and in total quantity than other basin crops. Irrigation scheduling for efficient water management was introduced to the basin during this period.

1990s

Total irrigated crop acreage in the Lower Umatilla Basin was approximately 180,000 acres (281 square miles) by 1992 (Table 3.3, Plate 3.1). Of this total acreage, about half produced irrigated wheat and potatoes. Center pivots--which were also used for fertilizer applications--irrigated nearly 90 percent of the total irrigated area (IRZ Consulting, 1993). Many of the farms using center pivots employed some form of irrigation scheduling service (IRZ Consulting, 1993).

About 11 percent (20,000 acres) of the total irrigated area was gravity irrigated. Soils--sands and coarse silt loams--at these sites permit rapid infiltration and make efficient water distribution in the fields difficult. A summary of water and fertilizer use by crop and by irrigation method is presented in Table 3.6.

Crop rotation--growing a series of different crops in a sequence to improve crop and soil quality--has been an on-going practice in the Lower Umatilla Basin. Rotated crops include alfalfa, field corn, potatoes and wheat in a variety of sequence combinations. One rotation may take eight to twelve years.

Irrigated agriculture in the Lower Umatilla Basin continues to change. At least two large farms have been purchased to grow poplar trees for paper production. Drip irrigation has begun at some of these farms.

Table 3.6 Amount of irrigation water used and fertilizer nitrogen applied to Lower Umatilla Basin irrigated agriculture in 1990: comparison between irrigation types.

Crop	System of Irrigation	Amount of Water Used (Range: in/yr).	Evapotranspiration for 9 out of 10 years (inches)	Nitrogen Fertilizer Used (Range: lbs/Ac/yr)[a]
Alfalfa Hay	Sprinkler, Center Pivot, Flood	22-48	34	24
Field Corn	Sprinkler, Center Pivot, Furrow	20-36	29	225-230 (190 = average)
Potatoes (Harvested in September)	Center Pivot, Sprinklers	22-42	31	250-410 (350 = average)
Pasture	Sprinkler, Flood	20-30	41	0-225 (60 = average)
Watermelon	Drip/Wheel Roll, Furrow	3-14 drip 20 other		96-180
Winter Wheat	Center Pivot, Wheel Roll	18-30	25	130-275 (194 = average)

a: Source is Pumphrey and others, 1991.

Irrigated Agriculture: Local Nitrogen Use and Potential Loading

Determining the nitrogen use for the approximately 180,000 acres of basin cropland is difficult. Specific crops are grown on specific acreages on a rotational basis, with each type of crop requiring various amounts of nitrogen. Basin irrigated agriculture does not report crop type, acreage or nitrogen use unlike some other basin land uses.

This investigation has developed a likely range of nitrogen applied to irrigated agriculture, beginning with a very conservative estimate for 1975. That calculated estimate assumes nitrogen applied to irrigated basin crops has annually exceeded 7 million pounds total since 1975 (Appendix 3B). This estimate multiplies 1975 acreage with a nitrogen application rate of 50 pounds per acre. This application rate is very low when compared to application rates in Table 3.6. This estimate appears even more conservative when compared to the basin project analysis of Pumphrey and others (1991). This analysis indicates nitrogen applied to basin irrigated crops in 1990 as exceeding 20.5 million pounds on nearly 132,500 acres.

Nitrogen may remain in the soil after the growing season (see Table 3.7). That nitrogen could leach beyond the crop root zone. A review of the IRZ Consulting (1993) and del Nero (1994) reports indicate nitrogen does penetrate beyond the root zone at some irrigated crop fields within the Lower Umatilla Basin. However, the IRZ Consulting (1993) investigation also indicates nitrogen leaching beyond the crop root zone in the Lower Umatilla Basin can be prevented when water and nitrogen applications are timed and limited to actual crop need.

Ritter (1989) and Vitosh (1991) indicate nitrogen loss to deep percolation at agricultural fields in the U.S. can range from 1 to more than 50 percent depending upon the amount of nitrogen applied, the time of application, soil texture, and the amount and timing of water applied.

Although nitrogen loss to deep percolation in unknown in the basin, a conservative figure applied to the estimated ranges of nitrogen application provides an example. Figuring a five percent nitrogen loss of the 7 million pounds nitrogen applied since 1975, deep percolation from basin fields may have exceeded 350,000 pounds of nitrogen annually. Using the same five percent loss for Pumphrey's estimated 1990 application of more than 20.5 million pounds, at least one million pounds of nitrogen may have been lost to deep percolation.

Table 3.7 The average annual nitrogen budget for intensively managed Lower Umatilla Basin crops.

	ALFALFA (HAY)	FIELD CORN, GRAIN	PASTURE	POTATO-TUBERS	WATER-MELONS	WINTER WHEAT (GRAIN)
YIELD	6.5 T	185 Bu	3 T	480 cwt	16 T	123 Bu
N REQUIRED, LB/A	360	190	190	295		190
N APPLIED/PRESENT:						
N IN CROP RESIDUE, LB/A	40	60	30	90		60
N APPLIED, LBS/A	25	280	110	350	140	195
N RELEASED FROM SOIL, LB/A	300	60	40	80	80	75
N AVAILABLE, LB/A	365	400	180	520	220	330
N OUTPUT:						
DE-NITRIFICATION, LB/A	0	25	0	40	10	10
RESIDUE, LB/A	0	50	0	10		50
N REMOVED, LBS/A	320	130	160	205	130	130
N REMAINING IN PROFILE, LB/A	45	195	20	265	80	140

From "Lower Umatilla Basin Water Management Area Crop Production Practices and Groundwater Quality, May 1991; and individual contact with L. Fitch, OSU Hermiston Ag. Research and Extension Ctr, and V. Pumphrey, Retired Professor, OSU.

Food Processing

Introduction

The food processing industry began small in the Lower Umatilla Basin and expanded quickly in response to the economic demand for processed foods, particularly potato products.

The industry produces large volumes of nutrient and salt-rich wastewater daily. Facilities have spent time and money to improve their wastewater management.

Wastewater has been land applied to crops or pasture and stored in unlined or lined ponds. Sometimes fresh water is used to supplement wastewater. Some solid food waste has been fed to livestock.

Food Processing Wastewater: A Local Groundwater Contamination Source and Concern

Food processing wastewater management through the 1980s has caused some local nitrate-nitrogen groundwater contamination and concern. For example, nitrate-nitrogen contamination of groundwater related to J.R. Simplot Co. sites was reported in 1978. A subsequent investigation in 1984 and 1985 found 30 percent of the nitrogen land applied via wastewater leached beyond the root zone at monitored fields (Sweet, Edwards and Associates, Inc., 1987). Barlow and Dillenberger (1990) included wastewater land application as a possible groundwater contamination source at a Port of Morrow site. In 1988, DEQ staff concluded that nutrient overloading from wastewater land application by the former Columbia Sun, Inc. threatened groundwater quality (DEQ Water Quality File 18702).

When some food processors upgraded facilities to improve efficiency, the amounts of wastewater or nutrients increased. An example can be found in A.E. Staley Manufacturing Co., whose 1990 upgrade increased process wastewater by 40 percent. A.E. Staley increased their total land application area and arranged for consultants to assess leaching losses in the land application soils.

Food Processing Wastewater: Management

Improving food processing wastewater management has followed a pattern of trial and error.

Wastewater management during the 1970s and 1980s included using unlined storage ponds, exceeding crop nitrogen needs, and not considering soil moisture or the growing season (DEQ Water Quality Files 4870, 70590, 81590, 18702). Additionally, some facility upgrades or expansions increased wastewater amounts and/or nitrogen concentrations beyond what existing land application sites could accommodate (DEQ Water Quality Files 18702 and 81590, Barlow and Scott, 1991, Barlow, Scott and Urban, 1992).

Eventually, groundwater contamination became a growing concern. Facilities gradually improved their wastewater management, and DEQ successively revised facility water quality permits with compliance schedules for reducing nutrient loading. Examples are documented in DEQ Water Quality Files 9584, 18702, 48780, 70590, 81590, Barlow (1990), Barlow and Dillenberger (1990), Barlow, Scott and Urban (1992), Barlow and Tipton (1993), Columbia Sun (1992), CH2MHill (1990, 1991a, 1991b, 1992), Port of Morrow (1991), Portwood and Rankin (1993), Ruby (1993), Ruby and Barlow (1991), Ruby, Scott, and Urban (1992), and Urban and Scott (1991).

The most common approach to improving wastewater management involved successive expansion of land application acreage. Nearly every food processing facility has increased land application acreage, with the large operations expanding from a few hundred acres to more than 2000 acres over the past decade (Appendix 3C, Plate 3.2). The acreage needed is figured according to the agronomic rates for both water and nitrogen of the crop being irrigated by the wastewater.

Other wastewater management improvements include using lined ponds, developing or increasing winter wastewater storage, and monitoring wastewater, freshwater, chemicals, crops, soils, and groundwater. Examples are found in Barlow (1990), Barlow and Dillenberger (1990), Barlow and Tipton (1993), CH2mHill (1991b), Columbia Sun (1992), Port of Morrow (1991), Portwood and Rankin (1993), Ruby (1993), Ruby and Barlow (1991), Urban and Scott (1991), and DEQ Water Quality File 70590.

Efforts to improve wastewater management have been executed using information provided by consultants. For example, early on it was believed by the industry and their consultants that year-round land application would not affect groundwater quality. Even recently, various industry reports have concluded that the season of applying process wastewater is relatively unimportant to nitrogen loading, that travel time to groundwater is long (11 to more than 30 years), and that the basalt aquifer is not hydraulically connected to the overlying alluvial aquifer (Barlow, 1990, 1991, Barlow and Dillenberger, 1990, Barlow and Scott, 1991a, 1991b, Ruby and Barlow, 1991, Barlow, Scott and Urban, 1992, Barlow, Urban, and Scott, 1992, Ruby, Scott and Urban, 1992). These conclusions are not born out by this investigation or by the presence of high nitrate values beneath some of the land application sites. This investigation found travel times from the land surface to groundwater to be 1-18 months. It also concluded that there is a hydraulic connection between the alluvial and basalt groundwater systems.

Food Processing History

Before 1945

Turkey slaughter houses operated in Hermiston from the 1920s through the 1950s and in Stanfield during the 1940s (Kopecz, 1994). A Hermiston cannery cooperative served local farming families by canning fruits, vegetables and fish from the 1920s through the 1950s. Any wastewater was discharged to city sewers (Kopecz, 1994).

1945-1960s

Very little vegetable food processing occurred in the basin before 1970 (Fitch, 1994, Kopecz, 1994). Potato fresh pack sheds such as Walchli Potato and Bud Rich operated in the Hermiston area during the 1960s. They produced little or no wastewater (Fitch, 1994). Kosmos Potato, the basin's first specialty potato processor, operated during the 1960s and 1970s (Fitch, 1994).

Meat slaughter houses operated north and northeast of Hermiston and in Stanfield (Fitch, 1994).

1970s-1980s

Large-scale potato processing for fast food and other uses settled into the region east of Boardman and south of Hermiston during the 1970s. The potato processing plants expanded to dominate all local food processing activities during the 1980s. Many facilities generate large volumes of nutrient and/or salt rich wastewater daily.

Potato processing wastewater some caused local nitrate-nitrogen groundwater contamination during this period (Sweet, Edwards and Associates, Inc., 1987). Wastewater management included land application at limited acreages, during all seasons, nutrient amounts exceeding crop needs, and storage in unlined ponds as noted earlier.

1990s

Today, the facilities are expanding their land application areas, building or expanding lined wastewater storage, scheduling wastewater application to meet crop nutrient and water needs, and increasing monitoring of crops, nutrients, water, soils, and groundwater as noted earlier.

Food Processing Nitrogen Loading

Estimated land application area and nitrogen loading for food processing facilities for selected periods are presented in Table 3.8, with individual facilities presented in Appendix 3C. The total wastewater land application acreage has expanded from nearly 825 acres in 1977, to nearly 7,500 by 1992. Nitrogen land application rates generally decreased after 1991. The rates ranged from 14 to more than 2,500 pounds per acre per year from the 1970s through 1991. Since 1991, the application rates have ranged from 3 to nearly 680 pounds per acre per year. The decrease coincided with application area expansion.

This investigation did not determine nitrogen lost to deep percolation. However, recent consultant estimates of nitrate-nitrogen escaping annually to deep percolation range from 10 to 27 pounds per acre (Barlow, 1990, Barlow and Scott, 1991a, 1991b, Barlow, Urban, and Scott, 1992). A mid-1980s Cascade Earth Science investigation found 30 percent of the nitrogen land applied via wastewater leached beyond the root zone at the fields monitored (Sweet, Edward and Associates, Inc., 1987).

The process wastewater also contains salt which crops do not use. Salt application rates currently range in excess of 3,000 to nearly 30,000 pounds per acre per year at some sites (Appendix 3C).

Future salt and nitrogen loading could be affected by several proposed power co-generation facilities that would coordinate with food processors to blend cooling tower water with food processing wastewater (Barlow and Tipton, 1993, IDA-West Energy Company, 1993). With any changes to the chemistry of the wastewater, food processors will need to adjust their wastewater management techniques accordingly.

Table 3.8 Approximate food processing industry total land application area and total nitrogen loading in the Lower Umatilla Basin for selected periods.

Period	Total Acreage (acres)	Total Nitrogen or TKN Loaded[a] (total pounds/yr)	Average Nitrogen or TKN Loading Rate (pounds/acre-yr)
1977 - 1980	824	-	-
1981 - 1984	2,097	>1,074,361[b]	>512[b]
1985 - 1989	2,805	2,506,446	894
1991 - 1992	7,492	1,591,898	212

Values in this table were derived from Table 3.9.

[a] Values in this column should be considered approximate values only

[b] These values are missing nitrogen loading by Port of Morrow.

Livestock

Introduction

Livestock, both historically and currently, are a potential source of groundwater contamination. Various livestock operations have been present in the Lower Umatilla Basin since approximately 1900 (Kopecz, 1994, Reed-no date). Livestock production has contributed to the local economy and provided valuable crop nutrients.

Livestock Waste: A Groundwater Contamination Source

Groundwater contamination by livestock waste has been documented in the U.S. (Stewart and others, 1967; Spalding and Fulton, 1988; Spalding and others, 1982.)

Livestock waste contains valuable nutrients. The nutrient content and other waste characteristics depend upon the animal species (Table 3.9). Nitrogen is the primary livestock waste component that contaminates groundwater (Goldberg, 1989). However, elevated chloride concentrations often accompanies that contamination (Spalding and Fulton, 1988). Phosphorous and potassium are often retained in the soil layer or other unsaturated material above groundwater (Goldberg, 1989).

How livestock waste contaminates groundwater depends on the management of waste stockpiles, waste ponds, and/or land application sites. At least one confined animal feeding operation in the basin has occasionally had problems with managing animal waste (DEQ Water Quality File 81591, J-U-B Engineers, Inc., 1987, 1989). Proper waste management can prevent most problems. Leakage from self-sealing lagoons can be expected, given basin soils. High nitrate-nitrogen concentrations detected around one self-sealing lagoon indicates seepage from local unlined lagoons is occurring (see Chapter 4). Additionally, high nitrate concentrations and some organic nitrogen detected near other livestock facilities, as well as some nitrogen isotopic analyses, indicate livestock operations have contributed to the basin's groundwater contamination (see Chapter 4).

Table 3.9 Nutrients in livestock manure at the time of land application.

Specie	Dry Matter	Ammonium-Nitrogen	Total Nitrogen	P_2O_5	K_2O
	percent	---------- Pounds per Ton Manure----------			
Swine	18	6	10	9	8
Beef (concrete lot)	52	7	21	14	23
Beef (dirt lot)	15	4	11	7	10
Dairy	18	4	9	4	10
Sheep	28	5	18	11	26
Poultry	45	26	33	48	34
Turkey	22	17	27	20	17
Horse	46	4	14	4	14

Source: Livestock manure management for efficient crop production and water quality preservation, Publication WQ 12, 1992; Michigan State University, Cooperative Extension Service.

Managing Livestock Waste

Animals confined to feedlots and other small areas produce waste that is often collected, stored, and land applied to crops or pasture. This investigation found limited information about annual waste management for basin facilities.

Generalized Lower Umatilla Basin confined animal waste management includes the following. Waste is drained or washed down out of the animal holding area or pens or it is excavated after drying. Liquid waste may contain manure, stormwater runoff, animal feed and water. Sludge is separated from the wastewater at some facilities. Sludge and wastewater are temporarily stored at stockpiles and self-sealing evaporative ponds or lagoons until removed, sold, or land applied to crops and pasture. The ponds and lagoons are cleaned seasonally (J-U-B Engineers, 1987, 1989, DEQ Water Quality File 81591, ODA CAFO General Permit File Facility ID Numbers 12903, 103222, 36630).

Some waste management problems have been observed at two large cattle feedlots. Staff involved in this investigation observed several feet of manure accumulated on bare ground in animal pens adjacent to a deep unlined Feedville Road ditch nearly full with animal waste runoff at C & B Livestock, Inc. C & B is a feedlot with a cattle population fluctuating between 12,000 and 25,000 head.

J.R. Simplot Co., a feedlot designed for 32,000 cattle, but operating with 20,000 head average, stockpiled manure on bare ground and used manure to fill low lying areas when crop land became unavailable for land application of waste from 1983 to 1987 and possibly after 1989 (J-U-B Engineers, Inc., 1987, 1989, DEQ Water Quality File 81591). Additionally, J.R. Simplot's groundwater monitoring indicates that seepage from self-sealing, evaporative, unlined lagoons is responsible for elevated nitrate-nitrogen concentrations in local groundwater (DEQ Water Quality File 81591, Chapter 4).

Livestock History

A summary of the basin's livestock history is presented in Figure 3.1. The location of current and historic livestock operations are shown on Plate 3.3. The locations were obtained from DEQ water quality permit files and field visits to sites identified by OSU Extension Service staff, OSU Experiment Station staff, and local residents. Many livestock facilities may be missing from Plate 3.3 due to the difficulty of obtaining a complete list of historic and active facilities.

Before 1945

Livestock operations have been present in the Lower Umatilla Basin since approximately 1900 (Kopecz, 1994). Dairies began operating in the basin around 1915 and grew into an important industry by World War II (Kopecz, 1994). Turkey and chicken operations became established in the Lower Umatilla Basin during the 1920s (Pumphrey, 1994). Sheep and hogs also were introduced early to the area.

Livestock manure has been valued and used in the Lower Umatilla Basin since the early settlements. Very little, if any, commercial fertilizer was applied to crops from 1910 to 1930 (Kopecz, 1994). Instead, manure additions to the soil provided necessary crop nutrients and improved the soil tilth, water holding capacity, and resistance to wind erosion.

1945-1960s

Beef cattle operations in the Lower Umatilla Basin grew in importance after the 1950s (Fitch, 1994). Many dairy operations closed or consolidated into beef operations when Oregon required sanitation improvements (Kopecz, 1994). Manure use for crops declined after World War II when the local dairy industry declined and produced less manure.

The rise and decline of hog operations in the Lower Umatilla Basin nearly parallels the history of Lower Umatilla Basin dairies. Canadian competition and other economic factors caused hog operations in the basin to decline (Kopecz, 1994, Pumphrey, 1994).

From 1945 through the 1960s, several large turkey facilities operated in the basin. Two facilities that remained active until the late 1960s operated with 45,000 and 90,000 turkeys, respectively (Kopecz, 1994, Fitch, 1994). Then, turkey operations in the basin declined due to economic conditions (Kopecz, 1994).

1960-1980s

Beef cattle remained active in the basin in the 1960s and 1970s. Permits for handling livestock waste were issued to four confined animal operations in the 1980s including two cattle feedlots, a dairy, and a hog facility (DEQ Water Quality File 81591, ODA CAFO General Permit File Facility ID Numbers 12903, 103222, 36630). Two fish hatcheries operated by Oregon Department of Fish and Wildlife received waste discharge permits from DEQ in the 1980s (DEQ Water Quality Files 64478, 107454).

1990s

Some sheep ranches and a few dairies remain in operation within the basin and a number of beef facilities currently operate across the Lower Umatilla Basin (Plate 3.3). The local cattle beef industry sustains continued manure use in the Lower Umatilla Basin. Of the facilities permitted in the 1980s, the hog facility ceased operation and one large cattle feedlot suspended operation for several years beginning mid-1991 (DEQ Water Quality File 81591, J-U-B Engineers, Inc., 1994).

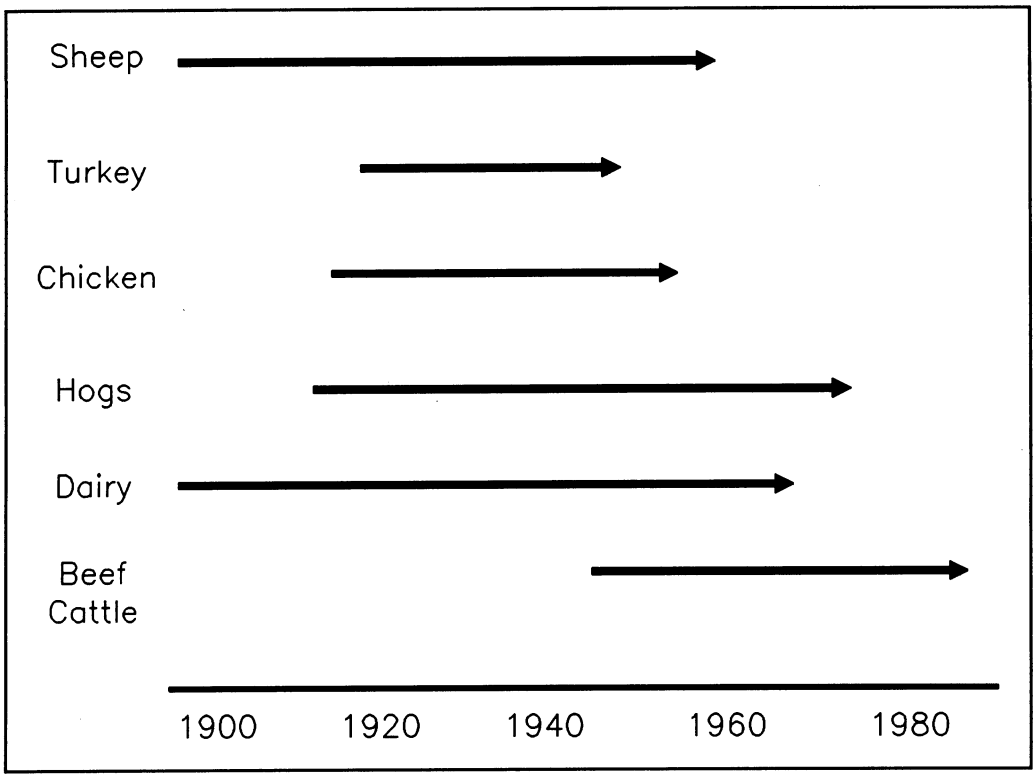


Figure 3.1 Approximate Operational Period for Several Livestock Commodities in the Lower Umatilla Basin.
(Source: Fitch, 1994, Pumphrey, 1994, and Kopecz, 1994).

Livestock Waste Nitrogen Loading

Information necessary to calculate basin nitrogen loading from livestock waste is very limited. Some 1980s information exists for two large beef cattle operations (averaging a total of 38,500 head), one large hog operation (averaging 13,500 head) and one dairy (averaging 200 head)(see Appendix 3D). Waste management at the facilities included waste removal from confined animal areas, waste storage in unlined ponds or stockpiles, and land application. The amount of waste stockpiled, stored in ponds and land applied varied by year.

Project calculations summarized in Appendix 3D indicate that basin livestock probably produced more than 3.4 million pounds of total nitrogen per year during the 1980s. However, nitrogen loss during storage possibly decreased the total nitrogen available for land application to about 780,000 pounds per year.

The total animal waste application acreage varied during the 1980s, while the amount of waste and total nitrogen remained relatively constant. The total acreage varied between 1,350 acres some years and more than 14,350 acres other years (Appendix 3D). The actual acreage utilized each year was not obtained.

Actual nitrogen load application rates were not determined due to insufficient information. However, limited data for three facilities indicates annual nitrogen application from livestock waste during the 1980s may have exceeded 15.7 to 78.2 pounds per acre. Consultants for one of these facilities recommended applying 300 to 450 pounds per acre (J-U-B Engineers, Inc., 1987, 1989). That facility occasionally stockpiled waste at a 10-acre site during years when no land application acreage was available. Nitrogen annually stockpiled possibly exceeded 35,000 pounds per acre.

Nitrogen leaching to deep percolation from land application, pond, stockpile and animal yard sites was not determined due to insufficient information.

Domestic Sewage

Introduction

Domestic sewage facilities can be separated into one of three types: municipal, large on-site, or individual on-site systems. Municipal sewage treatment systems serve cities with higher population densities. Large on-site systems serve small communities or large facilities while individual on-site systems generally serve single rural residences outside existing sewage treatment system connections.

Domestic sewage wastewater and sludge management at these facilities can include treatment, discharge to surface water, storage in ponds, land application, burial, or subsurface discharge through infiltration beds, sandfilters, drainfields or disposal wells.

All domestic sewage is regulated through a combination of local, state and federal laws which have been administered by the State Sanitary Authority until 1969, DEQ since 1969 and county agencies under contract to DEQ.

Municipal Domestic Sewage: A Groundwater Contamination Source

Infiltration to groundwater by some basin municipal sewage treatment facilities has been a concern. The Irrigon and Echo facilities have documented examples of infiltration to groundwater.

Irrigon uses a two-acre, 10-bed rapid infiltration basin system to treat and discharge the community's domestic wastewater. Nitrogen concentrations have been reported as high as 52 mg/L in the percolate below the infiltration beds (SCM Consultants, Inc., 1990). Groundwater sampling data submitted by Irrigon indicates the nitrogen concentration in groundwater upgradient of the treatment system may be higher than in the percolate from the infiltration beds (DEQ Water Quality File 42490, Chapter 4).

Seepage from the City of Echo's sewage treatment lagoons occurred from 1976 to 1985 due to incomplete construction. Approximately 85 percent of the sewage in the first cell escaped to the subsurface and at least one domestic well may have been impacted (DEQ Water Quality File 26200).

On-Site Domestic Sewage: A Groundwater Contamination Concern

North American septic systems have caused elevated nitrate-nitrogen and/or chloride in soils and groundwater (Salvato, 1972, Viraraghaven and Warnock, 1976; Brown and others, 1979, Chen, 1988, Robertson and others, 1991). A groundwater investigation for the Burbank-Wallula, Washington area, northeast of the Lower Umatilla Basin, found septic systems contributed less nitrate-nitrogen to local groundwater than other sources (Spalding and others, 1982).

Oregon examples of septic systems contaminating groundwater include mid-Multnomah County, Santa Clara/River Road, Clatsop Plains, LaPine and Irrigon. Most of these areas were required to build and use a sewer system. The City of Irrigon experienced groundwater contamination from Irrigon area septic systems in 1977 and 1978. Three hepatitis outbreaks involving 17 people prompted the Oregon Health Division to declare an "Imminent Health Threat" to Irrigon's groundwater supply (DEQ Water Quality File 42490). In 1978, City of Irrigon samples confirmed drinking water contamination and linked it to inadequately treated sewage percolating through shallow coarse soils (sand and gravel) to groundwater (DEQ Water Quality File 42490).

This investigation has concluded that individual septic systems are contributing to elevated nitrate-nitrogen in groundwater along the Columbia River between Irrigon and Umatilla and other areas (see Chapter 4). Some ares with a high density of septic systems have lower concentrations in groundwater due to dilution from local surface water. The Diagonal Road vicinity near Hermiston is a good example (see Chapter 4). Concentrations could increase with any changes to nearby canals operations.

A large on-site domestic sewage collection and treatment system serves the Administration Area of the U. S. Army Umatilla Depot Activity west of Hermiston (DEQ Water Quality File 91000). Nitrate-nitrogen concentrations in groundwater greater than 10 mg/L have been detected in the Administration Area. Ritchie and others (1992) identify crop and animal operations south of the Depot as the likely source.

Municipal Domestic Sewage: Waste Management

Municipal sewage treatment facilities generally have a limited operating life, with construction and improvements usually introduced to keep up with population growth, correct problems, and meet new regulations. Municipal plants either discharge treated wastewater to nearby surface water, land apply it to vegetation or allow it to infiltrate into groundwater. The solid waste, or sludge, is usually land applied, although it may also be disposed of in a landfill.

Municipal sludge is generally applied within agronomic rates. However, sludge may have a variety of potential contaminants in varying concentrations, so sludge is regulated by its most limiting factor. For example, if heavy metals are the most concentrated contaminant, sludge application may not achieve agronomic rates as it is applied at the safest rate for heavy metals.

Over the past three decades, basin municipal sewage treatment plants have shifted to more land application and less direct discharge to surface water. As part of this shift, municipal facilities have also introduced more ponds, stricter land application controls and consideration of the types of vegetation receiving land application of sludge and wastewater (DEQ Water Quality Files 9104, 26200, 38212, 84405). The land application loading for each facility is presented in Appendix 3E. Facility locations are shown on Plate 3.4.

Portland and Washington County's Unified Sewerage Agency ship sewage sludge to the Lower Umatilla Basin where it is land applied at Madison Ranch south of Hermiston. Sludge is applied within agronomic rates (DEQ Water Quality Files 70725, 90770). The land application loading for each facility is presented in Appendix 3E.

On-Site Domestic Sewage: Waste Management

Most basin large on-site facilities discharge domestic sewage water to drainfields or bottomless sand filters (DEQ Water Quality Files 91000, 100128, 100132, 03745, 105049). Some facilities may provide additional treatment through the use of recirculating sand filters prior to discharge. At least one system uses a lined faculative lagoon, and another continues to use dry wells (DEQ Water Quality Files 64710, 103746). Sewage sludge is often removed and treated off-site. At least one facility has buried its sludge at a landfill (DEQ Water Quality File 91000). Loading for each facility with a water quality permit is presented in Appendix 3F. Facility locations are shown on Plate 3.5.

Owners of individual on-site septic systems are responsible for maintaining their own systems. Proper maintenance includes removing solids from the septic tank at least once every five years.

Domestic Sewage History

In the basin, six cities operate municipal sewage treatment plants. Other facilities include six large on-site systems on file at the DEQ Water Quality Division and 4,375 individual septic systems identified by this investigation. Some sewage treatment facilities within the Portland metropolitan area currently export sludge for land application in the basin.

Before 1970

Individual on-site sewage systems offered the first basin sewage treatment. Hermiston provided one of the first municipal sewage treatment systems for the area, replacing it in 1951 (DEQ Water Quality File 38212). Stanfield constructed a sewage treatment system in 1952 as did Boardman before 1967 (DEQ Water Quality Files 9104, 84405). The Oregon Department of Transportation (ODOT) constructed public rest areas at two Interstate 84 locations, west of Boardman and west of Stanfield, by 1967 (DEQ Water Quality Files 64710, 105049).

1970s-1980s

The City of Echo started constructing and using of a sewage lagoon treatment plant in 1976, which remained incomplete until 1985 due to lawsuits and funding problems. Sewage seepage occurred during that period. Echo's current NPDES permit allows discharge of treated wastewater to the Umatilla River from April through December (DEQ Water Quality File 26200).

The City of Umatilla's current wastewater treatment facility was constructed in 1980. It replaced a treatment plant built in 1974 that had also serviced the community of McNary. This facility was built to serve a population of 10,000 in Umatilla and Port of Umatilla industries. Umatilla's NPDES permit allows wastewater discharge to the Columbia River (DEQ Water Quality File 90659).

In 1980, a Boardman facility capable of serving 4,000 people began operation. The facility includes wastewater storage in a lined lagoon and land application on a 40-acre site. Boardman's 1981 and 1987 WPCF permits required groundwater monitoring in the land application area (DEQ Water Quality File 9104).

In 1981, the city of Hermiston began using its current sewage treatment plant by servicing 10,000 people. The facility was constructed to service a population of 25,000. The NPDES permit, issued for the facility in 1983 and 1989, allows wastewater discharges either to the Umatilla River or by land application to vegetation. The 1989 permit added requirements to monitor influent and sludge as well as develop a sludge management plan. Hermiston land applies its sludge (DEQ Water Quality File 38212, Caldwell, 1993).

Irrigon addressed the late 1970s hepatitis outbreak and sewage contamination of groundwater by constructing a controversial sewage treatment system in 1989. Individual on-site septic tanks discharge to a two-acre, 10-bed rapid infiltration basin treatment area. The system failed to meet its WPCF permit requirements (DEQ Water Quality File 42490, SCM Consultants, Inc., 1990, D'Eagle, 1994).

Several large on-site disposal systems failed or were improved during this time. A lined lagoon replaced the Boardman public safety rest area's sewage disposal system in 1977 (DEQ Water Quality File 64710). The Hinkle Railroad Inn made efforts to correct problems with its septic system and drainfield in 1986 (DEQ Water Quality File 100132). The Shady Rest Mobile Home Court and the Vista Estate Mobile Home Court systems have failed. Improvements to the systems were accompanied by a DEQ requirement to connect to an approved sewer system when it becomes available (DEQ Water Quality Files 103745 and 100128).

1990s

Individual on-site septic systems continue to be commonly used outside of municipal areas. One large on-site system, the Stanfield rest area replaced septic systems with recirculating gravel filters in 1992 (DEQ Water Quality File 105049).

The City of Stanfield began upgrading its sewage treatment facility in 1993. It added a storage pond to spray-irrigate wastewater at its sludge land application site. By 1994, treated effluent was expected to be discharged to the Stage Gulch Irrigation Ditch from November to March and spray irrigated from April-October (DEQ Water Quality File 84405). Discharge to the Stage Gulch Irrigation Ditch may influence groundwater quality. Consultants have identified the unlined ditch as a local groundwater recharge source (Barlow, Scott, 1991, Barlow, Scott, Urban, 1992). Stanfield's sewage treatment facility is currently not required to conduct or report any groundwater monitoring.

In 1989, DEQ authorized land application of the City of Portland's Columbia Boulevard Wastewater Treatment Plant Triangle Lake Lagoon sludge at an agronomic rate to Madison Ranch property west of Butter Creek Highway and south of Interstate 84 (DEQ Water Quality File 70725). Land application began in March 1990, stopped after June 1991, and restarted in July 1992 (DEQ Water Quality File 70725). Sludge quality, a concern when Portland detected dioxin in the sludge in 1988, was declared safe in March 1991 by the U.S. Department of Agriculture (DEQ Water Quality File 70725, The Oregonian, 1991).

DEQ declined the City of Portland's 1990 requests to increase the sludge land application to greater than agronomic rates. However, DEQ did allow increasing the sludge application rate from 5.0 to 6.5 dry tons per year (150 pounds of nitrogen per acre per year) as long as dioxin was kept within an acceptable level. The land application of sludge operates under a DEQ authorization that includes limits on land application areas and rates, soil testing and a fallow period before livestock grazing or feed harvesting (DEQ Water Quality File 70725).

The Unified Sewerage Agency (USA) operates multiple wastewater treatment facilities in Washington County, Oregon. DEQ approved land applying digested, dewatered, cake sludge year-round to 803 acres at Madison Ranch in August 1993 (DEQ Water Quality File 90770). USA currently seeks to land apply its sludge year-round on 325 additional acres at Madison Ranch. The non-irrigated land application area could significantly expand if Madison Ranch purchases approximately 9,700 acres of dry land west of the Ranch (Richwine, 1994).

Domestic Sewage Nitrogen Loading: Municipal

The total acreage available to land apply treated municipal waste in the Lower Umatilla Basin expanded from less than 400 acres before land application of Portland and Washington County sludge to more than 2,700 acres by 1993. The historic and recent average annual land application rates for nitrogen from domestic sewage ranged from none applied to nearly 215 pounds per acre (Table 3.10, Appendix 3E).

Some deep percolation of municipal sewage wastewater does or did occur in the basin. The City of Irrigon discharges sewage wastewater to the subsurface via infiltration beds within a 2-acre area. The average nitrogen loading from the infiltration beds to the subsurface apparently increased from about 2,200 pounds per acre in 1990 to about 4,500 pounds per acre in 1992 (Appendix 3E). One City of Echo sewage treatment lagoon cell, that was at least partially sealed, reportedly lost 85 percent of the lagoon influent to subsurface seepage from 1976 until the lagoon's completion in 1985 (DEQ Water Quality File 26200). The average nitrogen loading from the lagoons to the subsurface in 1983 was about 195 pounds per acre (Appendix 3E).

Domestic Sewage Nitrogen Loading: On-Site

The large on-site sewage treatment systems identified by this investigation primarily discharge wastewater to the subsurface via drainfields or bottomless sand filters. One facility also uses dry wells and another uses a faculative lagoon with occasional land application. Deep percolation of nitrate-nitrogen from these systems appears to annually exceed 4,700 pounds over an area exceeding 10 acres (Table 3.11, Appendix 3F)

This investigation assumed all units identified outside sewer service areas are active and use individual on-site systems which discharge directly to the subsurface via drainfields. The annual average nitrate-nitrogen discharge from each household was calculated as 26 pounds per year per system, derived from local municipal sewage treatment facility data, literature and DEQ on-site system experiments. Deep percolation of nitrate-nitrogen from these systems may annually exceed 113,000 pounds for the entire basin, and range from 0 to about 6,200 pounds within square mile sections (Table 3.12, Appendix 3G).

Plate 3.5 shows the distribution density of all the unsewered units for each square mile. The highest densities occur near Hermiston, Boardman and Irrigon.

Table 3.10 Estimated nitrogen loading in the Lower Umatilla Basin by municipal sewage treatment facilities during 1992-1993.

Facility	Loading Area	Acres	Constituent	Units	Estimated Loading		
					Max	Min	Average
City of Boardman[a] (1993)	Poplar trees	10	Nitrogen	pounds/acre-year	-	-	69
City of Echo[b]	Sludge land application area	54.5?	Nitrogen	Pounds/acre-year	0	0	0
City of Hermiston (1992)	Poplar trees and Wadekamper Ranch	161	Nitrogen	pounds/acre-year	139	6	22
City of Irrigon (1992)	Infiltration beds	2	Nitrogen	pounds/acre-year	-	-	4,550[c]
City of Stanfield (1993)	Sludge land application area	48	Nitrogen	pounds/acre-year	-	-	16
City of Umatilla (1992)	Current sludge land application area	7.7[d]	Nitrogen	pounds/acre-year	-	-	212
City of Portland Sludge (1992)	Madison Ranch	1809	Nitrogen	pound/acre-year	-	-	75
Unified Sewerage Agency Sludge (1993)	Madison Ranch	630	Nitrogen	pounds/acre-year	-	-	-[e]

See Appendix 3E for estimated nitrogen loading tables for individual facilities.

[a] City of Boardman land applied wastewater to 40 acres of alfalfa from 1986 - 1990. No land application occurred in 1991 or 1992.

[b] From 1976 to July 1985, the City of Echo lagoons lost approximately 85 percent of the influent to subsurface seepage.

[c] This value reflects nitrogen leaving the infiltration bed to the subsurface after nitrogen reduction/losses in the beds.

[d] Historic sludge land application area was an 80 acre site.

[e] Land application began in September 1993.

Sources: DEQ files: 26200, 42490
DEQ Northwest Regional Office Staff
DEQ Pendleton Office Staff
SCM Consultants, Inc (1990)
Beyeler (1993)
Richwine (1994)

Table 3.11 Estimated nitrogen loading in the Lower Umatilla Basin by selected large on-site sewage treatment systems.

Year	Facility	Acres	Constituent	Units	Estimated Loading		
					Max	Min	Average
1978 - Present	Hinkle Railroad Inn (drainfield)	2.41	Nitrate-N	pounds/acre-year	551[a]	-	-
1993[b]	OR Dept of Transportation Boardman Rest Area (land application area)	5	Nitrogen	Pounds/acre	-	-	60
1993	OR Dept of Transportation Stanfield Rest Area West Bound (drainfield)	0.17	Nitrate-N	pounds total	-	-	244
1993	OR Dept of Transportation Stanfield Rest Area East Bound (drainfield)	0.17	Nitrate-N	pounds total	-	-	244
1991	Shady Rest Mobile Home Park (bottomless sand filter)	0.19	Nitrate-N	pounds total	-	-	441
1990	US Army Umatilla Depot Activity Administration Area (drainfield)	0.23	Nitrate-N	pounds total	-	-	2,483
1986	Vista Park Mobile Home Park (drainfield)	4.13	Nitrate-N	pound/acre	-	-	752

See Appendix 3F for estimated nitrogen loading tables for individual facilities.

[a] Value is based on the maximum discharge allowed by WPCF permit number 100195

[b] The only land application event since the facility began operating in 1977.

Facilities operating with drainfield values came from using available discharge flow information and by using a 40 mg/l nitrate-nitrogen concentration for drainfield effluent percolating by groundwater. The 40 mg/l nitrate-nitrogen concentration came from EPA (1980) and DEQ (Ronayne et al., 1982) literature as well as recent work conducted by DEQ employee Henning Larsen.

Sources: DEQ files: 100132, 105049, 103745, 91000, 100128
DEQ Pendleton Office Staff
Bochsler and Hansen (1990)
Joleen Odens (1994)

Table 3.12 Estimated annual total nitrate-nitrogen loading from domestic septic systems in the Lower Umatilla Basin.

Units	Units Counted[a]	Estimated Annual Nitrate Loading[b] (pounds/year)
Homes/Mobile Homes	4,015	103,846
Public Places (Churches, Schools, Parks, Public Buildings)	40	1,035[c]
Work Places (Business, Shop/Industry)	320	8,277[c]
Grand Total	4,375	113,157[d]

[a] Units outside of sewer services areas identified from Morrow and Umatilla County Records. Some units may not be occupied. Other units may be serviced by large on-site systems.

[b] Estimate calculations used 25•8,644 pounds of nitrate-nitrogen per year per unit. This value was derived from using an average 213.3 gallon per day wastewater discharge rate for households/small businesses and 40 mg/l average nitrate-nitrogen concentration in septic tank effluent percolating to groundwater. The wastewater discharge rate for households/small businesses was calculated from Lower Umatilla Basin sewage treatment facility data. The 40 mg/L average nitrate-nitrogen concentration was derived from EPA (1980) and DEQ (Ronayne et al., 1982) literature as well as recent work conducted by DEQ employee Henning Larsen.

[c] The total amount of nitrate-nitrogen loading for these units may be larger than the estimates shown. The total population served by these units was not determined from the sources reviewed. However, some of these units may be inactive, out buildings without toilet facilities, or units with an alternate sewage treatment system.

[d] The column total differs from the number shown by 1 pound/year due to errors introduced by rounding numbers to a whole number.

Military Sites

Introduction

A variety of military activities involving metals, ammunition, bombs and chemical agents have occurred over 180 square miles at two Lower Umatilla Basin facilities since 1941. These activities have involved the U.S. War Department, Army, Army Air Corp, Navy, and Air Force. The Oregon Department of Veteran's Affairs acquired 91 square miles in 1963, which it later leased to Boeing and the Port of Morrow. The currently active military areas are 30.8 square miles at the U.S. Army Umatilla Depot Activity and 58.3 square miles at the U.S. Navy Boardman Bombing Range (Dawson and others, 1982, Mahannah and others, 1993, Hafley, 1992, DEQ Environmental Cleanup File 1030).

The bombing range originally covered 150 square miles until 1960 (see Plate 3.6). Environmental concerns primarily relate to military ordnance. Bombing practice from 1942 to 1960 left unexploded bombs, practice bombs, incendiary bombs, artillery shells, rockets, and 50 caliber ammunition at target sites. Additionally, World War II war games littered a 36-square-mile area inside the range with military ordnance (Hafley, 1992, DEQ Environmental Cleanup Site File 1030). Inspection, assessment, and cleanup activity has occurred at range sites outside the current Navy bombing range since 1989. In 1992, DEQ environmental cleanup staff concluded these sites pose a minimal threat to the surrounding population and the environment (Hafley, 1992, DEQ Environmental Cleanup Site File 1030).

Military site cleanup primarily involves the 30.8 square mile U.S. Army Umatilla Depot Activity between Hermiston and Boardman, Oregon (Plate 3.6). The U.S. government owns 17,054 acres, and 2,674 acres is privately owned with rights reserved for farming and grazing livestock (Mahannah and others, 1993). The Depot primarily stores chemical and conventional munitions, but other activities included metal and ore storage, munition maintenance, disposing explosive washout water to lagoons, disposing missile fuels and pesticides at pits, and burning or burying sewage sludge, munitions, and scrap (Dawson and others, 1982). The Army has postponed closing the Umatilla Depot Landfill until 1997 to allow proper disposal of Depot environmental cleanup site materials (Liggett, 1994).

The Depot is scheduled to close under the Base Realignment and Closure (BRAC) program with plans for on-site incineration of chemical agents (Mahannah and others, 1993, Ritchie and others, 1992). The land may sell to private interests or shift to another government agency. Future use could include military training, light industry, residences, and agriculture (Ritchie and others, 1992, Mahannah and others, 1993).

Military Waste: A Groundwater Contamination Source

Soil and groundwater contamination exists at Depot sites (see Appendix 3H). Other investigators found contaminants in surface soil, subsurface soil, septic tanks, alluvial groundwater, and groundwater from basalt (Ritchie and others, 1992). Contaminants detected include some metals, explosives, cyanide, and nitrate-nitrite (Dawson and others, 1982, Ritchie and others, 1992).

Some Depot soil contaminants could become mobilized. For example, Dawson, and others (1982) noted that with insufficient water, TNT explosives remained attenuated in Depot soils. However, Dawson and others (1982) warned that the TNT could flush to groundwater with increased water applications. Dawson, and others (1982) noted rapid travel time to groundwater with seven inches of precipitation from November and December 1973 influencing alluvial groundwater elevations 14 months later.

Previous investigations have attributed Depot nitrate-nitrogen contamination to Depot and non-Depot sources. Depot groundwater with nitrate-nitrogen concentrations exceeding the drinking water standard of 10 mg/L was detected in five areas (Ritchie and others, 1992):

- the south boundary near the Administration Area
- the explosive washout lagoon vicinity
- the active landfill vicinity in the northeast Depot area
- well 005 in the central Depot area, and
- the ammunition demolition area (northwest portion) in the northwest Depot area.

Nitrate-nitrogen in the washout lagoon vicinity was attributed to breakdown of explosives which the Depot had discharged to the lagoons. Nitrate-nitrogen in the active landfill vicinity was attributed to nearby food processing wastewater land application and possibly the landfill which had accepted sewage for disposal. Agricultural activities outside the Depot were identified as nitrate-nitrogen sources at the south boundary and the ammunition demolition area. Nitrate-nitrogen in Well 005 was attributed to unknown sources (Ritchie, and others, 1992).

Explosives, metals and other Depot contamination identified by previous investigations is summarized by site in Appendix 3H.

Managing Military Waste

The U.S. Army, EPA and DEQ have proposed a groundwater cleanup plan to address explosives and elevated nitrate-nitrogen in the explosive washout lagoons (Bowen and others, 1992). The proposed cleanup includes extracting groundwater at the site, treating the water with granular activated carbon, and reinfiltrating the water through a washout lagoon at a cost of 5.8 million dollars (U.S. Army and others, 1994).

DEQ is preparing a draft environmental permit for an incineration facility to destroy the chemical weapons stockpiled at the Depot. The permit is expected to be issued by the end of 1995. Construction will take three years, followed by extensive testing. Actual operation is expected to last three years, after which the facility will be dismantled (Oliver, 1995).

The Umatilla Depot Landfill closure design includes a clean soil and geomembrane cap to keep water out of the landfill, and groundwater sampling at previously constructed monitoring wells (Liggett, 1994).

Military Site History

The Depot's chronological history, reviews of selected sites and types of contamination detected by other investigators can be found in Appendix 3H.

1940s

The U.S. Army acquired 16,000 acres for the Depot by purchase from private land owners and through a transfer from the U.S. Bureau of Land Management. The Army established the Umatilla Depot to store conventional munitions in 1001 ammunition storage igloos. The Army added ammunition demolition and renovation to the Depot's activity in the mid-1940s (Ritchie and others, 1992).

From 1941 to 1943, the U.S. War Department acquired 150 square miles for a precision bombing range. The site was originally named the Arlington Bombing Range, and later renamed the Boardman Air Force Range. The U.S. Army Air Corps used the Bombing Range from 1942 to 1948. War games were conducted within a 36-square-mile area during World War II, leaving the area littered with various military ordnance (DEQ Environmental Cleanup File 1030).

1950s-1960s

A U.S. Army plant began removing explosives from munitions, bombs and projectiles through water or steam cleaning. The residual wastewater was discharged to two lagoons. The Army purchased more acreage as a safety buffer and began storing chemical agents and munitions in 1962 (Ritchie and others, 1992).

The U.S. Air Force and U.S. Navy used the Bombing Range from 1948 to 1960. This use, along with previous Army Air Corp use, left unexploded bombs and a variety of ammunition at target sites. The Air Force transferred the entire Bombing Range to other government organizations, with ownership eventually going to the U.S. Department of the Navy in 1960. The state of Oregon acquired the range in 1963 and leased it out to Boeing Corporation for 77 years. Boeing renamed the leased area the Boardman Space Age Industrial Park (Hafley, 1992, DEQ Environmental Cleanup File 1030).

Since 1968, the U.S. Army has operated an unlined gravel pit as the Umatilla Depot Landfill (DEQ file: Solid Waste Disposal Facility Permit Number 320). Eight inactive disposal sites are located within the south central area of the U.S. Army Umatilla Depot Activity (Ritchie and others, 1992).

1970s-1980s

The Depot was included in a 1978 assessment to evaluate the environmental quality of past use, treatment and disposal of toxic and hazardous materials. The assessment found parts of the Depot to be contaminated with explosives. In 1985, the Army applied for an environmental permit to construct and operate an incineration facility to demilitarize obsolete chemical agents at the Depot (Ritchie and others, 1992).

An Initial Remedial Investigation in 1988 was conducted to determine the extent of contamination at the following sites: the explosive washout lagoons, ammunition demolition activity, active and inactive landfills, the deactivation furnace and septic tanks (Ritchie and others, 1992). The investigation found explosives, nitrate/nitrite, cyanide and certain metals in septic tanks, surface soil, subsurface soil, and both alluvial and basalt groundwater. Sources included Depot activities and fertilized farming outside the Depot (Roy F. Weston, Inc., 1989).

Boeing leased some acreage to Portland General Electric (PGE) coal fired plant that began operating in 1980 (DEQ Environmental Cleanup File 1030, Carter, 1987). Boeing also returned 2,700 acres to the state, which was leased to the Port of Morrow in 1983. A 1989 U.S. Army Corps of Engineers inspection of the Boardman Air Force Range found unsafe debris, hazardous and toxic waste contamination and unexploded ordinance. (DEQ Environmental Cleanup Site File 1030).

1990s

In a federal preliminary assessment for EPA, DEQ concluded that the Boardman Air Force Range posed a minimal threat to the surrounding population and environment (Hafley, 1992).

The Umatilla Depot Landfill was about half full by 1992 (Golder Associates, Inc., 1992). Because of landfill regulation changes, the U.S. Army had intended to close the Umatilla Depot Landfill by 1993 (DEQ file: Solid Waste Facility Permit Number 320). The U.S. Army submitted a draft closure and post-closure plan in 1992 (Golder Associates, Inc., 1992). However, the Army postponed closing the landfill until 1997 to allow proper disposal of Depot environmental cleanup site materials (Liggett, 1994).

Investigation and cleanup of contaminated Depot sites continue, particularly at the explosives washout lagoon and for the incineration of stored chemicals.

Military Waste Nitrogen Loading

Significant nitrogen loading apparently occurred at the Depot's explosive washout lagoons (0.09 acres total), and some nitrogen loading may have occurred within the Depot's 1750 acre ammunition demolition area and 10-acre active landfill area. Project information was not sufficient to calculate nitrogen loading at the Depot sites.

Groundwater contamination by the U.S. Army Umatilla Depot Activity includes metals, nitrate, explosives and other organic chemicals. Some of the nitrate-nitrogen observed has been attributed to non-Depot sources by other investigators (Ritchie and others, 1992).

Nitrogen loading at the unlined Explosive Washout Lagoons occurred from the mid 1950s to the mid 1960s via discharge of approximately 85 million gallons of explosive washout water to the lagoons. Other investigators have concluded loading at the washout lagoons has contaminated groundwater (Dawson and others, 1982, Ritchie and others, 1992, Bowen and others, 1993)

Nitrogen loading at the Ammunition Demolition Area may have occurred since 1945 via demolition and disposal of explosives and/or pesticides in the area. Other investigators have concluded activity at the Ammunition Demolition Area has not and will not contaminate groundwater (Mahannah and others, 1993).

Dried sludge from the U.S. Army Umatilla Depot Activity sewage treatment facility has been disposed within the 10-acre active landfill at the Depot since the early 1980s. Other investigators attributed nitrate-nitrogen in vicinity groundwater to an offsite source and possibly the landfill (Ritchie and others, 1992; Golder and Associates, Inc., 1992). Project information was insufficient to determine the nitrogen loading at the active landfill or any other solid waste disposal sites.

Debris in disposal trenches was discovered and removed during a 1989 U.S. Army Corps of Engineers inspection of the former Boardman Air Force Range, and removed in 1990. No contamination was reported (Hafley, 1992, DEQ Environmental Cleanup Site File 1030).

Solid Waste Disposal

Three active landfills are located within the Lower Umatilla Basin: Finley Butte, Umatilla Butte, and Umatilla Depot. Inactive landfill sites are present within the Umatilla Depot, at the former Boardman Air Force Range, and possibly at other sites unidentified by this investigation. Sites identified are shown on Plate 3.2.

Potential for Groundwater Contamination from Landfills

Of the three active landfills, only Finley Butte Landfill has a constructed liner to minimize deep percolation of leachate to groundwater. Some of the active and inactive landfills did and may still receive waste containing nitrogen. Landfills at Finley Butte and Umatilla Butte can accept waste loads with up to 25 gallons of free liquid, including sewage sludge and septic tank pumpings. The U.S. Army disposed of dried sludge at the Depot's Active landfill since the early 1980s to late 1993 (Ritchie and others, 1992, Golder and Associates, 1992, Dana, 1993, DEQ files: Solid Waste Facility Permit Numbers, 143, 320, 394).

The potential for groundwater contamination from the Umatilla Butte Landfill has been discussed, investigated and re-evaluated since at least 1985. In 1986, a DEQ review considered groundwater contamination from the landfill a low risk, given the arid climate, no recorded alluvial groundwater in nearby wells; low vertical permeability of individual basalt flows, and geologic structures compartmentalizing local groundwater. However, an attached 1985 WRD memo presented an unanswered cautionary question: did the Service Anticline folding create unobserved fractures through which contaminants can migrate? In 1992, DEQ staff reviewed existing reports and concluded that leachate from the landfill could potentially migrate to basalt groundwater (DEQ file: Solid Waste Disposal Facility Permit Number 143).

Solid Waste History

The active and inactive sites within the Depot and the former Boardman Air Force Range are discussed under Military Sites. A chronological history for the Umatilla Butte Landfill is presented in Appendix 3I.

1950s-1980s

The types of waste disposed of at the Umatilla Butte Landfill is presented in Appendix 3I.

From 1956 through 1972, open dumping occurred at Umatilla Butte near the current Umatilla Butte Landfill including a gravel quarry. Authorized dumping occurred from 1956 to 1961. Unauthorized dumping occurred from 1962 through 1972.

DBA Hermiston Sanitary Service operated the Umatilla Butte landfill during the early 1970s, apparently spreading a thin layer of waste with little compaction or covering (Advanced Sciences, Inc., 1992). Sanitary Disposal, Inc. compacted the trash, covered it with sand excavated nearby (weekly before 1979, daily after 1979), and controlled dust with water from 1972 to approximately 1983 (Advanced Sciences, Inc., 1992). From 1985 to at least 1992, Desert Wind, Inc. disposed of compacted trash in lifts covered daily with 6 inches of soil and intermediately with 12 inches of soil. The landfill design did not include engineered run-on or run-off control, leachate collection or treatment, liners, caps or groundwater monitoring (Advances Sciences, Inc., 1992).

The Umatilla Butte Landfill was inspected and audited from 1972 through 1992. The Bureau of Land Management reporting no major problems in eight compliance checks from 1972 to 1990. DEQ staff conducted five inspections and noted some permit compliance violations (Advanced Sciences, Inc., 1992, DEQ file: Solid Waste Disposal Facility Permit Number 143).

1990s

The Finley Buttes Landfill opened in 1990 about 10 miles south and east of Boardman (Plate 3.2). The facility was constructed and operates under a DEQ Solid Waste Disposal Facility Permit issued to the Finley Buttes Landfill Company of Vancouver, Washington in 1990 (DEQ file: Solid Waste Disposal Facility Permit Number 394). Finley Buttes Landfill disposes waste within 8 to 20-acre cells designed to prevent subsurface contamination (DEQ file: Solid Waste Disposal Facility Permit Number 394). A leak detection system revealed a leak in the upper liner of the evaporation pond which was reported in June 1992. The leak was confirmed and repaired the same year (DEQ file: Solid Waste Disposal Facility Permit Number 394).

The Finley Buttes Landfill Company began sampling groundwater from six monitoring wells in 1990. Nitrate-nitrogen concentrations have remained well below 1 mg/L with elevated manganese and total dissolved solids concentrations detected occasionally (Finley Buttes Landfill, 1992b). DEQ's laboratory staff have had similar results in groundwater sampled from the landfill's monitoring wells in 1992 (DEQ file: Solid Waste Disposal Facility Permit Number 394).

Advanced Sciences, Incorporated staff audited Umatilla Butte Landfill in 1991 for BLM. The auditors found a suitable existing site, adequate local soils for a landfill site, and no evidence of leachate generation at the landfill. However, the auditors also found numerous problems. The corrective actions they identified included a need to characterize groundwater, install monitoring wells, and implement a groundwater monitoring program (Advanced Sciences, Inc., 1992).

DEQ required the Umatilla Butte landfill to characterize the local groundwater and propose neighboring wells for groundwater quality monitoring in the facility's solid waste 1986 disposal permit renewal (DEQ file: Solid Waste Disposal Facility Permit Number 143). Landfill consultants recommended a regular groundwater monitoring program at the landfill using three existing offsite wells (Hickerson and Associates, 1987). In response, the landfill operation began monitoring groundwater at two well sites using only one of the wells recommended by the consultants (Advanced Sciences, Inc., 1992).

In 1992, DEQ staff used existing reports to review the physiographic, geologic and hydrogeologic conditions of the Umatilla Butte Landfill site. DEQ staff concluded that a potential existed for Umatilla Butte Landfill leachate to migrate to basalt groundwater below. The staff recommended the landfill operator characterize the landfill site and assess any potential groundwater quality impacts from past landfill activity (DEQ file: Solid Waste Disposal Facility Permit Number 143).

Potential Nitrogen Loading of Solid Waste

Information about nitrogen loading from solid waste disposal sites is limited. The nitrate-nitrogen concentrations in groundwater sampled at Finley Buttes Landfill are reported to be well below 1.0 mg/L (Finley Buttes Landfill, 1992b). DEQ has concluded that Umatilla Butte Landfill leachate could potentially migrate to basalt groundwater, as noted earlier.

At the Depot, consultants attributed elevated nitrate-nitrogen and other contaminants at the active landfill to an off-site source and possibly the landfill. (Ritchie and others, 1992). Depot consultants did not consider the Depot responsible for soil and/or groundwater contamination detected at or near some of the Depot's inactive landfill sites (Ritchie and others, 1992). This investigation attributes elevated nitrate-nitrogen in the active landfill vicinity to a Depot source and in the inactive landfill vicinity to an off-site source (Chapter 4).

Debris in disposal trenches was discovered and removed during a 1989 U.S. Army Corps of Engineers inspection of the former Boardman Air Force Range, but no contamination was reported (Hafley, 1992, DEQ Environmental Cleanup Site File 1030).

Electricity Generation

Electrical production is expanding in the Lower Umatilla Basin. Electricity generation facilities could potentially contaminate groundwater in two ways: constituent leaching from the incinerated coal ash at the PGE facility and salt from land applied co-generation cooling water.

Electricity Generation History

Before 1990s

Electric generation activity in the Lower Umatilla Basin began with the McNary hydroelectric dam north of Hermiston, which was constructed between 1947 and 1956. The 14-generator facility has a 100-year life expectancy (Stephenson, 1994) and presents no known groundwater contamination threat.

Portland General Electric (PGE) began operating a 530 mega-watt coal fired generating plant at the Carty site about 12 miles southwest of Boardman in 1980 (Carter 1979, 1987). Potential groundwater contamination sources at the PGE facility include fly ash and cooling water. The ash contains heavy metals, some low level radioactivity, and elevated pH (Carter, 1979). The ash is collected for commercial sale, or transported to a 240-acre disposal area southeast of the plant (Carter, 1979). PGE uses the adjacent Carty Reservoir south of the plant as a cooling and industrial waste pond for heat and selected chemicals resulting from plant operations (Carter, 1979).

PGE expected Carty Reservoir to leak between 1,000 to 4,000 acre-feet per year (Carter, 1979). Actual leakage is estimated as 4,000 acre-feet per year (Carter, 1987). PGE reports that reservoir leakage has created perched groundwater adjacent to the reservoir, and dominates the bicarbonate, potassium, and sodium concentrations and lowers the nitrate-nitrogen concentration in other groundwater (Carter 1987, 1988).

PGE has conducted groundwater monitoring and analyses through the 1980s to present. Groundwater monitoring wells are located within the ash disposal area, north and northwest of Carty Reservoir, and along Sixmile Canyon.

PGE's annual groundwater sampling analyses indicates agricultural activity rather than the ash disposal operation elevates the chloride, magnesium, and nitrate-nitrogen concentrations in groundwater at wells near the agricultural area west of Sixmile Canyon (Carter, 1987, 1988, 1989, 1990). At some of these wells, agriculture reportedly elevates the phosphorous concentration in groundwater occasionally (Carter, 1987, 1989, 1990, 1991). Elevated potassium concentrations in groundwater at one well site was also attributed to nearby agricultural activities (Carter, 1991). Lower nitrate-nitrogen concentrations in groundwater from a well within a marsh area northeast of the agricultural area was attributed to vegetation uptake and anaerobic nitrate-nitrogen reduction (Carter, 1987).

1990s and Future

Proposed natural gas electric co-generation facilities may be constructed in the Lower Umatilla Basin. Each proposed facility will provide steam to nearby potato processors for their potato processing activities. Salt enriched process wastewater from the co-generation facilities may be land applied (Barlow and Tipton, 1993, CH2M Hill, 1992, IDA-West Energy Company, 1993).

Locations proposed for the co-generation facilities include the Port of Morrow Industrial Zone (Barlow and Tipton, 1993), near Lamb-Weston Incorporated's potato processing plant (CH2M Hill, 1992) and adjacent to the J.R. Simplot Company potato processing plant (IDA-West Energy Company, 1993).

Potential Nitrogen Loading of Electrical Generation

Available information indicates possible loading from existing or proposed facilities is limited to salt and constituents other than nitrogen. PGE has reported elevated nitrate-nitrogen in groundwater sampled in the vicinity of the coal fired plant. PGE attributes the contamination to nearby agriculture (Carter, 1987, 1988, 1989, 1990). This investigation attributes the nitrate-nitrogen contamination to an off-site source.

Union Pacific Railroad

The history of the Union Pacific Railroad Co. primarily involves oil or diesel except for domestic sewage and grain washed out of railcars. DEQ files and databases record 48 accidents and spills between 1978 and 1992 (Appendix 3J). Most of these incidents involved 10 to 1,000 gallons of diesel. Only one spill involved nitrogen. This project expects no deep percolation of nitrogen from these accidents and spills.

Union Pacific Railroad History

Before 1970s

From 1951 to 1960, the Union Pacific Railroad Company consolidated three railroad terminals at Rieth, Oregon, Umatilla, Oregon, and Attalia, Washington into the Hinkle terminal, south of Hermiston. The consolidation accompanied a need to relocate railroad tracks away from the McNary Dam and a need to service diesel rather than black oil steam locomotives (DEQ Water Quality File 90860).

The facility installed septic tanks and drainfields for sewage disposal and allowed storm water runoff to discharge directly to the Umatilla River. A three-section concrete basin separated and collected grain wastewater from grain car cleaning washout water. The grain waste was hauled to a disposal pit while effluent water discharged to an open lagoon before discharging to the Umatilla River. Shop area oil, grease and cleaning detergent wastes were collected at an oil-water separator and removed for burial. Later, they were used with boiler fuel. Three settling basins/pools trapped remaining effluent waste before the effluent

discharged to the Umatilla River. The lower pools were skimmed or burned every 90 days. Burning apparently ended in 1971 (DEQ Water Quality File 90860).

1970s-1990s

The Union Pacific Railroad Company used a waste oil lagoon from 1971 through 1976 (DEQ Environmental Cleanup Site File 516). The lagoon was unlined in very sandy soil and approximately one-third of an acre. The company disposed of about 400,000 gallons total of waste oil sludge into the lagoon. Some of the oil may have been burned at the lagoon. Subsurface seepage was strongly suspected. In 1976, environmental cleanup occurred at the site (DEQ Environmental Cleanup Site File 516).

Union Pacific completed a new oil-water separation facility in 1973. It experienced wastewater treatment and management problems during the 1970s. Improvements included use of a multi-media filter, and land applying recovered oil sludge at a 16-acre site (DEQ Water Quality Files 90860 and 90861).

Potential Nitrogen Loading from Union Pacific Railroad

The facility uses septic tanks and drainfields for domestic sewage (DEQ Water Quality File 90860). Deep percolation of nitrate-nitrogen at the Hinkle Railroad Inn drainfield may annually reach 551 pounds per acres over a 2.4 acre site (Appendix 3F). Project information was not sufficient to identify other septic systems and drainfields servicing the Hinkle facility. Grain washed out of railcars is hauled to a pit. Project information was not sufficient to estimate nitrogen loading from this activity. It is considered small.

Pendleton Grain Growers, Incorporated - Stanfield

Chemicals and nitrogen released in a 1988 fire at Pendleton Grain Growers, Inc. (PGG) nearly two miles south of Hermiston, prompted an environmental cleanup (DEQ Environmental Cleanup Site File 639).

PGG History

The PGG fertilizer and agricultural chemical facility constructed in 1968 included a chemical warehouse, fertilizer mixing equipment, a hopper tower for loading fertilizers into application equipment, and a railroad spur (DEQ Environmental Cleanup Site File 639).

Fire destroyed the warehouse, the hopper towers, and an office on August 29, 1988 (DEQ Environmental Cleanup Site File 639). The fire involved an estimated 10,000 pounds of agricultural pesticide chemicals and 600,000 pounds of various fertilizers. Firefighting water carried contaminants to an evaporative pond and left standing water around the chemical buildings until the next day. Approximately 70,000 gallons were pumped from the pond to the tanks and bladder bags after DEQ staff observed pond leakage (DEQ Environmental Cleanup Site File 639).

Later, soil samples were collected at the facility from ground surface to 40 feet depth, and groundwater was sampled from two PGG wells about 100 feet from the site. Seventeen chemicals were detected in surface and near surface soil. Dinoseb and 2,4-D were detected between 30 and 40 feet below surface beneath the evaporative pond. No groundwater contamination related to the site was detected (DEQ Environmental Cleanup Site File 639).

Remedial action at the PGG cleanup site is completed (DEQ Environmental Cleanup Site File 639). The cleanup involved land application of the non-hazardous fire runoff water, excavation of contaminated soil which was placed in the evaporative pond, and caps constructed over the pond and excavated areas (DEQ Environmental Cleanup Site File 639).

PGG Potential Nitrogen Loading

Nitrate-nitrogen at concentrations greater than 10 mg/L was detected in groundwater from one PGG well, but the source was attributed to a neighboring animal feedlot (Gilles, 1993). Sufficient information to estimate nitrogen loading at this facility was not obtained.

Groundwater Recharge Projects

Groundwater use in some Lower Umatilla Basin areas has exceeded annual recharge, causing local groundwater level declines. The Oregon Water Resources Department (WRD) responded to the declines by declaring several areas Critical Groundwater Areas and restricting groundwater use. Local residents seek to improve the groundwater supply by artificially recharging local aquifers. One groundwater recharge project exists. Other projects are proposed.

Concern for Groundwater Contamination from Recharge Projects

The potential of groundwater contamination from groundwater recharge projects rests with the contamination concentrations found in the source of water used to artificially recharge aquifers.

History

1970s-1990s

The County Line Water Improvement District began operating an alluvial groundwater recharge project authorized by WRD in 1977 (Miller, 1985, OWRD Water Right File: Application 48966, Permit 41512). Using canal leakage to recharge groundwater, the project diverts Umatilla River water from the 18-mile High Line Canal 500 feet east of Lost Lake. The diverted water flows to a open canal near County Line Road, ending at a 7-acre catch lake (Miller, 1985, Henry, 1978). Reportedly, an estimated 11,000 acre-feet of recharge water per year percolates from the canal to the alluvial groundwater, which reportedly flows from the recharge area at a rate of 500-1000 feet per day (Miller, 1985).

Since 1991, the recharge project's potential for contaminating local groundwater has concerned DEQ, whose authority to protect groundwater quality is limited to a modification clause in the 1988 Water Right (Patton, 1992, Bidleman, 1992).

Future

The City of Hermiston seeks to recharge city wells supplied by underlying basalt aquifers with local alluvial groundwater via an injection well (City of Hermiston, 1986). Contaminants detected in the proposed recharge water have delayed this project (Loeb, 1992, Bidleman, 1993). WRD's Water Right permit prohibits recharge water from containing organic chemicals or volatile organic compounds (OWRD Water Right File: Application G-11891, Permit G-10935). The City has continued its efforts to implement the recharge demonstration project.

Groundwater withdrawal has exceeded the Butter Creek area's natural recharge since the late 1950s. WRD first declared Butter Creek a Critical Groundwater Area in 1976, but it did not take effect until 1988 (Norton and Bartholomew, 1984, Miller, 1994). Echo Junction area groundwater users must decrease their 1993-1997 groundwater withdrawal by 53 to 100 percent. They propose injecting Columbia River water through wells into basalt aquifers beneath the local alluvial sediments during wet months and withdraw the same water through the same wells in the dry months (CH2M HILL, 1993). Concerns about protecting the injection water quality and injecting into multiple basalt water bearing zones has delayed this project (Dulay, 1993, Grondin, 1993, Sellars, 1993).

Potential Nitrogen Loading from Groundwater Recharge

A project review found little nitrogen loading associated with existing or proposed groundwater recharge projects. The County Line Groundwater Recharge Project diverts Umatilla River water from High Line Canal for groundwater recharge via seepage. High Line Canal water collected by DEQ staff in June 1992 at the recharge project diversion site had a nitrate-nitrogen concentration of 0.03 mg/L (Appendix 4F).

The City of Hermiston Groundwater Recharge Demonstration Project proposes to inject shallow alluvial aquifer water into deeper Columbia River Basalt aquifers via a recharge well. Some nitrate-nitrogen loading from this project is anticipated given the recharge water's 2.6 mg/L of nitrate-nitrogen versus the receiving groundwater's 0.28 mg/L of nitrate-nitrogen. This has drawn less concern than the organic chemicals in the recharge water (City of Hermiston, 1986).

The proposed Echo Junction Aquifer Storage and Recovery Project intends to inject Columbia River water into Columbia River Basalt aquifers via recharge wells. Columbia River water samples collected by DEQ in 1992 had nitrate-nitrogen concentrations from not detected to 0.04 mg/L (Appendix 4F).

Project investigators found no information to support or refute rumors of unofficial groundwater recharge activity in the basin.

Miscellaneous Potential Sources

Reported Accidents/Spills

From 1981 through 1992, 83 accidents, spills and leaks in the Lower Umatilla Basin were reported to DEQ. Many accidents and spills involved 50 to 1,000 gallons of diesel fuel. Several other accidents included sewage overflows onto land surface. One accident involved 1,000 gallons of fertilizer along Powerline Road. A list of the accidents, spills and leaks can be found in Appendix 3K, and man of their locations are shown on Plate 3.7. Loading related to these accidents and spills primarily involved constituents other than nitrogen.

Hazardous Waste/Substance Handlers

Hazardous waste and substance sites located in the Lower Umatilla Basin and on file in the DEQ Hazardous Waste database are listed in Appendix 3L. These facilities generate, store, collect, dispose and/or treat useless, unwanted, or discarded pesticides and/or manufacturing residue that is toxic, corrosive, ignitable, or reactive. Less than 50 handlers are on file, although others may exist.

Lower Umatilla Basin facilities recorded in the State Fire Marshall Toxic Release Inventory database with potentially hazardous and toxic substances are listed in Appendix 3L. Less than five facilities are on file. Listed facilities handle more than 55 gallons of liquid hazardous and toxic substances, and/or 500 pounds of dry or solid hazardous and toxic substances, and/or 200 cubic feet of hazardous and toxic compressed or liquified gas. Some Lower Umatilla Basin facilities may be missing from the list.

No nitrogen or other loading should be occurring at Lower Umatilla Basin hazardous waste handling sites.

Underground Storage Tanks

Many underground storage tanks are present in the basin. Some have reportedly leaked. Appendix 3M lists the underground storage tanks located in the Lower Umatilla Basin, on file in DEQ's underground storage tank database, and the tanks having a reported petroleum product release. Some tanks may be missing from the lists. No nitrogen loading associated with underground storage tanks in the Lower Umatilla Basin is suspected.

Natural Nitrogen Sources

Natural nitrogen sources include lightning, rain, water-dissolving igneous rocks, organic decomposition, and nitrogen fixation by bacteria (Davis and DeWeist, 1966, Hem, 1985, Waring, 1949).

Loading information is not sufficient to determine the actual amount of nitrogen coming from natural sources. However, a USGS report and low background concentrations in upgradient Lower Umatilla Basin groundwater samples suggest the contribution from natural sources is small. The U.S. Geological Survey reports a median nitrate+nitrite-nitrogen concentration of 0.15 mg/L for 620 Oregon groundwater samples collected from various aquifers, and 0.46 mg/L for 142 samples collected from Oregon basin fill and alluvial aquifers (Miller and Gonthier, 1984). Project sampling has found groundwater nitrate-nitrogen concentrations well below 1 mg/L at some basin locations.

Summary

Diversity, change and growth best describes land use in the Lower Umatilla Basin. Former, existing and proposed land uses may contaminate basin groundwater with nitrate-nitrogen, salts, agricultural pesticides, explosives or petroleum products.

Given the basin soils, most land uses have the potential to contaminate groundwater. The potential for a land use to contaminate groundwater with nitrate-nitrogen or other constituents relates to loading. Groundwater contamination can occur whenever water (or another liquid) and nitrate-nitrogen (or another contaminant) is released and exceeds or bypasses:

- removal by crops or other vegetation
- removal by evaporation
- soil capacity to prevent deep percolation

Good management practices can reduce or prevent nitrate-nitrogen or other contaminant loss to groundwater.

Irrigated Agriculture

Irrigated agriculture covers almost half of the study area and is considered to be the greatest loading source in the basin, based on limited information. Deep percolation of nitrogen (or other constituents) to groundwater can occur when water or fertilizer exceed soil capacity and a crop's ability to remove nitrogen. Because of the high permeability of the soil in the area, irrigated agriculture, even when well-managed, remains a groundwater quality concern in the Lower Umatilla Basin.

Irrigated wheat and row crops (potatoes, field corn, watermelon, winter wheat, alfalfa hay, and pasture) replaced dryland wheat farming in the basin. This change led to increased total nitrogen fertilizer and pesticide use.

Irrigated agriculture has expanded to nearly 180,000 acres by the early 1990s due to available water, technologic improvements, and market demands. Of this total acreage, about half produced irrigated wheat and potatoes. Center pivots--which were also used for fertilizer applications--irrigated nearly 90 percent of the total irrigated area (IRZ Consulting, 1993). Irrigation technology continues to evolve with drip irrigation being introduced at large poplar tree farms.

Some of the highest nitrate-nitrogen concentrations in basin groundwater have been linked to irrigated agriculture. However, since this activity is among the least regulated, the least is known about how much nitrogen is applied to crops and escapes the root zone.

This investigation calculated a range of nitrogen applied to irrigated agriculture, beginning with a very conservative estimate for 1975. The minimum estimate assumes nitrogen applied to irrigated basin crops has annually exceeded 7 million pounds total since 1975. This estimate multiplies 1975 acreage with a nitrogen application rate of 50 pounds per acre. This estimate is conservative when compared to a project analysis of Pumphrey and others (1991). That analysis indicates more than 20.5 million pounds were applied to nearly 132,500 acres in 1990.

Current crop nitrogen application rates range from 0 to 410 pounds per acre per year depending upon the crop grown. Based on a nitrogen budget analysis, 20 to 265 pounds of residual nitrogen could remain after the growing season. Basin soil studies indicate some nitrogen has the potential to escape beyond the root zone on irrigated crop fields.

Ritter (1989) and Vitosh (1991) indicate nitrate-nitrogen loss to deep percolation at agricultural fields in the U.S. can range from 1 to more than 50 percent depending upon the amount of nitrogen applied, the time of application, soil texture, and the amount and timing of water applied. Applying a five percent deep percolation nitrate-nitrogen loss to the conservative estimate of 7 million pounds of nitrogen application per year means more than 350,000 pounds of nitrogen from irrigated agriculture have annually reached groundwater since 1975. The 1990 deep percolation loss may have exceeded one million pounds, assuming 20.5 million pounds were applied with a five percent loss to deep percolation.

Food Processing

Elevated nitrate-nitrogen concentrations have been linked to some food processing facilities. Very little vegetable food processing occurred in the Lower Umatilla Basin before 1970. The cannery, slaughterhouse and potato packing houses that did exist probably contributed very little nitrogen to basin groundwater.

Large-scale potato processing for fast food and other uses began in the basin during the 1970s, and expanded to dominate the local food processing industry in the 1980s. The industry produces large volumes of nutrient and/or salt rich wastewater which is land applied. Historically, wastewater storage occurred in unlined ponds, and the land application occurred at limited acreages, during all seasons at some sites, and at amounts exceeding crop nutrient needs.

Since the 1980s, food processors have produced more than one million pounds of nitrogen waste per year. In response to state permit requirements, the industry has expanded their land application areas, built or expanded lined wastewater storage, and limited land application to crop water and nutrient need.

Livestock

Livestock production began in the basin by 1900 and expanded to include sheep, turkeys, chickens, hogs, dairy and beef cattle. Livestock manure was the primary fertilizer for local crop production until the local dairy industry declined after World War II. Confined livestock facilities with thousands of animals have operated in the basin. Some remain active or have resumed operation. Waste management at these facilities is a groundwater quality concern, with one facility already identified as a groundwater contamination source before this technical investigation began.

Available but incomplete information indicates confined animal feeding operations are a major nitrogen source covering a limited area in the basin. Livestock activity involving nitrogen includes:

- livestock yards,
- waste lagoons or ponds,
- manure stockpile sites, and
- land application sites.

During the 1980s, basin livestock may have produced 3.4 million pounds of total nitrogen per year. The nitrogen amount land applied or stockpiled possibly dropped to more than 780,000 pounds per year after storage. Due to insufficient information, nitrogen leaching to deep percolation from land application, stockpiles, unlined livestock yards and waste ponds in the basin was not determined. Nitrogen estimates for the 1990s were not conducted due to insufficient information.

Domestic Sewage

Potential nitrogen sources from sewage include local municipal wastewater treatment facilities, sewage sludge imported from Portland and Washington County, large on-site systems at the U.S. Army Umatilla Depot Activity, unsewered mobile home parks, freeway rest areas, and hotels or other businesses, and possibly more than 4,300 individual septic systems.

Some of the local municipal wastewater facilities land apply their treated wastewater and/or sewage sludge within agronomic rates for nutrients and soil limits for metals. Sewage sludge from Portland and Washington County is land applied to irrigated and non-irrigated land within agronomic rates for nutrients, soil limits for metals, and limits for other constituents.

Land application of treated municipal wastewater and sewage has expanded. The land application area has expanded from less than 400 acres during the 1980s to more than 2,700 acres by 1993. The application rate ranged from 0 to 215 pounds per acre from the 1980s through 1992. The average annual nitrogen loading rate increased from more than 2,200 to more than 4,500 pounds per acre in 1990 and 1992 respectively.

The City of Irrigon uses rapid infiltration beds that discharge sewage wastewater directly to the subsurface over a two-acre area. Estimated subsurface nitrogen loading at the beds is 2,200 pounds per acre in 1990, increasing to 4,500 pounds per acre in 1992.

Most of the large on-site systems discharge wastewater directly to the subsurface via infiltration beds, bottomless sand filters, drainfields, and a few disposal wells. Mobile home parks, highway rest areas, hotels/motels, business and other facilities outside sewer service areas rely on large on-site sewage systems. Subsurface nitrogen loading from these facilities may exceed 4,700 pounds per year over an area exceeding ten acres.

Individual septic systems serve approximately 4,375 homes, mobile homes, and other units in the Lower Umatilla Basin. Wastewater from these units discharge directly to the subsurface and can affect an area where units are highly concentrated. Nitrogen loading from each unit was estimated as 26 pounds per year for individual units, 0 to 6,200 pounds annually per square mile section, and a total of 113,000 pounds per year for the basin.

Military Sites

A variety of military activities involving metals, ammunition, bombs and chemical agents have occurred over 180 square miles in the Lower Umatilla Basin since 1941. These activities have involved the U.S. War Department, Army, Army Air Corp, Air Force, and Navy. The Oregon Department of Veteran's Affairs eventually acquired 91 square miles in 1963, which it later leased to Boeing and the Port of Morrow. Current active military areas include the U.S. Army Umatilla Depot Activity and the U.S. Navy Boardman Bombing Range.

Soil and groundwater contamination exists at Depot sites. Other investigators found contaminants in surface soil, subsurface soil, septic tanks, alluvial groundwater, and groundwater from basalt (Ritchie and others, 1992). Contaminants detected include some metals, explosives, cyanide, and nitrate-nitrite (Dawson and others, 1982, Ritchie and others, 1992).

Previous investigations have attributed Depot nitrate-nitrogen to Depot and non-Depot sources. Depot groundwater with nitrate-nitrogen concentrations exceeding the drinking water standard of 10 mg/L was detected in five areas:

- the south boundary near the Administration Area
- the explosive washout lagoon vicinity
- the active landfill vicinity in the northeast Depot area
- well 005 in the central Depot area, and
- the northwest portion of the ammunition demolition area in the northwest Depot area.

Nitrate-nitrogen in the washout lagoon vicinity was attributed to the breakdown of explosives which the Depot had discharged to the lagoons. Nitrate-nitrogen in the active landfill vicinity was attributed to nearby food processing wastewater land application and possibly the landfill where sewage disposal occurred. Agricultural activities outside the Depot were the sources identified for nitrate-nitrogen at the south boundary and the ammunition demolition area. Nitrate-

nitrogen at Well 005 was attributed to an undetermined source (Ritchie, and others, 1992).

Significant nitrogen loading has occurred at the Depot's explosive washout lagoons, although information was not sufficient to calculate nitrogen loading at this or other Depot sites.

Solid Waste

Of the Lower Umatilla Basin's three active landfills--Finley Butte, Umatilla Butte and Umatilla Depot--only Finley Butte uses liners to prevent deep percolation of leachate to groundwater. At least two have disposed of sewage in dried or liquid form.

Information about nitrogen loading from solid waste disposal sites is limited. The Finley Buttes Landfill's nitrate-nitrogen concentrations in groundwater samples are reported to be well below 1 mg/L. In 1992, DEQ concluded that Umatilla Butte Landfill leachate could potentially migrate to groundwater.

Depot consultants attributed elevated nitrate-nitrogen and other contaminants at inactive landfills to background conditions or an off-site source. Elevated concentrations at the active landfill were attributed to an off-site source and possibly the landfill. This investigation attributes elevated nitrate-nitrogen in the active landfill vicinity to a Depot source and in the inactive landfill vicinity to an off-site source. No contamination was reported at the Boardman Air Force Range.

Electricity Generating Facilities

A project review found little or no nitrogen loading associated with existing or proposed electricity generation facilities. This includes the McNary hydroelectric dam, the Portland General Electric (PGE) coal fired plant and the natural gas electric co-generation facilities proposed for the basin.

Electricity generation facilities could potentially contaminate groundwater in two ways: constituent leaching from the incinerated coal ash at the PGE facility and salt from land applied co-generation cooling water. PGE has reported elevated nitrate-nitrogen concentrations in groundwater sampled at the ash disposal and other sites. PGE attributes the contamination to nearby agriculture. This investigation attributes the nitrate-nitrogen contamination to an off-site source.

Union Pacific Railroad

The history of the Union Pacific Railroad Co. primarily involves oil or diesel except for domestic sewage and grain washed out of railcars. This project expects no deep percolation of nitrogen from these accidents and spills.

Pendleton Grain Growers, Inc.

Environmental cleanup activity at the Pendleton Grain Growers site 3-acre site included a 1988 fire involving 10,000 pounds of agricultural pesticides and 600,000 pounds of various fertilizers. Soil cleanup at the site is completed. Observed groundwater contamination was attributed to a neighboring cattle feedlot.

Groundwater Recharge Projects

Existing or proposed groundwater recharge projects appear to add little nitrogen loading.

Miscellaneous Potential Sources

Reported Accidents and Spills

Numerous local accidents and spills at disperse sites in the Lower Umatilla Basin have been reported since the late 1970s. Only a few of the accidents and spills could have introduced nitrate-nitrogen to groundwater--three or more accidental sewage overflows onto land and 1,000 gallons of fertilizer spilled along Powerline Road near Hermiston.

Hazardous Waste/Substance Handlers

No nitrogen or other loading should be occurring in the Lower Umatilla Basin related to hazardous waste/substance handling or generation.

Underground Storage Tanks

No nitrogen loading associated with underground storage tanks in the Lower Umatilla Basin is suspected. Some tanks have reportedly released petroleum products.

Natural Sources

Lightning and rain contribute nitrogen at the land surface. Soil and rocks release nitrogen in the subsurface. These sources probably contribute nitrogen throughout the basin. Although actual loading is unknown, project sampling and analysis of a USGS report suggest the loading is small.

Chapter 4

Groundwater Chemistry

Hydrogeology, Groundwater Chemistry and Land Uses in the Lower Umatilla Basin Groundwater Management Area

Northern Morrow and Umatilla Counties
Oregon

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Chapter 4: Groundwater Chemistry

Table of Contents

Abstract 1

Support for Groundwater Quality Conclusions 3
Materials and Methods Used for the Groundwater Chemistry Investigation 4
Introduction 4
Groundwater Sampling 4
Reconnaissance Sampling 4
Bimonthly Sampling 5
Synoptic Sampling 6
Sampling for Nitrogen-Isotopic Analysis 6
Laboratory Chemical Analyses Conducted 7
Reconnaissance Sampling 7
Bimonthly Sampling 8
Synoptic Sampling 8
Nitrogen Isotope Analysis 8
Data Analyses Conducted 8
General Statistics 8
Chemical Constituent Maps 9
Graphical Analyses of Chemical Data 10
Computer Modeling Groundwater Chemistry Variations . . 11
Nitrogen-Isotopic Analyses 11
General Groundwater Chemistry Data Observations and Interpretations . . 12
Introduction 12
General Statistics and Occurrence 12
Nitrate+Nitrite-Nitrogen 12
Total Dissolved Solids 18
Arsenic 20
Sodium 22
Chloride 24
Phosphate, Boron, and Bromide 26
Vanadium 28
Volatile Organic Compounds and Pesticides 29
General Graphic Analyses 30
Nitrate Versus Other Chemical Constituents 30
Other Constituent Versus Constituent Relationships 32
Schoeller Diagram and Piper Trilinear Diagram Observations 33

Constituent Concentration Versus Time Observations 35
Constituent Concentration and Groundwater Elevation Versus Time Graphs Compared 39
Constituent Concentration Versus Groundwater Flow Path Location 42
Evidence of Evaporation and Mixing Affecting Alluvial Groundwater Chemistry 43
Evidence of External Influences Affecting Basalt Groundwater Chemistry 50
Evidence of Potential Nitrate Sources Influencing Groundwater Chemistry 54
General Groundwater Chemistry Computer Modeling Results . . . 63
General NETPATH Groundwater Chemistry Modeling Results 63
General PHREEQE Groundwater Chemistry Modeling Results 63
General Nitrogen Isotopic Analysis Results 64

Area Specific Groundwater Chemistry Data Observations and Interpretations . . . 66
Introduction 66
Threemile Canyon and Sixmile Canyon Area 66
Map and Data Set Observations: Nitrate 66
Map and Data Set Observations: Total Dissolved Solids . 69
Map and Data Set Observations: Other Constituents 70
Graphical Analyses: Nitrate versus Time 73
Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams 78
Graphical Analyses: Constituent Versus Constituent 80
Groundwater Flow Path Analysis 80
Groundwater Chemistry Computer Modeling 80
Nitrogen Isotopic Analysis 80
Threemile Canyon and Sixmile Canyon Area Summary and Conclusions 81
Boardman to West Umatilla 82
Map and Data Set Observations: Nitrate 83
Map and Data Set Observations: Total Dissolved Solids . 94
Map and Data Set Observations: Other Constituents 94
Graphical Analyses: Nitrate versus Time 101
Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams 117
Graphical Analyses: Constituent Versus Constituent 141
Groundwater Flow Path Analysis 144
Groundwater Chemistry Computer Modeling 146
Nitrogen Isotopic Analyses 147
Boardman to West Umatilla Area Summary and Conclusions 147

Butter Creek to City of Umatilla Area 150
Map and Data Set Observations: Nitrate 151
Map and Data Set Observations: Total Dissolved Solids . 156
Map and Data Set Observations: Other Constituents 157
Graphical Analyses: Nitrate versus Time. 159
Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams. 178
Graphical Analyses: Constituent Versus Constituent 188
Groundwater Flow Path Analysis 189
Groundwater Chemistry Computer Modeling 189
Nitrogen Isotopic Analyses 190
Butter Creek to City of Umatilla Area Summary and Conclusions 190
City of Umatilla to Hat Rock to Echo Meadows Area 192
Map and Data Set Observations: Nitrate 193
Map and Data Set Observations: Total Dissolved Solids . 197
Map and Data Set Observations: Other Constituents 198
Graphical Analyses: Nitrate versus Time 201
Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams 215
Graphical Analyses: Constituent Versus Constituent 231
Groundwater Flow Path Analysis 231
Groundwater Chemistry Computer Modeling 232
Nitrogen Isotopic Analyses 233
City of Umatilla to Hat Rock to Echo Meadows Area Summary and Conclusions 233

Evaluating Chemical Trends with Flow Path Analysis: Butter Creek Example . . 235
Introduction 235
Nitrate Versus Other Constituent Relationships Basin Wide Show Need for Flow Path Analysis 235
Flow Path Analyses in General 240
Butter Creek Flow Path 242
Alluvial Aquifer Along the Butter Creek Flow Path 242
Mineralogy 244
Groundwater Chemistry 244
Butter Creek Flow Path Analysis 248
Trends and Anomalies Observed Along the Flow Path . . 248
Nitrate Relationship to Other Constituents Along the Flow Path 250
Evaluation of Groundwater Chemistry Changes at a Wastewater Irrigation Circle 253
Evaluation of Groundwater Chemistry Changes Along Butter Creek Flow Path Segments 260
Analysis of UMA 185 to UMA 120: Natural Water-Mineral Reactions 260

Compositional Anomalies 261
Analysis of UMA 120 to UMA 122: Mixing and Evaporation-Dissolution Influences. 263
Analysis of Groundwater at UMA 122: Evaporation Influence 270
Analysis of UMA 081 to UMA 073: Surface Water Influence 271
Spatial versus Temporal Variations 274

Stable Nitrogen Isotope Analysis 275
Introduction 275
Sampling Results 275
Analysis of Groundwater at UMA 258 280
Analysis of Wastewater from the J.R. Simplot Company Surge Pond 281
Analysis of Lysimeter Samples 282
Analysis of Western Empire Farm Samples 282
Analysis of Groundwater Sampled at the U.S. Army Umatilla Depot Activity 282
Analysis of Groundwater Sampled at UMA 133 283
Analysis of Groundwater Sampled from Other wells 283
Influence of Mixing 283
Assessment of Natural Processes to Reduce Groundwater Nitrate Concentrations 284
Denitrification 284
Hydraulic Flushing 285

Lower Umatilla Basin Groundwater Chemistry Summary and Conclusions 287
Materials and Methods 287
General Observations and Interpretations 288
Nitrate Sources, Distribution, and Fate 288
Other Constituents in Lower Umatilla Basin Groundwater . 290
Other General Observations and Interpretations 291
Area Specific Observations and Interpretations 292
Threemile Canyon and Sixmile Canyon Area Summary and Conclusions 292
Boardman to West Umatilla Area Summary and Conclusions 293
Butter Creek to City of Umatilla Area Summary and Conclusions 296
City of Umatilla to Hat Rock to Echo Meadows Area Summary and Conclusions 298

Chapter 4: Groundwater Chemistry

Summary of Figures and Tables

Table 4.1 Statistics of maximum nitrate+nitrite-nitrogen concentration detected in groundwater sampled from each project well. 14

Figure 4.1 Cumulative frequency of maximum nitrate+nitrite-nitrogen concentrations detected in groundwater sampled from each project sampling site. 15

Table 4.2 Statistics of maximum total dissolved solids concentrations detected in groundwater sampled from each project well. 19

Table 4.3 Statistics of maximum total arsenic concentrations detected in groundwater sampled from each project well. 21

Table 4.4 Statistics of maximum total sodium concentrations detected in groundwater sampled from each project well. 23

Table 4.5 Statistics of maximum chloride concentrations detected in groundwater sampled from each project well. 25

Table 4.6 Statistics of maximum total phosphate concentrations detected in groundwater sampled from each project well. 26

Table 4.7 Statistics of maximum dissolved boron concentrations detected in groundwater sampled from each project well. 27

Table 4.8 Statistics of maximum bromide concentrations detected in groundwater sampled from each project well. 27

Table 4.9 Statistics of maximum total vanadium concentrations detected in groundwater sampled from each project well. 28

Table 4.10 Volatile organic compounds and pesticides concentrations detected in groundwater sampled from each project well. 29

Figure 4.2 Nitrate+nitrite-nitrogen concentrations versus total dissolved solids and sulfate concentrations for all project groundwater samples collected from July 1990 through March 1993. 31

Figure 4.3 Nitrate+nitrite-nitrogen versus time in alluvial groundwater at UMA 119 located southwest of Hermiston. 37

Figure 4.4 Nitrate+nitrite-nitrogen versus time in alluvial groundwater at Port of Morrow monitoring well MW-5 (MORR 0680) located northeast of Boardman. 38

Figure 4.5 An example of correlating nitrate concentration and groundwater elevation fluctuations at UMA 261 (LUB 042, Simplot MW-115). 41

Figure 4.6 Chloride versus potassium concentrations for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources. 45

Figure 4.7 Chloride versus nitrate+nitrite-nitrogen concentrations for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources sample. 46

Figure 4.8 Chloride versus sodium for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources. . . . 48

Figure 4.9 Chloride versus sulfate for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources. . . . 49

Figure 4.10 Total dissolved solids versus calcium for groundwater sampled from basalt water-bearing zones in the Lower Umatilla Basin. . . . 51

Figure 4.11 Total dissolved solids versus chloride for groundwater sampled from basalt water-bearing zones in the Lower Umatilla Basin. . . . 52

Figure 4.12 Total dissolved solids versus nitrate+nitrite-nitrogen for groundwater sampled from basalt water-bearing zones in the Lower Umatilla Basin. 53

Figure 4.13 Total dissolved solids versus nitrate+nitrite-nitrogen for groundwater sampled in the vicinity of potential nitrate sources. . 56

Figure 4.14 Potassium versus bromide for groundwater sampled in the vicinity of potential nitrate sources. 57

Figure 4.15 Potassium versus chloride for groundwater sampled in the vicinity of potential nitrate sources. 58

Figure 4.16 Magnesium versus sulfate for groundwater sampled in the vicinity of potential nitrate sources. 60

Figure 4.17 Calcium versus magnesium for groundwater sampled in the vicinity of potential nitrate sources. 61

Figure 4.18 Potassium versus bromide for groundwater sampled in the vicinity of potential nitrate sources, irrigation water sources, and a food processing wastewater lagoon. 62

Table 4.11 Arsenic, calcium, chloride, sodium, and sulfate concentration ranges for groundwater sampled in the Threemile Canyon and Sixmile Canyon area. 71

Table 4.12 Bromide, boron, total phosphate, and vanadium concentration ranges for groundwater sampled in the Threemile Canyon and Sixmile Canyon area. 72

Figure 4.19 Nitrate-nitrogen versus time in Threemile Canyon alluvial groundwater sampled near the J.R. Simplot Company confined animal feedlot wastewater lagoons. 74

Figure 4.20 Nitrate-nitrogen versus time in Sixmile Canyon alluvial and shallow basalt water bearing zone groundwater sampled near or within Taggares Farm. 75

Figure 4.21 Nitrate-nitrogen versus time in Sixmile Canyon shallow basalt water bearing zone groundwater sampled within the Portland General Electric ash disposal area. 77

Table 4.13 Threemile Canyon and Sixmile Canyon area groundwater characteristics. 79

Table 4.14 Nitrate concentration ranges detected in alluvial and basalt groundwater sampled from the Boardman to West Umatilla 85

Table 4.15 Volatile organic compounds and pesticides detected in the groundwater from Boardman to west Umatilla Area. 96

Table 4.16 Types of contamination detected at selected U.S. Army Umatilla Depot Activity sites as identified by other investigators. 97

Figure 4.22 Nitrate+nitrite-nitrogen versus time in Boardman area alluvial and basalt groundwater at project bimonthly sampling sites. 103

Table 4.17 Groundwater source and location information related to project bimonthly sampling sites in the Boardman area. 104

Table 4.18 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to Boardman area project bimonthly groundwater sampling sites. . . 105

Figure 4.23 Nitrate+nitrite-nitrogen versus time in Irrigon area alluvial and basalt groundwater at project bimonthly groundwater sampling sites. 107

Table 4.19 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Irrigon area. 108

Figure 4.24 Nitrate+nitrite-nitrogen versus time in alluvial groundwater between Irrigon and the Umatilla River at project bimonthly groundwater sampling sites. 110

Table 4.20 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Irrigon to Umatilla River area. 111

Figure 4.25 Groundwater elevation versus time and nitrate concentration versus time at UMA 243 (UMAT 5365, Lamb-Weston MW-5). 113

Figure 4.26 Nitrate+nitrite-nitrogen versus time in alluvial groundwater south of the U.S. Army Umatilla Depot Activity at project bimonthly groundwater sampling sites. 115

Table 4.21 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the area south of the U.S. Army Umatilla Depot Activity. 116

Table 4.22 Observed piper trilinear water chemistry classification of alluvial and basalt groundwater sampled in the Boardman to Irrigon area. 118

Figure 4.27 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the Irrigon vicinity. 121

Figure 4.28 Schoeller Diagram of synoptic sampling data for alluvial groundwater collected in the Irrigon vicinity. 122

Figure 4.29 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 034 located west of Irrigon. 123

Figure 4.30 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 034 located west of Irrigon. 124

Figure 4.31 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the crop irrigation area between Boardman and Irrigon. 125

Figure 4.32 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the crop irrigation area between Boardman and Irrigon. 126

Figure 4.33 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 144 located south of Irrigon and adjacent to an irrigated field. 127

Figure 4.34 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 144 located south of Irrigon and adjacent to an irrigated field. 128

Figure 4.35 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the western portion (Ammunition Demolition Area) of the U.S. Army Umatilla Depot Activity. . . . 130

Figure 4.36 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in active landfill area (northeast portion) of the U.S. Army Umatilla Depot Activity. 132

Figure 4.37 Piper Trilinear Graph of project synoptic sampling data for shallow unconfined and regional alluvial groundwater collected in the Lamb Weston Inc. wastewater land application area adjacent to the U.S. Army Depot's northeast corner. 133

Figure 4.38 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected south of the U.S. Army Umatilla Depot Activity. 135

Figure 4.39 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected along Interstate 84 south of the U.S. Army Umatilla Depot Activity. 136

Figure 4.40 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the inactive landfill area (southern portion) of the U.S. Army Umatilla Depot Activity. 137

Figure 4.41 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected at general sites in the U.S. Army Umatilla Depot Activity. 138

Figure 4.42 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the Port of Morrow wastewater land application area east of Boardman. 140

Figure 4.43 Bromide versus potassium graph of project synoptic sampling data for alluvial groundwater collected in the active landfill area (northeast portion) of the U.S. Army Umatilla Depot Activity. . . 142

Figure 4.44 Bromide versus potassium graph of project synoptic sampling data for shallow unconfined and regional alluvial groundwater collected in the Lamb Weston Inc. wastewater land application area adjacent to the U.S. Army Depot's northeast corner. 143

Figure 4.45 Calcium, chloride, and nitrate-nitrogen variation along a composite groundwater flow path passing through the U.S. Army Umatilla Depot Activity. 145

Table 4.23 Nitrate concentration ranges detected in alluvial and basalt groundwater sampled in the Butter Creek to City of Umatilla area 152

Table 4.24 Volatile organic compounds and pesticides detected in the Butter Creek to City of Umatilla area. 158

Figure 4.46 Nitrate+nitrite versus time in Butter Creek Highway area south of Interstate 84 alluvial groundwater at project bimonthly sampling sites. 160

Table 4.25 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek Highway area south of Interstate 84. 161

Figure 4.47 Nitrate+nitrite versus time in Butter Creek-Umatilla River confluence area alluvial groundwater at bimonthly sampling sites. 163

Table 4.26 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek - Umatilla River confluence area. 164

Figure 4.48 Nitrate-nitrogen and groundwater elevation versus time for shallow unconfined alluvial groundwater at UMA 261 (LUB 042, Simplot MW-11S). 166

Figure 4.49 Nitrate-nitrogen versus time for shallow unconfined alluvial groundwater at UMA 250 (LUB 044, Simplot MW-12). 167

Figure 4.50 Nitrate-nitrogen versus time for shallow unconfined alluvial groundwater at UMA 248 (LUB 050, Simplot MW-17). 168

Figure 4.51 Nitrate+nitrite versus time in Butter Creek Highway north of Interstate 84 and east of the Umatilla River area alluvial groundwater at project bimonthly sampling sites. 170

Table 4.27 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek Highway area north of Interstate 84 and east of the Umatilla River. 171

Figure 4.52 Nitrate+nitrite versus time in Butter Creek Highway north of Interstate 84 and west of the Umatilla River area alluvial groundwater at project bimonthly groundwater sampling sites. . . 173

Table 4.28 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek Highway area north of Interstate 84 and west of the Umatilla River. 174

Figure 4.53 Nitrate+nitrite-nitrogen versus time in City of Umatilla area alluvial groundwater at the project bimonthly groundwater sampling sites. 176

Table 4.29 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Umatilla area. 177

Table 4.30 Observed Piper Trilinear water chemistry classification of alluvial and basalt groundwater sampled from the Butter Creek to Umatilla area. 179

Figure 4.54 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 187 in the Butter Creek Highway area south of Interstate 84. 181

Figure 4.55 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 187 in the Butter Creek Highway area south of Interstate 84. 182

Figure 4.56 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 122 in the Butter Creek-Umatilla River confluence area. 183

Figure 4.57 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 122 in the Butter Creek-Umatilla River confluence area. 184

Figure 4.58 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the Butter Creek Highway area north of Interstate 84 and west of the Umatilla River, including the Lamb-Weston food processing wastewater land application area. 185

Figure 4.59 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the Butter Creek Highway area north of Interstate 84 and west of the Umatilla River area. 186

Figure 4.60 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the Lamb-Weston food processing wastewater land application area. 187

Table 4.31 Nitrate concentration ranges detected in alluvial and basalt groundwater sampled from different locations in the City of Umatilla to Hat Rock to Echo Meadows area. 194

Table 4.32 Volatile organic compounds and pesticides detected in the City of Umatilla to Hat Rock to Echo Meadows area. 200

Figure 4.61 Nitrate+nitrite-nitrogen versus time in City of Umatilla and Hat Rock area alluvial groundwater at project bimonthly groundwater sampling sites. 202

Table 4.33 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Umatilla and Hat Rock areas. 203

Figure 4.62 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the Hermiston area north terrace. 204

Table 4.34 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Hermiston area north terrace. 205

Figure 4.63 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the north Stanfield-Hermiston Loop Road area. 207

Table 4.35 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the north Stanfield-Hermiston Loop Road area. 208

Figure 4.64 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the Stanfield area. 210

Table 4.36 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Stanfield area. 211

Figure 4.65 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the City of Echo area. 213

Table 4.37 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Echo area. . 214

Table 4.38 Observed Piper Trilinear water chemistry classification of alluvial and basalt groundwater sampled from the City of Umatilla to Hat Rock to Echo Meadows area. 216

Figure 4.66 Piper Trilinear graph of project synoptic sampling data for alluvial groundwater collected from the terrace north of Hermiston. 217

Figure 4.67 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected from the terrace north of Hermiston. 218

Figure 4.68. Piper Trilinear graph of project bimonthly sampling data for alluvial groundwater collected at UMA 116 located on the terrace north of Hermiston. 219

Figure 4.69 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 116 located on the terrace north of Hermiston. 220

Figure 4.70 Piper Trilinear graph of project synoptic sampling data for alluvial groundwater collected from the terrace south of Hermiston. 222

Figure 4.71 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected from the terrace south of Hermiston. 223

Figure 4.72 Piper Trilinear graph of project bimonthly sampling data for alluvial groundwater collected at UMA 156 located on the terrace south of Hermiston. 224

Figure 4.73 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 156 located on the terrace south of Hermiston. 225

Figure 4.74 Piper Trilinear graph of project synoptic sampling data for alluvial groundwater collected in the Echo-Stanfield area. 227

Figure 4.75 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the Echo-Stanfield area. 228

Figure 4.76 Piper Trilinear graph of project bimonthly sampling data for alluvial groundwater collected at UMA 190 located south of Echo. 229

Figure 4.77 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 190 located south of Echo. 230

Figure 4.78 Nitrate+nitrite-nitrogen versus electrical conductivity for all project wells sampled in the Lower Umatilla Basin. 236

Figure 4.79 Nitrate+nitrite-nitrogen versus calcium for all project groundwater samples. 238

Figure 4.80 Nitrate+nitrite-nitrogen versus calcium for along the Butter Creek Flow path. 239

Figure 4.81 Diagrammatic representation of wells located along a groundwater flow path and obtaining water from the same aquifer. 241

Figure 4.82 Butter Creek flow path map. 243

Figure 4.83 Saturation indices for calcite, dolomite, and gypsum along the Butter Creek flow path. 246

Figure 4.84 Ion activity graph. 247

Figure 4.85 Variation of calcium, chloride, and nitrate+nitrite-nitrogen along the Butter Creek flow path for project synoptic sampling data. . . 249

Figure 4.86 Nitrate+nitrite-nitrogen concentrations along the Butter Creek flow path at different sampling times. 251

Figure 4.87 Sodium and sulfate concentrations along the Butter Creek flow path. 252

Figure 4.88 Schematic diagram of J.R. Simplot Company wastewater irrigation circle 1A showing shallow and deep well locations as well as groundwater flow directions. 254

Figure 4.89 Schoeller Diagram showing constituent concentrations in alluvial groundwater sampled from shallow and deep upgradient wells (MW-11S, MW-11D) and shallow and deep downgradient wells (MW-13S, MW-11D) at Simplot wastewater irrigation circle 1A. 256

Table 4.39 Comparison of upgradient versus observed and predicted downgradient constituent concentrations in MW 13D groundwater at Simplot wastewater irrigation circle 1A. 258

Figure 4.90 Piper Trilinear Diagram of Butter Creek flow path data. 262

Figure 4.91 Modified Schoeller Diagram of the groundwater chemistry at UMA 120, UMA 122 and Simplot MW-20 (UMA 258). 264

Figure 4.92 Ionic ratios for constituents in groundwater at UMA 185, UMA 120, UMA 122. 265

Figure 4.93 Ionic ratios for constituents in groundwater at UMA 120, UMA 122, and Simplot MW-20 (UMA 258). 266

Figure 4.94 Nitrate-nitrogen versus time in shallow unconfined alluvial groundwater collected at Simplot monitoring well MW-20 (UMA 258, LUB 053). 269

Figure 4.95 Modified Schoeller Diagram of UMA 073 and UMA 081 and Umatilla River water chemistry data. 273

Table 4.40 Compilation of nitrogen isotopic sampling results 276

Figure 4.96 Delta ^{15}N versus nitrate-nitrogen concentration in groundwater from some of the Lower Umatilla Basin wells sampled for nitrogen isotopic analyses. 278

Figure 4.97 Delta ^{15}N versus nitrate-nitrogen concentration in groundwater from all Lower Umatilla Basin wells sampled for nitrogen isotopic analyses. 279

CHAPTER 4: GROUNDWATER CHEMISTRY

Abstract

The Lower Umatilla Basin Groundwater Management Area technical investigation conducted a variety of activities to primarily understand the distribution and source of nitrate in local groundwater.

Sampling activities included reconnaissance, bimonthly, synoptic, and nitrogen isotopic sampling. Laboratory activities included analyzing samples for nitrate, other nutrients, major ions, metals, other inorganic constituents, volatile organic compounds, pesticides, and nitrogen isotopes.

Data analysis activities included general statistics, chemical constituent distribution maps, multiple graphical analyses, groundwater chemistry computer modeling for selected areas, and stable nitrogen isotope interpretations. Data analyses indicate multiple influences affect the groundwater chemistry in the basin. However, not all influences contribute nitrate. These other influences include cyclic evaporation and dissolution in the vadose (unsaturated) zone, canal leakage causing dilution, and a minor influence from water-rock interactions. Analyses also indicate a hydraulic connection exists between alluvial groundwater and basalt water-bearing zones.

Project sampling detected nitrate concentrations as high as 76 mg/L. Local facilities have reported groundwater nitrate concentrations greater than 100 mg/L. Groundwater samples from nearly 31 percent of the project sampling sites in the basin had a maximum nitrate concentrations greater than the 10 mg/L drinking water standard.

Nitrate concentrations greater than 10 mg/L in the Lower Umatilla Basin groundwater is not evenly distributed. Higher nitrate concentrations occur within these areas:

- Threemile and Sixmile Canyons,
- Boardman
- Port of Morrow
- north, west, and south of the U.S. Army Umatilla Depot Activity,
- two sites within the Depot,
- the Butter Creek-Umatilla River confluence, and
- the terrace south of Hermiston.

The highest concentrations detected by project sampling occur between the Port of Morrow and Irrigon.

Identified nitrate sources include food processing wastewater activity at established food processing land application sites, irrigated crop agriculture, animal waste, septic systems, and the U.S. Army Umatilla Depot Activity.

Evidence indicates the time required for nitrate to travel from land surface to groundwater ranges from less than one month to 18 months depending upon local conditions and water available for transport. This travel time is faster than suggested by other investigators.

Evidence also indicates local groundwater transport of nitrate is slow. For example, an apparent nitrate plume emanating from the U.S. Army Depot explosive washout lagoons has moved less than 4 miles in three to four decades. Hydrogeologic and other evidence indicate slow movement may occur at other locations also.

Support for Groundwater Quality Conclusions

Groundwater often contains many dissolved chemical constituents. Understanding and distinguishing various natural and/or human influences on the groundwater chemistry is possible with careful analyses of the groundwater chemistry and the hydrogeologic environment.

This understanding is useful. For example, understanding natural chemical changes in local groundwater aids the understanding of groundwater occurrence and flow in an area. It assists in the identification of human influences. Additionally, understanding any unique chemical characteristics of potential contamination sources can improve the identification of groundwater contamination sources.

Appendix 4A presents a background discussion about primary influences on groundwater chemistry. Appendix 4B presents a background discussion about nitrogen isotopes and how they relate to nitrate sources.

This report describes the groundwater chemistry observed in the Lower Umatilla Basin with an emphasis on the occurrence of nitrate. The discussion includes:

- data collection,
- general statistics,
- analyses used,
- spatial and temporal groundwater chemistry variations observed in the basin,
- natural processes influencing groundwater chemistry, and
- human activities contributing to nitrate contaminated groundwater.

Materials and Methods Used for the Groundwater Chemistry Investigation

Introduction

The groundwater chemistry phase of the Lower Umatilla Basin Groundwater Management Area technical investigation included multiple groundwater sampling, laboratory analyses, and data analyses. The groundwater sampling included reconnaissance, bimonthly, synoptic, and nitrogen-isotope sampling. The groundwater samples were chemically analyzed at Oregon Department of Environmental Quality (DEQ), Oregon Department of Agriculture, Oregon State University Department of Agricultural Chemistry, and Boston University Stable Isotope Laboratories. Data analyses conducted included some groundwater chemistry computer modeling, evaluation of stable nitrogen isotopes, and comparisons of constituent versus time, location, other constituents, and groundwater elevations.

Groundwater Sampling

The following presents how and why reconnaissance, bimonthly, synoptic, and nitrogen-isotope sampling were conducted. Wells used are presented in Appendix 4C and shown on Plate 4.1.

Reconnaissance Sampling

Lower Umatilla Basin reconnaissance groundwater sampling was conducted from July 1990 through October 1991. The sampling effort served to provide a preliminary understanding about the nature, extent and concentration range of local groundwater contamination in the basin. That understanding directed decisions about the data analyses and additional groundwater sampling needed to characterize the groundwater quality and contamination sources in the basin.

DEQ staff collected 206 total reconnaissance samples from 2 springs, one field drain, and 179 wells. The samples were collected and transported as directed by the field sampling protocol in DEQ's Laboratory mode of operations manual (Oregon DEQ, 1986) with subsequent attachments and a September 4, 1990 project sampling plan (see Appendix 4D). Initial reconnaissance sampling efforts collected samples with the greatest potential for groundwater contamination. Later reconnaissance sampling efforts improved the geographic distribution of samples, and collected samples representing little or no land use impacts.

Well construction was not considered for sample site selection during the initial reconnaissance sampling. As a result, samples were collected from 25 wells with no water well report (well log) and 9 wells that apparently mix water from the alluvial aquifer with water from one or more basalt water-bearing zones. Later reconnaissance sampling limited collecting groundwater from wells that have a water well report and appear to obtain water from a single source.

Bimonthly Sampling

Lower Umatilla Basin bimonthly groundwater sampling at 35 to 40 wells selected to represent the basin began in October 1991. The ongoing sampling effort serves to provide information about seasonal and long term nitrate and other constituent concentration trends at different locations and along groundwater flow paths. This data is needed to identify recharge and contamination sources at different locations, understand the fate of contaminants and other constituents along groundwater flow paths over time, and determine whether the groundwater quality is improving, degrading or remains unchanged at different locations.

Wells selected for the bimonthly sampling passed two screenings. The first screening selected wells that: Oregon Water Resources Department (OWRD) and/or DEQ staff had previously located and observed; received groundwater from alluvium only or from a single basalt water-bearing zone only; and appeared accessible for sampling throughout the year. The second screening selected wells that satisfied one or more of the following criteria:

- would provide data along a groundwater flow path; or
- would provide data in an isolated area; or
- had groundwater with moderate to high nitrate concentrations; or
- had groundwater with previously detected pesticides or volatile organic chemicals.

The list of the wells used for bimonthly sampling is presented in Appendix 4C.

Bimonthly groundwater sampling in the Lower Umatilla Basin occurs in January, March, May, July, September, and November. DEQ laboratory staff conducted the sampling field work from 1991 through 1994. In 1995, DEQ laboratory staff and a Umatilla County Soil and Water Conservation District staff person began alternately conducting the field work. Sample collection and transport has followed and will continue to follow the field sampling protocol found in the 1986 DEQ Laboratory mode of operations manual (Oregon Department of Environmental Quality, 1986) with subsequent attachments, the 1993 DEQ Laboratory Field Sampling Reference Guide (Oregon Department of Environmental Quality, 1993), and a November 1, 1991 project sampling plan with subsequent amendments (see Appendix 4E).

Synoptic Sampling

Synoptic sampling at 207 wells, 26 surface water locations, and a field drain in the Lower Umatilla Basin occurred during late June and early July 1992. Alluvial groundwater was collected from 179 wells, and groundwater from basalt water-bearing zones was collected from 28 wells. Sampling provided this information:

- concurrent data necessary for conducting basin-wide data analyses;
- characterizing the basin-wide distribution of nitrate and other constituents in alluvial groundwater;
- identifying different alluvial aquifer recharge and contamination sources at different locations in the basin; and
- understanding the fate of contaminants and other constituents along various alluvial groundwater flow paths.

An Oregon Strategic Water Management Group Groundwater Protection Grant ($30,000) made the synoptic sampling possible. Synoptic sampling was needed because reconnaissance and bimonthly sampling data were not sufficient for basin-wide data analyses. Reconnaissance samples were collected basin-wide over a 15 month period. Data differences could be time related. Bimonthly samples are collected concurrently and along some groundwater flow paths, but the number of samples collected are not sufficient for basin-wide data analyses.

Collecting the synoptic samples was a cooperative effort. Oregon Department of Environmental Quality, Oregon Water Resources Department, Oregon Department of Agriculture, and Oregon Health Division staff collected samples from 134 wells, 26 surface water locations, and a field drain. Port of Morrow, J.R. Simplot Company, A.E. Staley Manufacturing Company, Hermiston Foods, Lamb-Weston, Incorporated, Portland General Electric, City of Irrigon, and U.S. Army Umatilla Depot Activity staff or their consultants collected samples from 73 wells total at their facilities. The sampling sites are listed in Appendix 4C. Samples were collected and transported in a manner consistent with the field sampling protocol found in the 1986 DEQ Laboratory mode of operations manual (DEQ, 1986) with subsequent attachments.

Sampling for Nitrogen-Isotopic Analysis

Sampling for nitrogen-isotopic analysis occurred in the Lower Umatilla Basin during the fall of 1993, spring of 1994, and fall of 1994 at approximately 20 wells, 3 lysimeters, and a food processing wastewater surge pond. The sampling effort provides data to verify or improve the identification of processes and nitrate

sources influencing Lower Umatilla Basin groundwater. A U.S. Environmental Protection Agency 319 Grant to Dr. Dennis Nelson, Oregon Health Division, and Margot Truini, a Portland State University graduate student, funds this effort.

Truini and Nelson conducted the nitrogen isotope sampling. Wells selected for groundwater sampling are located in the Butter Creek drainage, the U.S. Army Umatilla Depot Activity Explosive Washout Lagoons vicinity, areas associated with food processing wastewater land application, areas associated with past animal feedlots, and areas associated with irrigated crop agriculture using commercial fertilizers. Lysimeters selected for sampling are located within food processing wastewater land application areas. Most wells were sampled in the fall of 1993, spring of 1994, and fall of 1994 to capture any variation with time, using standard techniques. Sampling occurred after three well bore volumes were purged and the temperature and electrical conductivity of the purge water had stabilized. The samples were shipped in ice to the Boston University Stable Isotope Laboratory for isotopic chemical analysis.

Laboratory Chemical Analyses Conducted

The laboratories used and laboratory chemical analyses conducted for the reconnaissance, bimonthly, synoptic, and nitrogen isotope samples in the Lower Umatilla Basin differed. The differences resulted from the availability of laboratories to conduct the chemical analyses and a need to conserve project resources.

Laboratory analysis procedures included conducting duplicate analyses to assess laboratory results. Those analyses assure the reliability and precision of the laboratory results. This in turn assures investigators that laboratory analytical uncertainty is far less than differences observed between samples.

Reconnaissance Sampling

Reconnaissance samples were chemically analyzed by DEQ, Oregon Department of Agriculture, and OSU Department of Agricultural Chemistry laboratories. The DEQ laboratory staff conducted chemical analyses for nutrients (including nitrate), total ions and metals, chemical oxygen demand, total organic carbon, volatile organic compounds, and physical parameters. The ODA and the OSU Department of Agricultural Chemistry laboratory staff analyzed all samples for pesticides. A September 4, 1990 project sampling plan (see Appendix 4D) describes the chemical analyses conducted and the laboratory methods used.

Bimonthly Sampling

Bimonthly groundwater sampling chemical analyses occurs primarily at DEQ and Oregon Department of Agriculture laboratories. DEQ laboratory staff conduct chemical analyses for nitrate, other inorganic constituents, and volatile organic compounds. The total list of constituents analyzed varies according to a sampling plan schedule. The ODA laboratory staff conduct chemical analyses for pesticides for a limited number of samples according to a sampling plan schedule. The OSU Department of Agricultural Chemistry laboratory staff has contributed chemical analyses for pesticides. A November 1, 1991 project sampling plan with subsequent amendments (see Appendix 4E) describes the chemical analyses being conducted, the schedule for the analyses, and the laboratory methods used.

Synoptic Sampling

DEQ laboratory staff conducted the synoptic sampling chemical analyses. The analyses included nutrients (including nitrate), major ions, and metals.

Nitrogen Isotope Analysis

The Boston University Stable Isotope Laboratory conducted the nitrogen isotope chemical analysis.

Data Analyses Conducted

Understanding the distribution and source of nitrate contaminated groundwater is the primary purpose of the Lower Umatilla Basin groundwater technical investigation. The complexity of natural processes, land uses, groundwater flow, and groundwater chemistry in the basin made using various data analyses necessary to achieve that understanding. Data analyses conducted and their purpose are summarized in the following subsections.

General Statistics

Basic statistical analyses of the reconnaissance sampling data was conducted to gain an initial understanding of the groundwater contamination in the Lower Umatilla Basin. The statistical analyses included nitrate, selected constituents, pesticides, and volatile organic compounds. The statistics were useful for defining the nature of the groundwater contamination problem in the Lower Umatilla Basin. They were not useful for characterizing the fate of the groundwater contamination or identifying the contamination sources.

Chemical Constituent Maps

Concentration contour maps and maximum constituent concentration maps were produced and analyzed (Plates 4.2 through 4.13). The maps show the concentration distribution of selected chemical constituents across the basin. That concentration distribution was compared to the distribution of current and historic land uses in the basin to identify groundwater contamination sources and other influences on the groundwater chemistry.

Nine maximum concentration maps were produced: nitrate+nitrite-nitrogen, total dissolved solids (TDS), sodium, arsenic, chloride, phosphate, bromide, boron, and vanadium. For each map, the maximum concentration detected in groundwater sampled from July 1990 through March 1993 at each sampling site was identified. The number of samples collected at each site during that period varied from one to more than ten. Concentration ranges were color-coded, and each groundwater source (alluvial, basalt, and uncertain) was assigned a symbol. The appropriate symbol and color was printed at each sampling location to make reviewing the concentration distribution easier. Data from other sources were added in areas where project data were not available.

The nine constituents used for the maximum concentration maps were selected for different purposes. Nitrate is the focus of this investigation. TDS became a concern during the land use review and constituent loading assessment phases of this investigation (see Chapter 3). Arsenic and sodium were mapped because they were detected in Lower Umatilla Basin groundwater samples at concentrations that could pose health concerns. Phosphate, chloride, bromide, and boron were mapped to help identify different sources of nitrate in local groundwater. Vanadium was mapped, because the unusual concentrations detected in Lower Umatilla Basin groundwater may be linked to local groundwater contamination.

The maximum concentration maps offer benefits and limitations for data analyses. The benefits relate to the fact that not all Lower Umatilla Basin project wells were sampled during a single sampling event, nor did maximum constituent concentrations at different sites occur at the same time. Using maximum concentrations detected increased the number of project wells represented on the map, highlighted contaminated groundwater areas, and helped preliminary assessment of groundwater contamination sources. Using data from multiple sampling events limited data analyses also. It prevented some well to well data comparisons.

Concentration contour maps showing the distribution of nitrate+nitrite-nitrogen and total dissolved solids in alluvial groundwater during June-July 1992 were produced using synoptic sampling data. Concurrent Simplot Feedlot data were also used for the nitrate+nitrite-nitrogen map. Nitrate was mapped, because it is the focus of this investigation. TDS was mapped for two reasons. TDS became a possible constituent of concern during this investigation, and TDS concentration distribution variations appear related to different nitrate sources and other groundwater chemistry influences in the basin.

Linear interpolation between alluvial groundwater sampling sites was used to draw the contours. Shallow unconfined alluvial groundwater and basalt groundwater sampling sites were not used for the contouring. However, these sampling sites and the associated nitrate+nitrite-nitrogen and TDS concentrations were printed on the map for comparison. Color between contours was added to make the concentration distribution patterns more readable.

The contour maps best show the pattern of high versus low concentration for nitrate and TDS. However, caution must be used when reading the maps. Some contour shapes are artifacts of the contouring method. For example, the shape and size of some higher concentration areas may be irregular and either enlarged or reduced due to sparse data in the area. Without careful review, the irregular shapes could cause some misinterpretations about contamination sources and the direction of contaminant movement. Similarly, the size of high concentration areas may be misinterpreted as larger or smaller than really exist. Despite these limitations, the contour maps are very useful for understanding area-wide groundwater chemistry and for identifying contamination sources.

Graphical Analyses of Chemical Data

Graphs used to analyze Lower Umatilla Basin groundwater and surface water chemistry data included a variety of x-y graphs, Piper trilinear graphs and Schoeller Diagrams. The x-y graphs show the relationship between a component, such as constituent concentrations and groundwater elevations, plotted along a vertical axis and another component such as time, location, or another constituent, plotted along a horizontal axis. Piper trilinear graphs and Schoeller Diagrams, show the relationship between multiple constituents. Project data analysis reviewed the graphs for relationships and variability to identify processes and nitrate sources that influence the basin's groundwater.

Computer Modeling Groundwater Chemistry Variations

This investigation used NETPATH (Plummer and others, 1991) and PHREEQE (Parkhurst and others, 1980) groundwater chemistry computer models for data analyses. The project selectively used computer models to understand and differentiate natural versus human influences upon Lower Umatilla Basin groundwater.

PHREEQE is a "forward" model that calculates how groundwater chemistry will change in a reaction with minerals identified by the model user. Mixing is an option also. This investigation used PHREEQE to assess the likelihood that constituent concentrations in some groundwater samples are a result of natural water-rock reactions.

This investigation used NETPATH to assess and refine interpretations of natural and human influences on groundwater chemistry along selected groundwater flow paths. NETPATH calculates the net geochemical mass-balance reactions (with or without mixing) that may be responsible for changing an initial water chemistry to a final water chemistry along a groundwater flow path segment. The model user must specify the appropriate initial water(s), final water, and mineral phases potentially reacting with the water based upon independent and site specific data. The equation the program attempts to solve is:

{[Initial water 1] + [Initial water 2 (if mixing)] + [Minerals dissolved]}
= {[Final water] + [Minerals precipitated]}

Often, NETPATH generates many possible solutions. The solutions represent groundwater chemical evolution possibilities rather than prove certain reactions have occurred. The solutions become useful when they provide chemical reaction pathways that appear consistent with observed groundwater chemistry changes between supposedly related sampling sites.

Nitrogen-Isotopic Analyses

The nitrogen isotopic composition of Lower Umatilla Basin groundwater was analyzed to identify sources of nitrogen at selected groundwater sampling locations. This was conducted as a supplement to other data analyses that identify nitrogen sources. Appendix 4B provides an explanation about nitrogen isotopes and how they can be used to identify sources of nitrogen in groundwater.

General Groundwater Chemistry Data Observations and Interpretations

Introduction

State agency staff conducted a variety of groundwater sampling and data analyses for this groundwater technical investigation. The materials and methods section presented the types of sampling and analyses conducted. Appendix 4F provides July 1990 through March 1993 project groundwater sampling data for selected inorganic constituents. Appendix 4G provides July 1990 through December 1994 data for pesticides and volatile organic compounds.

This section presents general groundwater chemistry data observations and interpretations. Local observations and interpretations are presented in area specific sections that follow. The area specific sections are included to help the reader find all local information more easily.

General Statistics and Occurrence

State agency staff collected and chemically analyzed more than 825 groundwater samples from more than 250 Lower Umatilla Basin wells from July 1990 through March 1993. Staff collected the samples during reconnaissance, bimonthly, and a synoptic groundwater sampling. The bimonthly groundwater sampling continues. Samples came from wells receiving groundwater from alluvial sediments, undifferentiated basalt water-bearing zone(s), both alluvial sediments and undifferentiated basalt water-bearing zone(s), and unidentified sources (no water well report found for these wells).

Nitrate+Nitrite-Nitrogen

The groundwater technical investigation focused primarily upon nitrate. Table 4.1 shows nitrate+nitrite-nitrogen statistics related to groundwater sampling in the basin from July 1990 through March 1993. It represents the maximum concentration detected in groundwater sampled from each project well. Figure 4.1 shows the maximum concentration distribution for all the project wells sampled. The number of samples collected at each site varied from one to more than ten.

Nearly 30 percent of the project groundwater samples and nearly 31 percent of the project groundwater sampling sites had nitrate+nitrite-nitrogen concentrations greater than the current 10 mg/L drinking water standard. The percent of samples and sites with concentrations exceeding 10 mg/L is greatest for groundwater from alluvial sediments. The greatest concentrations detected in groundwater sampled from alluvial sediments and basalt water-bearing zones were 76 mg/L and 64 mg/L, respectively. Conversely, approximately 26 percent of the groundwater sampling sites had nitrate+nitrite-nitrogen concentrations less than 2 mg/L.

Table 4.1 Statistics of maximum nitrate+nitrite-nitrogen concentration detected in groundwater sampled from each project well.

	Number of Wells With NO_3+NO_2-N Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)	Project Wells with Sample(s) > 10 mg/L	
						Number	Percent
All Wells With NO_3+NO_2-N Analyses	252	76.00	<0.02	9.66	5.80	78	30.95
Groundwater from Alluvium	186	76.00	<0.02	10.49	6.45	64	34.41
Groundwater from Basalt	32	64.00	<0.02	7.48	1.04	6	18.75
Groundwater from Basalt & Alluvium	9	20.00	0.02	6.72	3.60	3	33.33
Undetermined Source	25	31.00	<0.02	7.34	4.50	5	20.00

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The Maximum Contaminant Level for Nitrate in Drinking Water is 10 mg/L.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

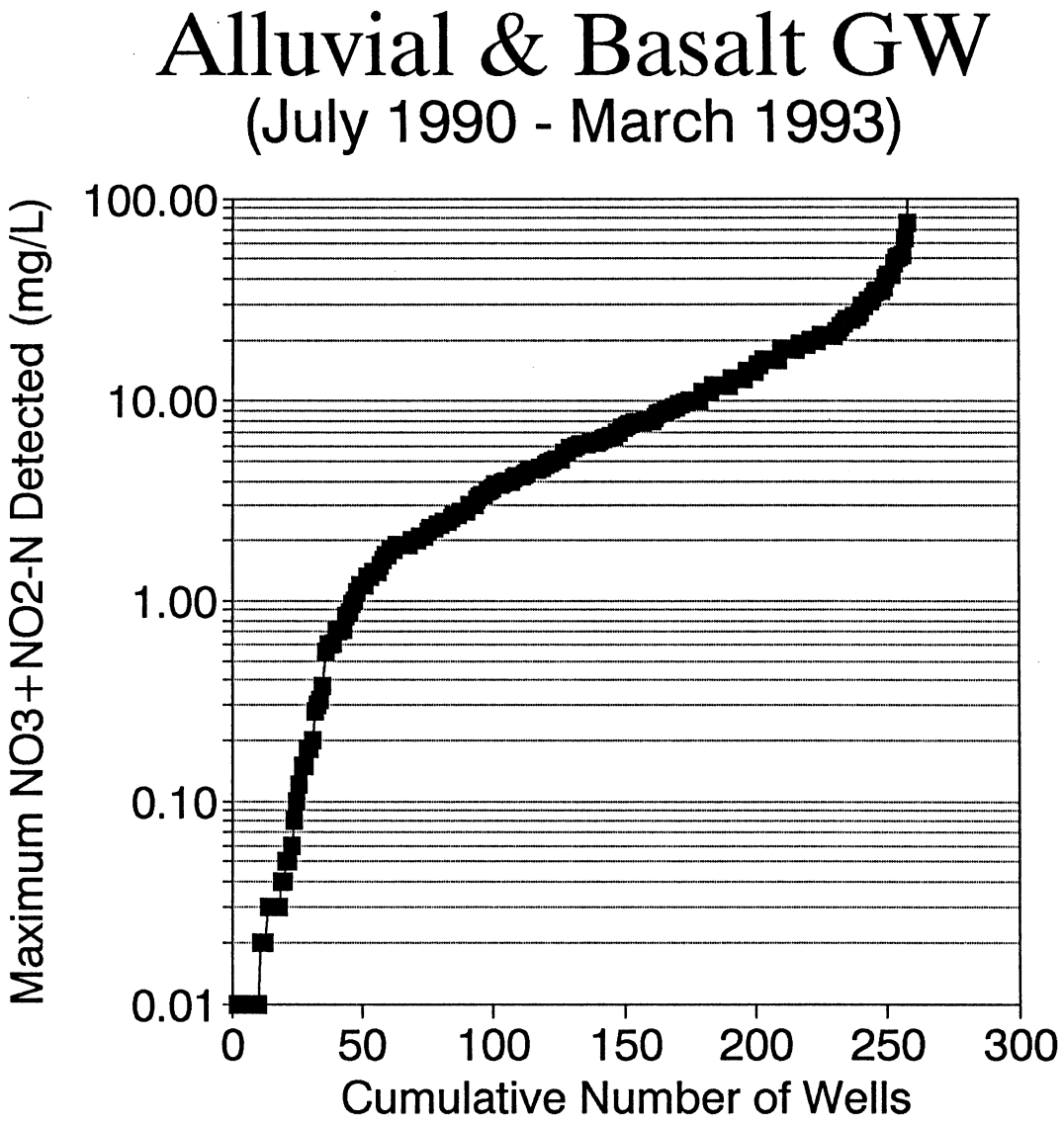


Figure 4.1 Cumulative frequency of maximum nitrate+nitrite-nitrogen concentrations detected in groundwater sampled from each project sampling site.

Note: The graph shows the number of project groundwater sampling site with a maximum nitrate+nitrite-nitrogen concentration less than a given concentration.

Areas of high and low nitrate+nitrite-nitrogen concentrations are not uniformly distributed across the basin. Plate 4.2 shows the interpolated concentration distribution for the June-July 1992 synoptic sampling. Plate 4.3 shows the maximum concentration detected at each project sampling site by color coded concentration ranges.

Areas where nitrate+nitrite-nitrogen concentrations in project groundwater samples exceed 10 mg/L include:

- the Three and Six Mile Canyon area;
- the Boardman area;
- the area between the Navy Bombing Range, U.S. Army Umatilla Depot Activity, Irrigon, and the wildlife refuge;
- the area between Irrigon and Umatilla;
- the northeast corner of the Army Depot;
- the central area of the Army Depot; the area between the Army Depot and Lost Lake;
- the general Butter Creek and Umatilla River confluence area;
- an area between Interstate 82 and the Umatilla River; and
- an area between Stanfield Loop Road and Diagonal Road near the Cold Springs Reservoir.

The highest concentration area is located between Boardman and Irrigon where center pivot crop irrigation currently occurs. Nitrogen isotopic analysis identifies commercial fertilizer as the nitrate source.

The sources responsible for the higher concentrations across the basin appear to vary by location. Past and/or current general sources include:

- agriculture using various irrigation methods including center pivots;
- food processing wastewater land application;
- livestock operations;
- U.S. Army Umatilla Depot Activity;
- sewage waste at municipal infiltration beds, large on-site systems, and areas with concentrated individual septic systems.

Local sources are presented in the area specific sections.

Low concentration areas include:

- locations in the Three and Six Mile Canyon area;
- the Irrigon area;
- the western and southwestern portion of the Army Depot;
- the Hermiston trough area;
- an area enclosed by Stanfield Loop Road;
- an area between Highway 395 and Butter Creek Road south of Highland Avenue;
- a small area near the Butter Creek and Umatilla River confluence;
- portions of Echo Meadows area; and
- some locations near and south of Lost Lake.

Background conditions and dilution appears responsible for some of the lower concentrations. This is discussed more in area specific sections.

Groundwater nitrate transport in portions of the basin appears slow. For example, an elevated nitrate+nitrite-nitrogen concentration area in the middle of the U.S. Army Umatilla Depot Activity appears to be a plume emanating from the Explosive Washout Lagoon area (Plate 4.2). The apparent plume extending through UMA 216 may be real, or it may a contouring artifact. Regardless, analysis of the nitrate concentration distribution, the local hydrogeology, and the site history indicates contaminant transport in the local alluvial groundwater may take decades. Depot explosive washout activity ended during the mid-1960s. If the apparent plume extending through UMA 216 is real, nitrate from the washout lagoons has moved less than four miles over three to four decades. If the plume through UMA 216 is not real, nitrate from the washout lagoons has moved less than 0.5 miles over the same time period. This apparently long travel time has important implications about the time needed for groundwater quality improvements to occur within the Depot and similar areas.

Total Dissolved Solids

Total Dissolved Solids (TDS) became a concern during the land use review and constituent loading assessment phases of this investigation. Table 4.2 shows TDS statistics related to project groundwater sampling from July 1990 through March 1993. It represents the maximum concentration detected in groundwater sampled from each project well.

More than 20 percent of the project groundwater samples and more than 25 percent of the project groundwater sampling sites had TDS concentrations greater than the current 500 mg/L secondary (aesthetic) drinking water standard. The percent of sampling sites with maximum concentrations exceeding 500 mg/L is greatest for groundwater from alluvial sediments. The greatest concentration detected in groundwater sampled from alluvial sediments and basalt water-bearing zones was 1200 mg/L and 1600 mg/L, respectively.

Areas of high and low TDS concentrations are not uniformly distributed across the Lower Umatilla Basin. Plate 4.4 shows the interpolated concentration distribution for the June-July 1992 synoptic sampling. Plate 4.5 shows the maximum concentration detected at each project sampling site by color coded concentration ranges.

High and low TDS concentration areas are similar to the distribution of high and low nitrate+nitrite-nitrogen concentration areas with some exceptions. The exceptions appear related to the nitrate sources. Areas with the highest TDS concentrations are located along Six Mile Canyon and between Boardman and Irrigon. A high TDS concentration area in the middle of the U.S. Army Umatilla Depot Activity is much less extensive than the high nitrate+nitrite-nitrogen concentration area. An area between Interstate 82 and the Umatilla River with nitrate+nitrite-nitrogen concentrations in groundwater exceeding 10 mg/L has TDS concentrations in groundwater less than 500 mg/L. Local influences upon the TDS concentration in groundwater are discussed in the area specific sections.

Table 4.2 Statistics of maximum total dissolved solids concentrations detected in groundwater sampled from each project well.

	Number of Wells With TDS Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)	Project Wells with Sample(s) > 500 mg/L	
						Number	Percent
All Wells With TDS Analyses	247	1600	140	425	370	63	25.51
Groundwater from Alluvium	183	1200	140	432	380	52	28.42
Groundwater from Basalt	32	1600	190	444	350	6	18.75
Groundwater from Basalt & Alluvium	9	540	260	361	330	2	22.22
Undetermined Source	23	740	230	372	320	3	13.04

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The Maximum Contaminant Level (secondary) for TDS in Drinking Water is 500 mg/L.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Arsenic

Arsenic in groundwater can pose a health risk. Table 4.3 shows the statistics for total arsenic related to project groundwater sampling from July 1990 through March 1993. The table represents the maximum concentration detected in groundwater sampled from each project well. Plate 4.6 shows the maximum concentration detected at each project sampling site by color coded concentration ranges.

Four dispersed alluvial groundwater sampling sites had total arsenic concentrations exceeding the current 0.05 mg/L drinking water standard. Their locations are: the northwest corner of the U.S. Army Umatilla Depot Activity; the east side of the Depot; east of the Depot's northeast corner; and west of Stanfield.

Arsenic was not detected in groundwater samples collected from some areas. Those areas include portions of Six Mile Canyon, most of Township 3 North from Range 25 through 29 East, portions of the northeast corner of the U.S. Army Depot, portions between Umatilla River Road and the U.S. Army Depot, an area south of Feedville Road and east of Highway 395, and a southeastern portion of Stanfield Loop Road.

Table 4.3 Statistics of maximum total arsenic concentrations detected in groundwater sampled from each project well.

	Number of Wells With Arsenic Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentrations (mg/L)	Project wells with sample(s) > 0.05 mg/L	
						Number	Percent
All Wells With Arsenic Analyses	253	0.120	<0.005	0.007	0.006	4	1.58
Groundwater from Alluvium	187	0.120	<0.005	0.008	0.007	4	2.14
Groundwater from Basalt	32	0.013	<0.005	0.003	< 0.005	0	0.00
Groundwater from Basalt & Alluvium	9	0.012	<0.005	0.004	< 0.005	0	0.00
Undetermined Source	25	0.013	<0.005	0.005	0.006	0	0.00

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The Maximum Contaminant Level for Arsenic in Drinking Water is 0.05 mg/L.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Sodium

Most natural water contains low levels of sodium. Sodium sources include human activity and natural processes. Water chemistry is frequently characterized by the relationship between sodium and other common ions such as magnesium, potassium, calcium, chloride, sulfate, carbonate and bicarbonate.

Elevated sodium concentrations in groundwater can pose a health risk to persons on a physician prescribed sodium restricted diet. These individuals should notify their doctor if the water they consume contains sodium exceeding 20 mg/L.

Table 4.4 presents total sodium statistics related to project groundwater sampling from July 1990 through March 1993, and Plate 4.7 shows the distribution of maximum concentration detected at each project sampling site by color coded concentration ranges. The table represents the maximum concentration detected in groundwater sampled from each project well. Nearly 85 percent of all project sampling sites had total sodium concentrations in groundwater greater than the 20 mg/L currently recommended for persons with a physician prescribed sodium restricted diet. The highest concentrations detected in groundwater from alluvial sediments versus basalt water-bearing zones was 300 mg/L and 140 mg/L, respectively. However, groundwater from basalt water-bearing zones had the highest average maximum concentration. The occurrence of sodium related to sources and other chemical constituents is discussed in the area specific sections.

Table 4.4 Statistics of maximum total sodium concentrations detected in groundwater sampled from each project well.

	Number of Wells With Sodium Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)	Project wells with sample(s) > 20 mg/L	
						Number	Percent
All Wells With Sodium Analyses	253	300.0	8.9	44.5	37.0	214	84.58
Groundwater from Alluvium	187	300.0	8.9	41.3	32.0	154	82.35
Groundwater from Basalt	32	140.0	15.0	62.8	60.5	28	87.50
Groundwater from Basalt & Alluvium	9	99.0	20.0	54.1	50.0	8	88.89
Undetermined Source	25	100.0	17.0	42.4	38.0	24	96.00

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The Maximum Sodium Concentration in Drinking Water Recommended for Persons with a Physician Prescribed Sodium Restricted Diet is 20.0 mg/L.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Chloride

Natural water commonly contains chloride. Chloride sources include human activity and natural processes. Water chemistry is frequently characterized by the relationship between chloride and other common ions such as magnesium, potassium, calcium, sodium, sulfate, carbonate and bicarbonate.

Table 4.5 shows the chloride statistics related to project groundwater sampling from July 1990 through March 1993. The table represents the maximum concentration detected in groundwater sampled from each project well. Only one sampling site had a groundwater chloride concentration exceeding the current 250 mg/L secondary (aesthetic) drinking water standard. That site obtains groundwater from basalt.

Plate 4.8 shows the distribution of maximum chloride concentration detected at each project sampling site by color coded concentration ranges. The occurrence of chloride related to sources and other chemical constituents is discussed in the area specific sections.

Table 4.5 Statistics of maximum chloride concentrations detected in groundwater sampled from each project well.

	Number of Wells With Chloride Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)	Project Wells with Samples > 250 mg/L	
						Number	Percent
All Wells With Chloride Analyses	253	490	3.3	32.4	19.0	1	0.40
Groundwater from Alluvium	187	190	3.3	30.6	19.0	0	0.00
Groundwater from Basalt	32	490	4.2	53.6	21.0	1	3.13
Groundwater from Basalt & Alluvium	9	73	11.0	25.0	16.0	0	0.00
Undetermined Source	25	53	6.7	20.7	17.0	0	0.00

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The Maximum Contaminant Level (secondary) for Chloride in Drinking Water is 250 mg/L.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Phosphate, Boron, and Bromide

The occurrence and relative proportions of phosphate, boron, and bromide to other chemical constituents in groundwater can occasionally help identify nitrate sources. Tables 4.6, 4.7, and 4.8 show total phosphate, dissolved boron, and bromide statistics related to project groundwater sampling from July 1990 through March 1993. They represent the maximum concentration detected in groundwater sampled from each project well. Groundwater from alluvial sediments had the maximum concentration detected for each constituent.

Plates 4.9, 4.10, and 4.11 show the distribution of maximum total phosphate, dissolved boron, and bromide concentrations detected at each project sampling site by color coded concentration ranges. The occurrence of these constituents relative to nitrate, other chemical constituents, and nitrate sources is discussed in area specific sections.

Table 4.6 Statistics of maximum total phosphate concentrations detected in groundwater sampled from each project well.

	Number of Wells With Total-PO_4 Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)
All Wells With Total PO_4 Analyses	252	50.80	<0.01	0.48	0.07
Groundwater from Alluvium	186	50.80	0.01	0.63	0.08
Groundwater from Basalt	32	0.14	<0.01	0.04	0.02
Groundwater from Basalt & Alluvium	9	0.05	<0.01	0.02	0.02
Undetermined Source	25	0.32	0.01	0.09	0.06

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Table 4.7 Statistics of maximum dissolved boron concentrations detected in groundwater sampled from each project well.

	Number of Wells With Boron Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)
All Wells With Boron Analyses	175	0.18	<0.03	0.03	0.04
Groundwater from Alluvium	114	0.18	<0.03	0.04	0.04
Groundwater from Basalt	27	0.08	<0.03	0.02	0.03
Groundwater from Basalt & Alluvium	9	0.07	<0.03	0.03	0.03
Undetermined Source	25	0.08	<0.03	0.02	0.03

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Table 4.8 Statistics of maximum bromide concentrations detected in groundwater sampled from each project well.

	Number of Wells With Bromide Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)
All Wells With Bromide Analyses	205	4.30	<0.05	0.26	0.13
Groundwater from Alluvium	176	4.30	<0.05	0.26	0.13
Groundwater from Basalt	27	1.90	<0.05	0.25	0.18
Groundwater from Basalt & Alluvium	1	0.07	0.07	0.07	0.07
Undetermined Source	1	0.08	0.08	0.08	0.08

Note: For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Vanadium

Vanadium concentrations in Lower Umatilla Basin groundwater are an unusual curiosity that other researchers may want to investigate. Typically, vanadium concentrations in groundwater rarely exceed 0.01 mg/L (Hem, 1985). However, average maximum vanadium concentrations in Lower Umatilla Basin basalt water-bearing zones and alluvial sediment groundwater samples are 0.02 mg/L and 0.04 mg/L. The maximum concentration detected was 2.00 mg/L in an alluvial sediment groundwater sample.

Table 4.9 shows the total vanadium statistics related to project groundwater sampling from July 1990 through March 1993. The table represents the maximum concentration detected in groundwater sampled from each project well. Plate 4.12 shows the distribution of the maximum total vanadium concentration detected at each project sampling site by color coded concentration ranges.

Table 4.9 Statistics of maximum total vanadium concentrations detected in groundwater sampled from each project well.

	Number of Wells With Vanadium Analyses	Maximum Concentration (mg/L)	Minimum Concentration (mg/L)	Average Concentration (mg/L)	Median Concentration (mg/L)
All Wells With Vanadium Analyses	250	2.00	<0.03	0.03	< 0.03
Groundwater from Alluvium	185	2.00	<0.03	0.04	< 0.03
Groundwater from Basalt	32	0.07	<0.03	0.02	< 0.03
Groundwater from Basalt & Alluvium	9	0.04	<0.03	0.01	< 0.03
Undetermined Source	24	0.09	<0.03	0.02	< 0.03

For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through March 1993.
Note: The average concentration calculations used 0 mg/L for concentrations below the laboratory detection limit.

Volatile Organic Compounds and Pesticides

Volatile organic compounds (VOCs) or pesticides in groundwater come from human activity. Table 4.10 shows the six constituents detected in Lower Umatilla Basin groundwater, the number of sampling sites associated with the detections, the maximum concentrations detected, and the maximum contaminant level for drinking water. Appendix 4G presents all the VOCs and pesticides detected from July 1990 through September 1994. Plate 4.13 shows the distribution of the different constituents detected.

Most of the Lower Umatilla Basin groundwater samples containing VOCs and/or pesticides came from alluvial sediments. Only ethylene dibromide (EDB) was detected at concentrations exceeding current drinking water standards. The occurrence of these constituents is discussed in the area specific sections.

Table 4.10 Volatile organic compounds and pesticides concentrations detected in groundwater sampled from each project well.

Constituent	Number of Groundwater Sampling Sites with Detections	Maximum Concentration Detected	Maximum Contaminant Level for Drinking Water
Ethylene Dibromide (EDB)	1	0.0026 mg/L	0.00005 mg/L
1,1,2,2 Tetrachloroethylene	1	0.0011 mg/L	0.0050 mg/L
Chloroform	4	0.0028 mg/L	0.1000 mg/L
Toluene	1	0.0013 mg/L	1.0000 mg/L
Atrazine	6	0.0023 mg/L	0.0030 mg/L
Dacthal Acid	4	0.0200 mg/L	---
For Groundwater Samples Collected from Lower Umatilla Basin Groundwater Management Area Project Wells: July 1990 through September 1994			

General Graphic Analyses

State agency staff conducted graphical analyses of Lower Umatilla Basin sampling data to identify the chemical and physical processes influencing observed groundwater chemistry variations. Alluvial groundwater data and basalt water-bearing zone groundwater data were analyzed separately, because they represent different hydrogeologic units. This section presents basin-wide observations. Area specific sections present local observations.

Nitrate Versus Other Chemical Constituents

A positive correlation exists between nitrate+nitrite-nitrogen and some chemical constituents in Lower Umatilla Basin groundwater. For example, the proportion of chloride and sulfate relative to other anions often increases with increasing nitrate+nitrite-nitrogen concentrations. Total dissolved solids and electrical conductivity best correlate with nitrate+nitrite-nitrogen concentrations. Basin-wide, a weaker correlation exists between nitrate+nitrite-nitrogen and other chemical constituents, such as calcium.

Significant correlations suggest a common influence. Processes or activities contributing nitrate contribute other constituents as well. The amount of correlation between nitrate+nitrite-nitrogen and other chemical constituents varies from constituent to constituent.

Figure 4.2 shows nitrate+nitrite-nitrogen concentrations versus total dissolved solids (TDS) and sulfate for all Lower Umatilla Basin groundwater samples. Both constituents correlate well with nitrate+nitrite-nitrogen for concentrations greater than 1 mg/L. The correlation exists despite significantly different groundwater chemistry histories represented by the data. The tighter and more linear grouping for TDS indicates TDS generally correlates better to nitrate+nitrite-nitrogen in the basin's groundwater than sulfate. The relationship between NO_3 and other constituents is even poorer and probably reflects variable sources contributing to groundwater along flow paths which are discussed later.

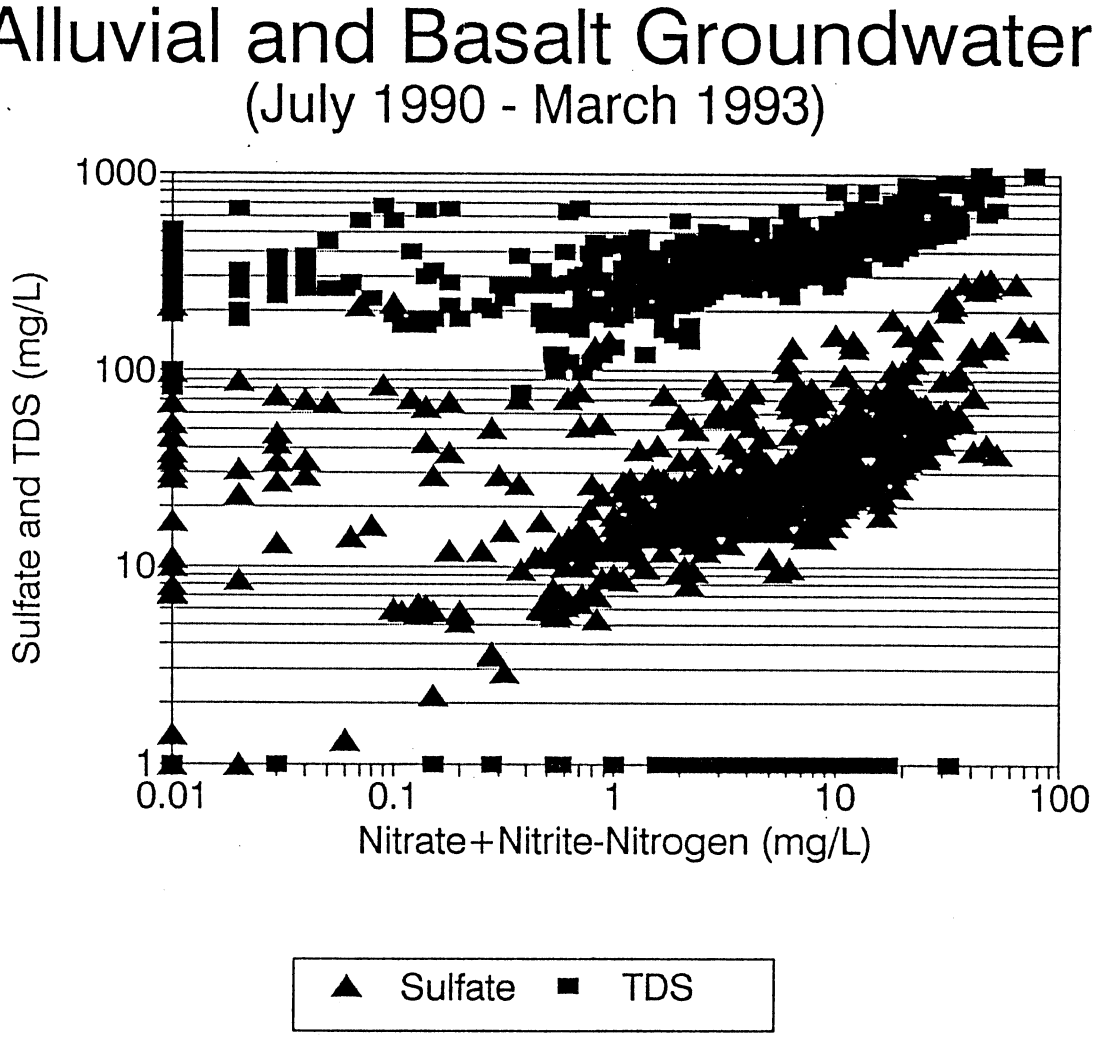


Figure 4.2 Nitrate+nitrite-nitrogen concentrations versus total dissolved solids and sulfate concentrations for all project groundwater samples collected from July 1990 through March 1993.

The graphical change from scatter below 1/mg/L nitrate+nitrite-nitrogen to correlation above 1 mg/L in Figure 4.2 suggests the dominating chemical influence upon local groundwater possibly changes from natural processes to human activity. This project interprets the 1 mg/L nitrate+nitrite-nitrogen concentrations as the maximum background concentration for groundwater in the basin. At lower nitrate concentrations, no clear correlation exists between nitrate, TDS, and sulfate, because the three constituents apparently have no common natural source. The correlation at higher nitrate concentrations indicates common external sources related to human activities.

This project analyzed the relationship between total dissolved solids (TDS) and nitrate+nitrite-nitrogen concentrations for Lower Umatilla Basin groundwater samples apparently impacted by a single land use activity. Activities represented included septic systems, land application of food processing wastewater, confined animal feeding operations, and irrigated crop agriculture. The TDS and nitrate+nitrite-nitrogen concentrations correlated well for each land use. Each correlation indicates the associated land use activity contributes nitrate and TDS to groundwater.

The good correlation for each land use activity represented means multiple sources in the Lower Umatilla Basin contribute nitrate and TDS to groundwater. However, the amount of nitrate and TDS contributed by each land use activity varies. For example, groundwater sampled in areas associated with septic systems generally have nitrate+nitrite-nitrogen concentrations less than 15 mg/L and TDS concentrations less than 500 mg/L. These analyses are discussed more in the potential nitrate sources section.

Other Constituent Versus Constituent Relationships

Project graphical analyses included plotting groundwater data for chloride, potassium, sodium, sulfate, bromide, calcium, magnesium, nitrate+nitrite-nitrogen, and total dissolved solids (TDS) in various combinations. The analyses yielded information about the influence of evaporation, mixing, and nitrate sources.

Graphical analyses of chloride versus potassium, sodium, sulfate, and nitrate+nitrite-nitrogen plotted as molar concentrations yielded several findings:

- Evaporation appears to influence groundwater at many sampling sites in the basin by changing the molar quantities of constituents present. However, the data graphed are often displaced from the evaporation line toward chemical compositions representing potential nitrate sources.

- The Umatilla River may be receiving nitrate and total dissolved solids from either groundwater or runoff.

- Groundwater in some basalt water-bearing zones appear hydraulically connected to alluvial groundwater. These analyses and findings are discussed more in the evaporation and mixing section.

This project conducted graphical analysis to distinguish sources contributing nitrate to groundwater. Graphs analyzed included:

- potassium versus bromide, chloride, and bromide,
- magnesium versus calcium and sulfate,
- chloride versus chloride-bromide ratios, and
- nitrate versus total dissolved solids.

Data used for the analyses were limited to groundwater samples obtained from areas presumably influenced by a single land use activity. The influence of food processing wastewater and septic systems appeared as distinct groupings on graphs showing chloride, potassium, and bromide. The influence of individual food processing wastewater sources were chemically distinguished on magnesium versus sulfate and calcium graphs. Chemical differences observed may relate to the source water used, human activity unique to the facility operation, or geochemical processes unique to the land application area. These analyses and findings are discussed more in the potential nitrate sources section.

Schoeller Diagram and Piper Trilinear Diagram Observations

Graphical analyses of constituent relationships included using Schoeller semi-logarithmic and Piper trilinear diagrams. Schoeller diagrams show concentration ranges in the vertical direction and constituents of interest along the horizontal axis. A line connects the constituent concentrations for each sample represented. Piper trilinear diagrams show the relative proportion of major ions for each sample represented.

Only project bimonthly and synoptic sampling data were graphed. Bimonthly sampling data were graphed by sampling site to observe time-related relationships. Synoptic sampling data were graphed by common geographic area and aquifer type to observe well to well relationships. General observations are presented here. Area specific observations are presented in the area specific sections.

Analysis of the Piper trilinear and Schoeller semi-logarithmic diagrams yielded the following general observations:

- Most groundwater samples plotted as mixed-cation/bicarbonate dominated and calcium/bicarbonate dominated water on the Piper trilinear diagrams. Few groundwater samples plotted as mixed-cation/chloride, calcium/mixed-anion, magnesium/mixed-anion, sodium+potassium/ bicarbonate, or no ion dominant type water on the Piper trilinear diagrams.

- Surface water sampled plotted as mixed-cation/bicarbonate dominated and calcium/bicarbonate dominated water on the Piper trilinear diagrams.

- All food processing and animal wastewater sampled from wastewater ponds plotted as sodium+potassium/bicarbonate dominated water on the Piper trilinear diagrams.

- Chloride and sulfate proportions on trilinear graphs often varied similarly to nitrate+nitrite-nitrogen concentration variations over time and by location. Occasionally, calcium proportions varied similarly or inversely to nitrate+nitrite-nitrogen concentrations. The proportion variations frequently plotted as mixing lines on Piper trilinear diagrams.

- Many major ion concentrations in Lower Umatilla Basin groundwater sampled often related similarly to nitrate+nitrite-nitrogen concentration variations over time and by location. This relationship frequently appeared on the Schoeller diagrams as similar line patterns shifting up, down, or superimposing when nitrate+nitrite-nitrogen concentration increased, decreased, or remained unchanged, respectively.

- Detectable phosphate concentrations in Lower Umatilla Basin groundwater sampled often related inversely to nitrate+nitrite-nitrogen concentration variations over time and by location.

Groundwater samples related to specific nitrate sources did not graph uniquely on these diagrams. However, the diagrams helped link some groundwater samples indirectly to nitrate sources as follows. When the source of nitrate detected in some samples was uncertain, the diagrams helped chemically relate those samples to a nearby group of samples where the nitrate source was better identified.

Constituent Concentration Versus Time Observations

Project graphical analyses included reviewing and comparing constituent concentrations versus time graphs. Data used for the analyses came from project bimonthly groundwater sampling and local facility groundwater monitoring reports. Project bimonthly sampling constituent versus time graphs included nitrate+nitrite-nitrogen, total dissolved solids, chloride, sulfate, bicarbonate, sodium, calcium, phosphate and boron. Local facility groundwater sampling constituent versus time graphs primarily included nitrate and total dissolved solids. The graphical analyses noted when peak concentrations occurred and compared constituent concentration graphs related to the same sampling site. Basin-wide observations are presented here. Area specific observations are presented in the area specific sections.

Nitrate concentrations fluctuate in Lower Umatilla Basin groundwater with some exceptions. Nitrate concentration peaks generally occurred in November, January, or March for project bimonthly groundwater samples (Figure 4.3). Nitrate concentration peaks for groundwater samples collected and reported by local facilities generally occurred primarily in September, October, November, December, March, April, or June depending on the site (Figure 4.4). Concentration peaks occurred less frequently during the mid-summer months for all samples analyzed. Concentration peaks for other constituents graphed occurred during fall, winter, and spring months also.

Concentration peaks occurring primarily during fall, winter, and spring may relate to one or more influences. The concentration peaks timing may relate to the time needed for nitrogen, other constituents, and water applied at land surface to travel to groundwater. It may also relate to when nitrogen, other constituents, and water can most easily leach to groundwater. For example, evaporation and uptake by crops and other vegetation may inhibit water, nitrogen, and other constituents from escaping to groundwater during mid-summer months. Conversely, sufficient moisture and little or no vegetative growth during fall, winter, and spring months may allow available nitrogen and other constituents to leach.

Relatively steady nitrate+nitrite-nitrogen concentrations over time were observed for groundwater sampled from some wells. Steady concentrations ranged from less than 0.1 mg/L to 20 mg/L. Steady nitrate+nitrite-nitrogen concentrations below 1 mg/L appear related to background conditions or constant dilution. Steady nitrate+nitrite-nitrogen concentrations above 1 mg/L appear related to a constant source like septic systems, or nitrate accumulating in areas with limited groundwater movement.

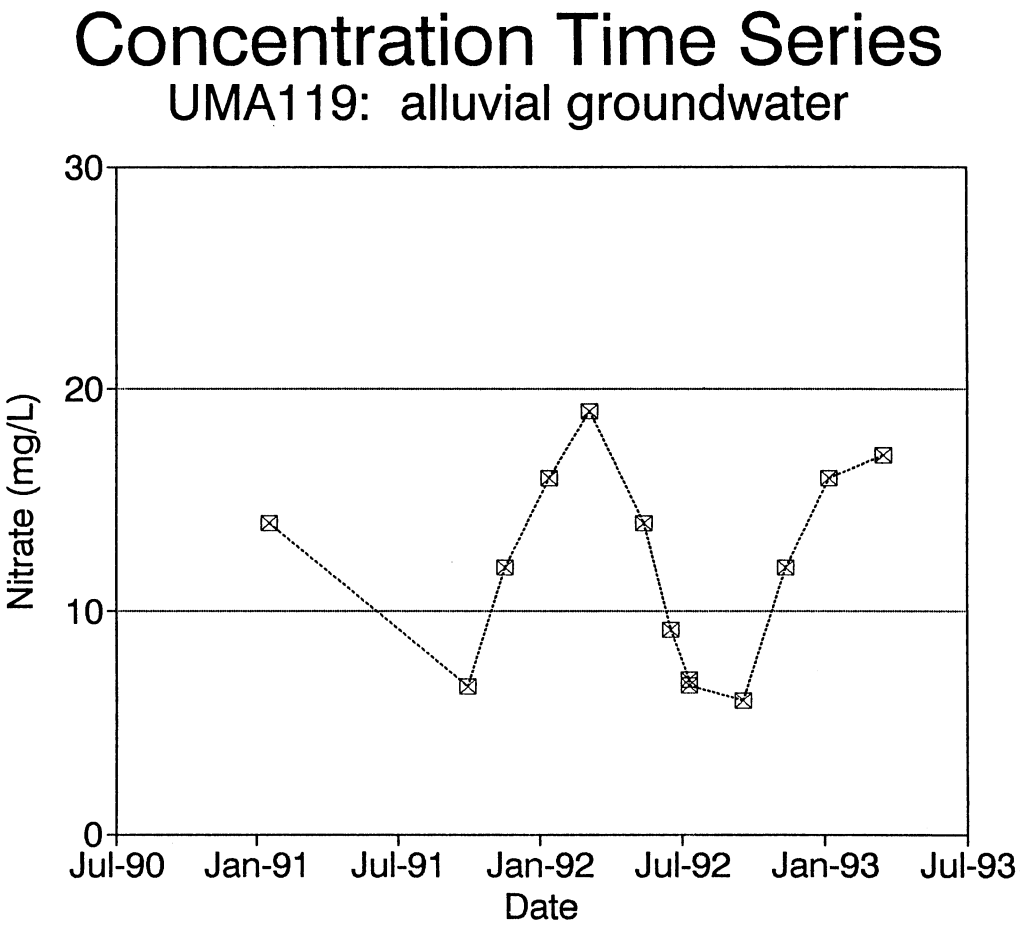


Figure 4.3 Nitrate+nitrite-nitrogen versus time in alluvial groundwater at UMA 119 located southwest of Hermiston.

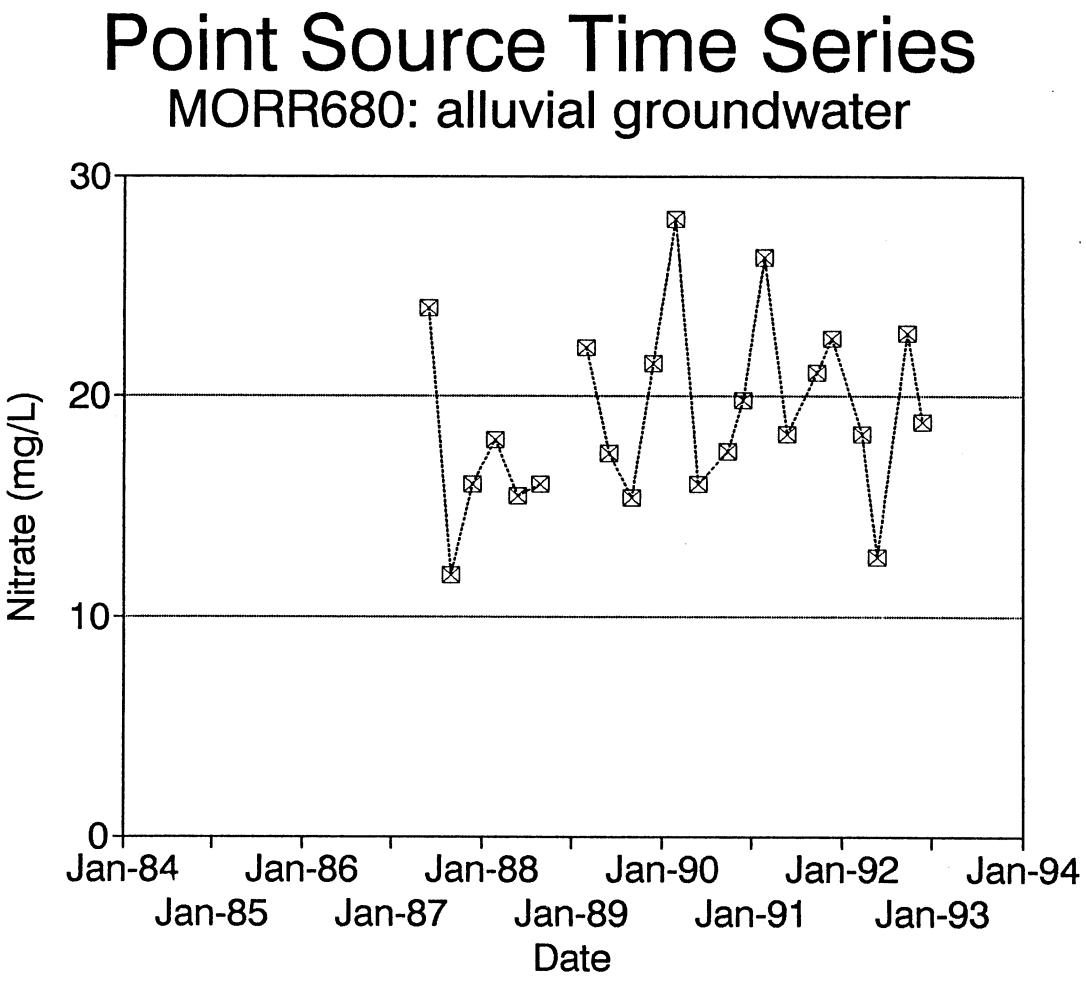


Figure 4.4 Nitrate+nitrite-nitrogen versus time in alluvial groundwater at Port of Morrow monitoring well MW-5 (MORR 0680) located northeast of Boardman.

Constituent concentration versus time graphs were compared to each other to observe similarities and differences that may distinguish sources or processes influencing the local groundwater chemistry. Only graphs that relate to the same sampling site were compared. Land use activities surrounding the sampling sites include septic systems, irrigated crop agriculture, food processing wastewater land application, and confined animal feeding operations.

The constituent concentration versus time graph comparisons did not distinguish different sources and processes. The set of constituents showing similar, opposite, or no concentration fluctuation correlations varied from sampling site to sampling site. Weak to strong correlation between nitrate+nitrite-nitrogen, TDS, chloride, sulfate, bicarbonate, sodium, and calcium graphs were observed. Many nitrate+nitrite-nitrogen graphs correlated best with total dissolved solids (TDS) graphs. Boron and phosphate showed no consistent relationship to the other constituents. Efforts to distinguish general sources or processes responsible for concentration fluctuations showing similar versus opposite or no correlation to other constituent concentration fluctuations did not succeed.

Constituent Concentration and Groundwater Elevation Versus Time Graphs Compared

Project graphical analyses included comparing constituent concentration versus time graphs to groundwater elevation versus time graphs related to the same sampling location. The analyses used long term nitrate, total dissolved solids, sodium and groundwater elevation data reported by Lower Umatilla Basin facilities. The facilities measured groundwater elevations concurrently with collecting groundwater samples, whereas project groundwater sampling did not. General observations related to these comparisons are presented here. Area specific observations are presented in the area specific sections.

Correlation between the constituent concentration and groundwater elevation graphs varied. This project explored possible explanations for the different correlations.

Constituent concentrations and groundwater elevations correlated over time for many graphs compared. Figure 4.5 is an example. The majority of these correlations related to sampling sites where groundwater came primarily from coarse-grained or flood plain alluvial sediments and constructed well depths ranging primarily between 19 and 110 feet. Several exceptions included sampling sites where groundwater came from fine-grained alluvial sediments or basalt water-bearing zones and one coarse-grained sediment site with a 200 feet deep well. The very similar correlations suggest constituent loading at these sites relates somehow to local groundwater recharge, and the travel time to groundwater is relatively short under conditions existing during the time periods compared.

Some constituent concentrations and groundwater elevations appeared to correlate inversely over time. Constituent concentrations were observed to decline when groundwater elevations rose, and rise when elevations declined.

The relationship between groundwater elevation and well construction was explored as an explanation for the apparently inverse constituent concentration and groundwater elevation correlations. A vertically fluctuating groundwater table close to where groundwater enters a well can influence the correlation when the constituent concentrations in groundwater are stratified. For example, groundwater near the water table having higher constituent concentrations than deeper groundwater below can yield an inverse correlation as follows:

- Constituent concentration in the groundwater samples collected increases when the water table drops near or intercepts the groundwater entrance to the well and shallow groundwater with the higher concentrations enters the well.

- Conversely, groundwater sample constituent concentrations decrease when the water table rises and deeper groundwater with lower concentrations enters the well.

The groundwater table in the Lower Umatilla basin does intercept or move within 10 feet of where groundwater enters many facility wells. However, inverse correlations did not dominate the graphical comparisons related to these sites. Instead, the graphical comparisons yielded a nearly equal number of similar, and inverse, and no correlations between constituent concentrations and groundwater elevation. These different correlations suggest the influence of groundwater elevations relative to well construction fails to apply in the Lower Umatilla Basin.

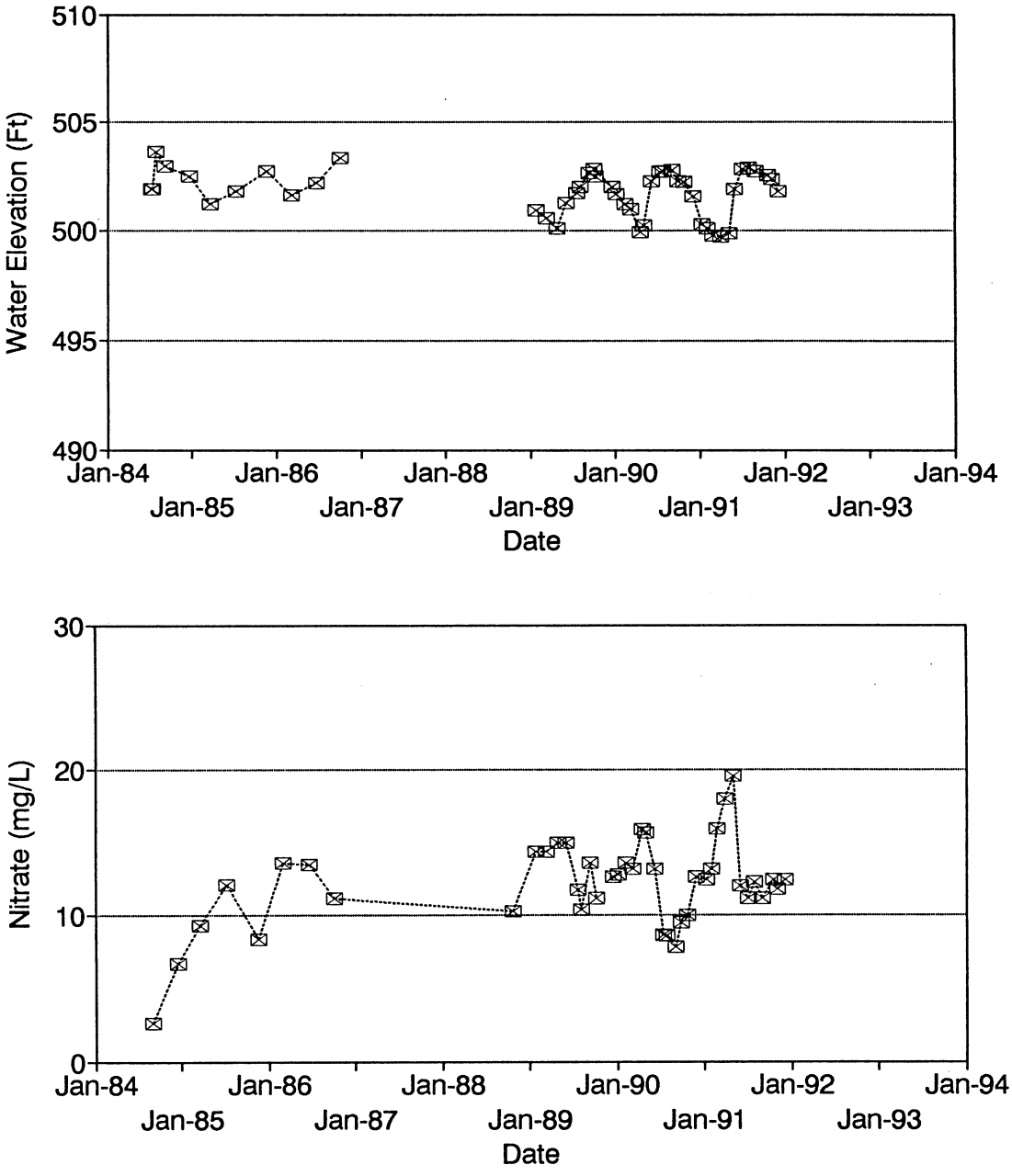


Figure 4.5 An example of correlating nitrate concentration and groundwater elevation fluctuations at UMA 261 (LUB 042, Simplot MW-115).

This project also explored time lags as an explanation for the apparently inverse and no correlation observed between groundwater elevation and constituent concentration. A true time lag implies groundwater elevations and constituent concentrations share common influences. However, the influences affect groundwater elevations more quickly than constituent concentrations. This situation appears to exist in the Lower Umatilla Basin at some locations.

A time lag became suspected after several groundwater elevation and constituent concentration graphs having uniquely similar fluctuations occurring at different times were observed. The graphs correlated when shifted to superimpose the uniquely similar fluctuations. Other apparently inverse or no correlation graph sets also correlated when a time lag shift was considered. A time lag correlation was not established for some graph sets due to insufficient data over time.

Graph sets with observed time lags primarily related to sampling sites where groundwater came from fine-grained sediments and constructed well depths exceeding 100 feet. Exceptions included several sites where groundwater comes from coarse-grained or flood plain sediments and sites with wells constructed less than 30 feet deep. Observed time lags for nitrate ranged from 0 to 18 months.

Analysis indicates the nitrate time lags may change significantly when sufficient water is available. For example, the observed time lag related to one flood plain site with a well 19 feet deep temporarily changed from 10 months to less than 1 month due to a flood event.

The time lag related correlations between groundwater elevations and constituent concentrations have very important implications for the Lower Umatilla Basin. The correlations indicate nitrate may move to groundwater more quickly than previously estimated by other investigators.

Constituent Concentration Versus Groundwater Flow Path Location

Project graphical analyses included reviewing and comparing constituent concentrations versus location and time along groundwater flow paths. This graphical analysis was limited to the Butter Creek and U.S. Army Umatilla Depot Activity areas where the hydrogeology and land use activities are more complex. The analyses observed the following:

- Multiple influences affect the groundwater chemistry along each groundwater flow path. This includes influences unrelated to nitrate;

- More than one source contributes nitrate to groundwater along each groundwater flow path;

- Nitrate concentrations correlate better to calcium and chloride than sodium and sulfate along each groundwater flow path; and

- Constituent concentrations in groundwater along the Butter Creek flow path do not progressively increase downgradient, which would be expected from chemical influences limited to progressive water rock reactions or non-point source loading. Instead, a stationary groundwater chemistry anomaly exists along the groundwater flow path.

Specific observations and discussions related to the groundwater flow path graphical analyses are presented in the area specific sections.

Evidence of Evaporation and Mixing Affecting Alluvial Groundwater Chemistry

Analyses of a series of constituent versus constituent graphs indicate evaporation and mixing processes influence the alluvial groundwater chemistry in the Lower Umatilla Basin. Graphs analyzed represent alluvial groundwater presumably sampled in areas influenced by a single nitrate source, samples from four potential nitrate sources, and samples from three irrigation water sources. The groundwater samples came from wells within or near areas with septic systems, animal feedlots, irrigated crop agriculture, and land application of food processing wastewater. Samples representing potential nitrate sources came from wastewater lagoons at a sewage treatment plant (STP), two food processors [(SP) and (LW)], and a dairy (HD). Samples representing irrigation water came from the Columbia River (CR), the Umatilla River (UR), and well UMA 082 cased into the uppermost basalt (BW).

The graphs show constituent concentrations as molar quantities, which represent the number of atoms or molecules present rather than mass. Using molar quantities was necessary for the analyses, because changes during evaporation and certain other reactions are based on molecules rather than mass. Simple evaporation appears as a 1-to-1 slope on graphs using molar quantities. Other processes will appear on the graphs as a departure from the theoretical evaporation line.

Figure 4.6 shows chloride versus potassium. Most samples from the wastewater lagoons and irrigation water sources show evidence of evaporation. They appear to graph along an approximate evaporation trend that begins with a dilute source such as the Columbia or Umatilla Rivers. Water from the basalt well and the sewage treatment plant graph within the trend of alluvial groundwater data where potassium remains low and relatively constant while chloride continues to increase. The higher chloride concentrations in the alluvial groundwater probably relates to evaporation. The relatively constant and low potassium concentrations in the alluvial groundwater may relate to cation exchange (Drever, 1982). Available clay mineral surfaces tend to adsorb potassium as water percolates from land surface to groundwater through the vadose (unsaturated) zone.

The observation that groundwater sampled from the basalt well graphed within the same trend as the alluvial groundwater samples is important. Basalt mineral chemistry can not explain the conformance. No mineral can serve as the chloride source. Additionally, potassium concentrations in minerals comprising basalt are very low. Instead, the conformance indicates alluvial groundwater and groundwater in the basalt water-bearing zones experienced the same processes such as evaporation. This shared experience indicate the alluvial groundwater and the basalt groundwater are connected. This observation is consistent with conclusions reached in the hydrogeologic section that the uppermost basalts are hydraulically connected to the alluvial aquifer. Analyses presented in the next section further supports a hydraulic connection.

Figure 4.7 shows chloride versus nitrate+nitrite-nitrogen. The alluvial groundwater samples show evidence of evaporation. However, they graph at nitrate concentrations greater than expected for simple evaporation from a dilute source. They graph in a manner consistent with a model of water mixing with nitrate enriched waters. The Umatilla River sample has a nitrate concentration higher than expected from evaporating a dilute source. The higher nitrate concentration may reflect nitrate loading from groundwater or surface water runoff. All but one of the potential nitrate source samples graph well below the evaporation line. Nitrogen occurring primarily as ammonia and Total Kjeldahl Nitrogen in these sources appears responsible. Nitrogen in these sources converting to nitrate during or subsequent to land application would result in nitrate concentrations similar to the other potential nitrate source sample.

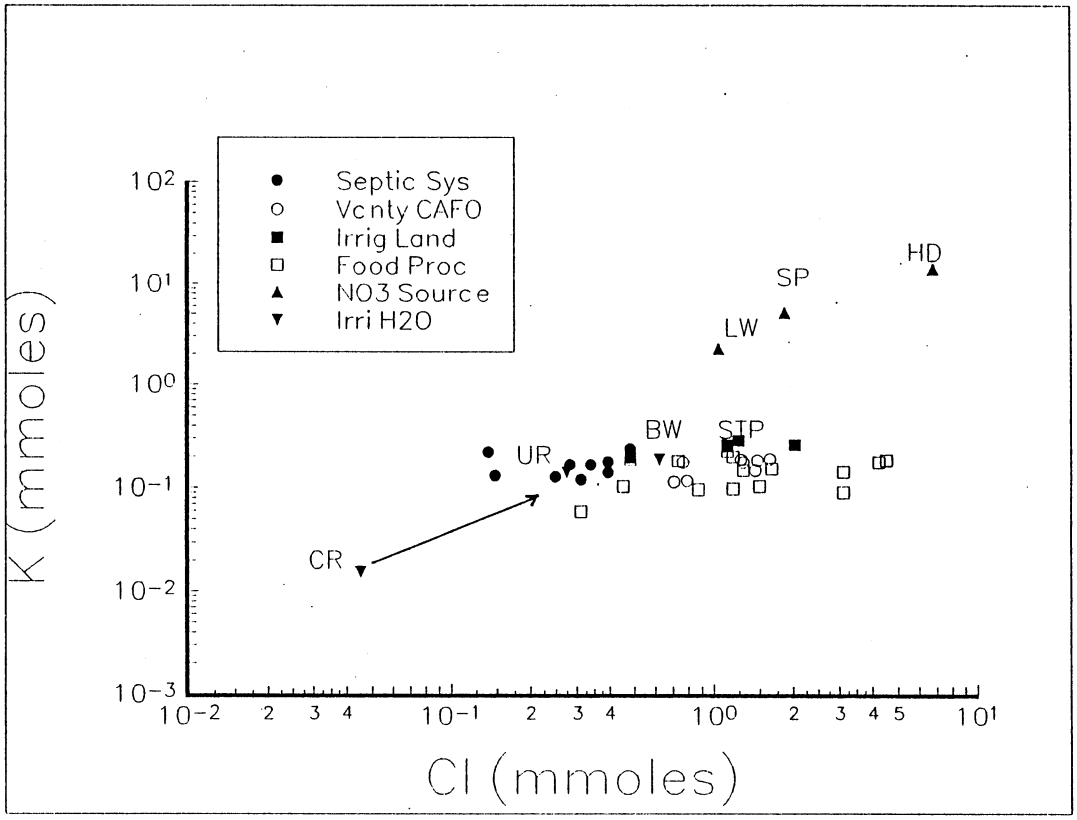


Figure 4.6 Chloride versus potassium concentrations for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources.

Note: The evaporation trend for irrigation water sources and potential nitrate sources, and the nearly constant potassium concentration.

Note: CR=Columbia River, UR= Umatilla River, BW=basalt well, STP=sewage treatment plant, LW=Lamb Weston, Inc. wastewater lagoon, SP=J.R. Simplot Co. wastewater lagoon, and HD=Hillview dairy wastewater lagoon.

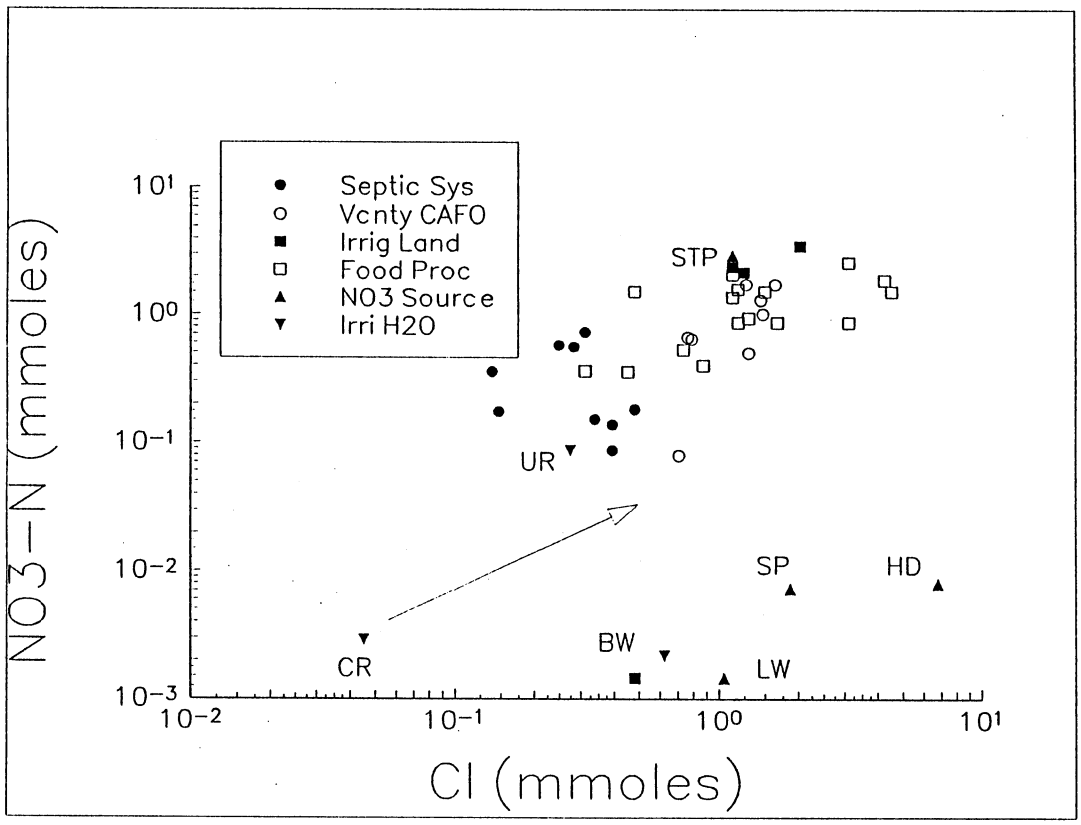


Figure 4.7 Chloride versus nitrate+nitrite-nitrogen concentrations for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources sample.

Note: The alluvial groundwater samples graph parallel to the evaporation trend at concentrations greater than predicted by simple evaporation and the low nitrate concentrations for potential nitrate sources due to nitrogen present as ammonia and TKN rather than nitrate.

Note: The symbol label abbreviations are the same as in Figure 4.6.

The groundwater sample from the basalt well graphs at a much lower nitrate+nitrite-nitrogen concentration in Figure 4.7 than the alluvial groundwater samples. Two possibilities may explain the lower concentration
despite chloride and potassium evidence indicating water with higher total dissolved solids has reached basalt water-bearing zones. Perhaps nitrate was not present in the high TDS water initially, or if nitrate was present, denitrification occurred. Denitrification can occur if chemically reducing conditions exist within basalt water-bearing zones.

Figure 4.8 shows chloride versus sodium. Samples representing the Columbia and Umatilla Rivers and groundwater from the basalt well appear related as they graph along the evaporation line. Samples representing potential nitrate sources do not graph along the evaporation line except for one food processing sample. Their diversion from the evaporation line suggests additional factors influenced the water chemistry. The water history probably plays a significant role. The alluvial groundwater samples graph along a trend to the right of the evaporation line and subparallel to the trend defined by the potential nitrate sources. Although the overall trend has similarities to the trend observed for potassium in Figure 4.6, differences exist.

Individual trends exist within the general alluvial groundwater trend in Figure 4.8. Alluvial groundwater samples collected in the vicinity of septic systems, animal feedlots, and other sources have individual trends with positive slopes toward the potential nitrate sources. Although cation exchange may be operating, there is indication that mixing between groundwater and nitrate source waters may impact the water quality also.

Similar arguments can be made using Figure 4.9 which shows chloride versus sulfate. Again, the alluvial groundwater samples on the graph are displaced from the evaporation line towards the field defined by the potential nitrate sources. Both the Umatilla River and the basalt well are displaced as well.

In summary, graphical analyses indicate evaporation and ambient groundwater mixing with water infiltrating from various nitrate sources influences the alluvial groundwater chemistry. Contributions from various individual nitrate sources can not be distinguished using the analyses presented in this section. Methods that can distinguish nitrate sources are presented in the potential nitrate source section.

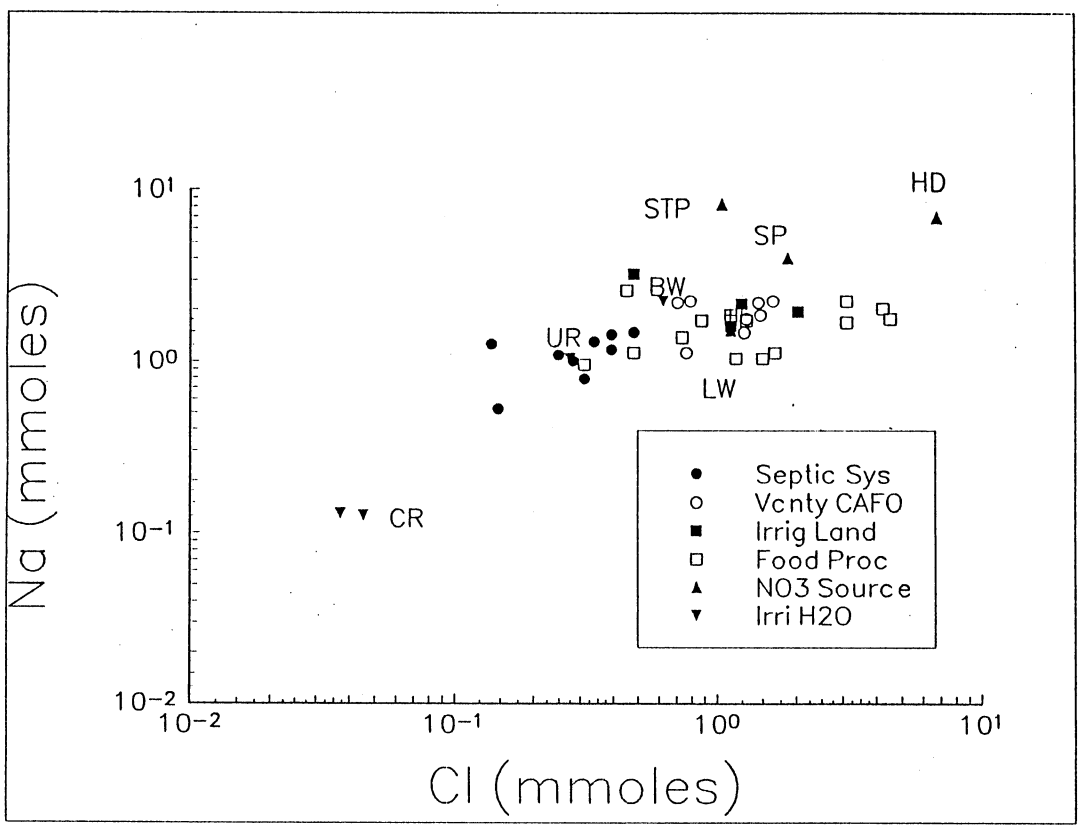


Figure 4.8 Chloride versus sodium for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources.

Note: The subtrends have positive slopes within the general trend.
Note: The symbol label abbreviations are the same as in Figure 4.6.

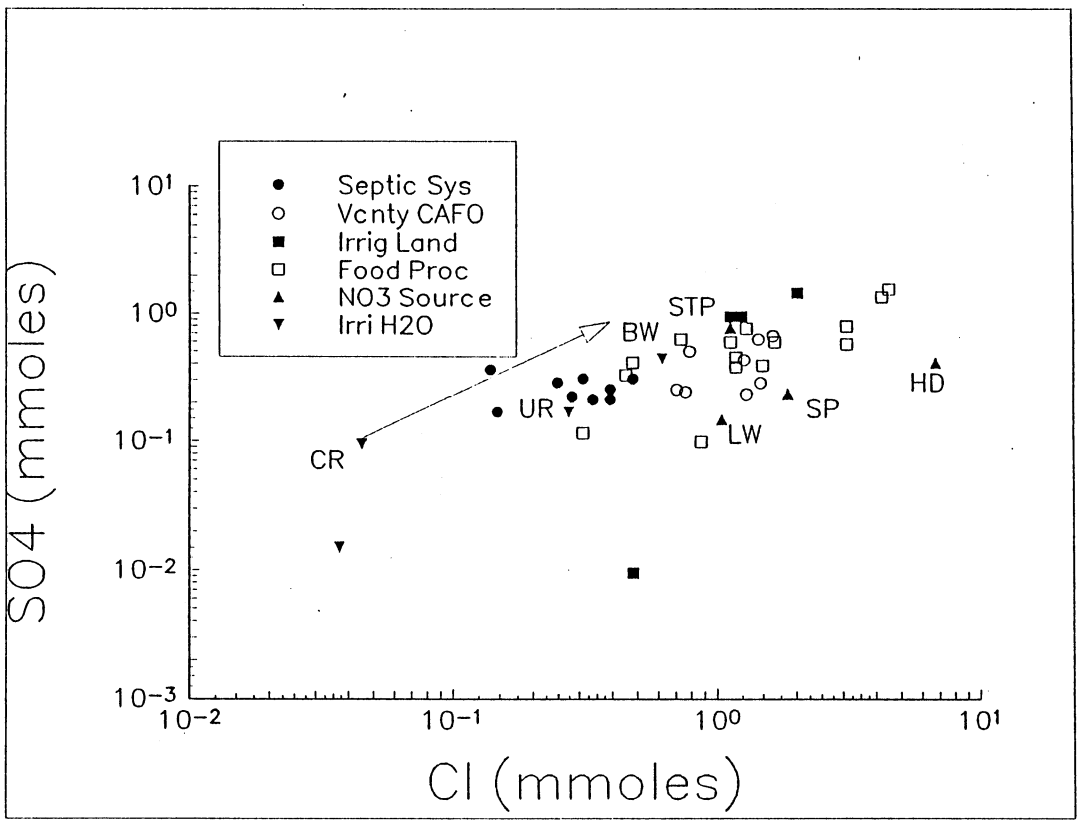


Figure 4.9 Chloride versus sulfate for selected alluvial groundwater samples, potential nitrate source samples, and irrigation water sources.

Note: The alluvial groundwater samples are displaced away from the evaporation trend toward potential nitrate sources.

Note: The symbol label abbreviations are the same as in Figure 4.6

Evidence of External Influences Affecting Basalt Groundwater Chemistry

This section presents a series of graphs and analyses representing groundwater samples collected from Lower Umatilla Basin basalt water-bearing zones. Constituents are graphed as milligrams per liter (mg/L). Analyses of the graphs support the observation that some groundwater from basalt wells follow trends similar to alluvial groundwater. This indicates a hydraulic connection exists between alluvial groundwater and some basalt water-bearing zones.

Figure 4.10 shows total dissolved solids (TDS) versus calcium. A positive correlation exists between the constituents. The highest calcium concentration shown is approximately 150 mg/L. Review of the graph raises questions about the source of calcium in the groundwater sampled. Basalt minerals can contribute calcium to groundwater. However, an analysis using groundwater chemistry computer modeling indicates achieving the higher calcium concentrations from natural water-rock reactions is unlikely. That analysis is presented in the general groundwater chemistry computer modeling section. The modeling result suggests calcium comes from an external source.

Review of other constituent versus constituent graphs also indicate an external source affects the groundwater chemistry in some basalt water-bearing zones. They include chloride versus total dissolved solids and nitrate+nitrite-nitrogen versus total dissolved solids.

Figure 4.11 shows chloride versus total dissolved solids. The chloride concentrations reach values exceeding 220 mg/L. The chloride probably did not come from the basalt, because no primary basalt mineral contains appreciable chloride. It probably did not come from halite, a highly soluble chloride mineral, because halite occurring with the saturated basalt water-bearing zone is unlikely.

Figure 4.12 shows nitrate+nitrite-nitrogen versus total dissolved solids. A positive correlation between TDS and nitrate+nitrite-nitrogen exists for some basalt groundwater samples. Nitrate does not occur naturally in basalt which again suggests an external source. Additionally, many of the samples plot within the same area of the graph as alluvial groundwater samples, which are shown as open squares in Figure 4.12. This correlation suggests alluvial and some basalt groundwater are related.

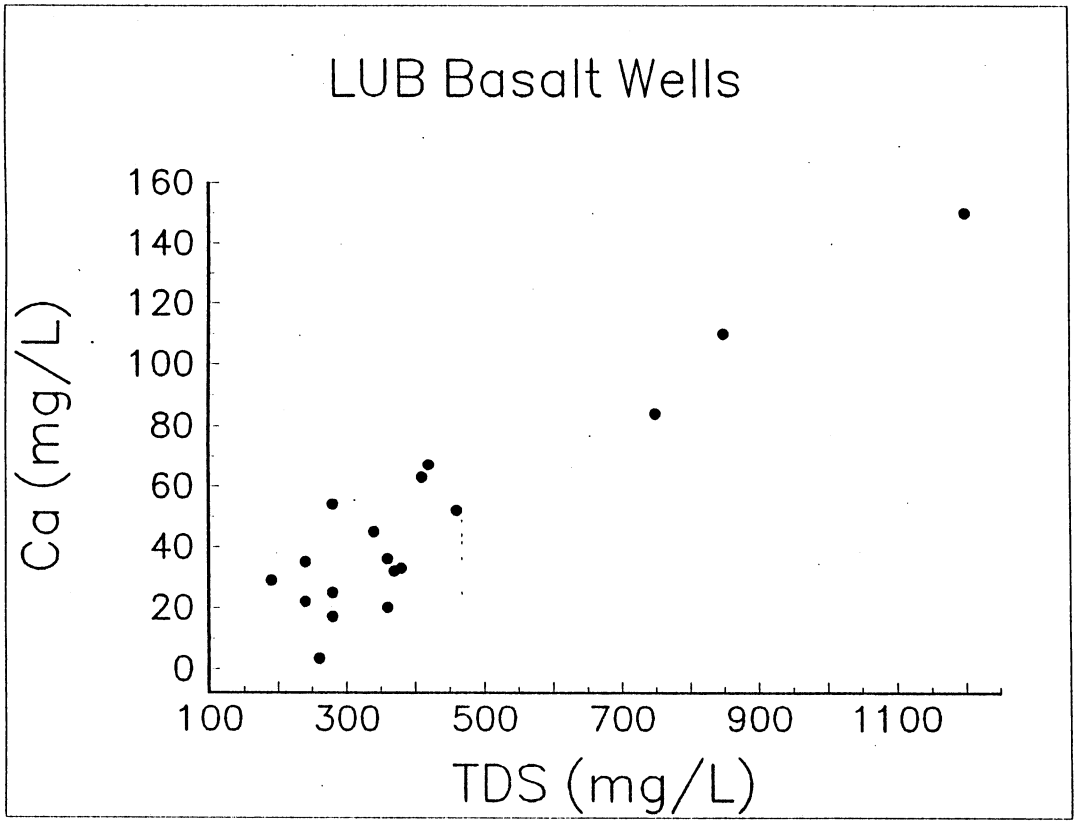


Figure 4.10 Total dissolved solids versus calcium for groundwater sampled from basalt water-bearing zones in the Lower Umatilla Basin.

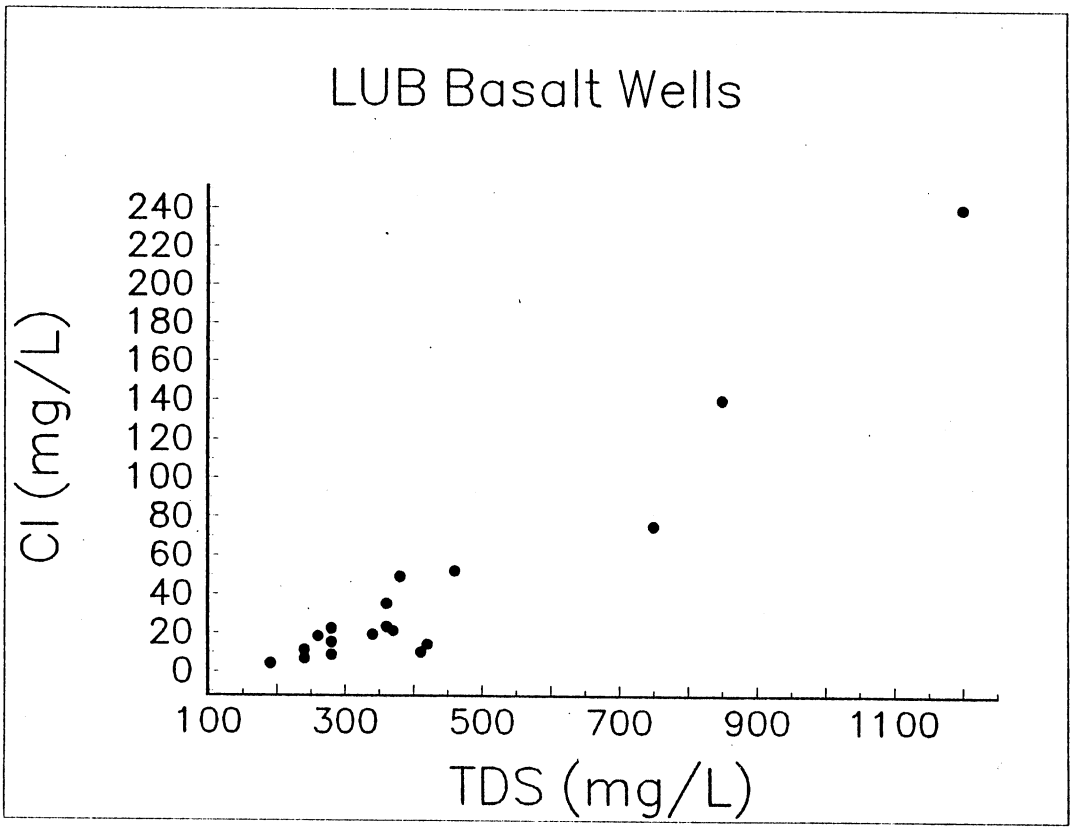


Figure 4.11 Total dissolved solids versus chloride for groundwater sampled from basalt water-bearing zones in the Lower Umatilla Basin.

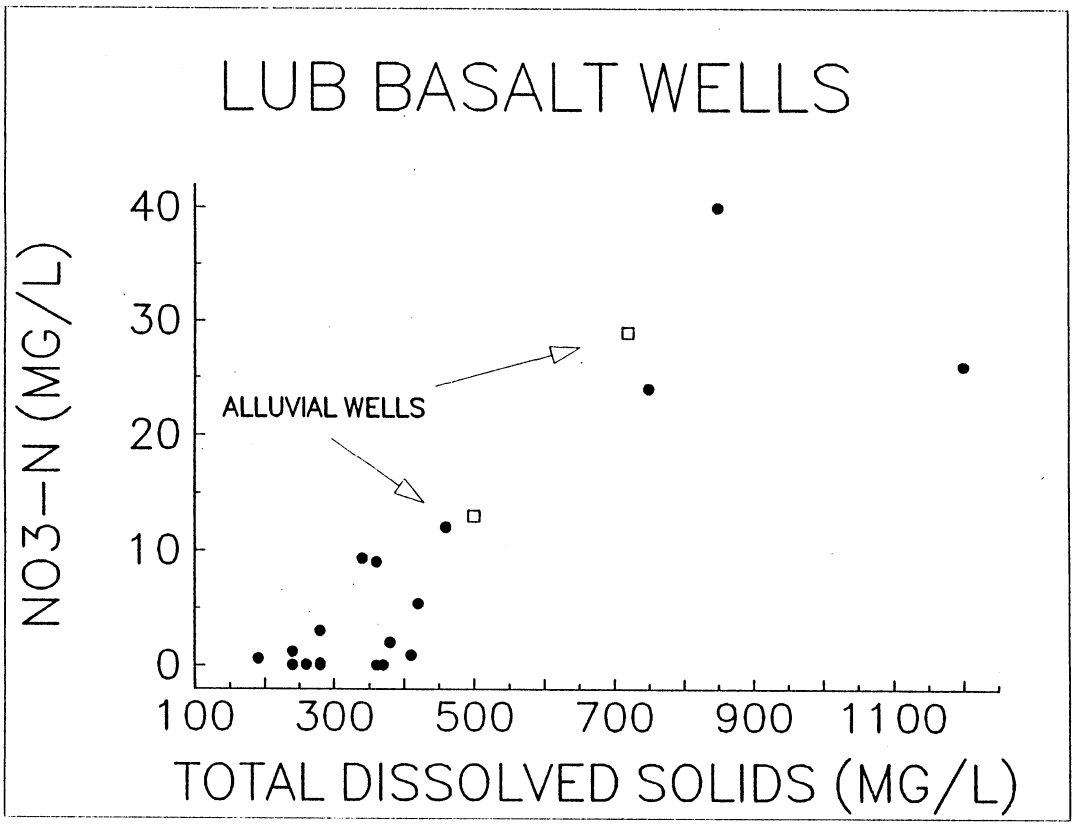


Figure 4.12 Total dissolved solids versus nitrate+nitrite-nitrogen for groundwater sampled from basalt water-bearing zones in the Lower Umatilla Basin.

Note: The dashed line encloses the nitrate+nitrite-nitrogen field for alluvial groundwater samples.

In summary, groundwater in some basalt water-bearing zones originally comes from shallow alluvial groundwater affected by surface activities. Information presented in the hydrogeology chapter support alluvial groundwater directly entering some basalt water-bearing zones. Saturated alluvial sediments directly contact basalt water-bearing zones in some areas. Additionally, some wells are constructed improperly. The wells provide a direct conduit from the alluvial aquifer to one or more basalt water-bearing zones below.

Evidence of Potential Nitrate Sources Influencing Groundwater Chemistry

Some constituent versus constituent graphs analyzed may potentially characterize the influence of some nitrate sources upon Lower Umatilla Basin groundwater. Each graph analyzed shows several groupings of groundwater samples each of which was presumably influenced by a single nitrate source. Assuming a single source may not be correct given the diverse land use history in the areas. Additionally, not all potential sources are represented. Omitting these other sources should not be interpreted as vindicating their role as a nitrate contributor to the basin's groundwater.

The groundwater samples graphed came from wells within or near areas with septic systems, animal feedlots, food processing wastewater land application areas, and irrigated crop agriculture. Samples representing potential septic system influences came from Hermiston and Irrigon rural residential home areas. Samples representing potential animal feedlot influences came from wells downgradient from C and B Livestock near Hermiston and from historic hog and poultry operations. Samples representing potential food processing wastewater influences came from wells within or near Lamb Weston, Simplot and Hermiston Foods land application sites. Samples representing potential irrigated crop agriculture came from Western Empire farm wells southwest of Irrigon. The analyses primarily used June-July 1992 synoptic sampling data. Groundwater samples influenced by sewage sludge land application only, nursery operations only, and other potential nitrate sources only were not obtained.

The rationale for this analysis is nitrate does not travel alone. Instead, nitrate must travel in water percolating from the surface downward to groundwater. That water will contain other constituents that reflect its source and the chemical modifications that occurred during its history. Therefore, nitrate delivered by water percolating downward from different land uses may have identifiably different chemical signatures. This hypothesis proved true in some cases.

Figure 4.13 shows total dissolved solids versus nitrate+nitrite-nitrogen for all categories. A positive correlation exists between these constituents. Analyses of the graph indicates no single source is solely responsible for the elevated nitrate in the basin. Instead, the data indicates all the sources represented contribute nitrate and TDS to groundwater in the basin.

Groundwater samples related to septic systems graph differently from samples related to the other potential nitrate sources in terms of TDS and nitrate+nitrite-nitrogen (Figure 4.13). Groundwater sampled near irrigated crop agriculture, animal feedlots, and food processing wastewater land application areas graph over a wide concentration range. The range associated with on-site septic systems is much more limited. The concentrations are generally less than 500 mg/L for TDS and less than 15 mg/L for nitrate+nitrite-nitrogen. This is consistent with the observations of Komor and Anderson (1993) for the Sand-Plains aquifers of Minnesota. A review of Lower Umatilla Basin groundwater data related to septic systems found the concentration ranges noted were retained over time except once, where the TDS concentration reached 560 mg/L and nitrate+nitrite-nitrogen reached 18 mg/L in the same sample. These generally lower values indicate septic systems can not explain the full TDS and nitrate concentration ranges observed in Lower Umatilla Basin groundwater.

Figures 4.14 and 4.15 show potassium versus bromide and chloride versus potassium. Graphical analysis yielded three findings:

- Groundwater influenced by septic systems has lower chloride concentrations than other sources in addition to having lower TDS and nitrate concentrations.

- The influence of food processing wastewater upon groundwater chemistry is significantly different from the influence of other sources in terms of bromide to potassium and chloride to potassium relations.

- Each potential source groups into separate fields on the graphs.

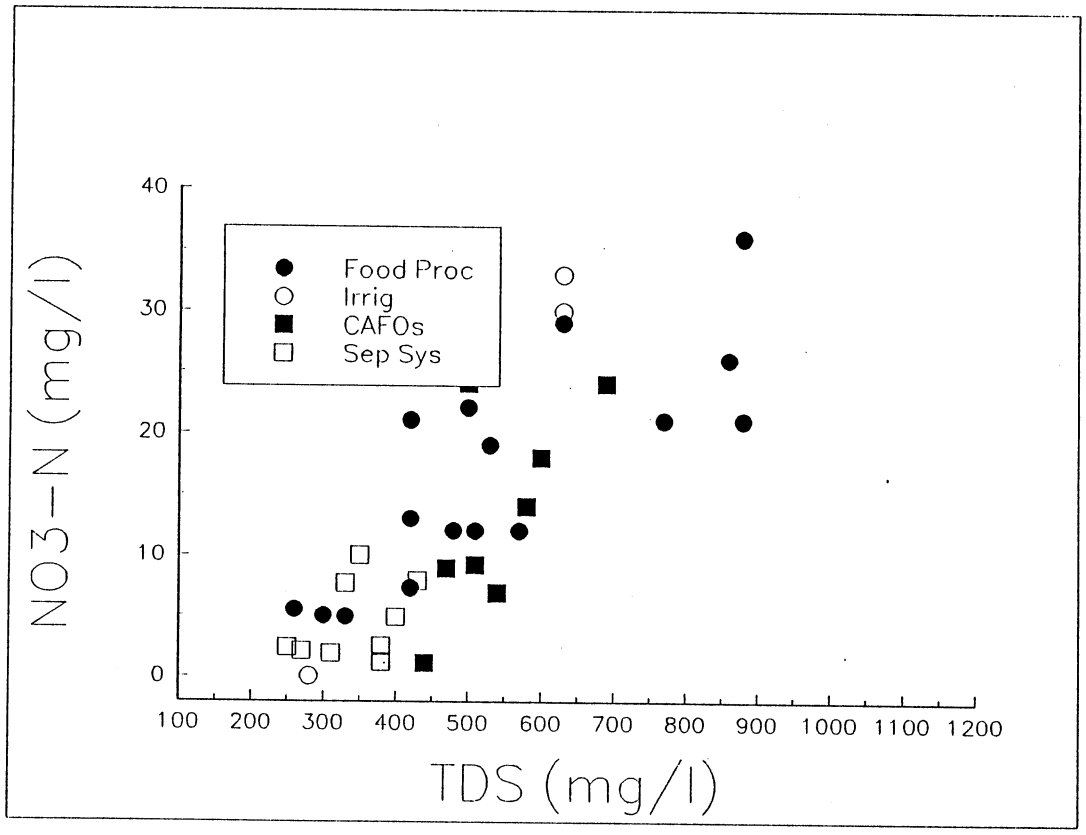


Figure 4.13 Total dissolved solids versus nitrate+nitrite-nitrogen for groundwater sampled in the vicinity of potential nitrate sources.

Note: The samples related to septic tank influences graph within a limited area.

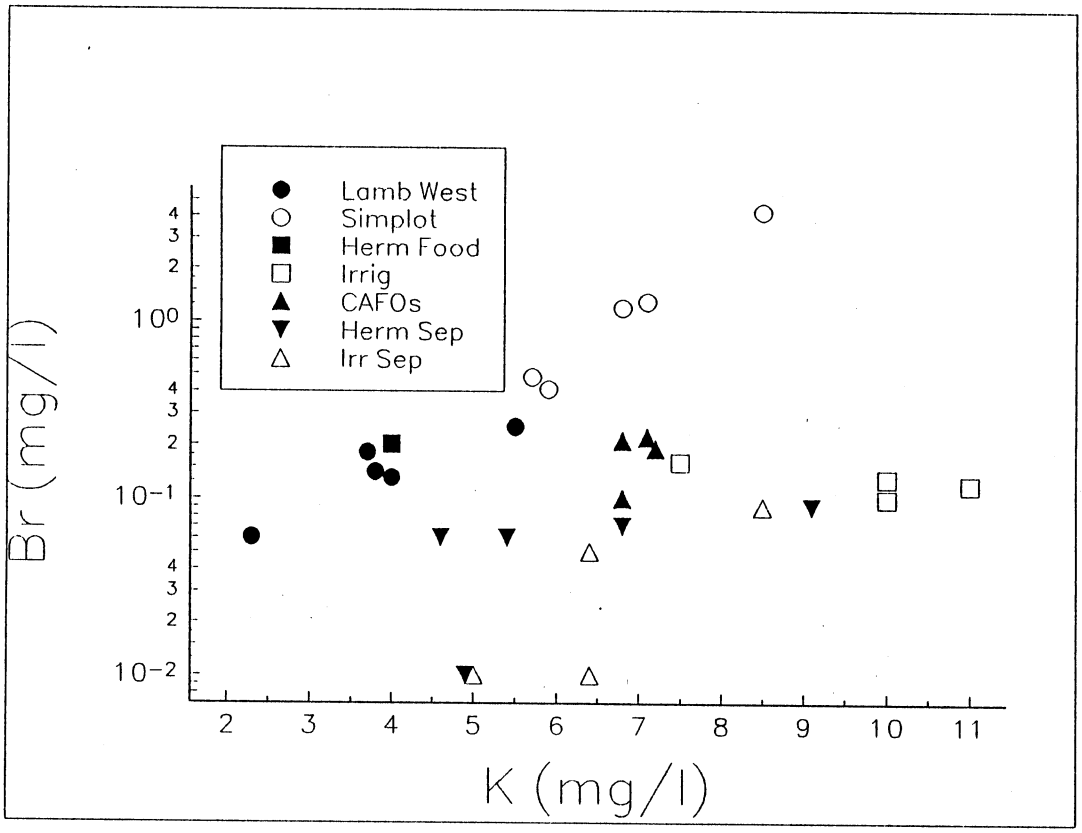


Figure 4.14 Potassium versus bromide for groundwater sampled in the vicinity of potential nitrate sources.

Note: The samples related to food processing wastewater influences graph within the same field regardless of sampling location. Samples related to septic systems also graph similarly despite different sampling locations.

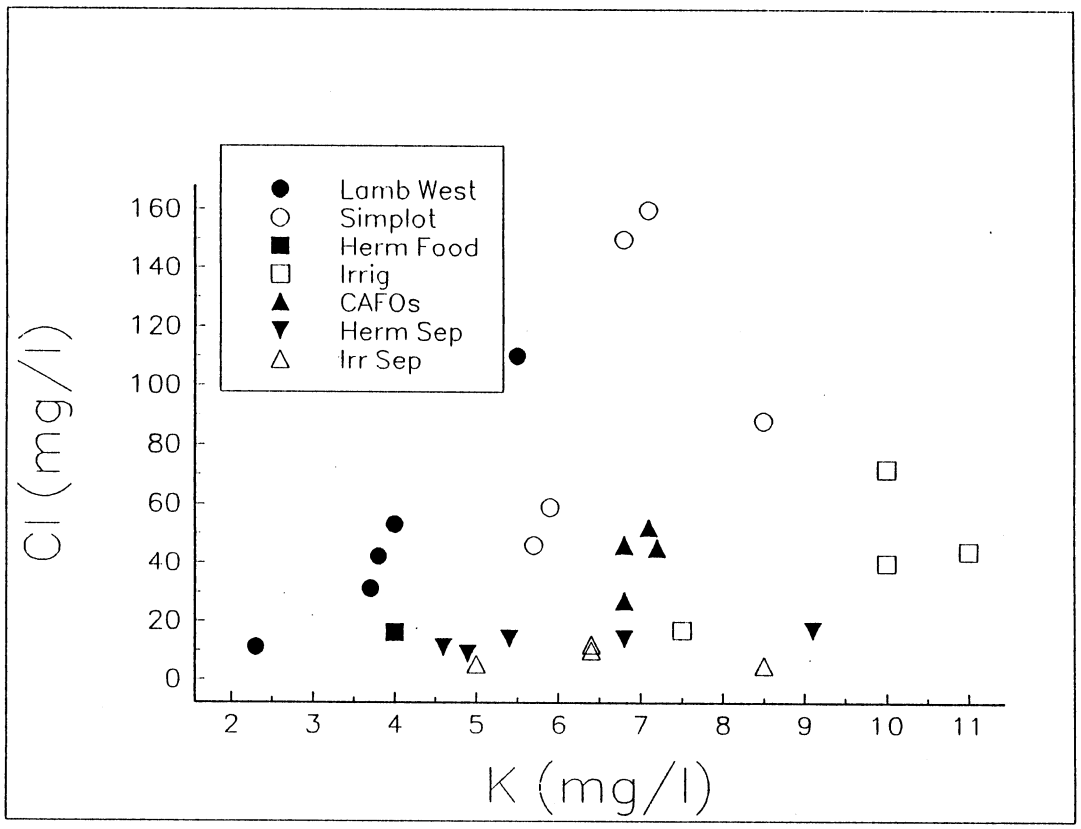


Figure 4.15 Potassium versus chloride for groundwater sampled in the vicinity of potential nitrate sources.

Note: The distinct fields for samples are related to food processing wastewater influences and are related to septic systems.

All septic system related samples graph along the same trend regardless of their sampling location. All food processing wastewater related samples graph along their unique trend regardless of the food processing source. All animal feedlot related samples graph within a small field despite sampling locations separated by several miles and being on separate flow paths. This observation suggests the chemical patterns displayed reflect chemical influences unique to each potential nitrate source category represented rather than influences common to geographic areas in the basin. As a result, these graphical comparisons can help identify land uses influencing groundwater sampled in the basin. Comparisons for the basin are presented in Appendix 4H.

In some cases, graphical analyses could distinguish individual sources within the same potential source category. Figures 4.16 and 4.17 are an example. They show magnesium versus sulfate and calcium versus magnesium, respectively. Note that groundwater sampled in the vicinity of Lamb Weston's land application area have higher magnesium with respect to both calcium and sulfate than samples related to Simplot or Hermiston Foods. Figure 4.14 previously shown is another example. Samples related to Simplot operations tend toward higher bromide concentrations than samples related to other food processing operations. These characteristics may reflect the chemical composition of the water that each facility uses for food processing as well as facility specific processes.

Data related to samples collected directly from potential nitrate sources were added to the graphs analyzed to see whether they would appear as end members to the trends observed (Figure 4.18). Septic systems and irrigated crop agriculture were not represented, because project sampling did not include obtaining water from these sources. In Figure 4.18, the trend defined by groundwater sampled in the vicinity of food processing wastewater land application sites is evident. That the Lamb Weston wastewater lagoon sample does not appear as an end member on the trend is equally evident. This observation does not diminish or invalidate the previous observations. Instead, the differences may reflect the influence of processes the water experiences in the vadose (unsaturated) zone prior to reaching groundwater.

In summary, the chemical composition of a given groundwater sample reflects several influences. Potential nitrate sources influence groundwater by imparting an overall identifiable chemical relationship pattern and vadose zone chemical processes also influence groundwater. Given the different influences, a lack of correlation between samples obtained directly from potential nitrate sources and groundwater influenced by those sources does not present a serious contradiction problem.

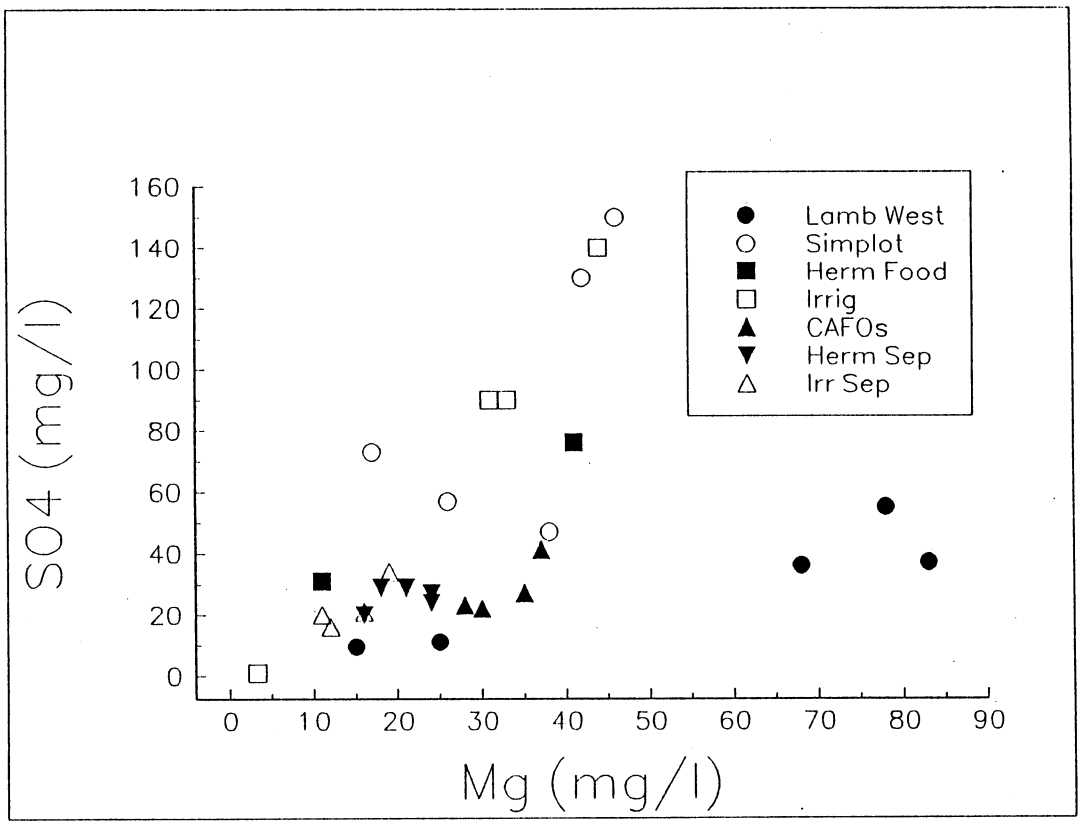


Figure 4.16 Magnesium versus sulfate for groundwater sampled in the vicinity of potential nitrate sources.

Note: Groundwater samples related to Lamb Weston wastewater influences graph separately from other food processing facilities, and the limited range of fields related to septic systems and animal feedlots.

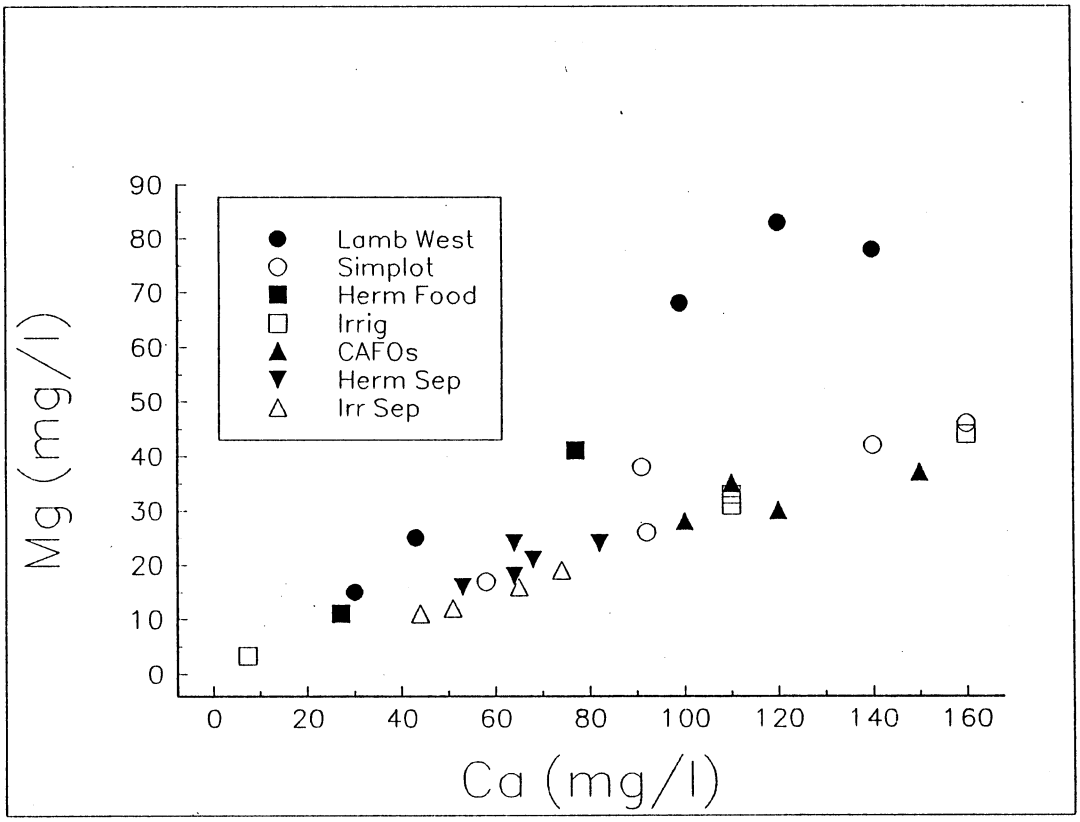


Figure 4.17 Calcium versus magnesium for groundwater sampled in the vicinity of potential nitrate sources.

Note: Groundwater samples apparently related to Lamb Weston wastewater influences are magnesium enriched relative to other food processing facilities.

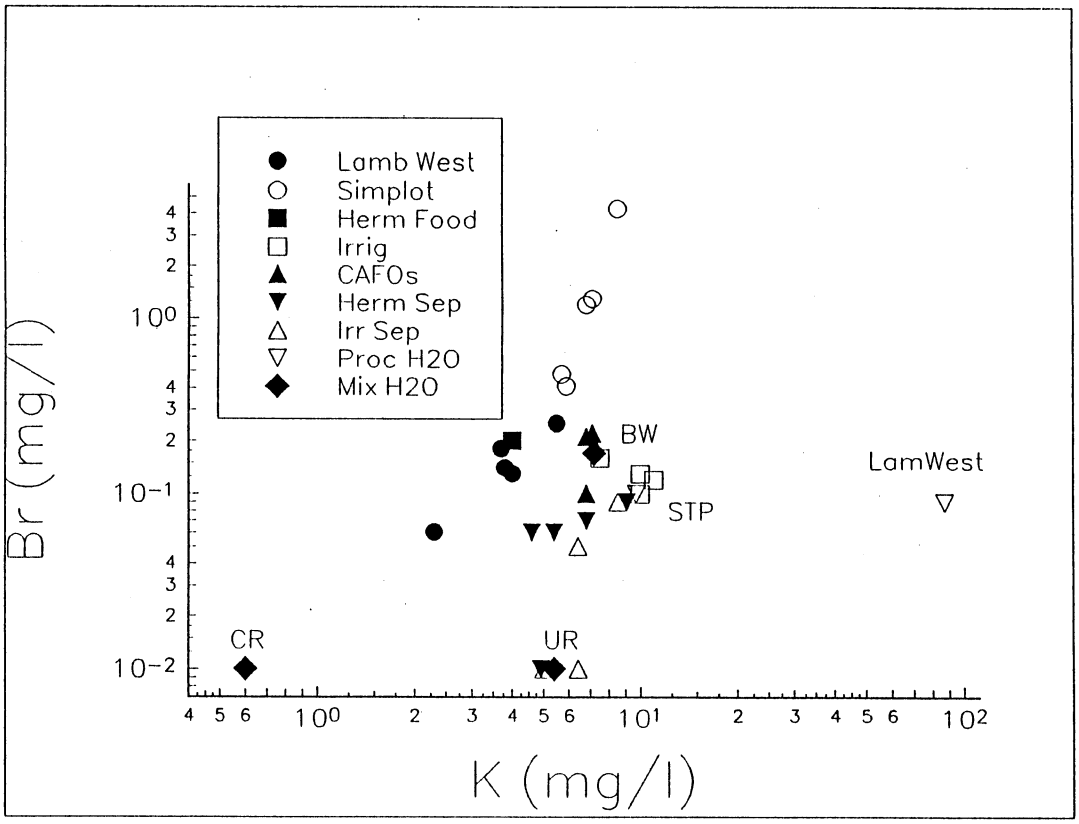


Figure 4.18 Potassium versus bromide for groundwater sampled in the vicinity of potential nitrate sources, irrigation water sources, and a food processing wastewater lagoon.

Note: Groundwater samples related to food processing wastewater appear unrelated to the food processing wastewater lagoon sample.

General Groundwater Chemistry Computer Modeling Results

This investigation used NETPATH (Plummer and others, 1991) and PHREEQE (Parkhurst and others, 1980) groundwater chemistry computer models for some data analyses. The models were selectively used to understand and differentiate natural versus human influences upon Lower Umatilla Basin groundwater. General results are presented in this section. Area specific results are presented in area specific sections.

General NETPATH Groundwater Chemistry Modeling Results

This investigation used NETPATH to assess and refine interpretations of natural and human influences on groundwater chemistry along selected groundwater flow paths. Groundwater concurrently sampled from a series of wells along the flow path provides the data needed to analyze and interpret how groundwater compositions evolved. This is true as long as different influences are not transitory.

Results from individual NETPATH analyses that apply to the entire Lower Umatilla Basin include:

- Mixing of deeper alluvial groundwater with infiltrating shallower water primarily explains the chemical composition observed in alluvial groundwater;

- Groundwater undergoes minor changes along a flow path as a result of water-rock mineral reactions typical of a groundwater basalt system;

- Cyclic evaporation-dissolution occurs locally in the vadose (unsaturated) zone; and

- Water from canal leakage does influence local groundwater chemistry;

General PHREEQE Groundwater Chemistry Modeling Results

The PHREEQE computer model was used to explore elevated calcium concentrations observed in Lower Umatilla Basin groundwater samples collected from some basalt water-bearing zones. The model calculates how groundwater chemistry changes as a result of prescribed reactions with minerals.

Two scenarios were explored. One had "unimpacted" basalt groundwater dissolve calcium bearing basalt minerals (plagioclase and clinopyroxene). The other had the same groundwater dissolve basaltic glass with a chemical composition described by Allan and Strope (1983). The results from both scenarios indicate obtaining the observed calcium concentrations from natural water-rock reactions is unlikely. For example, both scenarios indicate calcium in groundwater will reach saturation with calcite and dolomite at concentrations much lower than observed in groundwater samples collected. Reaching saturation should limit the calcium concentration in the groundwater when influenced by natural water-rock reactions only. The basalt glass scenario result indicates potassium and phosphate concentrations in groundwater should exceed 60 mg/l and 25 mg/L respectfully if water-basalt glass reactions were responsible for the calcium concentrations observed. These elevated potassium and phosphate concentrations were not observed in Lower Umatilla Basin basalt groundwater samples collected.

The results suggest an external calcium source influences some basalt groundwater through hydraulic connection with alluvial groundwater.

General Nitrogen Isotopic Analysis Results

Nitrogen-isotope sampling occurred in the Lower Umatilla Basin during the fall of 1993, spring of 1994, and fall 1994 at approximately 20 wells, 3 lysimeters, and a food processing wastewater surge pond. A summary of results is presented in this section. A complete discussion is presented in the Stable Nitrogen Isotope Analysis section.

Analysis of the nitrogen isotopic data found the following:

- The nitrogen isotopic compositions (delta ^{15}N) showed minor differences over time for most of the repeat samples collected;

- Current isotopic data indicates no area-wide denitrification occurs within the Lower Umatilla Basin. This finding does not preclude denitrification occurring locally in flood plain deposits adjacent to existing drainages if appropriate denitrification conditions exists.

- An organic waste influence is clearly evident from the delta ^{15}N values for groundwater sampled from well UMA 258. The well is located within an established food processing land application area north of the Umatilla River and east of the Butter Creek Highway.

- A commercial fertilizer influence is clearly evident from the delta ^{15}N values for groundwater sampled from three irrigation wells located north of Highway 730 between Boardman and Irrigon. The delta ^{15}N values remained constant over time despite nitrate+nitrite-nitrogen concentration fluctuations. That indicates the nitrogen source remains uniform and hydraulic flushing of nitrate is very slow. The delta ^{15}N values for the eastern wells are higher. That indicates an additional nitrate source influence is possible.

- The influence of animal waste appears evident from the delta ^{15}N values related to groundwater sampled from well UMA 133. This well is located along County Line Road approximately 2 miles south of Interstate 84. Historic and current animal waste sources are located nearby.

- Delta ^{15}N values related to groundwater sampled from wells near the U.S. Army Umatilla Depot Activity explosive washout lagoons indicates most of the nitrate in the groundwater came from explosive contaminants.

- Delta ^{15}N values related to other groundwater samples collected were not diagnostic of a single nitrogen source. Instead, the values indicate mixed nitrogen influences.

Area Specific Groundwater Chemistry Data Observations and Interpretations

Introduction

This section presents area specific groundwater chemistry data observations and interpretations. Some geographic areas have more observations and interpretations than other areas. This occurred because more information was available in some geographic areas. Also, more data analyses were needed for areas with more complex land uses, hydrogeology, and groundwater chemistry. Some data analyses were not repeated for each area, since results appear to apply basin wide.

Threemile Canyon and Sixmile Canyon Area

The Threemile Canyon and Sixmile Canyon area includes Ranges 23 and 24 East and Townships 3 and 4 North. Historic and current activity in the area includes the J.R. Simplot Company confined animal feeding operation, Taggares Farm irrigated agriculture, Portland General Electric (PGE) coal fired electric generating facility, Carty Reservoir, Boeing Company antenna field, the western half of the former Boardman Air Force Range, and some smaller activities. PGE and the Simplot Feedlot regularly collect groundwater samples and report the results to the Oregon Department of Environmental Quality. Project groundwater sampling in the area included reconnaissance and synoptic groundwater sampling. This section presents analysis of the project and private facility sampling data.

Map and Data Set Observations: Nitrate

Elevated nitrate concentrations have been detected in groundwater sampled from local alluvial sediments and basalt water bearing zones. Areas with elevated concentrations include the Simplot Feedlot lagoon vicinity, the southern portion of Sixmile Canyon, and a portion of the PGE ash disposal area. Plate 4.2 shows the June-July 1992 concentration distribution in alluvial groundwater based upon project synoptic sampling and concurrent sampling reported by the Simplot Feedlot. Concentrations detected in synoptic basalt groundwater samples are printed next to each sampling location. Plate 4.3 shows the distribution of maximum concentrations detected based upon project sampling only.

Threemile Canyon alluvial groundwater nitrate concentration data came from the J.R. Simplot confined feeding operation. The data represents groundwater sampled from three monitoring wells located adjacent to the facility's wastewater lagoons. This investigation found no water well reports for the wells. The wells were apparently constructed with a backhoe (Hammond, 1993). Reported nitrogen concentrations in the groundwater sampled varies geographically and over time. Reported nitrate-nitrogen concentrations range from 0.3 to 23.3 mg/L. Reported Total Kjeldahl Nitrogen (TKN) and ammonia-nitrogen concentrations range from 1.02 to 9.15 mg/L and non detect to 2.10 mg/L, respectively (DEQ Water Quality File 81591). Peak concentrations correspond to different well sites over time. This change over time may relate to the wastewater lagoon history. The TKN and ammonia values noted are unusually high for the basin. The values suggest nitrogen conversion to nitrate is incomplete. The TKN values also suggests animal waste or another organic source is the primary contributor of nitrate to groundwater locally.

Sixmile Canyon alluvial groundwater nitrate concentration data came from project synoptic sampling and PGE sampling at two PGE monitoring wells, UMA 274 (PGE 101) and UMA 275 (PGE 103). Both are located east of Taggares Farm where land application of animal waste did occur and where center pivot crop irrigation does occur. PGE apparently samples alluvial groundwater from additional wells, but data related to those wells were not found in PGE reports reviewed. PGE reported non-detect to 1.9 mg/L and 33 to 40 mg/L nitrate-nitrogen concentrations in groundwater collected from well UMA 274 and UMA 275, respectively (Carter 1987, 1988, 1989, 1990, 1991, 1992). Project synoptic sampling found non-detect and 32 mg/L nitrate+nitrite-nitrogen concentrations in groundwater collected from UMA 274 and UMA 275, respectively. Synoptic sampling data indicates nitrogen is present in groundwater at UMA 274 as TKN and ammonia rather than nitrate. The TKN and ammonia-nitrogen concentrations detected were both 18 mg/L. Those TKN and ammonia values are exceptionally high when compared to other project groundwater samples collected in the basin. The values suggest local reducing conditions may inhibit nitrogen conversion to nitrate. The nitrogen values and known land uses in the UMA 274 vicinity strongly suggest animal waste as the nitrogen source. Animal waste and/or commercial fertilizer could be the nitrogen source in the UMA 275 vicinity.

Sixmile Canyon shallow basalt water bearing zone nitrate concentration data came from project and/or PGE groundwater sampling at PGE basalt monitoring wells which are less than 100 feet deep. The wells are located in the Taggares Farm's southeast corner vicinity, Carty Reservoir vicinity, and the PGE ash disposal area. The Taggares Farm and Carty Reservoir vicinity wells obtain groundwater from the basal Elephant Mountain aquifer. The ash disposal area wells obtain groundwater from the upper Pomona aquifer. PGE reports nitrate-nitrogen concentrations ranging from 21 to 58 mg/L, non detect to 0.2 mg/L, and 0.3 to 70 mg/L in groundwater sampled from wells in the Taggares Farm vicinity, Carty Reservoir vicinity, and ash disposal area, respectively (Carter 1987, 1988, 1989, 1990, 1991, 1992). A review of the local hydrogeology and well construction indicates a likely connection exists between water in the alluvial sediments and the shallow basalt water bearing zones in the Taggares Farm vicinity and the ash disposal area. A connection would account for the higher nitrate concentrations observed. The connection appears to occur naturally and via well construction. An additional review of shallow basalt well site locations versus lower nitrate concentrations within the Carty Reservoir vicinity and the ash disposal area suggests the reservoir dilutes nearby groundwater.

Project shallow basalt groundwater sampling in Sixmile Canyon occurred at PGE 107 (UMA 271) and reportedly at PGE 104 (UMA 273) only. The wells are located in the Taggares Farm vicinity. The sampling found nitrate+nitrite-nitrogen concentrations at 26 and 0.10 mg/L, respectively. The 26 mg/L value compares well to PGE reported data related to the same well. The 0.10 mg/L compares poorly to the 33 to 58 mg/L values reported by PGE for groundwater sampled from well UMA 273. The other constituent values also compare poorly. Perhaps the synoptic sampling misidentified the PGE well sampled. The UMA 273 data compares best to PGE 018 rather than PGE 104.

Project shallow basalt groundwater sampling near Interstate 84 occurred at Castle (UMA 197) and the Wilson Golf Course (UMA 179). The wells are located approximately 3 and 6 miles east of Sixmile Canyon, and they are constructed 216 and 100 feet deep, respectively. Nitrate+nitrite-nitrogen concentrations in groundwater sampled from these wells measured as non detect to 1.3 mg/L.

Deeper basalt groundwater sampling occurred at wells more than 500 feet deep located within Taggares Farm (UMA 169), near Carty Reservoir (UMA 272), and within the Boeing antenna field (UMA 171). Project groundwater sampling measured nitrate+nitrite-nitrogen from these wells as non detect to 0.04 mg/L. PGE groundwater sampling at UMA 272 (PGE 001) measured nitrate-nitrogen from non detect to 0.7 mg/L (Carter 1987, 1988, 1989, 1990, 1991, 1992).

Map and Data Set Observations: Total Dissolved Solids

Elevated total dissolved solids (TDS) concentrations have been detected in groundwater sampled from local alluvial sediments and shallow basalt water bearing zones. The highest TDS concentrations detected in the basin came from this area. Plate 4.4 shows the June-July 1992 concentration distribution for alluvial groundwater based upon project synoptic sampling. Results for synoptic basalt groundwater samples are printed next to the sampling location. Plate 4.5 shows the distribution of maximum concentrations detected based upon project sampling only.

Local alluvial groundwater TDS data has been limited to samples collected from two PGE monitoring wells, UMA 274 and UMA 275, located east of Taggares Farm. PGE reports reviewed did not include data related to other PGE alluvial groundwater monitoring wells, and Simplot Feedlot groundwater monitoring data reviewed did not include TDS analyses. PGE reported TDS concentrations of 1,013 to 1,282 mg/L and 948 to 1,702 mg/L in samples collected from UMA 275 and UMA 274, respectively (Carter 1987, 1988, 1989, 1990, 1991, 1992). Project synoptic groundwater sampling detected TDS at 1200 mg/L and 1,100 mg/L in samples collected from UMA 274 and UMA 275.

TDS concentrations in local basalt groundwater varies. TDS measured less than 450 mg/L in groundwater collected from UMA 169, UMA 171, and UMA 272 (PGE 001) by this project and PGE (Carter 1987, 1988, 1989, 1990, 1991, 1992). These wells are more than 500 feet deep. TDS measured 400 to 420 mg/L in groundwater sampled by this project from shallow basalt water bearing zones near Interstate 84 east of Sixmile Canyon. Higher TDS concentrations have been measured in most Sixmile Canyon shallow basalt water bearing zone groundwater samples. PGE reported TDS at 805 to 1,654 mg/L, 252 to 277 mg/L, and 644 to 1154 mg/L in samples collected from wells in the vicinity of Taggares Farm southeast corner, Carty Reservoir vicinity, and the ash disposal area, respectively (Carter 1987, 1988, 1989, 1990, 1991, 1992). Project synoptic sampling at a Taggares Farm vicinity well, UMA 271, detected TDS at 1200 mg/L. A review of shallow basalt well site locations versus lower TDS concentrations within the Carty Reservoir vicinity and ash disposal area suggests the reservoir dilutes nearby groundwater.

Map and Data Set Observations: Other Constituents

Elevated arsenic calcium, chloride, sodium and sulfate concentrations have been detected in alluvial and basalt groundwater sampled in the area. Table 4.11 presents concentration ranges detected by project and PGE sampling. Plates 4.6, 4.7 and 4.8 show the maximum arsenic, chloride and sodium concentrations detected by project sampling only. Arsenic concentrations in alluvial groundwater sampled from UMA 275 (PGE 103) approach the drinking water standard of 0.05 mg/L. Sodium concentrations in local groundwater generally exceed 20 mg/L which is currently recommended for persons on a physician prescribed sodium restricted diet. Chloride concentrations exceeded the 250 mg/L secondary (aesthetic) drinking water standard in some Taggares vicinity and PGE ash disposal area shallow basalt water bearing zone samples. Some of the sulfate concentrations measured are among the highest detected in the Lower Umatilla Basin.

Groundwater sampling has detected bromide, boron, phosphate, and vanadium in local groundwater. Table 4.12 shows concentration ranges detected by project and PGE sampling. Plates 4.10, 4.11, 4.12, and 4.13 show the distribution of maximum concentrations detected by project sampling only. Bromide concentrations in groundwater samples from this area are generally among the higher concentrations detected in the basin. Boron concentrations reported by PGE (Carter 1987, 1988, 1989, 1990, 1991, 1992) are the highest concentrations detected in the basin.

Phosphate detected in Sixmile Canyon alluvial groundwater samples and in shallow basalt water bearing zone samples from the Taggares Farm vicinity and PGE ash disposal area are among the higher concentrations detected in the basin. Phosphate in alluvial groundwater samples from UMA 274 (PGE 101) are among the highest concentrations detected in the basin.

Vanadium concentrations in local groundwater samples are among the lower concentrations detected in the basin. They remain below 0.10 mg/L. However, the concentrations are higher than typically found in groundwater.

Table 4.11 Arsenic, calcium, chloride, sodium, and sulfate concentration ranges for groundwater sampled in the Threemile Canyon and Sixmile Canyon area.

Groundwater Sampling Categories	Constituents									
	Arsenic (mg/L)		Calcium (mg/L)		Chloride (mg/L)		Sodium (mg/L)		Sulfate (mg/L)	
	maximum	minimum	maximum	minimum	maximum	minimum	maximum	minimum	maximum	minimum
Alluvial: Sixmile Canyon UMA 274 and UMA 275	0.048	<0.002	132	31	195	108	342	127	945	125
Basalt Wells: More than 500 feet Deep (undifferentiated basalt)	0.014	<0.002	35	8	56	32	110	71	78	0.7
Shallow Basalt Wells: Taggares Farm SE Corner Vicinity (basal Elephant Mountain)	0.010	0.002	203	44	559	77.5	143	47	277	52
Shallow Basalt Well: Carty Reservoir Vicinity (basal Elephant Mountain)	0.014	0.007	37.8	30	20.6	15.4	76	25	19	13
Shallow Basalt Wells: PGE Ash Disposal Area (Pomona)	0.013	0.003	117	53	327.7	66.9	90	47	160	97
Shallow Basalt Wells: Near Interstate 84 UMA 179 and UMA 197	0.010	<0.005	65	11	36	7.6	120	37	98	20

Sources: Project Reconnaissance and Synoptic Data (July 1990 through July 1992)
Carter, 1987, 1988, 1989, 1990, 1991, 1992

Note: Alluvial groundwater data for the Simplot Feedlot wastewater lagoon vicinity is missing, because these constituents were apparently not analyzed.

Table 4.12 Bromide, boron, total phosphate, and vanadium concentration ranges for groundwater sampled in the Threemile Canyon and Sixmile Canyon area.

Groundwater Sampling Categories	Constituents							
	Bromide (mg/L)		Boron (mg/L)		Total Phosphate (mg/L)		Vanadium (mg/L)	
	maximum	minimum	maximum	minimum	maximum	minimum	maximum	minimum
Alluvial: Sixmile Canyon UMA 274 and UMA 275	1.30	1.00	0.4	<0.1	2.00	0.005	0.045	<0.005
Basalt Wells: More than 500 feet Deep (undifferentiated basalt)	0.28	0.28	0.2	0.05	0.034	0.01	0.022	<0.005
Shallow Basalt Wells: Taggares Farm SE Corner Vicinity (basal Elephant Mountain)	1.9	1.9	0.3	<0.1	0.145	0.012	0.055	0.018
Shallow Basalt Well: Carty Reservoir Vicinity (basal Elephant Mountain)	NA	NA	0.4	0.1	0.044	0.022	0.045	0.028
Shallow Basalt Wells: PGE Ash Disposal Area (Pomona)	NA	NA	0.3	<0.1	0.224	0.016	0.067	0.023
Shallow Basalt Wells Near Interstate 84 UMA 179 and UMA 197	<0.05	<0.05	0.04	<0.03	0.06	0.02	<0.03	<0.03

NA: Not Analyzed
Sources: Project Reconnaissance and Synoptic Data (July 1990 through July 1992)
Carter, 1987, 1988, 1989, 1990, 1991, 1992
Note: Alluvial groundwater data for the Simplot Feedlot wastewater lagoon vicinity is missing, because these constituents were apparently not analyzed.

Higher calcium, chloride, sulfate, bromide, and total phosphate concentrations occur in some Sixmile Canyon alluvial groundwater samples, and shallow basalt water bearing zone samples from the Taggares Farm vicinity and PGE ash disposal area. The pattern of occurrence suggests human activity in the area locally influences alluvial and shallow basalt water bearing zone groundwater chemistry.

Graphical Analyses: Nitrate versus Time

Graphical analysis of Threemile Canyon and Sixmile Canyon area groundwater data included reviewing nitrate versus time graphs. Data used for the analysis came from Portland General Electric (Carter 1987, 1988, 1989, 1990, 1991, 1992) and the J.R. Simplot confined animal feeding operation (DEQ Water Quality File 81591). This analysis included comparing the nitrate versus time graphs to available groundwater versus time and/or other constituent versus time graphs.

Figure 4.19 shows nitrate-nitrogen concentrations versus time in Threemile Canyon alluvial groundwater samples collected from three wells adjacent to the Simplot Feedlot wastewater lagoons. The concentration versus time patterns are not similar. This suggests different local influences. These influences may relate to different histories for the 8 cells comprising the lagoon. No groundwater elevation or other constituent data over time was found for comparison.

Figure 4.20 shows nitrate-nitrogen concentrations versus time in Sixmile Canyon alluvial and shallow basalt water bearing zone groundwater samples collected near or within Taggares Farm. The concentration versus time patterns are similar despite location, groundwater source, and concentration differences. The peak nitrate concentration for each time series similarly occurs during 1989. These similarities suggest a common nitrate influence. For example, the 1989 peak nitrate concentrations follow the resumption of land applying Simplot animal waste at Taggares Farm, and it coincides with a J-U-B Engineers (1989) recommendation to increase the application rate from 300 to 450 pounds per acre. Further analysis found the nitrate versus time graphs did not relate well to sodium, total dissolved solids (TDS), or groundwater elevation versus time graphs. This lack of similarity suggests other influences affected sodium, TDS, and groundwater elevations. For example, Carty Reservoir influences groundwater elevations in the Sixmile Canyon vicinity, and nitrogen sources applied to adjacent land may include both commercial fertilizer and animal waste. Different nitrogen sources can influence sodium and TDS differently.

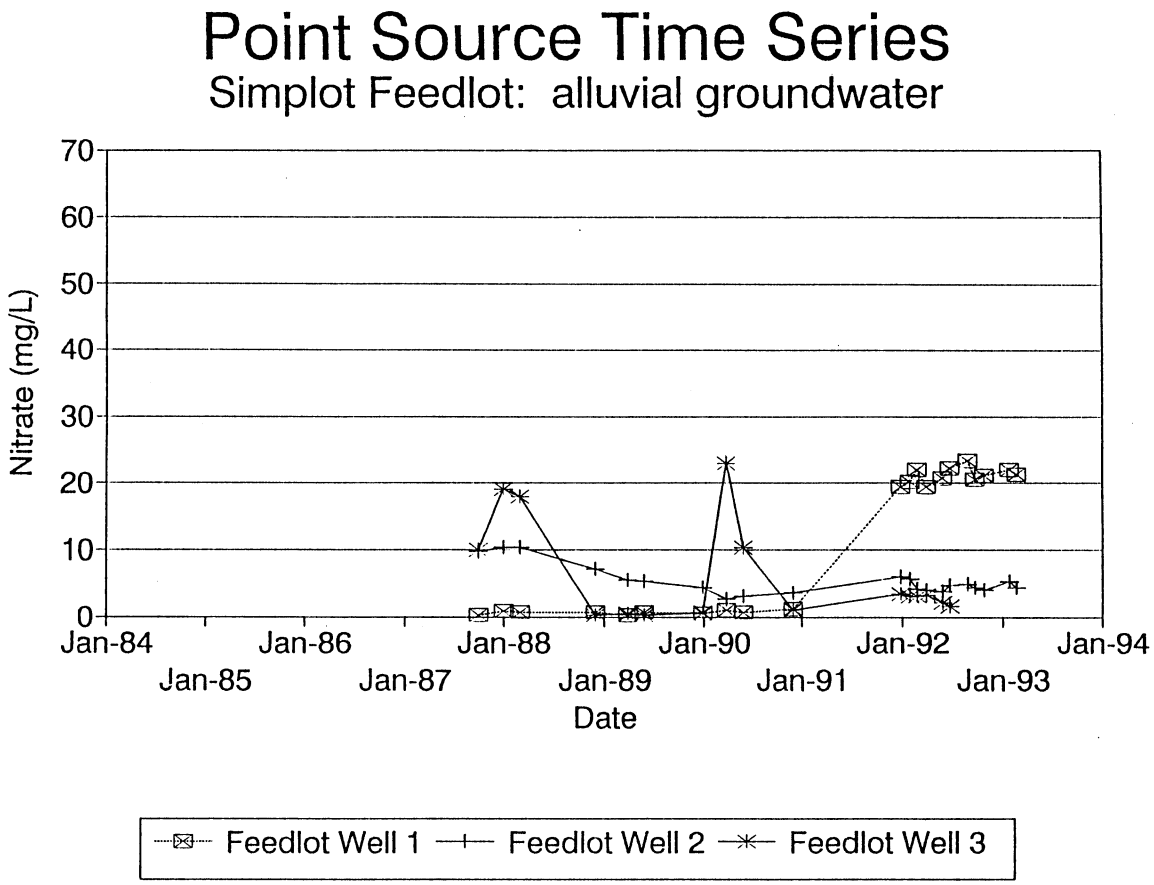


Figure 4.19 Nitrate-nitrogen versus time in Threemile Canyon alluvial groundwater sampled near the J.R. Simplot Company confined animal feedlot wastewater lagoons.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

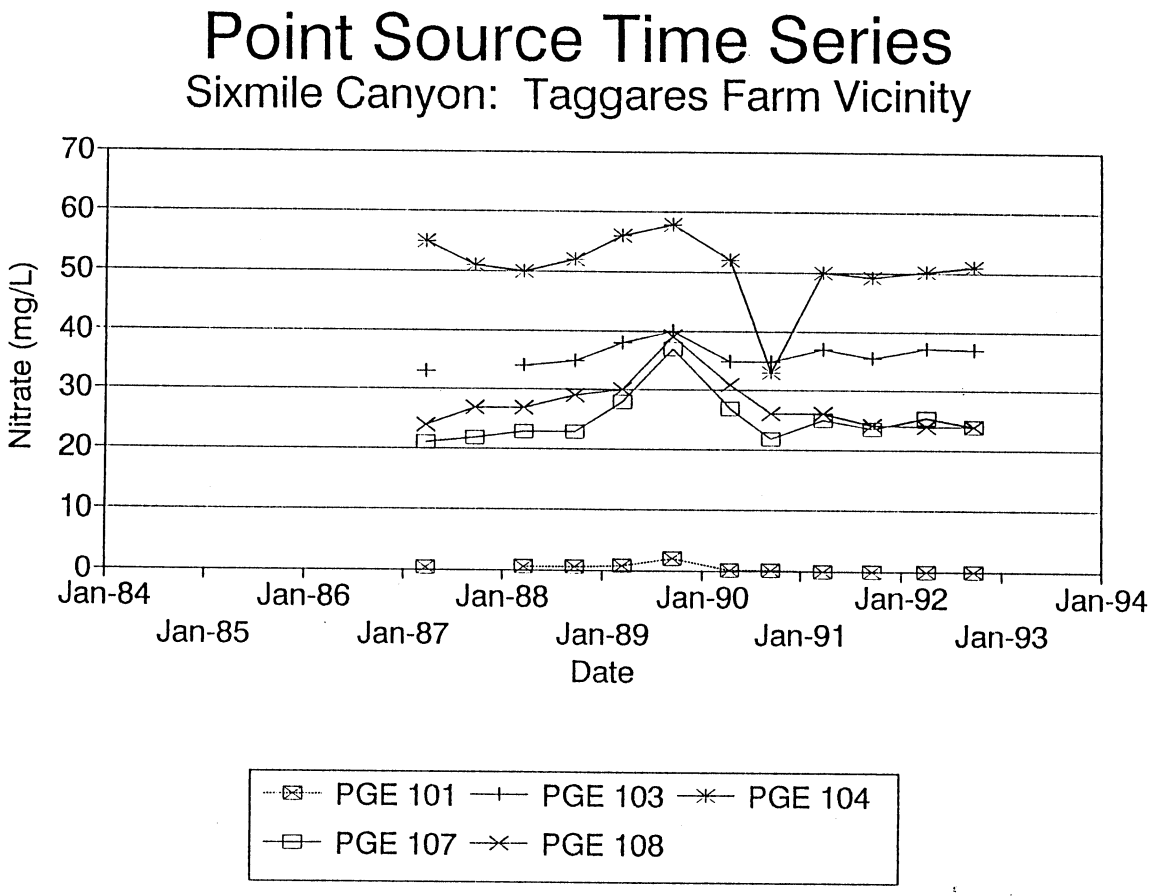


Figure 4.20 Nitrate-nitrogen versus time in Sixmile Canyon alluvial and shallow basalt water bearing zone groundwater sampled near or within Taggares Farm.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Figure 4.21 shows nitrate-nitrogen concentrations versus time in shallow basalt water bearing zone groundwater samples collected within the PGE ash disposal area. The concentration versus time patterns have some differences and similarity. The similarity relates to peak nitrate concentrations occurring during 1989. These peak concentrations coincide with peak nitrate concentrations observed in alluvial and shallow basalt water bearing zone groundwater samples collected near or within Taggares Farm. The differences may relate to dilution influences from Carty Reservoir. Further analysis found the nitrate versus time graphs generally did not relate well to sodium, total dissolved solids (TDS), or groundwater elevation versus time graphs. The general lack of similarity suggests other influences affected sodium, TDS, and groundwater elevations. One exception may be nitrate concentrations and groundwater elevations at PGE well 052. Nitrate concentration variations may lag groundwater elevation variations by 19 months.

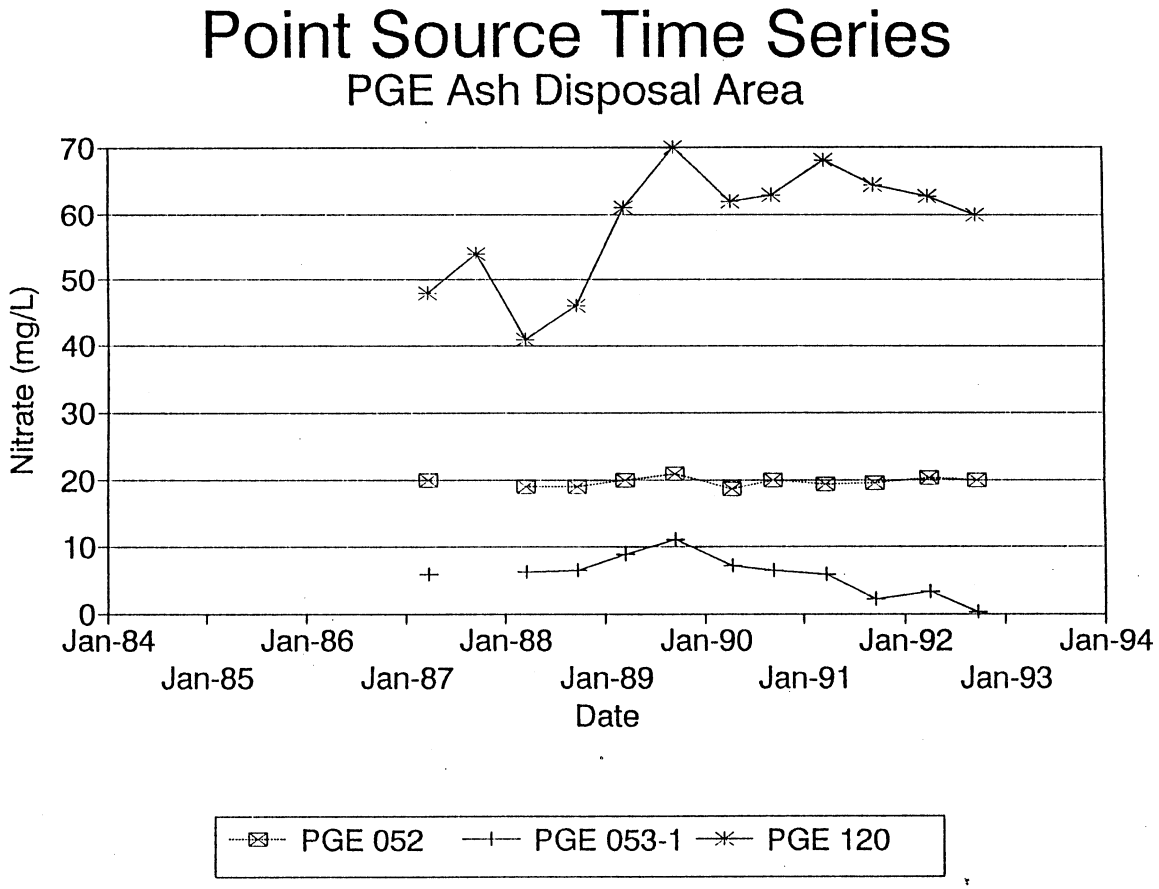


Figure 4.21 Nitrate-nitrogen versus time in Sixmile Canyon shallow basalt water bearing zone groundwater sampled within the Portland General Electric ash disposal area.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams

Project synoptic sampling data related to the Threemile Canyon and Sixmile Canyon area were plotted on Piper trilinear graphs and Schoeller diagrams. Nearly all the data graphed as a water type different from most of the basin. Additionally, data representing alluvial groundwater graphed differently from each other, and data representing various basalt groundwater graphed differently from each other. However, data representing alluvial groundwater graphed weakly similar to some data representing basalt groundwater.

Piper trilinear graphs were used to determine the water type for each synoptic sample graphed and to determine whether any major proportion variation trends correlated to tabulated nitrate concentrations. The Threemile Canyon and Sixmile Canyon data showed no major ion variation trends.

Table 4.13 shows the water type for each sample graphed, the source of groundwater, the sampling location, and the nitrate concentration in the sample. Most Lower Umatilla Basin groundwater graphed as mixed-cation/bicarbonate dominant or calcium/bicarbonate dominant water. Only one Threemile Canyon and Sixmile Canyon area synoptic sample graphed as mixed cation/bicarbonate dominant water. That sample came from a shallow basalt water bearing zone through well UMA 179 located at Wilson Golf Course. The remaining samples graphed as sodium or potassium/bicarbonate dominant, sodium or potassium/sulfate dominant, mixed-cation/chloride dominant, and no dominant type water. Those samples came from alluvial sediments and various basalt water bearing zones via wells located along or near Sixmile Canyon.

Synoptic samples with similar nitrate concentrations graphed as somewhat similar water types on the trilinear graphs. For example, two samples with elevated nitrate+nitrite-nitrogen concentrations graphed as mixed-cation/chloride dominant and no dominant type water. The no dominant type water sample graphed nearly as mixed-cation/chloride dominant water. One sample came from alluvial sediments at well UMA 275 located along Sixmile Canyon and the other from a shallow basalt water bearing zone at well UMA 271 located in the southeast portion of Taggares Farm. Two samples with nitrate+nitrite-nitrogen concentrations below detection limits graphed as sodium or potassium/bicarbonate dominant water. One sample came from alluvial sediments at well UMA 274 located in the northern portion of Sixmile Canyon and the other from deeper basalt water bearing zones at well UMA 272 near Carty Reservoir.

Table 4.13 Threemile Canyon and Sixmile Canyon area groundwater characteristics.

Sampling Site ID	General Location	Well Depth (feet)	Groundwater Source	Water Type	Nitrate+Nitrite-Nitrogen (mg/L)
UMA 179	Near Interstate 84 (more than 6 miles east of Sixmile Canyon)	100.0	Shallow Basalt Water Bearing Zone (basal Elephant Mountain/Rattlesnake Ridge)	mixed-cation/bicarbonate	0.89
UMA 271 (PGE 107)	Taggares Farm SE Corner Vicinity	43.5	Shallow Basalt Water Bearing Zone (basal Elephant Mountain)	mixed-cation/chloride	26.00
UMA 272 (PGE 001)	Carty Reservoir Vicinity	564.5	Multiple Basalt Water Bearing Zones	sodium or potassium/ bicarbonate	<0.02
UMA 273 (PGE 104?)	questioned			sodium or potassium/ sulfate	0.10
UMA 274 (PGE 101)	Sixmile Canyon	25.0	Aeolian Sand	sodium or potassium/ bicarbonate	<0.02
UMA 275 (PGE 103)	Sixmile Canyon	67.7	Aeolian Sand	no dominant type (almost mixed-cation/chloride)	32.00

Note: Water type was determined by graphing synoptic sampling data on Piper trilinear graphs
Note: Nitrate+nitrite-nitrogen concentrations came from synoptic sampling data
Note: Field sampling sheets indicate UMA 273 corresponds to PGE 104. However, UMA 273 data corresponds poorly to PGE 104. The data corresponds best to PGE 018.

Schoeller diagrams were used to observe any constituent to constituent relationship patterns. Little similarity between individual sample patterns was observed. An inverse correlation between nitrate and phosphate may exist for the six-mile canyon samples.

Graphical Analyses: Constituent Versus Constituent

Constituent versus constituent graphs were used to distinguish nitrate sources as described in the evidence of potential nitrate sources discussion within the preceding general observations and interpretations section. Data analyzed came from project synoptic sampling data (see Appendix 4F) and data submitted by Portland General Electric (Carter 1987, 1988, 1989, 1990, 1991, 1992). The synoptic sampling data was reviewed using chloride versus potassium, bromide versus potassium, chloride/bromide versus chloride, magnesium versus calcium, and sulfate versus magnesium graphs. The PGE data was reviewed using the chloride versus potassium graphs. No single nitrate influence was identified. A combination of nitrate sources and natural processes would account for how the data graphed.

Groundwater Flow Path Analysis

The available groundwater data was insufficient for groundwater flow path data analysis.

Groundwater Chemistry Computer Modeling

No groundwater chemistry computer modeling was conducted for the Threemile and Sixmile Canyon area.

Nitrogen Isotopic Analysis

No nitrogen isotope groundwater sampling occurred within the Threemile Canyon and Sixmile Canyon area.

Threemile Canyon and Sixmile Canyon Area Summary and Conclusions

Analysis of Threemile Canyon and Sixmile Canyon groundwater chemistry data led to the following observations and interpretations:

- Nitrate concentrations in Threemile Canyon and Sixmile Canyon area groundwater ranges from non-detect to 70 mg/L.

- Nitrate concentrations remained below 1 mg/L in groundwater samples collected from basalt wells constructed more than 500 feet deep.

- Nitrate concentrations were detected below 2 mg/L in shallow basalt water bearing zone groundwater samples collected near Interstate 84 east of Sixmile Canyon.

- Nitrate concentrations exceeding 10 mg/L were detected in alluvial and shallow basalt water bearing zone groundwater samples collected near the J.R. Simplot Feedlot wastewater lagoons, near or within Taggares Farm along Sixmile Canyon, and the PGE ash disposal area.

- A review of available nitrate, ammonia and Total Kjeldahl Nitrogen (TKN) data and local land uses indicates animal waste or another organic nitrogen source influences groundwater in the J.R. Simplot Feedlot wastewater lagoon vicinity and the PGE 101 (UMA 274) vicinity at least.

- Graphical analyses indicate a combination of nitrate sources and natural processes influences groundwater along Sixmile Canyon.

- Graphical analyses indicate Taggares Farm activity contributes nitrate to alluvial and shallow basalt water bearing zone groundwater within the farm vicinity. Past and/or current farm activity includes land application of animal waste and center pivot crop irrigation.

- Carty Reservoir appears to dilute shallow basalt water bearing zone groundwater near the reservoir.

- The nitrate source in groundwater within PGE's ash disposal area remains unresolved. Ash from the electric generating coal fired plant appears not to be a nitrate source, and Carty Reservoir separates the ash disposal area from Taggares Farm. Agricultural activity occurs south of the ash disposal area, but no data from that area was obtained for comparison analyses.

- Total dissolved solids (TDS) concentrations in local groundwater are among the highest detected in the Lower Umatilla Basin.

- Arsenic concentrations in alluvial groundwater sampled from UMA 275 (PGE 103) approached the drinking water standard of 0.05 mg/L.

- Sodium concentrations in local groundwater generally exceeded the 20 mg/L limit recommended for persons with a physician prescribed sodium restricted diet.

- Chloride concentrations exceeded the 250 mg/L secondary (aesthetic) drinking water standard in some Taggares vicinity and PGE ash disposal area shallow basalt water bearing zone groundwater samples.

- Some sulfate concentrations measured in local groundwater samples are among the highest concentrations detected in the Lower Umatilla Basin.

Boardman to West Umatilla

The Boardman to west Umatilla area includes Ranges 25, 26, and 27 East and Townships 3, 4, and 5 North. Groundwater generally flows northwesterly through the area with exceptions. Saturated alluvial sediments end south and west of Boardman. Historic and current land uses in the area include:

- City of Boardman and Irrigon municipal areas;

- City of Boardman sewage treatment facility and wastewater land application site;

- City of Irrigon sewage treatment facility infiltration beds;

- Unsewered rural residential home developments and mobile home parks;

- Port of Morrow Industrial Park and wastewater land application areas;
- Finley Butte Landfill;
- Crop agriculture using a variety of irrigation methods;
- Pastured and confined livestock operations;
- John Day Wildlife Management Area;
- Umatilla and Irrigon Fish Hatcheries;
- U.S. Army Umatilla Depot Activity; and U.S. Navy Boardman Bombing Range.

This section presents analyses of project and facility data. The Port of Morrow and Finley Butte Landfill regularly collect groundwater samples from facility wells and report the results to DEQ. The U.S. Army reports Depot groundwater sampling results to the U.S. Environmental Protection Agency and Oregon DEQ. Project groundwater sampling in the area includes reconnaissance, bimonthly, and synoptic sampling. Areas north, west, and southwest of the Depot have sparse data due to very few wells in those areas.

Map and Data Set Observations: Nitrate

Table 4.14 and Plates 4.2 and 4.3 show the nitrate+nitrite-nitrogen concentration range and distribution in the Boardman to west Umatilla area. Table 4.14 shows local concentration ranges detected by this project or reported by local facilities. Plate 4.3 shows the distribution of maximum concentrations this project detected in alluvial and basalt groundwater samples. Plate 4.2 shows the June-July 1992 concentration distribution in regional alluvial groundwater based upon project synoptic sampling. Nitrate+nitrite-nitrogen concentrations detected in shallow unconfined alluvial groundwater samples and basalt groundwater samples are printed next to each sampling location.

The shape and extent of each concentration range contoured on Plate 4.2 was derived by linear interpolation between data locations. Data control was sparse north, west, and southwest of the U.S. Army Depot. This needs to be considered to avoid misinterpreting nitrate sources and nitrate movement when reviewing the sparse data areas. This is especially true for contours north and northwest of the Army Depot and the northeast corner of the U.S. Navy Bombing Range.

Elevated nitrate+nitrite-nitrogen concentrations were detected in groundwater sampled south of Boardman between Interstate 84 and the U.S. Navy Bombing Range. Samples with the highest concentrations came from basalt and "alluvial"/top of basalt wells located within and immediately north of a primarily center pivot crop irrigation area north of the U.S. Navy Bombing Range. Plates 4.2 and 4.3 show increasing concentrations toward that area. A major portion of the area converted to Port of Morrow wastewater land application after 1990.

Table 4.14 Nitrate concentration ranges detected in alluvial and basalt groundwater sampled from the Boardman to West Umatilla area.

Area	Groundwater Source	Dominant Land Uses (Historic and Current)	Nitrate-N (mg/L)	
			Maximum	Minimum
Boardman Area: North (north of Interstate-84) (Project Sampling)	Alluvial	municipal	21.00	7.00
Boardman Area: South (Interstate-84 to West Extension Canal) (Project Sampling)	Alluvial	rural residential animal operations irrigated crops nearby	25.00	15.00
Boardman Area: South (Interstate-84 to West Extension Canal) (Project Sampling)	Basalt (shallow)	rural residential animal operations irrigated crops nearby	64.00	<0.02
Boardman Area: South (West Extension Canal to U.S. Navy Bombing Range) (Project Sampling: UMA 233)	Basalt Top	Irrigated crops converted to Port of Morrow wastewater land application	31.00	---
Boardman Area: South (West Extension Canal to U.S. Navy Boardman Bombing Range) (Port of Morrow Sampling)	Basalt top	irrigated crops converted to Port of Morrow wastewater land application	35.40	1.90
U.S. Navy Boardman Bombing Range: (Project Sampling: UMA 170)	Basalt (deep)	bombing range	9.60	9.00
Port of Morrow Land Application Area (east of Boardman and north of Interstate-84) (Project Sampling)	Alluvial	wastewater land application crop irrigation nearby Boardman sewage treatment facility nearby	29.00	4.70
Port of Morrow Area (east of Boardman and north of Interstate-84) (Port of Morrow Sampling)	Alluvial	wastewater land application crop irrigation nearby Boardman sewage treatment facility nearby	29.30	0.10

Crop Irrigation Area (east of Boardman: Range 26) (Project Sampling)	Alluvial	irrigated crops	76.00	1.00
Finley Butte Landfill (south end of Range 26) (Finley Butte Landfill and DEQ Solid Waste Division Sampling)	Alluvial	landfill	0.35	<0.02
Irrigon Vicinity (Project Sampling)	Alluvial	rural residential	22.00	0.02
Irrigon Vicinity (Project Sampling)	Basalt (shallow)	rural residential	3.00	0.02
Irrigon Sewage Treatment Facility Area (Project Sampling)	Alluvial	sewage treatment with infiltration beds irrigated crops and cemetery nearby	41.00	20.00
Irrigon Sewage Treatment Facility Area (City of Irrigon Sampling)	Alluvial	sewage treatment with infiltration beds irrigated crops and cemetery nearby	40.80	3.83
Irrigon Sewage Treatment Facility Area (Project Sampling: UMA 269)	Basalt (shallow)	sewage treatment with infiltration beds irrigated crops nearby	0.05	---
Irrigon to West Umatilla (along Highway 730) (Project Sampling)	Alluvial	rural residential small orchards and animal operations irrigated crops to south	35.00	9.80
Irrigon to West Umatilla (along Highway 730) (Project Sampling)	Basalt (shallow)	rural residential small orchards and animal operations irrigated crops to south	0.28	<0.02
Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial	wastewater land application Depot's active landfill nearby	22.00	0.18
Lamb-Weston, Inc. Land Application Area (Adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial (Shallow Unconfined)	wastewater land application Depot's active landfill nearby	36.00	21.00
Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Lamb-Weston, Inc. Sampling)	Alluvial	wastewater land application Depot's active landfill nearby	74.00	0.18

Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Lamb-Weston, Inc. Sampling)	Alluvial (Shallow Unconfined)	wastewater land application Depot's active landfill nearby	65.00	<1.0
U.S. Army Umatilla Activity: West (Ammunition Demolition and Deactivation Furnace Areas) (Project Sampling)	Alluvial	ordnance activity irrigated crops nearby	27.00	0.12
U.S. Army Umatilla Depot Activity: West (Ammunition Demolition and Deactivation Furnace Areas) (U.S. Army Sampling)	Alluvial	ordnance activity irrigated crops nearby	60.00	0.01
U.S. Army Umatilla Depot Activity: Central Explosive Washout Lagoons Area) (Project Sampling)	Alluvial	ordnance activity	47.00	6.70
U.S. Army Umatilla Depot Activity: Central (Explosive Washout Lagoons Area) (U.S. Army Sampling)	Alluvial	ordnance activity	150.00?	<0.01
U.S. Army Umatilla Depot Activity: Northeast (Active Landfill Area) (Project Sampling)	Alluvial	landfill wastewater land application nearby	18.00	6.20
U.S. Army Umatilla Depot Activity: Northeast (Active Landfill Area) (U.S. Army Sampling)	Alluvial	landfill wastewater land application nearby	17.00	4.70
U.S. Army Umatilla depot Activity: South (Administrative, Inactive Landfill, and Sewage Treatment Areas) (Project Sampling)	Alluvial	sewage treatment facility with drainfield inactive landfills irrigated crop agriculture nearby animal operations nearby	11.00	5.10
U.S. Army Umatilla Depot Activity: South (Administrative, Inactive Landfill, and Sewage Treatment Areas) (U.S. Army Sampling)	Alluvial	sewage treatment facility with drainfield inactive landfills irrigated crop agriculture nearby animal operations nearby	22.00	<5.00
U.S. Army Umatilla Depot Activity: General (all other areas) (Project Sampling)	Alluvial	ordnance activity	18.00	6.10

U.S. Army Umatilla Depot Activity: General (all other areas) (U.S. Army Depot Sampling)	Alluvial	ordnance activity	16.80	<0.01
Crop Irrigation Area (south of the U.S. Army Umatilla Depot Activity) (Project Sampling)	Alluvial	irrigated crops	41.00	0.74
Crop Irrigation Area (south of the U.S. Army Umatilla Depot Activity) (Project Sampling)	Basalt (shallow and deep)	irrigated crops animal operations	9.30	0.25

Note: Project sampling reports nitrate concentrations as nitrate+nitrite-nitrogen.
Note: Shallow refers to wells less than 300 feet deep.
Note: Deep refers to wells 300 feet or more deep.

Sources:
Project Sampling
DEQ file: Solid Waste Disposal Facility Permit Number 394
DEQ Water Quality File 42490
DEQ Water Quality File 48780
Finley Buttes Landfill, 1992b
Hemphill, 1992
Port of Morrow, 1993a
SCM Consultants, Inc., 1990
Torrisi, 1992

Basalt groundwater samples had concentrations that reached 64 mg/L. This indicates a route for nitrate to travel to basalt water bearing zones exists.

Port sampling detected nitrate-nitrogen concentrations up to 35.5 mg/L in groundwater from wells completed in the brecciated and fractured top of basalt which grades into the overlying alluvial sediments. Port sampling also detected TKN primarily between 1 and 3 mg/L (Port of Morrow, 1993a). That indicates a possible contribution from an organic nitrogen source. However, irrigated crop agriculture appears to be the primary source given the local land use history, the distribution of the higher nitrate concentrations, and the detection of Atrazine at UMA 003.

Other south Boardman basalt and alluvial groundwater samples with elevated nitrate+nitrite-nitrogen concentrations came from wells primarily located downgradient of the irrigated crop area and near animal operations and/or rural residential homes. Analyses indicate the septic systems and animal operations do influence local groundwater but at relatively lower concentrations.

Plates 4.2 and 4.3 show elevated nitrate+nitrite-nitrogen concentrations occur in alluvial groundwater west and northwest of the U.S. Army Umatilla Depot Activity. Concentrations increase from Irrigon, the Columbia River, the Army Depot, the Port of Morrow, and Interstate 84 toward Western Empires Corporation Farm where center pivot irrigation currently occurs and nitrate+nitrite-nitrogen concentrations reach 76 mg/L. Analysis of land use, nitrate concentration distribution, and nitrogen isotopes strongly indicate irrigated crop agriculture is the nitrate source for concentrations exceeding 30 mg/L.

Several sources appear responsible for the nitrate concentrations less than 30 mg/L in the area. Nitrogen isotopic analyses indicate sources in addition to irrigation contribute nitrate to alluvial groundwater in the vicinity of UMA 161 and UMA 173. Graphical and concentration distribution analyses indicate elevated nitrate concentrations along the Depot's western boundary comes from irrigated crop agriculture activity west of the Army Depot. Nitrate and TKN concentration distribution analyses indicate Port of Morrow wastewater land application activity locally dominates nitrate in the alluvial groundwater.

Elevated nitrate+nitrite-nitrogen concentrations occur in alluvial groundwater between Irrigon and the Umatilla River. Although locally sparse, the data is sufficient to indicate concentrations increase from the U.S. Army Depot to areas along Highway 730 (see Plate 4.2).

Nitrate concentrations in the Irrigon sewage treatment facility area range from 41 mg/L to 20 mg/L in samples collected from up- to downgradient of the facility, respectively. This indicates facility wastewater infiltration locally dilutes the nitrate concentration in groundwater while remaining a significant source of nitrate itself. SCM Consultants, Inc. (1990) report 1 to 52 mg/L total nitrogen in the effluent leaving the facility's infiltration beds to groundwater. This project used facility data to calculate 4,550 pounds total nitrogen per acre per year loading from the infiltration beds to groundwater. Land uses up gradient of the sewage treatment facility include irrigated crop agriculture and a cemetery.

Further east of Irrigon, nitrate concentrations in alluvial groundwater increase downgradient from 19 mg/L in a sample collected near the West Extension Canal (UMA 097) to 35 mg/L in a sample collected 0.3 miles east and immediately north of Highway 730 (UMA 096). Graphical analyses (Appendix 4H) suggest mixed sources influence the groundwater chemistry at UMA 097 and UMA 096.

The West Extension Canal and the Depot's active landfill are not likely major contributors. Canal water nitrate+nitrite-nitrogen concentrations measured less than 5 mg/L, and nitrate concentrations increased between the Depot's landfill and UMA 097.

The groundwater chemistry at UMA 097 appears to reflect the influence of activity upgradient (south) of the canal. That activity includes irrigated crop agriculture and Lamb-Weston Incorporated wastewater land application. The groundwater chemistry at UMA 096 appears to reflect the influence of land use activity both south and north of the canal. Nitrate+nitrite versus time and Piper trilinear graphs for UMA 096 compare similarly to irrigated agriculture influences. However, a review of local land uses and a NETPATH groundwater chemistry computer model analysis indicates septic systems north of the canal contribute more than 90 percent to the groundwater chemistry observed at UMA 096.

Plates 4.2 and 4.3 show elevated nitrate+nitrite-nitrogen concentrations occur in alluvial groundwater in the northeast corner area of the U.S. Army Umatilla Depot Activity where a groundwater mound exists. The shape and extent of the concentration contours north of the Depot is not well defined due to sparse data from that area. The highest concentration areas correspond to the Lamb-Weston Incorporated food processing wastewater land application area and the Depot's active landfill.

Hydrogeologic and groundwater chemistry evaluations identify wastewater land application as the source of nitrate in groundwater at the Lamb-Weston site. The site straddles the groundwater mound crest. No other activity is upgradient. Additionally, project and facility TKN data indicates a significant organic nitrogen source at the land application site. The detected and reported TKN concentrations range from non-detect to 18 mg/L.

The active landfill is located downgradient of the Lamb-Weston site, which is evident in the groundwater chemistry graphs reviewed. However, the landfill appears primarily responsible for the higher nitrate concentrations in its vicinity for several reasons.

- Data related to the landfill and Lamb-Weston sites graph in adjacent but separate areas on some groundwater chemistry graphs.

- An area of lower nitrate concentrations in alluvial groundwater appears to separate the Lamb-Weston and active landfill sites.

- Total dissolved solids concentrations in groundwater are higher at the landfill site than the Lamb-Weston site.

- Alluvial groundwater TKN concentrations increase downgradient across the landfill site. They increase from 0.5 mg/L to 1.3 and 2.4 mg/L.

- Disposal of dried sewage sludge at the landfill is a possible TKN and nitrate source.

Elevated nitrate+nitrite-nitrogen concentrations occur in alluvial groundwater within the central portion of the U.S. Army Umatilla Depot Activity (see Plate 4.2). The highest concentrations came from samples collected in the explosive washout lagoon area. Nitrogen isotope analysis of groundwater sampled near the washout lagoons found delta ^{15}N values consistent with contamination from explosives. Dawson and others (1982) and Ritchie and others (1992) identified the washout lagoon as a groundwater contamination source. The U.S. Army has begun implementing a groundwater clean-up plan at the site.

Plate 4.2 shows an apparent nitrate plume extending from the washout lagoons toward the south, then west and northwest of the washout lagoon area. The apparent plume may be real or a contouring artifact. Arguments against a real plume include:

- The November 1981 nitrate concentration distribution (50 to 400 mg/L) at the lagoon site indicating a net plume movement toward the south-southeast (Dawson and others, 1982);

- February 1991 groundwater flow directions (Plate 2.4) which suggest a plume emanating from the lagoons should move south and east;

- The 18 mg/L concentration at UMA 216 appears somewhat separated from similar nitrate concentrations closer to the lagoon site; and

- Nitrate concentrations greater than 20 mg/L appear much less dispersed (they remain close to the lagoon site) than the lower nitrate concentrations.

Arguments supporting a real plume include:

- Information provided by Dawson and others (1982):

  - The 1981 seasonal groundwater flow directions appear to locally change from northwesterly in April to south-southwesterly in October;

  - A projected net contaminant movement from the lagoon area toward the west-northwest; and

  - The 1981 RDX explosive concentration distribution at the lagoon site indicating a net plume movement toward the northwest;

- Current groundwater flow direction reversals and complexities in the area as described in the hydrogeology chapter; and

- Piper trilinear, Schoeller Diagram, and constituent versus constituent graphical analyses suggesting a chemical relationship between alluvial groundwater at the explosive washout lagoon vicinity and wells UMA 228, UMA 216, and UMA 218.

The nitrate distribution around the washout lagoons provides important information about the time required for groundwater contamination to flush through the alluvial groundwater system. Washout lagoon activity occurred from the mid-1950s through the mid-1960s. If the apparent plume extending through UMA 216 on Plate 4.2 is real, nitrate from the washout lagoons has moved less than four miles over three to four decades. If that plume is not real, nitrate from the washout lagoons has moved less than 0.5 mile over three to four decades.

Elevated nitrate+nitrite-nitrogen concentrations also occur in alluvial groundwater south of the U.S. Army Depot. Historic and current land use activities in the area include livestock operations, irrigated crops, and the Depot's administrative, sewage treatment, and inactive landfill facilities.

Analyses indicates activities outside the Depot are the prominent nitrate sources. A review of Plate 4.2 indicates the highest nitrate concentrations occur south of the Depot with groundwater flow near the Depot carrying the nitrate north-northeast onto the Depot. This nitrate transport interpretation is consistent with the complex alluvial groundwater flow conditions in the area.

Several analyses indicate multiple sources are responsible for the nitrate concentration in the area. Graphical analyses suggest mixed nitrogen sources. The highest nitrate concentration area on Plate 4.2 occurs in the vicinity of the former Hansell Brothers Incorporated hog operation, which suggests an animal waste source. Nitrogen isotopic analyses indicate animal waste influences alluvial groundwater at UMA 133 located near a horse pen and a former dairy and turkey operation. Additionally, project groundwater sampling in July 1994 found Dacthal acid, a chemical from the agricultural pesticide Dacthal, in groundwater sampled from UMA 133. That detection indicates an irrigated crop influence.

Lower nitrate concentrations were also detected in the Boardman to west Umatilla area. Groundwater with nitrate concentrations below 10 mg/L occurs within the general Boardman area, west of Irrigon along the Columbia River, south of Irrigon through the western portion of the U.S. Army Depot, and southeast of the Interstate 84 and Interstate 82 interchange through Lost Lake. River water dilution appears responsible for lower concentrations adjacent to the Columbia River. Lower nitrogen and/or hydraulic loading appears responsible for lower nitrate concentrations south of Irrigon and within the U.S. Army Depot. Rural residential home and ordnance activities occur within those areas. Background conditions, lower nitrogen loading, and/or dilution from High Line Canal and Lost Lake appear responsible for the lower concentrations southeast of the Interstate 84 and Interstate 82 interchange.

Map and Data Set Observations: Total Dissolved Solids

Plates 4.4 and 4.5 show the total dissolved solids (TDS) concentration distribution in the Boardman to west Umatilla area based upon project groundwater sampling. Plate 4.5 shows the distribution of maximum concentrations detected in alluvial and basalt groundwater samples. Plate 4.4 shows the June-July 1992 TDS concentration distribution in alluvial groundwater based upon project synoptic sampling. The shape and extent of each concentration range contoured was derived by linear interpolation between data locations. TDS concentrations detected in basalt groundwater samples are printed next to each sampling location.

Elevated versus lower TDS concentration distribution in the general area is similar to the nitrate concentration distribution with some exceptions. Concentrations exceeding the secondary (aesthetic) drinking water standard of 500 mg/L occurred in groundwater sampled within and south of Boardman, at Finley Butte Landfill, between Boardman and Irrigon, east Irrigon, the U.S. Army depot active landfill area, the immediate vicinity of the explosive washout lagoon area, and the agricultural area south of the Depot. Concentrations below 350 mg/L occurred in groundwater sampled west of Irrigon along the Columbia River, south of Irrigon, at Finley Butte Landfill, within the U.S. Army Depot, between the Depot's active landfill and the Lamb-Weston wastewater land application area, and northwest of Lost Lake. River water dilution appears responsible for the lower TDS concentrations adjacent to the Columbia River. Dilution from Lost Lake appears responsible for the lower TDS concentration northwest of the lake.

Map and Data Set Observations: Other Constituents

Project sampling detected arsenic in many Boardman to west Umatilla groundwater samples collected primarily north of Township 3 North. Plate 4.6 shows the maximum concentration distribution. Detected concentrations generally remained well below the drinking water standard of 0.050 mg/L. Groundwater samples containing arsenic greater than 0.025 mg/L came from multiple sites in the northwest portion of the U.S. Army Depot, and individual sites at the Irrigon sewage treatment site, the Depot's active landfill area, and the Lamb-Weston land application area. Several Depot sites and the Lamb-Weston site yielded samples with arsenic concentrations exceeding the drinking water standard.

Plate 4.7 shows the maximum concentration distribution for sodium. Concentrations in local groundwater sampled commonly exceeded the 20 mg/L limit currently recommended for persons on a sodium restricted diet. Samples with sodium exceeding 50 mg/L came from sites near and south of Boardman, along Highway 730, within the U.S. Army Depot northwest corner and explosive washout lagoon area, within the Irrigon sewage treatment facility vicinity, within the Lamb-Weston land application area, and south of the Depot. Some samples collected west of Irrigon near the Columbia River had sodium concentrations below 20 mg/L. The lower concentrations suggest dilution from the Columbia River.

Plate 4.8 shows the maximum concentration distribution for chloride. Concentrations in all area groundwater sampled by this project remained within the 250 mg/L secondary (aesthetic) drinking water standard. The greatest concentrations detected were 190 mg/L and 160 mg/L measured in basalt groundwater sampled from UMA 003 and UMA 029, respectively. Both wells are located south of Boardman. Well UMA 029 is located in a rural residential area nearly enclosed by irrigated crop agriculture. Well UMA 003 is located immediately downgradient of an irrigated crop area converted to Port of Morrow wastewater land application after 1990.

Plate 4.9 shows the maximum concentration distribution for total phosphate. This project generally measured concentrations below 0.10 mg/L in local groundwater samples. Groundwater samples with relatively higher (0.10 mg/L or greater) maximum total phosphate concentrations came from wells located within the Port of Morrow wastewater land application area east of Boardman, the Irrigon area, most of the U.S. Army Depot, south of the Depot, and the Lamb-Weston land application area. Samples with relatively lower total phosphate concentrations often came from within or near irrigated crop agriculture areas.

Plates 4.10, 4.11, 4.12 show the maximum concentration distribution for boron, bromide, and vanadium. Boron detections appear limited to the northern portion of the Boardman to west Umatilla area. Plate 4.10 does not show boron concentrations in groundwater at the U.S. Army Depot and several other areas, because project synoptic sampling did not include laboratory analysis for boron. Bromide was detected in most samples except some areas near the Columbia River.

Samples with relatively higher maximum bromide concentrations generally came from across the Depot's north central area as well as the Lamb-Weston site adjacent to the Depot, Boardman, south of Boardman, Port of Morrow, and south Irrigon vicinities. Samples with relatively lower concentrations came from irrigated crop agriculture areas west and southwest of the Depot, the southern Depot area, rural residential development near Irrigon, and the northern portion of the Lamb-Weston site next to the Depot.

Vanadium detections appear limited to samples collected from the central portion of the Boardman to west Umatilla area. The highest concentrations occurred in samples collected across the central portion of the Depot and the eastern portion of the Lamb-Weston site next to the Depot.

Table 4.15 lists and Plate 4.13 shows the Boardman to west Umatilla sites where project sampling detected volatile organic compounds and/or pesticides. A complete listing is presented in Appendix 4G. Table 4.16 shows the areas where U.S. Army Depot sampling detected explosives, pesticides, organic compounds, and other constituents. The occurrence of explosives, volatile organic compounds and pesticides strongly indicate the influence of human activity.

Table 4.15 Volatile organic compounds and pesticides detected in the groundwater from Boardman to west Umatilla Area.

Site	Groundwater Source	Location	Constituent	Concentration	Nitrate+Nitrite-Nitrogen Concentration (mg/L)
UMA 003	Basalt	south Boardman	Atrazine	3.00 ug/L	40.00 - 40.00
UMA 133	Alluvial	south of U.S. Army Depot	Dacthal acid	0.4 ppb	17.00 - 21.00
UMA 144	Alluvial	south Irrigon	Toluene	0.0013 mg/L	2.00 - 22.00
UMA 162	Alluvial	Western Empire Farm near Irrigon	Atrazine	0.4 ppb	12.00 - 12.00
UMA 198	Alluvial	Lamb-Weston site next to Depot	Chloroform	0.0009 mg/L	5.80 - 16.00
Note: Laboratory methods can occasionally cause chloroform detections at low concentrations Note: Data from Lower Umatilla Basin project sampling.					

Table 4.16 Types of contamination detected at selected U.S. Army Umatilla Depot Activity sites as identified by other investigators.

Site	Site #	Soil					Groundwater					
		Metals	Explosives	Nitrate/ Nitrite	Pesticide	Other Organics	Metals	Explosives	Nitrate/ Nitrite	Pesticide	Other Organics	No GW Sampling
Above ground open detonation area	17	X	X									X
Acid pit	8	X		X			X	X	X			
Active firing range	60	X										X
Aniline pit	7											X
Borrow/burn/disposal area	58	X										X
Dunnage pits	18	X			X	X						
Flare & fuse disposal area / bird cage area	14	X		X			X					
Former pit area locations	57	X	X				X					
GB/VX decontamination solution burial areas	41	X		X			X					
GB/VX decontamination solution disposal areas	59											
Missile fuel storage areas	21			X								X
Munitions crate burn area	56	X										X
Open burning trays	32	X	X	X								X
Open burning trenches pads	19	X	X	X		X	X		X		X	

Open detonation pits	16	X	X	X			X					
Pesticide pits	31	X	X	X	X	X	X	X	X		X	
Pit field area	38	X	X	X					X			
Smoke canister disposal area	13	X	X	X		X	X					
TNT sludge burial & burn area	15	X	X	X		X	X		X			
Trench/burn field	55	X	X				X					
Deactivation furnace	1	X	X	X								X
Disposal pit & graded areas	80					X						X
Former raw materials storage location I	81	X										X
Hazardous waste storage facility (bldg 203)	3											X
Malathion storage leak area	35				X							X
Metal ingot stockpiles	26	X										X
Metal ore piles location I	25	X										X
Bldg 131 paint sludge discharge area	37	X				X						X
Paint spray & shot blast areas	34	X		X		X						X
Railcar unloading area	46	X				X						X
Road oil application/disposal site location I	44					X						X
Boiler/laundry effluent discharge site	47	X			X	X	X	X				
Bldg 493 paint sludge discharge area	36	X		X		X						X
Bldg 493 brass cleaning operation area	67	X					X					
Coyote Coulee discharge gullies	52	X	X									X
Explosive washout plant (bldg 489)	5		X	X								X

Explosive washout lagoons	4		X					X	X			
Pipe discharge area	48	X		X	X	X						X
Sewage treatment plant	6	X		X	X	X						X
Stormwater discharge area	30	X			X	X						X
Defense re-utilization marketing office area	22	X			X	X						X
Pesticide storage building	27	X			X	X						X
Road oil application/disposal sites location II	44					X						X
Inactive landfills	12	X			X	X	X	X	X			
Railroad landfill areas	50	X				X	X	X	X		X	
Active landfill	11						X	X	X		X	
Building 433 collection sump/cistern and disposal area	53	X				X						X
Building 612 and bldg 617 boiler discharge areas	45	X										X
Drill transfer site	49											X
Former agent H storage area	10	X				X						X
Former gravel pit/disposal location	82					X						X
Former raw materials storage location II	81											X
Gravel pit disposal area	33											X
Metal ore piles - location II	25	X										X
QA function range	39	X		X								X
Remote munitions disassembly/GB bomb disassembly area	9	X	X	X								X

Septic tanks	29	X				X						X
Storage igloos	2											X

Sources: Dawson, and others, 1982
Ritchie, and others, 1992
Mahannah, and others, 1993
Machacek, and others, 1993
Woodland, and others, 1993
Brown, and others, 1993

Project sampling detected the agricultural pesticide atrazine in one basalt groundwater sample from UMA 003 and one alluvial groundwater sample from UMA 162. Well UMA 003 is immediately north of an irrigated crop agriculture area south of Boardman. Well UMA 162 is located in the northeast portion of Western Empire Farms. Nitrate+nitrite-nitrogen measured 40 mg/L in the sample collected from UMA 003 and 12 mg/L in the sample collected from UMA 162.

Project sampling also detected a pesticide related chemical, Dacthal acid, in an alluvial groundwater sample from UMA 133. Nitrate+nitrite-nitrogen measured 17 mg/L in the sample. The well is located along County Line Road south of the U.S. Army Depot.

Project sampling detected the constituent toluene in an alluvial groundwater sample collected from UMA 144 located south of Irrigon. Project staff observed a disassembled engine in the vicinity of the well. Nitrate+nitrite-nitrogen measured 18 mg/L in the sample.

Project sampling also detected chloroform in an alluvial groundwater sample from UMA 198 located at the Lamb-Weston site next to the U.S. Army Depot. A chloroform source is uncertain. Laboratory methods can occasionally cause very low concentration chloroform detections.

Graphical Analyses: Nitrate versus Time

Graphical analysis of Boardman to Irrigon area groundwater data included reviewing nitrate versus time graphs. Data used for the analysis came from project bimonthly sampling, the Port of Morrow (1993a), and Lamb-Weston, Incorporated (DEQ Water Quality File 48780). The analysis of bimonthly sampling data included comparing the nitrate versus time graphs to other constituent versus time graphs. Analysis of some Port of Morrow and Lamb-Weston data included comparing the nitrate versus time graphs to available groundwater elevation versus time graphs.

Figure 4.22 shows nitrate+nitrite-nitrogen concentrations versus time in basalt and alluvial groundwater sampled by this project in the Boardman and Port of Morrow areas. Table 4.17 presents groundwater source and land use information about each sampling site. Table 4.18 presents how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site. The nitrate data related to each sampling site graphed differently as shown in Figure 4.22, and they compared differently to the other constituent versus time graphs as summarized in Table 4.18.

The differences make sense given the different locations, land uses, and sources of water associated with each site. Nitrate access to basalt groundwater at UMA 028 and UMA 029 appear locally different. The difference may relate to well construction. Small nitrate fluctuations occur in alluvial groundwater at UMA 085 and UMA 201. A combination of influences may be responsible for the small fluctuations. Small concentration fluctuations are consistent with a constant loading source, a distant nitrate source, and/or a reservoir of nitrate accumulated in groundwater.

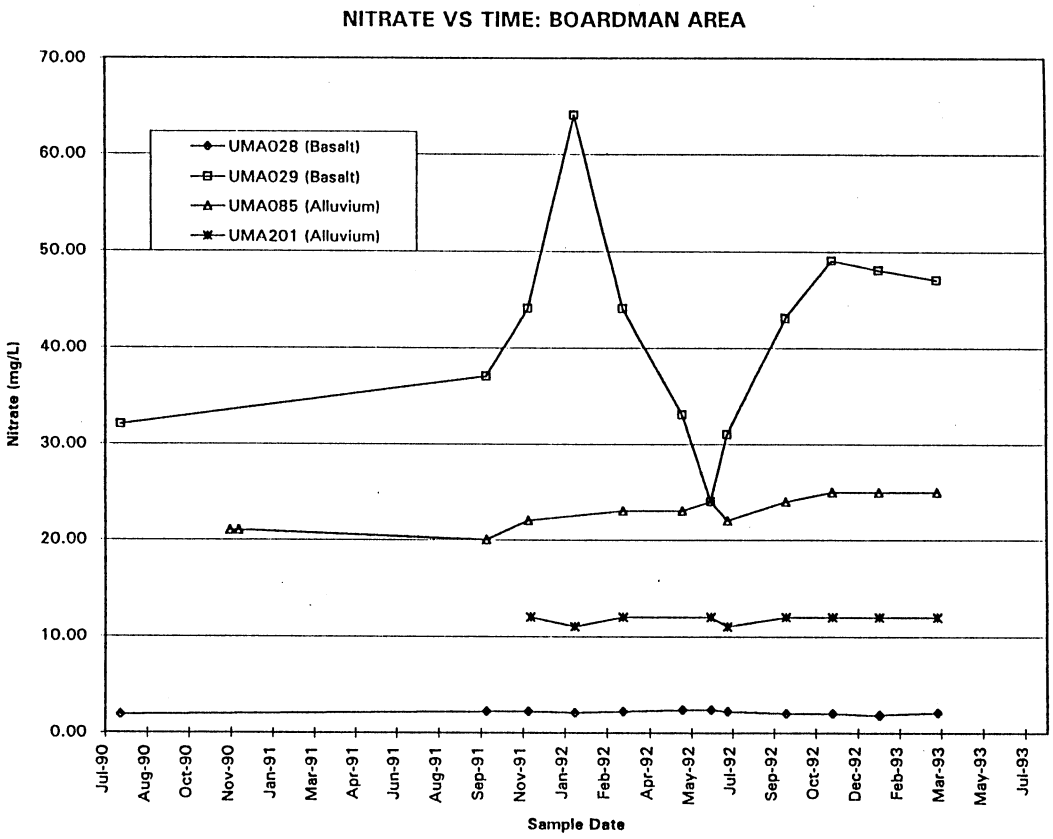


Figure 4.22 Nitrate+nitrite-nitrogen versus time in Boardman area alluvial and basalt groundwater at project bimonthly sampling sites.

Note: A 1 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.17 Groundwater source and location information related to project bimonthly sampling sites in the Boardman area.

Sampling Site	Groundwater Source	Location and Surrounding Land Uses
UMA 028	Basalt basal Elephant Mountain	south Boardman, north of Wilson Road rural residential with fields and pasture nearby
UMA 029	Basalt basal Elephant Mountain	south Boardman near West Extension Irrigation Canal rural residential area adjacent to irrigated crops
UMA 085	Alluvial	south Boardman, north of Wilson Road and east of Ripee Road surrounded by fields and several active and inactive animal operations
UMA 201	Alluvial	Port of Morrow wastewater land application area north of Interstate 84

Table 4.18 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to Boardman area project bimonthly groundwater sampling sites.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 028	WS		S	WS	NS	I	WS	I
UMA 029	S	S	S	I	S	WS	I	S
UMA 085	WS	S and I	S and I	S and I	S and I	WS and I	NS	
UMA 201	I	I	S	S	WS	S	I	I

Note: Comparisons were qualitative rather than quantitative.
Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph

This project reviewed Port of Morrow groundwater data for the Port's two wastewater land application sites using nitrate-nitrogen and groundwater versus time graphs. The nitrate-nitrogen versus time graphs show seasonal fluctuations with some exceptions. The fluctuations indicate seasonal influences. Fluctuations associated with sites within the land application area north of Interstate 84 often correlate or weakly correlate to groundwater elevation fluctuations. This suggests a relatively short travel time from land surface to groundwater in that area. A short travel time is reasonable given the local soils, unsaturated zone, and aquifer materials.

Groundwater nitrate concentrations often correlate inversely to groundwater elevation fluctuations at the land application area south of Boardman. Nitrate concentrations appear to increase when groundwater elevations decline and vice versa. This may relate to a travel time lag for nitrate to reach local groundwater. The sampling period was too short to confirm or determine any time lag.

Figure 4.23 shows nitrate+nitrite-nitrogen concentrations versus time in alluvial and basalt groundwater sampled by this project in the Irrigon vicinity. Each sampling site is located in or near a predominantly rural residential area. Table 4.19 presents how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site. A review of Figure 4.23 and Table 4.19 indicates similarities and differences between sampling sites. Nitrate data related to most sites graphed with relatively low concentrations and small fluctuations. The small concentration fluctuations in alluvial groundwater are consistent with a nearly constant loading source such as septic systems. The higher nitrate concentrations and larger fluctuations related to UMA 144 indicate a seasonal influence. Well UMA 144 is located adjacent to an irrigated field.

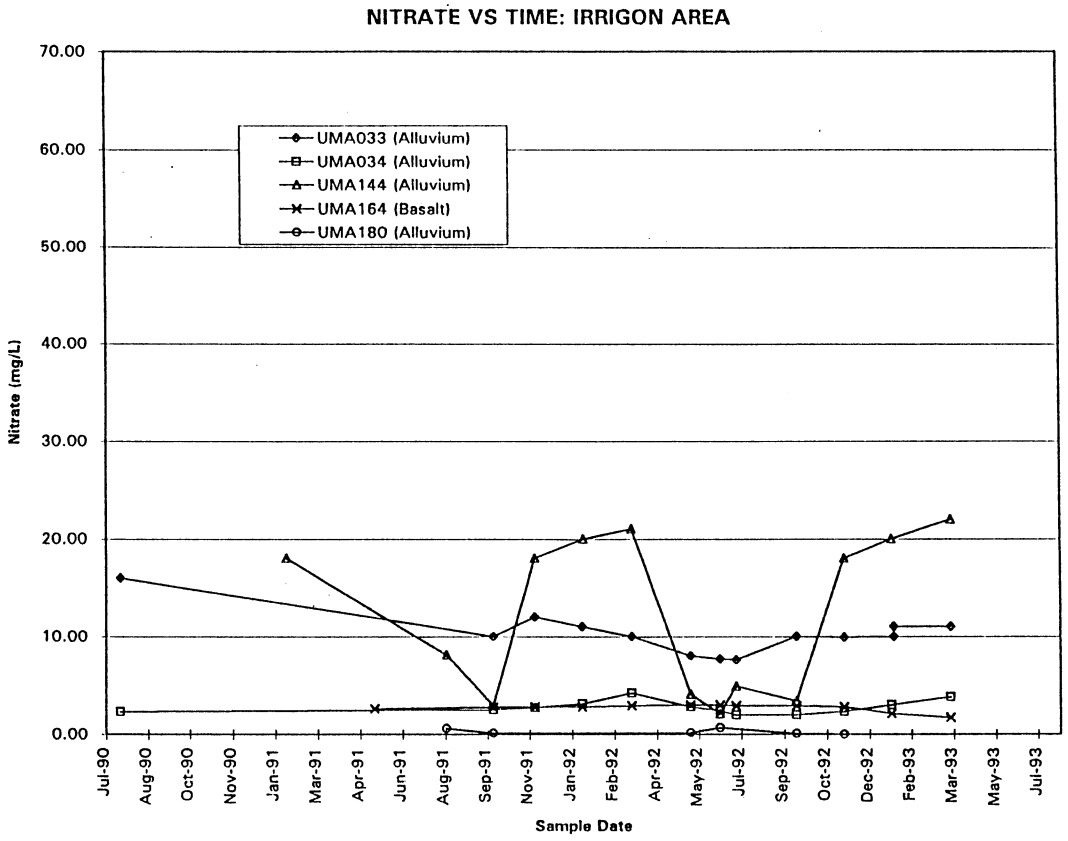


Figure 4.23 Nitrate+nitrite-nitrogen versus time in Irrigon area alluvial and basalt groundwater at project bimonthly groundwater sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.19 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Irrigon area.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 033 (Alluvial)	S			NS	WS			
UMA 034 (Alluvial)	S	S	S	S	S		NS	
UMA 144 (Alluvial)	S	S	S	S	S	S	I	WS
UMA 180 (Alluvial)	NS	S and I	S and I	I	I	I	NS	WS
UMA 164 (Basalt)	NS	WS	I	I	S and I	NS	WS	

Note: Comparison were qualitative rather than quantitative.
Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph

Figure 4.24 shows nitrate+nitrite-nitrogen concentrations versus time in alluvial groundwater sampled between Irrigon and the Umatilla River by this project. Table 4.20 presents how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site. Differences characterize Figure 4.24 and Table 4.20. Differences between sampling sites should be expected given the different locations and land uses related to each sampling site. Well UMA 198 is located in an upgradient area in the vicinity of a food processing wastewater pond and land application area. Irrigated crop agriculture occurs upgradient of both UMA 096 and UMA 103. However, more rural residential septic systems are located in the immediate vicinity of UMA 096, and more small agricultural activity appears present in the immediate vicinity of UMA 103. The higher nitrate concentrations and larger fluctuations in groundwater at UMA 096 are greater than expected for septic system influences.

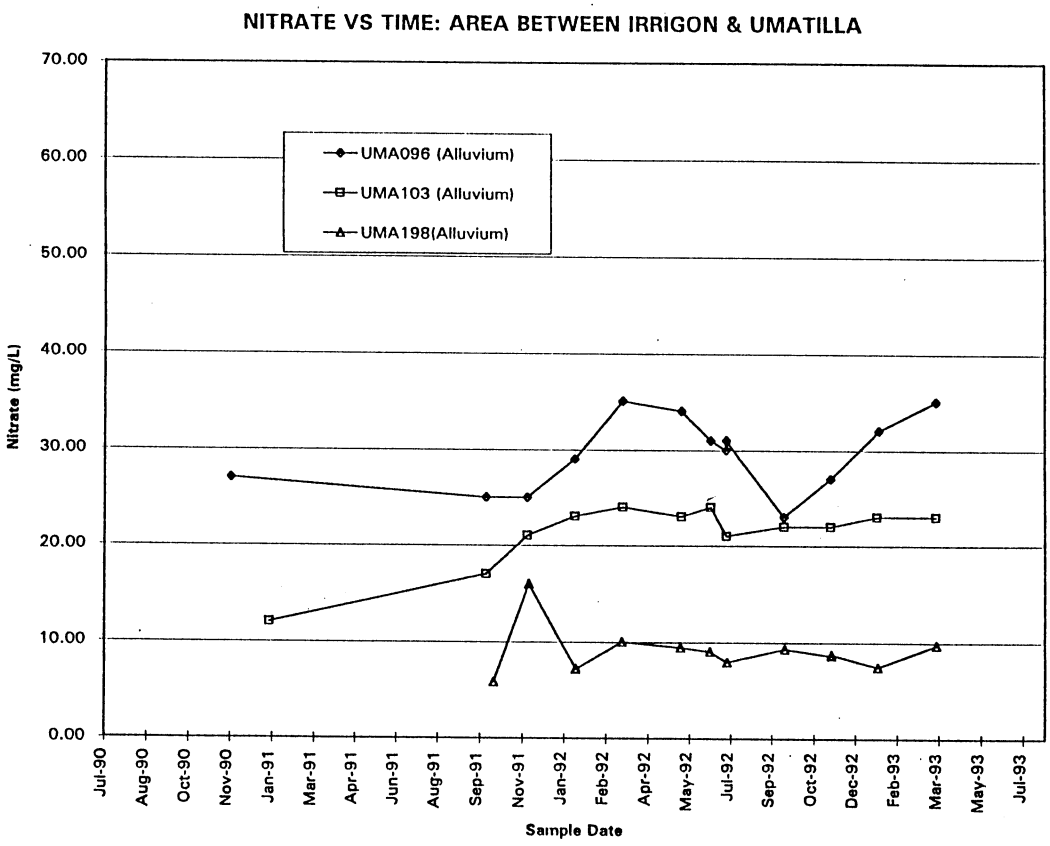


Figure 4.24 Nitrate+nitrite-nitrogen versus time in alluvial groundwater between Irrigon and the Umatilla River at project bimonthly groundwater sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.20 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Irrigon to Umatilla River area.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 096 (Alluvial)	S	S	S	I	NS	WS	NS	I
UMA 103 (Alluvial)	S and I	I	I	S and I	S and I	I	I	
UMA 198 (Alluvial)	S	S	S	S	S	S	I	

Note: Comparison were qualitative rather than quantitative.
Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph

This project reviewed Lamb-Weston, Incorporated alluvial groundwater data for the land application site adjacent to the U.S. Army Umatilla Depot Activity using nitrate-nitrogen and groundwater elevation versus time graphs. The nitrate-nitrogen versus time graphs generally show fluctuations that indicate seasonal influences. A comparison of those graphs to the groundwater elevation versus time graphs indicate some correlation. Figure 4.25 provides an example. Time lags ranging from less than 1 month to possibly 18 months were observed between unique groundwater elevation and nitrate concentration peaks. This time lag appears related to the time required for nitrate to travel to groundwater.

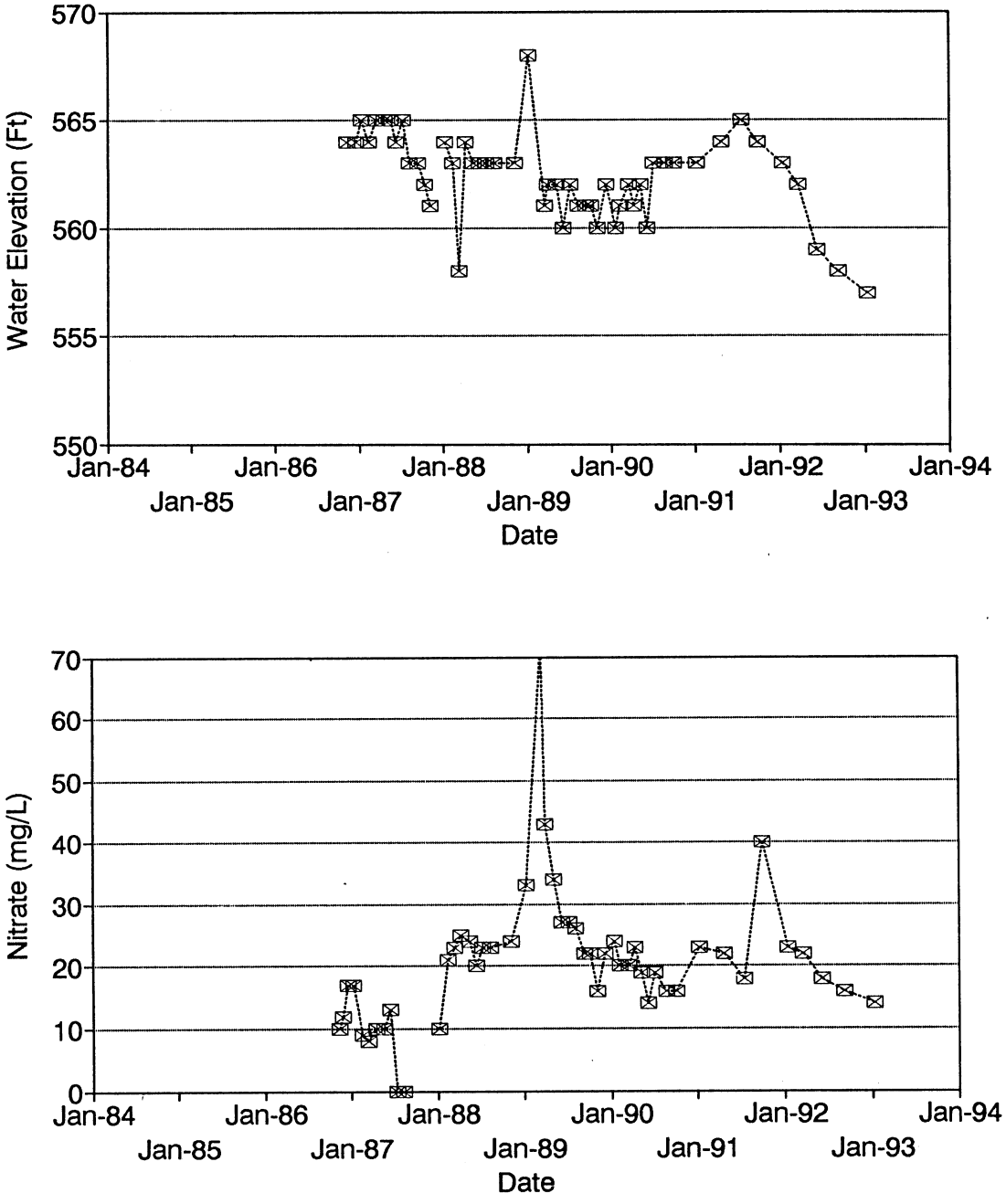


Figure 4.25 Groundwater elevation versus time and nitrate concentration versus time at UMA 243 (UMAT 5365, Lamb-Weston MW-5).

Figure 4.26 shows nitrate+nitrite-nitrogen concentrations versus time in alluvial groundwater sampled by this project south of the U.S. Army Depot. Table 4.21 presents how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site.

Similarity characterizes Figure 4.26 and Table 4.21. The nitrate concentration fluctuations at each site are generally small, and the nitrate versus time graphs generally correlate to the other constituent versus time graphs. The dominance of irrigated crops in the area with some former and existing animal operations rather than diverse land uses would account for similarities. The small nitrate fluctuations may relate to the relatively low groundwater hydraulic gradients and groundwater flow reversals in the area. Those conditions can allow nitrate to accumulate in local groundwater and dampen seasonal fluctuations. Additionally, the small nitrate fluctuation at UMA 112 may also relate to septic system discharges providing a constant nitrate source. Graphical analyses (Appendix 4H) suggest a local septic system influence.

Sampling site location relative to local land use would account for the higher versus lower nitrate concentrations observed. Well UMA 133 is located within the irrigated crop area and near former and existing livestock operations. Nitrate concentrations in the alluvial groundwater at the site range from 17.00 mg/L to 21.00 mg/L. Wells UMA 112 and UMA 168 are located along the margins of the active agricultural area. Additionally, alluvial groundwater at UMA 112 and UMA 168 may be experiencing some dilution from High Line Canal and possibly Lost Lake, respectively. Their nitrate concentrations range from 4.40 mg/L to 5.80 mg/L and 3.80 mg/L to 5.80 mg/L, respectively.

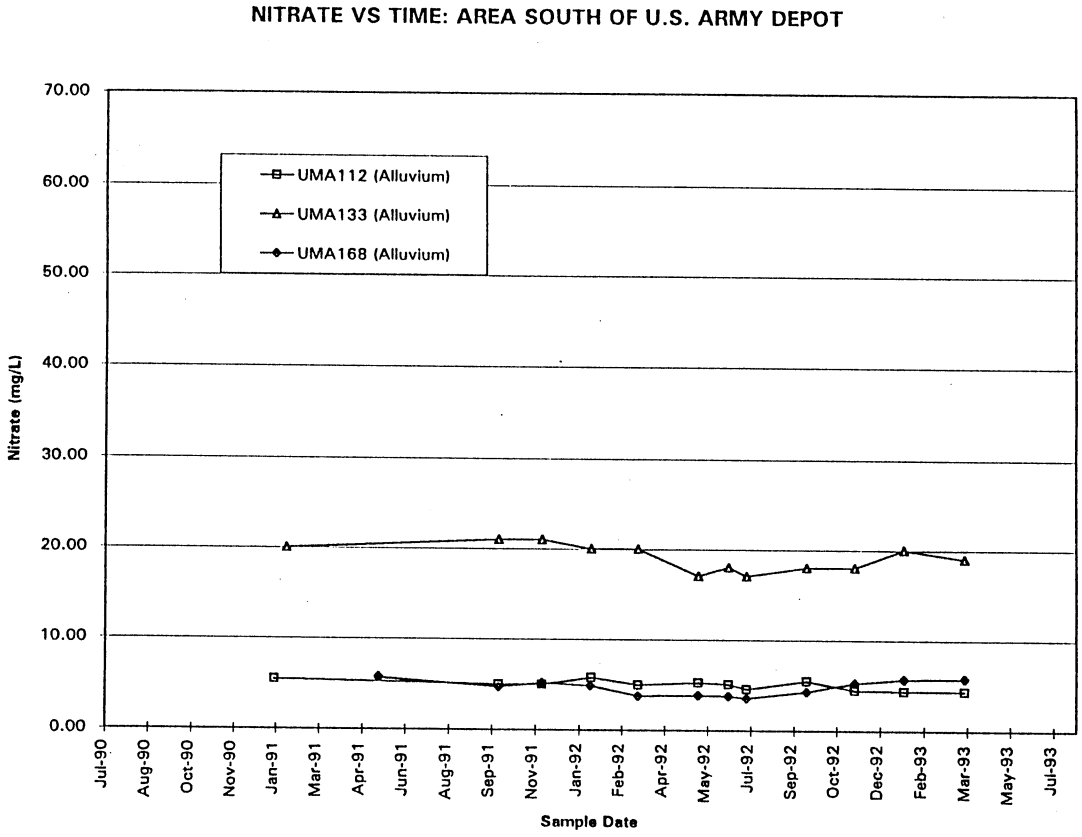


Figure 4.26 Nitrate+nitrite-nitrogen versus time in alluvial groundwater south of the U.S. Army Umatilla Depot Activity at project bimonthly groundwater sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.21 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the area south of the U.S. Army Umatilla Depot Activity.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 112 (Alluvial)	S	S	S	S	S	S	WS	WS
UMA 133 (Alluvial)	S	S	S	S	S	S	WS	WS
UMA 168 (Alluvial)	S	WS	S	S	S and I	S	NS	

Note: Comparisons were qualitative rather than quantitative.
Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph

Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams

Project bimonthly and synoptic groundwater sampling data related to the Boardman to west Umatilla area were plotted on Piper trilinear graphs and Schoeller diagrams. Generally, variation or lack of variation observed on the graphs correlated with nitrate variation or lack of variation. The trilinear graphs proved very useful for classifying the groundwater chemistry at different locations and for distinguishing nitrate source influences at neighboring sites. The groundwater chemistry classifications observed by location and groundwater source are presented in Table 4.22.

Table 4.22 Observed piper trilinear water chemistry classification of alluvial and basalt groundwater sampled in the Boardman to Irrigon area.

Area	Groundwater Source	Groundwater Chemistries Observed
Boardman Area: North (north of Interstate-84) (Project Sampling)	Alluvial	mixed-cation/bicarbonate
Boardman Area: South (Interstate-84 to West Extension Canal) (Project Sampling)	Alluvial	mixed-cation/bicarbonate no dominant type
Boardman Area: South (Interstate-84 to West Extension Canal) (Project Sampling)	Basalt	mixed-cation/bicarbonate sodium + potassium/bicarbonate mixed-cation/chloride no dominant type
Boardman Area: South (West Extension Canal to U.S. Navy Bombing Range) (Project Sampling: UMA 233)	Basalt Top	no dominant type
U.S. Navy Boardman Bombing Range: (Project Sampling: UMA 170)	Basalt	mixed-cation/bicarbonate
Port of Morrow Land Application Area (east of Boardman and north of Interstate-84) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Crop Irrigation Area (east of Boardman: Range 26) (Project Sampling)	Alluvial	calcium/bicarbonate calcium/mixed-anion
Irrigon Vicinity (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Irrigon Vicinity (Project Sampling)	Basalt	calcium/bicarbonate
Irrigon Sewage Treatment Facility Area (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate calcium/mixed-anion
Irrigon Sewage Treatment Facility Area (Project Sampling: UMA 269)	Basalt	sodium + potassium/bicarbonate
Irrigon to West Umatilla (along Highway 730) (Project Sampling)	Alluvial	mixed-cation/bicarbonate
Irrigon to West Umatilla (along Highway 730) (Project Sampling)	Basalt	sodium + potassium/bicarbonate
Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial	mixed-cation/bicarbonate sodium + potassium/bicarbonate

Lamb-Weston, Inc. Land Application Area (Adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial (Shallow Unconfined)	mixed-cation/bicarbonate
U.S. Army Umatilla Activity: West (Ammunition Demolition Area) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate sodium + potassium/bicarbonate calcium/mixed-anion
U.S. Army Umatilla Depot Activity: Central Explosive Washout Lagoons Area) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate calcium/mixed-anion
U.S. Army Umatilla Depot Activity: Northeast (Active Landfill Area) (Project Sampling)	Alluvial	mixed-cation/bicarbonate no dominant type
U.S. Army Umatilla depot Activity: South (Administrative, Inactive Landfill, and Sewage Treatment Areas) (Project Sampling)	Alluvial	calcium/bicarbonate
U.S. Army Umatilla Depot Activity: General (all other areas) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate magnesium/mixed-anion
Crop Irrigation Area (south of the U.S. Army Umatilla Depot Activity) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate no dominant type
Crop Irrigation Area (south of the U.S. Army Umatilla Depot Activity) (Project Sampling)	Basalt (shallow and deep)	mixed-cation/bicarbonate calcium/bicarbonate
Note: Project bimonthly and synoptic groundwater sampling data was used for the groundwater chemistry classifications Note: Shallow refers to wells less than 300 feet deep. Note: Deep refers to wells 300 feet or more deep.		

Nitrate variation by location or over time appears to correlate to the water chemistry variation observed on the trilinear graphs and Schoeller diagrams. Figures 4.27 through 4.34 provide examples.

The west Irrigon data graphed with little variation (Figures 4.27 and 4.28), which correlates to a smaller variation in nitrate+nitrite-nitrogen concentrations detected in samples from that area. The concentrations ranged from 2.50 mg/L to 7.70 mg/L. Similarly, figures 4.29 and 4.30 show project bimonthly sampling data for an alluvial groundwater sampling site, UMA 034, located in west Irrigon. The data graphed with small variation over time. Nitrate+nitrite-nitrogen concentrations in samples from the site ranged from 2.00 to 8.50 mg/L.

Figures 4.31 and 4.32 show project synoptic sampling data for alluvial groundwater in the irrigated crop agriculture area between Boardman and Irrigon. The data graphed with variations in the anion chemistry that correlates to nitrate concentration variations. Nitrate+nitrite-nitrogen concentrations in the samples ranged from 1 mg/L to 67 mg/L. Similarly, figures 4.33 and 4.34 show project bimonthly data for an alluvial groundwater site, UMA 144, located south of Irrigon and adjacent to an irrigated field. Nitrate+nitrite-nitrogen concentrations in samples from the site ranged from 2.10 mg/L to 22 mg/L. Both graphs show a distinct bimodal groundwater chemistry pattern. Additionally, figure 4.34 shows an inverse correlation between total phosphate and the other constituents.

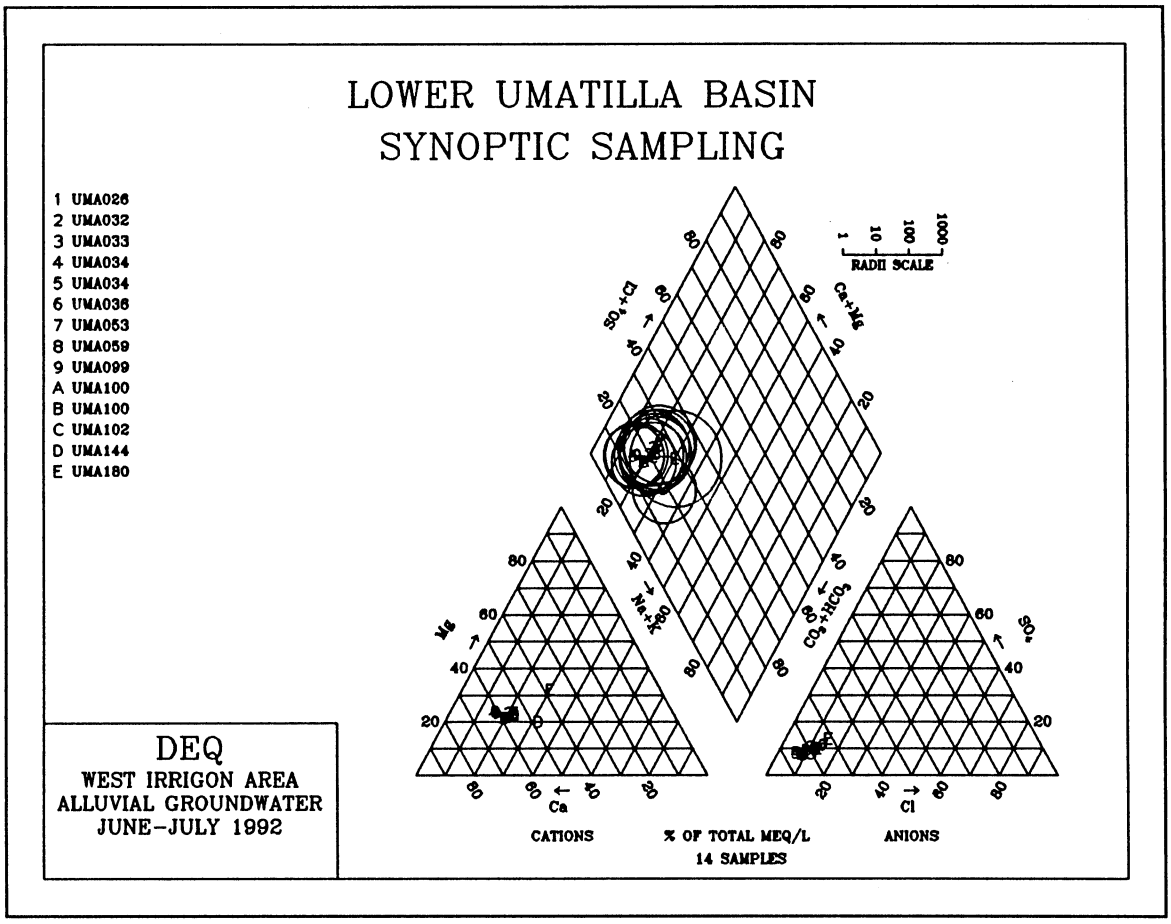


Figure 4.27 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the Irrigon vicinity.

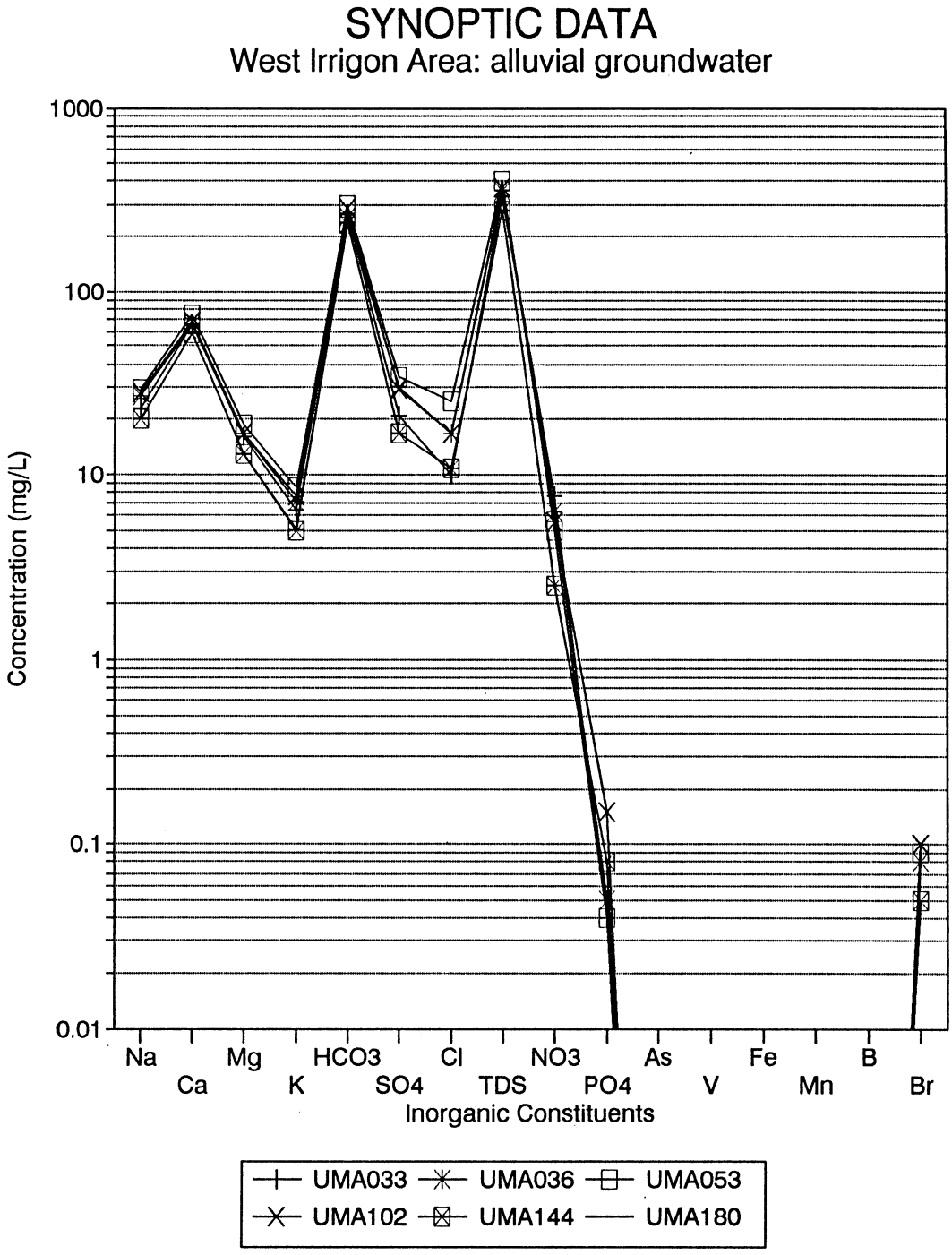


Figure 4.28 Schoeller Diagram of synoptic sampling data for alluvial groundwater collected in the Irrigon vicinity.

Note: The variation across the area is small.

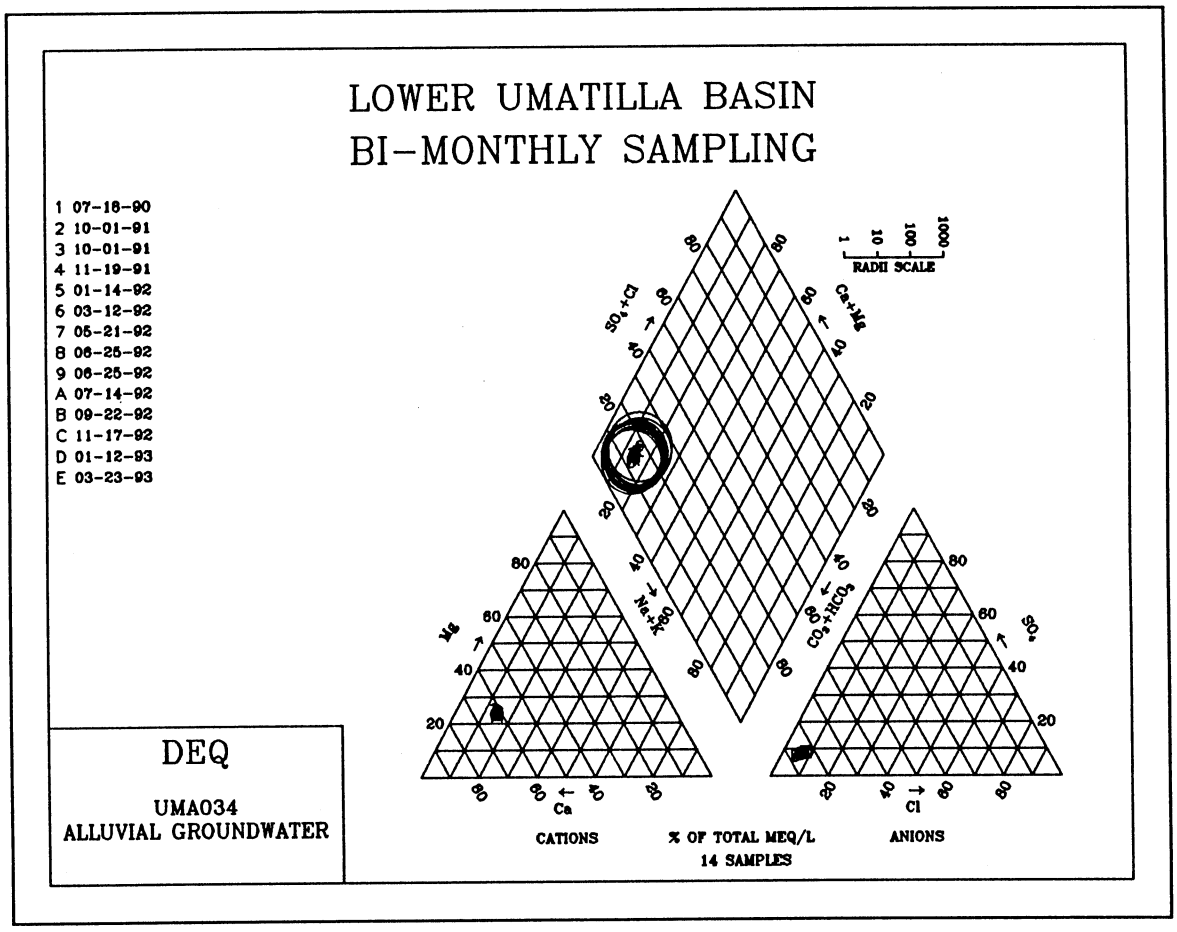


Figure 4.29 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 034 located west of Irrigon.

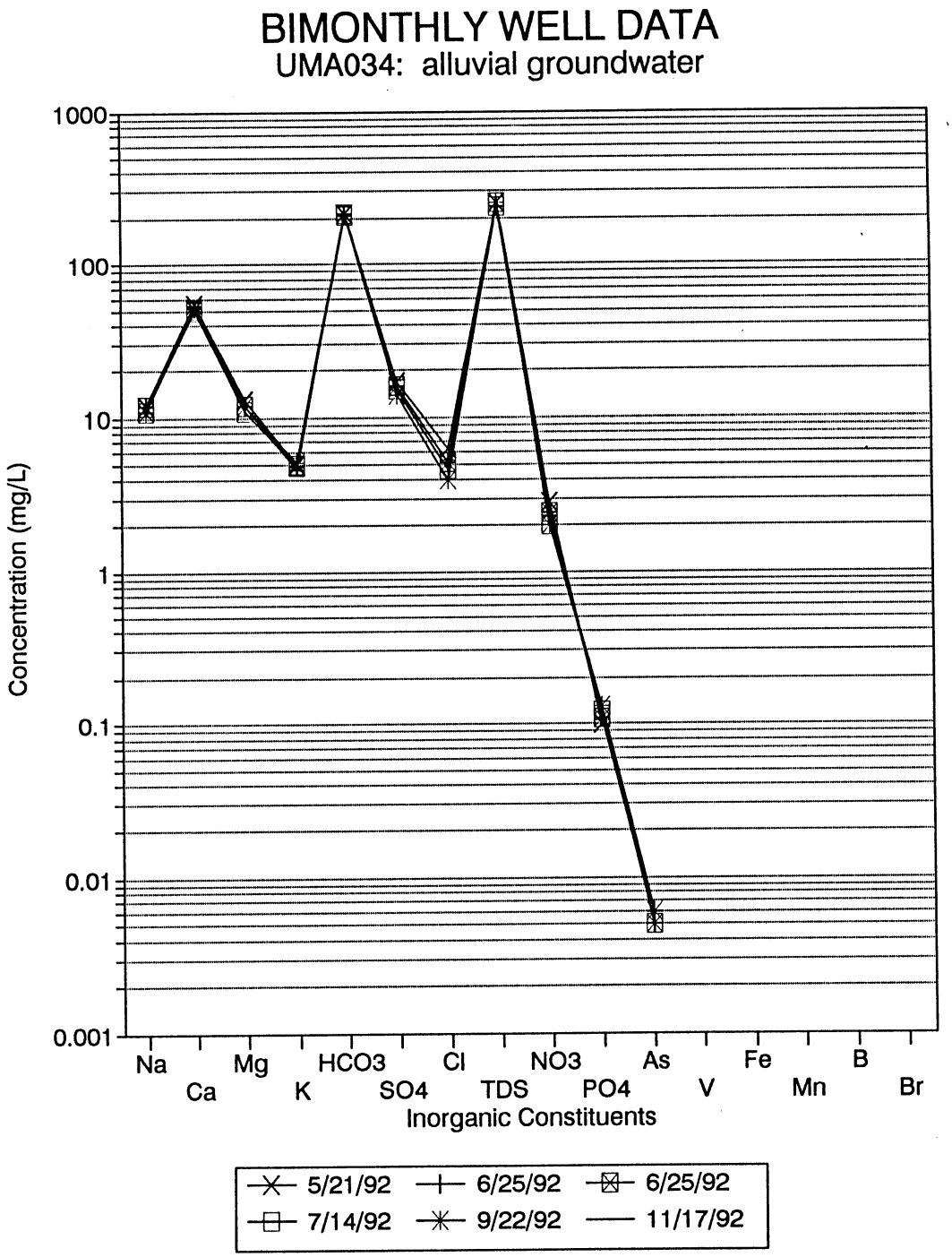


Figure 4.30 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 034 located west of Irrigon.

Note: The variation with time for this site is small.

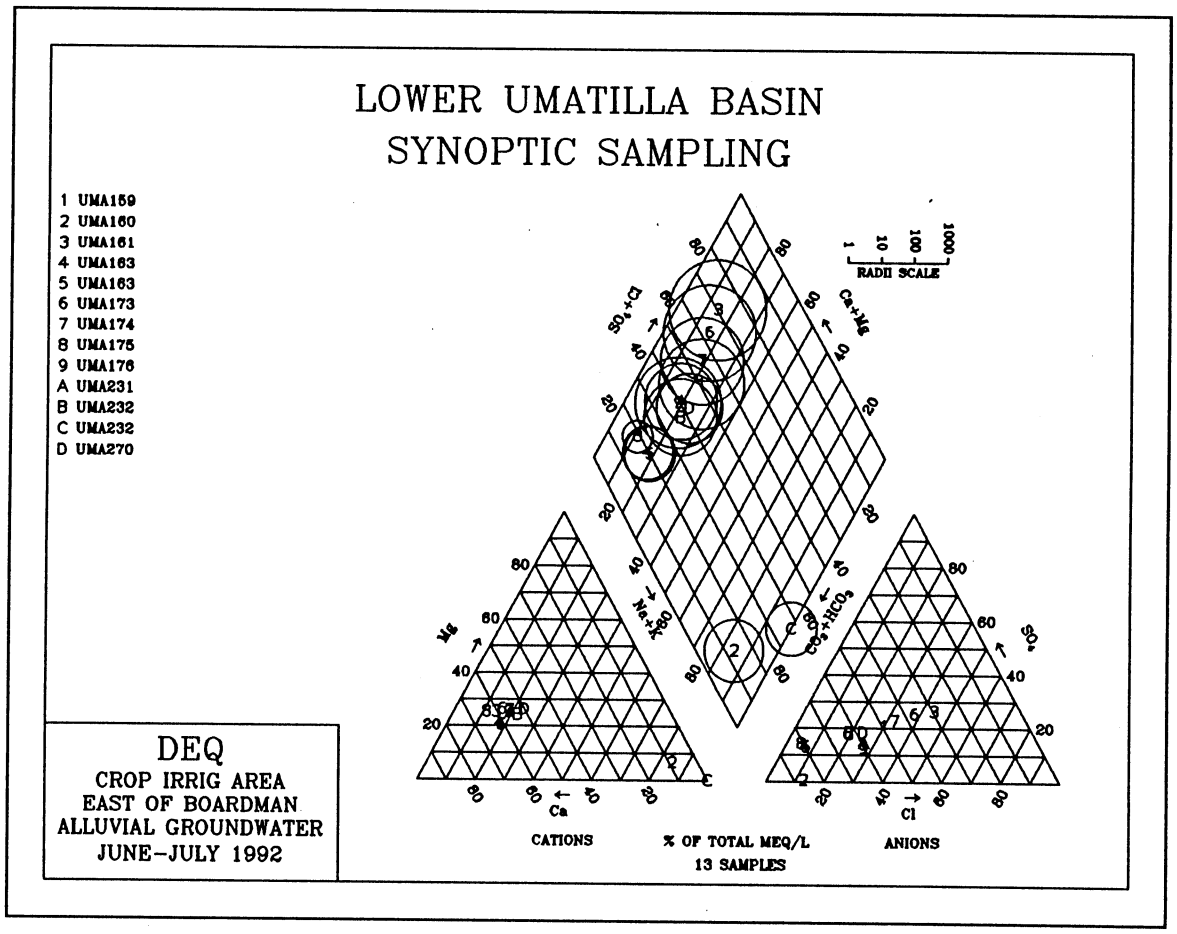


Figure 4.31 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the crop irrigation area between Boardman and Irrigon.

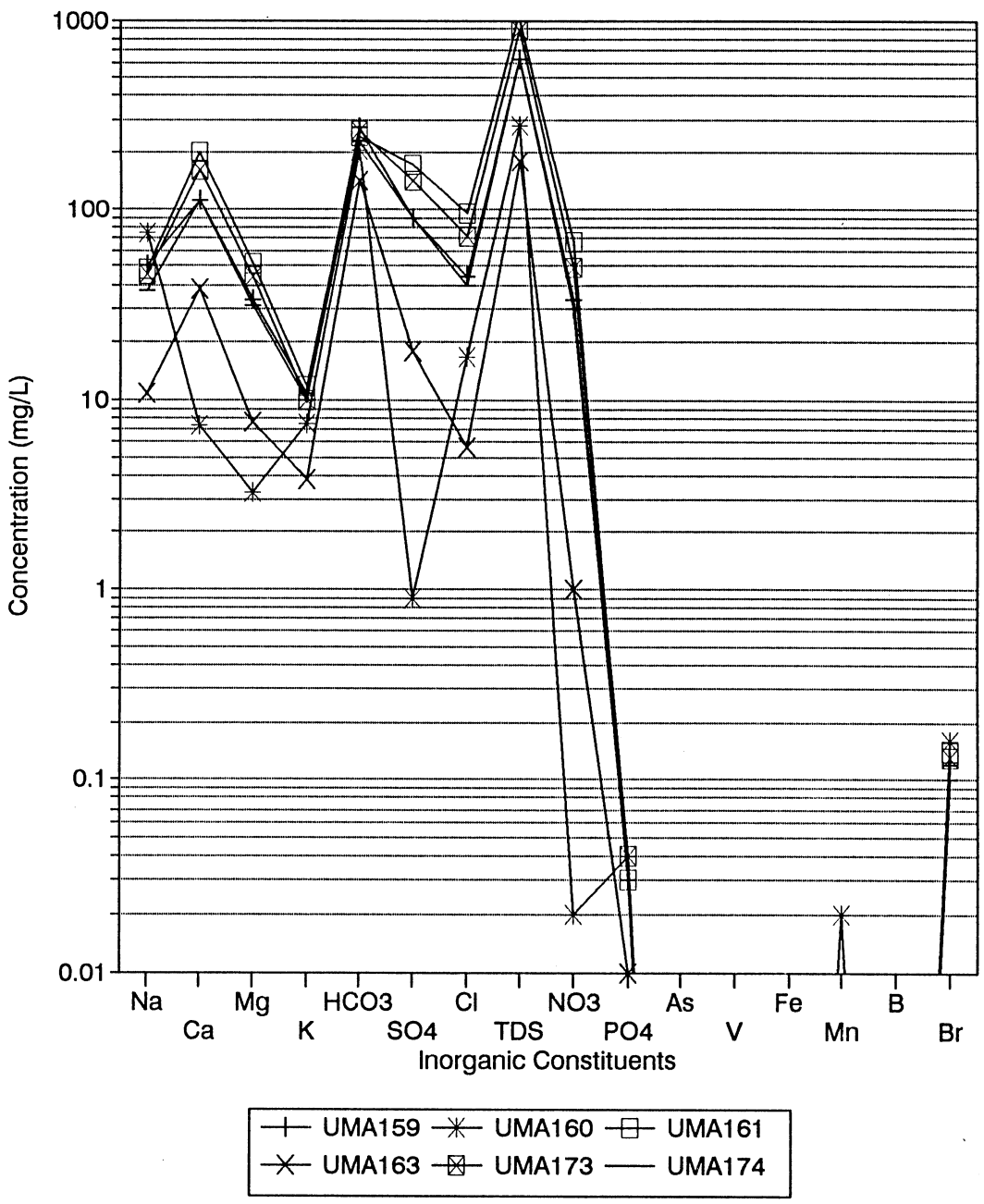


Figure 4.32 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the crop irrigation area between Boardman and Irrigon.

Note: The variation across this area is large, and there is significant differences in the compositional pattern.

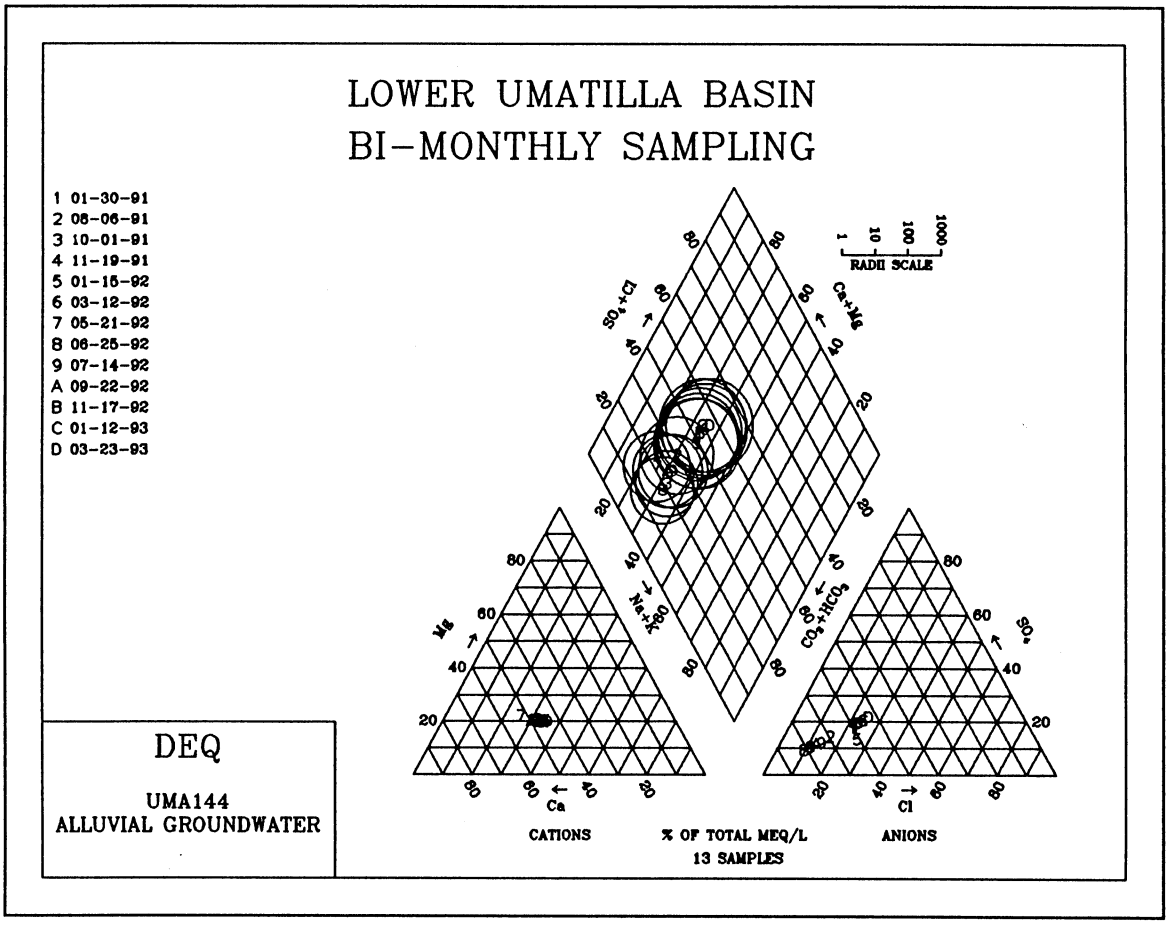


Figure 4.33 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 144 located south of Irrigon and adjacent to an irrigated field.

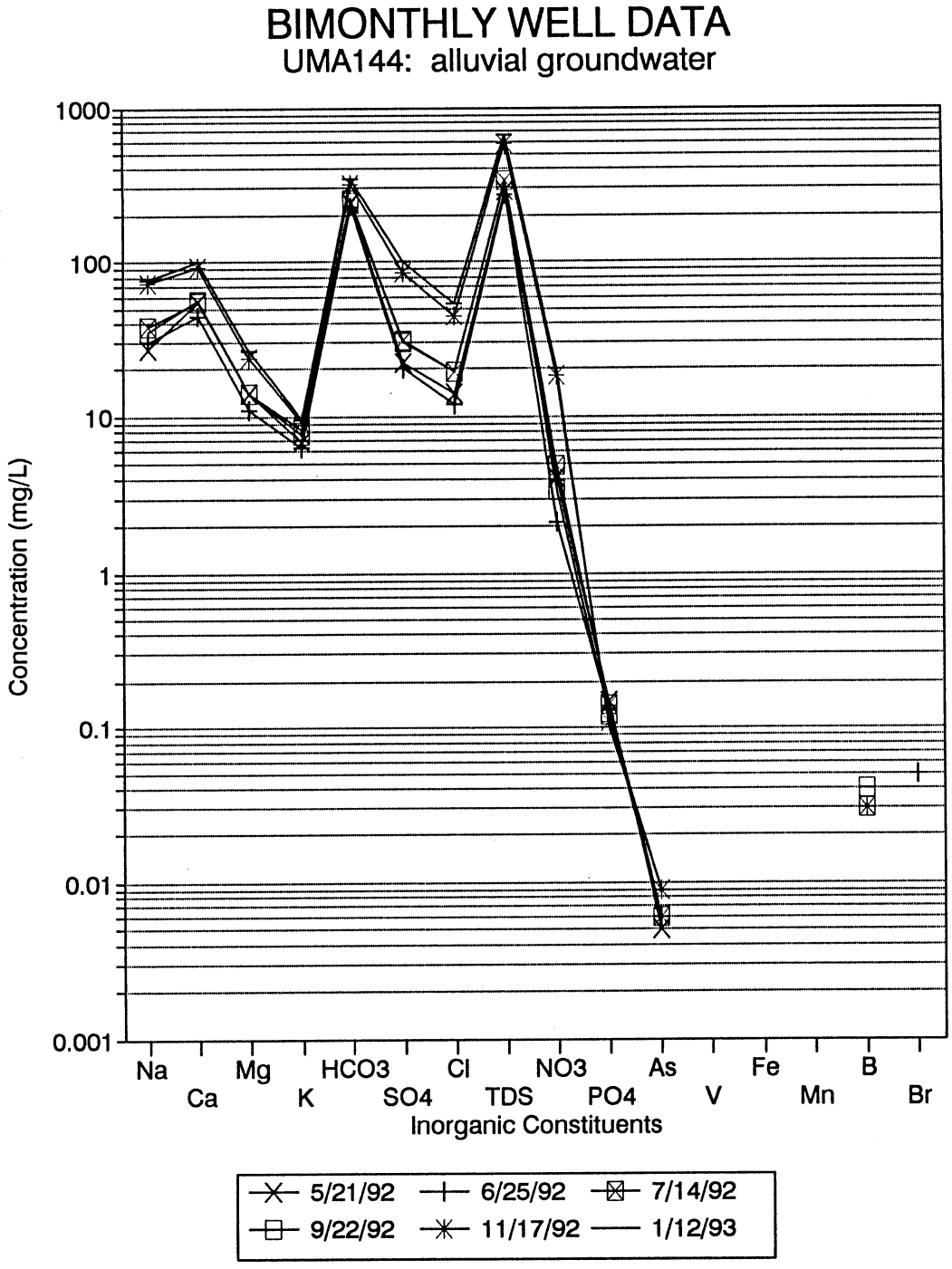


Figure 4.34 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 144 located south of Irrigon and adjacent to an irrigated field.

Note: The variation is larger, and suggests a bimodal pattern.

Piper trilinear graphs were used to distinguish the likely source of elevated nitrate in areas where the source may be questioned. Graphs of synoptic sampling data related to western, southern, and northeastern areas within the U.S. Army Umatilla Depot Activity were compared to graphs for data related to neighboring areas outside the Depot. Additionally, graphs of synoptic sampling at the Port of Morrow site east of Boardman were compared to graphs of related to neighboring irrigated crop agriculture. The results of those analyses follow.

Project synoptic groundwater sampling detected elevated nitrate concentrations at UMA 214 and UMA 204 located immediately inside the Depot's western boundary. Trilinear graphical analysis compared figures 4.35 and 4.31. That analysis indicates the alluvial groundwater chemistry at UMA 214 and UMA 204 is displaced away from the groundwater chemistry at nearby Depot sites having lower nitrate concentrations toward the groundwater chemistry at neighboring irrigated crop agriculture area sites having high nitrate concentrations. This indicates irrigated crop agriculture west of the Depot is the source of the elevated nitrate in groundwater at UMA 214 and UMA 204.

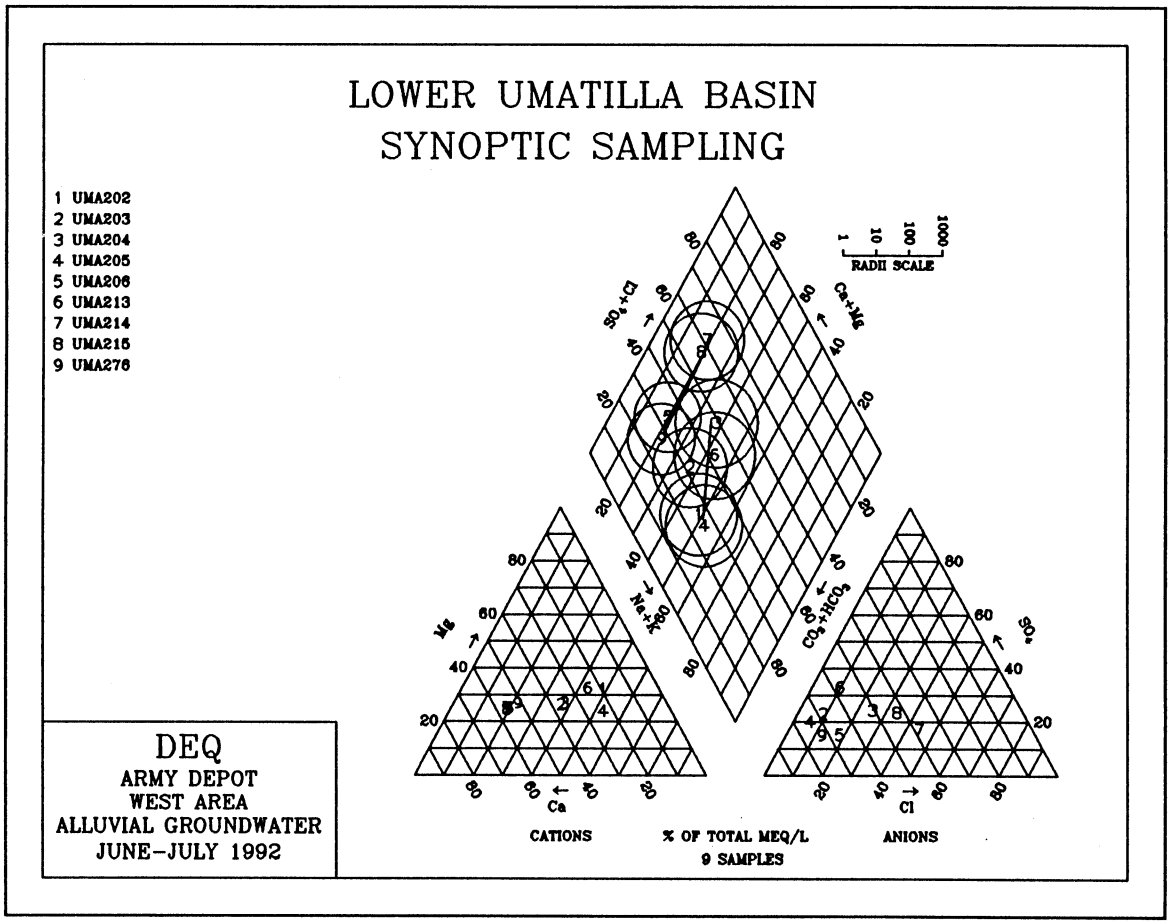


Figure 4.35 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the western portion (Ammunition Demolition Area) of the U.S. Army Umatilla Depot Activity.

Note: The two mixing lines are UMA 205 - UMA 202 - UMA 213 - UMA 204 and UMA 276 - UMA 206 - UMA 215 - UMA 214.

Project synoptic groundwater sampling detected elevated nitrate concentrations in alluvial groundwater samples from the U.S. Army Depot's active landfill area. The area is located downgradient from the Lamb-Weston food processing wastewater pond and land application area. Trilinear graphical analysis comparing figures 4.36 and 4.37 indicates groundwater at the landfill site is related but displaced from the groundwater chemistry at the Lamb-Weston site. The greatest displacement relates to landfill area samples having higher nitrate concentrations. The displacement combined with nitrate and TDS concentration distributions observed on Plates 4.2 and 4.4, TKN distribution analysis, and comparison of bromide versus potassium graphs (next section) suggests the Lamb-Weston land application activity is not responsible for the elevated nitrate observed at the Depot's active landfill. Instead, the active landfill or another Depot activity appears to be the nitrate source.

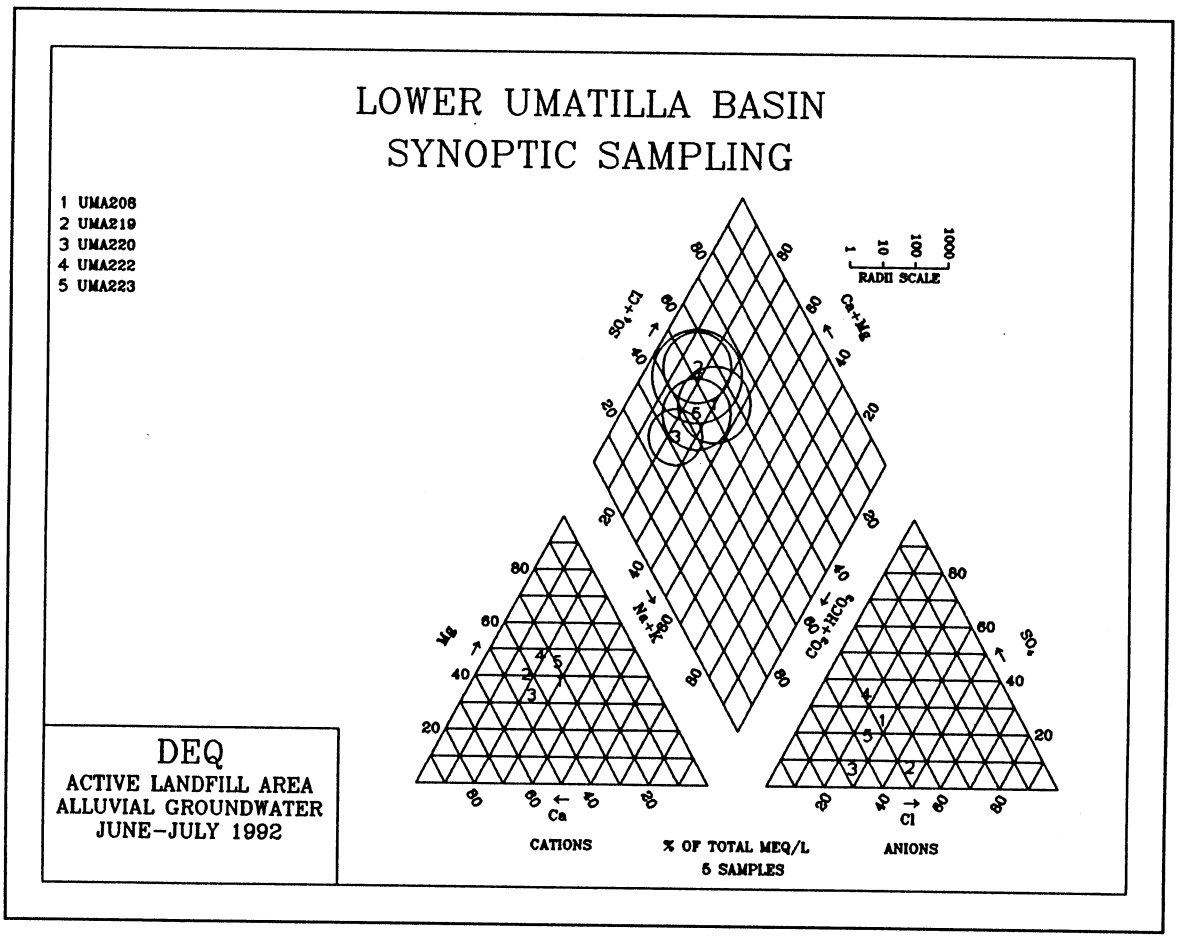


Figure 4.36 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in active landfill area (northeast portion) of the U.S. Army Umatilla Depot Activity.

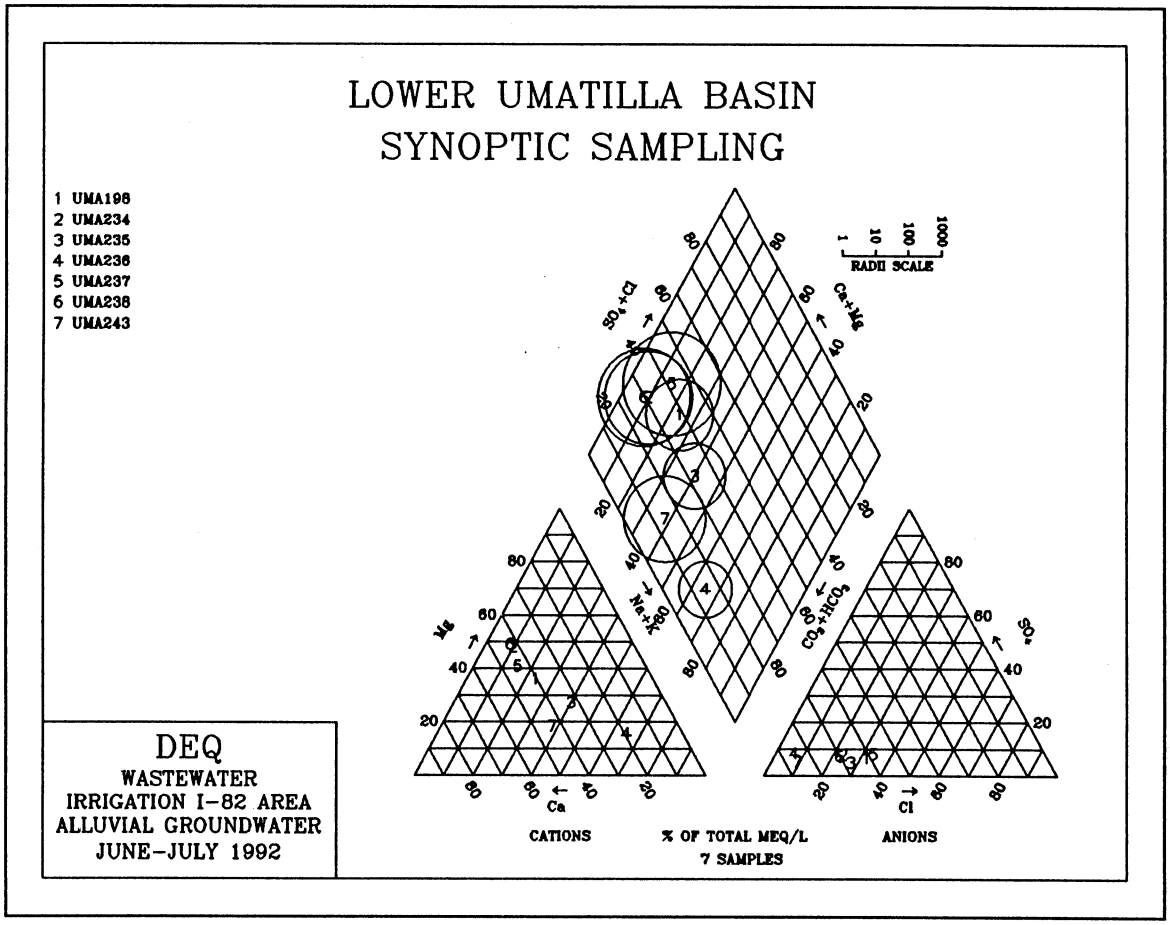


Figure 4.37 Piper Trilinear Graph of project synoptic sampling data for shallow unconfined and regional alluvial groundwater collected in the Lamb Weston Inc. wastewater land application area adjacent to the U.S. Army Depot's northeast corner.

Questions exist about the source of nitrate in the alluvial groundwater along the southern boundary of the U.S. Army Depot. Trilinear graphs were used to compare project synoptic sampling data related to southern U.S. Army Depot alluvial groundwater sites to data related to sites further inside the Depot and sites within the agricultural area south of the Depot (Figures 4.38, 4.39, 4.40 and 4.41). All the data graphed along a common mixing line indicating chemical continuity between groundwater south of the Depot to groundwater within the central portions of the Depot. Constituent graphical analysis suggesting an irrigation influence combined with hydrogeologic (flow toward the Depot) and nitrate distribution (higher concentrations south of the Depot) analyses indicate alluvial groundwater within the southern portion of the Depot is influenced by activity south of the Depot rather than vice versa.

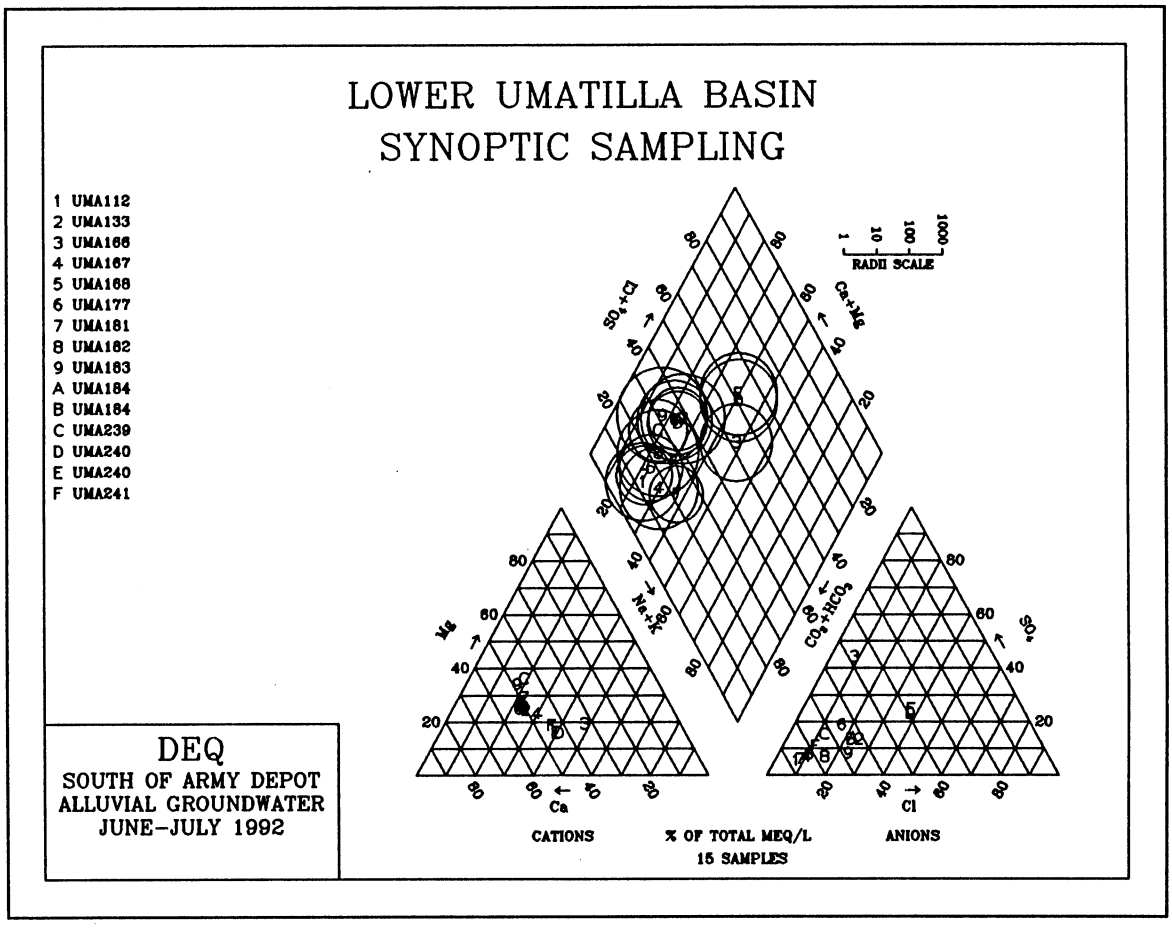


Figure 4.38 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected south of the U.S. Army Umatilla Depot Activity.

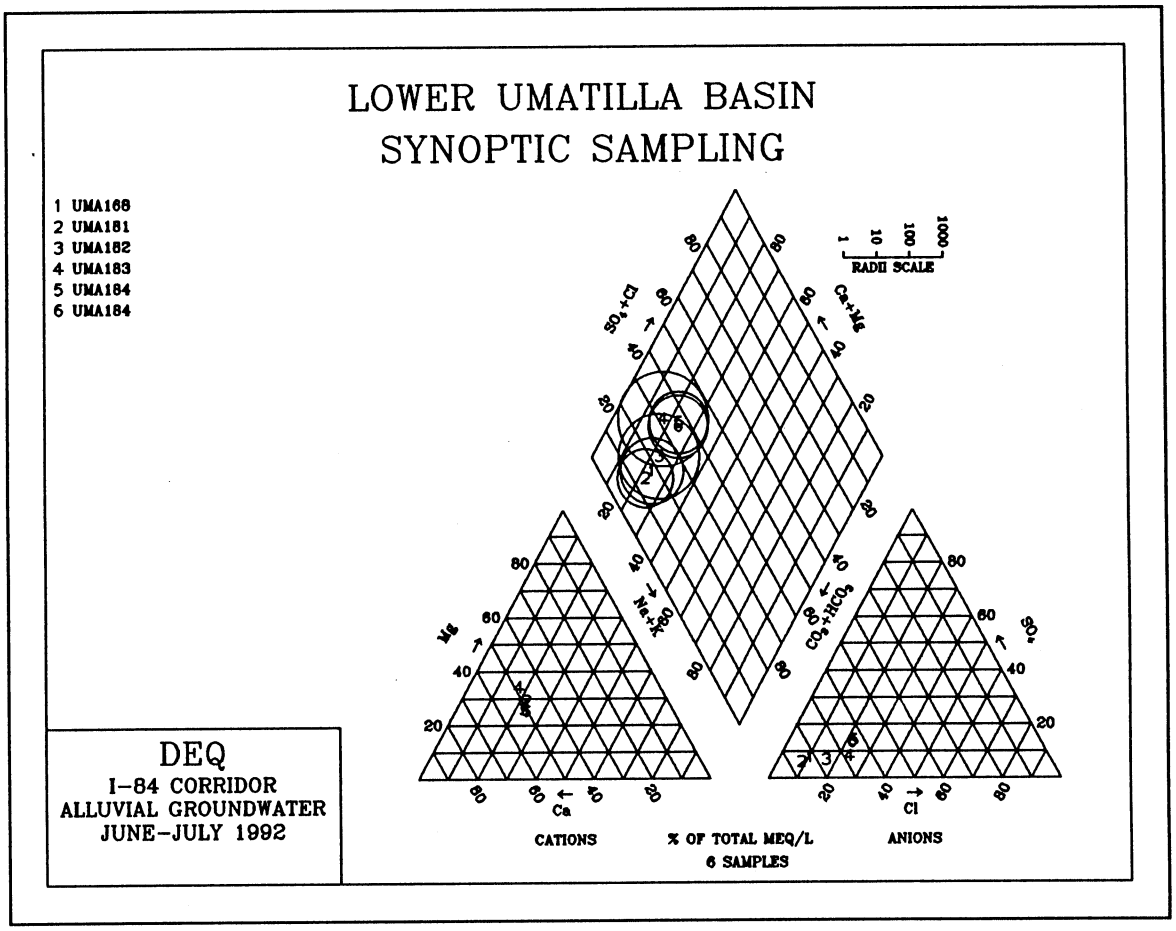


Figure 4.39 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected along Interstate 84 south of the U.S. Army Umatilla Depot Activity.

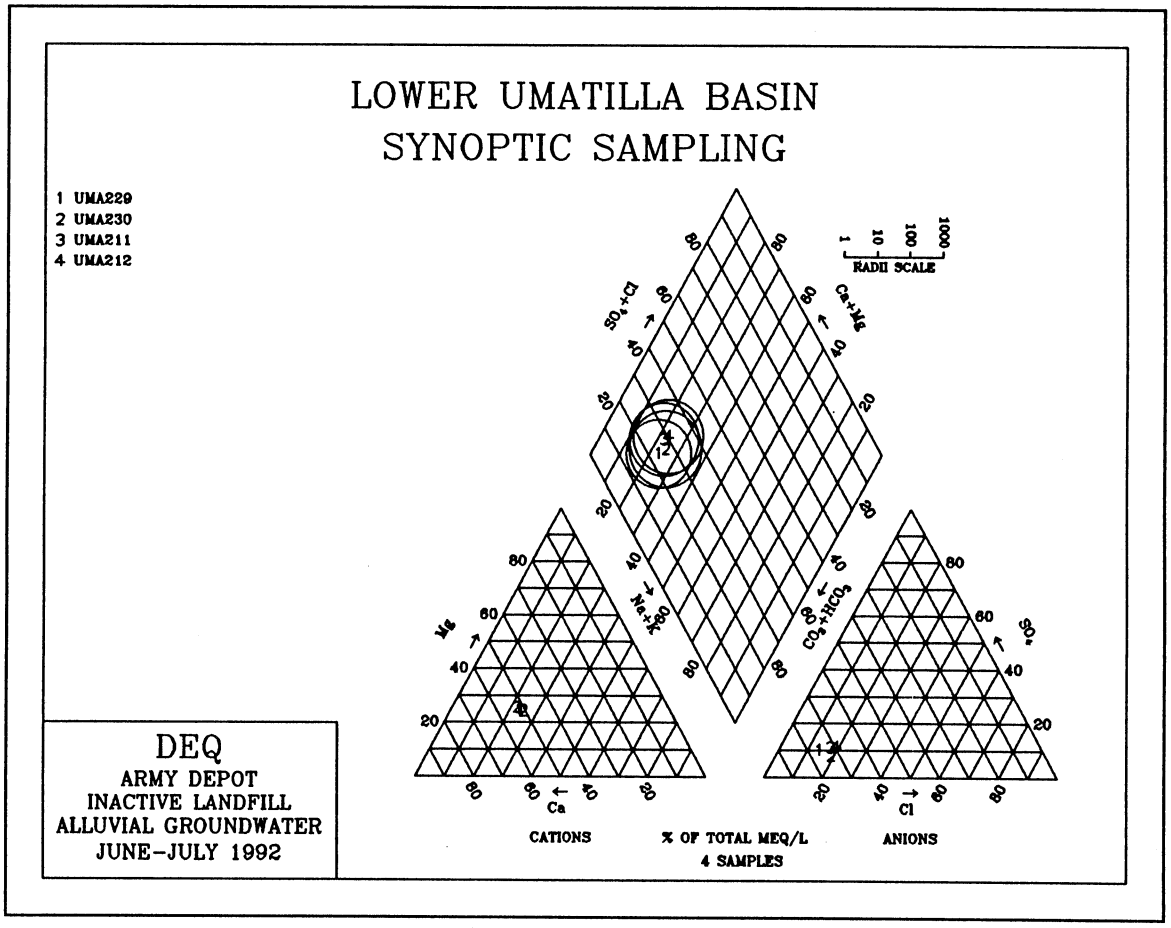


Figure 4.40 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the inactive landfill area (southern portion) of the U.S. Army Umatilla Depot Activity.

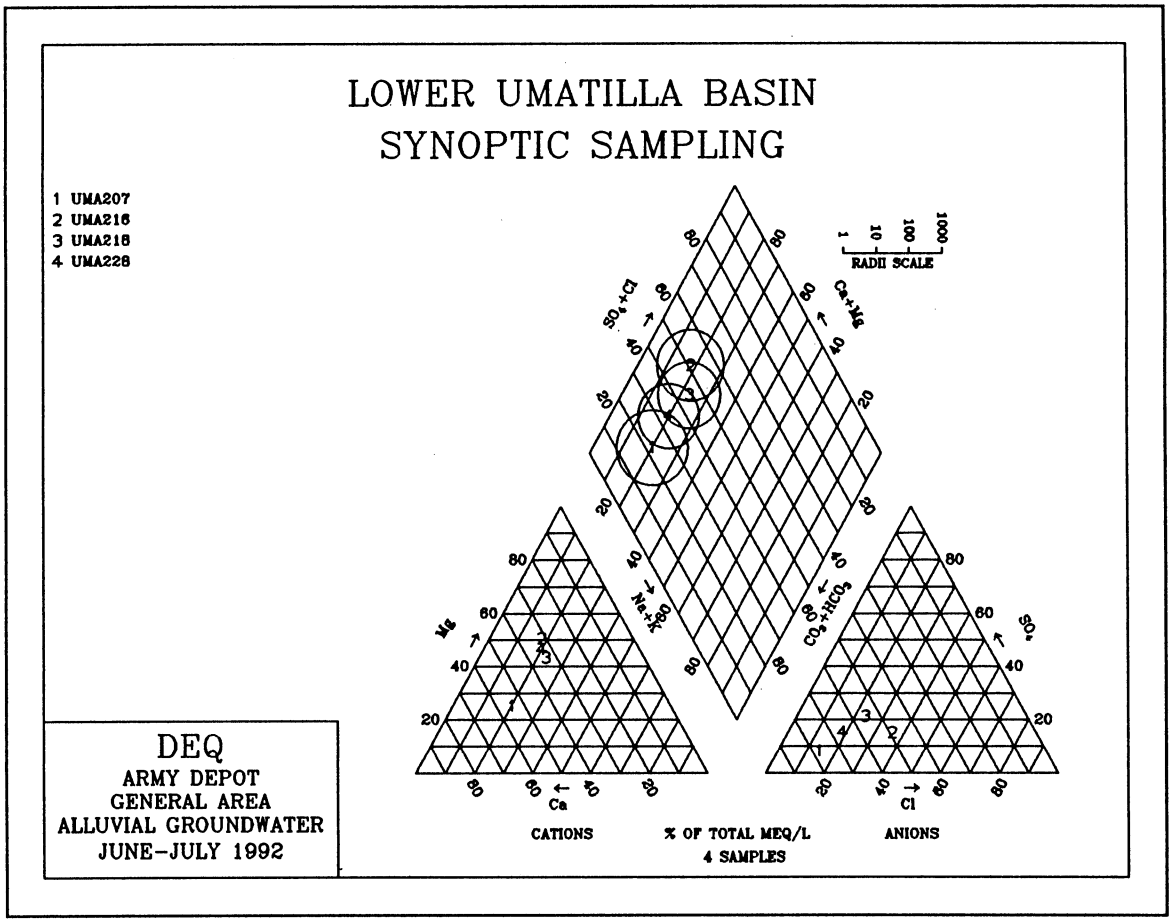


Figure 4.41 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected at general sites in the U.S. Army Umatilla Depot Activity.

Questions also exist about the source of nitrate within alluvial groundwater at the Port of Morrow land application area east of Boardman. Trilinear graphs (Figures 4.42 and 4.31) were used to compare project synoptic groundwater sampling data related to Port of Morrow and neighboring irrigated crop agriculture sites. All the data graphed along a common mixing line indicating chemical continuity between alluvial groundwater at the Port of Morrow and the irrigated crop agriculture areas. Constituent graphical analysis combined with hydrogeologic, nitrate distribution, Total Kjeldahl Nitrogen distribution, and nitrogen isotope analyses indicate wastewater land application or another organic nitrogen source is primarily responsible for the occurrence of nitrate in groundwater at the Port's land application site. Similarly, the analyses indicate irrigated crop agriculture is primarily responsible for the occurrence of elevated nitrate within the irrigated crop areas.

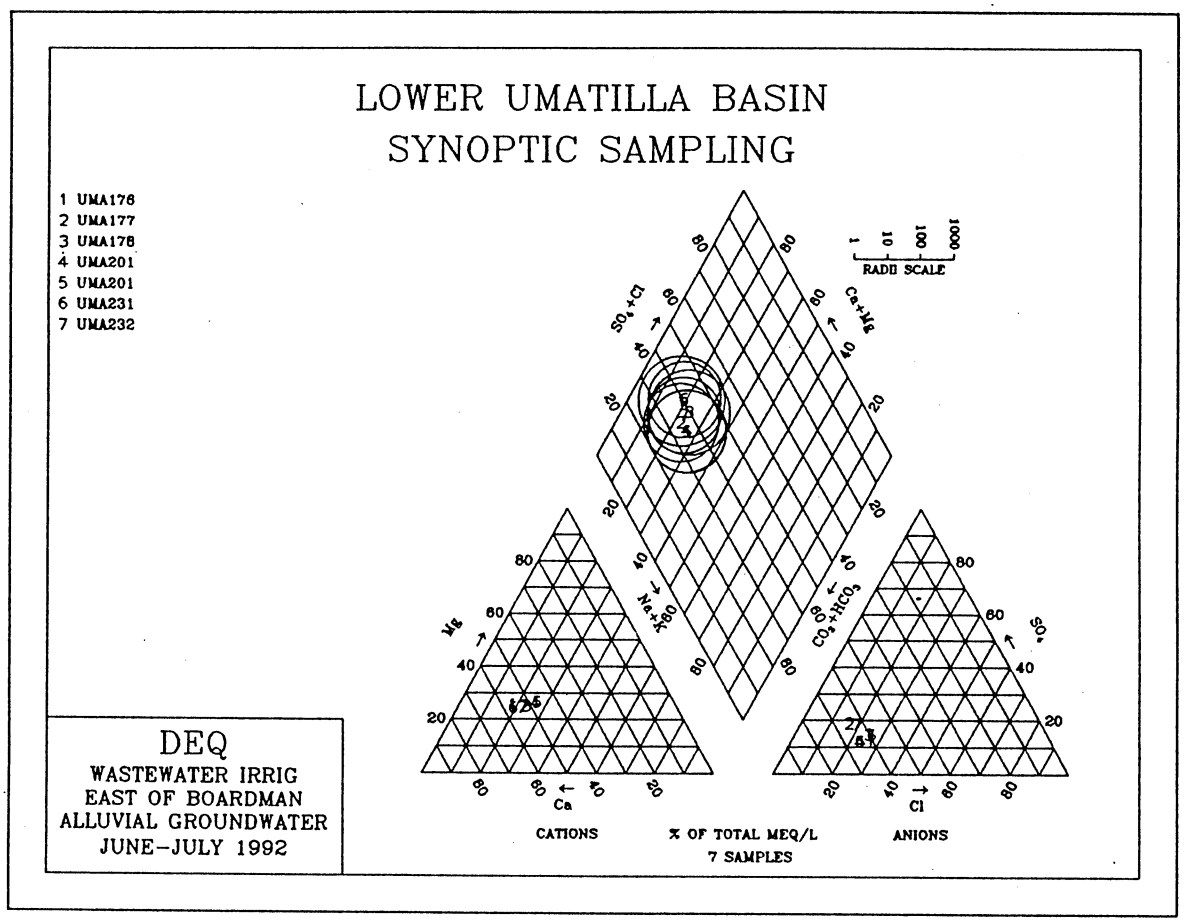


Figure 4.42 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the Port of Morrow wastewater land application area east of Boardman.

Graphical Analyses: Constituent Versus Constituent

Constituent versus constituent graphs were used to distinguish nitrate sources. The analysis primarily used synoptic sampling data. Graphs reviewed included chloride versus potassium, bromide versus potassium, and chloride/bromide versus chloride. Generally, the analyses indicate a variety of land uses influence the groundwater chemistry in the Boardman to Irrigon area (see Appendix 4H). Noteworthy results include the following:

- Alluvial groundwater chemistry data for the U.S. Army Depot active landfill area and the neighboring Lamb-Weston Inc. wastewater land application area graph in separate but adjacent fields on some constituent versus constituent graphs as shown by comparing figures 4.43 and 4.44. This observation combined with nitrate and TDS concentration distributions observed in Plates 4.2 and 4.4, TKN distribution analysis, and Piper Trilinear analysis suggests the active landfill or another Depot activity is responsible for elevated nitrate at the landfill instead of Lamb-Weston.

- Irrigation by crop agriculture and/or by the food processing industry influencing groundwater chemistry was observed for the south Boardman area, Port of Morrow wastewater land application area, areas south, north, and west of the U.S. Army Depot, and the Lamb-Weston wastewater land application area. Other analyses were necessary to distinguish between general food processing wastewater versus irrigated crop agriculture influences.

- Analyses suggest animal operation activity locally influences groundwater in the south Boardman area and south of the U.S. Army Depot.

- The analyses also suggest some animal waste influence upon groundwater between Irrigon and the Umatilla River. However, project investigators have not observed or confirmed any animal waste use in the area. A portion of the U.S Army depot is reserved for grazing livestock (Mahannah and others, 1993).

- Analysis suggest septic systems generally influence the groundwater chemistry in the Irrigon vicinity, and locally influence the groundwater chemistry in other areas.

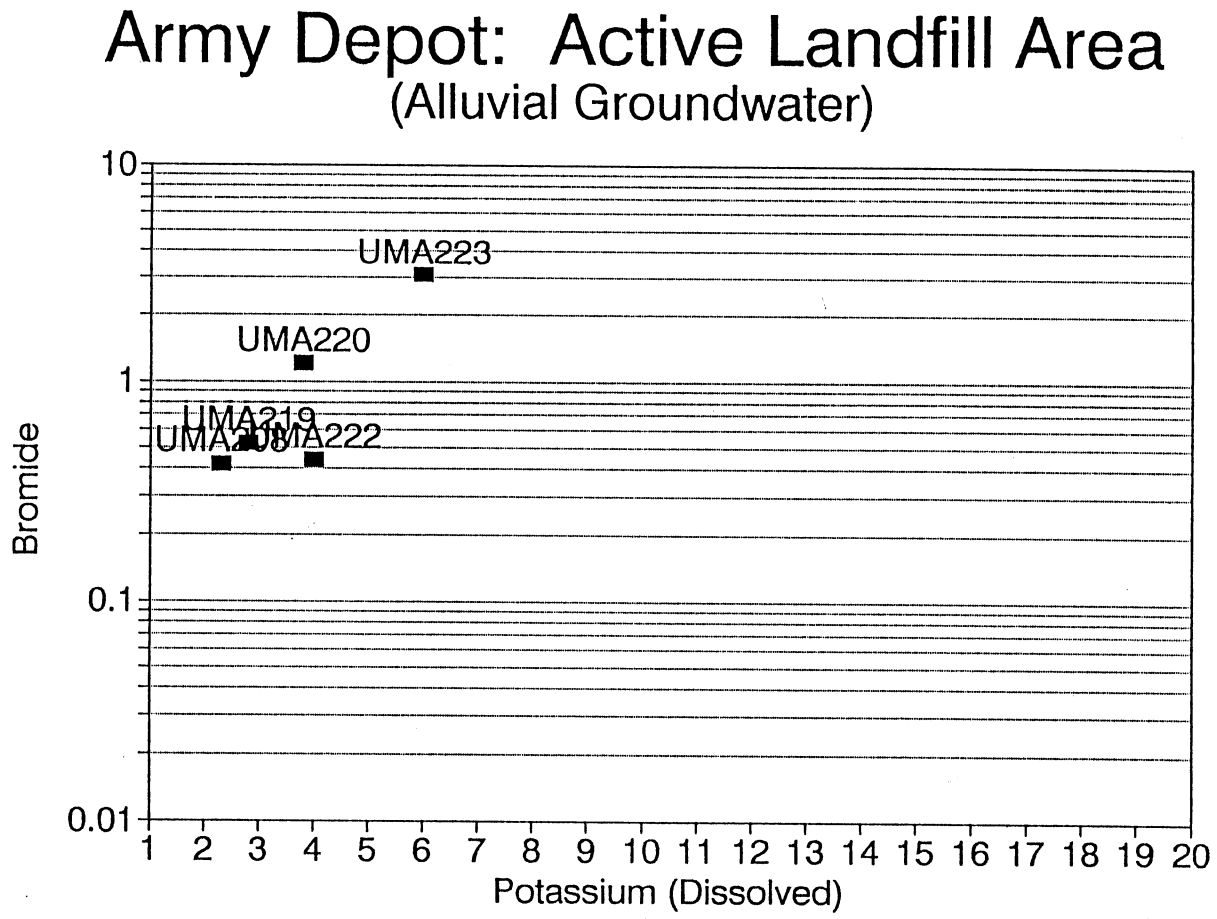


Figure 4.43 Bromide versus potassium graph of project synoptic sampling data for alluvial groundwater collected in the active landfill area (northeast portion) of the U.S. Army Umatilla Depot Activity.

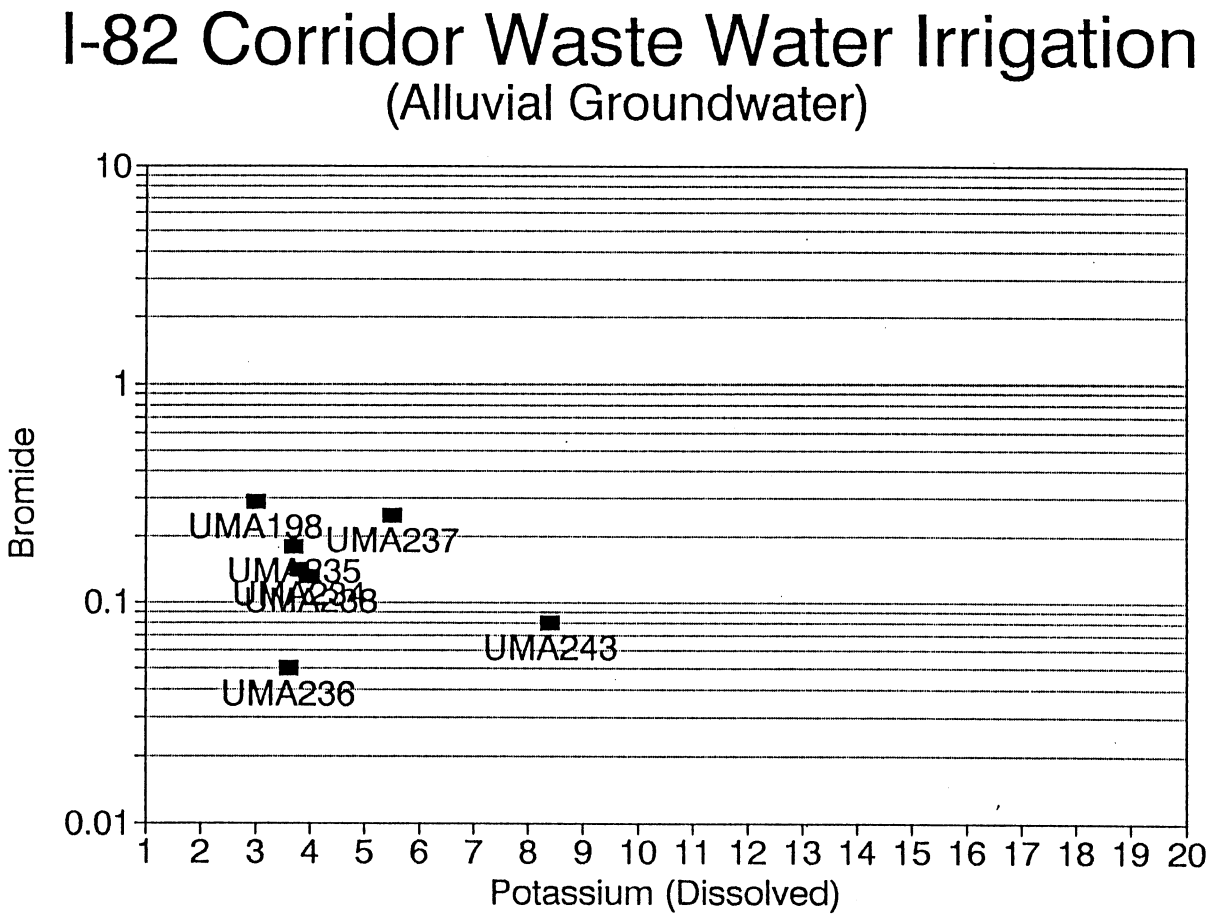


Figure 4.44 Bromide versus potassium graph of project synoptic sampling data for shallow unconfined and regional alluvial groundwater collected in the Lamb Weston Inc. wastewater land application area adjacent to the U.S. Army Depot's northeast corner.

Groundwater Flow Path Analysis

Project analysis included analyzing the groundwater chemistry along a groundwater flow path passing through the U.S. Army Umatilla Depot Activity. The concentration of nitrate and other constituents varies along that groundwater flow path. Figure 4.45 shows the variation of calcium and chloride. The nitrate variations correlated better with calcium and chloride than sodium and sulfate. The variations suggest more than one nitrate and total dissolved solids source influences groundwater along the flow path.

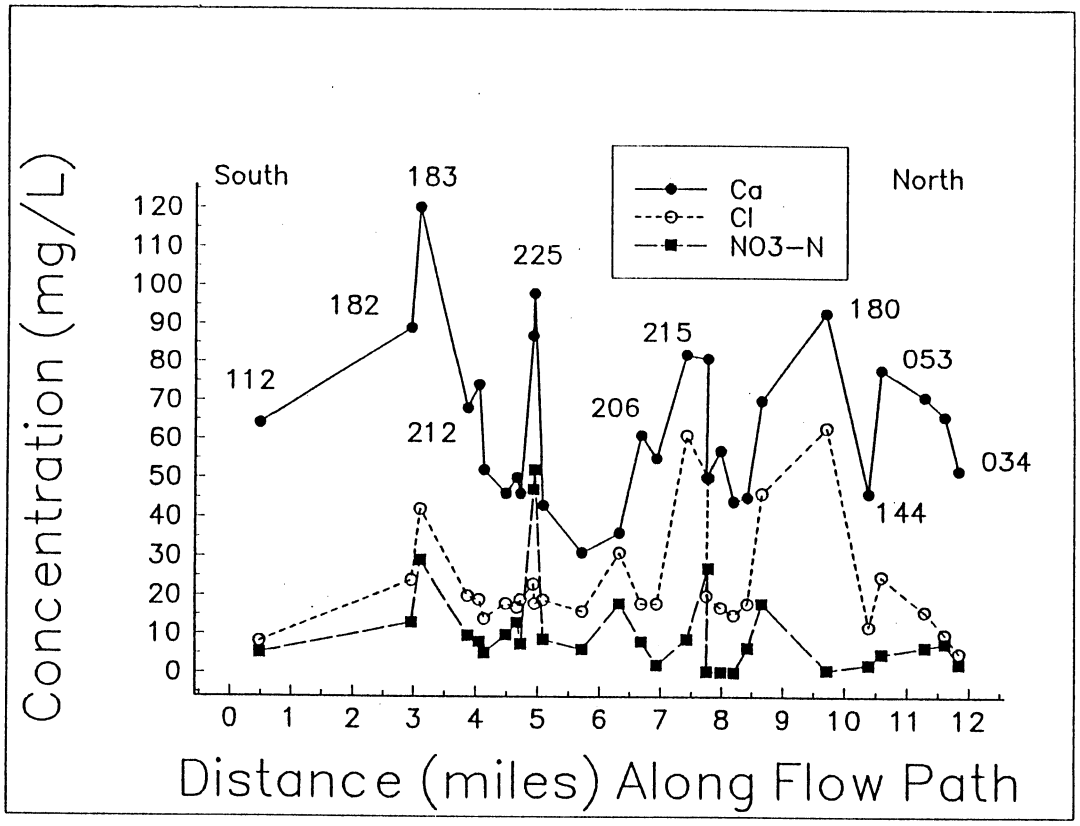


Figure 4.45 Calcium, chloride, and nitrate-nitrogen variation along a composite groundwater flow path passing through the U.S. Army Umatilla Depot Activity.

Note: The flow path begins at UMA 112 and ends at UMA 034. It crosses Interstate 84 between UMA 183 and UMA 212.

Note: Numbers identifying selected sites is shown for reference.

Groundwater Chemistry Computer Modeling

The NETPATH groundwater chemistry computer model was used to evaluate the source of increasing nitrate concentrations in alluvial groundwater within the vicinity of UMA 097 and UMA 096. The sites are located between Irrigon and the Umatilla River along Highway 730. Well UMA 097 is located close to the West Extension Canal. Well UMA 096 is located less than 0.5 miles east of UMA 097 and north of Highway 730.

Project sampling detected nitrate concentrations increasing from 19 mg/L at UMA 097 to 31 mg/L at UMA 096. Crop Irrigation and food processing wastewater land application occur upgradient of both sites. Rural residential homes with septic systems are located between UMA 096 and the West Extension Canal. Constituent versus constituent graphical analyses suggest both septic systems and food processing wastewater influence the groundwater chemistry at UMA 097 and UMA 096.

NETPATH was used to better identify influences upon the groundwater chemistry at UMA 096. The mixing of groundwater moving down gradient from the Lamb-Weston land application site with local groundwater as well as water rock reactions was evaluated. The modeling results indicate mixed sources influence the groundwater chemistry in the area:

UMA 096 = [7.10 percent food processing area groundwater (UMA 258)]
+ [92.90 percent septic system area groundwater (UMA 053)]
+ [17.95 basalt glass] + [0.22 gypsum]
- [1.79 cation exchange (sodium for calcium)]
- [1.66 illite] - [2.09 magnesium calcite]

The model yielded similar mixing proportions when other end members and target wells were used. The mixing proportions were independently evaluated by comparing the predicted barium and bromide concentrations for UMA 096 to observed concentrations. Concentrations predicted for barium and bromide were 0.10 mg/L and 0.06 mg/L, respectively agreed with observed barium and bromide concentrations observed in UMA 096 groundwater.

Nitrogen Isotopic Analyses

The Stable Nitrogen Isotope Analysis section presents the nitrogen isotopic data and data analysis discussion.

Analysis of nitrogen isotopic data related to the Boardman to west Umatilla area found the following:

- A commercial fertilizer influence is clearly evident from the delta ^{15}N values for groundwater sampled from three irrigation wells located north of Highway 730 between Boardman and Irrigon. The delta ^{15}N values remained constant over time despite nitrate+nitrite-nitrogen concentration fluctuations. That indicates the nitrogen source remains uniform and hydraulic flushing of nitrate is very slow. The delta ^{15}N values for the eastern wells are higher. That indicates an additional nitrate source influence is possible.

- The influence of animal waste appears evident from the delta ^{15}N values related to groundwater sampled from well UMA 133. This well is located along County Line Road approximately 2 miles south of Interstate 84. Historic and current animal waste sources are located nearby.

- Delta ^{15}N values related to groundwater sampled from wells near the U.S. Army Umatilla Depot Activity explosive washout lagoons indicates most of the nitrate in the groundwater came from explosive contaminants.

Boardman to West Umatilla Area Summary and Conclusions

This project used a variety of techniques to analyze the Boardman to west Umatilla area groundwater chemistry data. The data came from project sampling, or it was reported or provided by local facilities. The analyses led project investigators to the following observations and interpretations:

- Groundwater nitrate concentrations detected by this project or reported by local facilities range from non-detect to more than 100 mg/L.

- Groundwater with nitrate concentrations exceeding 10 mg/L occurs in large areas located:

  - south of Boardman,
  - between Boardman and Irrigon,
  - between Irrigon and the Umatilla River,
  - the northeast corner area of the U.S. Army Umatilla Depot Activity,
  - the Depot's washout lagoons area, and
  - south of the Depot.

- Elevated nitrate concentrations in groundwater south of Boardman appear to come primarily from irrigation activity with some contribution from animal operations and septic systems.

- Port of Morrow and Lamb-Weston wastewater land application activity east of Boardman and adjacent to the U.S. Army Depot, respectively, appear responsible for the elevated nitrate concentrations at their respective sites.

- Irrigated agriculture appears responsible for elevated nitrate concentrations detected in groundwater between the Port of Morrow and Irrigon and the elevated nitrate concentrations detected along the U.S. Army Depot's western boundary.

- Irrigation activity and septic systems appear responsible for the elevated nitrate concentrations detected in groundwater north of the U.S. Army Depot. Analyses also suggest an animal waste influence. However, this investigation has no information to confirm or refute usage of animal waste in this area.

- Elevated groundwater nitrate concentrations detected in the U.S. Army Depot active landfill area appears derived from a Depot source rather than from the upgradient Lamb-Weston wastewater land application site. Dried domestic sludge disposed at the landfill is a potential source.

- Past activity at the U.S. Army Depot washout lagoons appears responsible for elevated groundwater nitrate concentrations detected in the central part of the Depot. Nitrate movement away from the lagoons is less than four miles over three to four decades if the apparent plume on Plate 4.2 is real. Otherwise, nitrate has moved less than 0.05 mile over the same period.

    - Irrigated agriculture and animal operations appear primarily responsible for the elevated nitrate concentrations detected in groundwater south of the U.S. Army Depot.

- Groundwater nitrate concentrations below 10 mg/L were detected in samples from sites west of Irrigon along the Columbia River, south of Irrigon through the western portion of the U.S. Army Depot, and the Lost Lake vicinity.

- Total dissolved solids concentrations exceeded the 500 mg/L secondary (aesthetic) drinking water standard in groundwater:
    - south of Boardman,
    - between Boardman and Irrigon,
    - the east Irrigon area,
    - the U.S. Army Depot active landfill area,
    - the immediate vicinity of the Depot's explosive washout lagoons, and
    - south of the Depot.

- Sodium concentrations in the Boardman to west Umatilla area groundwater commonly exceed the 20 mg/L limit recommended for persons on a physician prescribed sodium restricted diet.

- Arsenic concentrations exceeded the drinking water standard of 0.050 mg/L in groundwater at several U.S. Army Depot sites and at a Lamb-Weston wastewater land application area site.

- Groundwater samples with relatively high (0.10 mg/L or greater) maximum total phosphate concentrations came from wells located within the Port of Morrow wastewater land application area east of Boardman, the Irrigon area, most of the U.S. Army Depot, south of the Depot, and the Lamb-Weston land application area.

- Samples with relatively low total phosphate concentrations often came from within or near irrigated crop agriculture areas.

- Agricultural chemicals have been sporadically detected in Boardman to west Umatilla area groundwater samples. Atrazine was detected in groundwater sampled south of Boardman and between the Port of Morrow and Irrigon. Dacthal acid was detected in groundwater sampled south of the U.S. Army Depot.

- Nitrate movement through the area appears slow. Decades may be required for nitrate to move through the local alluvial groundwater system.

- Explosives are present in groundwater at some U.S. Army Depot sites.

Butter Creek to City of Umatilla Area

The Butter Creek to City of Umatilla area includes the west half of Range 28 East and Townships 3, 4, and 5 North. Groundwater converges in the area and flows north toward the Columbia River. Historic and current land uses in the area include:

- City of Umatilla and western Hermiston municipal areas;

- City of Umatilla sewage treatment facility;

- City of Hermiston sewage treatment facility and land application area;

- Land application of City of Portland and Unified Sewerage Agency (Washington County) sludge;

- Unsewered rural residential homes;

- Multiple food processing plants, wastewater ponds, and land application sites;

- Confined animal operations with some wastewater ponds and land application sites;

- Irrigated crop agriculture.

Analysis of project and facility data is presented in this section. Lamb-Weston, Inc. and the J.R. Simplot Company regularly collect groundwater samples from facility wells and report the results to the Oregon Department of Environmental Quality. Project groundwater sampling in the area includes reconnaissance, bimonthly, and synoptic sampling.

Map and Data Set Observations: Nitrate

Table 4.23 and Plates 4.2 and 4.3 show the nitrate+nitrite-nitrogen concentration range and distribution in the Butter Creek to City of Umatilla area. Table 4.23 shows local concentration ranges detected by this project or reported by local facilities. Plate 4.3 shows the distribution of maximum concentrations this project detected in alluvial and nearby basalt groundwater samples. Plate 4.2 shows the June-July 1992 concentration distribution in regional alluvial groundwater based upon project synoptic sampling. Nitrate+nitrite-nitrogen concentrations detected in shallow unconfined alluvial groundwater samples and basalt groundwater samples are printed next to each sampling location.

The shape and extent of each concentration range contoured on Plate 4.2 was derived by linear interpolation between data locations. Data control was sparse in Township 5 North. This should be considered to avoid misinterpreting the source and movement of nitrate in that area.

Table 4.23 Nitrate concentration ranges detected in alluvial and basalt groundwater sampled in the Butter Creek to City of Umatilla area.

Area	Groundwater Source	Dominant Land Uses (Historic and Current)	Nitrate-N (mg/L)	
			Maximum	Minimum
Butter Creek Highway Area: South (south of Interstate 84 and west of Highway 207) (Project Sampling)	Alluvial	irrigated crop agriculture food processing wastewater land application municipal sludge land application in area pasture	2.80	<0.02
Butter Creek Highway Area: South (south of Interstate 84 and west of Highway 207) (Lamb-Weston Sampling)	Alluvial	irrigated crop agriculture food processing wastewater land application municipal sludge land application in area pasture	8.00	5.00
Butter Creek Highway Area: South (south of Interstate 84 and west of Highway 207) (Project Sampling)	Alluvial (Shallow Unconfined)	irrigated crop agriculture food processing wastewater land application municipal sludge land application in area pasture	11.00	2.80
Butter Creek Highway Area: South (south of Interstate 84 and west of Highway 207) (Lamb-Weston and J.R. Simplot Company Sampling)	Alluvial (Shallow Unconfined)	irrigated crop agriculture food processing wastewater land application municipal sludge land application in area pasture	16.00	1.10
Butter Creek Highway Area: South (south of Interstate 84 and east of Highway 207) (Project Sampling)	Alluvial	food processing wastewater land application confined animal operation	26.00	13.00
Butter Creek Highway Area: South (south of Interstate 84 and east of Highway 207) (J.R. Simplot Company Sampling)	Alluvial	food processing wastewater land application confined animal operation	26.50	0.40
Butter Creek - Umatilla River Confluence Area (Project Sampling)	Alluvial	irrigated crop agriculture food processing wastewater land application confined animal operations nearby	23.00	0.72
Butter Creek - Umatilla River Confluence Area (J.R. Simplot Company Sampling)	Alluvial	irrigated crop agriculture food processing wastewater land application confined animal operations nearby	10.90	<0.04

Butter Creek - Umatilla River Confluence Area (Project sampling)	Alluvial (Shallow Unconfined)	irrigated crop agriculture food processing wastewater land application confined animal operations nearby	21.00	0.03
Butter Creek - Umatilla River Confluence Area (J.R. Simplot Company Sampling)	Alluvial (Shallow Unconfined)	irrigated crop agriculture food processing wastewater land application confined animal operations nearby	100.00	<0.05
Butter Creek Highway Area: North (north of Interstate 84 and east of Umatilla River) (Project Sampling)	Alluvial	confined animal operation irrigated crop agriculture rural residential homes Hermiston STP and land application at north	25.00	0.75
Butter Creek Highway Area: North (north of Interstate 84 and west of Umatilla River) (Project Sampling)	Alluvial	irrigated crop agriculture Hermiston STP land application	14.00	2.00
Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial	wastewater land application Depot's active landfill nearby	22.00	0.18
Lamb-Weston, Inc. Land Application Area (Adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial (Shallow Unconfined)	wastewater land application Depot's active landfill nearby	36.00	21.00
Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Lamb-Weston, Inc. Sampling)	Alluvial	wastewater land application Depot's active landfill nearby	74.00	0.18
Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Lamb-Weston, Inc. Sampling)	Alluvial (Shallow Unconfined)	wastewater land application Depot's active landfill nearby	65.00	<1.0
City of Umatilla Area (Project Sampling)	Alluvial	municipal Umatilla sewage treatment facility	4.20	1.70

Note: Project sampling reports nitrate concentrations as nitrate+nitrite-nitrogen.

Sources:
Project Sampling
DEQ Water Quality File 81590
DEQ Water Quality File 48780
Barlow, Urban, and Scott, 1992
EMCON Northwest, Inc., 1992
Hemphill, 1992

Food processing facility sampling of shallow unconfined alluvial groundwater west of Highway 207 and south of Interstate 84 has occasionally detected nitrate-nitrogen concentrations exceeding 10 mg/L (see Table 4.23). They also report Total Kjeldahl Nitrogen (TKN) concentrations generally less than 3 mg/L (DEQ Water Quality Files 81590 and 48780, Barlow and others, 1992, EMCON Northwest, Inc., 1992, Hemphill, 1992). This TKN presence indicates a local organic nitrogen source influences the shallow unconfined groundwater. Determining the organic source from the nitrate and TKN data is difficult, because the facility data reviewed coincides with a period of land use transition from animal activity to food processing land application.

Project sampling detected elevated nitrate+nitrite-nitrogen concentrations in alluvial groundwater sampled at the J.R. Simplot land application site south of Interstate 84 and east of Highway 207. Wastewater land application appears to be the nitrate source given the local hydrogeology and groundwater chemistry. The site is located on the west flank of a groundwater divide, and it appears to be a local source of groundwater recharge. Project synoptic sampling data show nitrate+nitrite-nitrogen concentrations increasing downgradient across the site. Additionally, facility TKN data indicates an organic nitrogen source exists at the site. TKN concentrations detected by project or Simplot sampling ranged from non-detect to 35.50 mg/L.

Elevated nitrate+nitrite-nitrogen concentrations occur in shallow unconfined and regional alluvial groundwater within the Butter Creek-Umatilla River confluence vicinity. Land use versus nitrate concentration distribution and groundwater chemistry data analyses indicate local food processing wastewater is the likely nitrate source. The greatest nitrate concentrations detected and reported came from samples collected in the vicinity of the J.R. Simplot Company food processing wastewater land application area north of the Umatilla River. Simplot TKN data indicates an organic nitrogen influence at the site. TKN concentrations detected by project or Simplot sampling ranged from non-detected to possibly more than 25 mg/L. Nitrogen isotopic analysis of shallow unconfined alluvial groundwater sampled from UMA 258 clearly indicated an organic waste influence. Well UMA 258 is located in the confluence vicinity within the Simplot wastewater land application area north of the Umatilla River.

Project sampling detected elevated nitrate concentrations in some alluvial groundwater sampled west of C&B Livestock, Incorporated. Rural residential homes and crop irrigation occurs in the sampled area. C & B Livestock appears responsible for higher nitrate concentrations near the facility given the local hydrogeology, nitrate concentration distribution, and land use distribution.

Groundwater locally flows from the C&B Livestock area toward the Umatilla River. The highest nitrate concentrations detected in local alluvial groundwater came from sampling sites located closest to C&B Livestock. Nitrate concentrations generally ranged from 14 mg/L to 24 mg/L at these sites during project synoptic sampling. The concentrations generally decreased to below 10 mg/L in samples collected downgradient within the rural residential and crop irrigation areas. Canal leakage may be responsible for some of that decrease.

A comparison of C&B Livestock vicinity groundwater data with groundwater samples collected near animal operations south of Boardman also indicate an animal waste source in the C & B Livestock vicinity. The data from the two areas plot similarly on constituent versus constituent graphs, which indicates a common influence. They graph in an area adjacent but separate from septic system influences. (See Figures 4.14 and 4.15) This similarity indicates an animal waste influence.

Irrigated crop agriculture also appears responsible for elevated nitrate in alluvial groundwater sampled further west and downgradient of C&B Livestock. Evidence comes from Dacthal acid detected in alluvial groundwater sampled from UMA 119, located northwest of C&B Livestock and the rural residential homes near C & B Livestock. Nitrate concentrations in samples collected from UMA 119 range from 6 to 17 mg/L. Local groundwater flow directions preclude crop agriculture activity in this area from being responsible for the elevated nitrate concentrations detected in groundwater sampled closer to C & B Livestock.

Project synoptic sampling detected nitrate+nitrite-nitrogen concentrations exceeding 10 mg/L in an area between the Umatilla River and Agnew Road south of Bridge Road. Concentrations detected over time range from 8 mg/L to 13 mg/L. Determining the source is not conclusive. Rural residential home and irrigated crop land uses occur in the area. The shape of the greater than 10 mg/L nitrate+nitrite-nitrogen contoured area on Plate 4.2 coincides well with three irrigation circles observed on a LANDSAT photograph. However, constituent versus constituent graphical analyses (Appendix 4H) consistently indicate a septic system influence in the vicinity.

Plates 4.2 and 4.3 show elevated nitrate+nitrite-nitrogen concentrations occur in alluvial groundwater in the northeast corner area of the U.S. Army Umatilla Depot Activity where a groundwater mound exists. The concentration contours north of the Depot are not well defined due to sparse data from that area. The elevated concentration area corresponds to the Lamb-Weston Inc. food processing wastewater land application area.

Hydrogeologic and groundwater chemistry evaluations indicate wastewater land application is groundwater nitrate source at the Lamb-Weston site. The site straddles the groundwater mound crest. No other activity is upgradient. Additionally, project and facility TKN data indicates an organic nitrogen source at the land application site. Detected and reported TKN concentrations range from non-detect to 18 mg/L.

Project sampling detected relatively low nitrate+nitrite-nitrogen concentrations in regional alluvial groundwater sampled:

- along the Butter Creek drainage,
- west of the Simplot food processing plant,
- west and north of Hermiston, and
- east of the Lamb-Weston wastewater irrigation site near the U.S. Army Depot.

Lower concentrations in alluvial groundwater at the south end of the Butter Creek area may reflect background conditions. Lower nitrate concentrations further north in the Butter Creek drainage and west of the Simplot food processing plant may relate to dilution from surface water and/or canal leakage. The low concentration area west of Hermiston appears related to Hermiston basin groundwater with low nitrate concentrations discharging from the basin toward the Umatilla River. Lower nitrate concentrations east of the Lamb-Weston land application site may relate to dilution from canal leakage.

Map and Data Set Observations: Total Dissolved Solids

Plates 4.4 and 4.5 show the total dissolved solids (TDS) concentration distribution in the Butter Creek to City of Umatilla area based upon project groundwater sampling. Plate 4.5 shows the maximum concentrations detected in alluvial and nearby basalt groundwater samples. Plate 4.4 shows the June-July 1992 TDS concentration distribution in regional alluvial groundwater based upon linear interpolation of project synoptic sampling data. TDS concentrations detected in shallow unconfined alluvial groundwater samples and basalt groundwater samples are printed next to each sampling location.

The distribution of elevated versus lower TDS concentrations is similar to the nitrate concentration distribution. Concentrations exceeding the secondary (aesthetic) drinking water standard of 500 mg/L occurred east of Highway 207 and south of Minnehaha Road.

Some lower TDS concentration areas appear related to canal and/or surface water leakage, because the shape of their contoured area appear similar to the distribution pattern of some canals. The low concentration area west of Hermiston appears related to Hermiston basin groundwater with lower TDS concentrations discharging from the basin toward the Umatilla River.

Map and Data Set Observations: Other Constituents

Project sampling detected arsenic in groundwater sampled from a few Butter Creek to City of Umatilla sampling sites. Plate 4.6 shows the maximum concentration distribution. The arsenic detections generally remained well below the drinking water standard of 0.050 mg/L. However, a sample from the Lamb-Weston land application site next to the U.S. Army Depot did contain arsenic exceeding the drinking water standard.

Plate 4.7 shows the maximum concentration distribution for sodium. Concentrations in project groundwater samples frequently exceeded the 20 mg/L limit currently recommended for persons on a physician prescribed sodium restricted diet. Groundwater samples with sodium concentrations exceeding 50 mg/L came primarily from sites within or near food processing land application areas, as well as along Westland Road, along Highway 207, and within the City of Umatilla.

Plate 4.8 shows the maximum concentration distribution for chloride. Concentrations in all project groundwater samples collected in the area remained within the 250 mg/L secondary (aesthetic) drinking water standard. Project samples with chloride concentrations exceeding 100 mg/L came from UMA 251, UMA 252, and UMA 237. All three sites are located within food processing land application areas.

Plate 4.9 shows the maximum concentration distribution for total phosphate based upon project sampling. The distribution of lower concentrations versus relatively higher concentrations is nearly divided. Groundwater samples with lower concentrations generally came from sites located north of Interstate 84 and west of the Umatilla River with some exceptions. Crop irrigation generally occurs in this area. Samples with relatively higher total phosphate concentrations came primarily from sites along or near Highway 207 south of Hermiston. Other sites with higher concentrations include the City of Umatilla and the northeast portion of the Lamb-Weston land application site next to the U.S. Army Depot.

Plate 4.10, 4.11, and 4.12 show the maximum concentration distribution for boron, bromide, and vanadium in the area based upon project sampling. Groundwater samples with detected boron came from a limited area north of Interstate 84 and two City of Umatilla sites. Samples with relatively higher concentrations came from sites located along Highway 207 and within the City of Umatilla.

Bromide was detected in groundwater sampled from most sites in the area. Samples with relatively higher concentrations came from sites located within the Simplot wastewater land application areas east of Highway 207, near Highway 207 south of Minnehaha Road, the southeastern portion of the Lamb-Weston land application area next to the Army Depot, and the City of Umatilla.

Vanadium detections were limited to groundwater samples collected near the U.S. Army Depot's northeast corner, the Simplot plant site land application area, and near Highway 207 south of Interstate 84. Local samples with the highest vanadium concentrations came from the east side of the Lamb-Weston land application area located adjacent to the Army Depot.

Table 4.24 and Plate 4.13 shows the Butter Creek to City of Umatilla sites where project sampling detected volatile organic compounds and/or pesticides. Appendix 4G provides a complete listing. The occurrence of these constituents indicate the influence of human activity.

Table 4.24 Volatile organic compounds and pesticides detected in the Butter Creek to City of Umatilla area.

Site	Groundwater Source	Location	Constituent	Concentration	Nitrate+Nitrite-Nitrogen Concentration (mg/L)
UMA 062	Alluvial	Westland Estates (Agnew Rd south of Westland Rd)	Tetrachloro-ethylene	0.0009 mg/L	13.00 - 13.00
UMA 094	Alluvial	Agnew Rd north of Westland Rd	Chloroform	0.0007 mg/L	8.00 - 14.00
UMA 119	Alluvial	SW Hermiston near Highway 207	Dacthal acid	0.1 ppb	6.00 - 17.00
UMA 198	Alluvial	Lamb-Weston site next to Depot	Chloroform	0.0009 mg/L	5.80 - 16.00

Note: Laboratory methods can occasionally cause chloroform detections at low concentrations
Note: The UMA 062 tetrachloroethylene detection was not repeated in a laboratory duplicate analysis
Note: Data from Lower Umatilla Basin project sampling.

Graphical Analyses: Nitrate versus Time.

Graphical analysis of Butter Creek to City of Umatilla area groundwater data included reviewing nitrate versus time graphs. Data analyzed came from project bimonthly sampling, the J.R. Simplot Company (DEQ Water Quality File 81590, Barlow, Urban, and Scott, 1992, EMCON Northwest, Inc., 1992) and Lamb-Weston, Inc. (Hemphill, 1992, DEQ Water Quality File 48780). Analysis of the bimonthly sampling data included comparing the nitrate versus time graphs to other constituent versus time graphs. Analysis of some Simplot and Lamb-Weston data included comparing the nitrate versus time graphs to available groundwater elevation versus time graphs.

Figure 4.46 shows nitrate+nitrite nitrogen concentrations versus time in regional alluvial groundwater sampled by this project within the Butter Creek drainage. Irrigated crop agriculture and animal activity were the primary land uses within the drainage. Much of the area has converted to food processing wastewater land application with municipal sewage sludge land application nearby. Groundwater nitrate concentrations remain low at these sampling sites. However, Lamb-Weston and Simplot report higher nitrate concentrations in the shallow unconfined alluvial groundwater. Table 4.25 presents how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site. The graphs were generally incomparable due to the consistently low nitrate concentrations.

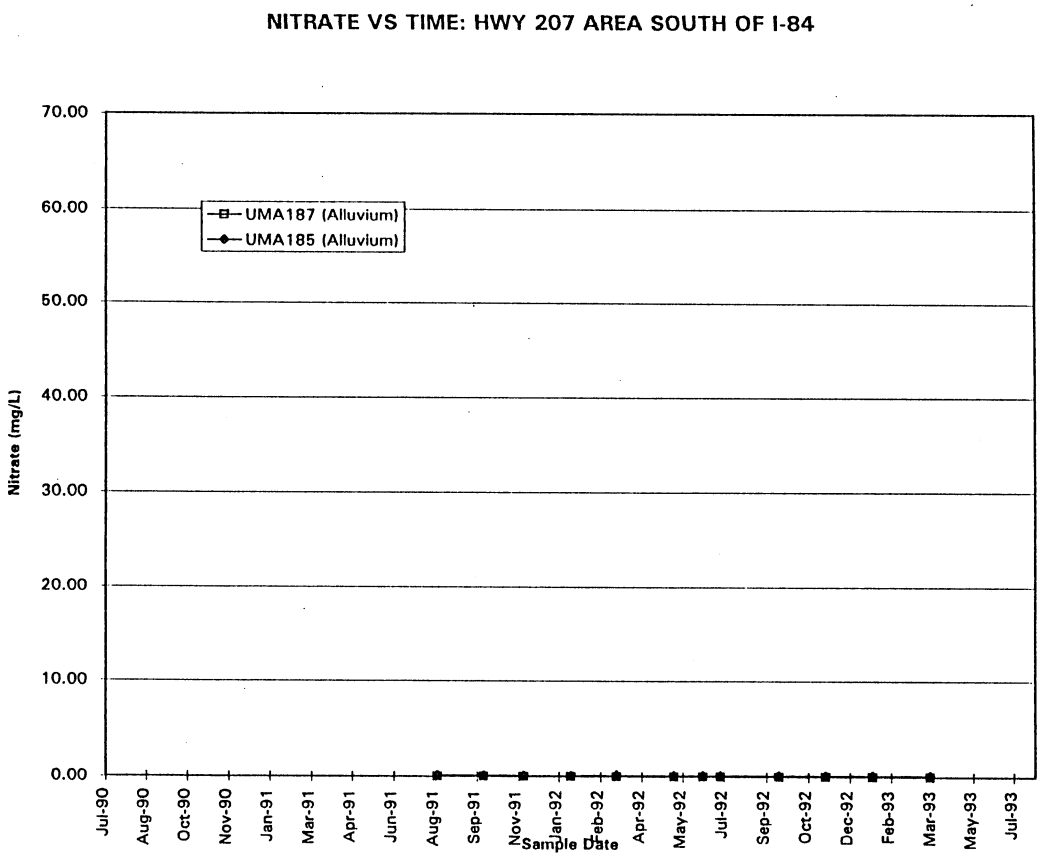


Figure 4.46 Nitrate+nitrite versus time in Butter Creek Highway area south of Interstate 84 alluvial groundwater at project bimonthly sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.25 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek Highway area south of Interstate 84.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 185 (Alluvial)	U		S	U	U	U	U	
UMA 187 (Alluvial)	U	U	U	U	U	U	U	

Note: The comparisons were qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

This project used nitrate-nitrogen and groundwater elevation versus time graphs to review Lamb-Weston and Simplot groundwater data for their land application sites south of Interstate 84. Data related to sites west of Highway 207 had a sampling period too short for useful analyses. The time period was sufficient for data related to the Simplot site east of Highway 207.

All the nitrate versus time graphs related to the Simplot east site show increasing concentrations for the sampling period represented (1989 to 1992). Nitrate concentrations and groundwater elevations generally fluctuate seasonally at sites within or downgradient of the land application area, which indicates seasonal influences. The nitrate fluctuations appear to lag 9 to 12 months behind the groundwater elevation fluctuations. This time lag appears related to the time required for nitrate to locally travel from land surface to regional alluvial groundwater.

Figure 4.47 shows nitrate+nitrite-nitrogen concentrations versus time in Butter Creek-Umatilla River confluence area regional alluvial groundwater sampled by this project. Table 4.26 presents how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site. Well UMA 122 is located south of the Umatilla River in the vicinity of crop agriculture, food processing wastewater land application, and a confined animal operation. Well UMA 058 is located at the Simplot food processing plant and wastewater land application site north of the Umatilla River. The nitrate data over time graphed somewhat similarly, and they compared somewhat similarly to other constituent versus time graphs. The similarities appear related to food processing water influences. The total phosphate and boron differences probably relates to additional influences in the UMA 122 vicinity.

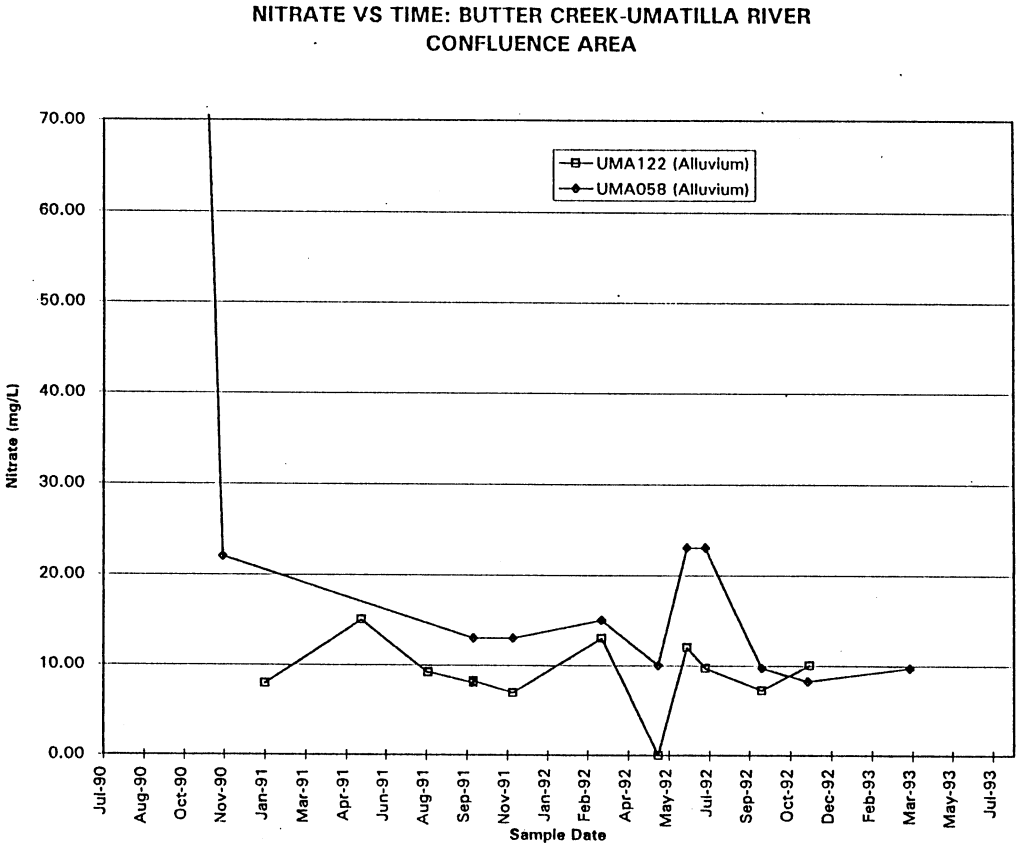


Figure 4.47 Nitrate+nitrite versus time in Butter Creek-Umatilla River confluence area alluvial groundwater at bimonthly sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.26 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek - Umatilla River confluence area.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 058 (Alluvial)	S	S	S	S	S	S	S	S
UMA 122 (Alluvial)	S	S	S	WS	S	S	I	I

Note: The comparisons were qualitative rather than quantitative

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

This project reviewed the J.R. Simplot Company nitrate-nitrogen and groundwater elevation data for the plant and land application site north of the Umatilla River and east of Highway 207. The data represents shallow unconfined and regional alluvial groundwater. The data reviewed varied indicating different influences affecting groundwater at each site. Three influences affecting the shallow unconfined groundwater are presented here.

Figure 4.48 shows nitrate-nitrogen and groundwater elevation versus time at UMA 261 (Simplot MW-11S). The site is located adjacent to a land application circle on the terrace north of the Umatilla River. The data show similar seasonal fluctuations with an approximately 8 month time lag for the nitrate fluctuations. This indicates the time required for nitrate to locally travel from land surface to the shallow unconfined groundwater.

Figure 4.49 shows nitrate-nitrogen versus time at UMA 250 (Simplot MW-12). The graph illustrates how local groundwater nitrate concentrations can respond when water and nitrate loading is controlled. Well UMA 250 is located near a wastewater pond. Nitrate concentrations rising above the top of the graph correspond to a period when the pond was unlined. Lining the pond to control seepage caused the nitrate concentrations to decline rapidly.

Figure 4.50 shows nitrate-nitrogen versus time at UMA 248 (Simplot MW-17) located in the Simplot land application area within Umatilla River flood plain. The generally low concentrations over time probably reflect a Umatilla River influence. The isolated concentration peak was detected by sampling that occurred two weeks after a Umatilla River flood event (EMCON Northwest, Inc., 1992). The nitrate peak occurrence suggests a reservoir of nitrate may have been in the soil, and it was mobilized when the flood provided sufficient moisture.

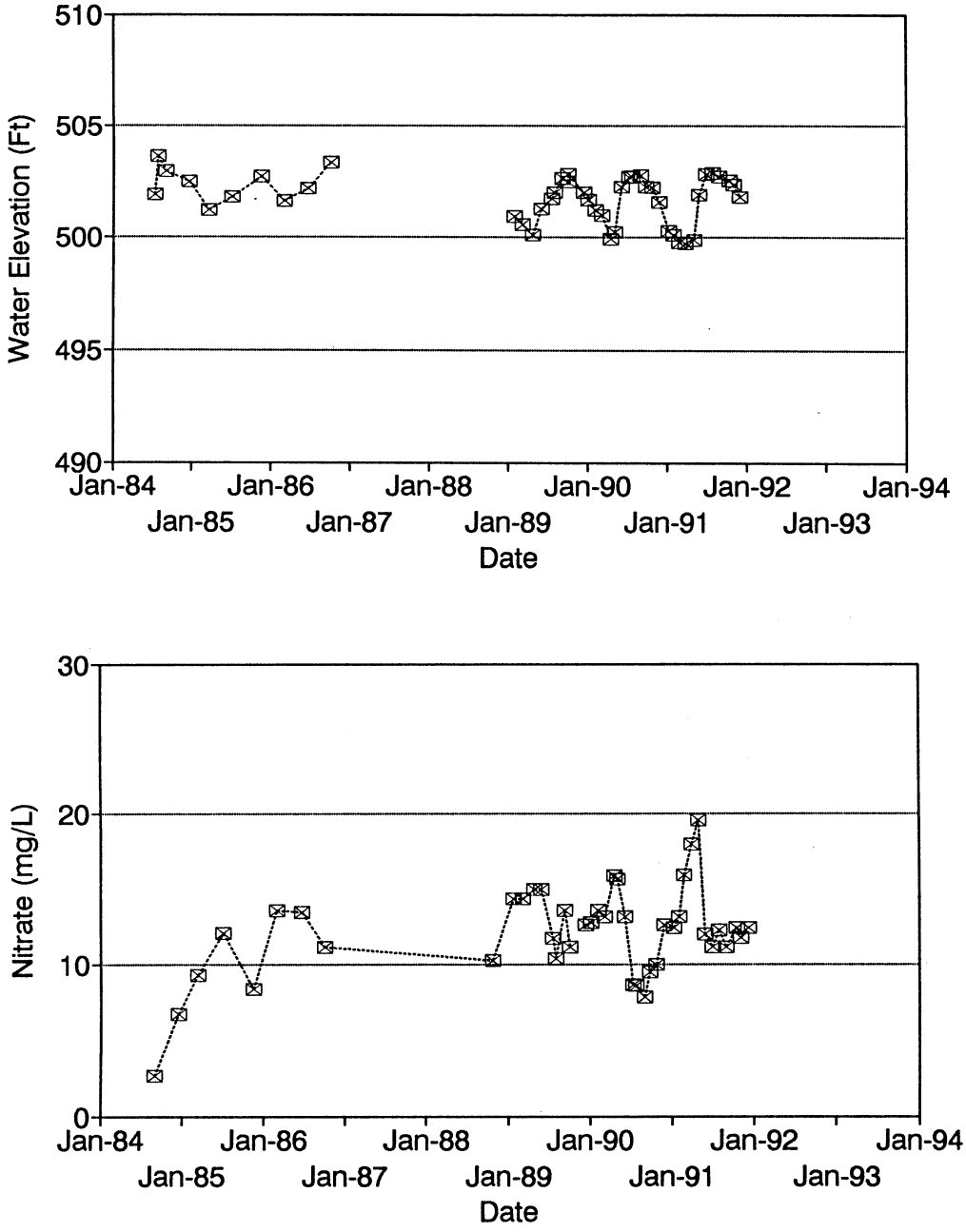


Figure 4.48 Nitrate-nitrogen and groundwater elevation versus time for shallow unconfined alluvial groundwater at UMA 261 (LUB 042, Simplot MW-11S).

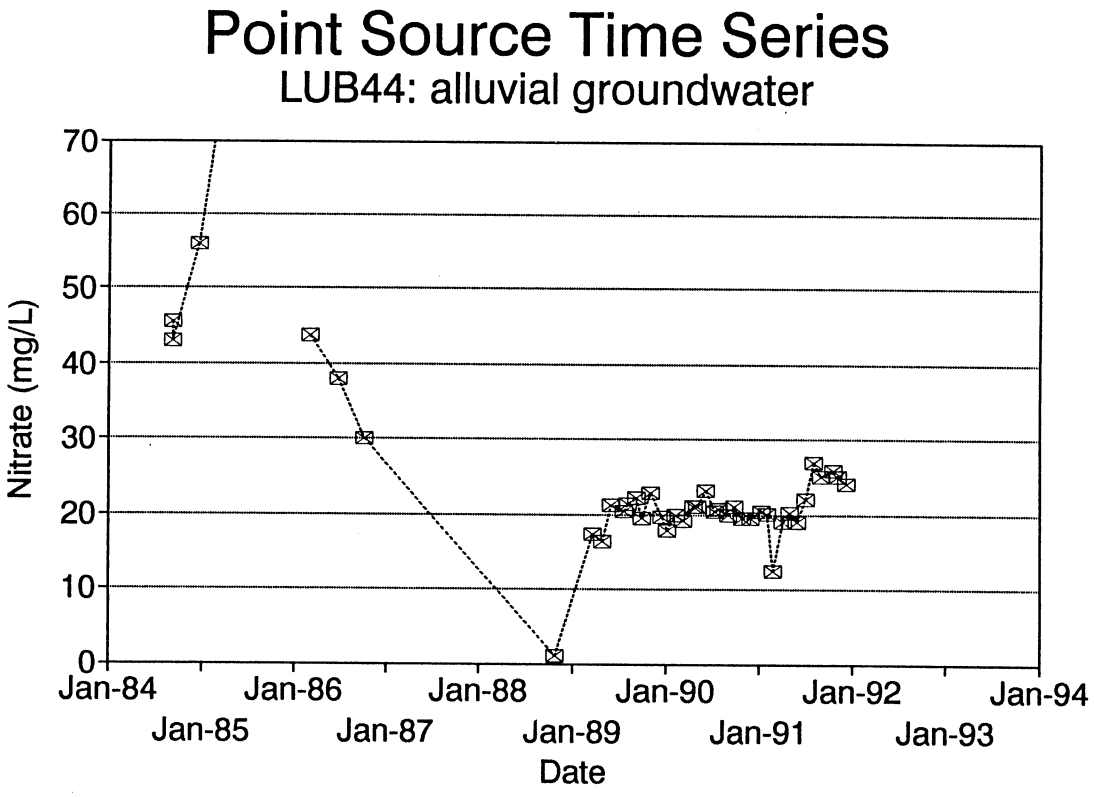


Figure 4.49 Nitrate-nitrogen versus time for shallow unconfined alluvial groundwater at UMA 250 (LUB 044, Simplot MW-12).

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

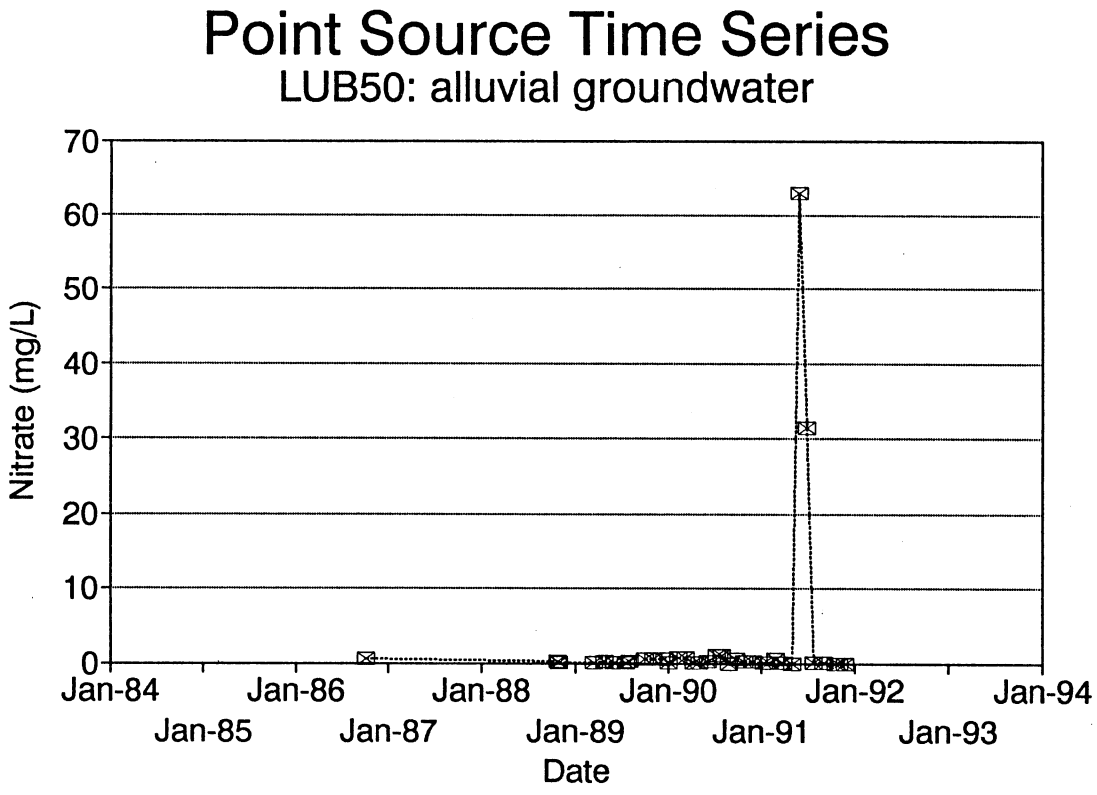


Figure 4.50 Nitrate-nitrogen versus time for shallow unconfined alluvial groundwater at UMA 248 (LUB 050, Simplot MW-17).

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Figure 4.51 shows nitrate+nitrite nitrogen concentrations versus time in alluvial groundwater sampled north of Interstate 84 and east of the Umatilla River by this project. Table 4.27 shows how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site. UMA 084 and UMA 119 data show some similarities but differ from UMA 077.

Similar land use influences would account for the similarities between UMA 084 and UMA 119. Well UMA 084 is located within a rural residential area, less than 0.3 miles from C&B Livestock, and less than 300 feet from A Line Canal. Well UMA 119 is located among irrigated fields and downgradient of Maxwell Canal, A Line Canal, rural residential homes and C&B Livestock. C&B Livestock appears to influence groundwater at both sites with irrigated crop agriculture an additional influence at UMA 119. Different influences appear to occur at UMA 077. The site is located in west Hermiston where alluvial groundwater with low nitrate concentrations discharges from the Hermiston basin toward the Umatilla River.

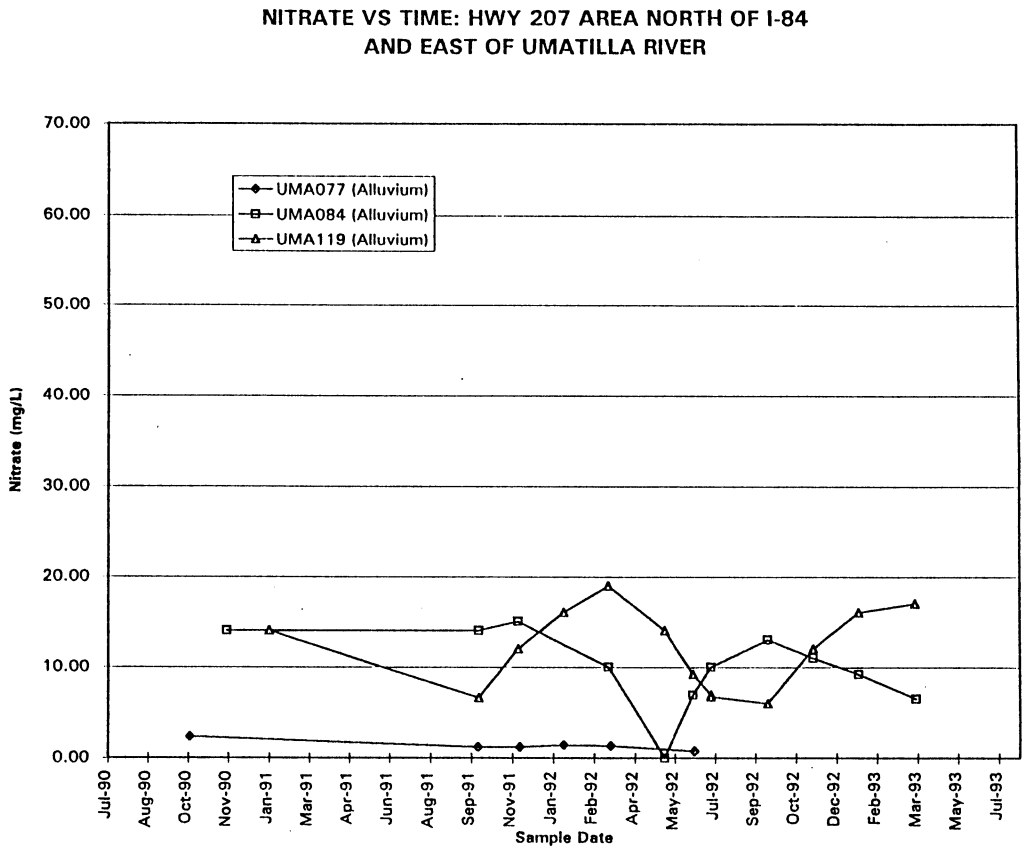


Figure 4.51 Nitrate+nitrite versus time in Butter Creek Highway north of Interstate 84 and east of the Umatilla River area alluvial groundwater at project bimonthly sampling sites.

Note: 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.27 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek Highway area north of Interstate 84 and east of the Umatilla River.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 077 (Alluvial)	WS	S	WS	WS	S	S	I?	U
UMA 084 (Alluvial)	WS	I	S	WS	I	S	WS and I	NS
UMA 119 (Alluvial)	S	S	S	S	S	S	I	S and I

Note: The comparisons were qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

Figure 4.52 shows nitrate+nitrite nitrogen concentrations versus time in alluvial groundwater sampled north of Interstate 84 and west of the Umatilla River by this project. Table 4.28 shows how each nitrate versus time graph compared to other constituent versus time graphs for each sampling site. Figure 4.52 and Table 4.28 show some similarity and differences between the sites.

Well UMA 198 is located within the Lamb-Weston wastewater land application area next to the U.S. Army Depot. Food processing wastewater is identified as the nitrate source in that area. The UMA 198 data shows some seasonal influence which is consistent with land application activity.

Wells UMA 094 and UMA 088 are located downgradient among rural residential homes and irrigated crop agriculture. Constituent versus constituent graphical analyses (Appendix 4H) and a nitrate concentration distribution comparison to local land uses indicates septic systems and/or irrigated crop agriculture influences groundwater at these sites. The UMA 094 and UMA 088 nitrate versus time graphs may be considered consistent with a septic system influence.

The comparison of UMA 088 nitrate versus time graph to other constituent versus time graphs differs from the UMA 094 and UMA 198 graphical comparisons (Table 4.28). This may relate to a possible Umatilla River influence. Well UMA 088 is located close to the river within a meander loop.

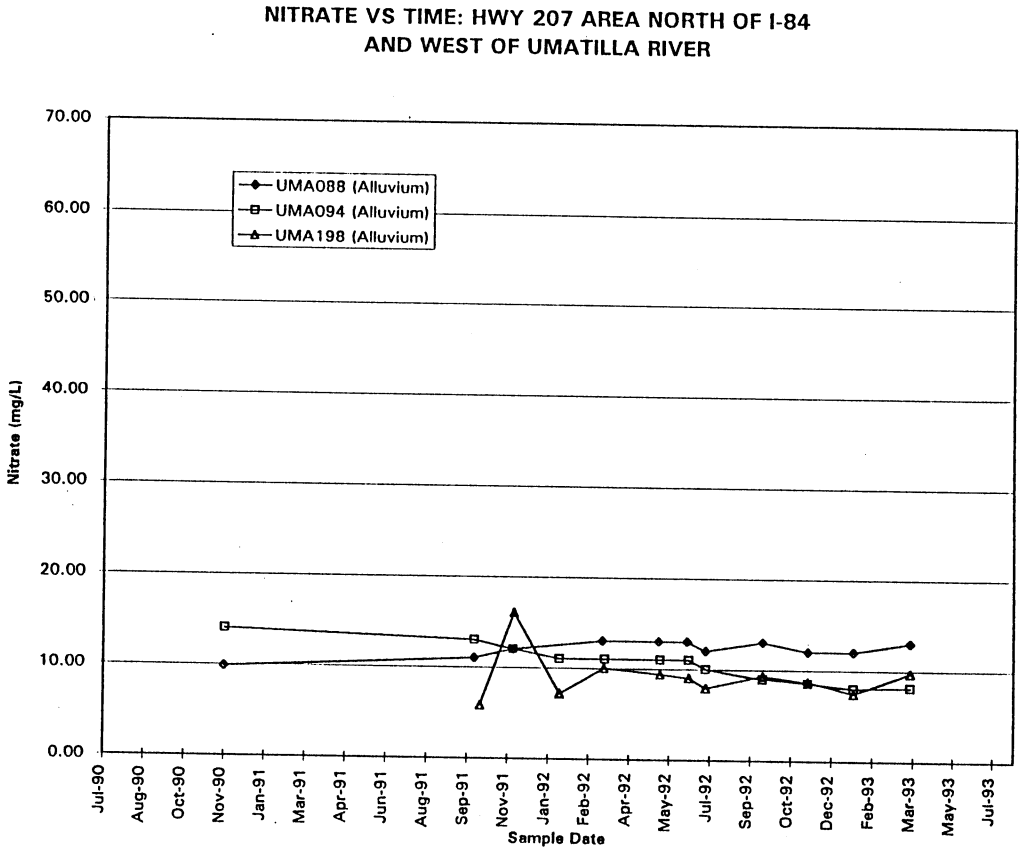


Figure 4.52 Nitrate+nitrite versus time in Butter Creek Highway north of Interstate 84 and west of the Umatilla River area alluvial groundwater at project bimonthly groundwater sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.28 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Butter Creek Highway area north of Interstate 84 and west of the Umatilla River.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 088 (Alluvial)	S	S	NS	S and I	S and I	S and I	S and I	U
UMA 094 (Alluvial)	S	S	S	S	S	S	I	NS
UMA 198 (Alluvial)	S	S	S	S	S	S	I	

Note: The comparisons were qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

This project reviewed Lamb-Weston, Incorporated alluvial groundwater data for the land application site adjacent to the U.S. Army Umatilla Depot Activity using nitrate-nitrogen and groundwater elevation versus time graphs. The nitrate-nitrogen versus time graphs generally show seasonal fluctuations. Some of those graphs correlate with a time lag to the groundwater elevation versus time graphs. Time lags ranging from less than 1 month to possibly 18 months were observed between unique groundwater elevation and nitrate concentration peaks. This time lag appears related to the time required for nitrate to travel to groundwater.

Figure 4.53 shows nitrate+nitrite-nitrogen concentrations versus time in City of Umatilla area alluvial groundwater sampled by this project. Table 4.29 presents how the nitrate versus time graph compared to the other constituent versus time graphs. The site is located in an unsewered residential and small agriculture area adjacent to the city. Constituent versus constituent graphical analysis (Appendix 4H) indicates a mixed septic system and animal waste influence. Animal activity does occur south of the city.

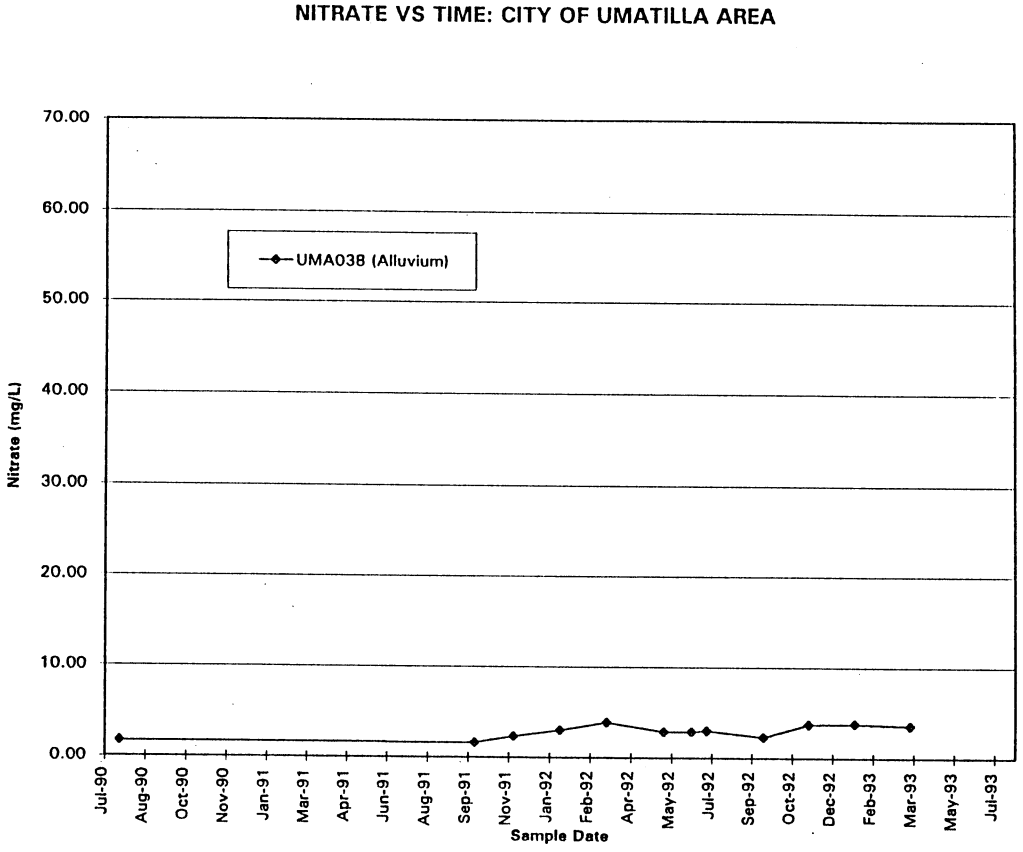


Figure 4.53 Nitrate+nitrite-nitrogen versus time in City of Umatilla area alluvial groundwater at the project bimonthly groundwater sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.29 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Umatilla area.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 038 (Alluvial)	WS	S	WS	S	WS	WS	I	NS

Note: The comparisons were qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams.

Project bimonthly and synoptic groundwater sampling data related to the Butter Creek to the City of Umatilla area were plotted on Piper trilinear graphs and Schoeller diagrams. Both graphs proved useful for observing data variations or lack of variation. Variation characterized most of the data graphed. The trilinear graphs proved useful for classifying the groundwater chemistry and observing mixing relationships. Table 4.30 shows the groundwater chemistry classification observed by location and groundwater source.

Table 4.30 Observed Piper Trilinear water chemistry classification of alluvial and basalt groundwater sampled from the Butter Creek to Umatilla area.

Area	Groundwater Source	Groundwater Chemistries Observed
Butter Creek Highway Area: South (south of Interstate 84 and west of Highway 207) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Butter Creek Highway Area: South (south of Interstate 84 and west of Highway 207) (Project Sampling)	Alluvial (Shallow Unconfined)	mixed-cation/bicarbonate
Butter Creek Highway Area: South (south of Interstate 84 and east of Highway 207) (Project Sampling)	Alluvial	calcium/mixed-anion no dominant type
Butter Creek - Umatilla River Confluence Area (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Butter Creek - Umatilla River Confluence Area (Project Sampling)	Alluvial (Shallow Unconfined)	mixed-cation/bicarbonate
Butter Creek Highway Area: North (north of Interstate 84 and east of Umatilla River) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate sodium + potassium/bicarbonate
Butter Creek Highway Area: North (north of Interstate 84 and west of Umatilla River) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Lamb-Weston, Inc. Land Application Area (adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial	mixed-cation/bicarbonate sodium + potassium/bicarbonate
Lamb-Weston, Inc. Land Application Area (Adjacent to U.S. Army Depot's northeast corner) (Project Sampling)	Alluvial (Shallow Unconfined)	mixed-cation/bicarbonate
City of Umatilla Area (Project Sampling)	Alluvial	mixed-cation/bicarbonate
Note: Project bimonthly and synoptic groundwater sampling data was used for the groundwater chemistry classifications		

Nitrate concentration variation or lack of variation over time correlates to water chemistry variation or lack of variation observed on the trilinear graphs and Schoeller diagrams. Nitrate and other constituents in regional alluvial groundwater at sites sampled in the southern portion of the Butter Creek area varied little over time as illustrated by UMA 187 data (Figures 4.54 and 4.55) Corresponding nitrate+nitrite-nitrogen concentrations range from non-detect to 0.02 mg/L. Most of the other data graphed varies over time. Figures 4.56 and 4.57 show variation over time related to alluvial groundwater at UMA 122 within the Butter Creek-Umatilla River confluence area as an example. The data is distributed along a mixing line on the trilinear graph. Corresponding nitrate concentrations range from 6.90 to 20 mg/L. The higher nitrate concentrations correlate with higher chloride and sulfate proportions on the trilinear graph.

Note in figure 4.56 that relative proportions of the major cations show little variation, while the anions, specifically the bicarbonate to chloride ration varies significantly. The Schoeller diagram (Figure 4.57) indicates a relative constant value for bicarbonate. Consequently, the bulk of the variations observed for UMA 122 in the trilinear diagram reflect variations in chloride, and to a lesser extent, sulfate concentrations.

Nearly all the Butter Creek to City of Umatilla area data vary by location. Figures 4.58, 4.59, and 4.60 show the variation in the Butter Creek Highway area north of Interstate 84 and west of the Umatilla River as an example. Analysis identified three mixing lines on the trilinear graph that correspond to three different conditions. Two mixing lines correspond to shallow unconfined (UMA 237 and UMA 238) and regional (UMA 198, 234, 235, 236, and 243) alluvial groundwater at the Lamb-Weston land application site next to the U.S. Army Depot. The third mixing line (UMA 063, 078, 088, 092, 094, 136, 181, and 207) corresponds to alluvial groundwater further downgradient primarily within a mixed irrigated crop agriculture and rural residential home area. The mixing line end members were not identified. However, higher chloride proportions correspond to higher nitrate concentrations for all three mixing lines. Higher calcium proportions correspond to higher nitrate concentrations also. However, the calcium proportions vary more in groundwater from the food processing land application area than from the downgradient area. This was observed in graphs of the Butter Creek-Umatilla River confluence area data also.

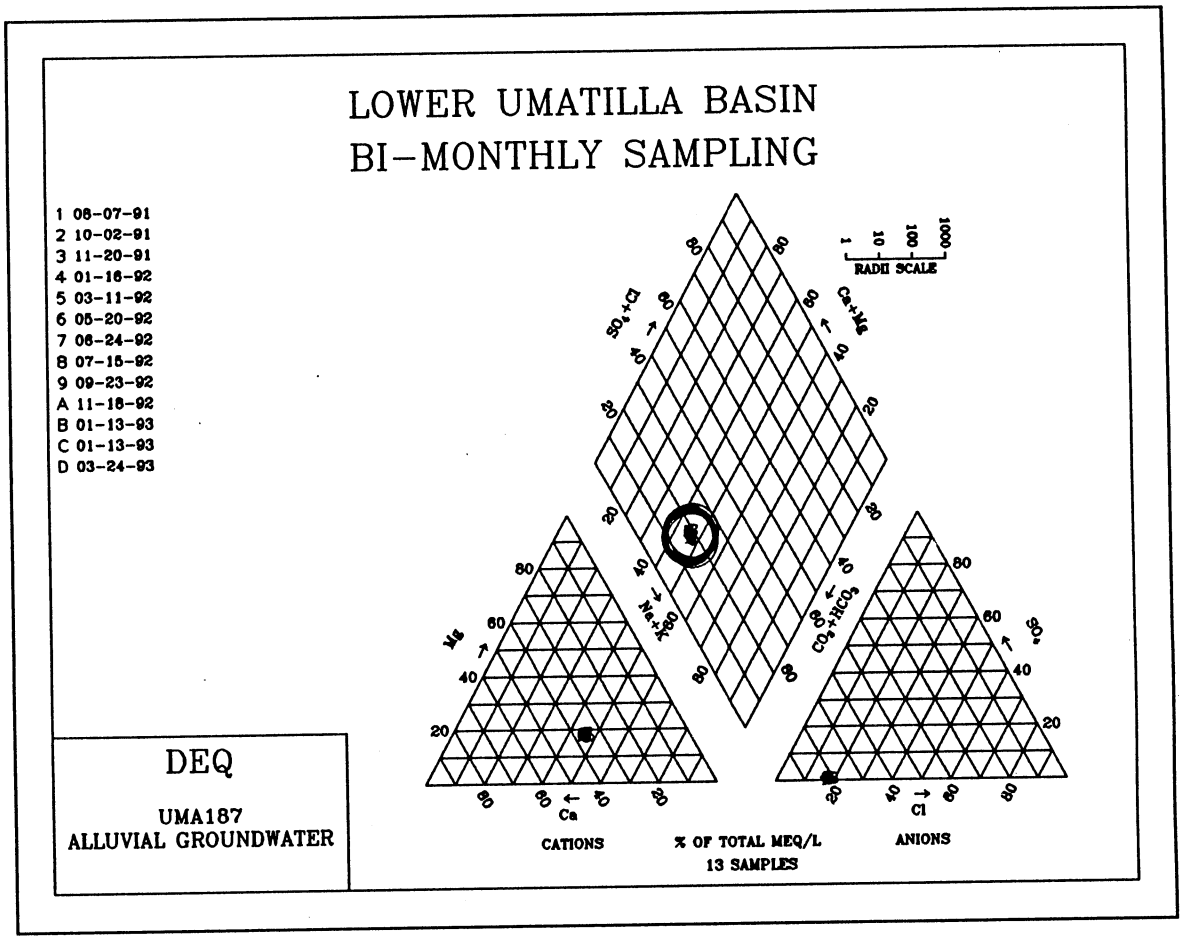


Figure 4.54 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 187 in the Butter Creek Highway area south of Interstate 84.

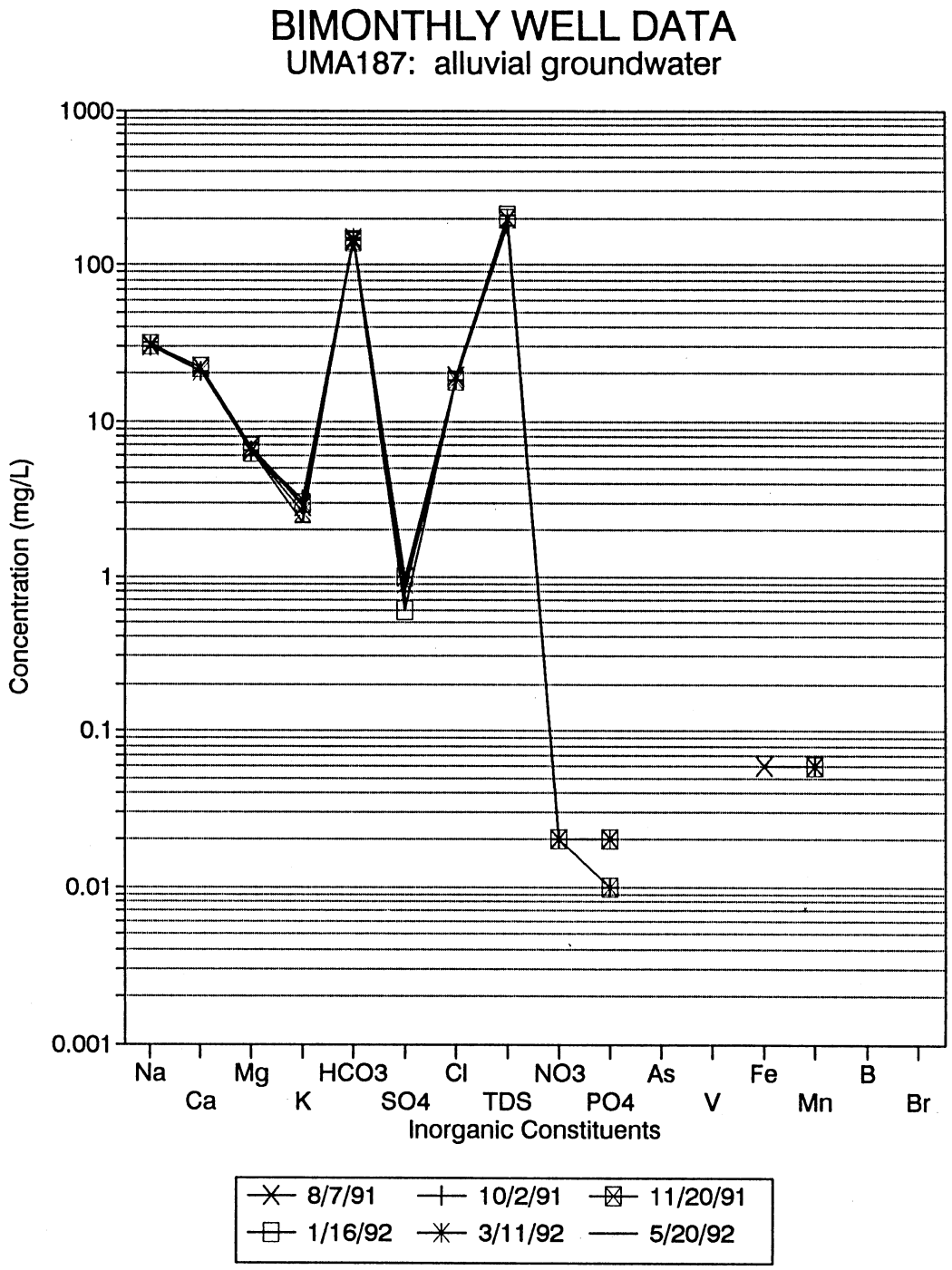


Figure 4.55 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 187 in the Butter Creek Highway area south of Interstate 84.

Note: The variation is small.

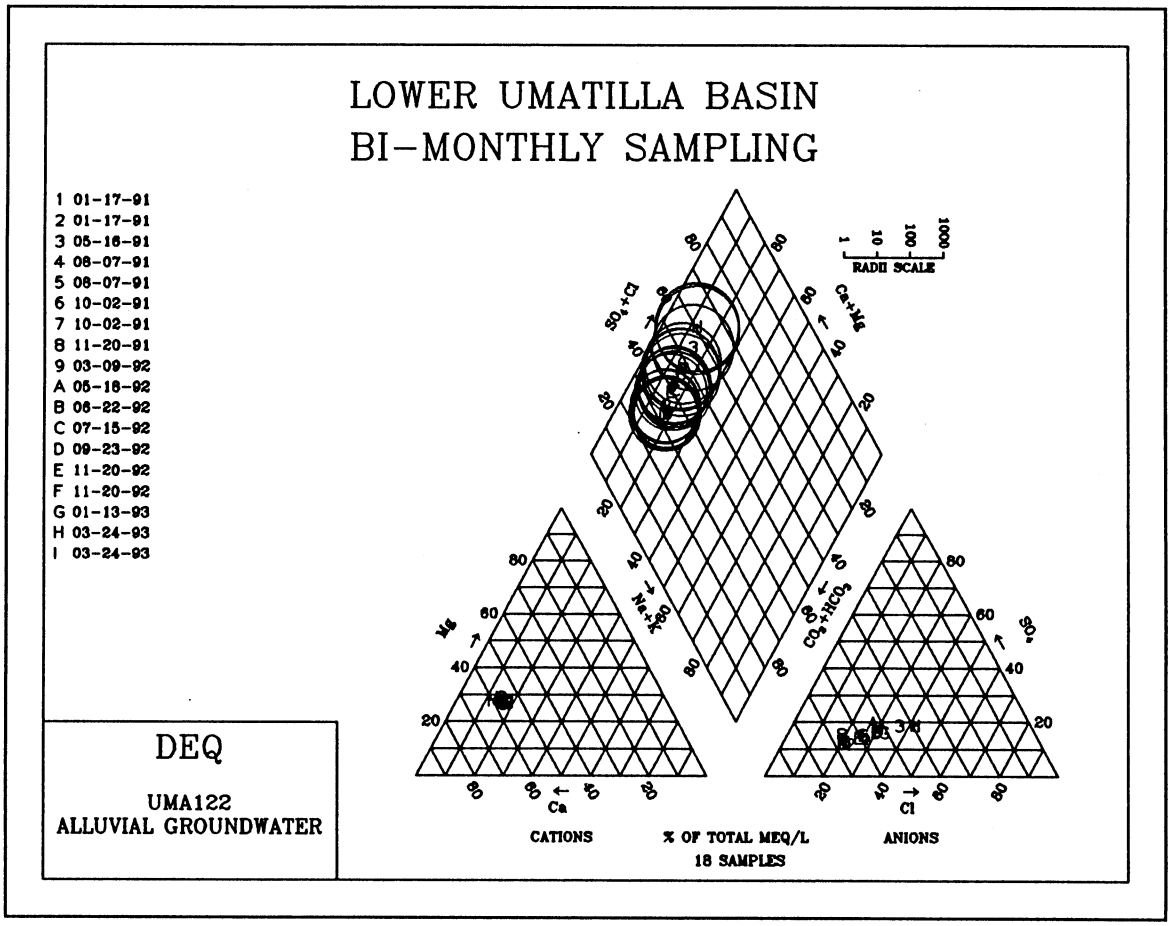


Figure 4.56 Piper Trilinear Graph of project bimonthly sampling data for alluvial groundwater collected at UMA 122 in the Butter Creek-Umatilla River confluence area.

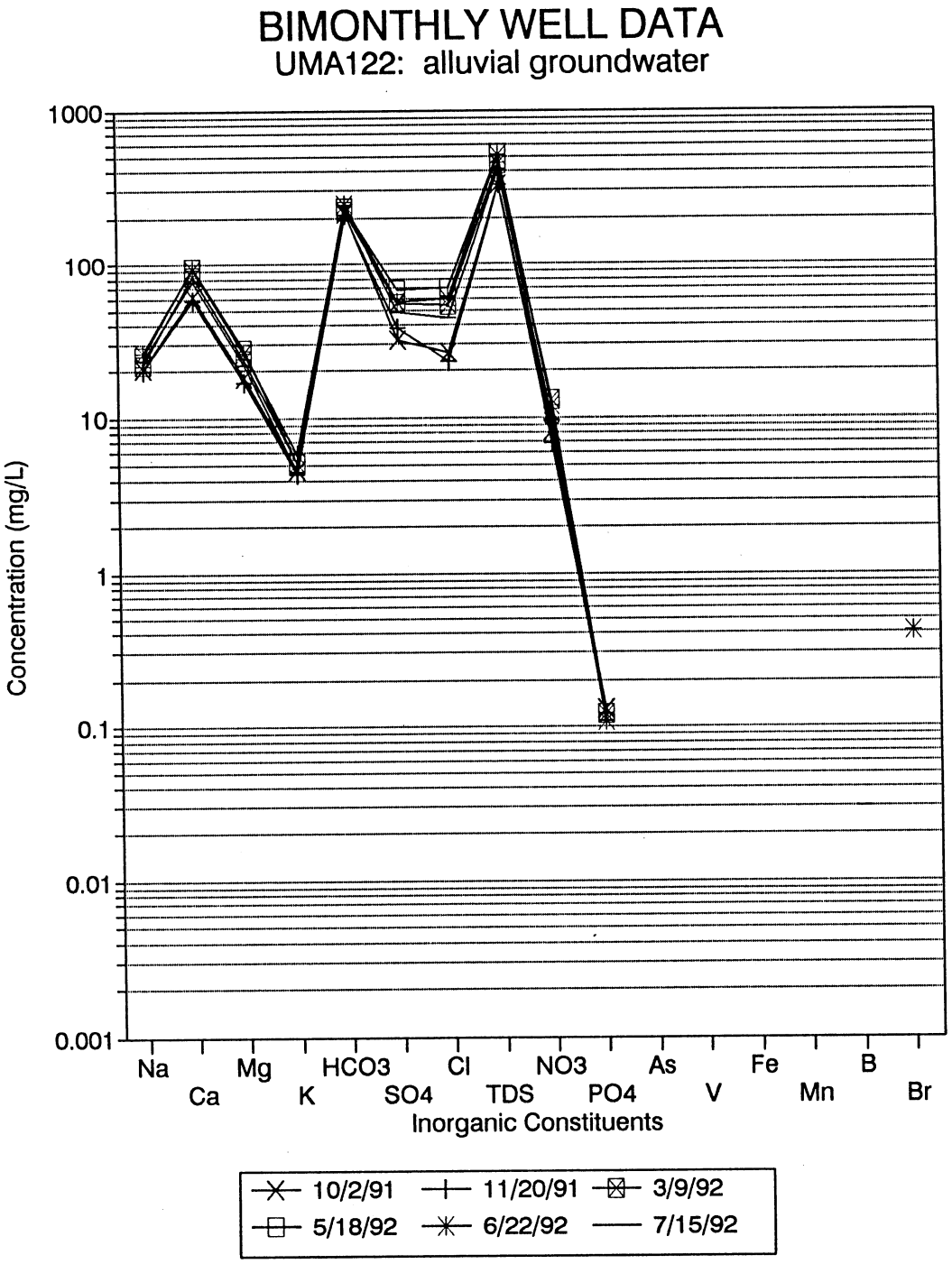


Figure 4.57 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 122 in the Butter Creek-Umatilla River confluence area.

Note: The variation is larger.

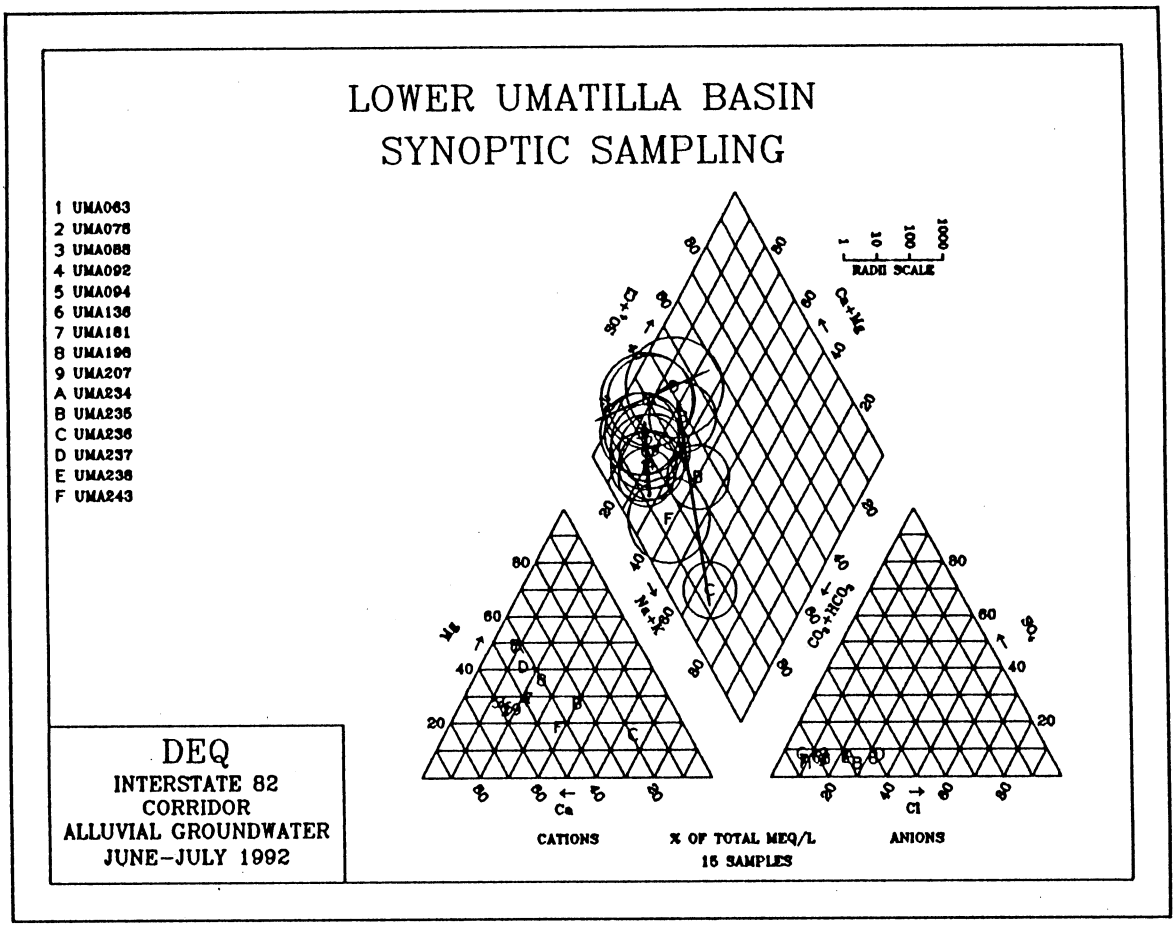


Figure 4.58 Piper Trilinear Graph of project synoptic sampling data for alluvial groundwater collected in the Butter Creek Highway area north of Interstate 84 and west of the Umatilla River, including the Lamb-Weston food processing wastewater land application area.

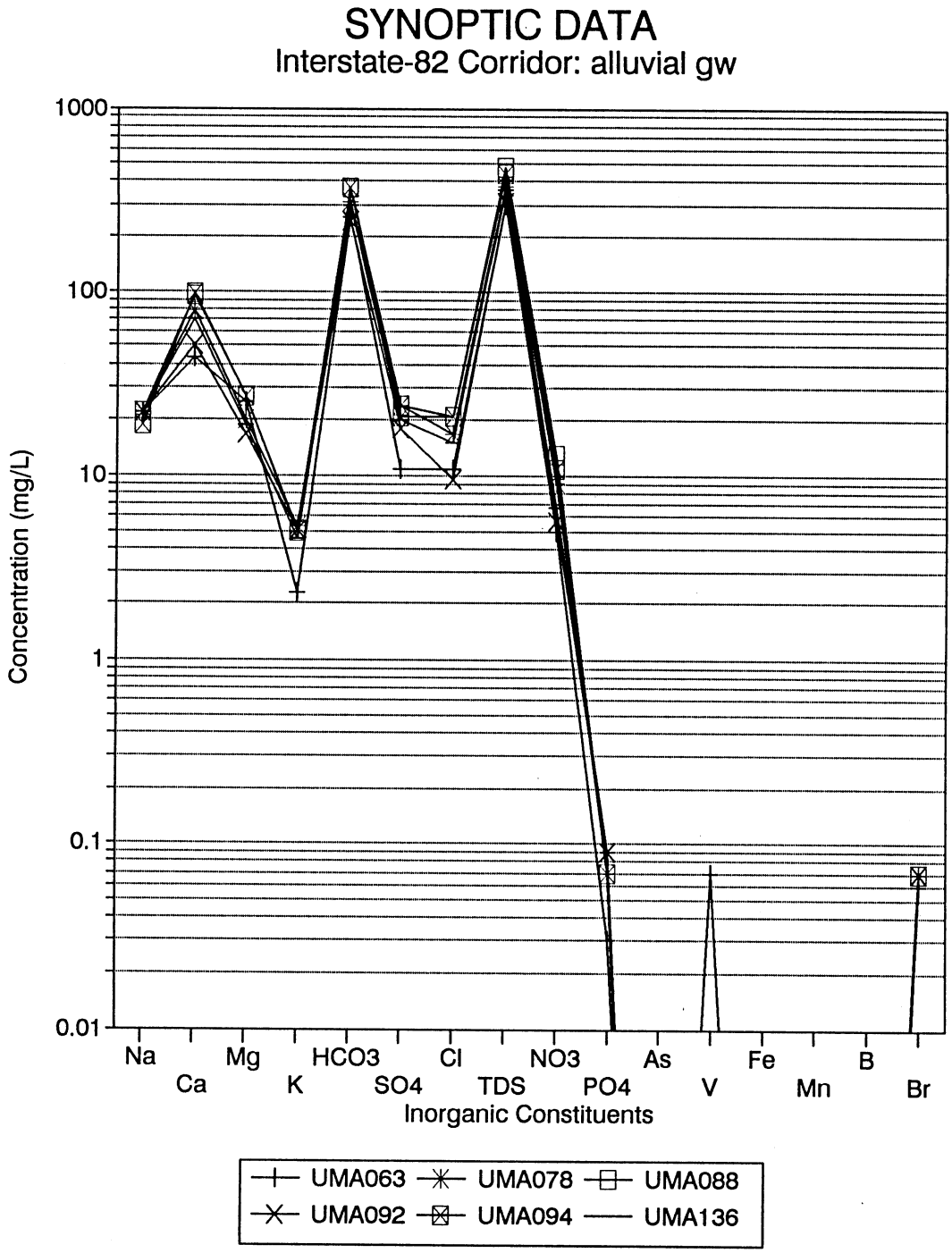


Figure 4.59 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the Butter Creek Highway area north of Interstate 84 and west of the Umatilla River area.

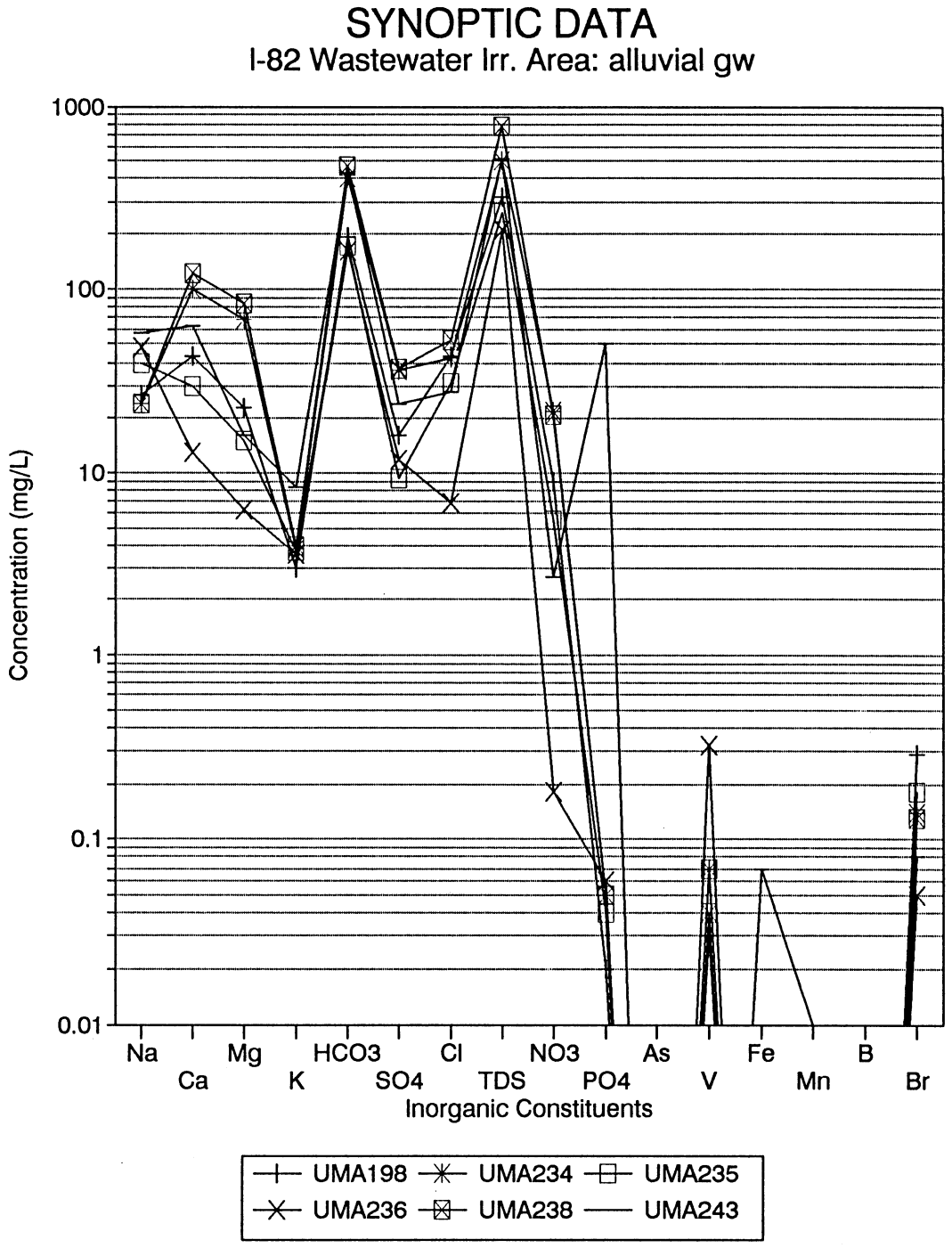


Figure 4.60 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the Lamb-Weston food processing wastewater land application area.

Graphical Analyses: Constituent Versus Constituent

Constituent versus constituent graphs were used to distinguish nitrate sources. The analysis primarily used project synoptic sampling data. Graphs reviewed included chloride versus potassium, bromide versus potassium, and chloride/bromide versus chloride. The analyses indicate a variety of land uses influence the groundwater chemistry in the Butter Creek to the City of Umatilla area (see Appendix 4H). Noteworthy results include the following:

- Irrigation by crop agriculture and/or by the food processing industry primarily influenced the groundwater chemistry in samples collected in the Butter Creek Highway area south of Interstate 84. Septic systems appear to be a possible secondary and local influence at some sites.

- The groundwater chemistry in the Butter Creek-Umatilla River confluence area reflects mixed influences. Irrigation by crop agriculture and/or by the food processing industry influences the groundwater chemistry in many samples. Animal waste and septic systems also appear to influence the groundwater chemistry at several sites.

- Animal waste appears to influence the groundwater chemistry in samples collected downgradient of C&B Livestock. The influence of irrigation and septic systems appears to increase further north.

- Septic systems appear to be an important influence upon the groundwater chemistry in the area north of Interstate 84 and west of the Umatilla River. However, irrigation by crop agriculture and/or the food processing industry appears the dominant influence at UMA 063.

- Food processing wastewater irrigation is the dominant influence upon groundwater at the Lamb-Weston wastewater land application area next to the U.S. Army Umatilla Depot Activity.

- Septic and animal waste influence alluvial groundwater in an unsewered area adjacent to the City of Umatilla. Animal activity occurs south of Umatilla.

Groundwater Flow Path Analysis

Project flow path analyses focused primarily upon the Butter Creek-Umatilla River drainage due to the complexity of the hydrogeolgy and land uses in the area. Some of the results apply to other areas in the Lower Umatilla Basin. The flow path analyzed extends from UMA 185 to UMA 077. A thorough discussion of the analysis is presented separately in a following section (Evaluating Chemical Trends with Flow Path Analysis: Butter Creek Example). The analysis found:

- Several influences affect the groundwater chemistry. Not all of the influences contribute nitrate.

- Nitrate and other constituent concentrations in alluvial groundwater peak in the Butter Creek-Umatilla River confluence area.

- The concentration peak fluctuates seasonally.

- The concentration peak appears not to move downgradient. That indicates a local influence(s) causes the peak.

Groundwater Chemistry Computer Modeling

This project used the NETPATH groundwater chemistry model to evaluate the influences responsible for a concentration peak in alluvial groundwater identified by flow path analysis. A thorough discussion of the analysis is presented separately in the following "Evaluating Chemical Trends with Flow Path Analysis: Butter Creek Example" section. The analysis found:

- Water mineral interactions contribute minor changes to the groundwater chemistry.

- Shallow unconfined alluvial groundwater in the Butter Creek-Umatilla River confluence area does impact the deeper regional alluvial groundwater.

- Infiltrating food processing wastewater is responsible for the nitrate peak in the alluvial groundwater in the Butter Creek-Umatilla River confluence vicinity.

- Cyclic evaporation-dissolution in the soil and unsaturated zone is an additional and important influence upon the groundwater chemistry.

- Significant mixing between Umatilla River water and groundwater appears to occur north of Interstate 84 and east of the Umatilla River. This mixing appears responsible for lower constituent concentrations detected downgradient of a concentration peak. The river water may come directly from river leakage or from canals conveying Umatilla River water.

Nitrogen Isotopic Analyses

Nitrogen isotopic laboratory analyses included a sample from shallow unconfined alluvial groundwater from UMA 258 within the Simplot plant site land application area. Isotopic data analysis indicates an organic waste influence.

Butter Creek to City of Umatilla Area Summary and Conclusions

This investigation used a variety of techniques to analyze the Butter Creek to City of Umatilla area groundwater chemistry data, which came from project sampling and local facilities. The data analyses led project investigators to the following observations and interpretations:

- Nitrate+nitrite-nitrogen concentrations detected in local project or facility groundwater samples ranged from non-detect to 74 mg/L in regional alluvial groundwater and non-detect to 100 mg/L in shallow unconfined alluvial groundwater.

- The time required for nitrate to locally travel from land surface to groundwater appears to vary from less than 1 month to 18 months which probably relates to available water.

- Food processing wastewater appears responsible for elevated nitrate concentrations detected in groundwater at established wastewater land application areas.

- Food processing wastewater appears primarily responsible for a stationary nitrate concentration peak in the Butter Creek-Umatilla River confluence vicinity.

- C&B Livestock appears responsible for elevated nitrate concentrations in alluvial groundwater sampled at nearby sites downgradient of the facility.

- Dacthal acid was detected in an alluvial groundwater sample collected at UMA 119 located northwest of C&B Livestock. That detection indicates an irrigated crop agriculture influence.

- Septic systems appear to be an important influence upon groundwater west of the Umatilla River and north of Interstate 84.

- Water-mineral interactions contribute minor changes to the groundwater chemistry in the area.

- Cyclic evaporation-dissolution in the soil and vadose (unsaturated) zone is an important influence upon the groundwater constituent chemistry.

- Significant mixing between Umatilla River water and groundwater appears to occur north of Interstate 84 and east of the Umatilla River.

- Total dissolved solids (TDS) concentrations greater than the 500 mg/L secondary (aesthetic) drinking water standard generally occurred east of Highway 207 and south of Minnehaha Road.

- The distribution of some lower TDS concentration areas suggest dilution from canal and/or surface water leakage.

- Arsenic greater than the 0.050 mg/L drinking water standard occurred in a sample collected from a site within the Lamb-Weston wastewater land application area next to the U.S. Army Depot.

- Sodium in area groundwater commonly exceeds the 20 mg/L limit recommended for persons on a physician-prescribed sodium restricted diet.

- The distribution of total phosphate concentrations in area groundwater is nearly divided. Lower concentrations were generally found in groundwater sampled north of Interstate 84 and west of the Umatilla River. Higher concentrations were generally found in samples collected along or near Highway 207, south of Hermiston.

City of Umatilla to Hat Rock to Echo Meadows Area

The City of Umatilla to Hat Rock to Echo Meadows Area includes the eastern half of Range 28 East, all of Range 29 East, and Townships 3, 4, and 5 North. Historic and current land uses in the area include:

- Cities of Umatilla, Hermiston, Stanfield, and Echo;
- Umatilla, Hermiston, Stanfield, and Echo sewage treatment facilities and land applications areas;
- Unsewered residential homes;
- Food processing plants, wastewater ponds, and land application sites;
- Animal operations;
- Irrigated agriculture.

Groundwater flow in the area varies. Alluvial groundwater in the Hermiston area generally flows west to southwest where it exits toward the Umatilla River through gaps between basalt buttes. Alluvial groundwater in the terrace between Hermiston and Stanfield generally divides and flows north to northwest toward Hermiston or south to southwest toward Umatilla and Echo Meadows. Alluvial groundwater in Umatilla and Echo Meadows area generally flows northwest where it exits through a basalt gap at the Butter Creek-Umatilla River confluence.

This section presents data analyses. The analyses relied primarily upon project reconnaissance, bimonthly and synoptic sampling data. The Hermiston Foods, Incorporated and A.E. Staley Manufacturing Company data obtained by this project was limited.

Map and Data Set Observations: Nitrate

Table 4.31 and Plates 4.2 and 4.3 show the nitrate+nitrite-nitrogen concentration range and distribution in the City of Umatilla to Hat Rock to Echo Meadows area. Table 4.31 shows local concentration ranges detected by this project or reported by local facilities. Plate 4.3 shows the distribution of maximum concentrations this project detected in alluvial and basalt groundwater samples. Plate 4.2 shows the June-July 1992 concentration distribution in regional alluvial groundwater based upon synoptic sampling. Nitrate+nitrite-nitrogen concentrations detected in shallow unconfined alluvial groundwater samples and basalt groundwater samples are printed next to each sampling location.

The shape and extent of each concentration range contoured on Plate 4.2 was derived by linear interpolation between data locations. Data control was sparse in the southern portions of the terrace between Hermiston and Stanfield. This needs to be considered to avoid misinterpreting the source and movement of nitrate in that area.

Table 4.31 Nitrate concentration ranges detected in alluvial and basalt groundwater sampled from different locations in the City of Umatilla to Hat Rock to Echo Meadows area.

Area	Groundwater Source	Dominant Land Uses (Historic and Current)	Nitrate-N (mg/L)	
			Maximum	Minimum
City of Umatilla Area (Project Sampling)	Alluvial	municipal sewage treatment facility	4.20	1.70
Hat Rock Area (Project Sampling)	Alluvial	irrigated crop agriculture rural residential	6.90	4.80
Hermiston Area: North Terrace (north of Punkin Center Road) (Project Sampling)	Alluvial	animal operations rural residential irrigated crop agriculture	9.90	<0.02
Hermiston Area: North Terrace (north of Punkin Center Road) (Project Sampling)	Uncertain	animal operations rural residential irrigated crop agriculture	31.00	0.72
Hermiston Area: Basin (south of Punkin Center Road) (Project Sampling)	Alluvial	municipal sewage treatment facility unsewered residential (high density)	3.80	<0.02
Hermiston Area: Basin (south of Punkin Center Road) (Project Sampling)	Uncertain	municipal sewage treatment facility unsewered residential (high density)	4.00	<0.02
Hermiston Area: General (Project Sampling)	Basalt	municipal with sewage treatment facility rural residential crop agriculture and animal operations	1.50	0.02
Stanfield-Hermiston Corridor (Highway 395) (Project sampling)	Alluvial (shallow and deep)	irrigated crop agriculture food processing wastewater land application	12.00	<0.02
Stanfield-Hermiston Corridor (Highway 395) (Hermiston Foods, Inc. Sampling)	Alluvial	food processing wastewater land application formerly irrigated crop agriculture	9.00	4.5

Stanfield-Hermiston Loop Road: North (Project Sampling)	Alluvial	irrigated crop agriculture rural residential	19.00	0.47
Stanfield-Hermiston Loop Road: North (Project sampling)	Basalt (shallow)	irrigated crop agriculture rural residential	29.00	17.00
Stanfield-Hermiston Loop Road: North (Project Sampling)	Uncertain	irrigated crop agriculture rural residential	20.00	4.30
Stanfield-Hermiston Loop Road: South (Project Sampling)	Alluvial	municipal with sewage treatment facility irrigated crop agriculture rural residential	7.30	1.20
Echo and Umatilla Meadows Area (Project Sampling)	Alluvial	municipal with sewage treatment facilities irrigated crop agriculture rural residential	8.60	0.44
Echo and Umatilla Meadows Area (A.E. Staley Manufacturing Company Sampling)	Alluvial	wastewater land application Stanfield sewage treatment facility	6.50	<0.50
Echo and Umatilla Meadows Area (Project sampling)	Alluvial (Shallow Unconfined)	wastewater land application Stanfield sewage treatment facility	4.50	0.60
Echo and Umatilla Meadows Area (A.E. Staley Manufacturing Company Sampling)	Alluvial (Shallow Unconfined)	wastewater land application Stanfield sewage treatment facility	10.00	<0.50
Echo and Umatilla Meadows Area (Project Sampling)	Basalt (shallow and deep)	municipal with sewage treatment facilities irrigated crop agriculture rural residential	2.70	<0.02

Note: Project sampling reports nitrate concentrations as nitrate+nitrite-nitrogen.
Note: Shallow refers to wells less than 300 feet deep.
Note: Deep refers to wells 300 feet or more deep.

Sources:
Project Sampling
DEQ Water Quality File 9584
DEQ Water Quality File 104738
Barlow and Scott, 1991a
Barlow, Scott, and Urban, 1992

Project sampling detected nitrate+nitrite-nitrogen exceeding the 10 mg/L drinking water standard in alluvial groundwater samples collected at UMA 153 and UMA 154 located on the terrace north of Hermiston. Concentrations measured 31 mg/L and 12 mg/L in samples from UMA 153 and UMA 154, respectively. Well UMA 153 is located at City Beef Feedlot and downgradient of crop agriculture where center pivot irrigation currently occurs. Well UMA 154 is located at a West Locust Road rural residential home among irrigated crop agriculture and some livestock. Chloride versus potassium graphical analysis indicates crop irrigation primarily influences groundwater at both sites (see Appendix 4H).

Nitrate+nitrite-nitrogen concentrations in alluvial groundwater sampled from other north terrace sites remained below 10 mg/L. Some sites had groundwater nitrate concentrations approaching 10 mg/L. Constituent versus constituent graphical analysis indicates different influences at each of those sites. For example, the analysis indicates a septic system influence at UMA 055 and UMA 057, an irrigation influence at UMA 158, and an animal waste influence at UMA 108. Additional analysis generally indicates a septic system influence at sites with groundwater nitrate concentrations below 5 mg/L.

Nitrate+nitrite-nitrogen concentrations remained below 5 mg/L in project samples collected in the Hermiston basin. Higher concentrations were anticipated in samples collected near Diagonal Road where numerous residential homes are located. Review of Plates 4.2 and 4.5 as well as a NETPATH computer groundwater chemistry model indicates dilution from canal leakage is primarily responsible for the lower concentrations in the alluvial groundwater.

Project sampling detected nitrate+nitrite-nitrogen exceeding the 10 mg/L drinking water standard in alluvial and basalt groundwater samples collected at sites on the terrace between Hermiston and Stanfield. Pesticides detected and constituent versus constituent graphical analysis indicates irrigation and septic systems influences. Pesticides detected in some samples strongly indicate an irrigated crop agriculture influence. Atrazine and ethylene dibromide were detected in alluvial samples collected from UMA 044 where groundwater nitrate concentrations ranged from 12 to 16 mg/L. Dacthal acid was detected in alluvial and basalt groundwater samples collected from UMA 156 and UMA 125, respectively. Nitrate concentrations ranged from 7.90 mg/L to 19 mg/L in UMA 156 samples and 17 to 29 mg/L in UMA 125 samples. Constituent versus constituent graphical analysis indicate septic systems influence groundwater at UMA 042, UMA 087 and UMA 152 where nitrate concentrations in project samples reached 13 mg/L, 20 mg/L and 12 mg/L, respectively (see Appendix 4H).

Nitrate+nitrite-nitrogen concentrations remained below 10 mg/L in project alluvial and basalt groundwater samples collected in the Echo and Umatilla Meadows area. However, nitrate-nitrogen reached 10 mg/L in a shallow unconfined alluvial groundwater sample collected by A.E. Staley Manufacturing. The sample came from a well located within the Staley wastewater land application area and near Stage Gulch. The gulch conveyed City of Stanfield treated sewage wastewater to the Umatilla River during the sampling period reported. Project TKN data related to the land application site indicates an organic nitrogen source. Constituent versus constituent graphical analysis of the project data indicates wastewater irrigation is the primary influence at the site.

Nitrate+nitrite-nitrogen concentrations in alluvial groundwater at UMA 193 reached 8.60 mg/L . The well is located in an Echo and Umatilla Meadows downgradient area. Constituent versus constituent graphical analysis indicate an irrigation related influence (see Appendix 4H).

Dilution from canal leakage may be responsible for nitrate concentrations remaining below 10 mg/L in the Echo and Umatilla Meadows area. Evidence of canal leakage influencing local groundwater chemistry came from sampling groundwater and ditch water at UMA 189 in August 1991. A major thunderstorm occurred in the area the day before project staff sampled at UMA 189. The storm caused river, canal and ditch sediment loads to increase. The UMA 189 well owner informed project staff that water from his well turned dirty shortly after the storm. This prompted project field staff to conduct field conductivity and alkalinity tests of nearby ditch water as well as for the groundwater sample. The field measurements for the two sources nearly matched indicating a likely surface water influence upon local groundwater.

Map and Data Set Observations: Total Dissolved Solids

Plates 4.4 and 4.5 show the total dissolved solids (TDS) concentration distribution in the City of Umatilla to Hat Rock to Echo Meadows area. Plate 4.5 shows the maximum concentration detected in alluvial and basalt groundwater samples. Plate 4.4 shows the June-July 1992 TDS concentration distribution in regional alluvial groundwater based upon project synoptic sampling. The shape and extent of each concentration range contoured was derived by linear interpolation between data locations. TDS concentrations detected in shallow unconfined alluvial groundwater samples and basalt groundwater samples are printed next to each sampling location.

The TDS concentration distribution is similar to the nitrate concentration distribution. Concentrations exceeded the 500 mg/L secondary (aesthetic) drinking water standard in project groundwater samples collected at some sites on the terraces north and south of Hermiston and at a Hat Rock site. Alluvial groundwater with lower TDS concentrations occurs within the Hermiston basin, the terrace south of Hermiston, and within Echo and Umatilla Meadows. Review of Plate 4.4 found the distribution of lower TDS concentrations in alluvial groundwater within the Hermiston basin and the terrace south of Hermiston coincided very well with surface water canals. This strongly indicates leaky canals locally influence alluvial groundwater chemistry.

Map and Data Set Observations: Other Constituents

Arsenic was detected in project samples collected primarily adjacent and north of Stanfield. Plate 4.6 shows the maximum concentration distribution. One sample contained arsenic above the drinking water standard of 0.050 mg/L. That sample came from UMA 260 located within the A.E. Staley wastewater land application area. The arsenic concentration measured 0.074 mg/L.

Plate 4.7 shows the maximum concentration distribution for sodium. Concentrations in project groundwater samples frequently exceeded the 20 mg/L limit currently recommended for persons on a physician prescribed sodium restricted diet. Groundwater samples with concentrations exceeding 50 mg/L came primarily from terrace sites.

Plate 4.8 shows the maximum concentration distribution for chloride. Concentrations in project groundwater samples remained within the 250 mg/L secondary (aesthetic) drinking water standard except for one UMA 125 sample. Project laboratory analysis reported the concentration as 490 mg/L. Chloride in other UMA 125 samples remained below 40 mg/L. The well is located on the north side of the south Hermiston terrace.

Plate 4.9 shows the maximum concentration distribution for total phosphate in groundwater sampled by this project. The concentration distribution appears nearly divided. Relatively higher concentrations were detected in samples from the terrace north of Hermiston, the eastern portion of the Hermiston basin, and the Echo and Umatilla Meadows area. The relatively lower concentrations were detected in groundwater sampled within the west Hermiston area and the terrace south of Hermiston.

Plate 4.10 shows the maximum concentration distribution for boron in project samples collected in the area. Groundwater samples with detected boron came from the City of Umatilla, Hat Rock, the terrace north of Hermiston, west Hermiston, along Diagonal Road, the northern portion of the terrace south of Hermiston, and the eastern portion of Umatilla and Echo Meadows areas. The highest boron concentrations detected for the area came from samples collected within the City of Echo vicinity.

Project sampling detected bromide in groundwater sampled from most of the area (see Plate 4.11). Bromide was not detected in groundwater from the central and southeastern portion of Umatilla and Echo Meadows area nor the northeastern portion of the terrace south of Hermiston. The greatest bromide concentrations detected area groundwater came from the central portion of the terrace south of Hermiston.

Plate 4.12 shows the maximum concentration distribution for vanadium for project samples collected in the area. Groundwater samples with detected boron came primarily from the Stanfield area and sites east of Highway 395 and southeast of Diagonal Road. Area samples with relatively higher vanadium concentrations came from the Stanfield vicinity.

Table 4.32 and Plate 4.13 show local sites where project sampling detected volatile organic compounds (VOC) and/or pesticides. Appendix 4G provides a complete listing. In addition to project sampling, the City of Hermiston reported detecting tetrachloroethene, 1,1,1-TCA, toluene, and total xylenes in alluvial groundwater as well as dacthal and picloram in basalt groundwater within the Hermiston area (Loeb, 1992, Bidleman, 1993). These detections strongly indicate a human activity influence upon groundwater.

Table 4.32 Volatile organic compounds and pesticides detected in the City of Umatilla to Hat Rock to Echo Meadows area.

Site	Groundwater Source	Location	Constituent	Concentration	Nitrate+Nitrite-Nitrogen Concentration (mg/L)
UMA 044	Alluvial	South Edwards Road north of Stanfield-Hermiston Loop Road	Ethylene Dibromide	0.0015 - 0.0026 mg/L	12.00 - 16.00
UMA 044	Alluvial	South Edwards Road north of Stanfield-Hermiston Loop Road	Atrazine	1.30 ug/L	12.00 - 16.00
UMA 067	Uncertain	Stanfield Junction area (Highway 395 - Interstate 84)	Atrazine	2.30 ug/L	3.40
UMA 068	Alluvial	Northwest Hermiston	Atrazine	0.60 ug/L	0.03 - 0.04
UMA 101	Alluvial	Hermiston-Stanfield Corridor	Chloroform	0.0028 mg/L	4.50 - 4.60
UMA 116	Alluvial	East Punkin Center Road	Tetrachloro-ethylene	0.0011 mg/L	3.00 - 3.60
UMA 125	Alluvial	north Stanfield-Hermiston Loop Road area	Dacthal acid	0.60 - 20.00 ppb	17.00 - 29.00
UMA 156	Alluvial	north Stanfield-Hermiston Loop Road area	Dacthal acid	0.10 - 11.00 ppb	7.90 - 19.00
UMA 191	Alluvial	City of Echo sewage lagoons site	Atrazine	non detect - 0.60 ug/L	0.44 - 1.20

Note: Data from Lower Umatilla Basin project sampling.

Note: Laboratory methods can occasionally cause chloroform detections at low concentrations

Graphical Analyses: Nitrate versus Time

Graphical analysis of City of Umatilla to Hat Rock to Echo Meadows area groundwater data included reviewing nitrate versus time graphs. Data analyzed came from project bimonthly sampling. The analysis included comparing the nitrate versus time graphs to other constituent versus time graphs.

Figure 4.61 shows nitrate+nitrite-nitrogen versus time in alluvial groundwater sampled in the City of Umatilla and the Hat Rock areas. Table 4.33 presents how the nitrate versus time graphs compared to the other constituent versus time graphs for each sampling site. The areas are geographically and hydrogeologically separated from each other.

Well UMA 038 is located in an unsewered residential and small agriculture area adjacent to the City of Umatilla. Constituent versus constituent graphical analysis (Appendix 4H) indicates a mixed septic system and animal waste influence. Animal activity does occur south of the city.

Well UMA 066 is located at Hat Rock within a mobile home park near irrigated crop agriculture. The nitrate concentration versus time is consistent with a constant nitrate source such as a septic system. However, constituent versus constituent graphical analysis indicates a mixed septic system, animal waste, and possible irrigation influence (see Appendix 4H). Project investigators are not aware of any animal operation or animal waste use in the area.

Figure 4.62 shows nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater sampled from the terrace north of Hermiston. Table 4.34 presents how the nitrate versus time graphs compared to the other constituent versus time graphs for each sampling site. The nitrate concentrations remain below 5 mg/L. Constituent versus constituent graphical analysis indicates a predominantly septic system influence at these particular sites.

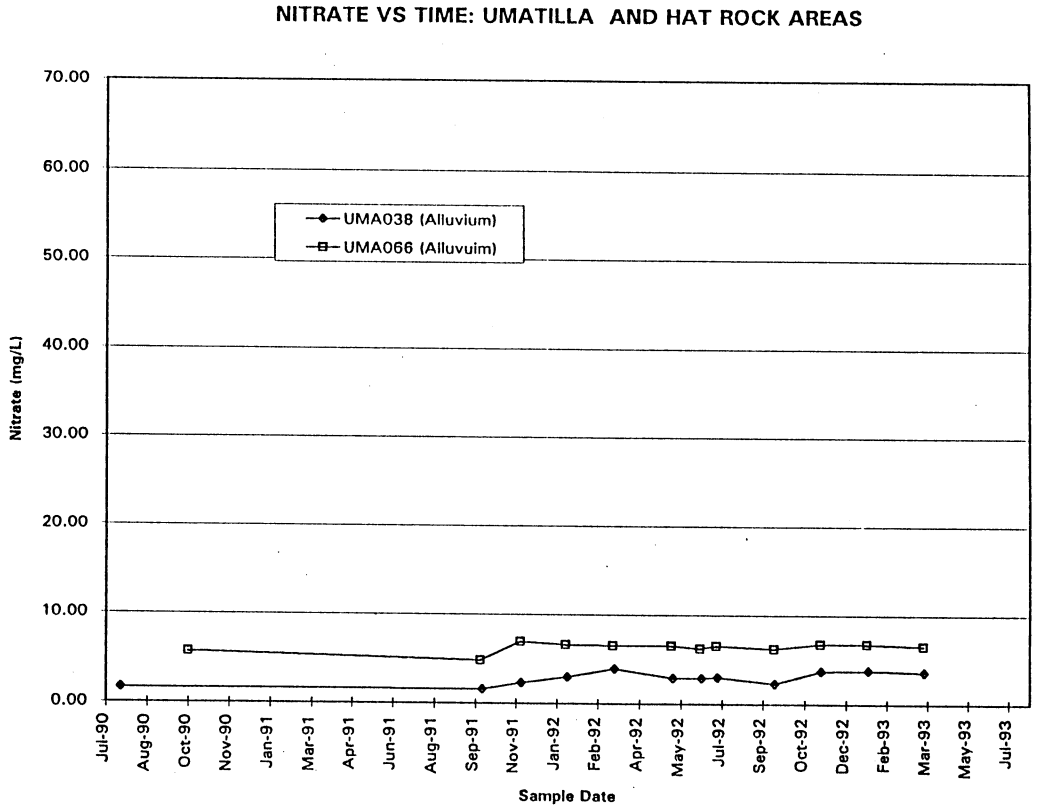


Figure 4.61 Nitrate+nitrite-nitrogen versus time in City of Umatilla and Hat Rock area alluvial groundwater at project bimonthly groundwater sampling sites.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.33 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Umatilla and Hat Rock areas.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 038 (Alluvial)	WS	S	WS	S	WS	WS	I	NS
UMA 066 (Alluvial)	NS	NS	S	NS	WS	S and I	WS	WS

Note: The comparisons were qualitative versus quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

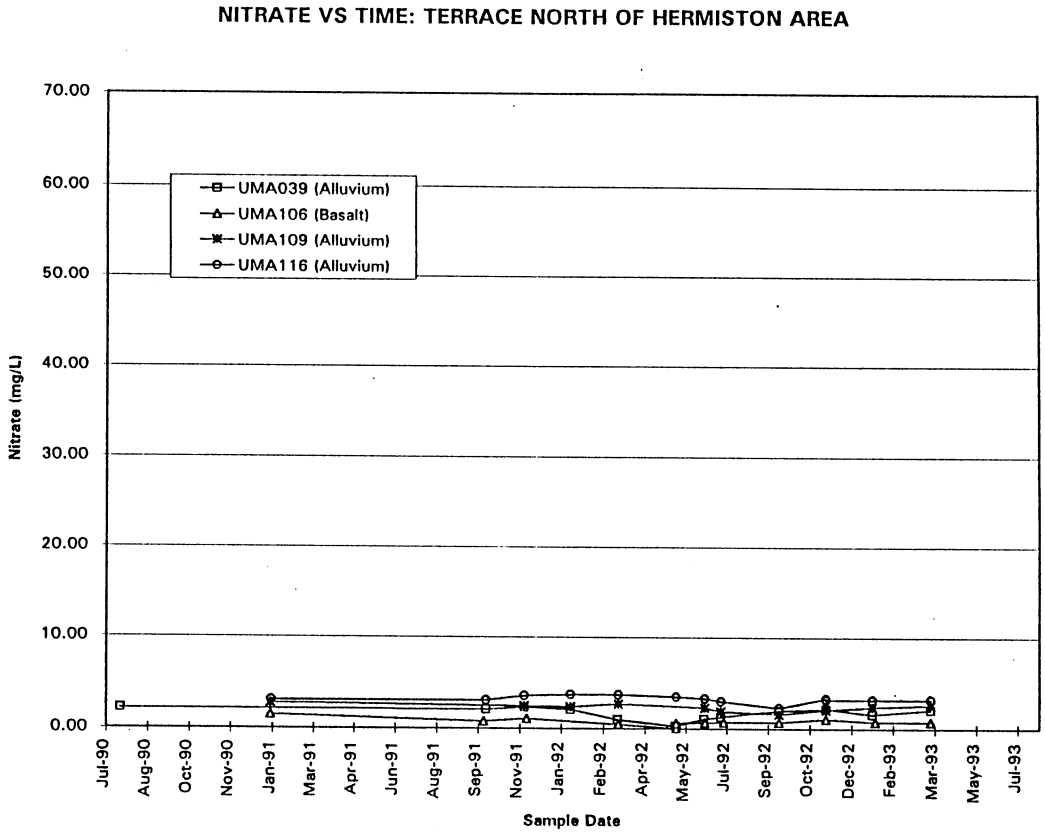


Figure 4.62 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the Hermiston area north terrace.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.34 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the Hermiston area north terrace.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 039 (Alluvial)	WS	S	S	S	S	S	I	NS
UMA 106 (Basalt)	WS	S	S	WS	WS	WS	I	WS
UMA 109 (Alluvial)	WS	S	I	WS	S and I	WS	I	S
UMA 116 (Alluvial)	S	S	S	S	S and I	WS	WS	WS

Note: The comparisons were qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

Figure 4.63 shows nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater sampled from the terrace south of Hermiston. Table 4.35 presents how the nitrate versus time graphs compared to the other constituent versus time graphs for each sampling site. All the sites are located within an irrigated crop agriculture area with some rural residential homes.

The nitrate concentration at UMA 046 remains below 5 mg/L with little to no variability. The site is located near the upgradient margin of local irrigated agriculture and close to a canal. The canal appears responsible for lower nitrate and TDS concentrations observed in the area.

Canals nearly surround UMA 056 which is located adjacent to a former hog operation and downgradient of irrigated crop agriculture. The nitrate versus time graph for the site shows small seasonal fluctuations. Constituent versus constituent graphical analysis of UMA 056 data (Appendix 4H) suggests an irrigation related influence, which could include canal leakage.

The nitrate versus time graphs for UMA 110, UMA 125, and UMA 156 show notable fluctuation. Each site is located among irrigated crops. The seasonal fluctuations as well as pesticide detections in UMA 125 and UMA 156 samples strongly indicate an irrigated crop agriculture influence. Constituent versus constituent graphical analysis suggests an additional influence from septic systems (see Appendix 4H).

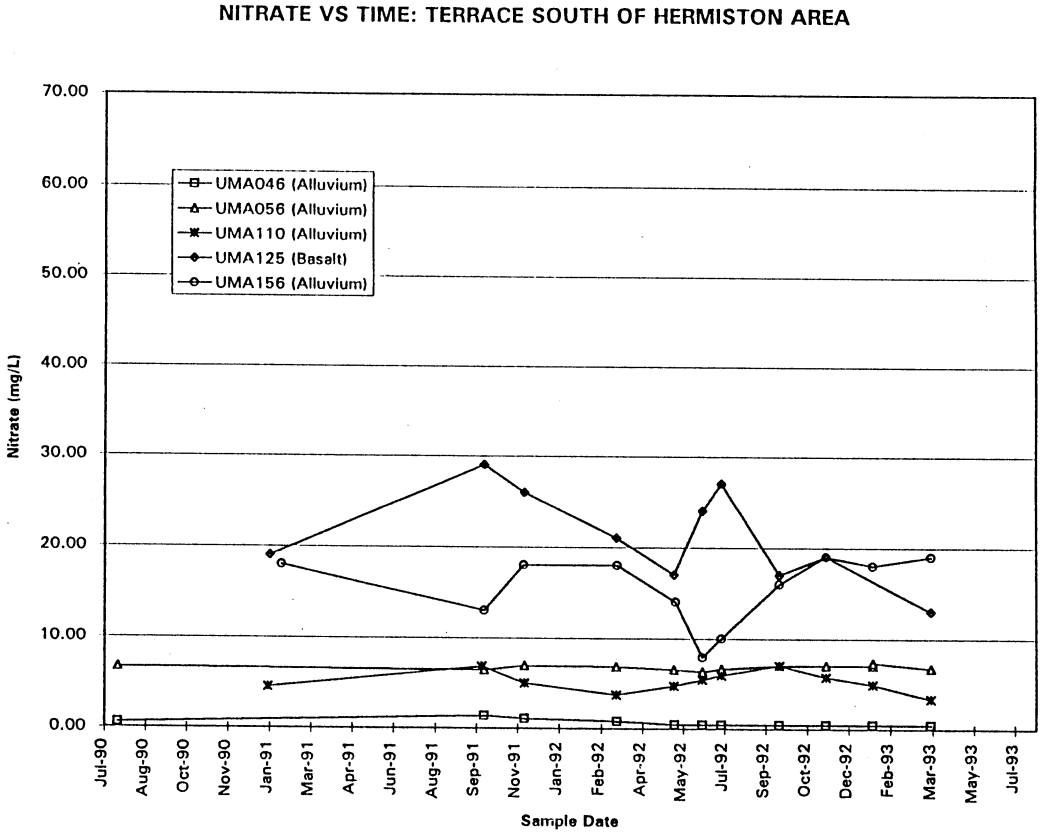


Figure 4.63 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the north Stanfield-Hermiston Loop Road area.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.35 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the north Stanfield-Hermiston Loop Road area.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 046 (Alluvial)	S and NS	S	S	S and NS	S	S	U	
UMA 056 (Alluvial)	WS	I	WS	U	S	S	S	S
UMA 110 (Alluvial)	S	S	S	S	S and I	S	S	WS
UMA 125 (Basalt)	S	S	S	S	S	S	NS	S
UMA 156 (Alluvial)	S	S	S	I	S	S and I	S	S and I

Note: The comparisons were qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

Figure 4.64 shows nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater sampled from the City of Stanfield vicinity. Table 4.36 presents how the nitrate versus time graphs compared to the other constituent versus time graphs for each sampling site. Nitrate concentrations in the project samples remained below 5 mg/L. Dilution could account for the lower nitrate concentrations since both sites are located near a canal.

Constituent versus constituent graphical analysis indicates an irrigation related influence at both sites and perhaps a septic system influence too (see Appendix 4H). Well UMA 047 is located within a unsewered area near an irrigated field. Well UMA 048 is located within a sewered area some distance downgradient of irrigated crop activity.

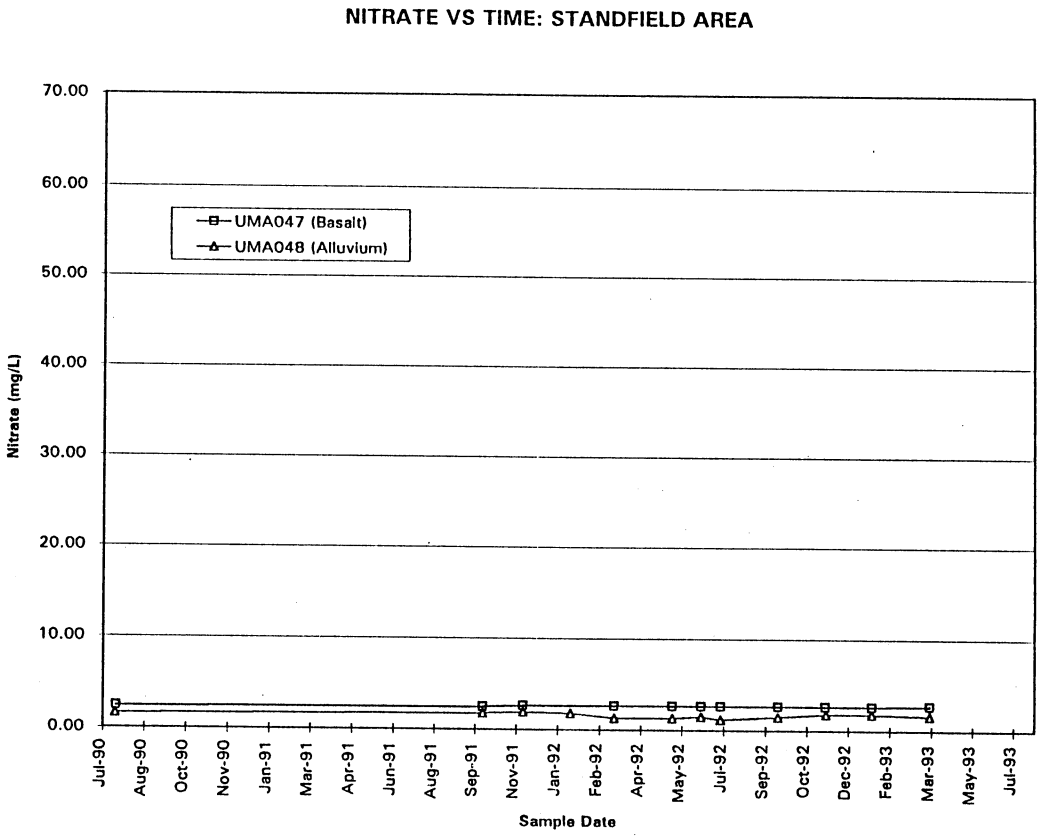


Figure 4.64 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the Stanfield area.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.36 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Stanfield area.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 047 (Basalt)	S	WS	WS	U	NS	NS	S	U
UMA 048 (Alluvial)	S	I	I	WS	S	S	I	NS

Note: The comparisons were qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

Figure 4.65 shows nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater sampled from the City of Echo area. Table 4.37 presents how the nitrate versus time graphs compared to the other constituent versus time graphs for each sampling site. Nitrate concentrations in the project samples remained below 5 mg/L. Dilution could account for the lower nitrate concentrations since both sites are located near canals.

Constituent versus constituent graphical analysis indicates an irrigation related influence at both sites (see Appendix 4H). Well UMA 190 is located in the Umatilla River flood plain near irrigated crop agriculture. Well UMA 191 is located in the flood plain adjacent to the City of Echo municipal wastewater lagoons and near field crops and irrigated pasture. The municipal lagoons are lined to control leakage. Atrazine was repeatedly detected in UMA 191 samples which strongly indicates an agricultural influence.

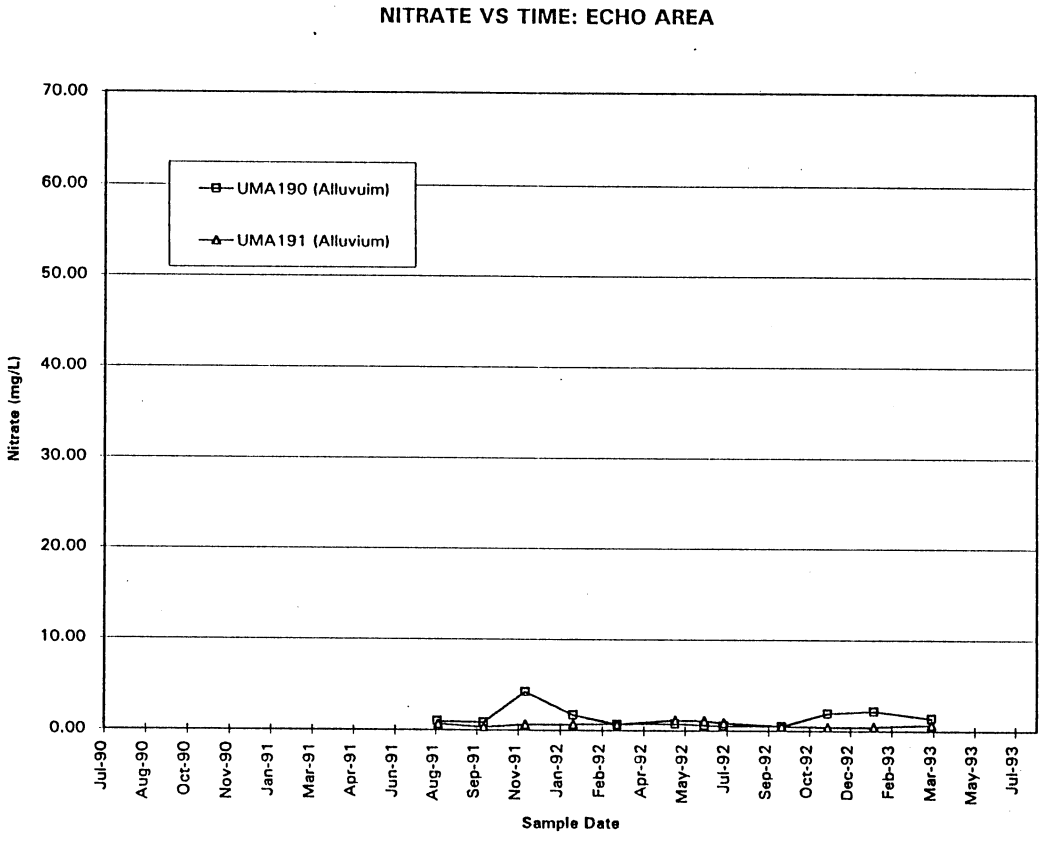


Figure 4.65 Nitrate+nitrite-nitrogen versus time in alluvial and basalt groundwater from project bimonthly groundwater sampling sites in the City of Echo area.

Note: A 0 to 70 mg/L concentration range is used to facilitate graphical comparisons.

Table 4.37 Results of comparing nitrate+nitrite-nitrogen versus time graphs to other constituent versus time graphs for data related to project bimonthly groundwater sampling sites in the City of Echo area.

Site	Other Constituent versus Time Graphs Compared to Nitrate+Nitrite versus Time							
	Total Dissolved Solids	Chloride	Sulfate	Bicarbonate	Sodium	Calcium	Total Phosphate	Boron
UMA 190 (Alluvial)	S	S	S	S	S	S	I	S
UMA 191 (Alluvial)	S	S	S	S	S and I	WS	U	U

Note: The comparisons are qualitative rather than quantitative.

Note: S = graphs similar to the nitrate+nitrite-nitrogen versus time graph
WS = graphs weakly similar to the nitrate+nitrite-nitrogen versus time graph
NS = graphs not similar to the nitrate+nitrite-nitrogen versus time graph
I = graphs inverse to the nitrate+nitrite-nitrogen versus time graph
U = unable to determine a similar, inverse, or no similarity relationship

Graphical Analyses: Piper Trilinear Graphs and Schoeller Diagrams

Project bimonthly and synoptic groundwater sampling data related to the City of Umatilla to Hat Rock to Echo Meadows area were plotted on Piper trilinear and Schoeller diagrams. Both graphs proved useful for observing data variation over time or location. The trilinear graphs were also used to classify the groundwater chemistry and observe any mixing relationships. Table 4.38 shows the groundwater chemistry classifications observed by general location and groundwater source.

The groundwater chemistry data related to smaller areas within the City of Umatilla to Hat Rock to Echo Meadows area graphed differently. The groundwater chemistry variability or lack of variability by location and/or time differed. Variability among cation proportions versus anion proportions also differed. However, for nearly all areas, the chemical variability correlated to nitrate variability. The following discussion presents observations for the terrace north of Hermiston, the Hermiston basin, the terrace south of Hermiston, and Echo-Stanfield areas.

Project data indicates that the composition of alluvial groundwater in the terrace north of Hermiston varies by location (Figures 4.66 and 4.67). Cation proportions vary little. The increasing sulfate and chloride proportions (in Figure 4.67) correspond to higher nitrate concentrations, and they graph in a manner indicative of a mixing relationship. Conversely, project bimonthly nitrate and other chemistry data for north terrace alluvial groundwater varied little over time (Figures 4.68 and 4.69). The lack of variation over time in project data does not eliminate the possibility of groundwater chemistry time variation at other north terrace sites.

Table 4.38 Observed Piper Trilinear water chemistry classification of alluvial and basalt groundwater sampled from the City of Umatilla to Hat Rock to Echo Meadows area.

Area	Groundwater Source	Groundwater Chemistries Observed
Hat Rock Area (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Hermiston Area: North Terrace (north of Punkin Center Road) (Project Sampling)	Alluvial	calcium/bicarbonate
Hermiston Area: Basin (south of Punkin Center Road) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Hermiston Area: General (Project Sampling)	Basalt (shallow and deep)	mixed-cation/bicarbonate sodium + potassium/bicarbonate
Stanfield-Hermiston Corridor (Highway 395) (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate sodium + potassium/bicarbonate no dominant type
Stanfield-Hermiston Loop Road: North (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate no dominant type
Stanfield-Hermiston Loop Road: North (Project Sampling)	Basalt (shallow)	mixed-cation/bicarbonate
Stanfield-Hermiston Loop Road: South (Project Sampling)	Alluvial	mixed-cation/bicarbonate no dominant type
Echo and Umatilla Meadows Area (Project Sampling)	Alluvial	mixed-cation/bicarbonate calcium/bicarbonate
Echo and Umatilla Meadows Area (Project Sampling)	Alluvial (Shallow Unconfined)	mixed-cation/bicarbonate calcium/bicarbonate sodium + potassium/bicarbonate
Echo and Umatilla Meadows Area (Project Sampling)	Basalt (shallow and deep)	mixed-cation/bicarbonate sodium + potassium/bicarbonate

Note: Project bimonthly and synoptic groundwater sampling data was used for the groundwater chemistry classifications
Note: Shallow refers to wells less than 300 feet deep.
Note: Deep refers to wells 300 feet or more deep.

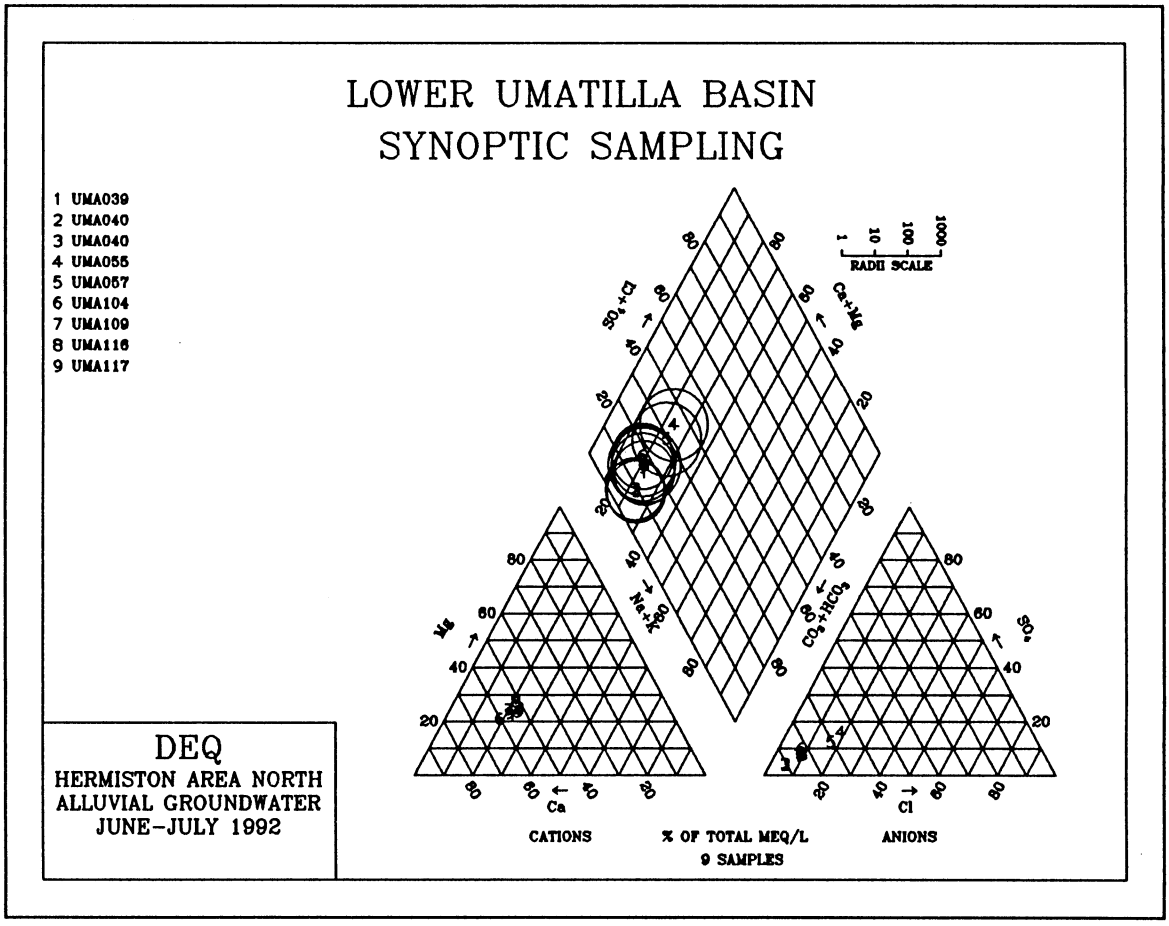


Figure 4.66 Piper Trilinear graph of project synoptic sampling data for alluvial groundwater collected from the terrace north of Hermiston.

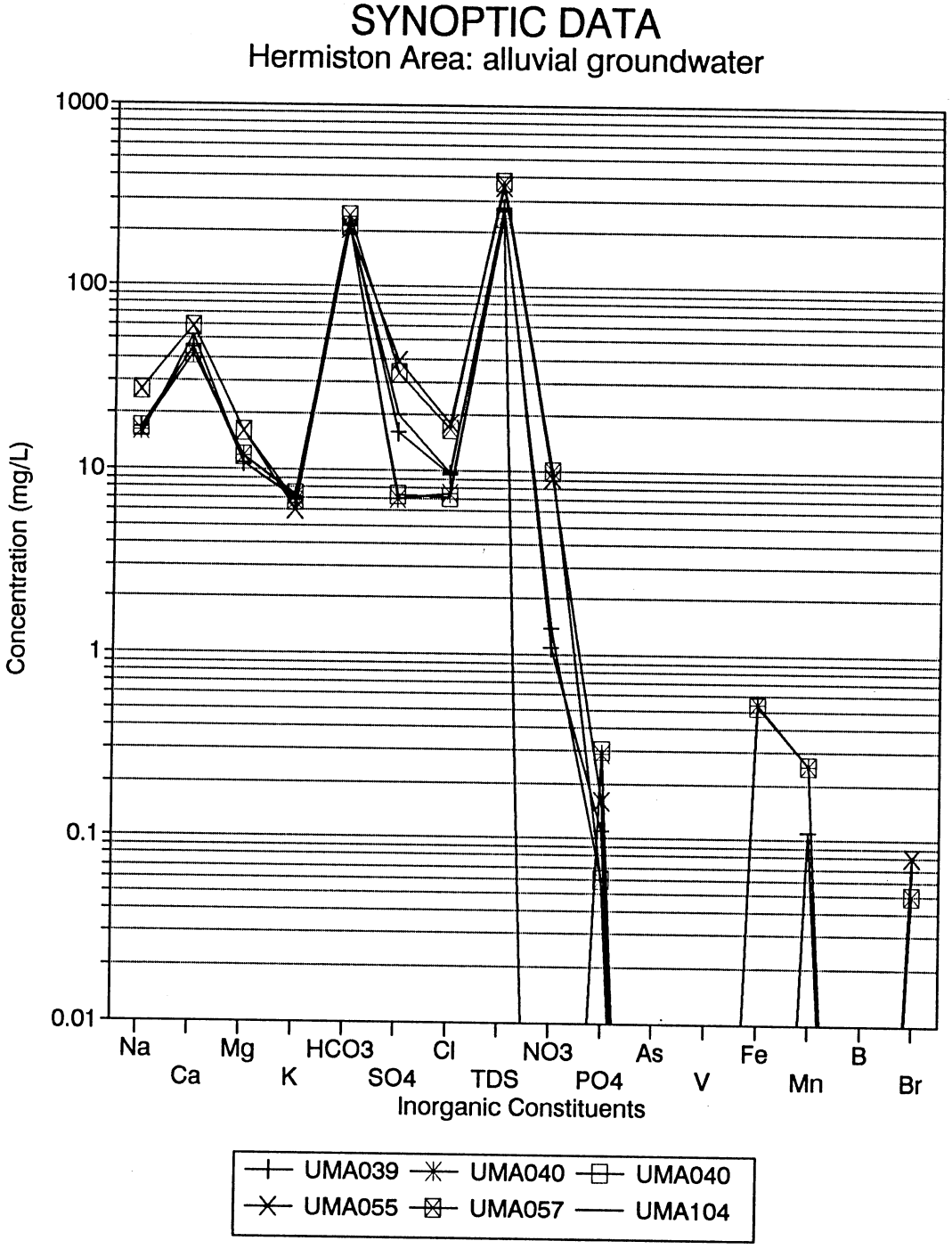


Figure 4.67 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected from the terrace north of Hermiston.

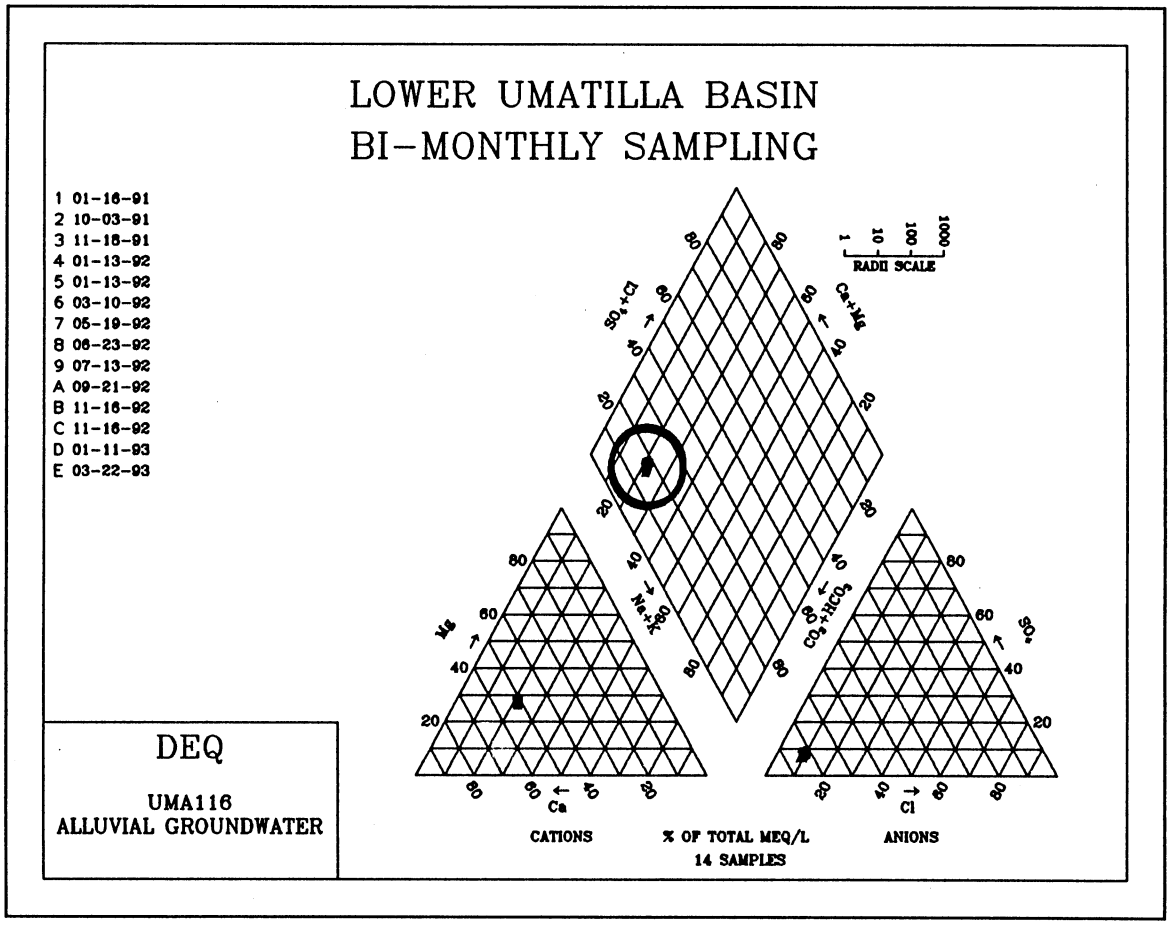


Figure 4.68. Piper Trilinear graph of project bimonthly sampling data for alluvial groundwater collected at UMA 116 located on the terrace north of Hermiston.

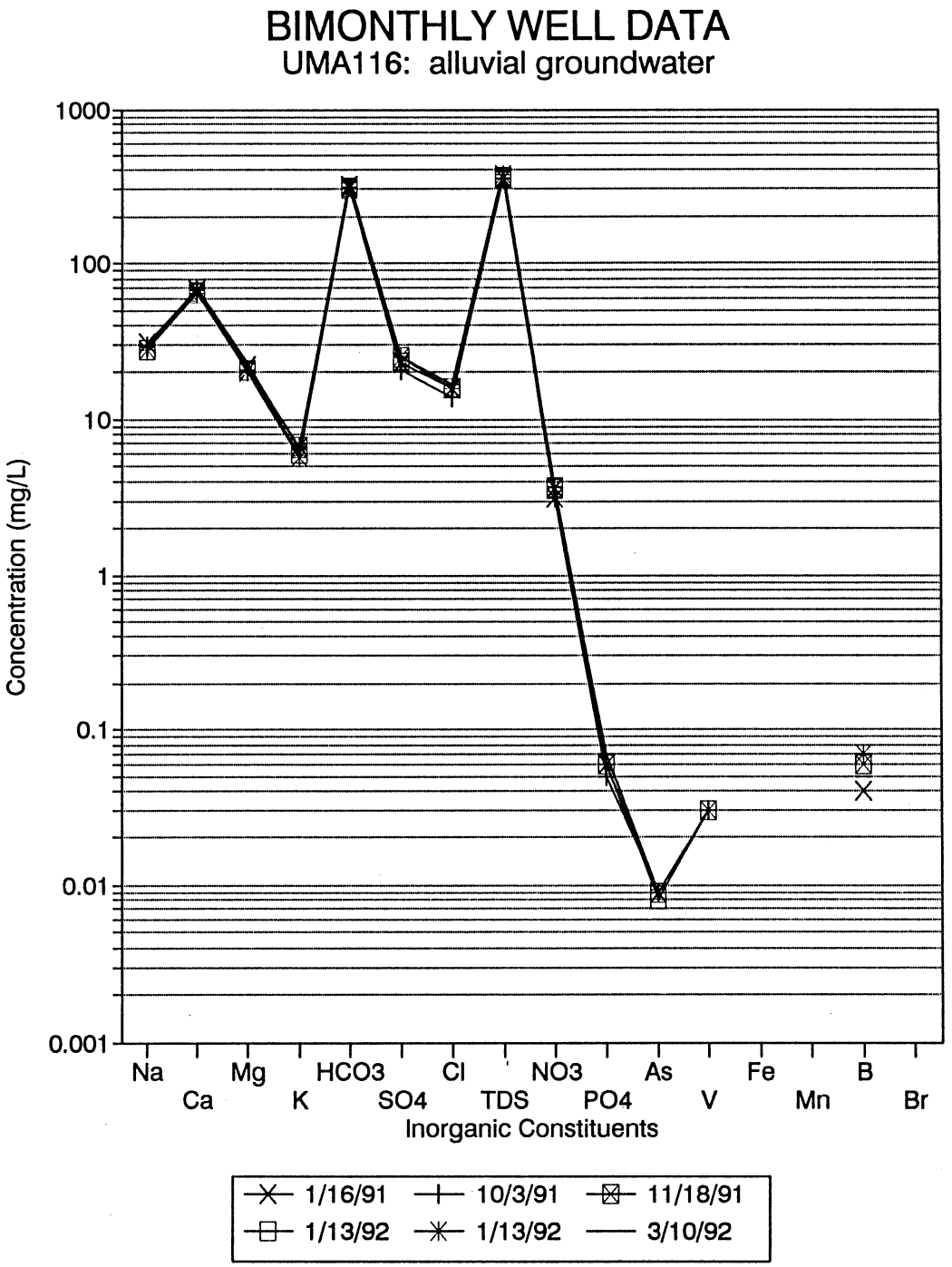


Figure 4.69 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 116 located on the terrace north of Hermiston.

Project data shows small variation in alluvial groundwater chemistry in the Hermiston basin by location and over time. Similarly, the nitrate concentrations vary little. Nitrate remained below 5 mg/L in Hermiston basin alluvial groundwater samples.

Project data indicates alluvial groundwater in the terrace south of Hermiston chemically varies by location and varies over time at most sites. Figures 4.70 and 4.71 show the variability by location. Both cation and anion proportions vary. Higher chloride and magnesium proportions correspond to higher nitrate concentrations for the two mixing lines apparent on Figure 4.71. The end members and processes responsible for the mixing lines were not identified. Figures 4.72 and 4.73 show the chemical variability over time in alluvial groundwater at UMA 156. Generally, higher chloride proportions corresponded to higher nitrate concentrations over time in project bimonthly samples from this area. The cation proportions relationship to nitrate concentration over time was not as consistent. For some sites, higher calcium and magnesium proportions corresponded to higher nitrate concentrations over time. They did not correspond at other sites.

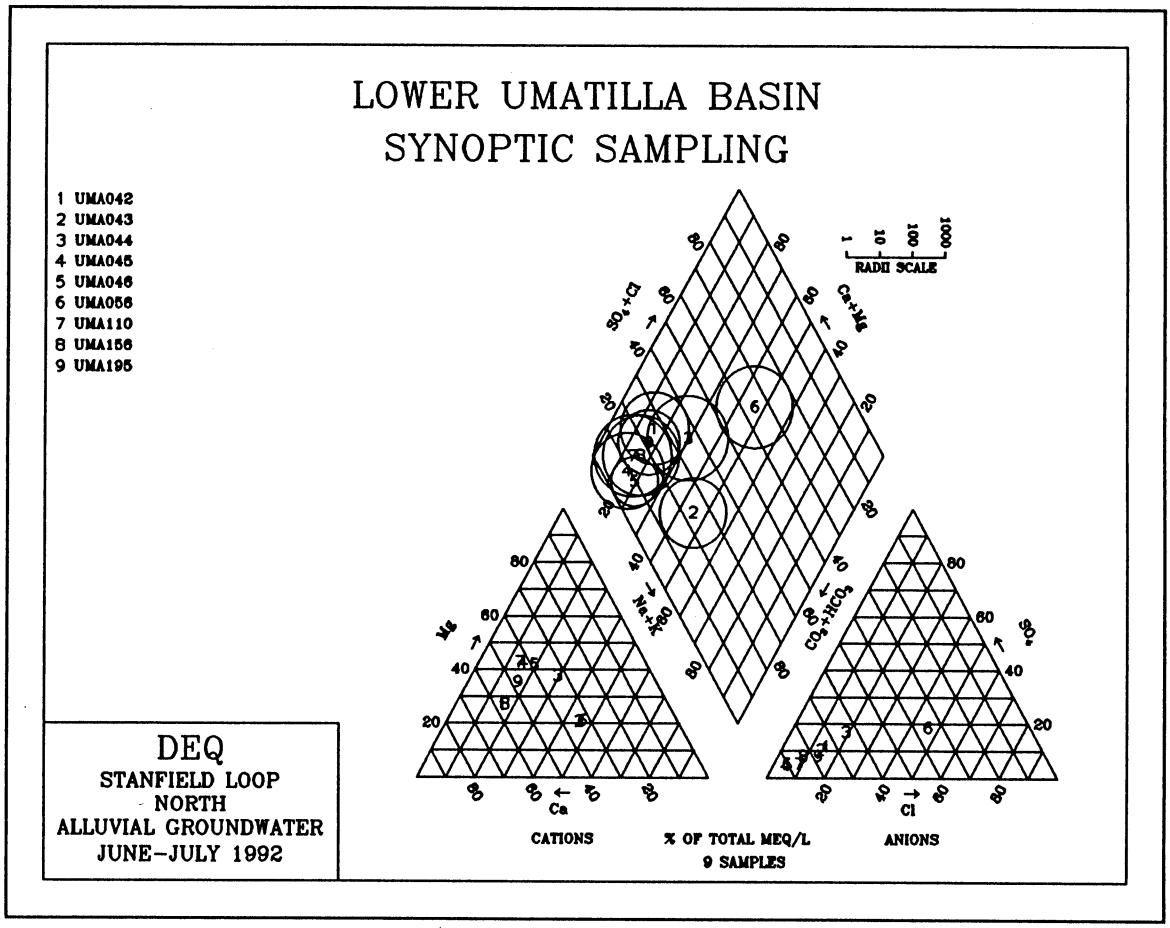


Figure 4.70 Piper Trilinear graph of project synoptic sampling data for alluvial groundwater collected from the terrace south of Hermiston.

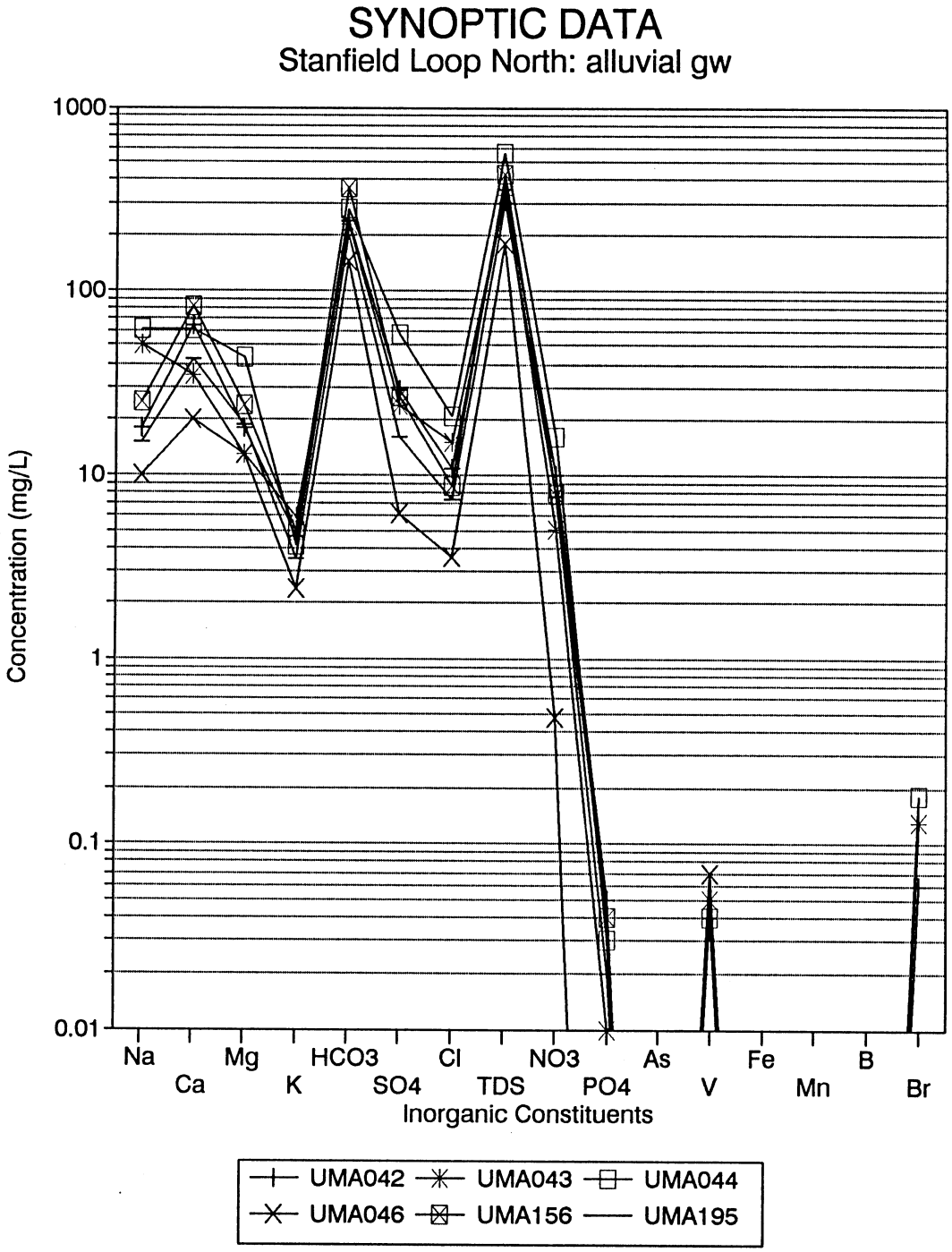


Figure 4.71 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected from the terrace south of Hermiston.

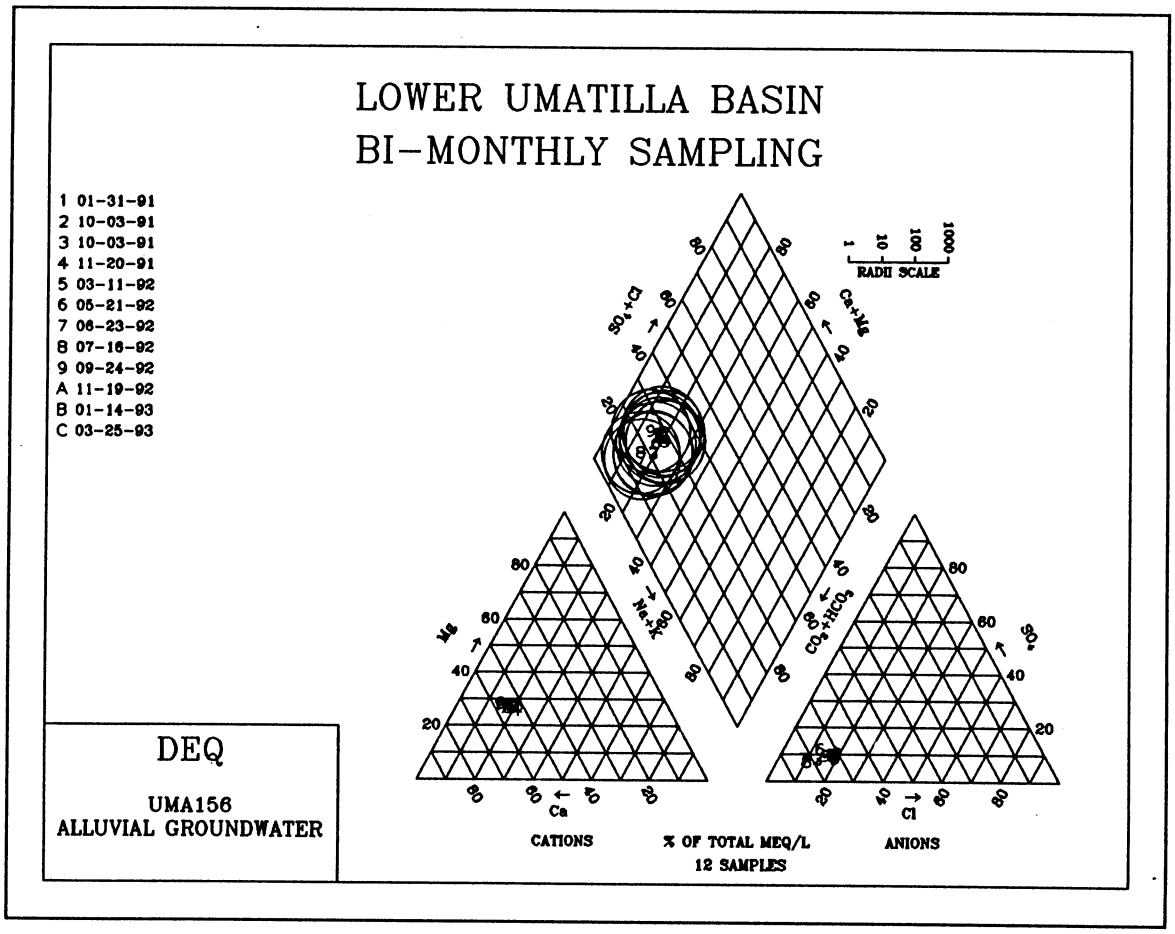


Figure 4.72 Piper Trilinear graph of project bimonthly sampling data for alluvial groundwater collected at UMA 156 located on the terrace south of Hermiston.

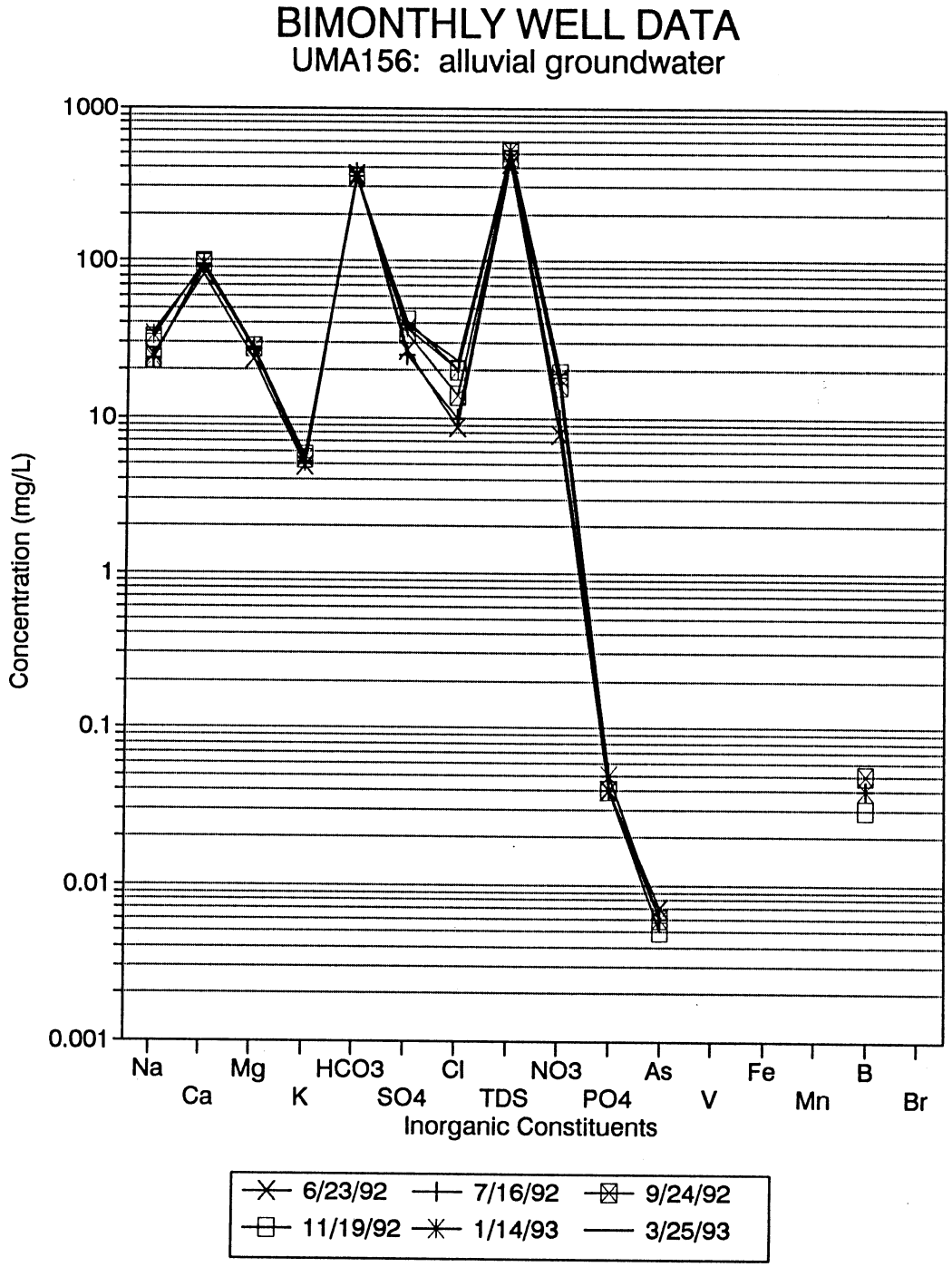


Figure 4.73 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 156 located on the terrace south of Hermiston.

Project data indicates alluvial groundwater in the Echo-Stanfield area chemically varies by location and over time at most sites. Figures 4.74 and 4.75 show the chemical variability in local alluvial groundwater by location. Cation proportions (primarily calcium versus sodium) vary the most. The usual nitrate concentration to ion ratio relationship was not observed. Figures 4.76 and 4.77 are an example of chemical variability in groundwater over time at UMA 190. The data varies along a mixing line Figure 4.77. Anion proportions vary the most and they relate in the usual manner to nitrate concentrations.

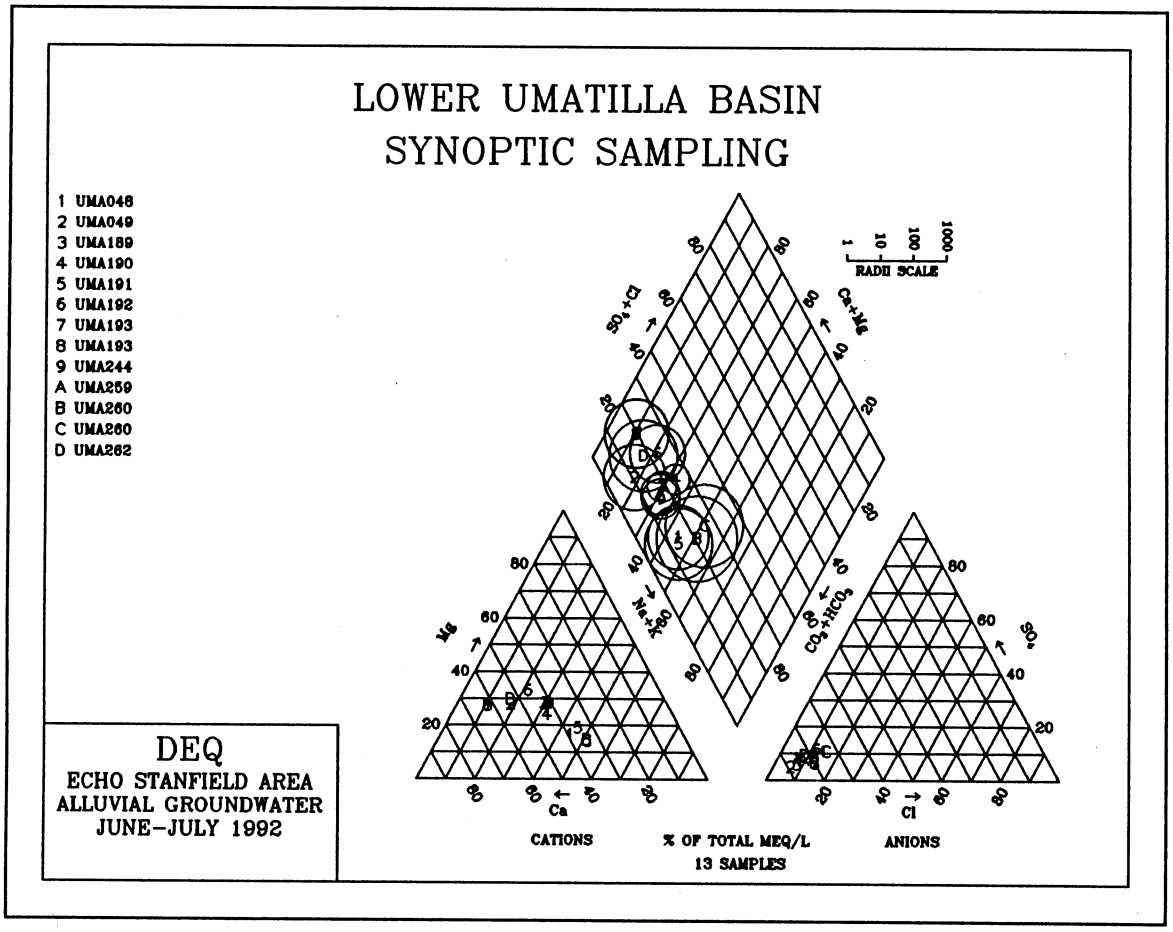


Figure 4.74 Piper Trilinear graph of project synoptic sampling data for alluvial groundwater collected in the Echo-Stanfield area.

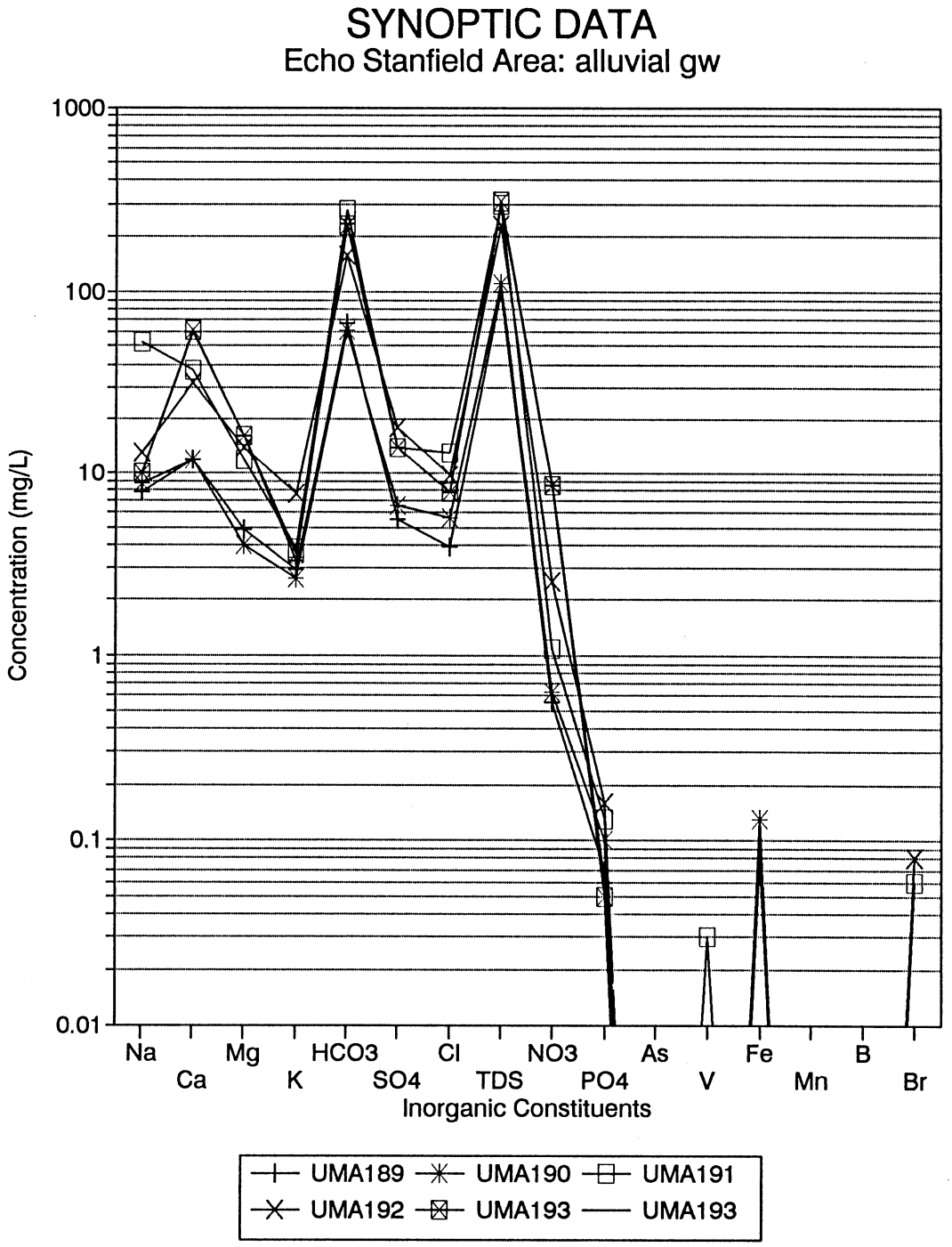


Figure 4.75 Schoeller Diagram of project synoptic sampling data for alluvial groundwater collected in the Echo-Stanfield area.

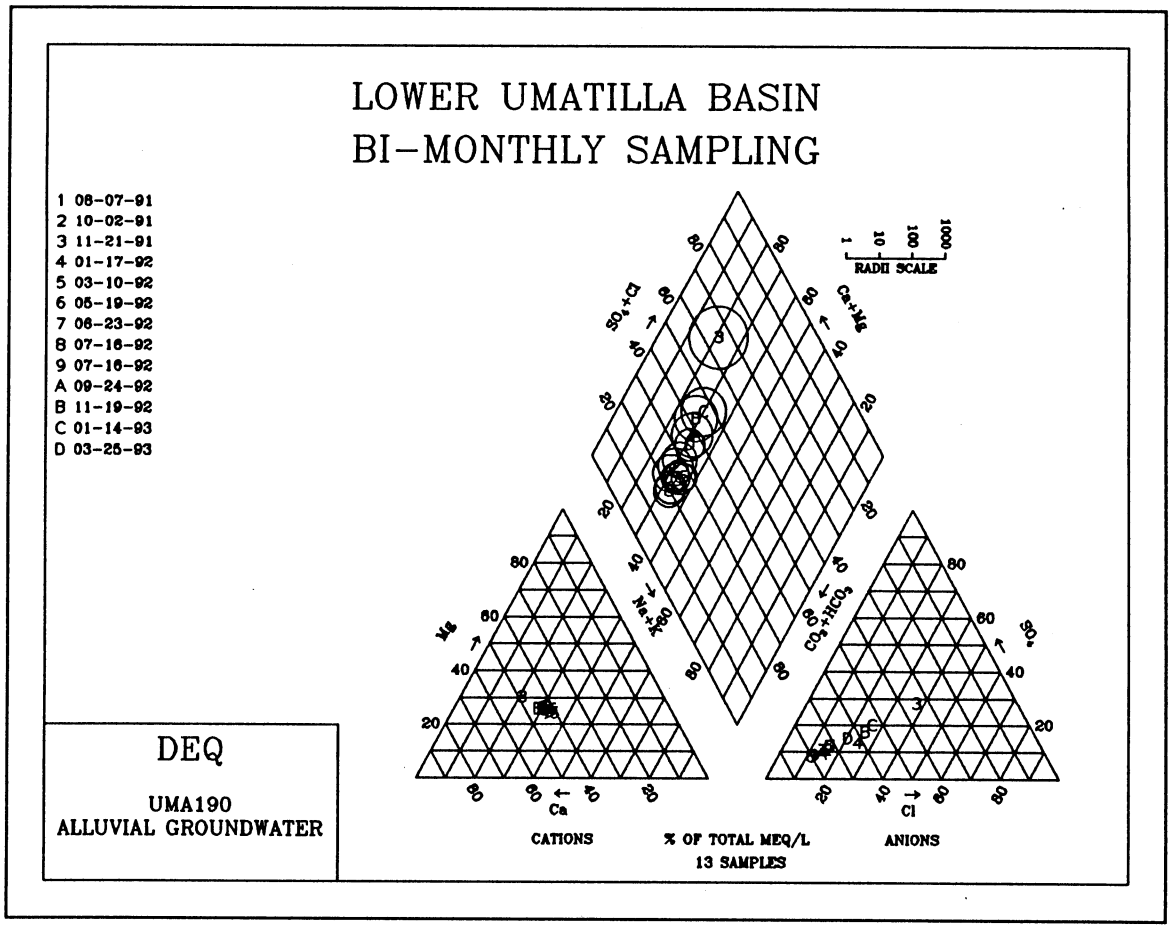


Figure 4.76 Piper Trilinear graph of project bimonthly sampling data for alluvial groundwater collected at UMA 190 located south of Echo.

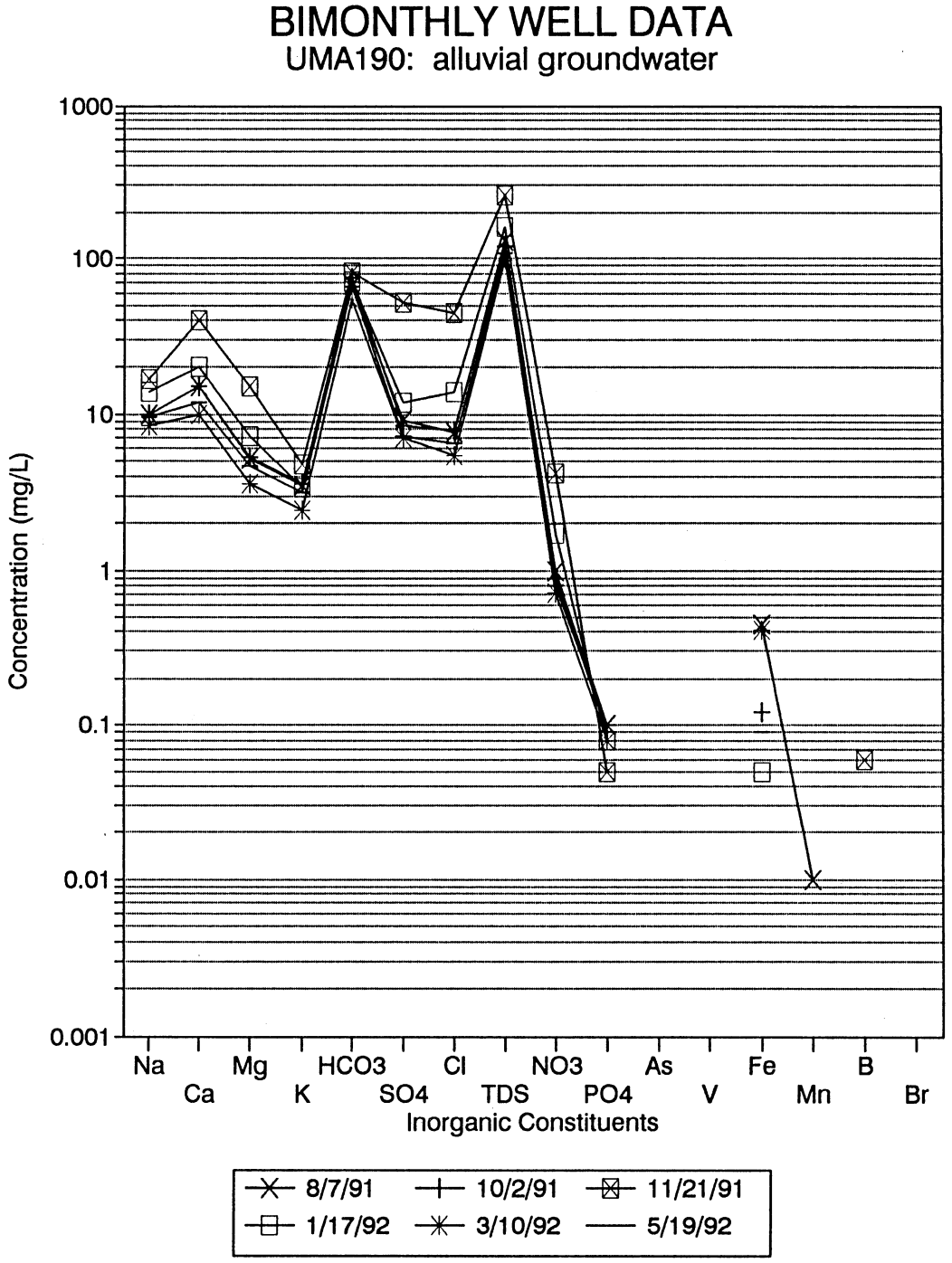


Figure 4.77 Schoeller Diagram of project bimonthly sampling data for alluvial groundwater collected at UMA 190 located south of Echo.

Graphical Analyses: Constituent Versus Constituent

Constituent versus constituent graphs were used to distinguish human influences on local groundwater chemistry (see Appendix 4H). The analysis primarily used project synoptic sampling data. Graphs reviewed included chloride versus potassium, bromide versus potassium, and chloride/bromide versus chloride. Analysis indicate the following:

- Influences affecting Hat Rock alluvial groundwater appears mixed. Analysis indicates a septic system, animal waste, and possibly irrigation influence. Project investigators are not aware of any animal operation or animal waste use in the area.

- Septic and animal waste appear to influence alluvial groundwater in an unsewered area adjacent to the City of Umatilla. Animal activity occurs south of Umatilla.

- Septic systems, local irrigation, and local animal waste appear to influence alluvial groundwater in the terrace north of Hermiston. Samples with higher nitrate concentrations generally corresponded to analysis indicating an irrigation or animal waste influence. For example, analysis indicates irrigation influences groundwater at sites UMA 153 and UMA 154. Nitrate+nitrite-nitrogen concentrations measured 31 mg/L and 12 mg/L in samples from those sites, respectively.

- Septic systems appear to be the most common influence at sites sampled in the Hermiston basin. Irrigation appears to be an additional influence at some sites.

- Irrigation related activity appears to be the most common influence at sites sampled on the terrace south of Hermiston. Septic systems appear to be an additional influence at some sites.

- Irrigation related activity appears to be the most common influence at sites sampled in the Stanfield and Echo-Umatilla Meadows area. Septic systems appear to be an additional influence at some sites.

Groundwater Flow Path Analysis

Project data analyses did not include flow path analysis for the City of Umatilla to Hat Rock to Echo Meadows area.

Groundwater Chemistry Computer Modeling

Nitrate concentrations in alluvial groundwater decrease markedly between upgradient sites located along the terrace south of Hermiston and downgradient sites in the Hermiston basin. Several canals convey water between the sites. Project analysis used the NETPATH groundwater chemistry computer model to evaluate the influence of canal leakage upon nitrate concentrations in groundwater flowing from the upgradient sites into the Hermiston basin.

Canal influences were evaluated by using alluvial groundwater data for UMA 043 and UMA 041. Well UMA 041 is located in the Hermiston basin downgradient of UMA 043 which is located on the terrace south of Hermiston. Maxwell and A Line Canals are located between the two well sites. Groundwater constituent concentrations at UMA 041 are lower than at UMA 043. For example, total dissolved solids and nitrate+nitrite-nitrogen concentrations measured 230 mg/L and 1 mg/L, respectively, in the down gradient UMA 041 sample and 330 mg/L and 5.1 mg/L, respectively, in the upgradient UMA 043 sample.

The model scenario allowed upgradient groundwater to mix with canal water while undergoing water-mineral reactions. The water chemistry at Cold Springs Reservoir was used to represent the canal water chemistry, because the reservoir is the canal water source. The scenario also utilized carbon dioxide, because water seeps through canal sediments containing organic matter. The model solutions indicate that canal water significantly affects the groundwater chemistry as it moves from UMA 043 downgradient to UMA 041. In fact, the groundwater chemistry at UMA 041 closely resembles the canal leakage water chemistry. Examples of the potential solutions for the model runs include:

UMA041 = [99.99% Cold Springs Reservoir] + [0.01% UMA043]
+ [0.44 Calcite] + [1.0 CO_2] + [0.14 dolomite]
+ [0.82 basalt glass]
- [0.06 exchange (Calcium and Magnesium exchange for Sodium)]

UMA041 = [99.99% Cold Springs Reservoir] + [0.01% UMA043]
+ [0.51 calcite] + [0.882 CO_2] + [0.165 dolomite]
+ [0.132 K-smectite]

The modeling results suggest that the canals do significantly impact groundwater in this area. The model runs indicate that mixing is limited between groundwater and infiltrating canal water locally. This suggests that canal leakage results in the lower salinity canal water displacing the higher salinity groundwater, limiting the mixing between groundwater and canal leakage. Some shallow wells may draw primarily from the low salinity water during periods of canal flow. Presumably,

the low salinity water mixes with ambient groundwater over time and/or distance downgradient.

Nitrogen Isotopic Analyses

The Lower Umatilla Basin groundwater investigation did not include nitrogen isotope sampling and analyses for the City of Umatilla to Hat Rock to Echo Meadows area.

City of Umatilla to Hat Rock to Echo Meadows Area Summary and Conclusions

Multiple techniques were used to analyze the City of Umatilla to Hat Rock to Echo Meadows area groundwater chemistry data. The data analyzed came primarily from project sampling. The analysis led project investigators to the following observations and interpretations:

- Nitrate+nitrite-nitrogen concentrations in samples collected from the area ranged from non detect to 31 mg/L.

- Total dissolved solids concentration exceeded the 500 mg/L secondary (aesthetic) drinking water standard in some samples from Hat Rock, and the terraces north and south of Hermiston.

- Arsenic detections occurred primarily in samples from the Stanfield vicinity. One shallow unconfined alluvial groundwater sample from the A.E. Staley Manufacturing Company wastewater land application site contained arsenic greater than the 0.050 mg/L drinking water standard.

- Area groundwater samples commonly had sodium concentrations greater than the 20 mg/L limit recommended for persons on a physician prescribed sodium restricted diet. Some groundwater samples from the terraces north and south of Hermiston contained sodium greater than 50 mg/L.

- Project and City of Hermiston sampling detected pesticides and volatile organic compounds in alluvial and basalt groundwater. Project sampling detected these constituents in samples from the Hermiston basin, the terrace south of Hermiston, Stanfield, and City of Echo sewage treatment facility areas.

- Analyses indicate dilution from canal leakage influences groundwater within the Hermiston basin and part of the terrace south of Hermiston.

- Nitrate+nitrite-nitrogen remained below 10 mg/L in project groundwater samples collected in the City of Hermiston and Hat Rock areas. Analyses indicate mixed influences.

- Nitrate+nitrite-nitrogen concentrations in most project samples from the terrace north of Hermiston generally measured less than 10 mg/L. However, samples from two sites had concentrations of 12 and 31 mg/L. Analyses indicate a variety of influences. Septic systems appear to influence groundwater at sites where measured nitrate concentrations are low. Septic systems, irrigation, and animal waste appear to independently influence groundwater at different sites where concentrations approach 10 mg/L. Irrigation appears responsible for concentrations exceeding 10 mg/L in groundwater at the two sites mentioned despite the proximity of a feedlot at one of those sites.

- Nitrate+nitrite-nitrogen concentrations measured less than 5 mg/L in project groundwater samples from the Hermiston basin despite the presence of numerous unsewered homes in some areas. Graphical analysis indicates septic systems do influence the local alluvial groundwater chemistry. However, analyses also indicate a significant dilution influence from canal leakage.

- Nitrate+nitrite-nitrogen concentrations exceeded the 10 mg/L drinking water standard in groundwater sampled from several sites on the terrace south of Hermiston. The detection of pesticides in some of these samples and analyses indicate an irrigated crop agriculture influence. Analyses also indicate a septic system influence at some sites.

- Nitrate+nitrite-nitrogen concentrations generally remained below 10 mg/L in project groundwater sampled from the Echo and Umatilla Meadows area. Analyses indicate wastewater influences groundwater at the A.E. Staley Manufacturing Company land application site. Irrigation related activity and canal leakage appear to influence groundwater at other locations.

Evaluating Chemical Trends with Flow Path Analysis: Butter Creek Example

Introduction

Many different chemical and physical processes contribute to natural variations in groundwater chemistry in the Lower Umatilla Basin. Two techniques can be used to identify these various processes and evaluate regional trends in the groundwater chemistry. First, data from individual sample results can be graphed and analyzed for relationships. Second, the chemical changes affecting the water quality along groundwater flow paths can be investigated. The Lower Umatilla Basin investigation did conduct flow path analyses. Despite interconnections, the analysis considered groundwater within the alluvial sediments separately from groundwater in basalt, because they generally occur in different hydrogeologic units.

Nitrate Versus Other Constituent Relationships Basin Wide Show Need for Flow Path Analysis

A basin wide positive correlation exists between nitrate+nitrite-nitrogen and conductivity in Lower Umatilla Basin alluvial groundwater shown in Figure 4.78. This correlation is important, because it indicates that elevated nitrate is associated with higher levels of conductivity which is related to the total dissolved solids (TDS) in the water. The data indicates that the process(es) or activity(ies) that provide nitrate also contribute to higher TDS concentrations. It is possible that the TDS could be acquired independently as water passes from land surface through the vadose (unsaturated) zone to groundwater. However, that would not explain why nitrate correlates so well with TDS.

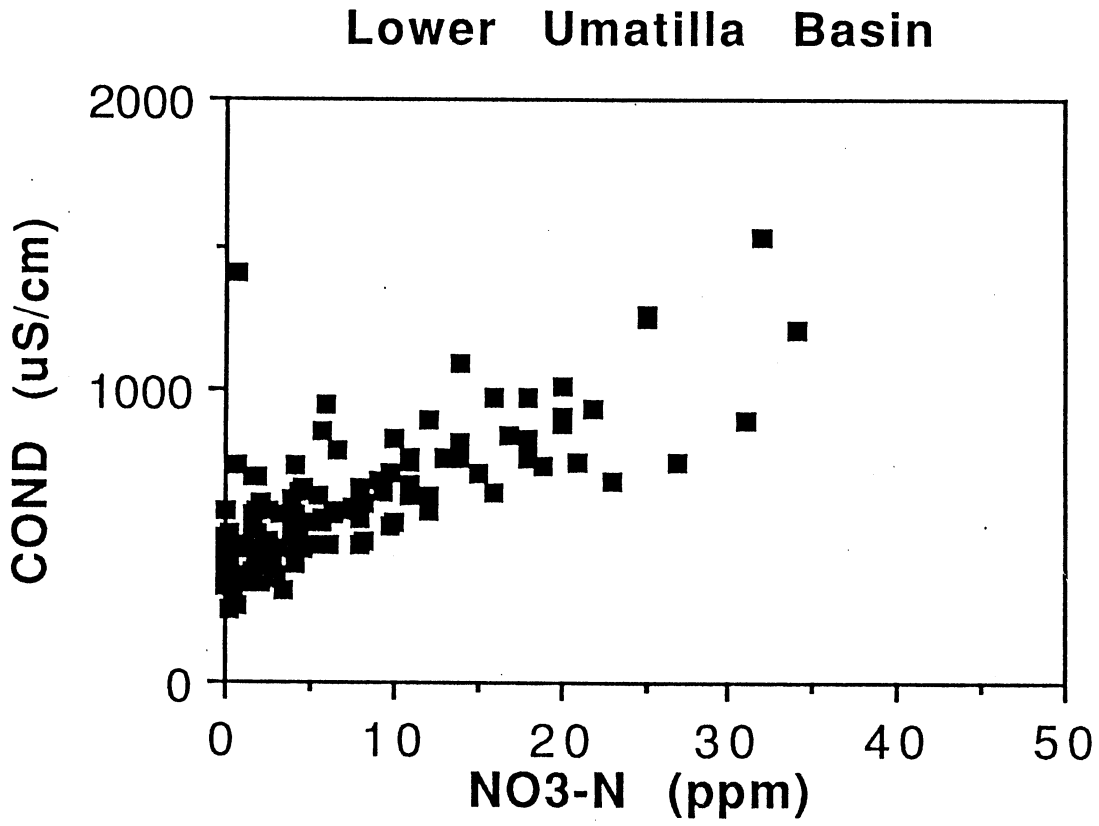


Figure 4.78 Nitrate+nitrite-nitrogen versus electrical conductivity for all project wells sampled in the Lower Umatilla Basin.

Note: The positive correlation.

The basin wide relationship between nitrate and other constituents is not as good as the correlation between nitrate and conductivity . For example, graphs of nitrate versus calcium shows considerable scatter (see Figure 4.79). Graphs of nitrate versus other constituents show even poorer correlations. The poor basin wide correlations indicate that groundwater of significantly different evolutionary histories are being displayed on the same diagram.

The good correlation with nitrate+nitrite-nitrogen exists because electrical conductivity and TDS in groundwater depend less upon the ionic species present than the total ionic concentration. Different groundwater histories can vary the constituents that accompany nitrate in groundwater. However, different chemistry histories can yield similar electrical conductivity values and TDS concentrations.

Nitrate versus other constituent relationships in the basin improves and becomes more understandable along identified groundwater flow paths. For example, Figure 4.80 shows nitrate+nitrite-nitrogen versus calcium for data related to the Butter Creek flow path analyzed. Some scatter is evident. However, the correlation for the Butter Creek flow path data is clearly better than basin wide data. A review of this figure indicates calcium is being added as nitrate is being added to groundwater moving along the Butter Creek flow path.

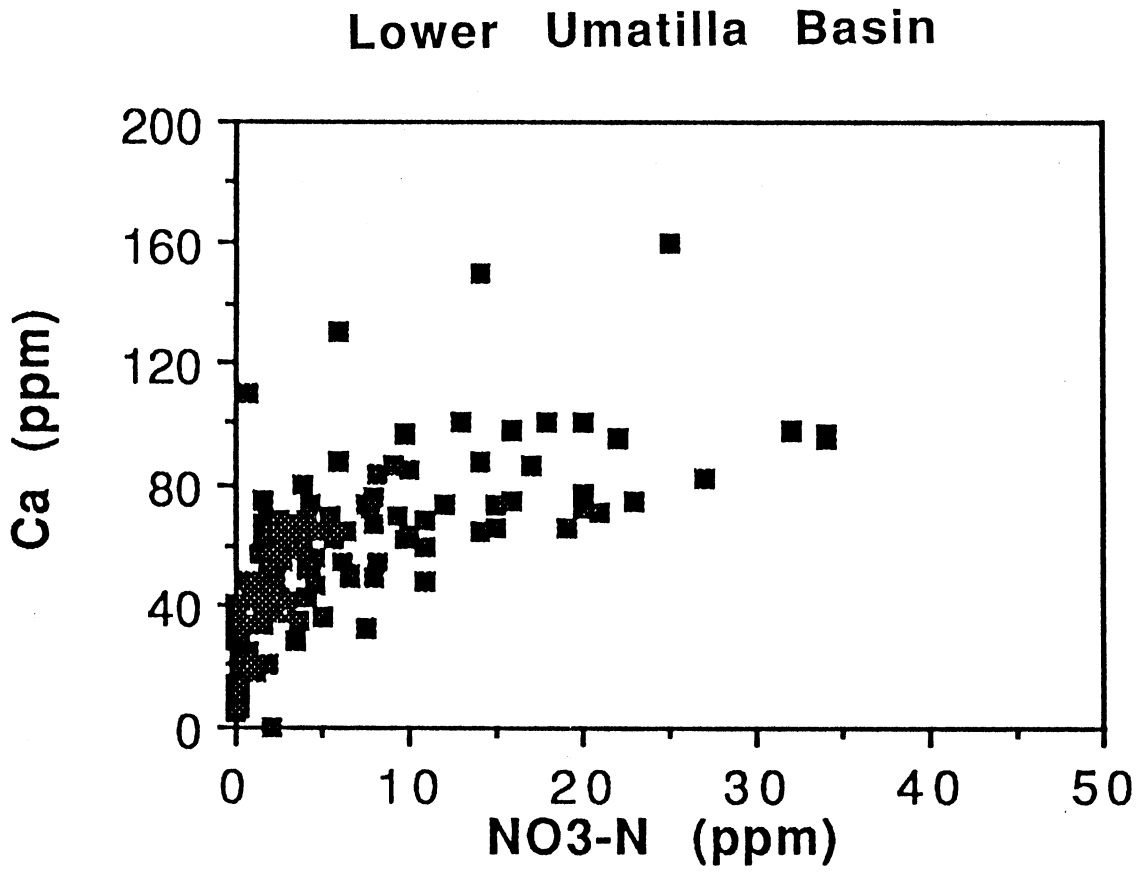


Figure 4.79 Nitrate+nitrite-nitrogen versus calcium for all project groundwater samples.

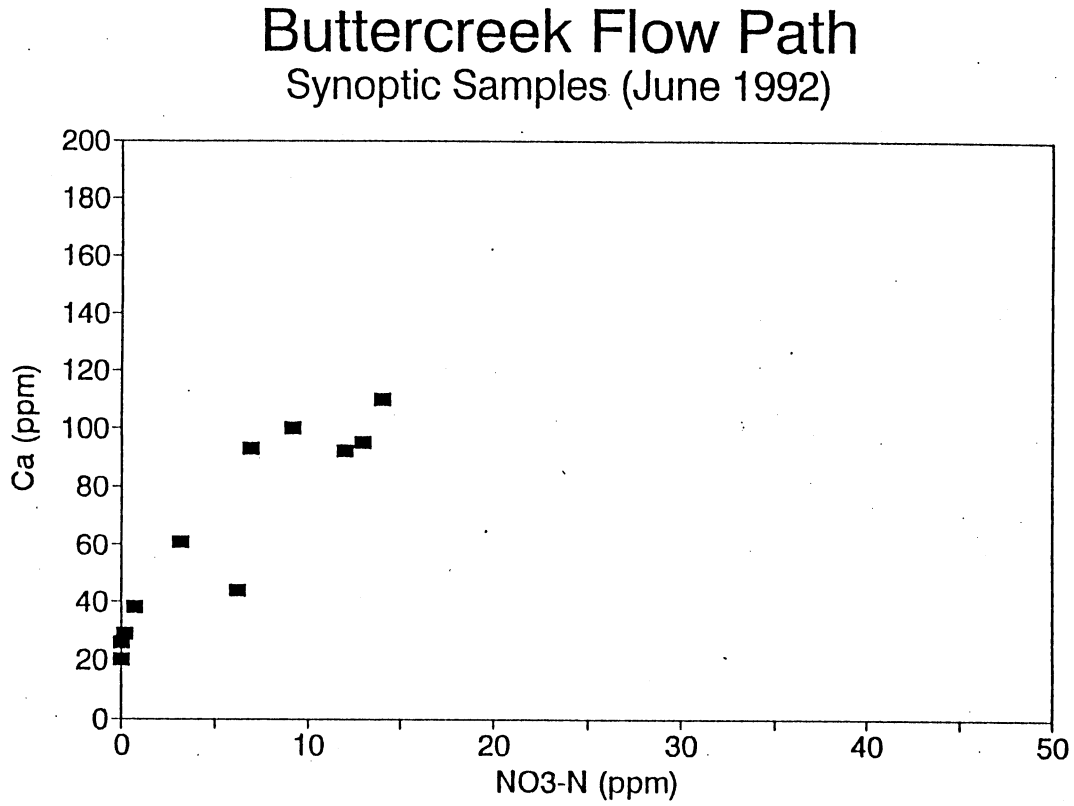


Figure 4.80 Nitrate+nitrite-nitrogen versus calcium for along the Butter Creek Flow path.

Flow Path Analyses in General

Interpreting the evolutionary processes affecting groundwater can best be accomplished by "following" a given mass of water as it migrates through the aquifer, recording the chemical changes that occur in the water, and relating the change to specific processes. "Following" a specific mass of groundwater through the aquifer is clearly not practical. However, the same result can be achieved by identifying an individual flow path and analyzing groundwater from wells along that flow path.

Figure 4.81 illustrates the flow path analysis concept. Recharge water enters the aquifer in an upgradient area where it begins to migrate downgradient. As the water moves along the flow path, it chemically evolves due to various processes and influences. Simultaneously sampling groundwater from wells along the flow path will provide a view of how the groundwater chemistry evolves along the flow path as long as no significant changes in the processes affecting the groundwater chemistry has occurred.

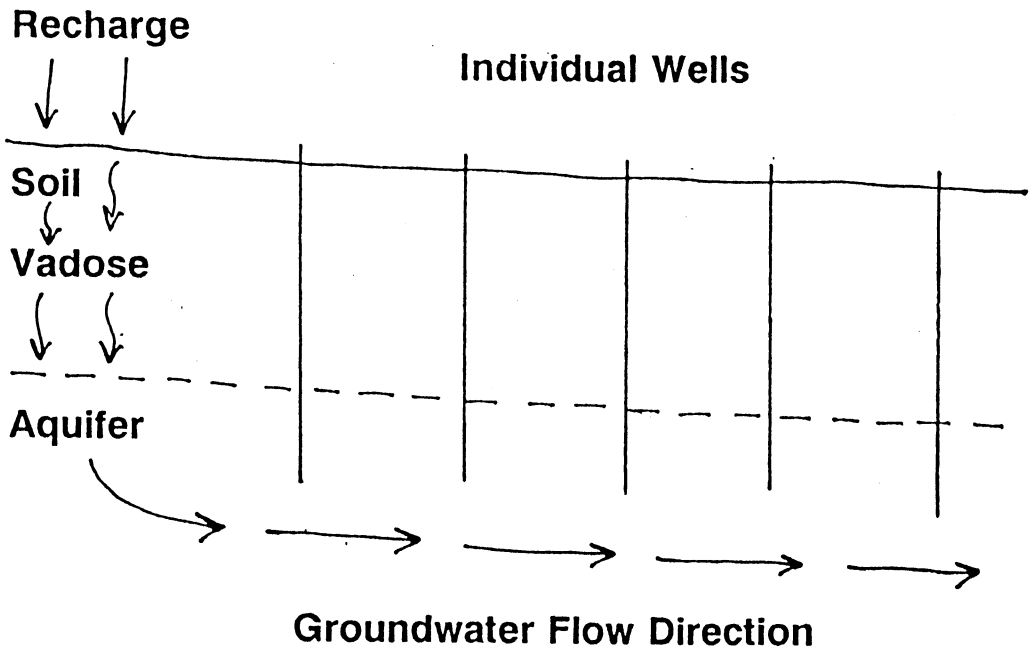


Figure 4.81 Diagrammatic representation of wells located along a groundwater flow path and obtaining water from the same aquifer.

Butter Creek Flow Path

The Butter Creek area was selected for a flow path analysis. Project hydrogeologic investigation results were used to identify groundwater flow paths within the drainage. The analysis used project sampling data related to wells located along a flow path of interest which obtain groundwater from the sediments only. This data selection constraint was necessary to obtain a view of the apparent chemical variations occurring in alluvial groundwater along a single flow path. This view would then provide a basis for determining the mechanism(s) by which chemical change was occurring and perhaps contributing to nitrate loading. Similar methods could be used for other geographic areas in the Lower Umatilla Basin.

Alluvial Aquifer Along the Butter Creek Flow Path

Data related to wells completed in the alluvial sediments only along the Butter Creek flow path of interest were selected for analysis. The path of interest passes among wells UMA 185, 120, 122, 081, 084, 073, 088, 119, 070, and 077. The well site locations are shown in Figure 4.82.

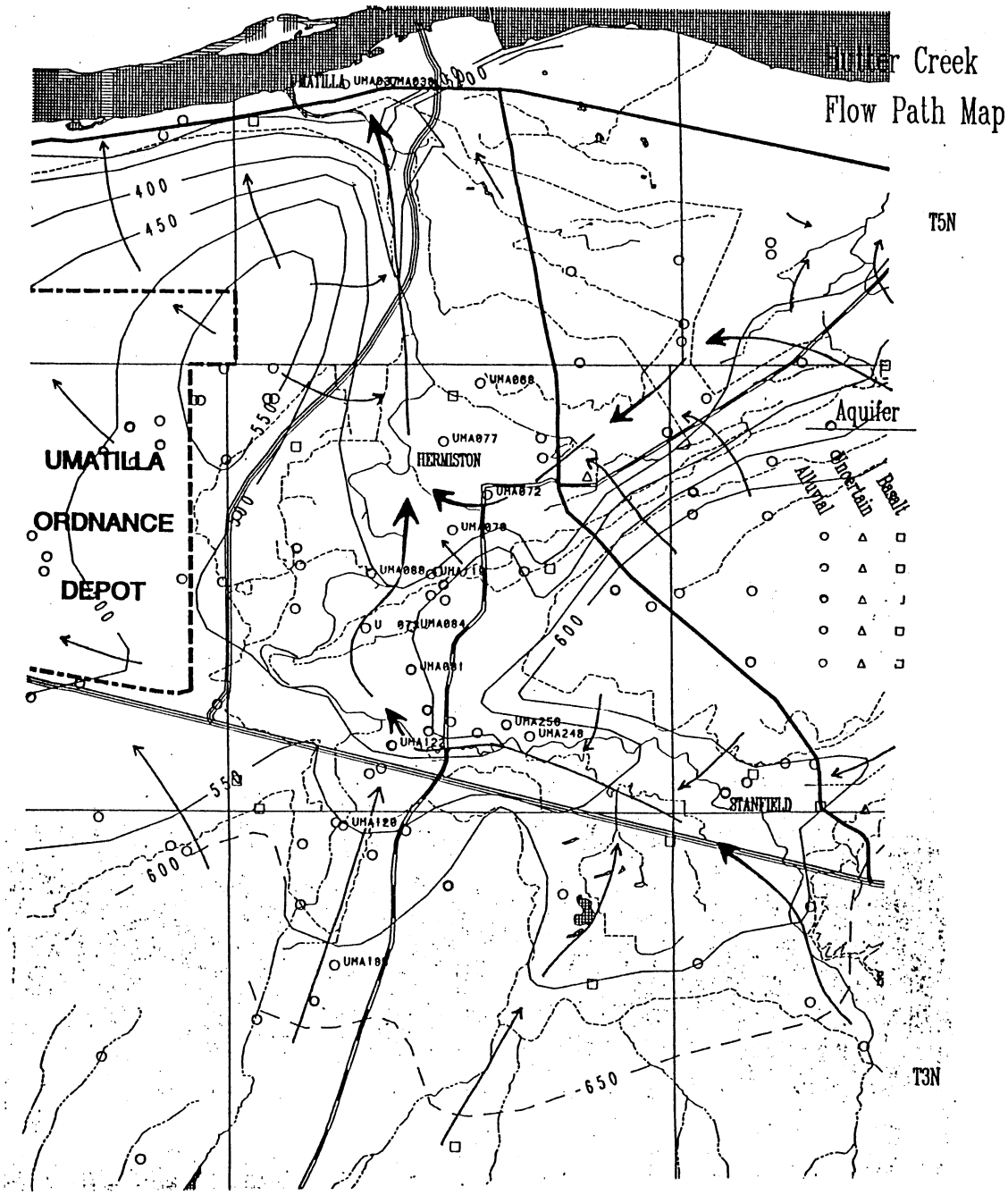


Figure 4.82 Butter Creek flow path map.

Note: Contours represent the potentiometric surface.

Note: Arrows indicate groundwater flow directions.

Mineralogy

The alluvial aquifer hosting the Butter Creek flow path is glaciofluvial in origin and consists largely of basaltic fragments varying in size from small boulders to sand. The primary mineralogy of the basalt fragments probably consists of plagioclase, clinopyroxene and volcanic glass. Allen and Strope (1983) indicate that volcanic glass may comprise from approximately 7 to over 30 percent of typical basalt.

Wright and others (1994) performed an extensive study of the mineralogy of similar sediments from the middle Ringold Formation at the Hanford site northwest of Richland Washington. Their analyses indicated a widely variable mineralogy including rock fragments (trace to 89%), quartz (4 to 84%), feldspar (1 to 29%) and clay (trace to 14%). The clay minerals were dominated by smectite and illite, with lesser chlorite and kaolinite. Hearn and others (1985) evaluated the secondary alteration products of Columbia River Basalt aquifers using drill cores and outcrops. They found smectite ($Si_{3.67}Al_{0.76}Fe_{1.11}Mg_{0.71}Ca_{0.15}Na_{0.07}K_{0.09}O_{10}(OH)_2$) and the zeolite clinoptilite ($Si_{14.34}Al_{3.66}Fe_{0.20}Mg_{0.10}Ca_{0.48}Na_{0.88}K_{0.94}O_{36}$), iron oxide and various forms of silica. In an arid environment like the Lower Umatilla Basin, additional secondary minerals may form in the unsaturated zone such as dolomite ($CaMg(CO_3)_2$), gypsum ($CaSO_4 \cdot 2H_2O$) and perhaps halite (NaCl). An assessment of the groundwater chemistry indicates mirabilite ($Na_2SO_4 \cdot 10H_2O$) may be the secondary mineral in some cases.

Groundwater Chemistry

Whether or not a given mineral will precipitate or dissolve from a specific water depends on the water's chemical state. For example, when a mineral such as calcite ($CaCO_3$) is placed in water undersaturated with respect to that mineral, calcite will begin to dissolve, contributing calcium [Ca^{2+}] and carbonate [CO_3^{2-}] to the solution. How much calcite dissolves depends on the solubility product of the mineral and the pH, temperature and dissolved load of the solution. When the product of their concentrations, or more precisely the activities, of calcium and carbonate reach a level equivalent to the solubility product, calcite will dissolve no further and the solution is saturated. The state of saturation can be expressed as the saturation index (SI), which for calcite is a ratio of the calcium and carbonate in solution to the solubility product. A SI index of 1 indicates saturation, greater than 1 indicates oversaturation, and less than 1 indicates undersaturation. The SI may change as water moves along a flow path owing to changes in the chemical state of the solution.

The groundwater chemistry computer model program NETPATH was used to evaluate the chemical relationship between groundwater and the aquifer material along the Butter Creek flow path. The program uses a modified version of WATEQF (Plummer and others, 1976) to calculate the identity and concentrations of dissolved species in a solution, and determine the saturation indices for a range of potential minerals for the water in question. The model input is a chemical analysis of the water.

The primary minerals in the alluvial aquifer include plagioclase and pyroxene. These primary minerals have very low solubilities and probably play a minor role in influencing the overall groundwater chemistry along a flow path. However, basaltic glass (Allen and Strope, 1983) may be an important influence on the chemical evolution of groundwater in the Lower Umatilla Basin area (Hearn and others, 1985, Hinkle, 1994) since basalt detritus makes up an important part of the alluvial sediments. The modeling effort used the composition of entablature glass as reported by Allen and Strope:

$$Si_{8.804}Ti_{0.1.69}Al_{2.272}Fe_{0.198}Mg_{0.105}Ca_{0.558}Na_{1.254}K_{0.466}P_{0.083}O_{24}$$

An additional concern are the secondary minerals that may occur in the alluvial sediments such as calcite, clay minerals, e.g smectite and clinoptilite are common (Hearn and others, 1985, Wright and others, 1994). Gypsum (or mirabilite), dolomite and halite may occur in small quantities.

Figure 4.83 shows the SI values for calcite, dolomite ($CaMg[CO_3]_2$) and gypsum ($CaSO_4.2H_2O$) along the flow path. Gypsum remains undersaturated (SI less than 1) in the groundwater along the entire flow path, while calcite and dolomite vary from undersaturated to oversaturated (SI greater than 1). These calculations indicate that none of the groundwater recognized along the flow path will precipitate gypsum (or mirabilite); calcite and dolomite can either precipitate or dissolve, depending where in the flow path the water is travelling. Other aspects of the water chemistry seen in Figure 4.84 indicates that the Butter Creek groundwater is in equilibrium with smectite. This clay mineral group is a common alteration product of basalt (e.g. Hearn and others, 1985, and Wright and others, 1994).

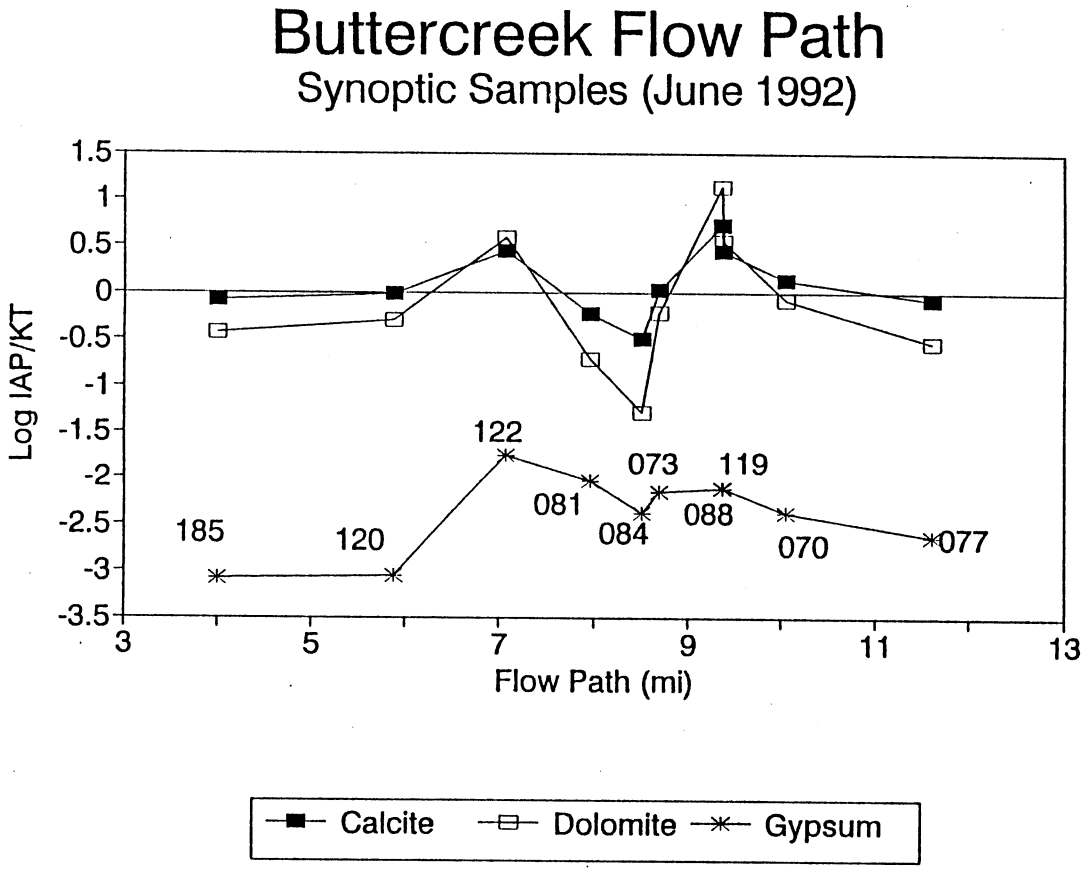


Figure 4.83 Saturation indices for calcite, dolomite, and gypsum along the Butter Creek flow path.

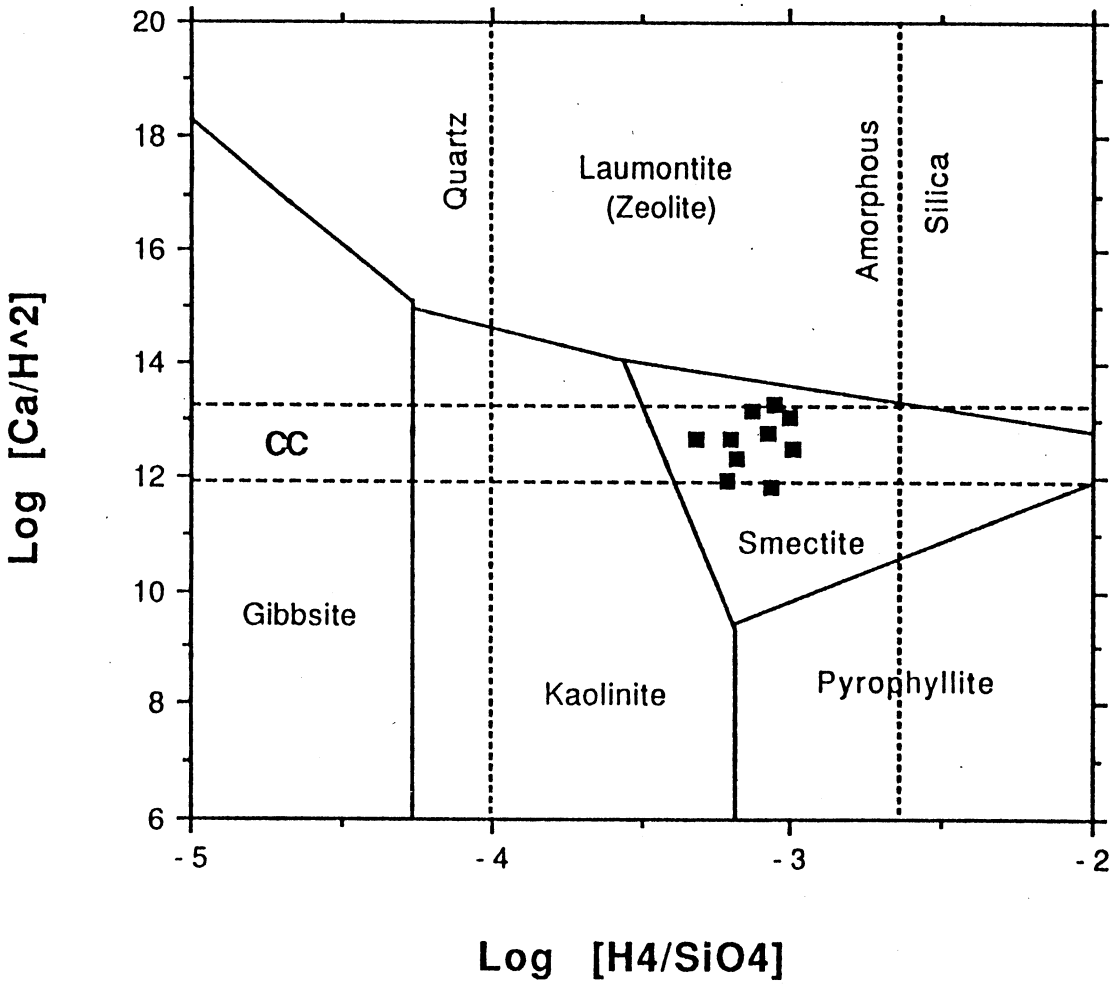


Figure 4.84 Ion activity graph.

Butter Creek Flow Path Analysis

Trends and Anomalies Observed Along the Flow Path

Analysis of the Butter Creek flow path data indicated several trends and anomalies. Figure 4.85 shows the variation of calcium, chloride, and nitrate+nitrite-nitrogen from the synoptic sampling along the flow path from an upgradient well, UMA 185, to downgradient wells such as UMA 077. It is apparent that the trends for all constituents are not characterized by progressive increases downgradient as might be expected if calcium and chloride resulted solely from progressive water-rock reactions or if NO_3-N resulting solely from nonpoint source loading. Instead, a concentration high is seen in the 7 to 9.5 mile range of the flow path. Several potential explanations exist to account for the compositional anomaly.

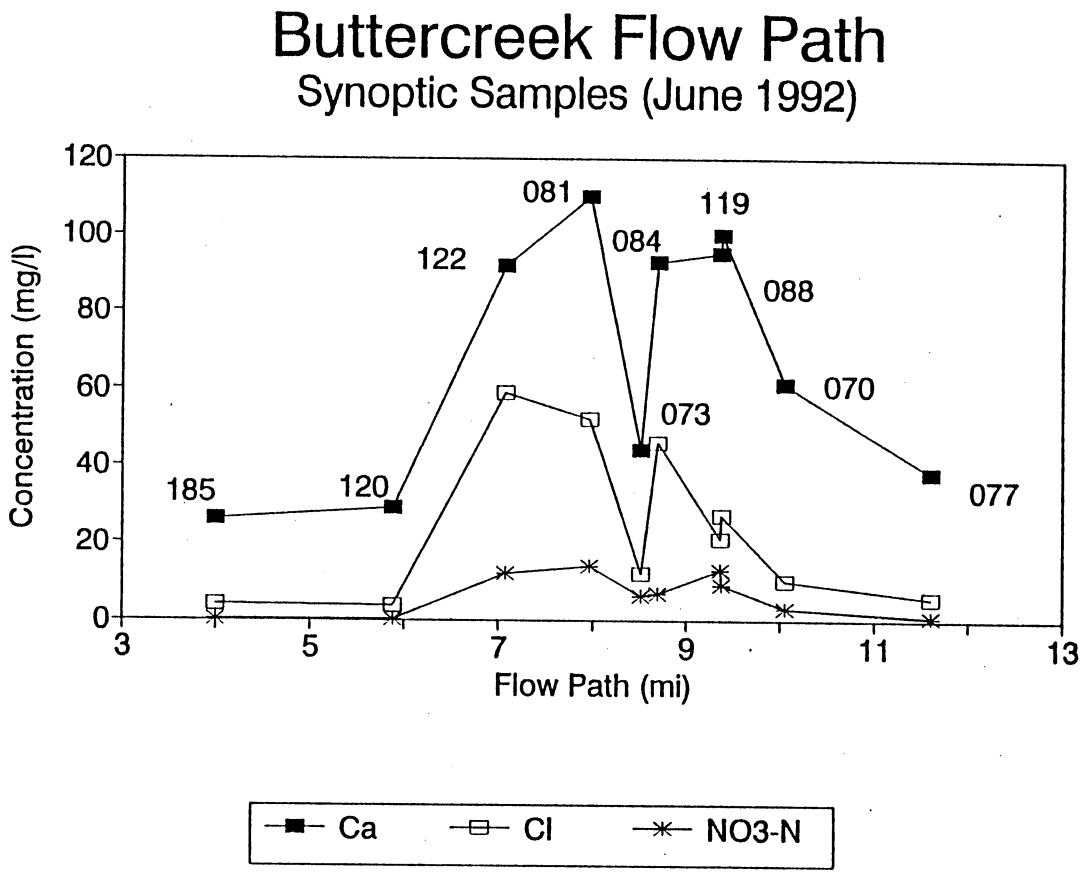


Figure 4.85 Variation of calcium, chloride, and nitrate+nitrite-nitrogen along the Butter Creek flow path for project synoptic sampling data.

One potential explanation for the concentration high is that the TDS compositions represent wells completed within the fine-grained sediments of the alluvial aquifer while the lower concentrations represent samples from the coarse-grained sediments. The rationale here is that water within the fine-grained sediments would experience a longer residence time owing to the lower hydraulic conductivity of those sediments.

As part of this hydrogeologic assessment, individual well logs were evaluated and the producing aquifer identified. Within the Butter Creek flow path, all wells except UMA 185, UMA 120, and UMA 122 are completed in the coarse-grained sediments. The other three wells are producing from the fine-grained sediments. It is evident from Figure 4.85 that the high (and low) concentrations occur in both sediments. Therefore, it is unlikely that residence time is the origin of all the chemical variation observed along the Butter Creek flow path.

A second potential explanation for the concentration high is that it represents a "snapshot" of a high TDS/nitrate pulse moving through the aquifer from some undetermined upgradient source. To evaluate this hypothesis, a representative set of Butter Creek wells were selected for bimonthly sampling. Figure 4.86 shows the nitrate+nitrite-nitrogen concentrations in groundwater along the Butter Creek flow path using data from the reconnaissance sampling phase (composite) and several of the bimonthly sampling events. The reconnaissance samples were collected over 14 months. The bimonthly samples were collected concurrently. The stationary peak implies that there is no tendency for concentrations to shift in the downgradient direction with time. The data suggests that the source of the dissolved constituents and elevated nitrate is local and, with some seasonal variations, is continuous. Concentrations in samples from a single well do vary over a short time period. For example, well UMA 119 samples varied in nitrate content from approximately 4 mg/L in October, 1991 to more than 15 mg/L in January 1992.

Nitrate Relationship to Other Constituents Along the Flow Path

A review of Figure 4.85 indicates calcium and chloride concentrations correlate well with nitrate. Correlations between nitrate and other constituents is less clear. For example sodium and sulfate reach elevated concentrations within the 7 to 9.5 mile flow path window (Figure 4.87). However, they vary independently from each other and from calcium, chloride, and nitrate. This indicates several influences affect the groundwater chemistry along the Butter Creek flow path, but not all of the influences contribute nitrate.

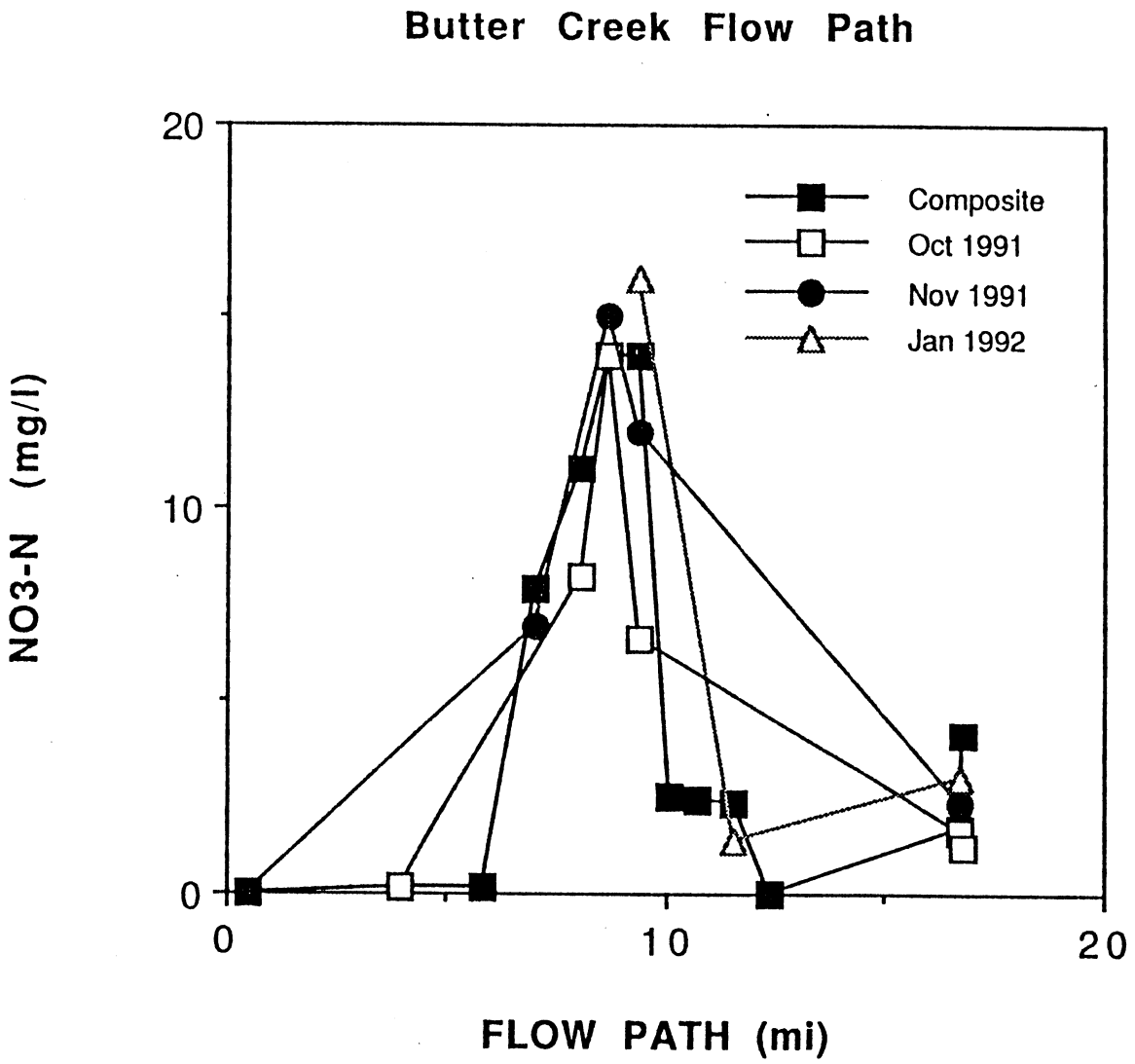


Figure 4.86 Nitrate+nitrite-nitrogen concentrations along the Butter Creek flow path at different sampling times.

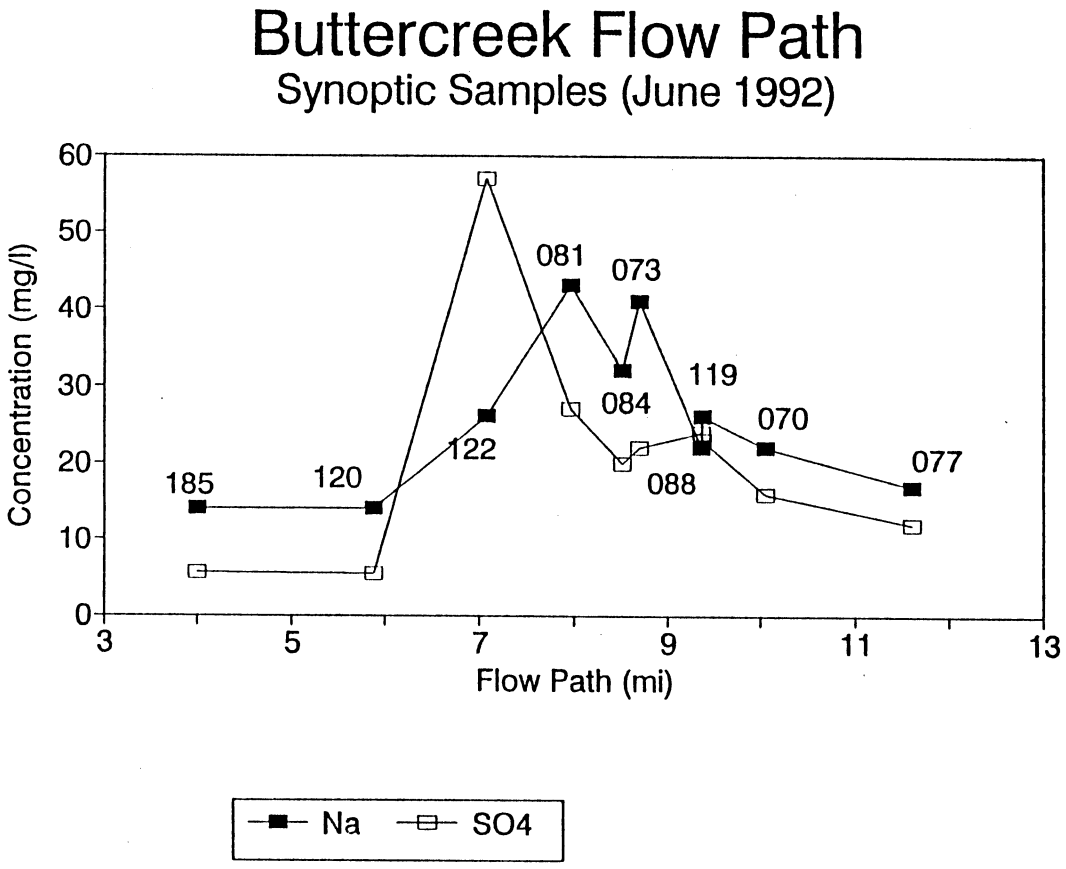


Figure 4.87 Sodium and sulfate concentrations along the Butter Creek flow path.

Similar arguments can be made for a "flow path" through the U.S. Army Depot. Figure 4.45 shows the variation of calcium and chloride along the flow path. Like the Butter Creek flow path, calcium and chloride correlate better with nitrate than do sodium and sulfate. Variations observed along the flow path indicate more than one source contributes nitrate and the higher TDS water which carries the nitrate to groundwater.

Evaluation of Groundwater Chemistry Changes at a Wastewater Irrigation Circle

A goal of the geochemical effort was to identify and characterize the natural processes by which groundwater evolves along a flow path. Once the natural processes are identified, the influence of human activity upon the groundwater chemistry may be more readily recognized. The NETPATH groundwater chemistry computer model was used to accomplish this task.

Chemical variations along the Butter Creek flow path were analyzed and appropriate compositions were evaluated using the mass balance program NETPATH. To test the application of NETPATH to groundwater in the area, samples that were hydrogeologically well-constrained were selected. For this exercise, wells immediately upgradient and downgradient of a single Simplot irrigation circle (field 1A) were chosen. A pair of shallow and deep wells occur in both the up- and downgradient positions (Figure 4.88). The shallow wells are in the coarse-grained portion of the alluvial aquifer while the deep wells produce from the fine-grained portion of the alluvial aquifer.

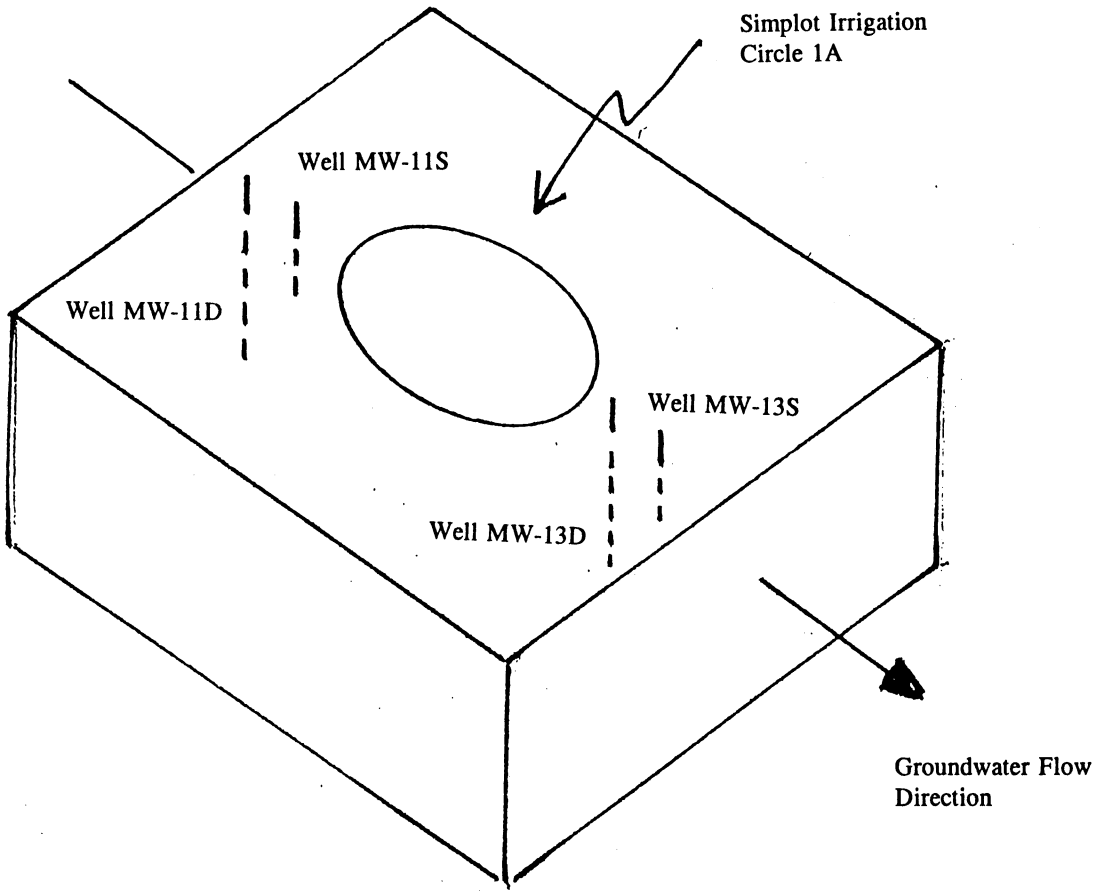


Figure 4.88 Schematic diagram of J.R. Simplot Company wastewater irrigation circle 1A showing shallow and deep well locations as well as groundwater flow directions.

Significant chemical differences exist between the shallow and deep wells and between the upgradient and downgradient wells as shown in Figure 4.89. The constituent concentrations in groundwater from the shallow well (Simplot MW-13S, UMA 246) are considerably higher than in groundwater from the corresponding deep well (Simplot MW-13D, UMA 247). Simplot well MW-13D is downgradient of Simplot well MW-11D (UMA 245). Most constituent concentrations in groundwater at MW-13D are higher than in groundwater at the upgradient well MW-11D.

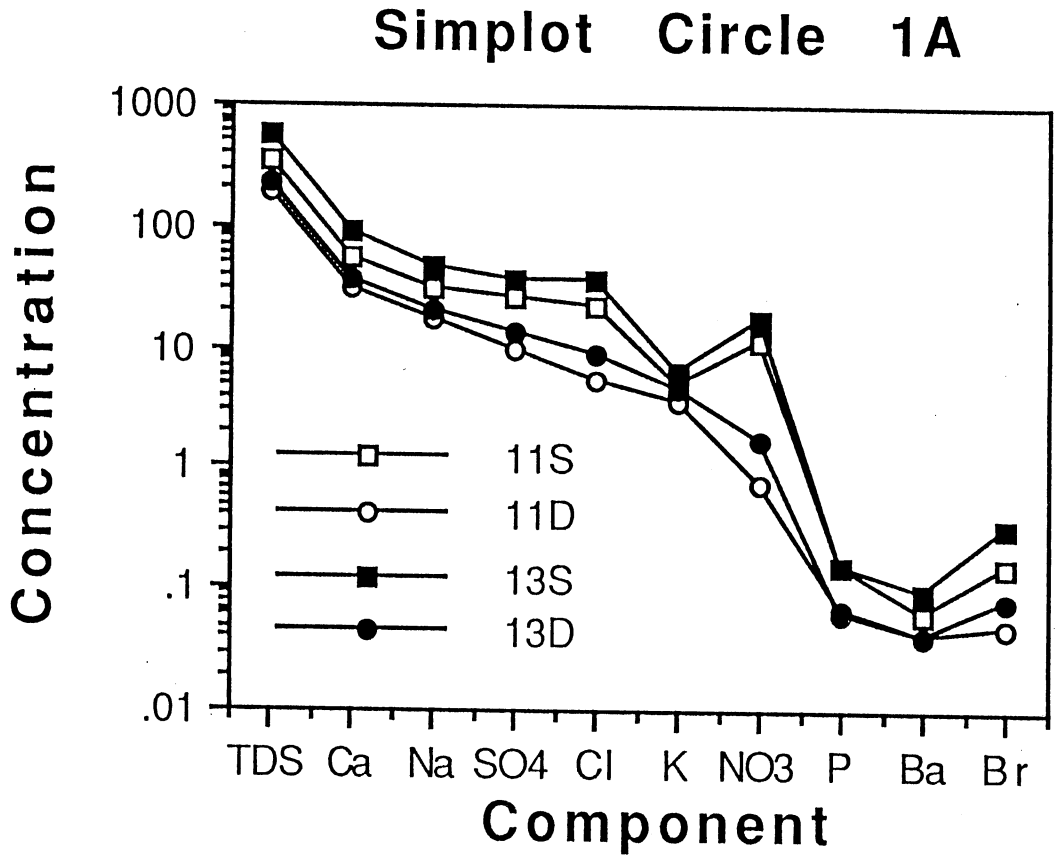


Figure 4.89 Schoeller Diagram showing constituent concentrations in alluvial groundwater sampled from shallow and deep upgradient wells (MW-11S, MW-11D) and shallow and deep downgradient wells (MW-13S, MW-11D) at Simplot wastewater irrigation circle 1A.

NETPATH was used to explore two hypotheses. First, could downward percolation of shallow unconfined alluvial groundwater explain the groundwater chemistry in groundwater samples from the deeper wells? Second, is the groundwater chemistry at the downgradient deep well a result of chemical evolution as groundwater flows from the upgradient deep well to the downgradient deep well? PCWATEQ was run on all four compositions in order to provide modeling constraints.

Relevant to the first question is the observation that groundwater from both the shallow and deep wells are undersaturated with respect to halite (NaCl) and gypsum. If the deeper groundwater originated solely through downward percolation of the shallow water, modeling results suggest it could do so only through extensive precipitation of these two phases which is not possible given the undersaturated conditions. This does not preclude the presence of the some shallow water in the deeper zone. It is evident, though, that the deeper groundwater must contain a significant portion of regional groundwater moving downgradient.

In evaluating the second question, a significant issue is the nitrate increase from 0.72 mg/L at the upgradient Simplot well MW-11D to 1.7 mg/L at the downgradient Simplot well MW-13D. No natural source of nitrate is known to occur in the alluvial groundwater. So, the increase implies the addition of nitrate from above. As a result, the evolution of deeper groundwater from Simplot MW-11D to Simplot MW-13 was considered to involve both water-mineral reactions and mixing between the deep and shallow waters.

The NETPATH program was used to search for solutions for the equation:

MW-11D + MW-13S + minerals dissolved = MW-13D + minerals precipitated

The program was directed to base its search on the constituents sulfur, calcium, magnesium, sodium, chloride, and carbon, and to assume that basalt glass, mirabilite, dolomite and halite could only dissolve, and smectite and clinoptilite could only precipitate. Cation exchange involving calcium, magnesium, and sodium was also allowed to operate. No unique solution was determined. The following summarizes the computer's solutions:

MW-13D = [88-92% MW-11D] + [8-12% MW-13S]
+ [dissolving minerals (mirabilite, halite, calcite, with lesser dolomite, augite and basaltic glass)]
- [precipitating minerals (smectite, clinoptilite and calcite)]
+ [cation exchange (Na replacing Ca and Mg on clay surfaces)]

All model runs required the dissolution of mirabilite. Most runs involved calcite either dissolving or precipitating and the precipitation of smectite. Dissolution of halite and the precipitation of clinoptilite occurred in many of the model runs. Dissolution of the primary phases augite and basalt glass appeared less important. Many model run results suggested that carbon dioxide was lost during the reaction.

Given the short distance between the shallow and deep wells (less than 1 mile), it is considered that mixing constitutes the bulk of the evolutionary changes along the flow path. To independently test this model, the concentrations of a number of components not considered in the model above were subjected to simple mass balance calculations to determine how predicted versus observed concentrations compared. Table 4.39 provides the results of the comparison. Although some discrepancies exist, the NETPATH model is supported by the calculations in Table 4.39. The results indicate that shallow groundwater, presumably originating as water applied within the irrigation circle, has impacted deeper regional groundwater.

Table 4.39 Comparison of upgradient versus observed and predicted downgradient constituent concentrations in MW 13D groundwater at Simplot wastewater irrigation circle 1A.

Component	11D	13S	Predicted	Observed	Difference
NO_3-N	0.72	18	2.8	1.7	1.1
K	3.6	6.5	3.9	4.5	0.6
Br	0.05	0.32	0.08	0.08	0
Ba	0.04	0.09	0.046	0.04	0.006
PO_4-P	0.07	0.15	0.08	0.06	0.02
TDS	190	550	233	230	3

Note: NETPATH model suggests an evolution involving ~88% upgradient deep well (MW-11D) + ~12% of the downgradient well (MW-13S) composition $\pm$ mineral reactions. The predicted values below are based on simple mass balance calculations alone using the above proportions of end members.

Note: All concentrations are in mg/L.

The origin of the shallow groundwater remains somewhat equivocal, although its location certainly suggests a relationship to land applied food processing wastewater. Comparison of the Simplot irrigation lagoon (project sampling site 404487) water chemistry with the chemistry of groundwater from MW-13S (UMA 246) indicates significant differences between the two. However, a direct comparison between the two is not conclusive, because of the potential processes that could occur in the unsaturated zone after the wastewater is land applied.

The impact of cyclic wetting and drying (Drever and Smith, 1978) on water chemistry was explored using the NETPATH model. In this process, complete evaporation of the applied water occurs during the periods between irrigation. All of the solutes within the water are deposited as mineral phases within the soil or vadose zone (Tedaldi and Loehr, 1992). Re-dissolution occurs during subsequent irrigation or precipitation. If sufficient water is applied, leaching of the "remobilized" solutes may occur.

To test this hypothesis, it was assumed that water similar to the lagoon water was allowed to evaporate to dryness within the vadose zone. The final concentration of solutes within the brine at the final stages of evaporation would be much higher than observed by this investigation. Obtaining samples with these concentrations should not be expected given the small volume of water remaining after evaporation. Evaporation would presumably cause all of the solutes to precipitate as solid phases. Using the model of Hardie and Eugster (1970), as modified by Drever (1982), and the chemistry of the lagoon water, specifically the ratio of alkalinity to calcium and magnesium, the following phases were considered likely to precipitate: magnesium-calcite, dolomite, nahcolite ($NaHCO_3$), mirabilite ($Na_2SO_4 \cdot 10H_2O$), halite (NaCl), potassium-smectite and magnesium-smectite. Cation exchange involving calcium and sodium ions was also considered.

Flushing the system with the lagoon water or water from Simplot's main production well (#3) could not account for the observed composition in groundwater from Simplot well MW-13S. The elevated chloride concentrations in these sources required the precipitation of halite, a process considered unlikely here.

Dilute water, represented as the Umatilla River water (project sampling site 404488), was allowed to flush through the system. This process yielded five successful model runs, involving the dissolution of variable proportions of the above phases. So, a possible origin of the shallow unconfined groundwater in MW-13S is cyclic evaporation-dissolution, where repeated application-evaporation of wastewater leads to the precipitation of dissolved salts in the soil and vadose zone. Subsequent "flushing" of this zone with more dilute waters leads to dissolution of those phases and leaching of the components downward.

Evaluation of Groundwater Chemistry Changes Along Butter Creek Flow Path Segments

Analysis of UMA 185 to UMA 120: Natural Water-Mineral Reactions

In order to recognize the various sources of nitrate loading that may have affected groundwater compositions in the Lower Umatilla Basin area, it is useful to understand the compositional controls that are the result of natural water-mineral reactions within the saturated zone. Because of the diverse and widespread array of potential nitrate sources within the Butter Creek drainage, it is difficult to find an unimpacted segment along the flow path. The most likely segment is upgradient from the TDS high, represented by wells UMA 185 and UMA 120. However, because of the short length of this flow path segment, chemical variations that occur along it are small. Real variations, here assumed to be greater than 5 percent, occur only in calcium, magnesium, and potassium.

The following solid phases were allowed to participate in the model: basalt glass, plagioclase and clinopyroxene, calcium-, magnesium- and potassium-montmorillonite (a clay mineral), calcite, dolomite, gypsum. Note that mirabilite could not be modeled because sodium and sulfate did not show significant variations. Basalt glass, plagioclase, and clinopyroxene are primary solid phases in basalt whereas the other phases represent minerals formed during the low temperature alteration of basalt. Modeling scenarios that required the precipitation of calcite or dolomite were rejected for reasons based on SI values found in Figure 4.83.

NETPATH generated a significant number of "solutions" since the model was constrained by only three elements. The "successful" models indicated that the bulk of the variation could be accounted for by interaction of the groundwater with basalt glass and clay minerals, with less contribution from the secondary minerals gypsum, calcite and dolomite. Primary phases, such as plagioclase or clinopyroxene, played only a minor role in the models. These results confirmed those generated from the SIMPLOT circle: groundwater does undergo minor changes along the flow path as a result of water-mineral reactions, typical of a groundwater-basalt system.

Compositional Anomalies

Abrupt constituent variations were observed along the Butter Creek flow path between UMA 120 and UMA 122 and between UMA 081 and UMA 073 (see Figure 4.85). In the first case, a significant increase in dissolved constituents occur, which includes nitrate. In the second case, an abrupt decrease in the same constituents is observed. Modeling was performed in order to determine the potential origin of these anomalies and how they might affect the distribution of nitrate in the area.

The local data plot as linear arrays on a Piper trilinear diagram (see Figure 4.89). The linear arrays are consistent with mixing as an evolutionary process. Two distinct trends diverge from Wells UMA 120 and UMA 185. One trend is defined by increasing potassium and sodium toward the chemistry of waters from a food-processing irrigation lagoon and a nearby Simplot monitoring well (MW-20, UMA 258). The second trend is defined by increasing chloride and sulfate ions. It is represented by temporal variation in Well UMA 122. An end member for this trend has yet to be identified, although the trend may be related to the evaporation-dissolution process discussed above. Similar arguments may be applicable to temporal variation observed in UMA 190, along the North Hermiston Terrace and in the Echo-Stanfield area discussed earlier in this chapter. Given the implication for mixing from the Piper diagrams, the evolution of the compositional anomalies was modeled as a combination of water mineral reactions (UMA 185 to UMA 120) and mixing with additional source waters.

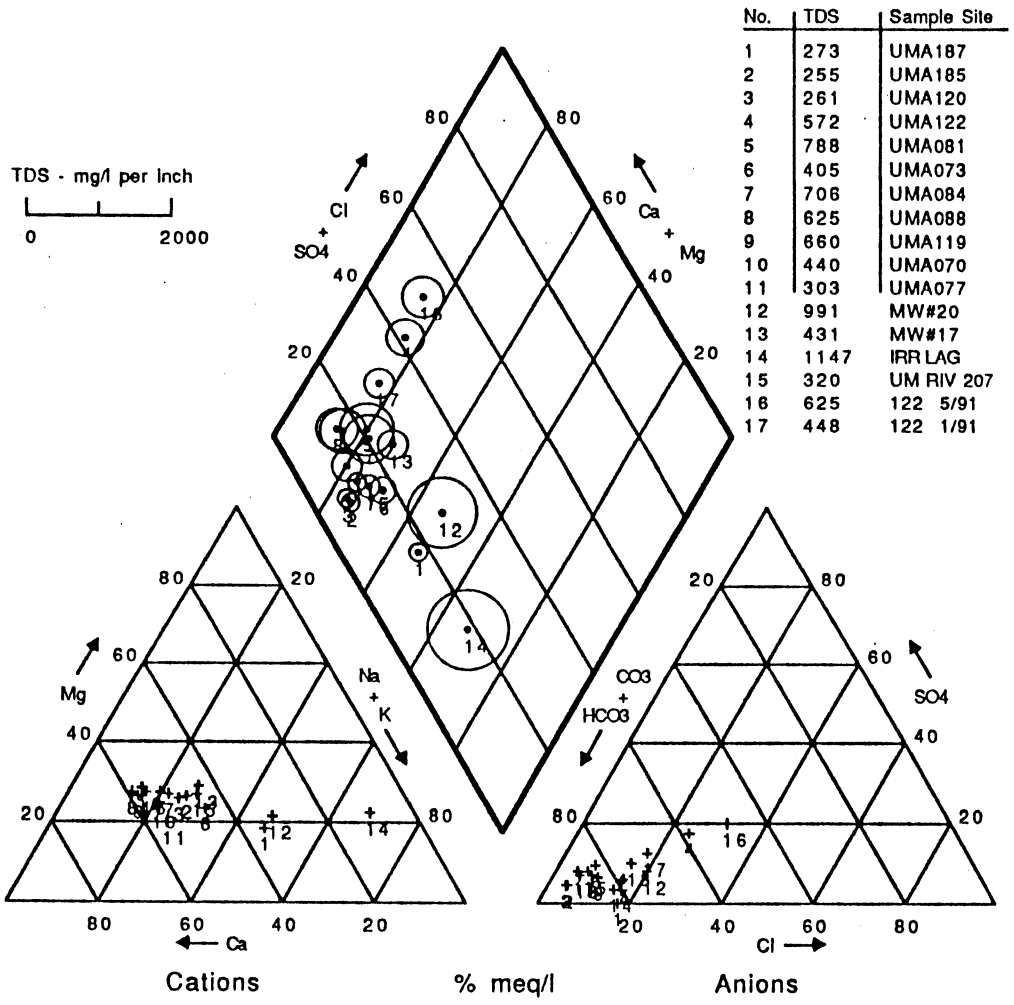


Figure 4.90 Piper Trilinear Diagram of Butter Creek flow path data.

Analysis of UMA 120 to UMA 122: Mixing and Evaporation-Dissolution Influences.

Abrupt increases in most constituents were detected in groundwater between the UMA 120 and UMA 122 sites during the June-July 1992 project synoptic sampling (see Figure 4.85). Figure 4.90, a modified Schoeller diagram (Tedaldi and Loehr, 1992) shows this increase. The various concentrations are normalized to (divided by) the least evolved chemical composition which is the sample from UMA 185. The pattern produced on the diagram represents a compositional fingerprint of the water. Also plotted on Figure 4.90 is the chemistry for shallow unconfined groundwater from Simplot monitoring well MW-20 (UMA 258). Although the chemistry related to MW-20 does not lie on the mixing line defined by temporal variations in UMA 122, the overall pattern is very similar. Similar arguments can be made based on ionic ratios. The ratio of elements shown in Figure 4.91 indicates the groundwater chemistry at UMA 185 and UMA 120 are very similar. Groundwater at UMA 122 differs significantly from groundwater at UMA 185 and UMA 120, but it is similar to groundwater at MW-20 as shown in Figure 4.90.

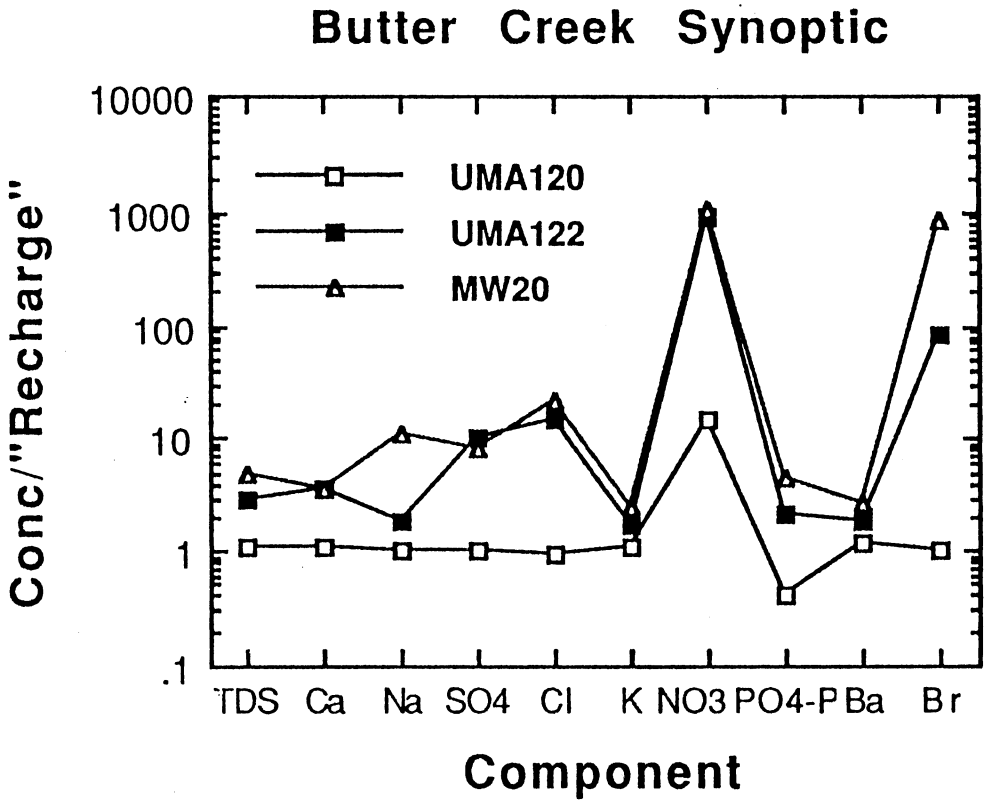


Figure 4.91 Modified Schoeller Diagram of the groundwater chemistry at UMA 120, UMA 122 and Simplot MW-20 (UMA 258).

Note: The "recharge" water compositions are normalized using UMA 185.

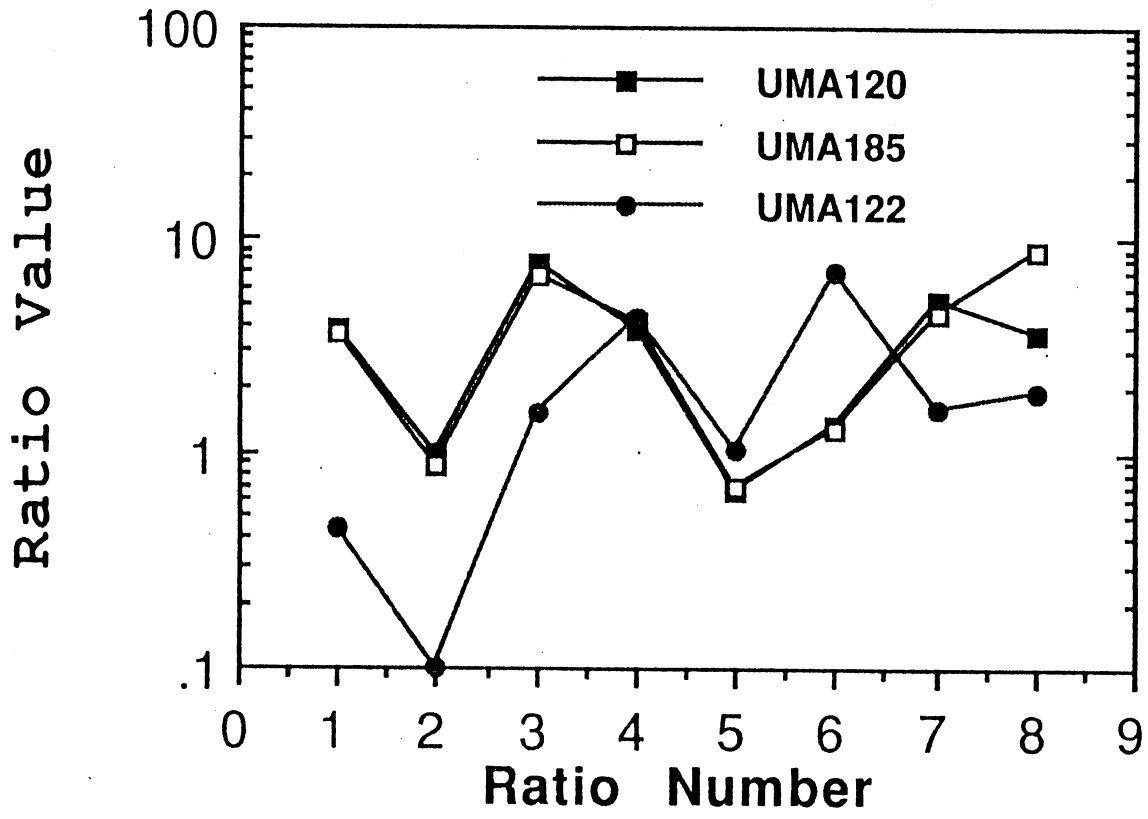


Figure 4.92 Ionic ratios for constituents in groundwater at UMA 185, UMA 120, UMA 122.

Note: There is a marked difference between UMA 122 and the upgradient compositions at UMA 120 and UMA 185.

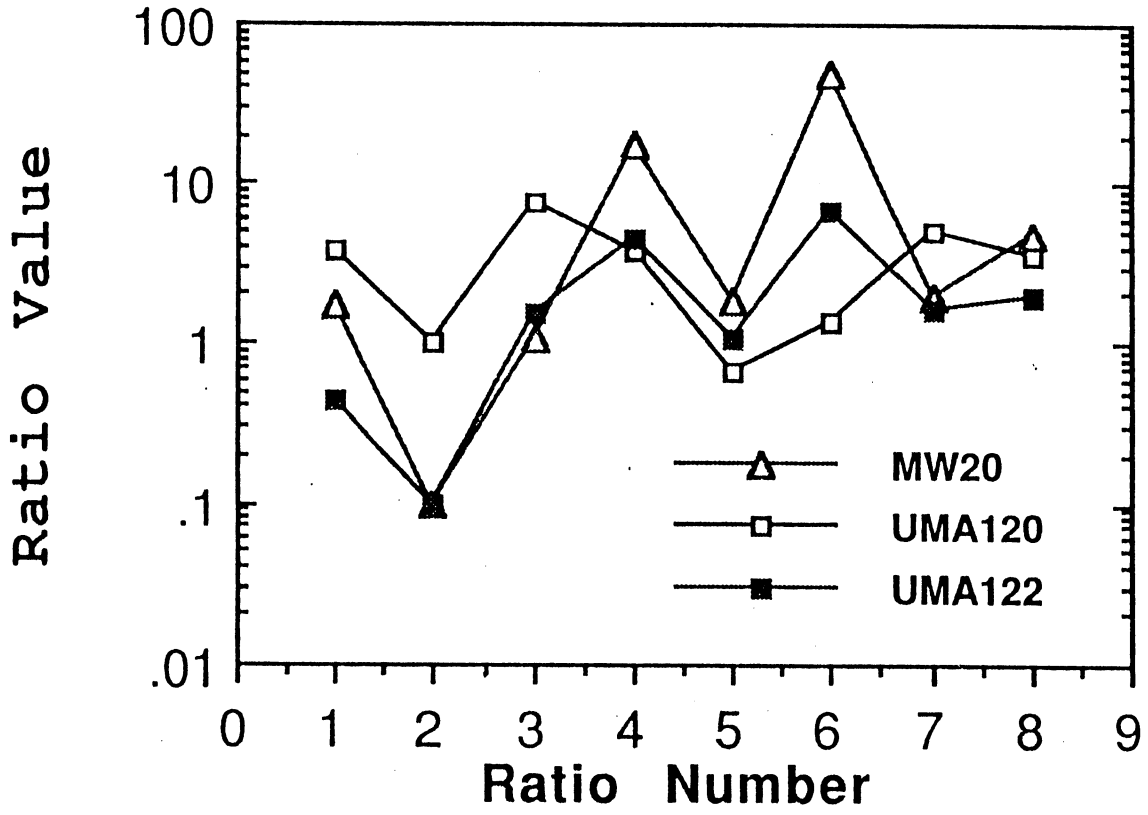


Figure 4.93 Ionic ratios for constituents in groundwater at UMA 120, UMA 122, and Simplot MW-20 (UMA 258).

Note: There is similarity between UMA 122 and MW-20.

The chemical evolution of groundwater from UMA 120 to UMA 122 was modeled by NETPATH as a mixing model. The shallow unconfined groundwater at Simplot well MW-20 (UMA 258) was mixed with groundwater from UMA 120. The natural evolution of groundwater from UMA 185 to UMA 120 was allowed to proceed. Ion exchanges were incorporated into the model to evaluate calcium, magnesium, and sodium variations. The calcium/magnesium molar ratio was held constant during this exercise. Model runs that involved the dissolution of calcite were considered unreasonable given the saturation indices found in Figure 4.83.

Dissolution of a sulfate phase, such as mirabilite, and the exchange of sodium for calcium and magnesium on clay mineral surfaces were common to all "successful" model runs. Typical results, with mixing of end members represented as percentages, are summarized in the following reactions:

UMA 122 = [34% UMA 120] + [66% MW-20]
+ [0.15 glass] + [0.25 mirabilite] - [0.72 calcite]
- [1.03 smectite] - [1.99 Na exchanging for 1.0 (Ca, Mg)] - [2.99 CO_2]

UMA 122 = [67% UMA 120] + [33% MW-20]
+ [0.39 mirabilite] + [0.77 NaCl] + [0.09 basalt glass]
- [1.04 CO_2] - [0.28 smectite]
- [1.54 Na exchanging for 0.77 (Ca, Mg)]

A few model runs indicated a much lower contribution of groundwater from Simplot well MW-20 in the reaction. The contribution was as low as 7 percent. These solutions were considered unreasonable, because of they failed to explain the total dissolved solids concentrations.

Given that it is unlikely that the highly soluble halite phase could remain in the saturated zone, the model runs containing that phase and mirabilite may reflect additional interactions with water from the vadose zone. Attempts to model the groundwater variation from UMA 120 to UMA 122 that included mixing shallow unconfined groundwater from Simplot well MW-13S (UMA 246) required an unreasonable amount of groundwater from MW-13S. The amount required exceeded 60 percent.

The modeling effort also included using the chemistry for shallow unconfined groundwater at Simplot well MW-17 (UMA 248). The well is located within the Umatilla River floodplain upgradient of UMA 122. Model runs suggest that MW-17 may reflect a mixture of groundwater similar to MW-20 and groundwater derived from infiltration of water from the Umatilla River. It is possible that the groundwater that interacts with the Butter Creek flow path has a similar history. Similar constraints and phases to those above were utilized, yielding the following as potential solutions:

UMA 122 = [41% UMA 120] + [59% MW-17]
+ [0.40 dolomite] + [1.10 halite] + [0.40 gypsum or mirabilite] - [0.11 calcite]
- [0.94 sodium exchanging for 0.47 calcium and/or magnesium]
- [0.56 carbon dioxide]

UMA 122 = [68% UMA 120] + [32% MW-17]
+ [0.53 dolomite] + [0.46 gypsum/mirabilite] + [0.6 basalt glass]
+ [1.32 halite] -[0.20 calcite] - [1.03 sodium for 0.52 calcium and/or magnesium]

Significant seasonal variations are observed in UMA 122, with higher nitrate and TDS occurring primarily in the summer months. NETPATH model runs of UMA 122 using a more dilute January 1991 analysis indicated that mixing of UMA 120 with an additional source was still required. However proportions of that source, such as shallow unconfined groundwater at MW-20, were less than that required for the summer samples, as was the extent of mineral reactions.

The model runs underestimate the nitrate concentration significantly. Figure 4.93 demonstrates that the nitrate concentration of Simplot MW-20 water used in the current calculation (14 mg/L) is significantly lower than the 1988 to 1992 four-year average ($\sim$25 mg/L). It is clear that the current levels of nitrate in the end members may not reflect the current nitrate levels in transit through the aquifer. It is apparent from the temporal variation in groundwater at UMA 122 that this conclusion may be extended to other constituents as well. It is significant that the overall chemistry pattern for impacted groundwater at well UMA 122 closely resembles the chemistry pattern of shallow unconfined groundwater at Simplot well MW-20 (UMA 258). Because the shallow unconfined groundwater chemistry at Simplot MW-20 and MW-17 reflects the infiltration of food processing wastewater, it is logical to extend that conclusion to UMA 122 as well.

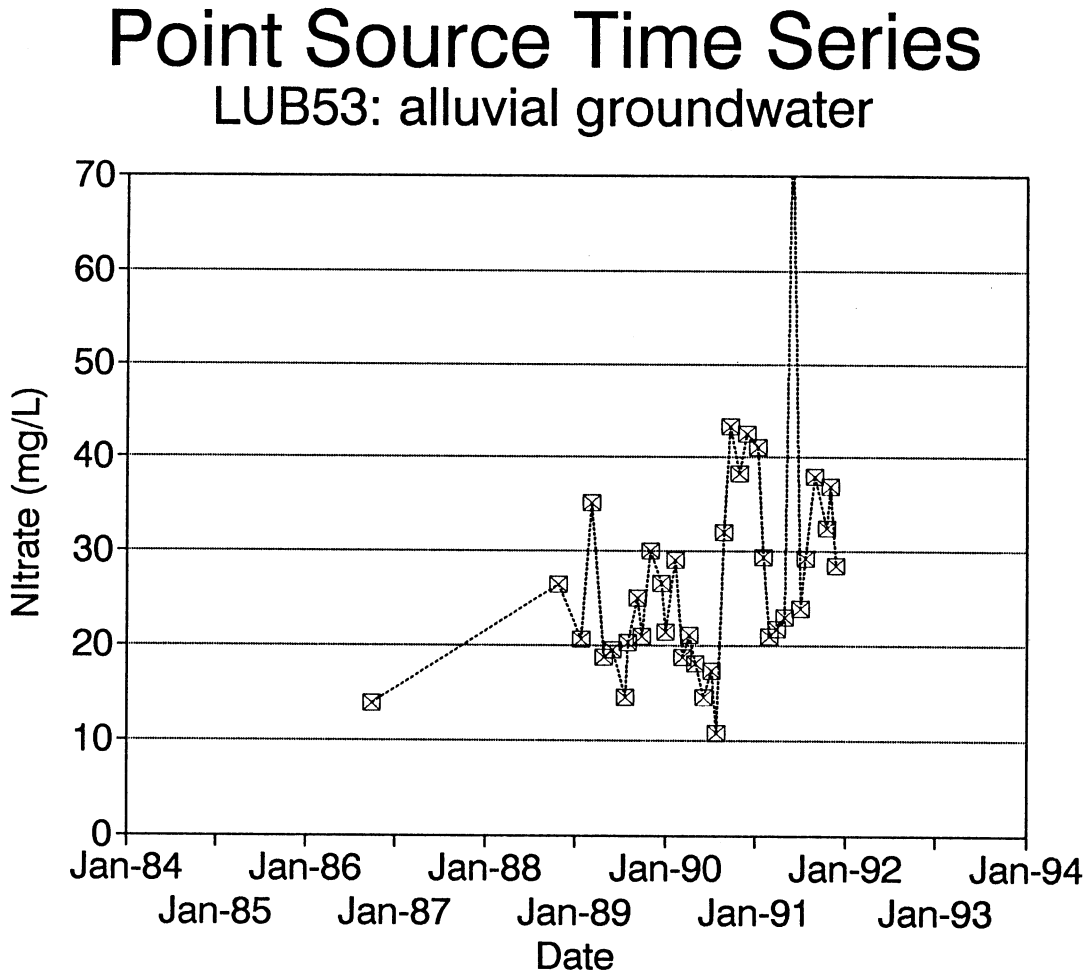


Figure 4.94 Nitrate-nitrogen versus time in shallow unconfined alluvial groundwater collected at Simplot monitoring well MW-20 (UMA 258, LUB 053).

Although the mass balance models presented here are consistent with a source of impact on groundwater being food processing wastewater, it must be noted that this application has focused upon a small area within the Lower Umatilla Basin. Therefore, although the approach to the problem can be applied elsewhere, the conclusions may not. Although there is evidence of food processing wastewater influencing groundwater at the wells discussed, additional evidence that follows indicates that food processing wastewater is not the sole contributor of nitrate within the basin.

Analysis of Groundwater at UMA 122: Evaporation Influence

An explanation for the observation that the temporal UMA 122 groundwater chemistry variation does not lie along a line towards the food processing wastewater end member in Figure 4.89 may be related to secondary processes that affect it.

As previously discussed, evaporation of vadose water or groundwater can occur in arid regions. With respect to groundwater, the evaporation may occur in the capillary fringe directly above the water table (Drever, 1982). It is notable that when evaporation occurs, the concentrations of the various constituents will increase, however, unless there is a precipitation or dissolution of a mineral phase accompanying the evaporation, the molar ratios of the constituents should remain constant. Groundwater at UMA 122 is oversaturated with respect to calcite. However, because of kinetic difficulties (Stumm and Morgan, 1981), precipitation may not occur over short time intervals unless the saturation is overstepped significantly (Krauskopf, 1979).

An evaluation of the molar ratios of the UMA 122 groundwater samples indicates that the ratios of calcium/magnesium (1.96-2.14) and calcium/sodium (1.89-2.13) show little temporal variations. In the cation portion of the Piper plot (left small triangle in Figure 4.89), the sample data will plot virtually on top of one another. In the anion field (right small triangle in Figure 4.89), significant variations are observed. It is notable that the molar ratio of sulfate to chloride also shows little variation (0.33-0.36). Similar observations have been recorded at wells elsewhere in the basin: UMA 190, north Hermiston terrace and in the Echo-Stanfield area.

The reason for the apparent anion variations is the bicarbonate concentration. This component remains relatively fixed in concentration while sulfate and chloride vary significantly. It is suggested that the bicarbonate concentration is buffered by carbon dioxide open to the surface. In the pH range of these waters, most of the carbon dioxide in the water will occur as bicarbonate [HCO_3^-]. If carbon dioxide does not vary significantly, it is unlikely that bicarbonate will vary. Under open system conditions, the partial pressure of carbon dioxide will remain fixed because the water is in chemical communication with the atmosphere (Freeze and Cherry, 1979). As a result, evaporation may not affect dissolved bicarbonate to the extent that it affects other constituents. Note that cation concentration (not necessarily proportions) changes must accompany the anions in order to maintain a charge balance.

In summary, two factors may be influencing the composition of groundwater at UMA 122. Mixing of ambient groundwater with infiltrating wastewater produces the characteristic pattern seen in Figure 4.90. A secondary process of evaporation-dissolution in the vadose zone, coupled with periodic rise and fall of the water table, produces variations in concentrations of certain constituents in the water.

Analysis of UMA 081 to UMA 073: Surface Water Influence

June-July 1992 project synoptic sampling detected a marked decrease in dissolved constituents in groundwater along the UMA 081 to UMA 073 segment of the Butter Creek flow path followed by an abrupt increase along the next segment, UMA 073 to UMA 084. Such reversals are difficult to explain along a presumably continuous flow path. Careful review of the hydrogeology suggested that the UMA 073 well was potentially influenced by the Umatilla River. The groundwater divide to the southeast of this well also suggests that a component of groundwater movement in this area is to the northwest towards the river.

The groundwater chemistry at UMA 081 and UMA 073 as well as the Umatilla River water chemistry is shown on Figure 4.94. The figure is a modified Schoeller diagram. The chemical compositions were normalized using UMA 185 data. It is apparent that groundwater at UMA 073 more closely resembles the chemical pattern of the Umatilla River waters. NETPATH model runs were successful in relating UMA 081 to UMA 073 through water-mineral reactions and significant interaction with the river. Potential solutions include the following:

UMA 073 = [5% UMA 081] + [95% Umatilla River]
+ [0.08 calcite] + [0.38 carbon dioxide] + [0.02 dolomite]
+ [0.13 (calcium, magnesium) exchanging for 0.26 sodium on clay minerals] + [0.04 mirabilite] - [0.03 clinoptilite]

UMA 073 = [5% UMA 081] + [95% Umatilla River]
+ [0.29 carbon dioxide] + [0.11 dolomite]
+ [0.12 (calcium, magnesium) exchanging for 0.24 sodium on clay minerals] + [0.04 mirabilite] - [0.04 potassium-smectite] - [0.13 smectite]

UMA 073 = [5% UMA 081] + [95% Umatilla Rive]
+ [0.50 carbon dioxide] + [1.08 potassium-smectite]
+ [0.04 mirabilite] + [0.72 basalt glass]
- [0.76 clinoptilte] - [0.06 smectite]

The data suggests that UMA 073 represents a mixture of surface water and groundwater. This conclusion is supported by the modified Schoeller diagram shown in Figure 4.94. Additional evidence comes from the project's investigation of the local hydrogeology. That investigation found the Umatilla River locally loses water to groundwater.

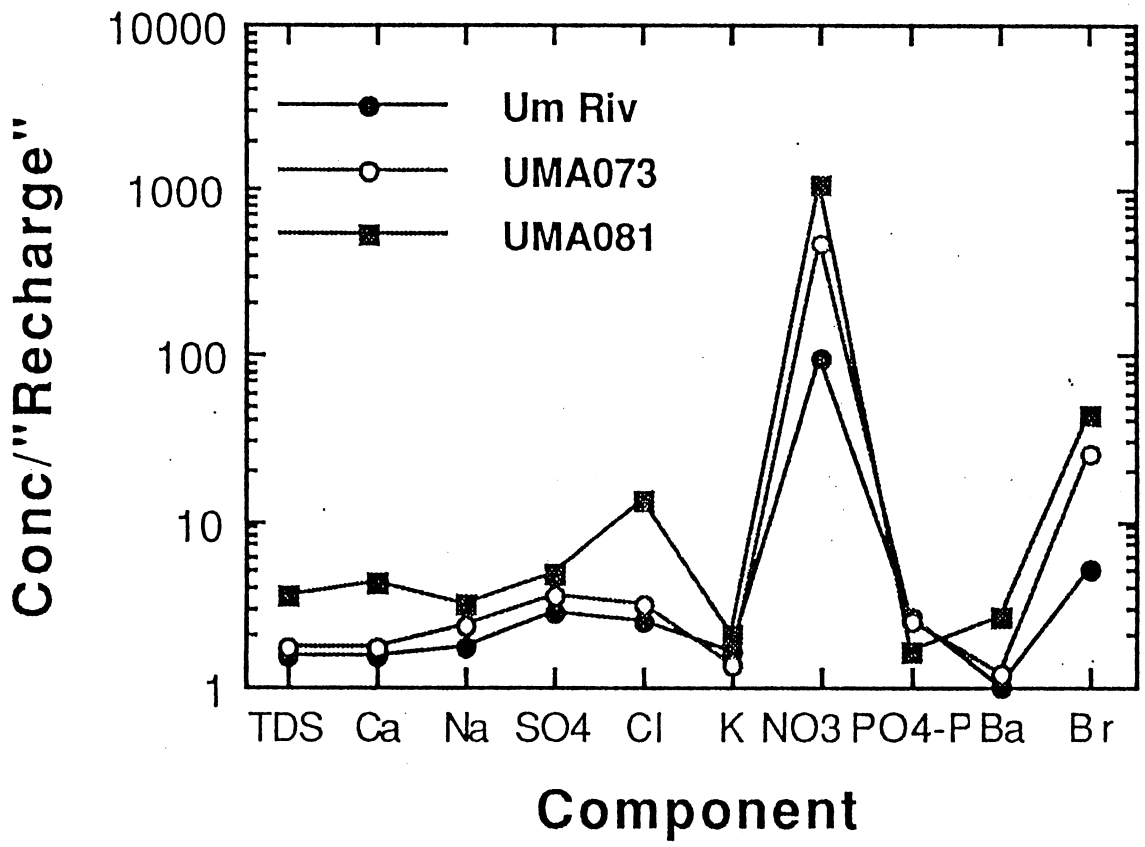


Figure 4.95 Modified Schoeller Diagram of UMA 073 and UMA 081 and Umatilla River water chemistry data.

Note: There is compositional similarity between UMA 073 and the Umatilla River.

Spatial versus Temporal Variations

The data presented thus far indicates that real variations in groundwater chemistry occur across the basin (spatial variations) and in some areas, significant compositional changes occur as a function of time (temporal variation). Discussions earlier in this document indicated that spatial variations most likely reflect source effects: specific surface activities in the area such as animal lots, septic systems, food processing waste water application or irrigated agriculture, or a mixture of these sources. Temporal variations, on the other hand, are related to process effects, reflecting changes in the type and/or magnitude of the processes such as canal leakage, proportion and composition of blending water during irrigation, evaporation-dissolution processes, mixing proportions, precipitation, and other processes.

Commonly we find separate wells bearing both similarities and differences with respect to groundwater composition. As an example, UMA 122 bears the impact of food processing waste water, UMA 190 has characteristics that suggest irrigation influence, and wells on the north Hermiston terrace have been impacted by septic systems, local irrigation and animal waste. All of these sites differ as a result of source effects, However, all display a similar temporal variation of increased chloride + sulfate with respect to bicarbonate as depicted in trilinear diagrams. This temporal variation is interpreted to reflect a process effect, specifically the evaporation-dissolution process within the vadose zone.

As a result of the combined source and process effects, the groundwater chemistry associated with a specific well is often difficult to interpret. The process effect, can obscure the signature of the source(s) effect.

Stable Nitrogen Isotope Analysis

Introduction

During Fall 1993 through Fall 1994, extensive nitrogen isotope sampling was performed in the Lower Umatilla Basin. Funding from the U.S. Environmental Protection Agency was obtained to determine the delta ^{15}N composition of nitrate from selected sampling points in the basin. Dr. Dennis Nelson of the Oregon Health Division and Margot Truini, a Portland State University graduate student, conducted sampling at over 20 wells, 3 lysimeters, and a food processing wastewater surge pond.

A description of the procedures used in collecting the samples can be found in the Materials and Methods section of this chapter. Preliminary results are reported here. At this writing, Truini is in the process of preparing a more comprehensive report with interpretation details for a Portland State University Masters thesis.

Sampling Results

A compilation of the isotopic sampling results is provided in Table 4.40. Samples were collected from:

- private wells in the Butter Creek drainage,
- wells in the area of the Depot's explosive washout lagoon,
- wells associated with the application of food processing wastewater,
- wells associated with past and present animal lots, and
- wells associated with irrigated agriculture that applies commercial fertilizers.

Most wells were sampled twice in order to capture temporal variation. With the exception of a few wells, most repeat samples showed only minor variation.

Table 4.40 Compilation of nitrogen isotopic sampling results

Land-Use	Site Identification	Date Collected	NO3-N (mg/L)	Delta 15N (per mil)
Animal Yard	UMA 183	F93	37	5.1
	UMA 183	S94	55-56*	6.3-6.4*
	UMA 183	F94	52.5	5.4
	UMA 184	F93	11	5.3
	UMA 133	F93	17	10.4
	UMA 133	S94	17	8.5
	UMA 133	F94	16.8-17.1*	9.9-10.0*
Depot: Explosive Washout Lagoon	UMA 226	F93	10	4.7
	UMA 225	F93	13	4.9
	UMA 227	F93	10	4.8
	UMA 224	F93	18	4.6
Food-Processing Wastewater Land Application Area	UMA 058	F93	8	4.8
	UMA 058	S94	9	5.5
	UMA 058	F94	17.8	5.1
	UMA 258	F93	11	29.5
	UMA 258	S94	6.4	33.4-33.7*
	UMA 258	F94	22.6	20.3
	UMA 246	F93	15	7.6
	UMA 246	S94	13	5.5
	UMA 246	F94	9.9	5.9
	UMA 248	F93	15	7.3
	LY1	F94	37.9-39.9*	21.1-21.9*
	LY2	F94	3.0-3.1*	6.4-6.5*
	LY4	F94	5.4	9.1
	Effluent	F94	60.5-60.9*	3.5-6.5*
Irrigated Agriculture	UMA 173	F93	48-50*	4.0-4.1*
	UMA 161	F93	75	4.7
	UMA 161	S94	81-87*	4.1-4.6*
	UMA 159	F93	28	3.1
	UMA 159	S94	29*	2.9-3.0*
	UMA 159	F94	25.0-28.5*	2.8-3.0*
	UMA 182	S94	15	4.5
	UMA 182	F94	16.2	4.9
Butter Creek: Domestic Wells	UMA 122	F93	12	5
	UMA 122	S94	18.1	2.7
	UMA 122	F94	9.3	4.5
	UMA 134	F93	19	6.8
	UMA 134	S94	21	6.9
	UMA 134	F94	15.2	6.8
	UMA 069	F93	10*	7.1*
	UMA 069	S94	19.5	6.5
	UMA 069	F94	6.2	6.1

Note:
Land-use = Dominant land use practice in the well vicinity.
Date = Fall 1993 (F93), Spring 1994 (S94), or Fall 1994 (F94)
UMA ### = Well identification number
LY# = Lysimeter
Eff = Effluent from the J.R.Simplot Company wastewater purge pond
* = Duplicate analysis result

The data from the sampling are displayed in Figures 4.95 and 4.96. Analysis of the data in Table 4.40 and the figures indicates that the range of delta ^{15}N for the sampled wells is +3.0 to +33.6 per mil. Only two categories of nitrate source can be clearly distinguished: UMA 258, a Simplot monitoring well, having a delta ^{15}N of +29.5 to +33.6 per mil and the Western Empire wells (UMA 159, -161, -173 and -182) which have delta ^{15}N ranging from +3.0 to +4.7 per mil.

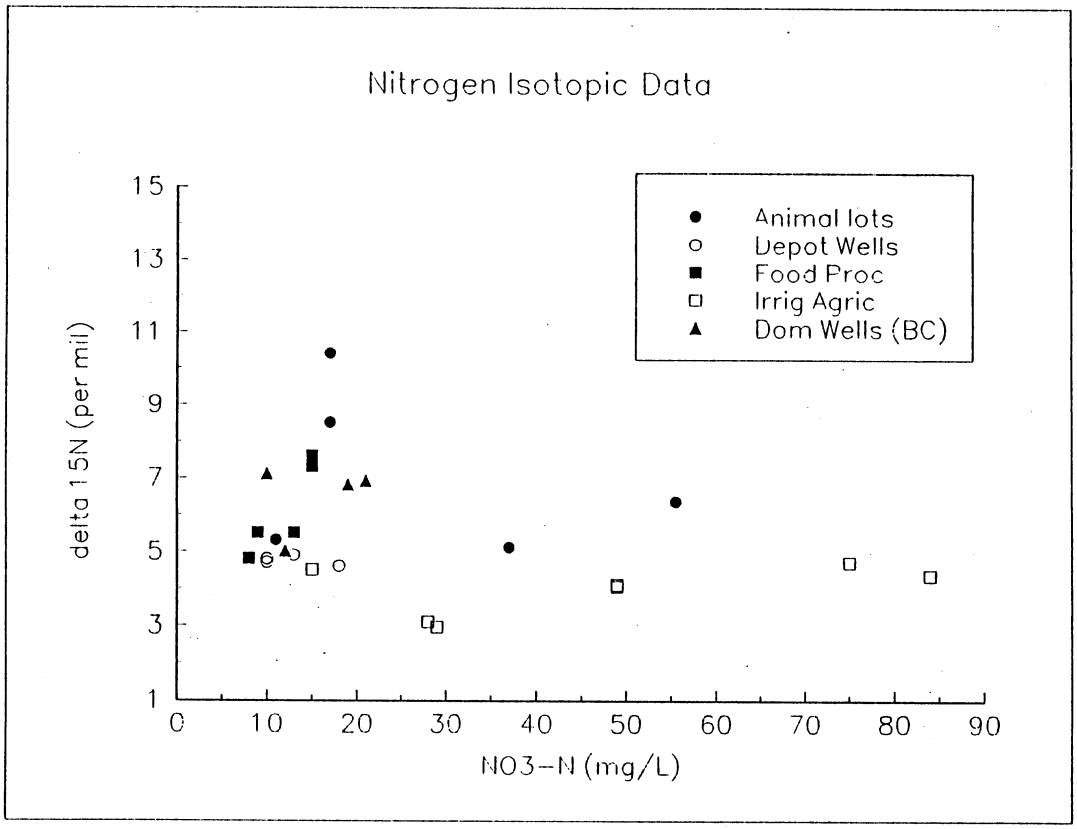


Figure 4.96 Delta ^{15}N versus nitrate-nitrogen concentration in groundwater from some of the Lower Umatilla Basin wells sampled for nitrogen isotopic analyses.

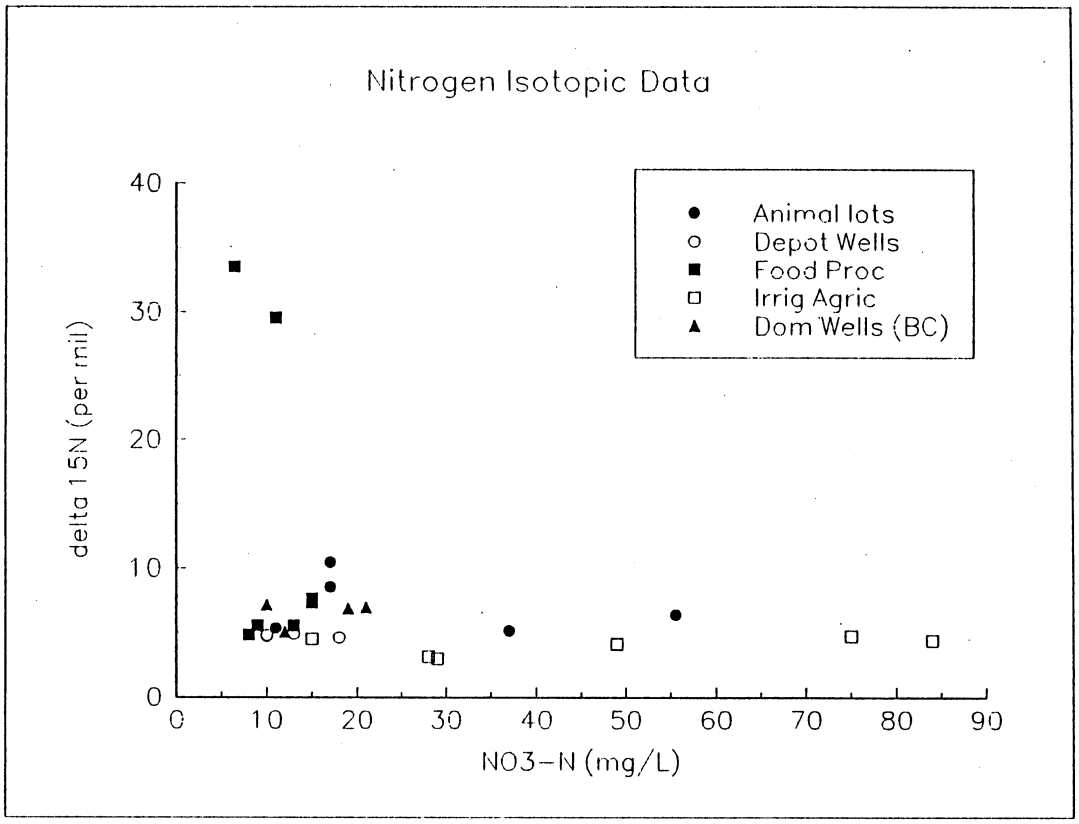


Figure 4.97 Delta ^{15}N versus nitrate-nitrogen concentration in groundwater from all Lower Umatilla Basin wells sampled for nitrogen isotopic analyses.

Analysis of Groundwater at UMA 258

The elevated delta ^{15}N for UMA 258 indicates organic wastes as a nitrogen source. Organic waste could indicate either food processing, animal waste effluent, or septic system effluent source. Well UMA 258 is located on J.R. Simplot Company property where food processing wastewater is land applied. The wastewater is identified as the primary nitrogen source at UMA 258. Samples from other wells at the Simplot facility yield lower delta ^{15}N values ranging from +4.8 to +7.6 per mil (see Figure 4.95). A question remains as to whether the elevated isotopic composition indicates organic nitrogen sources or reflects denitrification of the nitrogen represented isotopically by groundwater sampled from the other Simplot wells.

The sampling data shown in Figure 4.96 suggests a denitrification impact upon groundwater at UMA 258. A decrease in nitrate abundance and an increase in delta ^{15}N is considered an indication of denitrification (Mariotti and others, 1988). The fractionation of nitrogen isotopes during denitrification can be described by equations using the isotopic enrichment factor (ef). The equation is as follows:

$$\text{delta}_{(f)} = \text{delta}_{(i)} + \text{ef}(\ln[C_{(f)}/C_{(i)}])$$

where delta refers to the isotopic composition of the final (f) and initial (i) nitrate, C refers to the final (f) and initial (i) concentrations of nitrate, and ln is the natural log (Mariotti and others, 1988).

Using the initial (delta ^{15}N = +29.5 per mil, NO_3-N = 11 mg/L) and final (delta ^{15}N = +33.55 per mil, NO_3-N = 6.4 mg/L) values for UMA 258, the enrichment factor is calculated to be -7.5 per mil. This is within observed ranges reported elsewhere for denitrification in groundwater (Mariotti and others, 1988).

The hypothesis can be tested as to whether the elevated delta ^{15}N values of UMA 258 are derived from the lower isotopic values observed in groundwater samples collected elsewhere on the Simplot property using the above equation and the calculated enrichment factor. The Fall 1993 nitrate concentration and delta ^{15}N values for UMA 258 (11 mg/L and +29.5 per mil) and the Fall 1993 delta ^{15}N value of UMA 248 of +7.3 per mil can be used to determine whether the predicted concentration of UMA 248 is consistent with the denitrification model or not. Solving the equation with this new data indicates that in order for the UMA 258 values to have been derived from nitrate having a delta ^{15}N of +7.3, the concentration of the nitrate would have had to have been in excess of 200 mg/L. Producing the appropriate isotopic compositions and nitrate concentrations of UMA 258 solely through denitrification of typical Simplot well data would require enrichment factors of approximately -70 per mil, considerably different from any reported values in the literature (Mariotti and others, 1988). Consequently, the nitrogen in the nitrate from UMA 258 is considered to reflect organic waste material (delta $^{15}N = +10$ to +22) (see Appendix 4B).

Analysis of Wastewater from the J.R. Simplot Company Surge Pond

A sample was collected from the wastewater surge pond near the Simplot plant. As indicated in Table 4.40, the isotopic composition of nitrate in the sample is low. It measured less than +6.5 per mil. That is considerably less than what would be considered normal for organic wastes. A possible explanation for this low value is the presence of ammonia, carrying the bulk of the nitrogen. An earlier sample of this pond water indicated most of the nitrogen was in the form of ammonia and organic nitrogen. Progressive volatilization of ammonia would leave residual ammonia substantially enriched in delta ^{15}N (Mariotti and others, 1988). Nitrification of that ammonia would lead to nitrate having a significantly higher delta ^{15}N composition. Because the wastewater is stored in lagoons prior to land application, volatilization and nitrification are considered likely processes. This, coupled with additional volatilization and nitrification during and subsequent to land application may lead to the residual water having nitrate with much higher delta ^{15}N values.

Analysis of Lysimeter Samples

Table 4.40 and Figures 4.95 and 4.96 show the isotopic results from samples collected in shallow (5 to 7 feet) lysimeters located in Section 6, T3N, R28E. The lysimeters are located in an area where corn is grown and food processing wastewater is land applied. Two of the lysimeters, LY1 and LY2, are located adjacent to each another. LY4 is located within 100 feet of LY1 and LY2. As such, the lysimeter data indicate the potential diversity of nitrate concentrations (3.0 - 38.9 mg/L) and isotopic compositions (+6.4 to +21.5) within the area. Although the reason(s) for the diversity in nitrogen isotopic composition is not clear at this point, what is evident is that the lysimeters LY1 and LY2 cannot be related through denitrification processes. LY1 not only has a higher isotopic composition than LY2, it also has a significantly higher nitrate concentration.

Analysis of Western Empire Farm Samples

The delta ^{15}N of nitrate in groundwater sampled from Western Empire Farm wells are consistently low: +3.0 to +4.7 per mil. These low values are consistent with commercial fertilizer (-4 to +4 per mil) as the primary nitrate source. The delta ^{15}N values are consistent over a wide range of nitrate concentrations (see Figure 4.95). That suggests a constant uniform source of the nitrogen. The data for groundwater sampled from the Western Empire Farm wells produce a nearly horizontal trend, as shown in Figure 4.96. This trend suggests simple dilution affects the nitrate concentrations.

Analysis of Groundwater Sampled at the U.S. Army Umatilla Depot Activity

Groundwater samples were collected at the U.S. Army Depot in proximity to the explosive washout lagoon. Delta ^{15}N values for the samples range from +4.6 to +4.9 per mil. Explosives have low delta ^{15}N values similar to commercial fertilizers, because atmospheric nitrogen is incorporated in their manufacture. A. E. Fryer (personal communication, October, 1994) has studied nitrate contamination of groundwater in the vicinity of the U.S. Department of Energy's Pantex Plant near Amarillo, Texas. He reports that the nitrate derived from explosives, including RDX, a contaminant at the Depot site, has a delta ^{15}N varying from -4 to +4 per mil. Although slightly more enriched in delta ^{15}N, the data for the Depot indicates that the bulk of the nitrate in the groundwater near the explosive washout lagoon was derived from explosive contaminants.

Analysis of Groundwater Sampled at UMA 133

Site UMA 133 is located in the vicinity of a former turkey and dairy operation, an existing cattle operation, and grazing sheep. The well is also located adjacent to a horse pen. The delta ^{15}N is significantly greater than the bulk of the samples analyzed thus far. The values range from +8.5 to 10.4 per mil for UMA 133. These values are at the low end of the range generally accepted for nitrate derived from animal wastes (+10 to +22 per mil). It is reasonable to conclude that animal waste contributed nitrate to groundwater at this site.

Analysis of Groundwater Sampled from Other wells

Groundwater sampled from other Lower Umatilla Basin wells listed in Table 4.40 have delta ^{15}N for nitrate within the range of +4.8 to +7.6 per mil and are thus not diagnostic of any one particular source. A mineralized soil nitrate source is considered unlikely, because the history of tillage in the area would have depleted that source (Reinhorn and Avnimelech, 1974).

Influence of Mixing

Nitrogen isotope data for groundwater collected from wells at Hansell Brothers Inc., and J.R. SIMPLOT Company wells display positive slopes in the nitrate versus delta ^{15}N graph (see Figure 5-35). These slopes, along with the intermediate isotopic compositions suggest a potential mixing of two sources: a low nitrate-low ^{15}N source(s) and a high nitrate-high ^{15}N source(s). It is apparent that the same high nitrate end member probably does not contribute to groundwater at both the Simplot and Hansell Brothers wells. It is also apparent that the variation observed in the Simplot and Hansell Brothers wells is not simple dilution. Dilution would lower the nitrate concentrations, but would not decrease the delta ^{15}N value (Mariotti and others, 1988).

The water chemistry data from the UMA 122 well is suggestive of the result of mixing of groundwater from the Butter Creek drainage (UMA 120) with groundwater derived from below fields in which food processing wastewater has been applied (MW-17 and MW-20).

Figure 4.95 indicates that UMA 122 is located near the low delta ^{15}N of the Simplot array, qualitatively supporting a mixing origin. The isotopic data for the UMA 122 well, however, virtually precludes MW-20 (see Figure 4.96) as being an end member in the mixing process. The isotopic composition of UMA 120 (not available) would have to be unreasonably low. In contrast, if MW-17 is the end member, the delta ^{15}N of UMA 120 would have to be in the vicinity of +2.0, not an unrealistic value. Both the water chemistry and the isotopic data then are consistent with UMA 122 being derived by mixing of ambient groundwater and water derived from land application of food processing wastewater.

Assessment of Natural Processes to Reduce Groundwater Nitrate Concentrations

Two principle natural processes which can reduce nitrate concentrations in an aquifer include denitrification and hydraulic flushing. Denitrification converts dissolved nitrate into nitrogen gas. Hydraulic flushing involves relying upon natural groundwater movement to carry nitrate from recharge areas to discharge areas where the nitrate exits the aquifer.

Denitrification

Denitrification converts dissolved nitrate into nitrogen gas (Mariotti and others, 1988, Smith and others, 1991) which is accomplished by active bacteria (Korom, 1992). These bacteria require the presence of organic carbon and the absence of oxygen in order to accomplish the denitrification process. If oxygen is present in the aquifer, any organic carbon will be oxidized by the oxygen with no effect on the nitrate. Once oxygen is depleted, denitrifying bacteria may use nitrate as the electron acceptor during carbon oxidation.

As previously discussed, denitrification was recognized in groundwater sample from a single monitoring well (UMA 258) on the Simplot property. This well is located on the flood plain of the Umatilla River. The denitrification process may act locally, at sites like UMA 258: Holocene alluvium flood plain deposits proximal to existing drainages and a combination of high organic matter and a shallow water table providing an adequate reducing environment.

Chemical analyses of this water indicate a high dissolved organic carbon (DOC) content (7 mg/L), consistent with a reducing environment (Mariotti and others, 1988), where denitrification is occurring. UMA 248 is also located on the flood plain, but closer to the river. The DOC content of this water is considerably lower (3 mg/L), suggesting denitrification is not occurring. In the coarse alluvial sediments and in the basalt, organic carbon levels are generally too low to be effective as a reducing agent for dissolved nitrate.

There is no evidence of area-wide denitrification in the Lower Umatilla Basin. This may be a result of low concentrations of organic matter in the aquifer (Starr and Gillham, 1993) and the thick unsaturated zone. The trend of decreasing nitrate with increasing delta ^{15}N, considered indicative of denitrification (Mariotti and others, 1988), is not seen on an area-wide basis in the Lower Umatilla Basin. Trends in the Western Empire data suite are nearly horizontal (the isotopic composition is constant over a large range of nitrate concentrations). This trend reflects simple dilution. The data trend defined by the temporal variation in the Hansell Brothers wells and in the bulk of the Simplot wells is positive, reflecting some mixing (not denitrification).

Hydraulic Flushing

Hydraulic flushing refers to the natural processes of groundwater recharge, flow and discharge to remove nitrate from an aquifer. Three areas were identified in the Hydrogeology chapter as having coarse-grained flood deposits with high hydraulic conductivity and very low hydraulic gradients (<2-5 feet per mile). These include the Hermiston area, the Boardman-Irrigon area, and the U.S. Army Umatilla Ordnance Depot Activity vicinity. Local groundwater may move only a few feet per day in these areas. Periodically, the hydraulic gradient is reversed as a result of river stage or pumping influences. These flow velocities and reversals may prolong or hinder the potential natural hydraulic flushing process in these areas. The natural groundwater flux (or rate) moving through the aquifer may not be sufficient to reduce the nitrate levels within the remediation time frame desired.

The nitrogen isotope sampling results provide further evidence of low groundwater flow velocities. Nitrogen isotopic analyses were conducted on groundwater from irrigation wells in the Boardman-Irrigon area (UMA 159, UMA 161 and UMA 173). Although these wells differ from one another in terms of nitrate concentrations, there is only a minor variation at each individual well throughout the 13 month period during which the samples were collected. The isotopic compositions of the waters at each individual well also show no significant variation during that time period. This lack of variation through seasonal irrigation and nonirrigation periods is consistent with the conclusions reached in the Hydrogeology chapter. The Boardman-Irrigon area is underlain by a large volume of very slow moving groundwater.

The low groundwater flow velocities in the Hermiston, U.S. Army Umatilla Depot Activity, and Boardman-Irrigon areas leads to an important conclusion: the process of natural hydraulic flushing of the existing nitrate from the groundwater in these areas will be slow. Natural hydraulic flushing may require decades. Therefore, any practices implemented to reduce future nitrate loading may not have an immediate impact on the observed groundwater nitrate concentrations in these areas.

Lower Umatilla Basin Groundwater Chemistry Summary and Conclusions

The Lower Umatilla Basin Groundwater Management Area technical investigation conducted a variety of activities to primarily understand the distribution and source of nitrate in local groundwater. Those activities included different sampling events, laboratory analyses for multiple chemical constituents, and multiple data analyses. Those activities and their results are summarized in this section.

Materials and Methods

The Lower Umatilla Basin technical investigation conducted a variety of sampling events to obtain data appropriate for different analyses. Reconnaissance sampling at 179 wells, 2 springs, and 1 drain occurred from July 1990 through October 1991. This sampling provided preliminary information about the occurrence of nitrate groundwater contamination in the basin and where future efforts should focus. On-going bimonthly groundwater sampling began in October 1991. The sampling occurs repeatedly at 35 to 40 sites to record groundwater chemistry changes over time. Synoptic sampling occurred during late June and early July 1992 at 207 wells and 26 surface water sites to obtain concurrent data for basin wide analyses. Local facilities participated in the synoptic sampling. An Oregon Strategic Water Management Group grant funded this sampling effort. Stable nitrogen isotope sampling occurred at approximately 20 wells, 3 lysimeters, and a food processing surge pond in 1993 and 1994. The effort was conducted to obtain data useful for identifying nitrogen sources and processes that may influence groundwater nitrate concentrations. An U.S. Environmental Protection Agency 319 Grant funded this effort.

Four laboratories chemically analyzed the samples collected. The Boston University Stable Isotope Laboratory analyzed the stable nitrogen isotope samples. The Oregon State University Agricultural Chemistry Laboratory participated by analyzing some reconnaissance samples for agricultural pesticides. The Oregon Department of Agriculture Laboratory analyzed the reconnaissance and selected bimonthly groundwater samples for agricultural pesticides. The Oregon Department of Environmental Quality Laboratory analyzed all reconnaissance, bimonthly, and synoptic samples for nitrate, other nutrients, major ions, metals, and other inorganic constituents. The laboratory analyzed reconnaissance and selected bimonthly samples for volatile organic compounds.

Multiple techniques were used to analyze and interpret the project and local facility data. All analyses were conducted in an effort to understand the source, distribution, and fate of nitrate in Lower Umatilla Basin groundwater. The analyses included general statistics, chemical constituent distribution maps, multiple graphical analyses, groundwater chemistry computer modeling for selected areas, and stable nitrogen isotope interpretations. Results were derived independently. Then, they were compared to each other and to the current understanding of local hydrogeolgy and land uses to assess their reasonableness.

General Observations and Interpretations

Nitrate Sources, Distribution, and Fate

Data analysis led to the following general observations and interpretations regarding nitrate in Lower Umatilla Basin Groundwater.

- Human activity appears responsible for nitrate concentrations greater than 1 mg/L. Evidence comes from observing the relationship between nitrate and other chemical constituents in groundwater.

- No single source is solely responsible for the elevated nitrate concentrations observed in Lower Umatilla Basin groundwater.

- Project sampling detected nitrate below 2 mg/L in groundwater sampled from approximately 26 percent of the project sampling sites. The occurrence of some of these lower concentrations appear related to either dilution influences or background conditions.

- Project sampling detected nitrate concentrations exceeding the 10 mg/L drinking water standard in nearly 30 percent of the groundwater samples collected which came from nearly 31 percent of the project sampling sites. The highest concentration detected by project sampling was 76 mg/L. Local facilities have reported concentrations greater than 100 mg/L.

- Nitrate concentrations greater than 10 mg/L in the Lower Umatilla Basin groundwater are not evenly distributed. Higher nitrate concentrations occur within:

  - Threemile and Sixmile Canyons,
  - the Boardman and Port of Morrow vicinities,
  - north, west, and south of the U.S. Army Umatilla Depot Activity,
  - two sites within the Depot,
  - the Butter Creek-Umatilla River confluence vicinity, and
  - the terrace south of Hermiston.

  The highest concentrations detected by project sampling occur between the Port of Morrow and Irrigon where center pivot irrigation is used. Nitrogen isotopic analysis identifies commercial fertilizer as the nitrate source.

- Hydrogeologic, nitrate distribution versus land use, and nitrogen isotopic analyses indicate local groundwater transport of nitrate is slow. For example, an apparent nitrate plume emanating from the U.S. Army Depot explosive washout lagoons has moved less than 4 miles in three to four decades.

- Analysis comparing nitrate concentrations versus time to groundwater elevations versus time indicate the time required for nitrate to travel from land surface to groundwater ranges from less than one month to 18 months depending upon local conditions and water available for transport. This travel time is faster than suggested by other investigators.

- Analyses identify food processing wastewater activity responsible for elevated nitrate concentrations occurring in groundwater at wastewater land application sites located northeast and south east of the Butter Creek-Umatilla River confluence, northeast of the U.S. Army Depot, and east of Boardman.

- Analyses identify irrigated crop agriculture as contributing to elevated nitrate concentrations occurring in groundwater at Threemile and Sixmile Canyons, south of Boardman, north, west, and south of the U.S. Army Depot, southwest of Hermiston, northeast of Hermiston, and the terrace south of Hermiston.

- Analyses identify animal waste as contributing to elevated nitrate concentrations occurring in groundwater at Threemile and Sixmile Canyons, south of Boardman, south of the U.S. Army Depot, and south of Hermiston near Highway 207. Analyses suggest animal waste contributes to elevated nitrate north of the Depot, but project investigators are not aware of livestock activity or animal waste use in that area. Animal waste is identified as locally contributing to nitrate concentrations approaching 10 mg/L north of Hermiston.

- Analyses identify septic systems as locally contributing to elevated nitrate concentrations in groundwater south of Boardman, between Irrigon and Umatilla, between the U.S. Army Depot and the Umatilla River, and sites on the terrace south of Hermiston.

- Analyses identify the U.S. Army Umatilla Depot Activity responsible for elevated nitrate concentrations in groundwater at the explosive washout lagoons and the active landfill. Outside sources appear responsible for elevated nitrate concentrations detected along the Depot's south and west borders.

Other Constituents in Lower Umatilla Basin Groundwater

Data analysis led to the following general observations and interpretations regarding other constituents in Lower Umatilla Basin Groundwater.

- Project sampling detected total dissolved solids concentrations exceeding the 500 mg/L secondary (aesthetic) drinking water standard in more than 20 percent of the groundwater samples collected which came from more than 25 percent of the project sampling sites. Groundwater samples with the highest concentrations detected came from Threemile and Sixmile Canyons area and from between Boardman and Irrigon.

- Four project groundwater samples contained arsenic at concentrations greater than the 0.050 mg/L drinking water standard. Those samples came from dispersed sites.

- Project sampling detected sodium at concentrations greater than the 20 mg/L limit for physician prescribed sodium restricted diet in groundwater at 85 percent of the sampling sites.

- Project sampling detected vanadium at concentrations considered unusual. Investigating vanadium was beyond the scope of this project.

- Project sampling detected agricultural pesticides and/or volatile organic compounds (VOCs) in groundwater sampled from 16 sites. Pesticides were detected in groundwater from 10 sites. VOCs were detected in groundwater from 7 sites. Most of the sites are located east of the U.S. Army Depot. The presence of the constituents indicate a human activity influence.

- The U.S. Army Depot reports the presence of explosives in groundwater at some Depot sites. The presence of these constituents indicate a human activity influence.

Other General Observations and Interpretations

Analyses led to the following miscellaneous observations and interpretations.

- Both spatial and temporal variations are observed in basin groundwater, reflecting source and process effects.

- A hydraulic connection exists between alluvial groundwater and some basalt water bearing zones.

- Multiple influences affect the groundwater chemistry in the basin. Not all of these influences contribute nitrate.

- Cyclic evaporation and dissolution processes in the vadose (unsaturated) zone above groundwater influences the groundwater chemistry (such as increasing TDS) in the basin.

- Water-rock interactions cause minor groundwater chemistry variations in the basin.

- Mixing of groundwater with other groundwaters, infiltrating water from the surface, and with surface water is identified as an important contribution to variations in groundwater chemistry.

- Canal leakage does locally influence the groundwater chemistry. It dilutes constituent concentrations in the Hermiston vicinity.

- Food processing wastewater, irrigation, animal waste, and septic system influences on groundwater chemistry could be distinguished on some constituent versus constituent graphs.

- Most Lower Umatilla Basin groundwater graphs as mixed-cation/bicarbonate dominated or calcium/bicarbonate dominated on Piper trilinear graphs.

- Chloride and sulfate proportion variations in groundwater sampled often correlated to nitrate concentration variations. Chloride and/or sulfate proportions increased with higher nitrate concentrations. This was observed to occur between sampling sites and over time.

Area Specific Observations and Interpretations

Threemile Canyon and Sixmile Canyon Area Summary and Conclusions

Analysis of Threemile Canyon and Sixmile Canyon groundwater chemistry data led to the following observations and interpretations:

- Nitrate concentrations in Threemile Canyon and Sixmile Canyon area groundwater ranges from non-detect to 70 mg/L.

- Nitrate concentrations remained below 1 mg/L in groundwater samples collected from basalt wells constructed more than 500 feet deep.

- Nitrate concentrations were detected below 2 mg/L in shallow basalt water bearing zone groundwater samples collected near Interstate 84 east of Sixmile Canyon.

- Nitrate concentrations exceeding 10 mg/L were detected in alluvial and shallow basalt water bearing zone groundwater samples collected near the J.R. Simplot Feedlot wastewater lagoons, near or within Taggares Farm along Sixmile Canyon, and the PGE ash disposal area.

- A review of available nitrate, ammonia and Total Kjeldahl Nitrogen (TKN) data and local land uses indicates animal waste or another organic nitrogen source influences groundwater in the J.R. Simplot Feedlot wastewater lagoon vicinity and the PGE 101 (UMA 274) vicinity at least.

- Graphical analyses indicate a combination of nitrate sources and natural processes influences groundwater along Sixmile Canyon.

- Graphical analyses indicate Taggares Farm activities contributes nitrate to alluvial and shallow basalt water bearing zone groundwater within the farm vicinity.

- Carty Reservoir appears to dilute shallow basalt water bearing zone groundwater near the reservoir.

- The source of nitrate in groundwater within the PGE ash disposal area remains unresolved. Ash from the electric generating coal fired plant appears not to be a nitrate source, and Carty Reservoir is between the ash disposal area and Taggares Farm. Agricultural activity does occur south of the ash disposal area, but no data from that area was obtained for comparison analyses.

- Total dissolved solids (TDS) concentrations in local groundwater are among the highest detected in the Lower Umatilla Basin.

- Arsenic concentrations in alluvial groundwater sampled from UMA 275 (PGE 103) approached the drinking water standard of 0.05 mg/L.

- Sodium concentrations in local groundwater generally exceeded the 20 mg/L standard recommended for persons on a physician prescribed sodium restricted diet.

- Chloride concentrations exceeded the 250 mg/L secondary (aesthetic) drinking water standard in some shallow basalt water bearing zone groundwater samples from the Taggares vicinity and PGE ash disposal area vicinities.

- Some sulfate concentrations measured in local groundwater samples are among the highest concentrations detected in the Lower Umatilla Basin.

Boardman to West Umatilla Area Summary and Conclusions

Project analyses used data from project sampling and data reported or provided by local facilities. The analyses led project investigators to the following observations and interpretations:

- Groundwater nitrate concentrations detected by this project or reported by local facilities range from non-detect to more than 100 mg/L.

- Groundwater with nitrate concentrations exceeding 10 mg/L occurs in large areas located:
  - south of Boardman,
  - between Boardman and Irrigon,
  - between Irrigon and the Umatilla River,
  - the northeast corner area of the U.S. Army Umatilla Depot Activity,
  - the Depot's washout lagoons area, and
  - south of the Depot.

- Elevated nitrate concentrations in groundwater south of Boardman appears to come primarily from irrigation activity with some contribution from animal operations and septic systems.

- Port of Morrow and Lamb-Weston wastewater land application activity east of Boardman and adjacent to the U.S. Army Depot, respectively, appear responsible for the elevated nitrate concentrations at their respective sites.

- Irrigated agriculture appears responsible for elevated nitrate concentrations detected in groundwater between the Port of Morrow and Irrigon as well as the elevated nitrate concentrations detected along the U.S. Army Depot's western boundary.

- Irrigation and septic systems appear responsible for elevated nitrate concentrations detected in groundwater north of the U.S. Army Depot. Analyses also suggest an animal waste influence. However, this investigation has no information to confirm or refute the use of animal waste in this area.

- Elevated groundwater nitrate concentrations detected in the U.S. Army Depot active landfill area appears derived from a Depot source rather than from the upgradient Lamb-Weston wastewater land application site. Dried domestic sludge disposed at the landfill is a potential source.

- Historic activity at the U.S. Army Depot washout lagoons appears responsible for elevated groundwater nitrate concentrations detected in the central portion of the Depot. Nitrate movement away from the lagoons appears to be less than four miles over three to four decades if the apparent plume on Plate 4.2 is real. Otherwise, nitrate has moved less than 0.5 miles over the same period.

- Irrigated crop agriculture and animal operations appear primarily responsible for the elevated nitrate concentrations detected in groundwater south of the U.S. Army Depot.

- Groundwater nitrate concentrations below 10 mg/L were detected in samples from sites west of Irrigon along the Columbia River, south of Irrigon through the western portion of the U.S. Army Depot, and the Lost Lake vicinity.

- Total dissolved solids concentrations exceeded the 500 mg/L secondary (aesthetic) drinking water standard in groundwater:

  - south of Boardman,
  - between Boardman and Irrigon,
  - the east Irrigon area,
  - the U.S. Army Depot active landfill area,
  - the immediate vicinity of the Depot's explosive washout lagoons, and
  - south of the Depot.

- Sodium concentrations in the Boardman to west Umatilla area groundwater commonly exceed the 20 mg/L limit recommended for persons on a physician prescribed sodium restricted diet.

- Arsenic concentrations exceeded the drinking water standard of 0.050 mg/L in groundwater at several U.S. Army Depot sites and at a Lamb-Weston wastewater land application area site.

- Groundwater samples with relatively higher (0.10 mg/L or greater) maximum total phosphate concentrations came from wells located within the Port of Morrow wastewater land application area east of Boardman, the Irrigon area, most of the U.S. Army Depot, south of the Depot, and the Lamb-Weston land application area.

- Samples with relatively lower total phosphate concentrations often came from within or near irrigated agriculture areas.

- Explosives are present in groundwater at some U.S. Army Depot sites.

- Agricultural chemicals have been sporadically detected in Boardman to west Umatilla area groundwater samples. Atrazine was detected in groundwater sampled south of Boardman and between the Port of Morrow and Irrigon. Dacthal acid was detected in groundwater sampled south of the U.S. Army Depot.

- Nitrate movement through the area appears slow. Decades may be required for nitrate to move through the local alluvial groundwater system.

Butter Creek to City of Umatilla Area Summary and Conclusions

Project analyses used data from project sampling and local facilities. Data analysis led project investigators to the following observations and interpretations:

- Nitrate+nitrite-nitrogen concentrations detected in local project or facility groundwater samples ranged from non-detect to 74 mg/L in regional alluvial groundwater and non-detect to 100 mg/L in shallow unconfined alluvial groundwater.

- The time required for nitrate to locally travel from land surface to groundwater appears to vary from less than 1 month to 18 months given sufficient moisture is available for transport.

- Food processing wastewater appears responsible for elevated nitrate concentrations detected in groundwater at established wastewater land application areas.

- Food processing wastewater appears primarily responsible for a stationary nitrate concentration peak in the Butter Creek-Umatilla River confluence vicinity.

- C&B Livestock appears responsible for elevated nitrate concentrations in alluvial groundwater sampled at nearby sites downgradient of the facility.

- Dacthal acid was detected in an alluvial groundwater sample collected at UMA 119 located northwest of C&B Livestock. That detection indicates an irrigated crop agriculture influence.

- Septic systems appear to be an important influence upon groundwater west of the Umatilla River and north of Interstate 84.

- Water-mineral interactions contribute minor changes to the groundwater chemistry in the area.

- Mixing of groundwater with other water sources plays an important role in groundwater chemistry.

- Cyclic evaporation-dissolution in the soil and vadose (unsaturated) zone is an important influence upon the groundwater constituent chemistry.

- Significant mixing between Umatilla River water and groundwater appears to occur north of Interstate 84 and east of the Umatilla River.

- Total dissolved solids (TDS) concentrations greater than the 500 mg/L secondary (aesthetic) drinking water standard generally occurred east of Highway 207 and south of Minnehaha Road.

- The distribution of some lower TDS concentration areas suggest dilution from canal and/or surface water leakage.

- Arsenic greater than the 0.050 mg/L drinking water standard occurred in a sample collected from a site within the Lamb-Weston wastewater land application area next to the U.S. Army Depot.

- Sodium in area groundwater commonly exceeds the 20 mg/L limit recommended for persons on a physician prescribed sodium restricted diet.

- The distribution of total phosphate concentrations in area groundwater is nearly divided. Lower concentrations were generally found in groundwater sampled north of Interstate 84 and west of the Umatilla River. Higher concentrations were generally found in samples collected along or near Highway 207, south of Hermiston.

City of Umatilla to Hat Rock to Echo Meadows Area Summary and Conclusions

Project analyses for this area used data primarily from project sampling. The analysis led project investigators to the following observations and interpretations:

- Nitrate+nitrite-nitrogen concentrations in samples collected from the area ranged from non-detect to 31 mg/L.

- Total dissolved solids concentration exceeded the 500 mg/L secondary (aesthetic) drinking water standard in some samples from Hat Rock, and the terraces north and south of Hermiston.

- Arsenic detections occurred primarily in samples from the Stanfield vicinity. One shallow unconfined alluvial groundwater sample from the A.E. Staley Manufacturing Company wastewater land application site contained arsenic greater than the 0.050 mg/L drinking water standard.

- Area groundwater samples commonly had sodium concentrations greater than the 20 mg/L limit recommended for persons on a physician prescribed sodium restricted diet. Some groundwater samples from the terraces north and south of Hermiston contained sodium greater than 50 mg/L.

- Project and City of Hermiston sampling detected pesticides and volatile organic compounds in alluvial and basalt groundwater. Project sampling detected these constituents in samples from the Hermiston basin, the terrace south of Hermiston, Stanfield, and City of Echo sewage treatment facility areas.

- Analysis indicate dilution from canal leakage influences groundwater within the Hermiston basin and part of the terrace south of Hermiston.

- Nitrate+nitrite-nitrogen remained below 10 mg/L in project groundwater samples collected in the City of Hermiston and Hat Rock areas. Analyses indicate mixed influences.

- Nitrate+nitrite-nitrogen concentrations in most project samples from the terrace north of Hermiston generally measured less than 10 mg/L. However, samples from two sites had concentrations of 12 and 31 mg/L. Analyses indicate a variety of influences. Septic systems appear to influence groundwater at sites where measured nitrate concentrations are low. Septic systems, irrigation, and animal waste appear to independently influence groundwater at different sites where concentrations approach 10 mg/L. Irrigation appears responsible for concentrations exceeding 10 mg/L in groundwater at the two sites mentioned despite the proximity of a feedlot at one of those sites.

- Nitrate+nitrite-nitrogen concentrations measured less than 5 mg/L in project groundwater samples from the Hermiston basin despite the presence of numerous unsewered homes in some areas. Graphical analysis indicates septic systems do influence the local alluvial groundwater chemistry. However, analyses also indicate a significant dilution influence from canal leakage.

- Nitrate+nitrite-nitrogen concentrations exceeded the 10 mg/L drinking water standard in groundwater sampled from several sites on the terrace south of Hermiston. The detection of pesticides in some of these samples and analyses indicate an irrigated crop agriculture influence. Analyses also indicate a septic system influence at some sites.

- Nitrate+nitrite-nitrogen concentrations generally remained below 10 mg/L in project groundwater sampled from the Echo and Umatilla Meadows area. Analyses indicate wastewater influences groundwater at the A.E. Staley Manufacturing Company land application site. Irrigation related activity and canal leakage appear to influence groundwater at other locations.

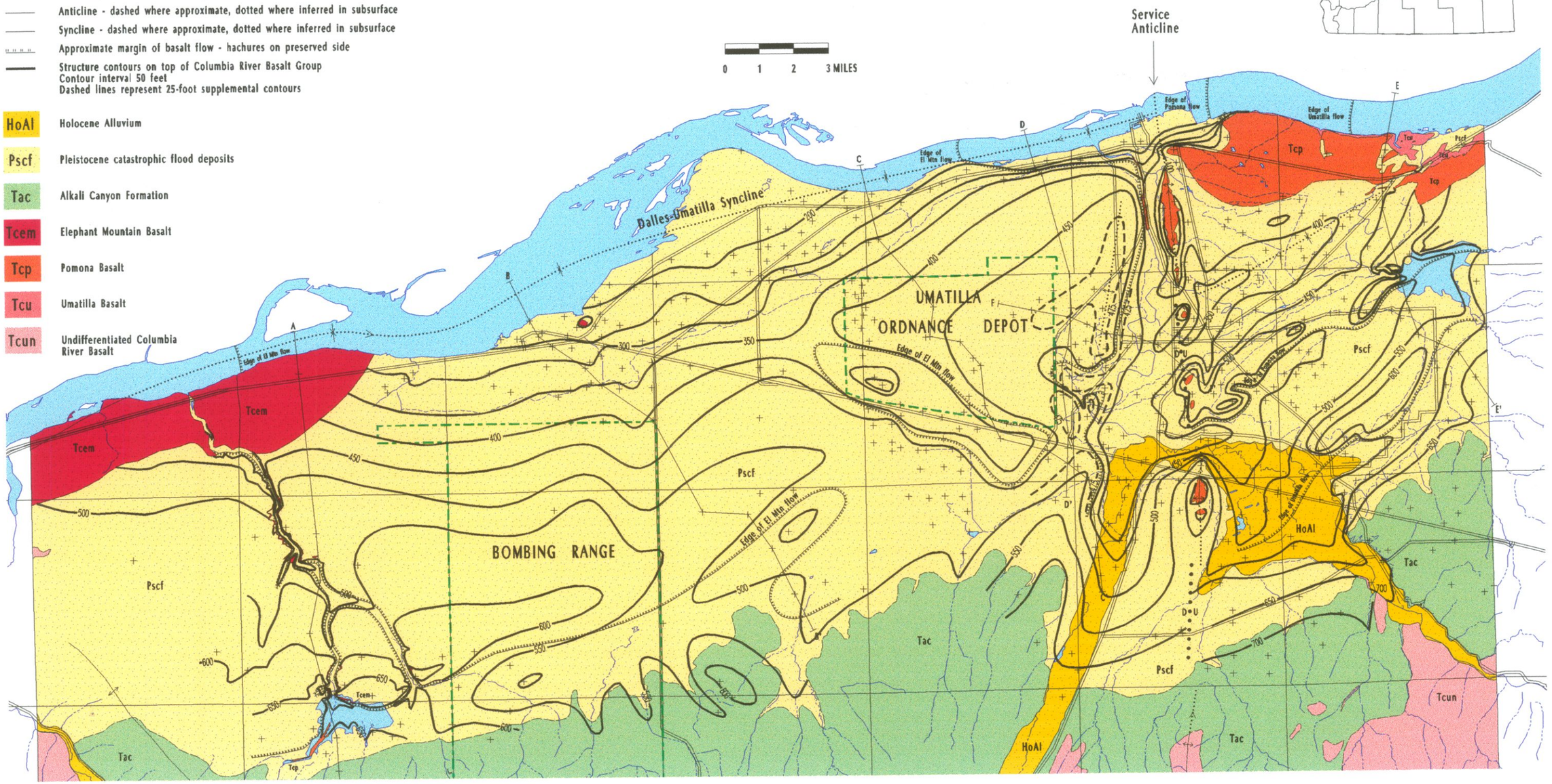
Geologic Map Showing Structure Contours on Top of the Columbia River Basalt Group

Explanation

- Location of well used to constrain contours•
- Geologic contact - dashed where approximate
- Fault - inferred location (U - Upthrown side; D - Downthrown side)
- Anticline - dashed where approximate, dotted where inferred in subsurface
- Syncline - dashed where approximate, dotted where inferred in subsurface
- Approximate margin of basalt flow - hachures on preserved side
- Structure contours on top of Columbia River Basalt Group
  Contour interval 50 feet
  Dashed lines represent 25-foot supplemental contours

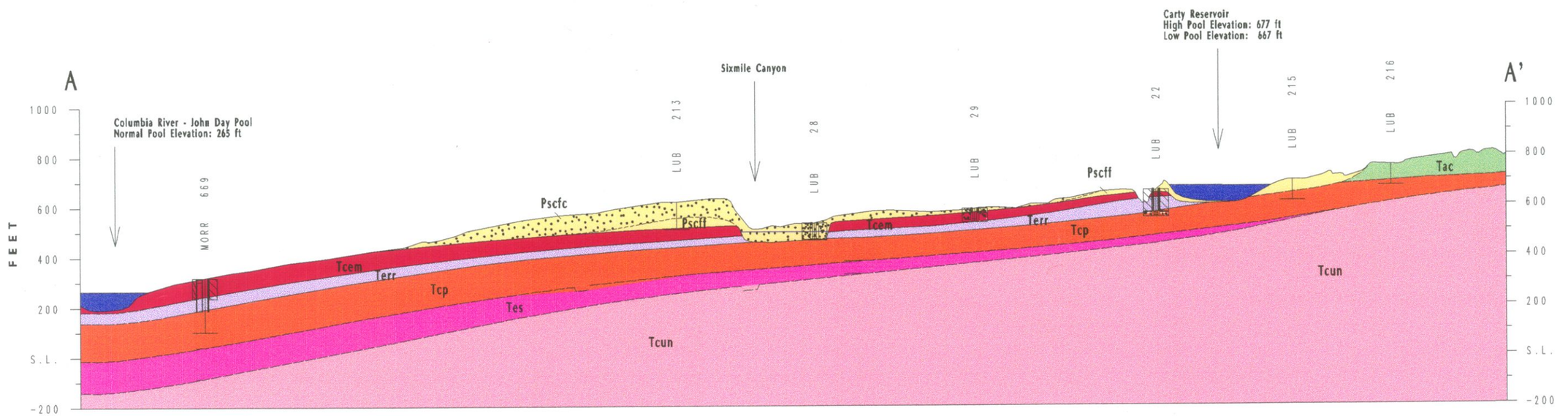
HoAl	Holocene Alluvium
Pscf	Pleistocene catastrophic flood deposits
Tac	Alkali Canyon Formation
Tcem	Elephant Mountain Basalt
Tcp	Pomona Basalt
Tcu	Umatilla Basalt
Tcun	Undifferentiated Columbia River Basalt

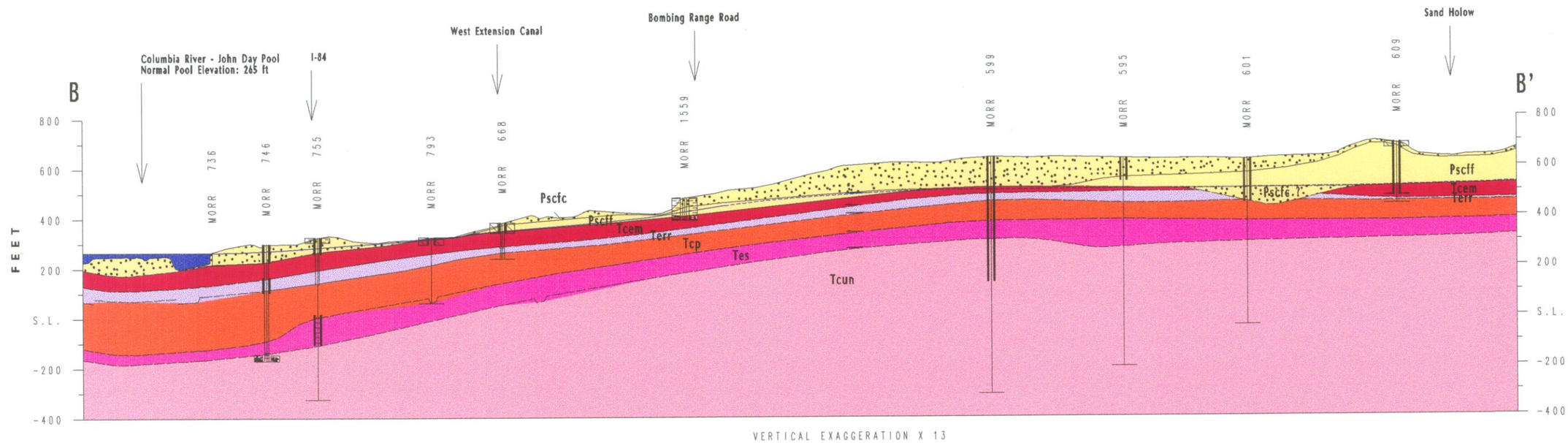




•Well numbers and basalt elevations not shown at this reduced scale. Request 1:62,500 scale map for more detail.

Geologic Cross Sections





Water-Level Contours of the Alluvial Aquifer

February 1991

Explanation

- Well location•
- Water-level contour
  Dashed where inferred
  Contour interval 50 feet
- Arrows show inferred flow lines
- Areas in which groundwater occurs under unconfined conditions in predominantly coarse-grained sediments
- Undifferentiated alluvial deposits
- Undifferentiated Columbia River Basalt (Miocene)



0 1 2 3 MILES

UMATILLA ORDNANCE DEPOT

BOMBING RANGE

5N
4N
3N

23E 24E 25E 26E 27E 28E 29E

•Well information and water levels at wells not shown at this reduced scale. Request 1:62,500 scale map for more detail

Well Density

Explanation

Number of Wells per Section

- 1 - 10
- 11 - 20
- 21 - 30
- › 30

Data from Oregon Water Resources Department water rights database as of July 15, 1991. Map shows all wells whether primary or secondary but acreage for primary water rights only.

PODs, or points of diversion, include wells [illegible] springs. If a given well is listed on more than o[illegible] water right it will be counted more than once.



0 1 2 3 MILES

UMATILLA ORDNANCE DEPOT

BOMBING RANGE

5N

4N

3N

23E 24E 25E 26E 27E 28E 29E