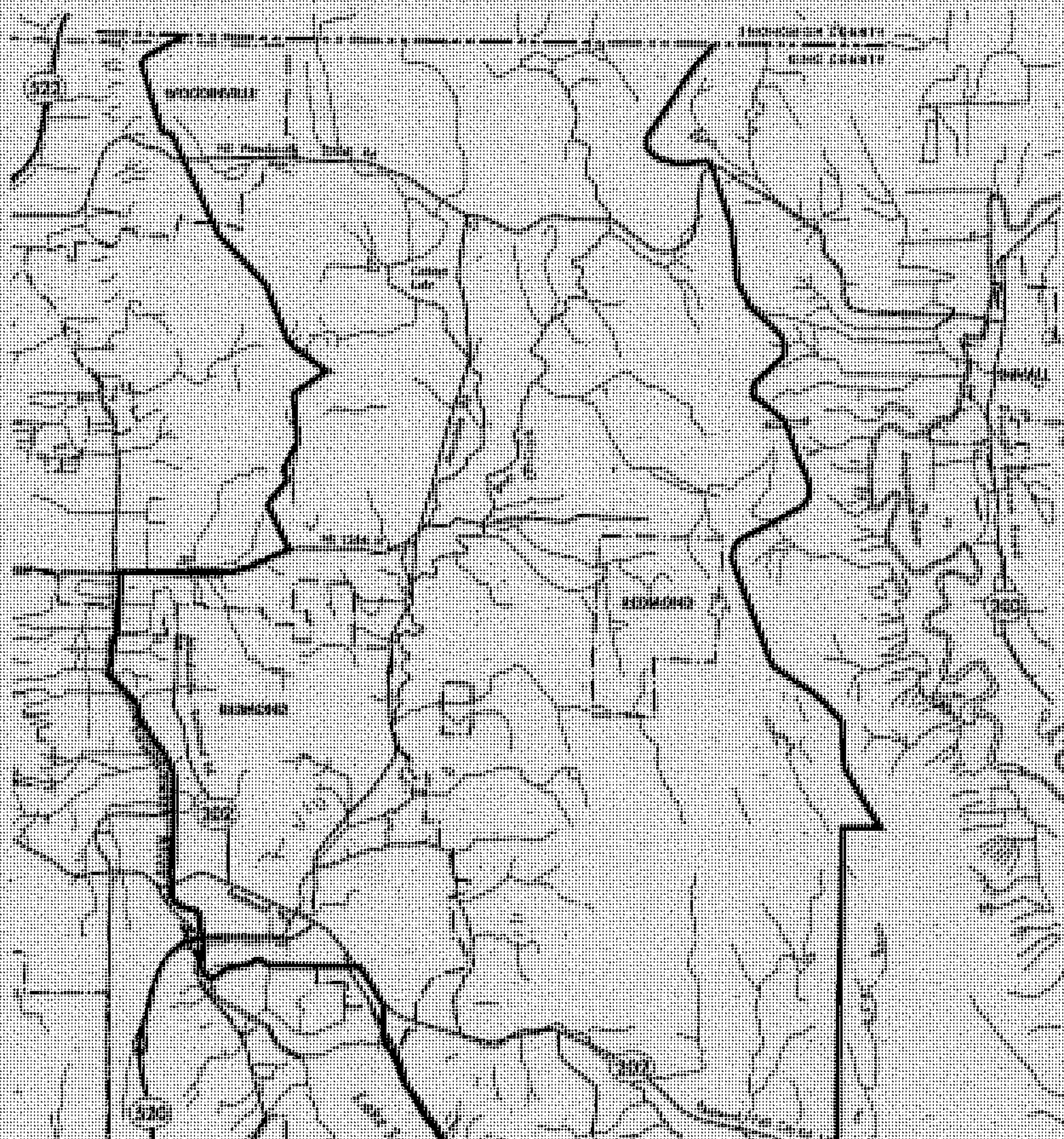
Redmond-Bear Creek Valley Ground Water Management Plan

Supplemental 1 - Area Characterization

Final



Submitted February 1999 by:

Redmond-Bear Creek Ground Water Advisory Committee

Redmond-Bear Creek
Ground Water
Advisory Committee

Supplement to the Redmond - Bear Creek Valley Ground Water Management Plan:

Area Characterization

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Final

Data and information contained in this document are current as of the period of project performance: 1989 - 1995.

Submitted by:

Redmond - Bear Creek Valley Ground Water Management Committee

King County Department of Natural Resources
Water and Land Resources Division
Suite 2200
700 Fifth Avenue
Seattle, WA 98104
(206) 296-6519

Seattle-King County Department of Public Health
Environmental Health Division
Suite 700
999 Third Avenue
Seattle, WA 98104
(206) 296-4722

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

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AREA CHARACTERIZATION

1.0 INTRODUCTION

This report provides an updated characterization of the Redmond-Bear Creek Valley Ground Water Management Area (Redmond-Bear Creek Ground Water Management Area). The report also summarizes the results of ground water data collection and analysis activities between 1989 and 1992 conducted as part of the Redmond-Bear Creek Valley Ground Water Management Plan.

The area characterization is a compilation of information from previous water investigations conducted in the Redmond-Bear Creek Ground Water Management Area and from data collection activities included as part of this ground water planning process. The area characterization includes information regarding the physical characteristics of the Redmond-Bear Creek Ground Water Management Area, land and water use management authorities in the Redmond-Bear Creek Ground Water Management Area and applicable regulations governing land and water use in the Redmond-Bear Creek Ground Water Management Area.

Section 2 presents a detailed description of the boundaries of the Redmond-Bear Creek Ground Water Management Area. Section 3 identifies and describes the various federal, state, and local agencies that have political jurisdiction over the Redmond-Bear Creek Ground Water Management Area.

Section 4 discusses the locale, including climate, topography, and drainage. Land use plans and policies affecting the ground water resource, and present and future land use impacts on ground water are discussed in Section 5. Water applications including population and water use projections, water rights, water purveyors, and conclusions regarding ground water quality and quantity are discussed in Section 6. Section 7 discusses geology, hydrogeology, new wells drilled as part of this process, data collection, ground water quality and conclusions. Section 8 discusses the water balance and Section 9 presents recommendations for protecting the ground water resources.

The development of this GWM Plan involved a data collection and analysis task wherein ground water quality and quantity data, rainfall data, and stream flow data were collected. The objective of the data collection and analysis task was and is to further the understanding of the water resources (quantity and quality) in the Redmond-Bear Creek Ground Water Management Area and to identify data gaps. The knowledge gained through this task is intended to direct actions to facilitate protection of the Redmond-Bear Creek Ground Water Management Area ground water. Data were collected by personnel from the City of Redmond, Union Hill, the N.E. Sammamish Sewer and Water District, Seattle-King County Health Department, the Redmond-Bear Creek Valley Ground Water Advisory Committee (RBC-GWAC), and the environmental firms of EMCON Northwest, Inc., and Adolfson Associates, Inc.

The data collection effort was based on recommendations by the project consultants EMCON Northwest, Inc., and Adolfson Associates, Inc., as defined in the Data Collection and Analysis Plan (June 1989, March 1990, and October 1990). This plan was reviewed and approved by the Department of Ecology (Ecology), Seattle-King County Health Department, the City of Redmond, N.E. Sammamish Sewer and Water District, Union Hill Water Association and the RBC-GWAC. This plan specified the types of data to be collected, the frequency of collection, the location of monitoring sites, and the rationale for collection of specific data. Additionally, all data that were collected were handled and maintained per the June 1989 and August 1989 Data Management Plan approved by Ecology and the RBC-GWAC. The data collected for this task are described below:

1.1 <u>Historical Record</u>

The Background Land and Water Use Report (July 1991) and the Background Hydrogeologic Characterization Report (November 1992) examined existing information on water and land uses, geology, hydrogeology, data collection activities, new wells drilled, and ground water quality. Data were collected to update the information in these two reports.

1.2 <u>Rainfall</u>

Rainfall data were collected from seven stations by personnel from the City of Redmond, Woodinville Water District, Union Hill Water Association, King County Surface Water Management, and volunteers who reside in the area.

1.3 <u>Stream Gauges</u>

Stream flow data were collected from six sites by personnel from United States Geological Survey, King County Surface Water Management Division, EMCON Northwest, Inc., and the Seattle-King County Health Department.

1.4 <u>Ground Water Levels and Water Quality</u>

Ground water elevation data were collected from eighty-one well sites, and water quality samples were collected from thirty-four wells, by personnel from the City of Redmond, Union Hill Water Association, N.E. Sammamish Sewer and Water District, EMCON Northwest, Inc., and the Seattle-King County Health Department.

1.5 <u>Monitoring Wells</u>

In 1990 five wells were drilled in areas where subsurface data were absent to evaluate current or future ground water supply. These wells were drilled in the northwest, southwest, south central, and Evans Creek Valley portions of the Redmond-Bear Creek Ground Water Management Area.

2.0 REDMOND-BEAR CREEK VALLEY GROUND WATER MANAGEMENT BOUNDARIES

The Redmond-Bear Creek Ground Water Management Area (Figure 2.1) is located in north central King County approximately 20 miles northeast of Seattle, Washington. The Redmond-Bear Creek Ground Water Management Area covers approximately 44 square miles. It is one of five Ground Water Management areas which have been designated in King County (Figure 2.2). It is bounded on the west by the Sammamish River and on the north by the Snohomish-King County line. The eastern boundary follows the topographic divide between the Bear Creek and Snoqualmie River valleys. The area is bounded on the south by Lake Sammamish and by the boundary of the water supply service area of the NE Sammamish Water and Sewer District.

The Bear Creek Valley bisects the study area north to south, and the Evans Creek Valley bisects the southern tip east to west. The boundaries are generally based on the presence of aquifer boundaries or divides.

In March 1996, after the publication of the Draft Ground Water Management Plan, the Department of Ecology approved a boundary change that affected the East King County, Issaquah Creek Valley and Redmond-Bear Creek Valley Ground Water Management Areas. The change moved all of Sammamish Plateau Water and Sewer District into the Issaquah Creek Valley Ground Water Management Area, and put part of the East King County GWMA into the Redmond-Bear Creek Valley GWMA. The majority of the addition is along the northeast side of Lake Sammamish, north of a line extending from the original southwest boundary corner to Lake Sammamish. Figure 2.3 shows the areal extent of the boundary change. This final version of the Ground Water Management Plan includes a number of text and graphics changes required by this boundary change. However, since most of the Area Characterization analysis had been completed for the March 1996 Draft Ground Water Management Plans, there may be some minor discrepancies in the data for the area of the change.

3.0 JURISDICTIONS IN THE REDMOND-BEAR CREEK VALLEY GROUND WATER MANAGEMENT AREA

This section discusses the role of public agencies with jurisdiction within the Redmond-Bear Creek Ground Water Management Area. The ground water related policies and activities of the agencies in the Redmond-Bear Creek Ground Water Management Area are discussed for federal, state, county, and local agencies, respectively.

3.1 Federal Agencies

The following federal agencies influence ground water management in various ways, both through their role as regulatory bodies, and in their capacities as policy makers.

Environmental Protection Agency

The United States Environmental Protection Agency administers numerous programs that influence ground water management in the Redmond-Bear Creek Ground Water Management Area. The U.S. Environmental Protection Agency also provides technical assistance to state and municipal officials on a variety of ground water-related issues, and acts as a regulatory agency. As a lead agency, the U.S. Environmental Protection Agency addresses issues concerned with water pollution, underground storage tanks, pesticide and herbicide use, hazardous waste management (including Comprehensive Environmental Response, Compensation, and Liability Act, and the Superfund Amendments and Reauthorization Act of 1986 sites and generators), and drinking water management. As a support agency, the U.S. Environmental Protection Agency is involved with regulation of sewage lagoons and holding ponds, sewage waste disposal, sludge application, spill control and prevention, solid waste handling, storm-water runoff, ground water, surface water, wetlands, and wells and water rights. The U.S. Environmental Protection Agency administers the Sole Source Aquifer Program, the Pesticides in Ground Water Study, and the Agricultural Chemicals in Ground Water Strategy. The U.S. Environmental Protection Agency also administers the Safe Drinking Water Act that mandates Washington State's Wellhead Protection Program.

The U.S. Environmental Protection Agency National Primary Drinking Water Regulations establish Maximum Contaminant Levels (MCL) for many chemical constituents. These standards reflect the maximum level of a contaminant in drinking water that is not expected to cause any adverse health effects over a lifetime of exposure. These standards apply to all public water supplies.

Department of Agriculture

The U.S. Department of Agriculture provides technical assistance to landowners and communities concerning municipal sludge application, livestock, irrigation design, wildlife, and animal-waste ponds. The Department of Agriculture is a lead agency for pesticide and herbicide programs, and administers programs such as fish and wildlife conservation programs and watershed projects.

The Soil Conservation Service/Natural Resources Conservation Service

As part of the Department of Agriculture, the Soil Conservation Service, now called the Natural Resources Conservation Service, provides technical assistance in soil erosion control and pesticide and herbicide use. It also plays a support role in agriculture, diking, drainage, forestry, lagoons, surface water, and wetlands issues.

3.2 Washington State Agencies

The following agencies operate at the state level, but also influence ground water affairs at the local level.

Washington State Department of Ecology (Ecology)

Ecology is responsible for protecting the waters of the state, therefore, the activities of Ecology both directly and indirectly affect ground water management decisions in the Redmond-Bear Creek Ground Water Management Area. Funding for the development of the Redmond-Bear Creek Valley Ground Water Management Plan was provided through the Centennial Clean Water fund, a grant program administered by Ecology. Ecology issues NPDES and state waste discharge permits, performs compliance monitoring, enforces discharge regulations, and responds to contaminant release incidents. Ecology is a lead agency in over 20 environmental categories, including aquifer depletion, seawater intrusion, water resources, well construction and abandonment, and water rights. As a regulatory agency, Ecology is responsible for the cleanup of leaks and spills of hazardous materials (except in navigable waters), oversight of Resource Conservation and Recovery Act facilities and state hazardous waste cleanup sites, and the regulation of underground storage tanks.

Washington Department of Health, Office of Environmental Health Programs

The Washington Department of Health is involved in a variety of programs that influence ground water management. The Northwest Drinking Water Operations Program of the Washington Department of Health is responsible for plan approval for Group A public water supplies, including well site inspections and final system completion certification.

The Washington Department of Health's On-Site Sewage Program is responsible for enforcing the rules and regulations of the State Board of Health per on-site sewage disposal, Chapter 346-272 WAC. These regulations are currently under revision to increase effectiveness in protecting public health and water quality. The Washington Department of Health is also responsible for guideline development and performance review of alternative wastewater disposal systems. The Washington State Department of Health conducted an area wide ground water monitoring project in the Spring of 1995. This project included a statewide sampling of 1326 wells for pesticides and herbicides including 77 sites in King County. Results of the analysis indicated two wells in King County exceeded U.S. Environmental Protection Agency's detection limit for pesticides/herbicides. The results of this project has allowed the Washington State Department of Health to grant area wide waivers to purveyors for ongoing monitoring.

Washington State Department of Natural Resources

The proprietary responsibility of the State Department of Natural Resources includes management of state lands for timber production; Christmas trees; evergreen brush such as salal, huckleberry, and other special forest products; and coal, sand, and gravel; as well as other mineral deposits.

Washington State Department of Trade and Economic Development

The Department of Trade and Economic Development provides guidelines for implementing the Growth Management Act.

3.3 King County Agencies

The following King County agencies have jurisdiction in the preparation of Comprehensive Land Use Plans within the Redmond-Bear Creek Ground Water Management Area. Each of these agencies conducts activities that either directly or indirectly affect ground water management in the area.

The Metropolitan King County Council

The Metropolitan King County Council has legislative authority to enact ordinances and regulations governing protection of ground water resources, including land use provisions. In the past, the Metropolitan King County Council has administered water resource, land use, and wetlands programs, in addition to assisting in community plan reviews. The Metropolitan King County Council has adopted the 1994 King County Comprehensive Plan and the Community Plans for Bear Creek, East Sammamish, and Northshore. It has also adopted the City of Redmond Community Development Guide.

King County Office of Budget and Strategic Planning

The Office of Budget and Strategic Planning is primarily involved in developing the King County Comprehensive Plan and in other land use policy plans. Additionally, this Office is involved in coordinating King County's review of comprehensive plans for all water and sewer systems operating in unincorporated King County.

King County Department of Development and Environmental Services

The King County Department of Development and Environmental Services regulates and enforces land development and zoning in portions of the Redmond-Bear Creek Ground Water Management Area. Its specific duties include development control, commercial and residential permitting, sensitive area monitoring, and environmental review.

Seattle-King County Health Department, Environmental Health Division

The Seattle-King County Health Department is an advisory and regulatory body involved in a variety of topics, including regulation of Group B public water systems. The Seattle-King County Health Department served as lead agency for the Redmond-Bear Creek Ground Water Management Plan from October 7, 1986 until December 31, 1995. In that capacity, the Seattle-King County Health Department coordinated the activities necessary for the development of the ground water management plan. Those activities included collecting ground water quality and quantity data, managing the ground water database, drafting technical issue papers, preparing and monitoring the budget for development of Redmond-Bear Creek Ground Water Management Plan, drafting the Redmond-Bear Creek Ground Water Management Plan, conducting a public hearing on the Redmond-Bear Creek Ground Water Management Plan and resolving issues of nonconcurrence with affected jurisdictions.

The Seattle-King County Health Department is responsible for evaluating site suitability for, and the permitting of, on-site wastewater disposal systems. Seattle-King County Health Department responds to complaints about, and regulates the repair of, failing systems; reviews all subdivision proposals for which on-site sewage disposal is proposed; and educates homeowners in the proper maintenance of their systems. The Solid Waste Program of Seattle-King County Health Department is responsible for permitting landfills, overseeing and permitting sludge application sites and sampling ground water in areas around the landfills.

The Local Hazardous Waste Management Program in King County helps businesses and households in identifying hazardous wastes, reducing the amount of hazardous waste and in managing these wastes properly. This Program is a joint effort by Seattle-King County Health Department, King County Department of Metropolitan Services, King County Solid Waste Division, the Seattle Solid Waste Utility, and 32 cities in King County. The goal of the program is to divert the maximum amount of household hazardous waste and small quantity generator waste from disposal in the municipal waste stream and from the environment.

King County Department of Natural Resources

The following divisions of the Department of Natural Resources conduct the activities described below in the Redmond-Bear Creek Ground Water Management Area.

<u>Solid Waste Division:</u> The Solid Waste Division operates and maintains the Cedar Hills Landfill. The agency's responsibilities include on-site ground and surface water quality monitoring.

<u>Surface Water Management/Water and Land Resources Division</u>: On January 1, 1996, the King County Surface Water Management (SWM) Division became a part of the new Department of Natural Resources. Subsequently, the division was renamed the Water and Land Resources (WLR) Division and assumed the lead agency role for the ground water program on January 1, 1996. Given the continuity between surface water and ground water in much of King County, WLR Division's management of surface water has a direct influence on the quantity and quality of water infiltrating to ground water.

The King County WLR Division is responsible for a variety of programs that address surface water quality and quantity in the Redmond-Bear Creek Ground Water Management Area. The programs include basin planning, non-point source pollution control, wetlands, and the construction and maintenance of drainage and water quality facilities.

Water Pollution Control/Wastewater Division: The Water Pollution Control Division, now called the Wastewater Division, oversees most of the sewage collection and treatment for sewered areas in the Redmond-Bear Creek Ground Water Management Area, and is the designated regional water quality planning agency under the 1972 Clean Water Act. The Wastewater Division provides sewage treatment services to the City of Redmond and the NE Sammamish Water and Sewer District, and the Lake Washington School District 414. The WPC Division was combined with the SWM Division to form the Water and Land Resources Division in 1997.

King County Department of Transportation

The Department of Transportation consists of the former Department of Metropolitan Services (formerly Metro) and the former King County Department of Public Works, Roads and Engineering Division.

Road Services Division. In addition to construction and maintenance of roads and associated drainage, the Road Services Division is responsible for vegetation control. Although the Division employs an Integrated Vegetation Management Plan, herbicides are applied along area roadsides.

3.4 Local Agencies

The following agencies operate at the local level to influence ground water management in the Redmond-Bear Creek Ground Water Management Area.

City of Redmond

The City of Redmond Planning Department's responsibilities include review and approval of proposed developments; review of the framework for future growth within the city limits, and assessment of patterns of growth for conformity with city, local, and state regulations.

The City of Redmond Public Works Department's responsibilities include: water and sewer system planning and administration; road maintenance; roadside vegetation control; stormwater facility maintenance and enhancement; and local water quality monitoring and protection.

City of Woodinville

A small portion in the northwest corner of the Redmond-Bear Creek Ground Water Management Area is in the city of Woodinville. As such, the city has planning and regulatory responsibility in this area.

Northeast Sammamish Water and Sewer District, Woodinville Water District, Union Hill Water Association

The jurisdiction of these water purveyors is limited to households and commercial services. Unlike the City of Redmond and King County, they do not have regulatory authority, nor do they have the police power necessary to enforce programs. Their role is to provide water and/or sewer service within a specific area, and to monitor and manage ground water quality and quantity.

3.5 Other Agencies

Discussed below are other local agencies that influence ground water management in the Redmond-Bear Creek Ground Water Management Area.

King Conservation District

The King Conservation District works with the urban and agricultural community to implement animal management and land use practices that increase productivity while minimizing soil erosion and water pollution. The district is neither a branch of county government nor an enforcement agency, but rather, a political subdivision of state government authorized by Chapter 89.08 RCW. The King Conservation District is dedicated to the conservation and best use of the natural resources of King County.

4.0 PHYSICAL GEOGRAPHY

4.1 Geographic Setting

The Redmond-Bear Creek Ground Water Management Area contains a number of lakes and streams. The primary streams include Cottage Creek, Daniels Creek, Seidel Creek, Bear Creek, and Evans Creek. The four largest lakes inside the Redmond-Bear Creek Ground Water Management Area boundary are Lake Leota, Cottage Lake, Welcome Lake, and Peterson Park.

4.2 Topography

Elevations in the Redmond-Bear Creek Ground Water Management Area range from approximately 30 feet above mean sea level in downtown Redmond to just over 600 feet near the Redmond watershed. Surface elevations rise steadily in a northerly direction from the City of Redmond up the Bear Creek Valley gaining approximately 450 feet of elevation.

4.3 Climate

Maritime air masses from the Pacific Ocean influence the climate of the Redmond-Bear Creek Ground Water Management Area and result in moderate temperatures. During the fall and winter months, prevailing winds are from the southwest bringing moist air about the same temperature as the ocean's surface. Precipitation is typically of light to moderate intensity and long duration. About 75 percent of the annual precipitation occurs during the period October through March. In the spring and summer prevailing winds are from the northwest. The summer can be described as the dry season, as less than 5 percent of the annual rainfall occurs between July and September.

The Redmond-Bear Creek watershed receives an average of 42 inches of rainfall annually. The precipitation varies seasonally with approximately 75 percent of the annual precipitation falling between October and March with January having the greatest amount of precipitation. Precipitation decreases sharply in summer with the least precipitation occurring in September. Rainfall was usually greatest at the higher elevations along the western boundary of the Redmond-Bear Creek Ground Water Management Area and lowest in the lower Bear Creek Valley around the cities of Redmond and Woodinville.

5.0 LAND USE IMPACTS ON GROUND WATER

Land use activities can have a significant impact on ground water quality and use. As area population grows, consumptive use of ground water will increase, particularly if alternative sources are not sufficient to meet demands. In addition, as development increases, the risk of contamination of ground water resources is likely to increase. Ground water reserves can also be depleted when development decreases the effective area of ground water recharge.

Based on population and employment growth forecasts prepared by the Puget Sound Regional Council, the Redmond-Bear Creek Ground Water Management Area will experience a significant (100-200 percent) increase in population during the next 30 years. Along with the increased population, employment opportunities in the Redmond-Bear Creek Ground Water Management Area will expand significantly as well. These two factors will have a major impact on land uses in the area. These impacts will include an increase in residential housing densities, expansion, and enlargement of vehicular transportation corridors and growth of commercial and industrial activities. Further discussion of population growth and resultant impacts on water use is provided in Section 6.0.

5.1 Community Plans, Policies, and Regulations Affecting Land and Water Use

This section discusses plans and policies relating specifically to ground water management for each agency and the impacts to ground water from various land use activities.

The Redmond-Bear Creek Ground Water Management Area is contained in all, or portions of, four community planning areas. These community-planning areas include King County's Bear Creek, East Sammamish, Northshore, and the City of Redmond community development guide. Specific land uses and accompanying area-wide zoning, consistent with the King County Comprehensive Plan's policies, are established in the community plans. The portions of the Redmond-Bear Creek Ground Water Management Area covered by each of the four community plans are shown on Figure 5.1. Based on information in the four local community plans, existing and proposed future land uses in the Redmond-Bear Creek Ground Water Management Area were compiled and mapped (January 1991). Figure 5.2 shows the existing (1989) land uses and Figures 5.3A -5.3C show the anticipated future land uses for the area. A summary of policies, plans and regulations relevant to ground water management in the Redmond-Bear Creek Ground Water Management Area are provided in Appendix A (available upon request).

As ground water management alternatives are developed for the ground water management plan, existing policies and regulations will be reviewed and incorporated if appropriate. In areas where deficiencies exist, these will be noted and recommendations developed to revise or prepare new policies or regulations.

Growth Management Act (GMA, Chapter 36.70A RCW)

The GMA addresses ground water issues in two ways -- designation of critical areas and the land use element. Critical areas are defined, in part, as areas with a critical recharge effect on aquifers used for drinking water (Chapter 36.70A.030(5)(b) RCW. The land use element is required to "provide for the protection of the quality and quantity of ground water used for public water supplies" (Chapter 36.70A.070(1) RCW). A summary of policy and maps contained in the plan are provided below.

Countywide Planning Policies (Ordinance 114446, 7/19/94)

The Countywide Planning Policies recognize the Ground Water Management Plans are being prepared. Authors of the Countywide Planning Policies noted that each plan was to identify aquifer recharge areas and propose strategies to protect ground water resources. Two policies are in the Countywide Planning Policies relevant to aquifer protection:

CA-5 All jurisdictions shall adopt policies to protect the quality and quantity of ground water where appropriate:

a. Jurisdictions that are included in the Ground Water Management Plans shall support the development, adoption, and implementation of the Plans and

b. The Seattle-King County Department of Public Health and affected jurisdictions shall develop countywide policies outlining best management practices within aquifer recharge areas to protect public health; and

c. King County and ground water purveyors including cities, special purpose districts, and others should jointly;

1. Prepare ground water recharge area maps using common criteria and incorporating information generated by Ground Water Management Plans and Purveyor studies;
2. Develop a process by which land use jurisdictions will review, concur with, and implement, as appropriate, purveyor Wellhead Protection Programs required by the Federal Safe Drinking Water Act;
3. Determine which portions of mapped recharge areas and Wellhead Protection Areas should be designated as critical; and
4. Update critical area maps as new information about recharge areas and Wellhead Protection Areas becomes available.

CA-6 Land use actions should take into account the potential impacts on aquifers determined to serve as water supplies. The depletion and degradation of aquifers needed for potable water supplies should be avoided or mitigated; otherwise a proven, feasible replacement source of water supply should be planned and developed to compensate for potential lost supplies.

King County Comprehensive Plan (Ordinance 11575, 11/18/94)

The King County Comprehensive Plan provides policy direction related to ground water in three topic areas -- planning and coordination, land use, and storm water management. The Plan recognizes that the quantity and quality of water resources in the County are two fundamental issues to be addressed in future land use decisions and programmatic actions. However, emphasis is placed on contamination and relies on the adoption of the Ground Water Management Plans and Wellhead Protection Programs to develop information on quantity issues. In summary:

- the County should work in concert with affected jurisdictions and purveyors to plan for the continued protection of the aquifer;
- urban land uses should remain at high densities with an appropriate level of resource protection and rural areas should be allowed to develop only at very low densities with development restrictions protecting the natural environment; and
- storm water management techniques should encourage infiltration.

<u>Planning and Coordination</u>

NE-302 Future watershed plans should integrate surface water, ground water, drinking water and wastewater planning to provide efficient water resource management.

NE-332 In unincorporated King County, areas identified as sole source aquifers or as areas with high susceptibility for ground water contamination where aquifers are used for potable water are designated as Critical Aquifer Recharge Areas as shown on the map entitled Areas Highly Susceptible to Ground Water Contamination. Since this map focuses primarily on water quality issues, the County shall work in conjunction with cities and ground water purveyors to designate and map recharge areas which address ground water quantity concerns as new information from ground water and wellhead protection studies adopted by County or state agencies become available. Updating and refining the map shall be an ongoing process.

NE-333 King County should protect the quality and quantity of ground water countywide by:

a. Placing a priority on implementation of the Ground Water Management Plans;
b. Developing a process by which King county will review, and implement, as appropriate, adopted Wellhead Protection Programs in conjunction with cities and ground water purveyors;
c. Developing, with affected jurisdictions, Best Management Practices for new development and for forestry, agriculture, and mining operations recommended in the Ground Water Management Plans and Wellhead Protection Programs as appropriate (sic). The goals of these practices should be to promote aquifer recharge quality and to strive for no net reduction of recharge to ground water quantity.
d. Refining regulations as appropriate to protect critical aquifer recharge areas when information is evaluated and adopted by King County.

<u>Land Use</u>

U-206 Environmental standards for urban development should emphasize ways to allow maximum permitted densities and uses of urban land. Mitigating measures should be encouraged to serve multiple purposes, such as drainage control, ground water recharge, stream protection, open space, cultural and historic resource protection and landscaping. When technically feasible, standards should be simple and measurable, so they can be implemented without lengthy review processes.

NE-335 In making future zoning and land use decisions that are subject to environmental review, King County shall evaluate and monitor ground water policies, their implementation costs, and the impacts upon the quantity and quality of ground water. The depletion or degradation of aquifer needed for potable water supplies should be avoided or mitigated, and the need to plan and develop feasible and equivalent replacement sources to compensate for the potential loss of water supplies should be considered.

NE-336 King County should protect ground water in the Rural Area by:

a. Preferring land uses that retain a high ratio of permeable to impermeable surface area and that maintain or augment the infiltration capacity of the natural soils; and

b. Requiring standards for maximum vegetation clearing limits, impervious surface limits, and, where appropriate, infiltration of surface water. These standards should be designed to provide appropriate exceptions consistent with Policy R216.

R-216 Rural development standards should be designed to protect the natural environment by addressing seasonal and maximum clearing limits, impervious surface limits, surface water management standards that emphasize preservation of natural drainage systems and water quality, ground water protection, and Best Management Practices for resource-based activities. These standards should be designed to provide appropriate exceptions for lands that are to be developed for kindergarten through twelfth grade public schools and school facilities, provided that the school project shall comply at minimum with the requirements of the King County Surface Water Drainage Manual or revisions thereto.

NE-302 Development should occur in a manner that supports continued ecological and hydrological functioning of water resources. Development should not have a significant adverse impact on water quality or water quantity. On Vashon Island, development should maintain base flows, natural water level fluctuations, ground water recharge in Critical Aquifer Recharge Areas and fish and wildlife habitat.

Storm Water Management

NE-310 Management of storm water runoff shall occur through a variety of methods. Storm water runoff caused by development shall be managed to prevent unmitigated significant adverse impacts to water resources caused by flow rates, flow volumes or pollutants to promote ground water recharge, infiltration of storm water, when feasible given geological, engineering and water quality constraints. King County's current practice is to pursue non-structural methods whenever possible. In the Urban Growth Area, methods which are land consumptive will need to be balanced with the need to protect the supply of developable land.

NE-334 King County should protect ground water recharge quantity in the Urban Growth Area by promoting methods that infiltrate runoff where site conditions permit, except where potential ground water contamination cannot be prevented by pollution source controls and storm water pretreatment.

City of Redmond Comprehensive Plan

The City of Redmond Comprehensive Plan was adopted on July 18, 1995. It provides policy direction for environmental review and future land use determinations in compliance with the Growth Management Act (Beam, C. personal conversation, January 29, 1996). Ground water related policies in the plan are listed below.

FV-11 The Redmond Comprehensive Plan should limit development in areas with significant natural resource values to protect the resources from serious adverse impacts.

NE-3 Redmond should minimize and, where practicable, eliminate the release of substances into the air, water, soil and ground water that may degrade the quality of these resources or contribute to global atmospheric changes.

NE-35 Impervious surfaces should be minimized outside the Urban Center. Redmond shall adopt appropriate limits on the amount of impervious surfaces allowed within all zoning districts. These standards should allow for efficient land use, accommodate the level of development intensity planned for the area and protect environmental resources such as streams and ground water recharge.

NE-43 Redmond and other jurisdictions shall protect the quality of ground water used for public water supplies to insure adequate sources of potable water for Redmond and the region. The level of protection provided shall correspond with the potential for contaminating the municipal water supply aquifer. The overall goal should be nondegradation of ground water quality. Waste water and potentially contaminated stormwater should not be discharged to ground water.

NE-44 Redmond should adopt and implement an aggressive program to protect the municipal water supply aquifer.

NE-45 Redmond and other jurisdictions shall retain aquifer recharge capacity in areas that have not already been committed to urban uses.

NE-46 Open spaces, tree protection areas and other areas of protected native vegetation should be encouraged in those areas with a high potential for ground water recharge and which can be protected from contaminated stormwater runoff.

NE-48 Contaminated sites that may affect the Redmond ground water supplies shall be cleaned to such a standard that the sites will not present a risk to drinking water supplies.

NE-62 Redmond should support public education to protect and improve surface and ground water resources by:

1. Increasing the public's awareness of the potential impacts on water bodies and water quality.

2. Encouraging the proper use of fertilizers and chemicals on landscaping and gardens.
3. Encouraging proper disposal of materials.
4. Educating businesses on surface and ground water protection best management practices in cooperation with other government agencies and other organizations.
5. Educating the public and businesses on how to substitute materials and practices with a low risk of surface and ground water contamination for materials and practices with a high risk of contamination.

LU-27 Where clustering is used, the clustered buildings and impervious surfaces shall not be located within the following areas: 3. Lands classified as having a high recharge potential by the Redmond-Bear Creek Ground Water Management Plan and not previously planned for high-intensity urban uses. 3. Lands classified as having a high recharge potential by the Redmond-Bear Creek Ground Water Management Plan and not previously planned for high-intensity urban uses.

LU-72 After adoption of the Redmond Wellhead Protection Program, Redmond should incorporate any applicable recommendations into the Comprehensive Plan. This process also should evaluate whether existing heavy industrial uses located on high-and moderate-potential ground water recharge areas need additional development or operating standards. This process also should evaluate whether uses that use or store significant quantities of hazardous materials and petroleum storage facilities located on high- and moderate-potential ground water recharge areas should be phased out.

LU-77 Redmond shall monitor and comment on the review and enforcement of gravel mine reclamation plans by the State Department of Natural Resources. Reclamation plans should show that the site will be graded to provide for appropriate redevelopment. Any proposed fill material shall be tested. The grading and proposed fill material shall be shown to adequately protect ground water resources while allowing for appropriate levels of ground water recharge.

UT-23 Maintain a Wellhead Protection Program as long as ground water sources remain viable. This program shall guide land use decisions, development regulations, stormwater facilities requirements and other measures necessary to protect the Redmond well system.

UT-59 Limit the use of on-site wastewater disposal systems to agricultural areas or areas where the zoned density is less intense than one unit per acre and allow them only if soil conditions are suitable and ground water would not be negatively impacted.

UT-60 The stormwater system shall be designed to a level of service standard that provides adequate drainage for the appropriate design storm to ensure the safety, welfare and convenience of the developed areas. It shall also be designed to a level of service such that it adequately protects the quality of surface and ground water.

UT-66 Design of stormwater management facilities should approximate pre-development levels of infiltration and recharge in areas where appropriate.

Redmond Community Development Guide

- The Redmond Community Development Guide addresses development within the Redmond city limits and areas outside the city limits that are being considered for future annexation. The Redmond Community Development Guide is currently being updated to meet the requirements of the City of Redmond Comprehensive Plan, July 1995 (Beam, C. personal conversation January 22, 1996).

Community Plans

Community Plans represent another legally binding policy document with jurisdiction in the Redmond-Bear Creek Ground Water Management Area. King County is divided into community planning areas allowing citizens and planning officials to develop local area goals, plans, and policies. Once adopted by the Metropolitan King County Council, a community plan becomes an official document affecting development and municipal expenditures in the community.

King County Community Planning Areas in the Redmond-Bear Creek Ground Water Management Area are Bear Creek, N.E. Sammamish, Northshore, and the City of Redmond Community Development guide. Policies are developed for each community and if adopted by the Metropolitan King County Council, they become law and are included in the community plan.

<u>Bear Creek Community Plan</u>

The Bear Creek Community Plan covers approximately two-thirds of the Redmond-Bear Creek Ground Water Management Area. Although, the King County Comprehensive Plan designated the Bear Creek planning area as a Transitional Area, the adoption of the 1989 Bear Creek Community Plan redesignated the area for urban and rural uses. Subsequently, in November 1993, Interim Urban Growth Areas were designated in King County to meet the requirements of the State of Washington Growth Management Act. All properties currently zoned S-E, S-C, and GR-5 (except for the Novelty Hill Master Plan Development Area) are now considered Rural under the Interim Urban Growth Areas as adopted by Ordinance 11110. The ordinance also prohibits subdivision of lots smaller than five acres in size until December 31, 1994.

Significant goals of the Bear Creek Community Plan are:

- Meet the need for land for housing and population growth and, at the same time, protect existing rural character, natural resources and environmentally sensitive features.
- Direct most commercial and industrial development to locate in existing urban activity centers.
- Designate the eastern plateau of the planning area Urban/Master Plan Development.
- Use on-site disposal systems as the long-term approach to sewage disposal in the low-density residential and rural areas.
- Allow existing water purveyors to continue to serve the study area. Expansion of systems in rural areas would require county approval subject to specific policies and criteria.

East Sammamish Community Plan

The Redmond-Bear Creek Ground Water Management Area includes a portion of the East Sammamish Community Planning Area. An updated East Sammamish Community Plan was adopted on June 25, 1993.

In the East Sammamish Community Planning Area, the southern most portion of the Redmond-Bear Creek Ground Water Management Area is urban. The area immediately south of State Route 202 is predominately rural. A small amount of manufacturing is located at the intersection of State Route 202 and 228th Avenue NE. Significant features of the East Sammamish Community Plans include:

NE-6 Public sewers are the preferred method for wastewater treatment in Urban Areas, including Urban Reserve Areas. Within Rural Areas, and Urban Areas where sewers are not yet available, proper siting and maintenance of septic systems should continue to receive special attention for new and existing land development to preserve the valuable ecological functions and beneficial public uses of water resource.

NE-8 Upon adoption, the recommendations of the Redmond Bear Creek Ground Water Management Plan should be implemented through zoning and other mechanisms to protect ground water resources.

NE-11 All golf course proposals shall be carefully evaluated for their impact on surface and ground water quality and quantity, sensitive areas and fish and wildlife resources and habitat.

NE-12 Water used for irrigating golf courses should come from non-potable water sources wherever possible. Use of natural surface water sources, such as streams should be avoided due to impacts on fish and other wildlife habitat. A water conservation plan shall be submitted with golf course applications that should address measures such as the use of drought tolerant plant species.

GM-4 Lands within the Urban Reserve Area should be reclassified to their potential zones, either through an amendment to the area zoning or an individual reclassification application, only when it can be demonstrated to King County and determined that area wide service deficiencies in water, roads, electrical service and parks are remedied or do not apply to a particular property or subarea. County approval of the reclassification should occur only when King County finds that by the time a development is ready to be occupied the following criteria will be met not withstanding the foregoing, the underlying potential zone shall be effective on June 30, 1996:

- Domestic water supplies are adequate to support planned growth, either by virtue of an intertie between the Plateau and the regional water supply in cooperation with Seattle, the development of new ground water resources, conservation measures sufficient to guarantee capacity, or the property is located in or can be served by the Northeast Sammamish Sewer and Water District.
- The East Lake Sammamish and Non-point plans are adopted, and those projects that are identified by the Council during adoption of these plans as necessary to accommodate future growth are operational.

Northshore Community Plan

The Northshore Community Plan (adopted Feb. 1993) affects only the northwestern edge of the Redmond-Bear Creek Ground Water Management Area.

Primary goals for the Northshore Community Plan are:

- Population growth should fill in already partially developed suburban areas with low and medium density residential use.
- Development should occur along existing patterns set by commercial/industrial centers and major street and highways.
- As development occurs, agricultural uses, open space and the area's many natural amenities should be preserved as much as possible.

The Plan should also provide greater detail about land use designations within the planning area. Areas adjacent to the City of Redmond are planned for high-density single-family residential growth, while Hollywood Hill is designated as rural residential. Portions of the Redmond-Bear Creek Ground Water Management Area within the City of Woodinville will ultimately be developed at urban densities.

Bear Creek Basin Plan

The Bear Creek Basin Plan focuses on drainage and flooding, water pollution, and programs with fish and wildlife habitat in the 51 square mile Bear Creek basin. The plan recommends a set of regulatory, programmatic, and capital improvement actions to address these problems. While the plan focuses on surface water issues, the maintenance of ground water quality and recharge was considered in the development of the recommendations. The plan was adopted by the King County Council in August 1992. The City of Redmond has adopted portions of the plan.

5.2 Residential and Commercial Land Use

Residential Development

Existing Development. As can be seen from the existing land use map (see Figure 5.2), the dominant land uses in the Redmond-Bear Creek Ground Water Management Area are low (≤1 home/acre) to moderate (2 to 3 homes/acre) density residential and undeveloped land. About 50 percent of the unincorporated Redmond-Bear Creek Ground Water Management Area is zoned for minimum lot size of five acres. Most of the area east of Avondale Road and north of Union Hill Road is currently undeveloped or in rural development with minimum lot sizes of five to ten acres per dwelling. Most higher density residential development is located west of Avondale Road and along State Route 202 (Redmond-Fall City Road) within the City of Redmond. In areas where local sewer service is available, (within the City of Redmond, at the southern end of the Redmond-Bear Creek Ground Water Management Area and the north side of Northeast 128th), residential development is generally denser than in the rest of the Redmond-Bear Creek Ground Water Management Area (see Figure 5.2).

Approximately 40 percent of the City of Redmond north of Northeast 88th Street and South of Northeast 116th Street, is zoned to accommodate single family residences with four to six dwellings per acre. Most of the remaining northern portion is zoned to accommodate one to three dwelling units per acre.

Multiple family development in the Redmond-Bear Creek Ground Water Management Area is limited to areas within the City of Redmond (see Figure 5.2). These areas are located immediately north of the commercial district along Avondale Road and the Redmond-Woodinville Road, along the Sammamish River, and on the east edge of the city along the Redmond-Fall City Road.

Future Development. In the rural area, with an absence of public sewers, the density of new housing development will be limited to a maximum density of one house per 2.5 to 5 acres. Areas serviced by sewer will provide for higher density residential development. The intersection of Avondale Road and NE 116th Street has been zoned to provide for multifamily residential development and neighborhood commercial development and the area southeast of the City of Redmond will allow for higher density residential development of up to six dwelling units per acre. The majority of high density and multifamily residential development will be located within the City of Redmond and the Novelty Hill Urban Planned Developments, (if the Urban Plan Developments are approved). Figure 5.3A shows proposed future land use for King County. Figures 5.3B and 5.3C show proposed future land use for the cities of Redmond and Woodinville, respectively.

Multifamily residential development within the City of Redmond will be confined to the center, southeastern boundary, and near the northwestern boundary of the city limits. High density single family residential development will remain concentrated in the northern section of the City of Redmond.

The Novelty Hill Urban Planned Developments include two large contiguous landholdings: the 1,500-acre Northridge (Quadrant) site and the 1,000-acre Blakely Ridge site. This Urban Planned Development area is planned to have moderate density single-family (3 to 6-dwelling units/acre) and multifamily (18-dwelling units/acre) units on sewers.

Commercial/Industrial Development

Existing Development. Most commercial development in the Redmond-Bear Creek Ground Water Management Area is within the City of Redmond. Neighborhood commercial development is restricted to scattered locations in the Evans and Bear Creek valleys, along the major arterials including Avondale Road, Woodinville-Duvall Road, and State Route 202 (Redmond-Fall City Road). A new specialty shopping district is located at the intersection of State Route 520 and Avondale Road, near the City of Redmond Well No. 5.

Significant light industrial areas are located in the lower Sammamish Valley immediately east of Marymoor Park and east of the intersection of State Route 520 and State Route 202. Business park type development occurs in these areas, as well east of State route 520 and Avondale Road between Redmond-Fall City Road and Union Hill Road and in Overlake and on the hills west of the Sammamish Valley.

Future Development. Major new commercial and industrial development is planned to occur within the City of Redmond. An outdoor regional shopping mall has been approved for the north side of State Route 520 on the former Redmond golf course. Light industrial and high technology manufacturing, research, and development will continue to be developed in southeast Redmond, east of the State Route 520 and State Route 202 intersection. Three neighborhood-scale centers at Avondale Road/NE 116th, Avondale Road/Woodinville-Duvall Highway, and probably along Redmond-Fall City Road will provide for future local retail and service uses.

Potential Land Use Impacts to Ground Water

The vulnerability of ground water to contamination is related to the hydrogeologic environment and contaminant characteristics as well as the type of land use activity. The hydrogeologic characteristics of the Redmond-Bear Creek Ground Water Management Area are discussed in Section 7, Hydrogeology. A comparison of various land use activities and their potential impacts to the ground water system are summarized in Table 5.1. Some specific factors that affect the vulnerability of the ground water system include:

- Physical characteristics of contaminants (e.g. solubility, viscosity, density, biodegradation potential, volatility);
- Source, type, and quantity of contaminants;
- Hydrogeologic factors such as soil permeability, geologic material, and depth to water;
- Aquifer characteristics such as gradient, ground water flow velocities, hydraulic head, and hydraulic conductivity; and
- Existing and future beneficial use of ground water resources and intensity of these uses.

The following land use activities potentially affect ground water quality and quantity. It is important to evaluate all potential threats to ground water quality and quantity to effectively manage the ground water resource.

5.3 <u>Sewerage Service</u>

Existing Conditions

The 1994 King County Comprehensive Plan concludes that sanitary sewers are the best means of treating wastewater in urban areas. However, it needs to be recognized that this management technique may pose localized threats to ground water under unusual circumstances. The protection and development of aquifer resources needs to consider sewage service in its overall strategy.

The City of Redmond sewer system is the principal sewer utility operating within the Redmond-Bear Creek Ground Water Management Area. In addition to the City of Redmond sewer system, there are several other local sewer service areas within the Redmond-Bear Creek Ground Water Management Area including the Northeast Lake Sammamish Sewer District, the Woodinville Sewer and Water District, and a small private district operated by the Lake Washington School District 414. In the future, the City of Redmond sewer service may be extended to an area on Novelty Hill proposed for a Master Plan Development. Discharges from all of the facilities are pumped to Metro's Renton Sewage Treatment Plant. The current and future areas served by sewer systems are indicated in Figure 5.4.

Future Data Collection Needs

Additional information relating to sanitary sewer systems will be required to more adequately manage the potential risk to ground water. Specific items that need to be addressed include:

- Mapping of existing and proposed sewer alignments; and
- Historic information on sewer line leaks or breaks.

5.4 On-Site Sewage Treatment and Disposal

Existing Conditions

Outside of the portion of the Redmond-Bear Creek Ground Water Management Area served by the identified sewer systems, disposal of sewage is accomplished through the use of on-site systems, primarily septic tanks and gravity drainfields (subsurface absorption systems). The Seattle-King County Health Department estimates that over 3,000 individual on-site sewage systems are in operation within the Redmond-Bear Creek Ground Water Management Area. These systems typically serve single family residences on suburban or rural parcels. The population within the unsewered areas is estimated to be over 7,000 people.

When properly sited, designed, and constructed, on-site sewage systems can represent a satisfactory long-term form of wastewater disposal. However, when improperly located, constructed, or misused, such systems can adversely affect both surface and ground water quality as well as public health. Contaminants typically present in domestic septic tank effluent include bacteria, viruses, nitrates, and phosphates. Effluent can also contain solvents or other home use chemicals. Nitrate is generally considered the most significant contaminant found in domestic wastewater because of its resistance to removal by treatment mechanisms normally present in the soil profile. Abnormal levels of nitrate in ground water can be an indicator of non-point pollution from on-site sewage systems.

The effect of septic tank effluent on ground water will have the most significant impact where sewage from a number of residences is collected and disposed of in a single community on-site system. Community systems may also serve shopping centers, institutions, or recreational areas. While individual residential on-site systems are diffused throughout an area, community systems concentrate effluent in a relatively small disposal area increasing the likelihood of local adverse impacts on ground water.

In addition to the aforementioned contaminants, effluent from on-site systems serving commercial and industrial facilities can also be a significant source of organic chemicals particularly those used in solvents, degreasers, and paint products. The typical chemical characteristics of various types of wastewater are summarized in Table 5.2.

The performance of an on-site sewage system must be evaluated based on two criteria, the efficiency of effluent treatment, and the effectiveness of effluent disposal. Traditionally, the viability of an on-site system has been considered only in terms of its effluent disposal capability, that is, the ability of soils around a drainfield to absorb or accept effluent. Traditionally on-site system failure is considered to occur when the amount of effluent entering a drainfield exceeds the absorptive capacity of surrounding soil causing effluent to either back up into a building sewer or overflow onto the ground surface.

An on-site sewage system can also fail to function properly from the standpoint of its treatment efficiency. Failure of this type is more insidious than a disposal capacity failure (surfacing effluent) since there are no physical indications of the malfunction. It is generally accepted that filtration through 20 to 36 inches of fine-to-medium textured, unsaturated soil is necessary for removal of contaminants from septic tank effluent (Tyler et al., 1979). Soils that are limited by depth, or that are made up of large particles, such as coarse sand and gravel, may not provide adequate treatment.

Unlike a disposal capacity failure, which can generally affect only surface water quality, a treatment efficiency failure may affect either surface or groundwater quality, depending on local conditions. In shallow soils that are underlain by a relatively impervious substratum, such as a hardpan (glacial till) or clay, there is a high potential for horizontal migration of poorly treated effluent. The potential for horizontal effluent migration is greatest in areas where a perched water table develops as a result of intense precipitation during the winter months. Contaminants carried in the perched water table can be released to the surface water system through road cuts, springs, or exposed banks.

A qualitative approach to evaluating the potential threat to ground water from septic tank drainfields in the Redmond-Bear Creek Ground Water Management Area was accomplished by compiling and mapping the locations of repair permits on file with the Seattle-King County Health Department. Since a septic system repair permit is required for any modification or expansion of an on-site sewage system it does not necessarily indicate a failed system. Figure 5.5 shows the distribution of repair permits issued in 1987. The highest concentration of repair permits were issued for systems in the northwest portion of the study area just south and west of Cottage Lake. The relative aquifer vulnerability in this area will be discussed in Section 7; Hydrogeology.

Soils and Effluent Treatment

Ground water contamination from on-site sewage systems is generally associated with their use in coarse textured soils, such as large grained sands and gravel that overlie an unconfined, permanent aquifer. Effluent travel time through a coarse textured soil is often too rapid for treatment mechanisms to effectively remove or attenuate contaminants prior to their reaching ground water.

The most dominant soil in the unsewered portion of the Redmond-Bear Creek Ground Water Management Area is a gravelly sandy loam referred to by the Natural Resources Conservation Service as the Alderwood series (see Figure 5.6). The distribution of Alderwood soil as well as other soil series within the Redmond-Bear Creek Ground Water Management Area are outlined in maps presented in the Soil Survey of the King County Area published by the Soil Conservation Service in 1973.

The Alderwood series is a moderately well drained soil that is formed in glacial till. Glacial till, commonly known as hardpan, is an unsorted, unstratified, compacted glacial drift consisting of a mixture of gravel, sand, silt, and clay. The typical profile of the Alderwood series consists of approximately 27 inches of gravelly sandy loam overlying weakly to strongly consolidated glacial till that extends to a depth of 60 inches or more.

The glacial till substratum of the Alderwood series generally restricts the vertical or downward movement of septic tank effluent and precipitation. Depth to maximum seasonal water table can range from about 24 to 42 inches below the ground surface. The limited depth of the Alderwood soil above the saturated zone may not provide adequate treatment of effluent prior to reaching the water table. Further, the consolidated glacial till is typically less than 4 feet below ground surface and hydraulic conductivity of the till is very low (less than 0.6 inches per hour). The poorly treated effluent can move laterally with the perched water table and be released to surface water drainage courses or directly to surface water bodies such as a lake or nearby stream. On-site sewage systems installed in Alderwood soils must be carefully designed to maximize the separation between the drainfield trench bottom and the seasonal water table. When adequate separation is not available, alternate engineering design will be required, or development may be prohibited.

The Everett series is another soil found sporadically within the Redmond-Bear Creek Ground Water Management Area. The Everett series is made up of somewhat excessively drained soils that are underlain by very gravelly sand at a depth of 18 to 36 inches. The Everett series substratum is black to brown, gravelly to very gravelly sandy loam about 32 inches thick. The substratum extends to 60 inches or more. The depth to water table exceeds 6 feet below ground surface in these well-drained soils. Although soils having a rapid or very rapid percolation rate do not impede downward movement of effluent from the subsurface absorption system (e.g., drainfield), they may permit the effluent to contaminate nearby water supplies. In many parts of the King County area, soils that have a rapid percolation rate to a depth of 4 to 5 feet meet the minimum requirements established by health codes (King County Board of Health, Rules and Regulations No. 3, April 1, 1987) for on-site treatment systems. These soils include Everett series. Everett soils may be expected to be suitable from a capacity standpoint, but high septic system densities may lead to shallow aquifer contamination. Existing regulations address this concern for new systems by requiring enhanced treatment of effluent to protect ground water quality.

Instances of ground water contamination associated with the operation of on-site sewage systems have not been documented in the Redmond-Bear Creek Ground Water Management Area. This may be more a function of limited monitoring and evaluation rather than trouble-free sewage systems.

Future Data Collection Needs

Future data collection needs relating to on-site sewage system should focus on special data needs that will include:

- Updating the information on the number and location of septic system repair permits;
- Developing a mechanism to identify repair permits issued for failed septic systems;
- Identification of older (>15 years) septic systems located in critical aquifer recharge areas; and
- Increased ground water monitoring and sampling using existing or new wells in areas of highest density of on-site systems.

5.5 Solid Waste Disposal

Existing Conditions

Landfills are potential sources of ground water contamination, especially those constructed prior to implementation of new standards for construction of these solid waste facilities. In the Redmond-Bear Creek Ground Water Management Area, an old King County landfill (Duvall Custodial Landfill) is located on the northeastern border of the Redmond-Bear Creek Ground Water Management Area, just off of the old Woodinville-Duvall Road. This landfill is not currently active and was closed in 1981 under Chapter 173.301 WAC. The landfill was capped with a clay layer during closure to minimize leachate production. A leachate collection system surrounds the landfill to collect leachate generated from the landfill. Leachate is routed to a tank that is pumped routinely into a tanker truck and disposed outside the Redmond-Bear Creek Ground Water Management Area. The King County Department of Natural Resources, Solid Waste Division is conducting quarterly ground water sampling in the vicinity of the old landfill. No detectable levels of dangerous/hazardous constituents have been found to date. The Seattle-King County Health Department has monitored wells for priority pollutants off site in the past. Results have always been satisfactory. Further monitoring off site is not planned in the foreseeable future given the past results and the fact that the landfill occupies a small area on a large parcel of land (Bishop, Hickok, personal communication).

The Department of Natural Resources, Solid Waste Division conducted a detailed hydrogeologic investigation at the landfill. Test pits were dug and a well survey conducted to characterize the geology, locate near-surface saturated areas, and define the hydrology beneath the landfill (Holmes, 1996). Six dual completion wells were drilled on the site to depths ranging from 35 feet to 250 feet, and 3 surface wells were completed to 10 feet. These wells have were sampled twice for priority pollutants, volatile organic compounds, inorganics and pesticides and herbicides. The results from these sampling events met water quality standards. Three wells were drilled on the site in 1986. Of these, two wells were discontinued for sampling purposes. No contaminants have been detected in samples collected quarterly from the remaining well (MW-2) since 1986 (personal conversation Holmes, 1996).

Another closed landfill site was located between 155 Place N.E., 152 Place N.E., and N.E. 172 Street east of Woodinville. This site, the H. H. Oleson site, operated for seven years and accepted demolition waste consisting of inert materials and wood. There has been no methane found and no leachate detected from limited sampling (one time) of the site by the Seattle-King County Health Department (Bishop, 1994). No other former or current landfills are known to be located within the Redmond-Bear Creek Ground Water Management Area.

Future Data Collection Needs

A more detailed understanding of ground water flow and ground water quality conditions is required to assess ground water impacts at the Duvall Custodial landfill site. Continued monitoring, conducted as part of this investigation, will be used to characterize the effects the landfill may have on surface or ground water, and any potential contaminant transport pathways (Holmes, 1996).

The data collected by the Solid Waste Division from the Duvall Custodial landfill site should be integrated into the Redmond-Bear Creek Ground Water Management Area Plan.

5.6 <u>Hazardous Waste</u>

Hazardous waste, as defined in the Washington State Administrative Code (Chapter 173-303-070 to 120 WAC), is a material that is ignitable, corrosive, reactive, or toxic. Hazardous wastes can be introduced to the environment, including ground water, in a number of ways. If hazardous wastes are discharged to septic systems (through sinks, toilets, or floor drains) the waste discharged may contaminate ground water. Inadvertent or intentional discharges to stormwater disposal systems represent another mechanism of release to ground water. Hazardous wastes that are discarded along with normal solid waste refuse can be placed in landfills and contribute to leachate contamination of underlying ground water. Finally, hazardous wastes that are deposited on exposed ground surfaces from traffic accidents, spills, or from improper storage can percolate into the soil and may migrate via recharging precipitation into the ground water environment.

Hazardous Waste Disposal

No sites listed on the Superfund National Priorities List or Comprehensive Environmental Response Compensation and Liability Information System are located within the Redmond-Bear Creek Ground Water Management Area. Additionally, no listed Washington State confirmed hazardous substances sites, potential hazardous substances sites, or sites undergoing long-term monitoring are located within the Redmond-Bear Creek Ground Water Management Area. There is little or no likelihood that the Redmond-Bear Creek Ground Water Management Area will ever be considered for potential siting of a hazardous waste disposal site.

Hazardous Waste Generators

To be regulated under the federal Resource Conservation and Recovery Act, a commercial or industrial facility must generate at least 220 pounds of hazardous waste per month; transport dangerous/hazardous waste; treat, store, or dispose of dangerous/hazardous waste; or burn or blend dangerous waste fuels. Several commercial and industrial facilities located within the Redmond-Bear Creek Ground Water Management Area generate quantities of hazardous or extremely hazardous waste regulated under the Resource Conservation and Recovery Act. A "windshield" survey of the major arterials in the Redmond-Bear Creek Ground Water Management Area was conducted and several other businesses were observed that are not regulated under the Resource Conservation and Recovery Act but may produce hazardous wastes in quantities below regulated amounts (i.e., small quantity generators). Small quantity generators produce less than 220 pounds of hazardous waste each month. The Seattle-King County Health Department and Metro assess how small quantity generators store, use, and dispose of hazardous waste. Hazardous waste spillage at small quantity generators is a priority of the Seattle-King County Health Department Local Hazardous Waste Management Program. Businesses where hazardous waste spillage is observed are referred to Ecology for follow-up. These businesses must continue to handle their waste properly according to Chapter 173-303 WAC and Title 10 of the King County Board of Health Regulations.

Ecology maintains a record of businesses that generate, store, treat, or transport hazardous waste in the state. This list (notifier's list) was reviewed to identify businesses that may handle hazardous waste in the Redmond-Bear Creek Ground Water Management Area. Generators regulated by the Resource Conservation and Recovery Act as well as other potential generators of hazardous waste in the Redmond-Bear Creek Ground Water Management Area are listed in Table 5.3. At least one type of hazardous material is associated with the normal operations of each type of generator (Resource Conservation and Recovery Act regulated generator or potential small waste generator). For example, automotive repair shops typically handle large quantities of volatile solvents and oil-based products containing organic compounds such as benzene, chlorinated ethylenes, toluene, and methylene chloride. Dry cleaners use solvents and cleaning solutions containing chlorinated ethanes and ethenes, especially trichloroethane and tetrachloroethane. Paint supply stores may deal with products containing heavy metals, phenols, and toluene. When these materials are discarded because their usefulness has diminished due to age or over-use (e.g., spent solvents), they will probably be classified as hazardous wastes.

Table 5.4. lists businesses in the Redmond-Bear Creek Ground Water Management Area where Ecology is investigating or monitoring the clean-up of toxic material spills. In most instances, ground water contamination is either suspected or confirmed.

5.7 Underground and Above-ground Storage Tanks

Existing Conditions

Underground Storage. Underground storage of petroleum hydrocarbons and other chemical substances represent a potential hazard to ground water in the Redmond-Bear Creek Ground Water Management Area. Releases may not be readily detected from all types of underground storage tank systems. Releases go undetected when operators ignore their responsibility to monitor the systems on a regular basis. Releases from underground storage tank systems occur above ground, as associated with sloppy surface handling practices (i.e. during bulk deliveries or dispensing episodes), and from below ground, from failed piping or tank components. Underground storage tank system components may fail from corrosion, however, failure from careless workmanship during installation and assembly is more common (Knowlton, 1994).

The purpose of federal and state Underground Storage Tank Regulations are simply to preserve the quantity and protect the quality of our country's ground water resources (Knowlton, 1994).

Ecology implements Washington's Underground Storage Tank Regulations (Chapter 173-360 WAC). Written into this regulation are performance standards that must be achieved for all operational systems. These standards address released detection for tanks and ancillary piping, corrosion protection for tanks and ancillary piping; spill and overflow prevention and financial responsibility (i.e., an insurance policy for each system whose owner certifies compliance with Chapter 173-360 WAC). The cost of the annual permit is $75 (1994). The purpose of underground storage tank regulations is to preserve the quality and quantity of ground water (i.e., a pollution prevention program). The underground storage tank system's owner or operator is responsible for complying with Chapter 173-360 WAC. Ecology does not maintain underground storage tanks, but it does work to facilitate the owner's comprehension of the regulation. By regulation design, compliance with performance standards translates into pollution prevention. State regulation requires that underground storage tanks be upgraded to include a leak detection system (water and home heating oil tanks are exempt). Ecology regularly coordinates facility inspections to ensure compliance with Chapter 173-360 WAC (Knowlton, 1994).

Regulation of underground storage tanks began with a federal law passed in 1984, Hazardous and Solid Waste Amendments to Resource Conservation and Recovery Act. The Environmental Protection Agency drafted the first set of requirements for underground storage tank owners and operators (revised and codified as 40 CFR Parts 280 and 281 effective December 22, 1988). These required the following activities: notification (e.g. providing the Environmental Protection Agency details about the underground storage tank owner, operator, and protection for tanks and piping, spill protection, overfill prevention), release reporting, and financial responsibility (i.e. liability insurance for the property owner) (Knowlton, 1994).

In 1989, the Washington State Legislature passed House Bill 1086 that was signed by the governor as State Law 90.76 RCW. It became effective July 1, 1990 and expires July 1, 1999. This new law directed Ecology to write and implement underground storage tank regulations at least as stringent as the Environmental Protection Agency's. Ecology's regulations (Chapter 173-360 WAC) are similar but not identical (more stringent) to the Environmental Protection Agency's.

In addition, some petroleum products are considered hazardous substances in Washington. They are taxed, transported, stored, and consumed as such, but wastes derived from petroleum products are not always considered hazardous. The recovery and cleanup of spills (a surface phenomenon) and releases (the subsurface version) of petroleum products that contact soil, surface water, or ground water are regulated by the Model Toxics Control Act and Cleanup Regulation (Chapter 173-340 WAC). Response and reporting requirements associated with releases from underground storage tanks are described under Chapter 173-340-450 WAC. According to Ecology's underground storage tank records, 73 underground storage tanks ranging in size from 111 gallons to 20,000 gallons are in operation at 23 sites within the Redmond-Bear Creek Ground Water Management Area (Table 5.5.). The Ecology list included in the 1991 Background Land and Water Use Report showed 193 underground storage tanks in operation at 57 sites. This is consistent with a statewide trend of fewer underground storage tanks in operation. This list is not all-inclusive, it only reflects those systems reported to Ecology. This list does represent the majority of regulated underground storage tank systems in the area. This number does not include home heating oil tanks. The 73 reported tanks hold a variety of petroleum products including leaded and unleaded gasoline, diesel fuel, lubricating oil, fuel oil, kerosene, and waste oil. The total number of underground storage tanks in the Redmond-Bear Creek Ground Water Management Area is much greater than Ecology records indicate because: some owners have yet to notify Ecology about the systems they use; systems that are not regulated by Ecology are not tracked (i.e. heating oil tanks or tanks less than 110 gallons); and many systems were emptied and taken out of service prior to the Environmental Protection Agency's notification requirement but still remain in place (Knowlton, 1994). The approximate location of some of these underground storage tanks is shown on Figure 5.7.

Many different types of facilities in the Redmond-Bear Creek Ground Water Management Area own and operate regulated underground storage tanks. The most common examples are gasoline stations and vehicle repair shops. Other, less common examples include hospitals, fire and police stations, bakeries, dry cleaners, telecommunication utilities, schools, city parks, and equipment rental shops. Most establishments that one would expect to own or operate regulated underground storage tanks have notified Ecology and are on the enclosed lists.

The changes in tank design, or manufacturing standards, are direct results of the Environmental Protection Agency's "Interim Prohibition". Interim Prohibition describes the period of time between the authorization of the Resource Conservation and Recovery Act Subtitle I (November 1984) and the final publication of 40 CFR Part 280 (September 1988). The Resource Conservation and Recovery Act Subtitle I created federal Underground Storage Tank Law; 40 CFR Part 280 are the final set of the Environmental Protection Agency regulations that implement that Law. Interim Prohibition was nothing more than an Environmental Protection Agency milestone in the 40 CFR Part 280 development process. Its purpose was to establish minimum standards for underground storage tank design and installation that would help reduce the incidence of releases from old or poorly engineered systems (i.e., prevent the re-installation of old, bare steel tanks and the continued manufacture of unprotected steel tanks). Interim prohibition went into effect May 1985. In summary, Interim Prohibition required that no underground storage tank could be installed unless: 1) it was engineered to prevent releases from structural failure for its operational life; 2) it would prevent releases from corrosion for its operational life; and 3) it was compatible with the product stored. Interim Prohibition has been replaced by "New Tank Performance Standards" under 40 CFR Part 280. Chapter 173-360 WAC parallels the Environmental Protection Agency's regulation in this regard (Knowlton, 1994).

Table 5.6 lists the age of the 73 underground storage tanks in operation in the RBC-GWMA. There are 27 underground storage tanks between 11 and 15 years old, 12 underground storage tanks between 21 and 30 years old, and one underground storage tank older than 30 years.

Table 5.7 lists the substances contained is the 73 underground storage tanks in operation. There are 28 underground storage tanks containing unleaded gasoline and 17 underground storage tanks containing diesel fuel. Table 5.8 lists the size of underground storage tanks in operation. There are 27 underground storage tanks in operation with a size between 10,000 and 19,999 gallons.

Twelve leaking underground storage tanks sites have been confirmed in the Redmond-Bear Creek Ground Water Management Area to date (Table 5.9). Of these twelve sites, four sites where clean up is in progress/ongoing have ground water contamination. As older underground storage tank systems are removed or replaced with newer systems one would expect this number to increase (Knowlton, 1994).

Above-Ground Storage. No aboveground chemical storage tanks other than home heating oil tanks were identified during the windshield survey in the Redmond-Bear

Creek Ground Water Management Area. Bulk fuel storage tank farms identified in the Redmond-Bear Creek Ground Water Management Area are underground facilities.

Future Data Collection Needs

Underground storage tanks represent a threat to ground water in the Redmond-Bear Creek Ground Water Management Area since leaks may go either unreported or undetected. The location of potentially hazardous underground storage tanks is difficult to determine due to their hidden nature and the lack of reliable records.
A priority of future data collection efforts should be the identification of underground storage tanks located in sensitive aquifer recharge areas. Additional research should also attempt to locate small private underground storage tanks, especially residential heating oil tanks. An effort should be made to obtain access to underground storage tank sites where ground water monitoring networks have been installed so that long-term cleanup or impacts can be monitored.

5.8 Stormwater

Existing Conditions

Stormwater can enter ground water by several means. In undeveloped areas, stormwater infiltrates into the soils and is carried downward via gravity to underlying aquifers. In developed areas, stormwater can be routed into drainage swales and/or retention/detention systems used to reduce peak flows from these areas. The stormwater then infiltrates into the ground water, or is released to a surface water body. Another common practice used to manage stormwater is the construction of dry wells in rapidly percolating unsaturated soils. In these situations, stormwater is discharged directly into the substratum. Infiltration of stormwater into ground water through dry wells is the most direct subsurface disposal method. Subsurface disposal methods bypass the vegetative land surface and relatively fine textured topsoils that are effective in removing some contaminants, especially particulates, from stormwater. Infiltration of stormwater may provide direct contamination of the ground water with oils, greases, nitrates, and heavy metals often found in urban stormwater runoff.

Quantities of stormwater runoff generated within given areas will vary with the nature of local land-use. Forested open spaces may absorb nearly all precipitation and generate very little runoff. Conversely, a shopping center consisting largely of impervious surfaces such as rooftops, asphalt parking lots, and sidewalks, will absorb almost no precipitation. Therefore, precipitation must either evaporate or enter a stormwater collection and disposal system. Typically, runoff from forest areas may be as little as 10 to 25 percent of total precipitation while runoff from highly impervious developments may rise to 60 to 80 percent of precipitation.

In general, stormwater from developed areas may contain heavy metals, organic pollutants, coliform bacteria, nutrients, and suspended solids. The quality of stormwater varies depending on the land-use. Typically, runoff from industrial areas can contain metals, soluble solvents, and other hydrocarbons including benzene, chloroform, TCE, oil and grease, phthalates, less volatile solvents, or chemicals associated with a specific manufacturing process. Commercial land uses, particularly those involving extensive parking lots, generate runoff carrying particulates laden with heavy metals. The most prevalent heavy metals are typically copper, lead, and zinc associated with automobile operation (National Urban Runoff Program, 1983). Runoff from residential areas also have detectable levels of heavy metals present but more typically contain nitrates, pesticides, and coliform bacteria. Ranges in values for different chemical constituents expected to occur in storm water are presented in Table 5.10.

Certain areas of the Redmond-Bear Creek Ground Water Management Area are characterized by rapidly percolating soils, and contain swales, retention ponds, and dry well systems that are used to manage stormwater runoff. Within the City of Redmond alone, some 122 retention systems have been installed. These systems discharge untreated stormwater directly into the underlying aquifer system. According to the King County Department of Natural Resources, Water and Land Resources (WLR) Division no drywells operate in the unincorporated portions of the County. However, retention ponds are used widely throughout the rural county areas for control of drainage along right-of-way. Contaminant loading to the ground water from surface water runoff is therefore of concern for the Redmond-Bear Creek Ground Water Management Area particularly in areas where retention is employed because of the potential degradation of ground water quality.

Another potential risk to ground water associated with stormwater disposal in the Redmond-Bear Creek Ground Water Management Area is infiltration of hazardous materials released to open roadside ditches or retention ponds as the result of transportation spills.

Future Data Collection Needs

Additional information needs relating to potential storm runoff impacts in the Redmond-Bear Creek Ground Water Management Area include:

- The number and location of stormwater retention basins in the Redmond-Bear Creek Ground Water Management Area.
- The monitoring of stormwater quality in retention ponds located in critical aquifer recharge areas.

5.9 Transportation Spills

Existing Conditions

Transportation related spills of contaminants can pose a great threat to ground water in the Redmond-Bear Creek Ground Water Management Area. Everett Associated Soils underlie the majority of major transportation corridors in the Redmond-Bear Creek Ground Water Management Area (Figure 5.6). Everett Association Soils are characterized as well drained and do not impede downward percolation.

The Avondale Road transportation corridor is primarily underlain by Everett Association soils from the intersection of Woodinville-Duvall Road in the north to the intersection of State Route 202 in the south. Woodinville-Duvall Road in underlain by these permeable soils from the intersection of Avondale Road west to Daniels Creek. Novelty Hill and Union Hill roads are underlain by Everett Association soils primarily on their western segments. State Route 202 is underlain by permeable soils along most of the land it traverses in the Redmond-Bear Creek Ground Water Management Area.

Ecology does not maintain records on the number of transportation related hazardous waste spills in the Redmond-Bear Creek Ground Water Management Area. Ecology's Spill Response Section indicated that numerous transportation-related hazardous waste accidents have occurred in the past in the Redmond-Bear Creek Ground Water Management Area (Personal Communication, April 1990). These accidents have occurred mainly on State Route 202, State Route 520, and Avondale Road.

The Washington State Department of Transportation records do not contain specific files of the number of transportation related hazardous waste spills for the Redmond-Bear Creek Ground Water Management Area. Statewide information suggests that approximately 1 in 10,000 reported motor vehicle collisions involve vehicles where hazardous waste is transported. Actual accident rates will vary from roadway to roadway depending on speed limit, traffic load, and highway conditions. In general, accident rates of 1.0 to 15 per million vehicle miles have been encountered in similar areas (Gig Harbor GWMA (data developed by Sweet Edwards/EMCON), and Thurston County Public Works, McAllister/Easton Creek Stormwater Management Plan and Ground Water Risk Assessment (draft report May 1990). Hazardous waste spills do not necessarily occur at every accident involving a hazardous waste vehicle.

According to Ecology's Spill Response Section (April, 1990), the potential for transportation related hazardous waste accidents in the Redmond-Bear Creek Ground Water Management Area is high due to the relatively frequent number of trips by trucks carrying hazardous materials. Traffic counts and accident information was obtained from the City of Redmond Public Works Department for the major arterials within the Redmond-Bear Creek Ground Water Management Area. Table 5.11 shows the average daily traffic counts for the reaches within the Redmond-Bear Creek Ground Water

Management Area, and the total traffic accidents reported for those reaches (by roadway location) within the Redmond-Bear Creek Ground Water Management Area in 1993.

The Washington Utilities and Transportation Commission provided statistical information of truck accidents occurring in the City of Redmond between 1989 and 1991 (Table 5.12). In 1991, there were 33 truck accidents, none of which involved hazardous materials. In 1990, there were 45 truck accidents with one involving hazardous materials. Similarly, in 1989 one truck accident involving hazardous materials also occurred. Statistics were unavailable prior to 1989.

Traffic volumes on all roadways within the Redmond-Bear Creek Ground Water Management Area are expected to increase significantly in the future. The King County Public Works Department indicated that the expected increase in traffic on Avondale Road is expected to be approximately 12 percent per year to the year 2000. The City of Redmond Public Works traffic projections indicate that traffic at Union Hill Road and Avondale Road is expected to increase by 10 to 12 percent per year. Based on past Washington State Department of Transportation traffic increases, travel on State Route 202 in the Redmond-Bear Creek Ground Water Management Area is also expected to increase by approximately 10 percent per year.

With an estimated average annual increase in the traffic on the major arterials within the Redmond-Bear Creek Ground Water Management Area of between 10 and 12 percent, traffic in the Redmond-Bear Creek Ground Water Management Area may almost double by the year 2005. The increased volumes will result in significantly higher numbers of accidents. In all likelihood, the greatly increased traffic congestion will also result in higher transportation related hazardous waste accident rates.

Future Data Collection Needs

A better understanding of traffic patterns and volumes in the Redmond-Bear Creek Ground Water Management Area will be necessary before there can be a significant effort to evaluate the potential risks to ground water from transportation related spills. Specific data that needs to be collected include:

- Accurate traffic volume estimates for all the major transportation routes in the Redmond-Bear Creek Ground Water Management Area, including the proportional volume for each significant section of a transportation corridor.
- Statistics on the number of truck accidents occurring on the major transportation routes.
- Intersection/highway stretches where accidents occur most frequently.
- Location of hazardous waste generators in the Redmond-Bear Creek Ground Water Management Area which use, dispose, or transport hazardous waste via trucks or railroad which enter the study area.

5.10 Well Construction and Abandonment

Existing Conditions

Although not actually a source of contamination, the methods used to construct a well can have a significant impact on water quality. For instance, unless a well is sealed properly, the casing can act as a conduit for pollutants originating at the ground surface to travel to an underlying aquifer. Additionally, if a well penetrates more than one aquifer unit, water from the various aquifer units can mix. If the water of one aquifer unit is contaminated, it can, under certain hydrologic conditions, introduce contaminants to other aquifer units. Adequate well design and construction standards must be enforced to prevent water quality problems of this nature.

There are 53 Group B small public water systems in the Redmond-Bear Creek Ground Water Management Area. There is also an unknown number of private wells (Cox, 1994). Similarly, an unknown number of wells may no longer be in use or may be abandoned in the near future due to growth of centralized public water systems in the Redmond-Bear Creek Ground Water Management Area. Many of these wells were drilled prior to the introduction of well construction standards and are not equipped with adequate sanitary seals. Thus, they will continue to provide an opportunity for land surface contaminants to migrate to ground water. After their use has been discontinued, wells, including test wells, must be properly abandoned to prevent them becoming an avenue for contamination to reach ground water.

The Minimum Standards for Construction and Maintenance of Water Wells (Chapter 173-160 WAC) requires that well drillers submit a report on the construction of every new water well to Ecology. Such reports should include the information necessary to describe the well location, surface elevation, and the type of well construction. In addition, the report should provide pertinent data concerning the geologic conditions encountered during construction and the characteristics of the aquifer.

Well reports serve as an important database for the evaluation and management of ground water resources within the Redmond-Bear Creek Ground Water Management Area. Meeting future demands for drinking water in the Redmond-Bear Creek Ground Water Management Area may be dependent on ground water; thus, the accuracy and completeness of well reports is necessary to develop future water planning for the area.

Future Data Collection Needs

Future data collection efforts should attempt to identify improperly abandoned wells or wells that were improperly constructed and should be abandoned in the Redmond-Bear Creek Ground Water Management Area. A data sort showing locations of wells that predate subsequent service by a water system can be used to define areas of higher probability for the existence of unused wells. An additional task should be the identification of shallow, particularly dug wells, located in critical aquifer recharge areas.

5.11 Fertilizer Use

Existing Conditions

Since commercial agriculture is virtually absent in the Redmond-Bear Creek Ground Water Management Area, fertilizer use is largely restricted to turf applications at public golf courses, residential lawns, and institutional lawns. Turf fertilizers are a source of two potential contaminants, nitrate, and phosphate. Of the two, nitrate represents the greatest risk to ground water contamination because of its high water solubility and high mobility in the soil column.
Phosphates in turf fertilizers generally do not pose a significant threat to ground water for a number of reasons. First, the water solubility of phosphate is low and much of the available phosphorus will be utilized within the root zone. The pH of the turf and underlying soil is conducive to the rapid binding of phosphate with aluminum ions found in abundance in western Washington soils (Braun, 1989). The use of phosphate on turf is essentially self-limiting. Grasses use only a relatively small amount of phosphate and little of that is actually bound up in plant tissue. Excessive application of phosphate will result in undesirable seed head growth, diminishing the aesthetic quality of the turf.

Two golf courses are located within Redmond-Bear Creek Ground Water Management Area. The 200-acre Sahalee Golf Course is situated in the southern portion of the Redmond-Bear Creek Ground Water Management Area. The 182-acre Redmond-Bear Creek Golf Course is located in the east central portion of the study area. Fertilizing practices are essentially the same for most golf courses in western Washington. Nitrogen is applied to the fairways at relatively low rates, about 2 to 2.5 pounds per 1,000 square feet. The 2 to 2.5 pounds is split into two annual applications. The greens receive nitrogen at a much higher rate, about 6 pounds per 1,000 square feet, split into 10 to 12 annual applications. These application practices are generally consistent with those recommended by the Washington State University Cooperative Extension Service (Personal communication). The Cooperative Extension Service suggests that nitrate contamination of both ground and surface water associated with turf fertilizers can be avoided through frequent, low-level applications of no more than 4 to 6 pounds of nitrogen per 1,000 square feet per year in 0.5 pound increments. Over-watering the turf after fertilizer application should be avoided to reduce the opportunity for nitrate wash-through. Use of urea should be avoided since it converts rapidly to nitrate. Ammonia sulfate is the recommended form of nitrogen because it is assimilated quickly, becomes tied up in the organic matter of the turf, and converts slowly to nitrate.

The nature of turf fertilizer use for residential and institutional lawns in the Redmond-Bear Creek Ground Water Management Area is not documented. Presumably, the amount applied and the frequency of application varies widely. However, an informal telephone survey conducted by HDR (subconsultant on the Redmond-Bear Creek Ground Water Management Area project) of fertilizer suppliers in the vicinity of the Redmond-Bear Creek Ground Water Management Area indicated that most are currently recommending application practices that are consistent with those of the Cooperative

Extension Service. Specifically, they recommended 3 to 4 pounds of nitrogen per 1,000 ft^2/year in the form of ammonia sulfate and 1 pound of phosphate per 1,000 ft^2/year, divided into several low-level applications.

Future Data Collection Needs

Sampling of selected wells in 1989 and 1990 indicated that elevated nitrate levels were not an issue at that time in the Redmond-Bear Creek Ground Water Management Area. Continued monitoring of nitrates should be conducted to determine whether fertilizer use poses a threat to ground water in the future. Future data collection efforts should focus on obtaining information on the types and quantities of agricultural fertilizers used at the few commercial businesses that use fertilizers, such as golf courses and nurseries.

5.12 Pesticide Use

Existing Conditions

Currently, no significant pesticide use has been documented within the Redmond-Bear Creek Ground Water Management Area. The King County Department of Transportation (DOT), Roads Services Division maintains the unincorporated portions of the Redmond-Bear Creek Ground Water Management Area. DOT staff apply herbicides to control noxious weeds on the right of way, and weed and grass growth on gravel shoulders and around guard rails. Either Escort or Garlon are used for broad leaf control. Oust or Roundup are used for the non-selective control on the shoulders. The use of the chemicals Simazine and Atrazine were discontinued in 1989 because they are water soluble, and should not be used in permeable soils. All herbicides including those that lack a "restricted use" designation are applied by certified pesticide applicators (Matsuno, 1994). Herbicide use at golf courses is limited to occasional applications of small quantities of Roundup.

Puget Sound Energy has an integrated vegetation management plan for its entire service area. The vegetation management plan is on a five-year rotation cycle in most cases. Herbicide use is a tool of the integrated vegetation management program. The Union Hill Transmission line right-of-way, as well as other transmission and distribution lines in the Bear Creek area, are subject to selective herbicide use, along with mechanical and hand cutting methods in prescribed areas (Dennison, 1994). All herbicides are used selectively and no broadcast spraying is done. Garlon 3A, Garlon 4, and Rodeo are herbicides most frequently used on a selective basis. Selective treatment is low volume basal, low volume foliar, and stump treatment prescribed for each specific site (Dennison, 1994).

The nature of residential pesticide use in the Redmond-Bear Creek Ground Water Management Area is not documented.

Future Data Collection Needs

Pesticide use does not appear to pose a significant threat to ground water in the Redmond-Bear Creek Ground Water Management Area. Future data collection efforts should focus on the types and quantities of pesticides used by King County, Puget Sound Energy, and commercial businesses, with particular attention focused on activities in sensitive aquifer recharge areas.

5.13 Mining Operations

Existing Conditions

Gravel mining operations can impact ground water quality because they often leave portions of an aquifer directly exposed to surface water and contaminants from adjacent land use activities. Historic undocumented fills used in reclamation of gravel mine sites may have contaminated ground water. These areas may also be a significant source of ground water recharge for an aquifer.

Several active gravel-mining operations are located in the Redmond-Bear Creek Ground Water Management Area. The majority of these are located south of the Union Hill Road (Pierce, 1994), some contain off-site fill. Active mining operations are sites that have a Washington State Department of Natural Resources permit to mine. Permits have no completion date. A mine is still designated as active by the Washington State Department of Natural Resources even if the site is not physically in operation. A mining site becomes inactive when reclamation is completed to the Washington State Department of Natural Resource's requirements (Pierce, 1994).

Future Data Collection Needs

Because of the potential vulnerability to ground water quality posed by gravel mining operations, future data collection efforts should include development of ground water monitoring networks to enable evaluation of any existing or future impacts to aquifers.

5.14 Sludge (Biosolids) Disposal

Existing Conditions

No sewage treatment plant sludge (biosolids) land application sites exist in the Redmond-Bear Creek Ground Water Management Area and is unlikely to occur given existing regulations and land use plans.

5.15 Conclusions

In each description of land use activities in the Redmond-Bear Creek Ground Water Management Area, the effects of existing and potential land use activities on ground water is still uncertain. The purpose of this report is to present information relevant to the

Redmond-Bear Creek Valley Ground Water Management Plan and to point to areas where additional information will provide decision makers with a complete picture of ground water management issues in the study area.

Future research priorities should focus on the following:

5.15.1 Ground Water Recharge Zones

The location of surface areas where aquifers are most heavily recharged is important to every land use activity previously described. These are areas where surface contamination is most likely to lead to ground water contamination. Also, ground water loss can occur if these areas are covered by impervious surfaces such as roads, parking lots and buildings, or if native vegetation is removed over a large area.

These sensitive aquifer areas with significant infiltration potential (indicating susceptibility of ground water to contamination and recharge) are identified in Figure 5.8. Efforts to minimize the possibility of contaminants reaching these areas and sealing of these areas with impervious cover should be undertaken. Land and water use activities are relevant to ground water management only in as much as they affect ground water quality and quantity. Surface activities described in this report will have the greatest impact on ground water when they take place in ground water recharge zones. Figure 5.8 should be further refined as more information becomes available from studies such as wellhead protection and SEPA reviews. Further discussion of groundwater susceptibility and recharge is provided in Sections 7.2 and 8.3.

5.15.2 Future Development

A detailed analysis of existing land use activities in the Redmond-Bear Creek Ground Water Management Area together with projected residential, commercial, and industrial development trends is needed to assess the land use activities that could potentially cause ground water contamination, and to determine the future increased demand for ground water.

5.15.3 Septic Systems

The overloading, inadequate treatment of sewage, and the threat to ground water quality from septic tanks and drainage fields should be of particular concern as development becomes more concentrated in areas where sewer service is not available. The location of all septic tanks, especially those with a history of failure and those older than 15 years located in potential ground water recharge zones, should be evaluated for their impacts on ground water quality. On-site systems located in the highest density residential areas should be monitored for their impacts on ground water by sampling existing and new wells in those areas.

5.15.4 Sewers

Additional information is needed on sewer line leaks or breaks concerning impacts to ground water quality and quantity. Existing and proposed sewer alignments need to be mapped.

5.15.6 Underground Storage Tanks

Without proper prevention or detection systems in place, there is a high risk of ground water contamination due to an underground storage tank leak or accident. Additional information on appropriate commercial and residential underground storage tank locations, especially in sensitive aquifer recharge areas is necessary to determine the extent and type of ground water contamination. Underground storage tank sites, which have ongoing long-term cleanup programs, should be monitored.

5.15.7 Stormwater

The number and location of stormwater basins in the Redmond-Bear Creek Ground Water Management Area should be identified. The water quality of stormwater outlets should be monitored during storm events, especially where these outlets discharge to ground water and creeks in sensitive aquifer recharge areas.

5.15.8 Landfills

Evaluating the extent of ground water contamination from landfills is a complex process. The water quality data collected by the Solid Waste Division at the Duvall Custodial landfill site should be monitored by the ground water program lead agency and entered into the database.

5.15.9 Hazardous Waste

Monitor and evaluate the impacts on ground water quality from data collected from small and large quantity hazardous waste generator facilities.

5.15.10 Hazardous Material Spills

Hazardous material spills particularly transportation spills and their impacts on ground water, should be monitored. Hazardous waste generation in the Redmond-Bear Creek Ground Water Management Area which use, dispose, or transport hazardous waste via trucks or railroads which enter the study area should be located. Accurate traffic volume data for all major transportation routes in the Redmond-Bear Creek Ground Water Management Area, including the proportional volume for each significant section of transportation corridor, should be collated. Statistics on the number of truck accidents occurring on the major transportation routes and where these accidents most frequently occur should also be collated.

5.15.11 Fertilizer, Pesticide and Herbicide Use

Pesticides, herbicides, and fertilizers could pose a future threat to ground water quality in the Redmond-Bear Creek Ground Water Management Area. These chemicals are applied in a broad range of activities including: residential use, agriculture, the maintenance of powerline corridors, roadside spraying, and park and landscape maintenance. Additional information is needed as to the types and quantities of fertilizer applications at commercial businesses (golf courses, nurseries) and their impacts on ground water quality, as well as the types and quantities of pesticides used in the Redmond-Bear Creek Ground Water Management Area by government agencies and businesses particularly in sensitive aquifer recharge areas.

5.15.12 Mines

Additional information pertaining to the effect of existing operations on ground water quality is necessary. At this time, little is known about the impacts of industrial contaminants that seep into exposed aquifers at mines, and of the potential for hazardous material spills at a mining operation.

5.15.13 Non-Point Contaminants

Non-point pollutants from urban runoff (oils, greases, and other materials washed from impervious surfaces) and agricultural practices may contribute to ground water contamination in the Redmond-Bear Creek Ground Water Management Area. Although very few studies of non-point contaminants have been conducted in the Redmond-Bear Creek Ground Water Management Area, studies in other areas have indicated that non-point sources can contribute to ground water contamination.

6.0 WATER APPLICATIONS

6.1 Water Sources

With the exception of the small area serviced by the Woodinville Water District, most of the water used for private, municipal, industrial and agricultural purposes in the Redmond-Bear Creek Ground Water Management Area is supplied by ground water. The primary beneficial uses of ground water in the Redmond-Bear Creek Ground Water Management Area are for domestic and public water supply, fire suppression, and recharge to streams and lakes.

The City of Redmond is currently under contract with the City of Seattle to purchase water to augment its existing ground water supply. Water obtained from the City of Seattle is not currently used in the GWMA, but in the Redmond service area to the west of the GWMA boundaries. The contract specifies that the amount of water from Seattle is dependent on Redmond's ground water supply and the quantity of water Redmond pumps on a daily and annual basis. Redmond is currently negotiating the Seattle contract with regards to the quantity of water they are required to withdraw from the aquifer(s) and potential water supply to the proposed UPDs (S. Thomasson, City of Redmond Utilities, February, 1996).

In a review of potential new sources of drinking water to service burgeoning population growth within this area of King County, the Coordinated Water System Plan (October, 1989) identified several potential water supply options located within the Redmond-Bear Creek Ground Water Management Area. These include the following ground water (aquifer) systems:

- Redmond Aquifer
- Evans Creek Aquifer
- Sammamish Plateau Aquifer

The Redmond and Evans Creek Aquifers are located in relatively shallow (<200 feet) fluvial deposits (material deposited by a stream or river) in Evans Creek and lower Bear Creek valleys. These systems are relatively susceptible to contamination. The Sammamish Plateau Aquifer, as the name implies, occurs beneath the Sammamish Plateau in relatively deep (<400 feet) glacial outwash deposits (sand and gravel deposited by an advancing glacier). The Coordinated Water System Plan concluded that the water supply potential of these aquifers was not significant enough for meeting future regional supply demands. Specific information regarding these aquifers is included in Section 7.0 Hydrogeology and Section 8.0 Water Balance.

6.2 Water Services

The establishment of existing and future service areas provides a partial basis for water system planning. The Coordinated Water System Plan (October 1989) identifies both existing and future service areas for water purveyors in East King County. These service areas are on record with the Seattle-King County Health Department. Service boundaries for Group A purveyors in the Redmond-Bear Creek Ground Water Management Area have been identified from the service area information provided in the Coordinated Water System Plan and are shown in Figure 6.1. There are four Group A purveyors in the Redmond-Bear Creek Ground Water Management Area. They are:

- Union Hill Water Association
- City of Redmond
- Northeast Sammamish Sewer and Water District
- Woodinville Water District

The Washington State Department of Health has two classes of public water systems, the larger systems are known as Group A systems and the smaller systems are known as Group B systems. Group A systems generally serve 15 or more service connections. Group B systems are those between two and 15 permanent service connections.

Information concerning water purveyors and water rights within the Redmond-Bear Creek Ground Water Management Area was obtained through a review of the Seattle-King County Health Department, Washington State Department of Health, and Ecology records. Approximately 57 approved public water systems operate within the Redmond-Bear Creek Ground Water Management Area, including the four Group A systems listed above. The 53 Group B public water systems in the Redmond-Bear Creek Ground Water Management Area presently serve two to nine service connections each.

A preliminary assessment of problems related to water supply and reliability of service was performed for all of King County in 1985. Based on the results of this evaluation, East King County was declared a Critical Water Supply Service Area in 1986 (Coordination Act, Chapter 70.116 RCW). As a result, a comprehensive Coordinated Water System Plan was prepared (October 1989) to address service needs and supply problems. The Redmond-Bear Creek Ground Water Management Area is located within the Critical Water Supply Service Area and was included in the 1989 Plan. A primary reason the eastern portion of King County was cited as a Critical Water Supply Service Area was concern over coordination of regional ground water service provision.

6.3 <u>Water Rights</u>

A water right is a purveyor's permitted right to withdraw water. A water right is specified in two ways:

- A maximum pumping rate (expressed in gallons per minute or GPM) is specified based on the capacity of the well (note that well capacity is a function of construction specifications and the pump, and not an indication of aquifer capacity).
- A maximum annual volume of ground water that can be withdrawn from the well (typically expressed as Acre Feet per year). This volume is based upon the water needs of the population served by the well and is not typically a function of well or aquifer capacity.

Ecology is the state agency responsible for granting or denying a water right application. Water rights are required for any well that pumps 5000 gallons per day or greater. Water rights have been granted historically to three of the four Group A systems in the Redmond-Bear Creek Ground Water Management Area (these include City of Redmond, Union Hill Water Association and NE Sammamish Water and Sewer District). The existing water rights for these three purveyors are listed in Table 6.1. Thirty group B public water systems have water rights in Redmond-Bear Creek Ground Water Management Area. These 30 systems can presently use 0.128 MGD based on their allocated water rights

Woodinville Water District's water is supplied by the City of Seattle. The District was denied their most recent applications for two ground water rights (for 500 and 1000

GPM; respectively) by the Department of Ecology in January, 1996 (B. Bandarra, January 1996).

In January of 1996, the Washington State Department of Ecology denied a water right application from Union Hill Water Association for a new water right at Well #3 of 500 GPM. Denial of water rights is based on the justification that there is hydraulic continuity between the aquifer to be pumped and surface water in the area, and that pumping could decrease surface water flows.

Ecology has not yet responded to Union Hill's application to transfer water rights from an existing well to two new wells. Three development permits are hinging on Union Hill Water Association's approval of new water rights or transfer of water rights. The NE Sammamish Water and Sewer District and the City of Redmond have also applied to transfer existing water rights.

6.4 Existing and Potential Water Demand

Current Domestic Ground Water Usage

Nearly all of the ground water rights that have been issued in the Redmond-Bear Creek Ground Water Management Area are for public water supply purposes. Based on water utility estimates from Union Hill and Woodinville Water Districts (East King County Coordinated Water System Plan, 1989), actual consumption of ground water by Group A water utilities in the Redmond-Bear Creek Ground Water Management Area averages about 8 million gallons per day (MGD). A maximum of 8.5 MGD could be withdrawn by Group A purveyors if they utilized their full water right simultaneously. Using purveyor water use data in addition to Ecology and the Seattle-King County Health Department well records, a total ground water consumption of 0.28 MGD by individual wells in the Redmond-Bear Creek Ground Water Management Area has been estimated.

Ground water use for individual water supply wells is not currently managed. A driller's report must be filed with Ecology at the time of construction of each domestic supply well; however, under Chapter 90.44.050 RCW, water rights (permits to appropriate) are not required for wells that supply less than 5,000 gallons of water per day. No known official estimate has been made of water consumption by individual wells in the Redmond-Bear Creek Ground Water Management Area. The East King County Coordinated Water System Plan (1989) did not address water usage by individual wells. According to the Bear Creek Community Plan (January 1989), most of the Bear Creek Planning area is within the approved service and planning areas of Group A water systems. The Bear Creek Community Plan recognizes these King County approved service and planning areas and encourages any new development to be served by these systems. Portions of the Bear Creek planning areas outside the boundary of Group A water service systems must rely on Group B systems or individual wells.

Existing and Future Water Supply Needs

As previously indicated, nearly all of the ground water rights that have been issued in the Redmond-Bear Creek Ground Water Management Area are for public water supply purposes. On an average day, Group A purveyors are currently withdrawing an estimated average quantity of 8 million gallons per day. Based on population projections developed by Puget South Regional Council, the East King County Coordinated Water System Plan estimates that the 1989 average consumption of 65 to 67 million gallons per day of water within East King County will increase to 77 to 84 million gallons per day by the year 2000 and 134 to 185 million gallons per day by 2040 (see Table 6.2). Estimated consumption volumes have not been developed specifically for the Redmond-Bear Creek Ground Water Management Area but usage can be expected to increase at about the same percentage as that for the rest of East King County (i.e., 16 to 27 percent by the year 2000; 103 to 108 percent by the year 2040).

The volume of ground water that is estimated to be withdrawn by individual wells currently exempt from water rights requirements is not expected to significantly increase in the future. Since the use of individual wells for new residential development within the Redmond-Bear Creek Ground Water Management Area is now primarily restricted to large-lot, rural applications, most of the additional growth in the Redmond-Bear Creek Ground Water Management Area, which is expected to be primarily urban and suburban residential, will be served by existing public water systems. This would imply that Group A public water system use would increase from 8 MGD in 1990 to 9.3 to 10.1 MGD by the year 2000 and 16.16 to 22.4 MGD by the year 2040.

Growth Projections

Future growth and development within the Redmond-Bear Creek Ground Water Management Area will result in increased demand on existing sources. Preparing for this growth requires planning, identification, and development of new sources. For East King County, an evaluation of future water supply needs was made as part of the development of the East King County Coordinated Water System Plan. The future demand for water was calculated in 1989 based on growth projections provided by the Puget Sound Council of Governments (now the Puget Sound Regional Council) and King County. From review of projected growth data, the need for new or expanded regional supply and distribution facilities was identified by comparing anticipated demand with existing source capacities.

For East King County, a water supply deficit was projected beyond 1997. Since information specific to the Redmond-Bear Creek Ground Water Management Area was not provided, whether this deficiency will actually occur in the Redmond-Bear Creek Ground Water Management Area in the later 1990s is unknown. Future study is required to quantify the exact need and time frame for development of new sources to serve the expanding population projected to live within the Redmond-Bear Creek Ground Water Management Area.

Small Area Zones (SAZ) were used for the purpose of population forecasts specifically in the Redmond-Bear Creek Ground Water Management Area. Thirty-two SAZ lie within the Redmond-Bear Creek Ground Water Management Area boundary. For those SAZ that lie on the boundary, a percentage of each zone was used in the forecasts. SAZ projections are taken from the King County Comprehensive Plan, and are current as of February 1995. SAZ projections include only those areas that lie within unincorporated King County. Therefore, they do not include the City of Redmond. Preliminary projections for the City of Redmond were obtained from Cathy Beam, City of Redmond Planner.

SAZ projections were used to estimate household growth between 1990 and 2012. Table 6.3 indicates estimated growth between 1990 and 2012 for unincorporated areas within the Redmond-Bear Creek Ground Water Management Area and between 1995 and 2010 for the City of Redmond. The data indicate that the total number of households requiring water in the Redmond-Bear Creek Ground Water Management Area is currently approximately 21,266 and projected to be at least 43,302 in the year 2012, reflecting an 104 percent increase in water service by the year 2012. The majority of the growth predicted to occur within the City of Redmond is expected to occur within the Ground Water Management Area Boundary.

6.5 Ground Water Quality

Ground Water Quality Conditions

Ground water supplies in the Redmond-Bear Creek Ground Water Management Area are drawn from several different aquifers (water-bearing zones). The primary producing aquifers are located in valley alluvial deposits along Bear Creek and Evans Creek, at relatively shallow depths (<150 feet). Specific information regarding the hydrologic conditions and distribution of these aquifers is provided in Section 7.0 (Hydrogeology). Existing and historical water quality data for all aquifers in the study area are primarily limited to Group A public water systems and resource protection wells around the closed Woodinville-Duvall landfill and new data collected during this study in 1989 and 1990. Additional limited ground water quality data are available for private domestic wells from the Seattle-King County Health Department, Washington State Department of Health, and Ecology. Historical data are discussed briefly here. The results of the data collection effort conducted in 1989 and 1990 will be discussed in detail in Section 7.

The ground water quality, on the basis of existing (and historical) data generally meets all the primary and secondary state and federal drinking water standards. The primary problems identified from the historical data are as follows:

- Elevated levels of iron and manganese are common, particularly in deeper wells. This condition is common throughout glacial deposit aquifers of western

Washington and is usually due to natural mineralization of the ground water system.

- Problems with bad tasting or odorous water occur sporadically. Hydrogen sulfide, a by-product of natural organic material decay, is often the cause of the bad taste and odor.
- As a result of a sewer line break in 1987, coliform contamination was detected in one of the Redmond municipal wells (No. 5). The well was pumped at a high rate of discharge for several months and the coliform contamination was eventually eliminated.

This last incident underscores the vulnerability of the shallow Redmond Aquifer in particular and shallow aquifers throughout the study area in general. Widespread contamination from surface sources or as the result of specific incidents (e.g., accidental spills or accidents) has not been recorded to date.

Ground Water Quality Monitoring

Successful management of a ground water resource is at least partially dependent upon the maintenance of an effective ground water monitoring program. Ongoing or long-term collection and analysis of ground water data are necessary to detect significant changes in the quality and quantity of water or in water levels. Early detection of problems allows them to be mitigated at an early stage of their development, when they are generally easier and less costly to correct.

The best available source of ground water quality data is the monitoring conducted by the Group A water purveyors within the Redmond-Bear Creek Ground Water Management Area. Pursuant to the requirements of Chapter 246-290 WAC, the Rules and Regulations of the Washington State Board of Health Regarding Public Water Systems, systems must be monitored on a regular basis for bacteria, inorganic chemicals, corrosivity, pesticides, radionuclides, trihalomethanes, and priority pollutants.

If conducted on each individual well in a public water system, such monitoring would provide critical information concerning the condition of ground water within the Redmond-Bear Creek Ground Water Management Area. Unfortunately, systems served by multiple wells are often tested at random locations within the distribution system. Water from such random locations is often a composite or mixture of water from several different wells and fails to identify general trends. Monitoring data obtained from composite samples offer little information regarding the quality of ground water coming from any specific well in the system and provides essentially no basis for comparison with future sampling results. Monitoring data must be tied to specific wells to track water quality trends over time. Monitoring of Group B Public water systems can also provide important water quality information.

7.0 HYDROGEOLOGY

This section summarizes existing and new geologic, hydrogeologic, and ground water quantity and quality information for the Redmond-Bear Creek Ground Water Management Area. The purpose of this section is to provide a framework for understanding the geologic and hydrogeologic conditions in the Redmond-Bear Creek Ground Water Management Area and to provide information necessary for short- and long-term water resource planning and protection. Information contained in this section was obtained from existing sources and through new data collection activities. The data used in this section were collected by personnel from EMCON Northwest, Inc., Seattle-King County Health Department, the City of Redmond, Union Hill, and Northwest Lake Sammamish Water Districts, and members of the RBC-GWAC.

The scope of work performed to prepare this section included the following tasks:

- Existing data collection and analysis;
- An electrical resistivity survey;
- Design and implementation of a ground water monitoring network;
- Water level monitoring;
- Well installation and testing;
- Water quality sampling and analysis;
- Stream flow gauging;
- Precipitation monitoring;
- Evaluation of data; and
- Preparation of this report documenting findings and conclusions.

7.1 Geology

7.1.1 General Description

The Redmond-Bear Creek study area contains three basic rock types: tertiary or older sedimentary and crystalline bedrock, semi-consolidated to unconsolidated fluvial, glacial, and marine Pleistocene sediments, and recent alluvium (Figure 7.1).

The depth to bedrock in the study area ranges from 0 feet to greater than 1,500 feet below ground surface. Bedrock may occur at the surface only in a small outcrop near Peterson Pond in the southeast corner of the Redmond-Bear Creek Ground Water Management Area.

In most of the study area, bedrock exists beneath 400 to 1,200 feet of Pleistocene sediments (Hall & Otherberg, 1974). These sediments appear to be thickest near the City of Redmond at the north end of Lake Sammamish.

Glacial deposits typically include outwash deposits, glacial till, and interglacial lacustrine deposits. Outwash deposits are composed of sands and gravel deposited as the glacial ice advanced (advance outwash) or receded (recessional outwash). Glacial till, a compact mixture of gravel, sand, silt, and clay, is formed by glaciers overriding, grinding, and compacting outwash material. Lacustrine (lake) sediments typically include finer-grained materials such as clay, silt, and fine sand, and often contain organic debris.

Individual geologic units in the Redmond-Bear Creek Ground Water Management Area are difficult to distinguish based only on the descriptions provided on the driver's well logs. Using data derived from a combination of sources including well logs, field investigations, and geophysical surveys, seven geologic units have been identified beneath the Redmond-Bear Creek Ground Water Management Area. The units, from youngest to oldest, are as follows:

- Alluvium
- Vashon Recessional Outwash
- Vashon Glacial Till
- Vashon Advance Outwash
- Transitional Beds
- Olympia Gravel
- Older Undifferentiated Deposits

A stratigraphic column indicating the estimated age relationships of these units is shown on Figure 7.2. A description of these units is provided below:

7.1.2 Geologic Units

Alluvium. Post-glacial depositional and erosional processes have modified the glacial land forms and former stream and river valleys. Today, alluvial sediments are found primarily in the Evans Creek and Bear Creek valleys and in the downtown portion of the City of Redmond, north of Lake Sammamish. The alluvial deposits are composed of organic-rich fine sand, silt, and clay. Their maximum thickness is approximately 40 feet.

Vashon Recessional Outwash. The Vashon Recessional Outwash consists primarily of well-drained stratified sand and gravel with some silt and clay deposited from meltwater flowing from the receding glacier. In the study area, Recessional Outwash deposits range up to 90 feet in thickness. The Recessional Outwash deposits are generally discontinuous and occur as isolated surface deposits in the upper Bear Creek Valley, around Cottage Lake, on the western edge of Union Hill, and in the Evans Creek Valley.

Vashon Till. Commonly known as "hardpan" due to its compacted nature, the Vashon Till consists of non-sorted clay, silt, sand, gravel, and boulders deposited directly by glacial ice and compacted by the weight of the overriding glacier. The Vashon Till is present at the surface over much of the Redmond-Bear Creek Ground Water Management

Area, including Education Hill, Hollywood Hill, Novelty Hill, and Union Hill. The till is typically only slowly permeable and causes water percolating down from the surface to pond or perch on the top of the unit, forming a perched water table and swampy areas. The till ranges up to 100 feet thick in the study area and appears to be thickest in the northern portion of the Redmond-Bear Creek Ground Water Management Area.

Vashon Advance Outwash. Vashon Advance Outwash deposits underlie the Vashon Till and consist of stratified clean sand and gravel with some thin clay beds. The thickness of this unit ranges up to 90 feet in King County and comprises one of the thickest and most extensive aquifers in the area.

Deposits of Advance Outwash are exposed on the upper portions of the steep slopes bordering the Snoqualmie River, Evans Creek, Bear Creek, and Cottage Lake Creek. In the study area, Advance Outwash generally underlies the Vashon Till except where it has been eroded away by creeks.

Pre-Vashon Deposits

Transitional Beds. The Transitional Beds are made up of glacial and non-glacial lacustrine deposits which consist mainly of laminated or thin-bedded to thick-bedded blocky jointed clay, silt, and fine sand. This unit was formed mainly from sediments deposited in a large lake which 14,000 years ago, covered much of the Puget Sound region between the Olympia Interglacial period and the early Frasier Glaciation. The Transitional Beds range up to 180 feet thick in King County, with the thickest exposures visible along the west bank of the Snoqualmie River. The Transitional Beds are also visible at the surface on the slopes along Evans Creek and in a small area of the Hollywood Hills.

Olympia Gravel. The Olympia Gravel consists of stratified fine to very coarse sand and gravel with minor thin silt and clay beds deposited by streams. This unit ranges up to 135 feet in thickness and is visible in the Redmond-Bear Creek Ground Water Management Area on the lower slopes bordering Lake Sammamish and the Evans Creek Valley. Elsewhere, the Olympia Gravel underlies the transitional beds at elevations ranging from 200 feet above mean sea level to 200 feet below mean sea level.

Older Undifferentiated Deposits. Older undifferentiated deposits include both glacial and non-glacial sediments deposited by glacial events older than the Vashon Glaciation 18,000 years ago. The materials consist of stratified and unstratified silt, sand, gravel, and clay deposited as glacial drift and interglacial lacustrine clay and silt. These deposits are generally not visible at the surface in the Redmond-Bear Creek Ground Water Management Area, but underlie most of the region. These deposits have been penetrated by several of the deep wells in the Redmond-Bear Creek Ground Water Management Area, including the Woodinville Water District and Redmond test wells. Where present in the GWMA, the deposits have a minimum thickness of 400 feet.

7.1.3 Geologic History

The Puget Sound basin has been in existence since Tertiary times when sedimentary and volcanic basement rocks were folded downward between the Olympic and Cascade ranges. The resulting basin provided an avenue for several episodes of piedmont or ice sheet-type glacial flow from southwestern Canada, with concurrent sedimentary deposition during the Pleistocene. Recent post-glacial topographic modifications by erosion and deposition have been minor, occurring primarily along river floodplains.

Two and perhaps four glacial episodes occurred during the Pleistocene age. A maximum of 1,000 feet of glacial, river, lake, and marine sediments were deposited (Thorsen, 1983). The final episode of glaciation, termed the Vashon stage, was the most significant geologic influence on the development of ground water in the study area. Approximately 20,000 years ago, the ice sheet was in the vicinity of Vancouver, British Columbia. Approximately 18,000 years ago, the ice sheet had reached the Port Townsend area and effectively isolated the Puget Sound Basin from the Strait of Juan de Fuca.

A large lake developed in front of the ice front, and thick sequences of fine-grained sediments were deposited in the basin. As the ice advanced and reached the maximum southern limits 14,000 years ago, lateral streams from the Olympic and Cascade ranges were blocked by ice, diverting flow through temporary channels. Thick sequences of coarse sands and gravel flowed from the ice front, spreading over the basin and mixing with river sediments. The ice front overrode the coarse sediments and deposited a veneer of till (a mixture of clay, silt, and fine gravel). The ice reached a maximum thickness of 3,000 feet and an elevation of approximately 5,000 feet above mean sea level in King County. The weight of the ice compressed the till and depressed the basin. Soon after the glacial maximum, the ice front began to recede as the rate of accumulation of snow and ice became lower than the rate of melting. By 12,500 years ago, the ice had retreated from the study area. Isolated lenses of sand and gravel were deposited from the ice margins as the glacier retreated. After the ice had retreated beyond the lateral streams and into the strait, rivers returned to former channels and marine deposition continued (Thorsen, 1983).

The geologic history throughout King County includes the following chronology (listed from youngest to oldest):

- Non-glacial recent deposits
- Frasier Glaciation
- Olympia Interglaciation
- Possession Glaciation
- Pre-Possession Interglaciation
- Double Bluff Glaciation
- Pre-Double Bluff fluvial and lacustrine deposition
- Compaction of sediments into layers of shale, sandstone, and peat

- Deposition of volcanic debris and sedimentary material into a subsiding basin which covered most of western Washington during the Tertiary Period

The surficial and subsurficial geologic deposits form distinct layers exposed at the surface and in deep borings in the study area. These deposits are presented in five geologic cross-sections shown in Figures 7.3 to 7.7. Figure 7.1 indicates the location of each cross section. Well logs used to prepare these cross-sections are presented in Appendix B (available upon request).

7.2 Hydrogeology

This section describes the occurrence, movement, recharge, and discharge of ground water within the Redmond-Bear Creek Ground Water Management Area. The Redmond-Bear Creek Ground Water Management Area is underlain by at least four major water-bearing zones, which, for the purpose of this report, have been termed the Alluvial Aquifers, the Sea Level Aquifers, the Local Upland Aquifers, and the Regional Aquifers.

The Alluvial Aquifers consist of a number of different deposits including recent and older alluvium deposited in and along stream channels in the Redmond-Bear Creek Ground Water Management Area. The Sea Level Aquifers consist of the Olympia Gravel and some older undifferentiated deposits found at elevations near mean sea level. The Local Upland Aquifers are made up of discontinuous Advance Outwash deposits and permeable zones within the Vashon Till. The upland aquifers underlie the ridges on the eastern, western, and southern boundaries of the Redmond-Bear Creek Ground Water Management Area. The Regional Aquifers are composed of the older undifferentiated glacial and interglacial deposits which underlie most of the Redmond-Bear Creek Ground Water Management Area (refer to Figures 7.3 to 7.7).

7.2.1 Occurrence of Ground Water

Geologic materials able to store and transmit ground water are considered to be aquifers. In the Redmond-Bear Creek Ground Water Management Area, the major aquifer systems can be divided into shallow, intermediate, and deep ground water systems. Shallow ground water systems occur as alluvial deposits along the major streams and the shallow portions of the upland aquifers. Intermediate ground water systems occur as Sea Level Aquifers and the deeper portions of the Local Upland Aquifers. Below the intermediate and shallow aquifer systems, the deeper Regional aquifers are contained in older undifferentiated deposits of sand, gravel, and silt deposited during past glacial, interglacial, and Pre-glacial periods.

7.2.2 Major Hydrostratigraphic Units

The hydrostratigraphy of the Redmond-Bear Creek Ground Water Management Area includes a number of aquifers and aquitards. The major hydrostratigraphic units, delineated based on field activity findings and discussed in section 7.3, include four aquifer zones (Alluvial, Local Upland, Sea Level, and Regional) and at least two major aquitards (Vashon Till and Transitional Beds). Each of the wells used to collect water level and water quality data were delineated based on location and water intake elevation into one of the four aquifer zones. Table 7.1 shows which aquifer zone each well was assigned to and the corresponding water intake elevations. The distribution of wells monitored for this study in each aquifer zone is shown on Figure 7.8. Each of the major aquifer zones contains more than one water-bearing zone that may or may not be in hydraulic connection with other water bearing zones in the same unit. For example, the local upland aquifers include discontinuous shallow perched water bearing zones which are separated by an aquitard (a geologic material that inhibits the vertical flow of water) from underlying water bearing zones. Similarly, the regional aquifers include all water bearing zones approximately 100 feet below sea level. In the future, as more data become available, these hydrostratigraphic units may be further subdivided into additional, more distinct units. The remainder of this section provides a brief description of the major hydrostratigraphic units in the study area.

Alluvial Aquifers

The Alluvial Aquifers appear restricted to alluvial deposits along Cottage Lake Creek, Bear Creek, and Evans Creek. These deposits consist of sand, gravel, and silt deposited in and along stream channels as alluvium, alluvial fan deposits, and older alluvium. The deposits range up to 40 feet in thickness.

At least 36 wells used in this study are screened in the Alluvial Aquifers. Depth to water ranges from less than 10 feet to about 100 feet below ground surface. Static ground water elevations measured in wells screened in these aquifers range from approximately 140 feet above mean sea level near Evans Creek at the eastern boundary of the Redmond-Bear Creek Ground Water Management Area and 100 feet above mean sea level at the northern boundaries to less than 20 feet above mean sea level at the discharge area near the northern edge of Lake Sammamish. Monthly ground water elevations in the alluvial aquifers appear to vary by up to 6 feet with seasonal changes in precipitation (Figure 7.9), however, seasonal variations are not large.

Vashon Till

The Vashon till typically forms a low permeability barrier to downward water percolation on the upland surfaces of the study area. Shallow ground water may occur at the base of the upper 8 feet of weathered till, perching on the upper surface of the unweathered till. The presence of till close to the surface is manifested by swampy areas and poor drainage. Ground water is sometimes found within the unweathered portion of the Vashon till, typically restricted to thin, discontinuous lenses of sand and gravel. These sources of water are occasionally tapped by older private wells yielding up to 25 GPM, but are subject to seasonal fluctuations and may completely dry up during the summer months.

Recharge of rainwater to the unweathered Vashon till is slow because of low infiltration capacities, and most water is lost through surface runoff. Increased infiltration occurs in the locally higher permeable zones with the ability to transmit and store ground water. Topographic depressions in the upper surface of the unweathered till will trap ground water that slowly infiltrates into underlying geologic units and aquifers.

Local Upland Aquifers

The Local Upland Aquifers occur beneath the ridge of the Redmond-Bear Creek Ground Water Management Area and may be discontinuous. Their occurrence appears to be largely controlled by topography. These aquifers are mainly comprised of Vashon Advance Outwash, which ranges up to 90 feet thick in the Redmond-Bear Creek Ground Water Management Area. The Local Upland Aquifers may also include the more permeable portions of the Vashon Till.

At least 18 wells in the Redmond-Bear Creek Ground Water Management Area are screened in the Local Upland Aquifers. Depth to water ranges from less than 10 feet in perched water bearing zones to about 350 feet. The Local Upland Aquifers may recharge the Alluvial Aquifers along the valley walls. The typical response of ground water levels to precipitation is shown in Figure 7.10. Ground water levels in these aquifers show some seasonal variation, however, it is generally less than 5 feet.

Transitional Beds

This major hydrostratigraphic unit is an important aquitard separating the Local Upland Aquifers from the Sea Level Aquifers. This unit consists of 50 to hundreds of feet of continuous fine-grained lakebed deposits that restrict vertical ground water movement between aquifers. Scattered isolated lenses of sand within the transitional beds are locally capable of supplying less than 100 GPM of water. The transitional beds are recharged from above by advance outwash sediments and from below by Olympia gravel and deeper units.

Sea Level Aquifers

The Sea Level Aquifers underlie the entire Redmond-Bear Creek Ground Water Management Area and appear to be relatively independent of topography. These aquifers consist of the Olympia Gravel and may include some of the older undifferentiated deposits. The thickness of these aquifer units is not known, but appears to range from 50 to 135 feet. Sea level aquifers are more regional in nature and continue westward beyond the Redmond-Bear Creek Ground Water Management Area boundary.

At least 13 wells in the Redmond-Bear Creek Ground Water Management Area are screened in the Sea Level Aquifers. Depth to water ranges from less than 50 feet to almost 400 feet, depending on surface topography. Ground water levels are higher in autumn than in spring as shown on Figure 7.11. Seasonal variations in the ground water elevation of 10 to 20 feet may result from higher precipitation during the autumn months and lower precipitation in the spring.

Regional Aquifers

The Regional Aquifers underlie the entire Redmond-Bear Creek Ground Water Management Area and are independent of topography. They are composed of the older undifferentiated deposits more than 400 feet thick in the Redmond-Bear Creek Ground Water Management Area. In portions of the Redmond-Bear Creek Ground Water Management Area, the Regional Aquifers occur below the Olympia Gravel and Transitional Beds, usually under confined conditions.

Only five wells used in this study are screened in these aquifers. Depth to water in the regional aquifer can range from about 100 feet to over 400 feet. Static ground water elevations range from 31 to 123 feet above mean sea level. Ground water levels in the Regional Aquifers response to changes in precipitation is evident from the graph of ground water elevation and precipitation over time (Figure 7.12), however, the variations are less than 3 feet.

7.2.3 Ground Water Flow Conditions

Water level elevation data collected during this study were plotted and contoured to determine ground water flow directions for the Alluvial, Local Upland and Sea Level aquifers. Because of the paucity of wells in the Regional Aquifers, there were insufficient data to contour. After review of the water level elevation data, maps were produced from the October 1989 and April 1990 data. These months were selected as being representative of the average potentiometric surfaces during generally low and high annual water table periods.

Alluvial Aquifers

Ground water in the Alluvial Aquifers is usually under unconfined or semi-confined conditions. In general, ground water in the Alluvial Aquifers flows toward local discharge points along valley streams, the Sammamish River and in Lake Sammamish. Ground water flow maps (Figures 7.13 and 7.14) indicate that ground water flows south along Bear Creek and Cottage Lake Creek and west along Evans Creek. Horizontal gradients range from 0.004 ft/ft from north to south to 0.01 ft/ft from east to west.

Local Upland Aquifers

Ground water conditions in the Local Upland Aquifers may be unconfined or confined depending on the depth and presence of overlying aquitards. In the Local Upland Aquifers, ground water flows away from the highland area north of the City of Redmond toward the Alluvial Aquifer along the Sammamish River and Bear Creek. At the eastern edge of the Redmond-Bear Creek Ground Water Management Area, ground water in these aquifers flows west toward Bear Creek and southwest toward Evans Creek (Figures 7.15 and 7.16). In these aquifers, horizontal gradients range from 0.02 to 0.05 ft/ft.

Sea Level Aquifers

Because the sea level aquifers occur beneath one or more aquitards, ground water in this zone is under confined conditions. Except for the extreme southern part of the Redmond-Bear Creek Ground Water Management Area, ground water in the Sea Level Aquifers generally flows west from high elevations of 160 to 200 feet above mean sea level near the Redmond watershed to low elevations ranging from 60 to 80 feet above mean sea level near the western boundary of the Redmond-Bear Creek Ground Water Management Area (Figures 7.17 and 7.18). Horizontal gradients range from 0.002 to 0.01 ft/ft. In the extreme southern part of the Redmond-Bear Creek Ground Water Management Area, ground water in these aquifers flows southwest toward Lake Sammamish.

Regional Aquifers

Ground water in the Regional Aquifer is under confined conditions. From the limited data available on these aquifers, it appears that ground water generally flows toward the west. In the deeper zones, the discharge area is probably Puget Sound.

7.2.4 Ground Water Recharge

Ground water systems are replenished (recharged by the addition of water to the zone of saturation) through precipitation, overland flow, and infiltration from surface water bodies. For this discussion, a recharge area is an area where water (primarily precipitation) infiltrates the ground, and where there is a downward hydraulic gradient that causes water to flow through the subsurface to an aquifer.

Aquifer recharge areas occur where permeable geologic materials and other physical conditions including land use allow water to percolate down to the water table and into an aquifer system. These areas are said to have "infiltration potential," indicating that not only can precipitation easily reach an underlying aquifer, but contaminants also may reach an aquifer.

The likelihood that water will infiltrate and pass through the surface materials to recharge the underlying aquifer system is called the infiltration potential. The infiltration potential depends on a number of physical conditions. These include:

- Soil permeability
- Surficial geologic material
- Depth to water, and
- Topography.

For purposes of this discussion, it should be emphasized that infiltration potential is the ease with which water can percolate downward through native soil materials to the uppermost aquifer. Recharge potential is based on infiltration potential coupled with the amount of precipitation that occurs over a land area, the land cover or land use that contributes to impervious surface over the area, and the net gradient driving downward flow of water. This section addresses only ground water infiltration and does not attempt to quantify recharge potential. By assessing infiltration potential, those areas where surface contaminants may reach the shallow aquifer systems may be evaluated.

Mapping of Physically Susceptible Ground Water

A map of surficial infiltration potential for the Redmond-Bear Creek Ground Water Management Area was created and presented in the November 1994 Draft Redmond-Bear Creek Valley GWMP. The physical parameters (criterion) used to prepare this map included soils, geologic materials, depth to ground water and topography. Subsequent to the November 1994 Draft, a countywide methodology was adopted to define and rank areas that are physically susceptible to ground water contamination (King County Department of Development and Environmental Services; August, 1995). The county map of physically susceptible ground water supersedes the previous infiltration potential map. The King County Department of Natural Resources has plans to develop a county-wide map of ground water recharge areas based on the strategies used to rank areas in the ground water susceptibility mapping process coupled with precipitation data and impervious surface coverage. The recharge areas would also be ranked as high, medium, and low.

The countywide map of areas of physically susceptible ground water is presented in Figure 5.8. This map shows areas where ground water is ranked by its relative susceptibility to contamination. Areas are ranked as being of high, medium, and low susceptibility to ground water contamination. The map, initially presented in the 1994 King County Comprehensive Plan, was created under requirements of the Growth Management Act. Since the initial map was published, a revised countywide map has been created using criteria specifying surficial geology, soils and depth to ground water. Each criterion was rated individually as high, moderate, or low according to the protocols listed in Tables 7.2 through 7.4. The three individual scores were combined to yield an overall rating of aquifer susceptibility. It should be noted that soils were assigned one-quarter of the weight assigned to surficial geology and depth to ground water because their occurrence is a result of the physical and chemical weathering processes of surficial geology. A full rating for soils would duplicate surficial geology in the mapping equation.

Soils that are excessively drained or are somewhat excessively drained are rated highly susceptible; soils that are well drained or moderately well drained are rated moderately susceptible, and soils that are somewhat poorly drained, poorly drained, or very poorly drained are rated as low susceptibility. Table 7.2 indicates the susceptibility ranking of the USDA, NRCS soil units.

For surficial geology, a clean sand and/or gravel were rated as highly susceptible, tight silt or clay were rated low, and materials (mixtures of sand, silt or clay) that fall between the two categories were rated as moderate. Table 7.3 indicates the susceptibility ranking of USGS geologic units.

The data used to determine depth to groundwater was obtained from well logs from the Department of Ecology. Only wells with water levels less than or equal to 100 feet were used in constructing water level contour maps. This reflects the assumption that where depth to water was greater than 100 feet, a relatively impermeable layer would likely exist above the water table. The susceptibility ranking for the depth to ground water criterion is presented in Table 7.4.

Physically Susceptible Areas

Areas of high, medium and low susceptibility to ground water contamination were determined from the countywide map discussed above. The areas that have the highest potential for infiltration, and hence are most physically susceptible in the GWMA, are the Cottage Lake Creek, Bear Creek, and Evans Creek valleys. The remainder of the Redmond-Bear Creek Ground Water Management Area appears to be moderately susceptible based on the criteria discussed above.

Although not evident from the map of ground water susceptibility (Figure 5.8), the Redmond watershed area also appears to be a ground water recharge area in the Redmond-Bear Creek Ground Water Management Area. Vertical potential head gradients between wells in the Sea Level Aquifers (82 and 10) and the Local Upland Aquifers (27, 28, and 30) suggest the possibility of downward flow from the Local Upland Aquifers to the Sea Level Aquifers which may indicate recharging conditions in this area. Along Bear Creek in the center of the Redmond-Bear Creek Ground Water Management Area, the local Upland Aquifers (well 26) appear to recharge the Alluvial Aquifers (well 23). In the western part of the Redmond-Bear Creek Ground Water Management Area, the Local Upland Aquifers (well 15) appear to recharge the Regional Aquifers (well 16).

The entire Redmond-Bear Creek Ground Water Management Area is classified as being either highly susceptible or moderately susceptible to ground water contamination. This means that in most areas, significant surface infiltration will probably occur and may eventually reach the uppermost aquifer system. Therefore, at the scale shown on this map, all areas are important to the continued recharge and preservation of the aquifer system. The location of the surface areas where there is potential infiltration is important to know, relative to land use activities, because these are areas where surface contamination is most likely to lead to ground water contamination. Also, ground water loss may occur if these areas are covered over by parking lots, buildings, or if other changes are made to the topsoil that reduces the amount of water that infiltrates into the soil.

7.3 Data Collection Activities

New data collection activities were accomplished to expand and refine the understanding of geology, hydrogeology, and ground water quality in the Redmond-Bear Creek Ground Water Management Area. The new data collection activities performed for this study consisted of:

- Design of a regional geophysical investigation and collection of electrical resistivity data at thirty-seven locations in the study area;
- Installation of five test wells to evaluate the geology, aquifer conditions, and water quality in areas where data were lacking;
- Pump testing of three test wells to obtain information on aquifer properties;
- Collection and analysis of precipitation data from seven stations in the study area;
- Collection and analysis of stream flow data from six sites in the study area;
- Collection of periodic water level data from eighty-one private and public wells; and
- Sampling and chemical analysis of ground water samples from thirty-five wells.

The specific activities and interpretation of the data are discussed below.

7.3.1 Geophysical Investigations

Geophysical resistivity is a tool used to aid in the interpretation of regional stratigraphy. When used in conjunction with a well drilling program, it is useful in providing stratigraphic correlation between known data points (wells) and in investigating deep subsurface geologic conditions where no data are available. The geophysical investigation program consisted of 41 vertical electrical soundings completed from November 7, 1988, to December 18, 1988, and from March 1, 1989, to March 29, 1989. Fieldwork was performed by a three-person field crew from GeoRecon International of Seattle, Washington. Each electrical sounding site is shown on Figure 7.19. The soundings were performed within the existing road right-of-way to alleviate any legal access problems. Locations of underground utilities were noted throughout the project area when possible, and sounding locations were adjusted to decrease the impact of utilities on the results. A description of the electrical resistivity data collection methodology and general resistivity theory is presented in Appendix C (available upon request).

Discussion of Results

Five geophysical cross-sections were developed throughout the study area and are shown in Figures 7.20 through 7.24. The assigned number of each vertical electrical sounding is shown above the interpreted solution on the geo-electrical sections. Each geo-electrical section has a geologic interpretation of the electrical resistivity values. Table 7.5 shows typical resistivity values representative of the types of geologic materials found in the study area.

The cross-sections were constructed by using existing well logs, surficial geologic data, and geophysics to identify apparent resistivity patterns and corresponding geologic conditions. These cross-sections were expanded to other areas and depths lacking direct geologic information. The sections show a mixture of fine to coarse-grain soil units ranging from clay to gravel. Generally, these are not discrete units of clay or gravel, but mixtures of each material type with the resistivity indicating the predominant grain-size present. Bedrock was also interpreted to exist at depth in three of the sections (Figures 7.20, 7.22, and 7.24).

Section 1 (Figure 7.20) is oriented west-east along Northeast 116th Street from the Sammamish River to 209th Avenue Northeast. This section shows a general trend of geologic material dipping to the west. There is an apparent change in the dip near vertical electrical soundings where it appears that the low resistivity marker units (32 ohm-meters overlying much lower resistivities) may rise toward the surface. The low resistivities found above the interpreted rock surface may indicate interbedded sand, silt, and gravel.

Section 2 (Figure 7.21) is oriented in a west-east direction along the Woodinville-Duvall Road, centered approximately at Avondale Road. Along this section, the upper resistivity values are considerably higher than those encountered along Section 1. The high resistivity values found within 100 to 200 feet of the surface in this section may indicate the presence of relatively coarse-grained units that could be water bearing.

Section 3 (Figure 7.22) is a west-east section along the Redmond-Fall City Road from Redmond to the roadway adjacent to approximately 236th Avenue Northeast. This section is similar to Sections 1 and 2 in that it is generally underlain by an approximate 30-ohm-meter to 66-ohm-meter unit. Like the two previous sections, this section may exhibit an apparent dip to the west. Additionally, soundings completed in March 1989 indicate there may be considerable variation in the electrical properties of the interpreted bedrock material. This may depend upon grain size, saturation, and depth of burial. Vertical electrical sounding-40 was completed near a bedrock outcrop. The resistivities interpreted for vertical electrical sounding-40 are shown in Table 7.6. Field observations indicate the probable occurrence of bedrock, at the sounding location, to be nearly 40 feet in depth. This corresponds to an interpreted electrical layer at 36 feet where the resistivity drops from 539-ohm-meters to 246-ohm-meters.

Vertical electrical sounding-40 was completed at a Northeast Lake Sammamish Water District well site (TW-1), approximately 2,500 feet south of Sections. A section was planned from well TW-1 to soundings north of Section 3, but unusually high influences from utilities and fencing did not permit completion north of Section 3. The data for vertical electrical sounding-37 (well TW-1) are also shown on Table 7.6.

Also, of considerable interest are the extremely high resistivity values encountered west of vertical electrical sounding-15. These values indicate very coarse-grained alluvial deposits.

Section 4 (Figure 7.23) is a north-south section along Avondale Road from the Woodinville-Duvall Road to NE 85th Place. The southern end of this section correlates well with Section 3 which ends just east of Section 4. The central portion is indicative of interbedded silt/sand/gravel deposits seen elsewhere in the Puget Sound area. From vertical electrical sounding-12 north, it was not possible to establish any direct correlation in the deeper portion of this section. Considerable lateral changes appear to occur in the northern 3,000 feet of this section. Further study will be required to define the nature of these lateral changes.
Section 5 (Figure 7.24) is a north-south section along 208th Avenue NE from NE 100th Street to the Fall City Road. Based on the previously established premise for identifying bedrock along Section 3, interpretation of the local bedrock projects north along this section. In the vicinity of vertical electrical sounding-27 northward to vertical electrical sounding-9, a thick section of 90- to 100-ohm-meter material may represent an extensive thickness of silty to coarse-grained materials between a depth of 200 to more than 900 feet.

7.3.2 Monitoring Well Installation and Pump Testing

As part of the Redmond-Bear Creek Ground Water Management Area study, five test wells were completed to collect stratigraphic and hydrologic data for characterization of subsurface conditions and evaluation of ground water resource potential. Well location selections, shown on Figure 7.25, were based on two primary factors:

- Areas where subsurface data were absent, and
- Current or future potential ground water supply areas.

At each of the selected sites, a 6-inch-diameter borehole was drilled to a depth between 160 and 500 feet. Subsurface materials were collected every 5 feet to evaluate geologic conditions. During drilling, water-bearing zones (aquifers) were noted and, if significant in terms of water resource potentials, a 6-inch test well was installed. At two sites, no significant water resource was identified so small diameter (2-inch) monitoring well(s) were installed. In addition to well drilling, aquifer testing was performed in three of the test wells to evaluate certain aquifer parameters such as potential pumping capacity and aquifer transmissivity. The testing consisted of a variable rate and a 24-hour constant rate pump test. A synopsis of drilling, well completion, and aquifer testing details is provided in Table 7.7. Copies of the water well reports for each well are included in Appendix D (available upon request). Copies of the pump testing data are included in Appendix E (available upon request).

A brief description of the findings and interpretations derived from the drilling and testing at each of the five sites is given below.

Woodinville Test Well

The Woodinville test well site is located in the extreme northwestern portion of the study area just north of the Woodinville-Duvall Road. Drilling work was accomplished between February 26 and March 2, 1990. The test hole was drilled to a depth of 490 feet below ground surface. The geologic material encountered consisted of unconsolidated glaciofluvial and lacustrian deposits of sand, gravel, silt, and clay.

During drilling, sandy silt (till) was present to a depth of 10 feet. Between 10 and 85 feet below ground surface, saturated fine-to-coarse sand and occasional silt layers were encountered. A significant (>200 gallons per minute [GPM]) water bearing zone was identified between 72 and 88 feet. Below a depth of approximately 90 feet, the material was predominantly dense silt and clay deposits with occasional interbeds of sand and gravel. No significant aquifers were found below a depth of 90 feet.

Following drilling, a 6-inch stainless steel well screen was installed between 75 and 85 feet below ground surface to evaluate aquifer conditions. A 24-hour pump test was performed on May 3, 1990. Results of the pump test are presented in Table 7.7. In summary, the pump test indicated a moderately permeable aquifer with a extrapolated projected well yield of 700 to 1,200 GPM. Water quality testing showed relatively low (below secondary drinking water standards) levels of iron and manganese and no elevated levels of primary standards.

Redmond Test Well

The Redmond test well site is located in the south central portion of the study area on the southwest corner of Union Hill Road and 196th Avenue NE. Drilling work was accomplished between February 8 and 14, 1990. The test hole was drilled to a depth of 500 feet below ground surface. The geologic materials encountered were from depositional environments similar to those in the Woodinville well.

From ground surface to a depth of 75 feet, geologic materials consisted of fine to coarse sand and gravel. A significant (>200 GPM) aquifer was present between 20 and 70 feet. Below a depth of 75 feet, the material consisted predominately of silt and clay mixtures with occasional interbeds of sand and gravel. No significant aquifers were found below the upper water-bearing zone.

Since the upper water-bearing zone is currently being used by the City of Redmond wells, significant aquifer data have already been collected. For this reason, and due to limited funds for pump testing, one 2-inch monitoring well was installed at the base of the shallow aquifer. Water quality testing of this well did not indicate any parameters exceeding primary or secondary drinking water standards.

Lower Evans Creek Test Well

The site for this test well is the lower Evans Creek Valley on the north side of State Route 202. Drilling work was accomplished between March 8 and March 9, 1990. The test hole was drilled to a depth of 160 feet below ground surface. The geologic materials encountered were predominantly sand and gravel glaciofluvial deposits.

The borehole penetrated predominantly sandy gravel and gravelly sand from ground surface to a depth of 156 feet. The bottom of the boring (156 to 160 feet) encountered a clayey silt. A significant water-bearing zone (50 to 100 GPM) was present between 90 and 100 feet, but there was a strong hydrogen sulphide odor. A more productive zone (>200 GPM) was found from 120 to 156 feet. A slight hydrogen sulphide odor was also present in the lower zone.
Six-inch stainless steel well screen was installed between 143 and 153 feet below ground surface. A 24-hour pump test was performed on April 30, 1990. Results of the pumping test are presented in Table 7.7. The pump test indicated a moderately permeable aquifer with a potential well yield of 400 to 700 GPM. Water quality testing showed elevated levels of iron and manganese.

Upper Evans Creek Test Well

The upper Evans Creek test well site is in the Upper Evans Creek Valley on the south side of State Route 202. Drilling work was accomplished between March 6 and 8, 1990. The test hole was drilled to a depth of 237 feet and encountered geologic materials with depositional histories similar to those at the Lower Evans Creek site.

Drilling at this site encountered sandy gravel from ground surface to 44 feet overlying a silt/sandy silt zone between 44 and 80 feet. Interbedded layers of fine sand, silt, and silty gravel were found from a depth of 80 feet to about 120 feet.

Potential yields in this interval appeared to be less than 50 GPM. At a depth of 122 feet and continuing to 160 feet, the material became predominantly gravelly sand. Potential yields appeared to increase slightly, but are probably less than 100 GPM. From 160 to 237 feet, the geologic material consisted of fine to medium sand. The water bearing capacity of the lower sand did not appear significant.

Since no significant water bearing zones were encountered, pump testing was not performed at this site. The borehole was completed with two 2-inch diameter monitoring wells installed at different depths (see Table 7.7). In addition to providing information on water quality and water levels, these wells may provide information on hydrologic and geologic conditions within the Evans Creek aquifer(s) if aquifer testing is performed on new or existing production wells in the valley.

Marymoor Park Test Well

The well site is located in the southwestern portion of the study area just south of the East Lake Sammamish Parkway. Drilling work was accomplished between August 30 and September 5, 1990. The test hole was drilled to a depth of 180 feet below ground surface. The geologic materials encountered reflect deltaic and lacustrian depositional environments.

The drilling encountered coarse sand and gravel, typical of deltaic deposits from ground surface to a depth of 115 feet. Saturated conditions existed below about 8 feet. Very significant quantities of water appear to exist in this aquifer. From 120 to 140 feet below ground surface, a dense silt and clay unit was penetrated. Below this low permeability unit, a gravelly sand and sand unit was encountered from about 145 to 165 feet. This confined aquifer also appears to have the potential for producing significant quantities of water. From 165 to 180 feet, the material encountered consisted predominantly of fine to medium sand that appeared to be getting finer with depth.

After drilling was completed, a 6-inch diameter well screen was installed from 151 to 161 feet below ground surface. Due to budget constraints, a 24-hour pump test could not be performed on this well. Two short-term pump tests (40 and 60 minutes) indicated a potential well yield of at least 100 GPM.

7.3.3 Precipitation

Precipitation data were compiled from measurements at seven weather stations in the Redmond-Bear Creek watershed during 1989, 1990, and 1991. The location of each precipitation collection station is shown on Figure 7.26. Monthly precipitation data are compiled in Table 7.8. Daily precipitation data are included in Appendix F (available upon request).

The Redmond-Bear Creek watershed receives an average of 42 inches of rainfall annually, approximately 8 inches more than the Everett weather station to the north. Total monthly precipitation data for each weather station during the years 1989, 1990, and 1991 are shown in Figures 7.27, 7.28, and 7.29. Precipitation totals for weather stations with no data in a particular month have not been plotted for that month. Incomplete or no data were available for a few months at certain stations including the Union Hill Site from August through November 1990, and the Woodinville Station between September and December 1989.

The monthly precipitation plots illustrate how precipitation varies seasonally in the watershed with approximately 75 percent of the annual precipitation falling during the fall and winter months (October through March). On average over the three-year period, the month of January had the greatest amount of precipitation. The Redmond-Bear Creek Ground Water Management Area-wide averages of precipitation for January ranged from approximately 4.5 to 9.1 inches. The highest recorded monthly rainfall, 10 inches, occurred at the North Ridge Station in January 1990. Precipitation decreases sharply during the summer with the least precipitation typically occurring during September. Average precipitation over the watershed during the month of September ranged from 0.15 to 0.30 inches during the three years of study.

To evaluate precipitation patterns within the Redmond-Bear Creek Ground Water Management Area, monthly precipitation totals for each station were plotted for both a high and low precipitation month. July and October of 1990 were selected because there are data at all of the precipitation stations for both months. The isohyetal maps, Figures 7.30 and 7.31, show the distribution of precipitation during July and October of 1990, respectively. The maps show that precipitation generally increases from west to east across the watershed. As expected, rainfall was usually greatest at the higher elevations along the western boundary of the Redmond-Bear Creek Ground Water Management Area and lowest in the lower Bear Creek Valley around the cities of Redmond and Woodinville. As shown graphically on Figure 7.32, the Sahalee and North Ridge stations consistently recorded the highest monthly precipitation totals.

7.3.4 Streamflow

The Redmond-Bear Creek Ground Water Management Area is drained by four major streams: Cottage Lake Creek, Daniels Creek, Bear Creek, and Evans Creek. Daniels Creek, located in the northern part of the watershed, flows south into Cottage Lake which is drained by Cottage Lake Creek. Evans Creek originates in a marshland at the southern end of the watershed and flows northwest toward the Sammamish River. Cottage Lake Creek and Bear Creek both flow south until they merge north of Avondale and empty into Evans Creek at Union Hill Road just east of Redmond. Evans Creek eventually discharges to the Sammamish River.

During this study, stream discharge data were collected for six gauging stations in the Redmond-Bear Creek Ground Water Management Area from 1989 through 1991 (Figure 7.33). Station Number 1 was located on Daniels Creek at the Woodinville-Duvall Road, Station Number 2 on Upper Bear Creek along the Woodinville-Duvall Road, Station Number 3 on Cottage Lake Creek at Avondale Road, and Station Number 4 on Lower Bear Creek at NE 132nd Street. Two stations (Numbers 5 and 6) were located on Evans Creek at Union Hill Road, approximately 1.5 miles apart. At stations 1 and 2, stream flow data were collected periodically by EMCON personnel. Data from Station Number 3 were collected by the Seattle-King County Health Department, using a continuous recorder. Data from the Lower Bear Creek station Number 4 were collected by the United States Geological Survey with a continuous recorder, and data from Evans Creek stations 5 and 6 were collected by the King County Water and Land Resources Division using continuous recorders.

Gauging Methods

At each site, an attempt was made to collect measurements from a reach of stream with a smooth shoreline, no brush hanging in the water, no large rocks, and no back-eddies. These optimum conditions were found only in culverts beneath roads, so they were the location of choice for stream gauging. Stream sections exhibiting fair to good conditions were used where culverts were not available.

At the Daniels Creek site, and the upper and lower Bear Creek sites, stream velocity measurements were made with a Swoffer impeller-type current meter (number M-1-01-K). Velocity and water depths were measured at 6 to 24 equally spaced points along a tape stretched perpendicularly across the stream. Each point represents the midpoint of a flow segment whose vertical sides are located midway between neighboring measurement points on the tape. Velocity measurements at each point were made at a depth corresponding to six-tenths of the depth of the stream. At each point, at least three 20-second velocity measurements were collected and averaged.

Discharge for each segment is the product of the average velocity and the area of the segment. Discharges for each segment were summed to determine the total stream discharge at each site. Stream flow measurements collected during the study are presented in Appendix G (available upon request).

Hydrographs of stream discharge were prepared for the two Evans Creek stations and for the Lower Bear Creek station for the years 1989 through 1991. These streams flow throughout the year. Seasonal variations in stream flow appear to correspond to changes in precipitation and are generally characterized by high flows in the winter and spring and low flows in the summer and fall. Hydrographs for Evans Creek at Union Hill Road (Station 5) are shown in Figures 7.34, 7.35, and 7.36. Hydrographs for Evans Creek at Union Hill Road (Station 6) are shown in Figures 7.37, 7.38, and 7.39 and hydrographs for Lower Bear Creek near Redmond (Station 4) are shown in Figures 7.40, 7.41, and 7.42. Stream discharge data for the Daniels Creek and Upper Bear Creek stations are summarized in Appendix G (available upon request).

During each year, base flow comprised most of the flow in each creek during the summer months from July through September. This period also corresponds with the months of lowest precipitation. Storm flows typically occur between November and April, with the largest peak flow in each stream recorded in January 1990. Along Evans Creek, baseflow increases greatly between the upstream and downstream gauging stations, indicating ground water discharge to Evans Creek. In 1990, baseflow ranged from approximately 5 cubic feet per second upstream to 25 cubic feet per second downstream. Base flow in Evans Creek was highest in 1991 and lowest in 1990.

The Evans Creek hydrographs (Figures 7.34 through 7.39) show that flow varied from about 5 cubic feet per second to 200 cubic feet per second from January 1989 to September 1991 at the upstream Union Hill Road station and from 15 cubic feet per second to 1332 cubic feet per second during the same period at the downstream station near Avondale. At the Bear Creek gauging station near Redmond, streamflow varied from about 5 cubic feet per second to 250 cubic feet per second from April 1989 through September 1991 as shown on the Bear Creek hydrographs (Figures 7.40 to 7.42).

7.3.5 Water Level Monitoring

Existing ground water data available prior to this study were too limited and too sporadic to use in determining long-term water level trends or ground water flow directions. In the winter of 1989, a water level monitoring network was developed including 81 private and public water supply wells and monitoring wells. Water levels were collected periodically, generally once a month, beginning in February 1989 and continuing through July 1991. Not all wells were monitored the entire period and monitoring of some wells is still ongoing. Table 7.9 is a summary of the wells used in the monitoring network. Well locations are shown on Figure 7.43.

Well Selection

Well driller's logs obtained from Ecology were reviewed. Several wells were selected for possible monitoring and each potential well was field checked. Wells were selected for monitoring based on the following criteria: (1) location of the well within the study area, (2) well construction, (3) aquifer zone, and (4) usefulness of data on the well logs. Each well was identified as producing from a shallow aquifer zone or a lower deep aquifer zone. Representative wells were selected to provide a uniform distribution for aquifers throughout the study area. Finally, each owner's permission was obtained before water levels were measured. Driller's well logs for the wells selected for monitoring are presented in Appendix H (available upon request).

Water Level Measurements

Water level measurements were obtained by personnel from the City of Redmond, Seattle-King County Health Department, EMCON Northwest, Inc., Union Hill, Northeast Lake Sammamish Water Districts, and volunteers from the RBC-GWAC. Water level data forms were used to record depth-to-water measurements. The data were then entered into the Seattle-King County Health Department database. Copies of water level measurements for each well are provided in Appendix I (available upon request).

Water levels were measured with either a Slope Indicator (Model 51453) water level indicator or an Actat Olympic Well Probe (by Seattle-King County Health Department). These devices electrically measure the point at which the probe makes contact with water. The distance from the top of the well casing to the probe is then recorded to the nearest 0.01 foot. Before lowering the probe into each well, the first twenty feet of well probe is disinfected with liquid chlorine bleach in a distilled water solution.

The water level elevation for each well was calculated by subtracting the depth to water from the elevation at the top of the well casing. Elevations were obtained from survey data collected by Phillips and Associates, Engineers of Bellevue, Washington. City of Redmond Surface Water Management also supplied elevations for wells in the Redmond area.

7.3.6 Ground Water Quality Sampling

The chemical quality of ground water in the Redmond-Bear Creek Ground Water Management Area affects the potential development and use of the area's ground water resources. Ground water chemistry in the Redmond-Bear Creek Ground Water Management Area was evaluated using the results of samples collected from wells throughout the area that were analyzed for a variety of constituents. The analyzed constituents were selected to provide information about the quality of ground water in the Redmond-Bear Creek Ground Water Management Area aquifers.

Ground water samples were collected from each of 35 wells in the Redmond-Bear Creek Ground Water Management Area. Samples were collected in December 1989 and May 1990. For the December 1989 ground water sampling, samples were collected from all wells and analyzed for primary and secondary drinking water standards and characteristic constituents (including major and minor ions). Selected wells were also tested for total organic halogens. For the May 1990 ground water sampling, analysis of ground water from selected wells was expanded to include volatile organic compounds, semivolatile organic compounds, chlorinated pesticides, polychlorinated biphenyls, and the priority pollutant metals which were not already included in drinking water standard constituent testing. During the May 1990 sampling, a reduced number of wells were tested for total organic halogens.

Analytical testing parameters were selected to allow characterization of ground water quality and characteristics in the Redmond-Bear Creek Ground Water Management Area. All wells were tested for primary and secondary drinking water standard constituents to determine whether ground water in the Redmond-Bear Creek Ground Water Management Area generally meets national drinking water standards. Results were compared with state and national primary and secondary drinking water standards. Total organic halogens analyses were used to scan for potential ground water contamination. Volatile organic compounds, semivolatile organic compounds, and additional priority pollutant metals testing were used to assess potential ground water contamination. The locations of wells sampled for this study are shown on Figure 7.43. Constituents tested at each well are listed in Table 7.10.

All ground water samples were collected in accordance with standard procedures described in the Redmond-Bear Creek Ground Water Management Area Quality Assurance Project Plan (Sweet-Edwards/EMCON, March 2, 1990), and the Redmond-Bear Creek Ground Water Management Area Data Collection and Analysis Plan (Sweet-Edwards/EMCON, March 5, 1990). All chemical data were reviewed and were considered valid for the purposes and limitations of this report. Copies of the laboratory testing results for each well are included in Appendix J (available upon request).

The concentrations of major and minor ions were evaluated to determine the general characteristics and type(s) of ground water in the management area aquifer(s) and can sometimes be used to indicate associations and/or connections between aquifers. The significance of the major and minor ions evaluated for this study is discussed in the Results of Ground Water Sampling section below and the results of the analyses are presented and discussed in the Summary of Results section.

Chemical analyses of priority pollutant metals, phenol, cyanide, and other potential contaminants can be used as indicators of ground water contamination. The significance of each of these analytes is discussed in the Additional Potential Contaminants section and the results of these analyses are summarized and discussed in the Summary of Results.

7.4 <u>Results of Ground Water Quality Sampling</u>

Inorganic and organic materials occur in ground water as dissolved solids. Some of these materials occur naturally in ground water and some occur only as introduced contaminants. The relative abundance of naturally occurring dissolved solids analyzed for this study is indicated in Table 7.11. This section describes the analytes examined during this study and discusses the occurrence of each analyte in natural (uncontaminated) ground water and in samples collected from wells within the Redmond-Bear Creek Ground Water Management Area. The analytes were selected by the Seattle-King County Health Department in accordance with Ecology guidelines.

Sources used to develop the discussions presented in this section include Callahan et. al. (1979a, 1979b), Hem (1985), Davis and DeWiest (1966), Driscoll (1986), Salomons and Forstner (1984), Stumm and Morgan (1981), Todd (1980), and Tuerkian and Wedepohl (1961).

7.4.1 Primary Drinking Water Standard Analytes

Primary drinking water standard analytes are defined by the National Primary Drinking Water Regulations (40 CFR 141), which have been adopted by the State of Washington in Chapter 246-290 WAC and the Ground Water Quality Standards Chapter 173-200 WAC. These regulations address constituents that potentially affect public health if consumed in drinking water. Ground water must meet all primary drinking water standards to be suitable for development as a drinking water supply. All public water supplies must be regularly tested for all of the primary drinking water analytes. For this study, ground water samples were collected and analyzed for the following selected primary drinking water standard analytes: arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, nitrate, and total and fecal coliform bacteria. Each of the analytes is described below.

Arsenic. Arsenic is considered ubiquitous in rocks and soil, generally occurring at concentrations ranging from 1 to 13 parts per million (PPM). Higher concentrations of naturally occurring arsenic are associated with some types of ore deposits. Concentrations of arsenic in ground water are typically low (less than 0.010 PPM), but greater concentrations can occur either naturally or due to contamination. The primary drinking water standard for total arsenic is 0.05 PPM. In the Redmond-Bear Creek Ground Water Management Area, arsenic was not detected above the primary drinking water standard except for one well (64) completed in the alluvial aquifers, where it was detected at 0.43 PPM.

Barium. Barium is abundant in rocks and soils, ranging in concentration from less than 1 to greater than 2,000 PPM. The most common barium mineral is barite (barium sulfate). Barium concentrations in natural waters are generally about 0.045 PPM, with greater concentrations found under special conditions (such as in oil field brines). The primary drinking water standard for total barium is 1.0 PPM. Barium concentrations in the ground water samples from the Redmond-Bear Creek Ground Water Management Area were below the primary drinking water standard in all but well 64. The sample from well 64 contained 5.4 PPM of barium.

Cadmium. Cadmium is a relatively rare, naturally occurring element concentrated in zinc-bearing ores. As a result, low concentrations of cadmium are found in all zinc products. Cadmium concentrations in natural rocks and soils are generally less than 0.6 PPM. Many cadmium-bearing minerals are soluble. The normal concentration of cadmium in seawater is less than 0.0002 PPM, and the normal concentration of cadmium in surface waters is generally about 0.001 PPM. Little information is available about the normal concentrations of cadmium in ground water. The primary drinking water standard for total cadmium is 0.01 PPM. Cadmium was not detected above the laboratory method reporting limit in any of the ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Chromium. Chromium occurs naturally in soils and rocks. Although chromium concentrations of 1,600 PPM have been reported for some ultrabasic igneous rocks, concentrations are generally lower than 200 PPM. Chromium-bearing minerals generally have low solubilities. Although chromium concentrations in natural waters are usually very low (less than 0.01 PPM), naturally occurring chromium concentrations up to 0.2 PPM have been reported for ground water. The primary drinking water standard for total chromium is 0.05 PPM. Chromium concentrations were below the laboratory method reporting limit in all ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Fluoride. Fluoride is an element that occurs naturally and commonly in soils and rocks. Fluoride is an essential nutrient and component of bones and teeth. Excessive fluoride can, however, cause mottling of tooth enamel and cause teeth and bones to become brittle. Fluoride is a component of many minerals, the most common being fluorite (calcium fluoride). The concentration of fluoride in soils and rocks is generally less than

1,500 PPM. Although fluoride concentrations in natural water are generally less than 1 PPM, concentrations as high as 50 PPM have been reported. Relatively high fluoride concentrations can occur in water with high (greater than 9) pH values, thermal water, and water affected by volcanism. The primary drinking water standard for fluoride is 4.0 PPM. Fluoride was not detected above the primary drinking water standard in any ground water sample from the Redmond-Bear Creek Ground Water Management Area. Fluoride concentrations exceeded the laboratory method reporting limit only in well 16 which is completed in the Regional aquifers.

Lead. Lead occurs naturally in soils and rocks at concentrations up to 80 PPM, but may range to percent levels in some ore deposits. The most common lead-bearing mineral is galena (lead sulfide). Natural lead compounds have low solubilities, so lead concentrations in natural waters are generally low (less than 0.01 PPM). However, synthetic lead compounds (including the organic lead compounds added to leaded gasoline), have much higher solubilities, and lead concentrations in urban rainwater and snow can exceed 0.1 PPM. The primary drinking water standard for total lead is 0.05 PPM. Lead was not detected above the primary drinking water standard in ground water samples from the Redmond-Bear Creek Ground Water Management Area with the exception of one well in the regional aquifer (16), where it was detected at 0.33 and 0.13 PPM, and one well (64) in the Alluvial aquifers where it was detected at 0.31 PPM.

Mercury. Mercury is a trace element that usually occurs in trace (less than 1 PPM) concentrations in rocks and soils, but can be concentrated in ore deposits. Mercury concentrations in water are generally lower than 0.001 PPM, with the typical concentration in seawater of 0.0002 PPM. Mercury concentrations up to 0.01 PPM can occur in water associated with thermal ground water or mercury ore deposits. The primary drinking water standard for total mercury is 0.002 PPM. Mercury concentrations were below the laboratory method reporting limit in all samples from the Redmond-Bear Creek Ground Water Management Area except well 64 where it was detected at 0.0028 PPM.

Selenium. Selenium is a trace element that occurs naturally in soils and rocks, with concentrations in soils and fine-grained sediments generally being 1 PPM or lower, and concentrations in other rocks generally being lower (0.1 PPM or lower). Although metal selenides have low solubilities, other selenium compounds are soluble. Although selenium concentrations in surface and ground water are usually lower than 0.001 PPM, concentrations up to 3 PPM have been reported for irrigation water draining through soils with naturally high selenium concentrations. The primary drinking water standard for total selenium is 0.01 PPM. Reported selenium concentrations in the Redmond-Bear Creek Ground Water Management Area were generally at or below the laboratory method reporting limit. There were no reported concentrations above the primary drinking water standard in any ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Silver. Silver is a trace element that occurs naturally in rocks and soils, normally at concentrations lower than 0.4 PPM. In ore deposits, silver usually occurs as a native metal (often in a mixture with native gold), as argentite (silver sulfide), or associated with the sulfides of lead, copper, or other metals. Although metallic silver and argentite are virtually insoluble in natural waters, some silver compounds are slightly soluble. Silver concentrations in seawater and river water are generally about 0.0003 PPM. Little is known about the normal concentrations of silver in ground water. The primary drinking water standard for total silver is 0.05 PPM. Silver concentrations were all at or below the laboratory method reporting limit in ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Nitrate. Nitrogen occurs naturally in rocks and soils, generally at concentrations of 30 PPM or lower. There are two nitrate minerals; niter (potassium nitrate, or saltpeter), and soda niter (sodium nitrate). These minerals are easily dissolved in water, and are, therefore, only found in arid climates. They are thought to be formed by processes like evaporation or come from the accumulation of materials such as bat guano. Atmospheric nitrogen combines with oxygen to form nitrate through common metabolic processes of several types of bacteria and fungi found in soils. Concentrations of nitrate in natural water are generally lower than 1.0 PPM. The concentration of nitrogen (which normally occurs as nitrate) in seawater is generally lower than 1 PPM. The natural concentration of nitrate in surface and ground water is not well understood, since the nitrate contributions from natural sources (human waste, barnyard waste, and fertilizers) vary widely. The primary drinking water standard for nitrate is 10 PPM. Nitrate concentrations ranged from the laboratory method reporting limit to 3.6 PPM in ground water samples from the Redmond-Bear Creek Ground Water Management Area. In the alluvial aquifers, nitrate concentrations ranged from the method reporting limit to 3.1 PPM. In the Local Upland Aquifers, nitrate concentrations ranged from the method reporting limit to 3.6 PPM. Nitrate concentrations in the Sea Level Aquifers ranged from the method reporting limit to 1 PPM. Nitrate samples from wells in the Regional Aquifers did not exceed the method reporting limit.

Total and Fecal Coliform Bacteria. Large populations of coliform bacteria occur naturally in the intestinal tracts of all warm-blooded animals. Coliform bacteria also occur naturally in both surface and (less commonly) ground water. Coliform bacteria usually are not harmful in and of themselves, but are used as an index of fecal pollution since they are numerous, and the test is easy and inexpensive. Large counts of any fecal coliform bacteria indicate other pathogenic organisms may be present. The tests for these other pathogenic organisms, which include other bacteria, protozoans, and viruses, are considerably more difficult and expensive to perform. The primary drinking water standard for total coliforms is 1/100 ml. Total and fecal coliform bacteria were detected in ground water samples from all four aquifers. In the Alluvial Aquifers, total coliform bacteria were detected at concentrations ranging from 2 to 110 organisms per 100 ml. In the Local Upland Aquifers, total coliform bacteria were detected in four wells at concentrations from 7 to 17 organisms per 100 ml, respectively. Coliform bacteria were detected at 11 org/100 ml in one well in the Sea Level Aquifers, and at 2 org/100 ml in one well in the Regional Aquifers. Fecal coliform bacteria were not detected in any of the ground water samples submitted for analysis.

7.4.2 Secondary Drinking Water Standard Analytes

Secondary drinking water standard analytes are defined by the National Secondary Drinking Water Regulations (40 CFR 143), which have been adopted by the State of Washington in Chapter 246-290 WAC and the Ground Water Quality Standards Chapter 173-200 WAC. The federal regulations are not enforceable and were prepared as guidelines for the states. These regulations address ground water constituents primarily affecting the aesthetic qualities (and, therefore, public acceptance) of drinking water. For this study, ground water samples were collected and analyzed for the following selected secondary drinking water standard analytes: chloride, copper, fluoride, iron, manganese, sulfate, total dissolved solids, and zinc. The primary drinking water standard analyte, fluoride, has been discussed above in the Primary Drinking Water Standards Analytes section. Chloride, copper, iron, manganese, sulfate, total dissolved solids, and zinc are discussed below.

Chloride. Chlorine is a common element that occurs naturally in deep-sea sediments and clays at concentrations of approximately 21,000 PPM, and in rocks and soils at concentrations generally less than 600 PPM. More than three-fourths of the chlorine on earth is found in the oceans, with concentration of chlorine in seawater generally being about 19,000 PPM. Chlorine normally occurs in water as the chloride ion (Cl^-). Chloride is present in all natural waters and is considered a major component of ground water. Natural chloride concentrations in ground water vary widely and can range from less than 10 PPM in some spring water up to 189,000 PPM in brines. The concentration of chloride in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for chloride is 250 PPM. Chloride concentrations ranged from 1.3 to 15 PPM in ground water samples from the Redmond-Bear Creek Ground Water Management Area, well below the secondary drinking water standard of 250 PPM.

Copper. Copper is an essential nutrient and occurs naturally as a trace metal in rocks and soils. Copper commonly occurs as a native metal as chalcocite (copper sulfide) and in sulfides in conjunction with other metals (e.g., chalcopyrite and bornite are important iron/copper sulfide minerals). Average concentrations of copper in natural rocks and soils range to 1,000 PPM in clays and to 100 PPM in other rocks and soils. Copper concentrations in natural water are normally lower than 0.01 PPM, but can exceed 300 PPM in water affected by acid mine drainage. The concentration of copper in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total copper is 1.0 PPM. Copper was not detected above the laboratory method reporting limit in any of the ground water samples from the Redmond-Bear Creek Ground Water Management Area with the exception of well 64 where it was detected at 1.5 PPM.

<u>Iron</u>. Iron is an essential nutrient, and is one of the most abundant elements on earth. It occurs naturally at high concentrations (up to 7 percent in rocks and soils with higher concentrations in ore deposits). Iron occurs in most natural water, usually as the ferrous iron ion (Fe^{+2}). The concentration of iron in natural water depends upon the concentration of oxygen and oxygen-containing compounds. Where oxygen concentrations are high (for example, in a flowing stream), iron concentrations are typically 0.01 mg/l or less. Iron concentrations in ground water often range from 1 to 10 PPM and can exceed 50 PPM. The concentration of iron in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total iron is 0.30 PPM. Iron concentrations were detected above the secondary drinking water standard in several wells in each of the four principal aquifer systems in the Redmond-Bear Creek Ground Water Management Area. It was detected in five wells in the Alluvial Aquifers at concentrations ranging from 0.71 to 1,000 PPM, and in six wells in the Local Upland Aquifers at concentrations ranging from 0.31 to 9.1 PPM. Iron concentrations in the Sea Level Aquifers were above the standard in samples from three wells and ranged from 0.31 to 29 PPM. Iron concentrations in the Regional Aquifers were above the standard in three wells and ranged from 0.31 to 11 PPM.

<u>Manganese</u>. Manganese is an essential nutrient and is an abundant element. Manganese concentrations in rocks and soils generally range up to 6,700 PPM. Manganese occurs commonly in silicate minerals and can occur in other forms (for example, oxides and carbonates). Manganese occurs in most natural water, usually as the ion Mn^{+2}. Manganese concentrations in seawater are generally about 0.002 PPM and are usually less than 1 PPM in surface and ground water. The concentration of manganese in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total manganese is 0.05 PPM. Manganese concentrations were detected above the secondary drinking water standard in ground water samples from several wells in the Redmond-Bear Creek Ground Water Management Area. In the Alluvial Aquifers, manganese concentrations were above the standard in seven wells and ranged from 0.055 to 0.111 PPM. In the Local Upland Aquifers, manganese was detected above the standard in five wells at concentrations ranging from 0.055 to 0.161 PPM. Manganese concentrations in the Sea Level Aquifers were above the standard in ground water samples from one well at 0.056 and 0.07 PPM and in four wells in the Regional Aquifers at concentrations ranging from 0.06 to 0.21 PPM.

<u>Sulfate</u>. Sulfur is a common element that occurs in concentrations to 2,400 PPM in rocks and soils. Sulfur often occurs as sulfide minerals, such as pyrite (iron sulfide) and galena (lead sulfide). Many of the most important ore minerals are sulfides. Although some sulfate minerals like calcium sulfate (gypsum) are easily dissolved, some (like barite, which is barium sulfate) are virtually insoluble in water. Sulfate occurs naturally in most water and is almost always present in brackish or saline water. Seawater generally contains about 2,700 PPM of sulfate. The sulfate concentration in ground water is generally expected to be the same as the sulfate concentration in rainwater, about 1 to 3 PPM. Where sulfate is absent from ground water, it has generally been transformed into sulfide by microorganisms. The concentration of sulfate in drinking water is not

regulated, but the national and state secondary drinking water (aesthetic) standard for sulfate is 250 PPM. Sulfate concentrations in ground water samples from the Redmond-Bear Creek Ground Water Management Area ranged from the method reporting limit to 75 PPM, well below the secondary drinking water standard.

Total Dissolved Solids. The total dissolved solids present in a sample is determined by filtering the water into a weighed evaporation dish, evaporating the filtered water, and weighing the dish with the dried residue. After correcting for the volume of sample filtered, the total dissolved solids of the sample is calculated as the difference in weight between the empty dish and the dish-plus-residue. The concentration of total dissolved solids in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for total dissolved solids is 500 PPM.

Waters with greater than 500 PPM total dissolved solids concentrations may have an unpleasant flavor and may be difficult to digest for consumers of the water. Since total dissolved solids is a rough measure of the mineralization of the water, samples with high dissolved solids concentrations may be unsuitable for industrial applications. In these cases, the analyses of individual elements of concern (such as calcium and iron) should be reviewed to determine whether further testing is necessary prior to approving the water supply. Total dissolved solids concentrations in ground water samples collected in the Redmond-Bear Creek Ground Water Management Area ranged from 6 to 590 PPM, with the highest concentrations found in the samples from the Regional Aquifers.

Zinc. Zinc is an essential nutrient that occurs naturally and is fairly common in rocks and soils. Zinc concentrations in soils and rocks are generally less than 200 PPM, however, zinc concentrations in ore deposits are generally several percent. The most common zinc mineral is zinc sulfide (sphalerite). Zinc concentrations in ground water are generally low (less than 1 PPM) under most conditions. The concentration of zinc in drinking water is not regulated, but the national and state secondary drinking water (aesthetic) standard for zinc is 5 PPM. Zinc was not detected above the secondary drinking water standard in any ground water samples submitted for analysis. Zinc concentrations ranged from the method reporting limit to 3.2 PPM.

7.4.3 Other Chemical Indicators

For the purposes of this study, ground water characteristic constituents are those dissolved solids that are major and secondary constituents of potable water (see Table 7.11). These materials occur as both natural constituents of and introduced contaminants in ground water. The primary drinking water standard analytes fluoride and nitrate have been discussed in the Primary Drinking Water Standard Analytes section above. The secondary drinking water standard analytes chloride, iron, and sulfate have been discussed in the Secondary Drinking Water Standard Analytes section above. Bicarbonate, carbonate, hydroxide, calcium, magnesium, nitrite, potassium, silica, sodium, and total hardness are discussed below.

Alkalinity. Alkalinity measures the ability of a water sample to neutralize an acid. All ground water typically has measurable alkalinity. Alkalinity is caused by carbon dioxide gas dissolved in the ground water. The main sources of dissolved carbon dioxide gas are carbon dioxide in the atmosphere, gas in the soil, and carbonate minerals in the aquifer.

The total alkalinity of a sample equals the sum of all titratable bases in that sample and, for natural waters, is typically a function of the carbonate, bicarbonate, and/or hydroxide concentrations in the sample. The measurement method assumes that carbonate, bicarbonate, or hydroxides are the only bases that occur in the sample. This is a reasonable assumption as other naturally occurring bases (such as borates, phosphates, and silicates) are generally minor and will not contribute much to the total.

In practice, a laboratory measures alkalinity by titrating a sample using two different pH indicators (i.e., methyl orange and phenolphthalein). The laboratory calculates the relative contribution(s) of the carbonate, bicarbonate, and hydroxide alkalinities using the ratio between the methyl-orange ("total") and phenolphthalein alkalinities. The laboratory reports the total alkalinity and the calculated carbonate, bicarbonate, and hydroxide alkalinities. Alkalinity concentrations in drinking water and ground water are not regulated. The total alkalinity of the ground water samples from the Redmond-Bear Creek Ground Water Management Area ranged from 2 to 300 mg/L as calcium carbonate ($CaCO_3$). Alkalinity was generally less than 100 mg/L in most Local Upland Aquifer samples and approximately 100 mg/L in the Alluvial Aquifer samples. The highest alkalinity was measured in ground water samples from wells in the Regional Aquifer.

Calcium. Calcium is an essential nutrient common in rocks and soils, and occurs in a wide variety of minerals. The general concentrations of calcium in rocks and soils range from about 5,100 PPM in some granites to over 312,000 PPM in some carbonates. Calcium is a major constituent of natural waters, where it occurs only as the ion Ca^{+2}. The general concentration of calcium in seawater is about 410 PPM. Calcium concentrations in ground water range from lower than 50 PPM in some limestones, to greater than 93,500 PPM in an oil-field brine. Calcium concentrations in drinking water and ground water are not regulated. Calcium concentrations in ground water samples from the Redmond-Bear Creek Ground Water Management Area ranged from 4.7 to 260 PPM, with the highest concentration occurring in the ground water sample from well 64 in the Alluvial Aquifers.

Magnesium. Magnesium is an essential nutrient common in rocks and soils. Magnesium occurs in a wide variety of minerals, with concentrations in rocks and soils ranging from 1,600 PPM in some granites, to over 200,000 PPM in ultrabasic rocks. Magnesium is a major constituent of natural waters, where normally it occurs only as the ion Mg^{+2}. The general concentration of magnesium in seawater is about 1,350 PPM. Magnesium concentrations in ground water range from less than 4 PPM in some limestones, to greater than 12,000 PPM in an oil-field brine. Magnesium concentrations in drinking water and ground water are not regulated. Magnesium concentrations in all but one of the wells sampled ranged from 0.01 PPM up to 19 PPM. Magnesium was detected at 400 PPM in well 64.

Nitrite. Nitrogen has been addressed in the discussion of nitrates (see Primary and Secondary Drinking Water Standards Analytes section above). Unlike nitrate, nitrite does not occur as a mineral. Nitrite (NO^{2-}) is formed by removing one oxygen atom from nitrate (NO^{3-}). This process is called "nitrate reduction" and generally results from the metabolic processes of some microorganisms, which occur naturally in soil and ground water. Although nitrate is common in ground water, nitrite is uncommon. Little is known about the natural concentrations of nitrites in surface or ground water. Nitrite concentrations in drinking water and ground water are regulated as total nitrogen and must meet the primary drinking water standard of 10 mg/L. Nitrite was detected at or below the laboratory method reporting limit of 0.5 PPM in all ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Potassium. Potassium is an essential nutrient common in rocks and soils. Although potassium concentrations are about 40 PPM in ultrabasic rocks, they generally range from 2,700 to 48,000 PPM in most rocks and soils. Potassium occurs in most natural waters and is normally found as the potassium ion (K^+). Potassium concentrations in seawater are generally 390 PPM. Concentrations of potassium in ground water generally range from 1 to 20 PPM, but can exceed 120 PPM in an oil-field brine. Potassium concentrations in drinking water and ground water are not regulated. Potassium concentrations in ground water samples from the Redmond-Bear Creek Ground Water Management Area generally ranged from 1 to 12 PPM with the highest concentrations in wells screened in the Regional Aquifers. Potassium levels of 135 PPM were detected in well 64.

Silica. Silicon is the second most abundant element in the earth's crust (oxygen is the most abundant). Although the concentration of silicon in carbonates is usually low (less than 50,000 PPM) the general concentration of silicon in rocks and soils usually exceeds 200,000 PPM. Many minerals contain some silicon. Silicon occurs in most natural waters, usually as a form of dissolved silicic acid $Si(OH)_4$. By convention, dissolved silicon ions are represented as silica (the oxide, SiO_2). Concentrations of silica in natural water generally range from 1 to 30 PPM, although concentrations of 100 PPM are typical for some ground water systems. Elevated silica concentrations are usually associated with elevated ground water temperatures and silica-rich aquifer materials. Silica concentrations in drinking water and ground water are not regulated. Silica concentrations generally ranged from 11 to 58 PPM in ground water samples collected in the Redmond-Bear Creek Ground Water Management Area. Silica was detected at 300 PPM in the sample from well 64.

Sodium. Sodium is an essential nutrient common in rocks and soils. Sodium occurs in a wide variety of minerals ranging from silicates, such as feldspars, to evaporites, such as halite (NaCl, or common table salt). Sodium is found in most natural waters and generally occurs as the sodium ion (Na^+). Sodium concentrations in seawater are generally about 10,500 PPM. Concentrations of sodium in ground water vary widely, ranging from less than 1 PPM in some limestones to over 10,000 PPM in some brines. Sodium concentrations in drinking water and ground water are not regulated. Sodium concentrations ranged from 0.02 PPM to 130 PPM with the highest concentrations occurring in wells in the Regional Aquifers.

Total Hardness. Total hardness is a measure of the calcium and magnesium cations in water which form an insoluble precipitate with soap. In practice, the calcium and magnesium concentrations are measured, combined, and expressed as the equivalent concentration of calcium carbonate. (Note that this is not the same as simply adding and reporting the combined concentrations of calcium and magnesium). Therefore, the total hardness of a sample is proportional to its relative concentrations of calcium and magnesium. The actual hardness concentrations for the Redmond-Bear Creek Ground Water Management Area samples are meaningful only in relationship to each other. The total hardness of drinking water and ground water are not regulated. Total hardness of the ground water samples in the Redmond-Bear Creek Ground Water Management Area ranged from 31 to 128 mg/L as CaCO3, indicating soft to moderately hard water in most areas. The sample from well 64 had a hardness of 2,300 mg/L as CaCO3 and is considered very hard.

7.4.4 Additional Potential Contaminants

All ground water samples collected during the December 1989 sampling round were analyzed for total organic halogen. All ground water samples collected during the May 1990 sampling round were analyzed for total organic halogen except for the Doughty, Paradise Park, Kloepfer, Sharp, Thenos Dairy, King County Shops, and Campton Community wells. The Doughty, Bondo, Kloepfer, Sharp, Thenos Dairy, Olympian Precast, King County Shops, Campton Community wells, and Redmond Well 2 were sampled for cyanide, phenol, volatile organic compounds, semivolatile organic compounds, chlorinated pesticides, polychlorinated biphenyls, and several additional priority pollutant metals (antimony, beryllium, nickel, and thallium) during the May 1990 sampling.

Generally, the organic compounds detected with the total organic halogens, phenol, volatile organic compounds, and semivolatile organic compounds analyses do not occur naturally in ground water. The compounds detected with the cyanide, chlorinated pesticides, and polychlorinated biphenyls analyses do not occur naturally in water. The detection of any of these compounds may be indicative of ground water contamination.

Arsenic, cadmium, chromium, lead, mercury, selenium, and silver are priority pollutant metals which have been discussed in the Primary and Secondary Drinking Water Standards Analytes section above. The priority pollutant metals copper and zinc are secondary drinking water standard analytes which were discussed in the Ground Water Characterization Constituents section above. Antimony, beryllium, nickel, and thallium are discussed below. These metals can occur naturally in ground water and their presence does not necessarily indicate ground water contamination. The concentrations of these metals in ground water are not regulated by either Washington State or the federal government.

Total Organic Halogen. The total organic halogen analysis refers to compounds that contain the halogens chlorine, bromine, or iodine. The total organic halogen analytical method is used to estimate the total quantity of organic halogens in a sample. This analysis returns a total concentration of organic chloride, bromide, and iodide, but does not detect fluorinated organics. Compounds which contribute to the reported total include trihalomethanes, some halogenated organic solvents, chlorinated and brominated pesticides and herbicides, polychlorinated biphenyls, and several other halogenated volatile and semivolatile organic compounds. Since no halogenated organic compounds occur naturally in ground water, this analysis provides a relatively inexpensive screening tool which can be used to determine whether more expensive analyses for specific organic contaminants are warranted. However, if the natural ground water concentrations of inorganic halogens (such as chloroform, which is commonly produced by microorganisms in ground water) are high, then some of the inorganic halogens may be included in the total organic halogen value, giving a "false positive" result, or an overestimated total organic halogen concentration.

Concentrations of total organic halogen in ground water are not regulated as such. If total organic halogen are detected in ground water, then the sample source must be retested to determine which specific organic compounds are present and at what concentrations. Total organic halides were detected above the analytical detection limit in eight samples at concentrations ranging from 7 to 23 ppb.

Antimony. Antimony occurs naturally as a trace (0.2 to 0.5 PPM) constituent of rocks and soils, but also as an ore mineral. Little is known about the normal concentrations of antimony in ground water. Antimony concentrations in drinking water and ground water are not regulated. Antimony was not detected above the laboratory method reporting limit in any of the ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Beryllium. Beryllium is a rare element that occurs naturally in rocks and soils. The most important source of beryllium is the mineral beryl, a silicate compound that occurs in some igneous rocks. The solubility of beryllium is extremely low (in the ppb range), and few data on normal concentrations of beryllium in ground water exist. Beryllium concentrations in drinking water and ground water are not regulated. Beryllium was not detected above the laboratory method reporting limit in any of the ground water samples collected in the Redmond-Bear Creek Ground Water Management Area.

Chlorinated Pesticides. Chlorinated pesticides include a wide variety of compounds with widely varying physical, chemical, and biological properties. These compounds are created by chemical synthesis. Examples of chlorinated pesticides include DDD, DDE, DDT, chlordane, endrin, and toxaphene. Where data are available, chlorinated pesticides are usually considered potential human carcinogens. Although chlorinated pesticides usually have very low solubility in water, they tend to bioaccumulate. Because of the potential health concerns, the Washington State water quality standards for chlorinated pesticide concentrations in drinking water and ground water are generally less than 0.001 mg/L. These standards are set on a compound-by-compound basis. No chlorinated pesticides were detected in any of the ground water samples collected during this study.

Cyanide. Cyanides are a group of organic and inorganic compounds, which contain the cyanide ion. Although cyanides are produced by many natural metabolic processes in plants and animals (for instance, apple seeds contain low concentrations), they do not normally occur in rocks or soils. The most common and toxic form of cyanide is hydrogen cyanide gas that can dissolve in water. When low concentrations of cyanide are present in water, it tends to form insoluble metal compounds and, therefore, be removed from the water. At higher concentrations, however, cyanide forms soluble complexes with many cations (such as sodium, iron, gold, nickel, copper, or zinc). Because cyanide soluble complexes with many cations the "heap-leaching" process (where mined ore is washed with a cyanide solution) is effective at dissolving and recovering gold from ore. Cyanides do not occur naturally in ground water. When present, cyanides generally occur as either hydrogen cyanide gas or as the cyanide ion complexed with some cation (such as sodium or a metal). Cyanide concentrations are not regulated in drinking water and ground water. Cyanide was not detected above the laboratory method reporting limit in any of the ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Nickel. Nickel is a common metal that occurs naturally in rocks and soils. Economically viable nickel deposits are generally associated with igneous ores. Concentrations of nickel in ground water are generally low (less than 50 ppb). Nickel concentrations in drinking water and ground water are not regulated. Nickel was not detected above the laboratory method reporting limit in any of the ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Phenol. Phenol, or carbolic acid, is a benzene ring with one attached hydroxyl (OH^-) group that dissolves easily in water. Phenols occur naturally and are found in seawater at low (less than 2 ppb) concentrations. Little is known about the natural concentrations of phenol in ground water. Phenol concentrations are not regulated in drinking water and ground water. Phenol was not detected above the detection limit in any of the ground water samples from the Redmond-Bear Creek Ground Water Management Area submitted for analysis.

Polychlorinated Biphenyls. Polychlorinated biphenyls are a family of compounds with widely varying physical, chemical, and biological properties. These compounds are created by chemical synthesis and do not occur naturally. The name "polychlorinated biphenyls" refers to the basic chemical structure of the family where two phenyl groups are joined by a single bond and have varying numbers of chlorine atoms attached in various positions. About 100 of the possible 209 polychlorinated biphenyl compounds have actually been synthesized. Because of the variety of possible chemical structures, polychlorinated biphenyls have wide uses. Polychlorinated biphenyls are used as heat-transfer liquids in transformers, as insulators for electrical condensers, as additives in very high pressure lubricants, and to synthesize a variety of other compounds (such as epoxies and polyvinyl acetate). Normally, mixtures of polychlorinated biphenyls (called Aroclors) are utilized, rather than the individual polychlorinated biphenyls compounds.

Where data are available, polychlorinated biphenyls are considered potential human carcinogens. Although polychlorinated biphenyls (and, therefore, Aroclors) have very low solubility in water they tend to bioaccumulate. Because of the potential health concerns, the Washington State water quality standards for total polychlorinated biphenyls concentrations in drinking water and ground water are 0.00001 mg/L. Polychlorinated biphenyls were not detected in samples tested for these constituents.

Semivolatile Organic Compounds. Semivolatile organic compounds include a wide variety of compounds with varying physical, chemical, and biological properties. Although many of these compounds are created by chemical synthesis and do not occur naturally, some (such as the coal tar derivatives, including acenapthene, anthracene, fluorene, naphthalene, and other polycyclic aromatic hydrocarbons) occur in natural organic deposits such as coal, tar, and oil. Semivolatile organic compounds are widely used and occur in a wide variety of products including dyes, medications, mothballs, wood preservatives, and petroleum derivatives. Some semivolatile organic compounds are considered potential human carcinogens. Because of the potential health concerns, the Washington State water quality standards for semivolatile organic compounds concentrations in drinking water and ground water are generally less than 0.001 mg/L. These standards are set on a compound by compound basis. No semivolatile compounds were detected above the laboratory method reporting limit in the samples tested.

Thallium. Thallium occurs naturally in the earth's crust at concentrations around 1 PPM. Although thallium is soluble in most aquatic systems, there is little known about natural concentrations of thallium in ground water. Thallium concentrations in drinking water and ground water are not regulated. Thallium was not detected above the laboratory method reporting limit in any of the ground water samples from the Redmond-Bear Creek Ground Water Management Area.

Volatile Organic Compounds. Volatile organic compounds include numerous compounds with widely varying physical, chemical, and biological properties. Although many of these compounds are created by chemical synthesis and do not occur naturally, some (such as benzene) occur in natural organic (petroleum) deposits. Volatile organic compounds are widely used and occur in a wide variety of products including gasoline and other petroleum derivatives, medications, and solvents. Some volatile organic compounds are considered potential human carcinogens. Because of the potential health concerns, the Washington State water quality standards for volatile organic compound concentrations in drinking water and ground water are generally less than 0.001 mg/L. These standards are set on a compound-by-compound basis. Methylene chloride, carbon tetrachloride, and acetate were detected at very low levels in several samples. The specific significance of this is discussed below.

7.4.5 Summary of Results of Ground Water Quality Sampling

This section presents the analytical testing results for ground water samples collected from wells in the Redmond-Bear Creek Ground Water Management Area in December 1989 and May 1990. The results of all chemical analyses are presented in Table 7.12. The classification of each analyte and its maximum permissible concentration in drinking water (if any) are listed in Table 7.13.

7.5. Discussion of Water Quality

7.5.1 Primary and Secondary Drinking Water Standard Analytes

Ground water must meet all primary drinking water standards to be suitable for development as a drinking water supply. Ground water which meets primary, but does not meet secondary, drinking water standards can be developed as a drinking water supply, but the supply may be aesthetically unappealing. For example, water with elevated iron concentrations may be safe to drink, but can stain sinks and clothes and have an offensive flavor. The maximum acceptable concentrations for primary and secondary ground water standard constituents are presented in Table 7.13.

Ground water need not meet primary and secondary drinking water standards to be suitable for development as an irrigation, stock, or industrial water supply. The suitability of a ground water resource for any purpose other than drinking water supply depends on the nature and concentrations of its constituents and the proposed use of the resource. For example, ground water with elevated fluoride concentrations may be unfit for drinking but usable for industrial cooling purposes. Water, which is usable as drinking water but has elevated silica concentrations, may be unsuitable as an industrial cooling supply since the silica may foul the cooling system piping.

At least one sample from each of eight wells (Wells 1, 5, 12, 16, 29, 62) failed to meet the primary drinking water total coliform standard, a most probable number (MPN) of 1 total coliform bacterium per 100 milliliters of ground water. Total lead concentrations exceeded the primary drinking water standard, and total iron and manganese exceeded the secondary drinking water standard in well 12. Total arsenic, barium, chromium, mercury, and lead exceeded the primary drinking water standards, and total copper, iron, and manganese exceeded secondary drinking water standards for well 64. Ground water from all other wells sampled met the primary drinking water standards.

One ground water sample from well 14 did not meet the secondary drinking water standards for total dissolved solids, total iron, or total manganese. One or more of the ground water samples collected from wells 1, 3, 6, 10, 12, 14, 16, 20, 21, 27, 33, 35, 38, 40, 43, 51, 62, 64, 69, 73, 74 76, and 79 did not meet the secondary water quality standards for iron and/or manganese.

7.5.2 Chemicals Characteristic of the Ground Water

All samples were analyzed for selected ground water characteristic constituents. These constituents include major ions (i.e., ions which are normally found at PPM to percent concentrations), and minor ions (ions which are normally found at concentrations less than a few PPM). Piper diagram plots of major ions were used to type the ground water and to group similar types of ground water. Major ions analyzed include bicarbonate, calcium, carbonate, chloride, hydroxide, magnesium, potassium, sodium, and sulfate. Minor ions are used to confirm and/or subdivide ground water types. Minor ions that were analyzed include nitrite and silica. The major cation and anion concentrations, as well as some common minerals were also graphed according to distribution and occurrence in each of the four primary aquifer systems. In addition to the major and minor ions, arsenic, copper, lead, nitrate, iron, and manganese were evaluated and graphed.

In the Redmond-Bear Creek Ground Water Management Area, all sampled ground water is characterized as being a bicarbonate type. Samples from wells 4, 5, 34, 61, and 62, have relatively elevated sulfate concentrations (see Figure 7.44). Samples from wells 14 and 16, which are located in the Sammamish River valley, have relatively elevated sodium concentrations (see Figure 7.45). These samples also have relatively high total bicarbonate and total sodium concentrations (see Figures 7.44 and 7.45). Typically, concentrations of arsenic, copper, lead, iron, and manganese appear to be relatively uniform in all four aquifer systems (Figures 7.46 through 7.49). Although elevated levels of iron and manganese occur in well 74 in the Sea Level Aquifers and well 16 in the deep aquifer, other wells in these aquifers do not show significantly higher levels of those minerals. Nitrate concentrations (Figure 7.50) do appear to be higher in the Alluvial and Upland Aquifers; this is expected since these aquifers are generally closer to the surface and at greater risk from land use activities such as septic tank drainfields, residential fertilizing, and agricultural practices.

Of the minor ions reviewed (Figures 7.50 and 7.51) no trends in analyte distribution or aquifer association were apparent. Most of the water sampled can be characterized as bicarbonate type waters. Figure 7.52, shows a plot of selected water quality data presented in a trilinear diagram developed by Piper (1944). The diagram is a plot of the normalized major ion concentrations, in millequilivents per liter, expressed as percentages of the total ion concentration. Figures 7.53 through 7.56 are plots of the ground water chemistry data segregated into aquifer groups; Alluvial Aquifers, Local Upland Aquifers, Sea Level Aquifers, and Regional Aquifers, respectively.

Data for the Alluvial Aquifer (Figure 7.53) were plotted in two groups. The smaller group consists of data for wells 51, 61, and 62. This group has anion levels higher in percentage sulfate and lower in percentage alkalinity than the larger group. Anion data for the smaller group plotted in the HCO_3-SO_4-Cl, mixed anion type field. These anion data are the only data collected for this study to plot outside the bicarbonate type field. The cation data plotted in the Ca-Mg-Na+K, mixed cation type field.

Local Upland Aquifer data were plotted in a single group (Figure 7.54). The waters can be characterized as mixed cation and magnesium type and bicarbonate type.

Sea Level Aquifer data were plotted in two groups (Figure 7.55) The smaller group consists of data for wells 27 and 29. Water from the smaller group can be characterized as sodium-bicarbonate type, whereas waters from the larger group can be characterized as calcium-mixed cation types and bicarbonate type. The difference in the two groups is distinguished by the level of percentage sodium. Waters from the smaller group are higher in percentage sodium and lower in percentage of other major cations.

Data from the Regional Aquifer were plotted in two groups (Figure 7.56). The smaller group is composed of wells 14 and 16. Data from these two wells plotted in the sodium plus potassium apex of the cation triangle. The larger group of wells plotted in the mixed cation-calcium fields.

Figure 7.52 is an overlay of all the data on one trilinear diagram. Generally, the anion data overlap the ranges in the bicarbonate field. The exception is the small group from the Alluvial Aquifers. Although the differences between the aquifer groups are small, a general trend can be seen. The trend starts with the small group of the Alluvial Aquifers in the Ca+Mg-Cl+SO_4 field, then progressing to the Ca+Mg-HCO_3 field where most of the data plot. The data trend then crosses into the HCO_3+CO_3 field and progresses towards the sodium apex. The cause of the trend is unclear, but may represent the geochemical evolution from the Alluvial Aquifers to the Regional Aquifers. The data are plotted as relative percentage, so differences in absolute concentration will be overlooked with this diagram.

7.5.3 Additional Potential Contaminants

Total organic halogen was reported at concentrations ranging from 7 to 23 μg/l for one or more of the ground water samples collected from the Kloepfer, Sharp, Thenos Dairy, Goss, King County Shops, Cedar Lawns, Campton Community wells, and Evans Creek Well 1. Total organic halogen was reported at 8 μg/l in the December 1989 sample and was not detected at or exceeding 5 μg/l in the May 1990 sample from Redmond Well 5.

Methylene chloride was reported in several samples. Since the laboratory method blank(s) associated with every sample reported methylene chloride, and the concentrations of methylene chloride reported in the laboratory method blanks are similar to the concentrations reported in the associated samples, all occurrences of methylene chloride in these samples are assumed to be a result of laboratory contamination. Acetone was reported at 0.0207 mg/l in the May 1990 sample, and carbon tetrachloride was reported at 0.0016 mg/l in the duplicate from the King County Shops well. Since each compound was detected in only one of the duplicated samples, the detection of these compounds probably reflects laboratory error or laboratory contamination of the sample rather than ground water contamination. Acetone is not a regulated ground water contaminant. The concentration of carbon tetrachloride reported for the duplicate King County Shops sample is less than the National Drinking Water Standard of 0.005 mg/l, but exceeds the Washington State Drinking Water standard of 0.0003 mg/l. No other volatile organic compounds, pesticides, polychlorinated biphenyls, or semivolatile organic compounds were detected in the analyzed samples.

7.6 Conclusions

Precipitation

The Redmond-Bear Creek watershed receives an average of 42 inches of rainfall annually. The precipitation varies seasonally with approximately 75 percent of the annual precipitation falling between October and March with January having the greatest amount of precipitation. Precipitation decreases sharply in summer with the least precipitation occurring in September.

Rainfall is usually greatest at the higher elevations along the western boundary of the Redmond-Bear Creek Ground Water Management Area and lowest in the lower Bear Creek Valley around the cities of Redmond and Woodinville. However, at some weather stations no data were available for certain months for various reasons. These locations could have automatic rain gauge data loggers installed.

Stream Gauges

Seasonal variations in stream flow appear to correspond to changes in precipitation and are generally characterized by high flows in winter and spring and low flows in summer and fall. Baseflow along Evans Creek, (indicating ground water discharge) ranged from 5 cubic feet per second upstream to 25 cubic feet per second downstream. Stream flow varied in the creeks from 5 cubic feet per second to 1,332 cubic feet per second.

Resistivity Study

Five geophysical cross sections were developed using well logs, surficial geologic data, and geophysics to identify apparent resistivity patterns and corresponding geologic information. The sections show a mixture of fine to coarse grain soil units, which range from clay to gravel. These are not discrete units of clay or gravel but mixtures of each material type with the resistivity indicating the predominant grain-size present. Bedrock was also interpreted to exist at depth.

Monitoring Wells

Five test wells were completed to collect stratigraphic and hydrologic data for characterization of subsurface conditions and evaluation of ground water potential. Of the five wells drilled, two wells had a moderately permeable aquifer; one well had a significantly permeable aquifer; one well had an upper water bearing zone where the City of Redmond water supply is withdrawn; and the remaining well had no significant water bearing zone.

Water Level Monitoring

Water levels were monitored periodically in 81 wells between 1989 and 1991. Although the data was useful to develop ground water flow maps and document seasonal variations, the time period was to short to identify any long-term trends.

Water Quality

The ground water samples collected from the Redmond-Bear Creek Ground Water Management Area generally met all primary and secondary state and federal drinking water standards. Several wells did not meet the primary water quality standards for coliform. These wells penetrate different aquifers in different parts of the study area, indicating microbial contamination problems are restricted to individual wells, and there is no general microbial contamination of ground water in the Redmond-Bear Creek Ground Water Management Area. The Sharp well failed to meet the primary state drinking water standards for coliform and lead, and the secondary drinking water standards for iron and manganese. The source of the metals in the Sharp water samples may be the water supply piping system rather than the ground water.

Many wells in the Redmond-Bear Creek Ground Water Management Area do not meet state secondary (aesthetic) drinking water standards for total dissolved solids, iron, and manganese. Although this does not impact consumer health, these water supplies are less desirable and their industrial use may be restricted.

Although total organic halogen was reported at detectable levels for several wells, no specific organic contaminants were confirmed by resampling. It is possible acetone and carbon tetrachloride occurs in groundwater samples from the King County Shops well. However, since these compounds were present only in low concentrations and only in one of two duplicated samples, their presence in ground water has not been confirmed. The methylene chloride detected in several samples is likely due to laboratory contamination and does not reflect contamination of the ground water supply. No other organic contaminants were detected in ground water samples, however, the King County Shops well should be resampled to confirm the absence of organic contaminants. Ground water samples collected in the Redmond-Bear Creek Ground Water Management Area is generally free from the organic compounds tested.

7.7 Post Data Collection and Analysis Activities

Since completion of data collection and analysis activities for the Redmond-Bear Creek Ground Water Management Study, a number of additional hydrogeologic related studies have been completed on the Novelty/Union Hill plateau. These studies have focused on two related issues:

- characterization and protection of the Union Hill Water Association aquifer; and
- potential impacts to water quality and quantity from two proposed urban planned developments.

Many reports and studies have been done for the Novelty/Union Hill plateau area. Documents that are available for review are listed in Appendix M.

Most of the studies performed for the urban planned developments have focused on characterizing the shallow (< 50 feet) subsurface soil and ground water conditions. New hydrogeologic data collection activities have included test pits, surface soil mapping, installation of shallow monitoring wells and piezometers, limited water level monitoring, and water quality testing. In November of 1995, AESI drilled four additional borings on the Northridge site (ranging from 122 to 182 feet deep) which penetrated through the Vashon Advance aquifer, through the underlying aquitard and, in some cases, into a lower water bearing unit. Monitoring wells were completed in these borings and data loggers were installed. The studies have also used existing information (including the Carr resistivity data) to develop a conceptual model of deeper hydrogeologic conditions on the plateau, including aquifer occurrence, stratigraphic correlations and ground water flow patterns. In addition, AESI used the data to construct a MODFLOW model. The studies have provided a more accurate understanding of the occurrence and thickness of the upper geologic units (Vashon till, Vashon advance outwash, and the aquitard underlying the advance unit) and ground water flow within these units, primarily within the boundaries of the urban planned developments.

The Union Hill Water Association completed an aquifer characterization and protection study in 1993. The study included drilling and testing of two new water supply production wells. Well 2, located about 1200 feet southwest of Union Hills existing supply well 1 (well 73 on Figure 7.8), was 220 feet deep and completed at an elevation just below sea level. Well 3, located about 7800 feet northeast of Union Hill well 1, was drilled 490 feet and completed at an elevation just above sea level. In addition to the new wells, electrical resistivity testing was performed to characterize subsurface stratigraphy beneath the plateau south of Novelty Hill road. A report prepared by Carr/Associates Inc. (January 11, 1993) documents the resistivity testing methodology and interpreted results. The resistivity testing data provides some support to the idea of a water bearing zone between sea level and an elevation of about 200 feet elevation on the plateau. It also suggests that an area of relatively permeable material between elevation 300 and 500 feet just south of Novelty Hill road may be a potential recharge area for deeper aquifers. The approximate extent of this recharge area, estimated by EMCON during their review of Carr/Associates Inc. (January 11, 1993) report, is illustrated in Figure 7.57. Until deep wells are installed in this recharge area, the resistivity data provide the best indication of deep subsurface conditions.

In response to Washington State Department of Health requirements for public water supply wells (Chapter 246-290 WAC), Union Hill also delineated their wellhead protection area. A wellhead protection area defines the area around well where surface land use activities, precipitation, or ground water use could impact the water quality or quantity of the public well. Figure 7.58 shows the proposed wellhead protection area for the three Union Hill wells as determined in the 1993 Carr/Associates report. The wellhead protection area is based on 1993 data. The actual size of the wellhead protection area could be larger or smaller depending on the specific aquifer conditions that were not well understood at that time.

8.0. WATER BALANCE

The availability of ground water in the unconsolidated deposits (shallow aquifers) of the RBC GWMA was estimated by evaluating the quantity of ground water recharged or introduced into the area and the quantity of water used or discharged from the area. In other words, the change in ground water storage was calculated by estimating the quantities of water lost or gained through natural or human processes.

Ground water recharge occurs from ground water flowing into the area via subsurface flow, surface water leakage, infiltration of precipitation, recycled water following human use (i.e., wastewater discharge), and vertical flow from underlying water bearing units. Water loss from the area occurs through subsurface flow out of the area, discharge to streams or springs, evapotranspiration, stormwater runoff, and human consumption. Many of the parameters in a hydrologic budget can be measured directly: precipitation, stream flow, and transported water. Ground water inflow and outflow are determined from the hydraulic characteristics of the aquifer (conductivity and gradient). The water balance can be expressed in the form of a simple equation:

> Ground Water Recharge = (precipitation + surface water inflow + imported water + ground water inflow) - (evapotranspiration + surface water outflow + exported water + ground water outflow)

The methods used to evaluate the change in storage parameters for the Redmond-Bear Creek Ground Water Management Area are described below.

8.1 Surface Area

The area investigated in the evaluation of the basin storage calculations is the area of the Redmond-Bear Creek Ground Water Management Area underlain by the shallow unconsolidated aquifers. This area is termed the Uppermost Aquifer Areas. The surface area of the Uppermost Aquifer Area is approximately 50 square miles.

8.2 Ground Water Discharge

Ground water discharges (losses) from the Uppermost Aquifer Area include ground water extraction for municipal purposes, loss of ground water to streams, ground water transpired from phreatophytes (plants whose roots tap into the saturated zone), and ground water discharged to underlying aquifers. The quantity of water transpired by phreatophytes is unknown and is not factored into the storage calculation. The quantity of ground water discharged to underlying units is incorporated via the ground water flux calculations (refer to the Ground Water Flux section below).

Ground Water Extraction - City of Redmond

Ground water consumption rates for the City of Redmond were obtained from the City of Redmond draft water system plan (CH2M Hill, 1990). The entire ground water supply is currently being extracted from the shallow uppermost aquifers. Based on this data, the average daily demand from the unconsolidated aquifers is an estimated 4,000 acre-feet per year (3.61 MGD) and the per capita use is 0.12 acre-feet per year (107 gallons per day).

Ground Water Extraction - Rural Area Use

The per capita water consumption for the population outside the City of Redmond and within the Uppermost Aquifer Area was estimated based on the per capita use within the city (0.3 acre-feet/capita/year). The population in the Uppermost Aquifer Area was based on population data supplied by the local community plans that estimated 12,000 persons outside the urban centers.

If each person in the rural area of the Uppermost Aquifer Area extracted 0.12 acre-feet/year from the unconsolidated aquifer, then 1,440 acre-feet/year would be used. This value is unrealistic because a portion of the ground water is extracted from aquifers below the Uppermost Aquifers or receives water from outside the study area (City of Seattle). For the purposes of this storage calculation, it was assumed that one-quarter of the population uses ground water from the unconsolidated aquifer (3,000 people); although the actual number is not known. Therefore, it is assumed that a 360 acre-feet/year of ground water is extracted from the unconsolidated aquifer for human use in the rural area.

Water Loss to Streams

The Redmond-Bear Creek Ground Water Management Area contains a number of large streams that flow year-around. Most of these streams originate in the Redmond-Bear Creek Ground Water Management Area. Eventually, all streams discharge into Evans Creek, which discharges into the Sammamish River. For purposes of this water budget, gauging measurements taken at Station 5 on Evans Creek were used to estimate losses to surface water. In 1990, an average flow of 50 cubic feet per second (35,000 acre-feet/year) was estimated for Station 5 on Evans Creek.

Evapotranspiration

Evapotranspiration is the total loss of water from the soil as a result of evaporation from the soil and transpiration from the growing crop or vegetation. Evaporation due to residential/commercial watering and crop irrigation, based on an estimate by the Natural Resources Conservation Service, 24 inches of actual evapotranspiration annually in the Seattle area. The amount of water transpired by plants depends on such factors as the plant type, moisture supply, heat available, and the temperature of the air surrounding the plant; 24 inches per year is, therefore, a rough estimate of the evapotranspiration. Actual evapotranspiration is defined as the computed amount of water lost under existing conditions of temperature and precipitation. Therefore, 64,000 acre-feet/year is calculated into the storage formula as a ground water loss due to evapotranspiration.

Surface Runoff

The amount of surface runoff directly affects the quantity of water recharged to the aquifer. Overland flow occurs when water drains across the land into stream channels. Overland flow may occur during precipitation events and from irrigation when surface soils are saturated or frozen impacting downward movement. For convenience, the quantity of water tallied as runoff in these storage calculations is listed as ground water loss. This number could just as easily be subtracted directly from the values calculated from precipitation and irrigation output.

Mean annual runoff from the precipitation events was calculated using published mean annual runoff data from the Soil Conservation Service (1972). The quantity of water lost to runoff based on the published data of 5 inches of runoff annually over the Uppermost Aquifer Area, is 13,300 acre-feet per year.

8.3 Ground Water Recharge

The unconsolidated aquifers are recharged by direct infiltration from precipitation, septic systems, and ground water recharge through underlying hydrostratigraphic units. Sources of ground water recharge contributing to the unconsolidated aquifer are discussed below. Ground water recharge from underlying hydrostratigraphic units was not calculated specifically, but is incorporated in the ground water flux calculations.

Precipitation

Average annual precipitation data from the National Oceanographic and Atmospheric Administration (NOAA) was used to determine the average precipitation that falls over the Redmond-Bear Creek Ground Water Management Area. Based on an average of 42 inches of precipitation each year, estimated average annual precipitation over the Redmond-Bear Creek Ground Water Management Area is approximately 112,000 acre-feet/year.

Wastewater Infiltration

In the rural areas not serviced by the city sewage treatment system, the quantity of effluent generated for each person is based on the daily quantity of effluent generated by each person in the city (approximately 109 gallons per person). It is assumed that all outlying areas are serviced by septic systems, no effluent is lost to evapotranspiration, and all effluent recharges the unconsolidated aquifer system. Using a rural population of 12,000 people (see Ground Water Extraction - Rural Area Use section above) the total recharge from wastewater in the GWMA to the unconsolidated aquifer is 1,465 acre-feet per year.

8.4 <u>Ground Water Flux</u>

Ground water flux is an approximation of the transient ground water flow in a region. Ground water flux calculations interpret the quantity of ground water that flows into and out of the region. The flux in a region will change based on the aquifer thickness, hydraulic gradient, and quantities of ground water extracted and recharged from/to the aquifer. This approach assumes there are currently no net losses or gains in ground water in the system.

In the Redmond-Bear Creek Ground Water Management Area, difficulties in evaluating the quantity of ground water flowing through the region include an unknown contribution from lower aquifers. To compensate for this difficulty, the flux out of the area was evaluated in the southern portion of the Redmond-Bear Creek Ground Water Management Area and the flux into the area was calculated as the difference of the sum of all recharge and discharge parameters evaluated in the storage calculation. This method of calculation assumes that the ground water budget is equal to zero (input equals output), and accounts for non-calculable parameters such as discharge and recharge from/to the underlying aquifers.

Flux Out

Ground water flow out of the unconsolidated aquifer was evaluated using a cross-section of the southern portion of the Redmond-Bear Creek Ground Water Management Area. The ground water flow through the cross-sectional area was calculated using (1) the area between the water table and the underlying confining unit, (2) the hydraulic gradient in the vicinity of the section, and (3) the hydraulic conductivity.

A hydraulic conductivity of 147 feet per day was used in the calculations. This value is the geometric mean of three hydraulic conductivities determined in pumping tests conducted in three wells in the study area. The use of a single value does not account for variations in occurrence or distribution of facies comprising the glaciofluvial deposits of the study area.

The estimated quantity of ground water that flows out of the area at the south was calculated to be 1,626 acre-feet per year.

Flux In

The flux into the Redmond-Bear Creek Ground Water Management Area was calculated as the difference between the recharges and discharges to the aquifer. The sums of the recharges and discharges to/from the aquifer are 113,465 acre-feet/year and 118,286 acre-feet/year, respectively. Based on these values, the flux into the Redmond-Bear Creek Ground Water Management Area is 4,821 acre-feet/year.

8.5 Hydrologic Budget

The hydrologic budget for the area was determined assuming that the net change in the basin's ground water storage in the uppermost aquifer is equal to zero. Based on this assumption, the quantity of ground water lost and gained from the aquifer each year is approximately 118,286 acre-feet (see Table 8.1).

Based on the calculations presented above, a minimal quantity of ground water is available in the Uppermost Aquifers for additional development. Potentially available quantities of ground water include ground water flowing out of the study area via subsurface flow and ground water loss to surface water. Ground water flowing out of the area via subsurface flow accounts for a total of 1,626 acre-feet per year. It should be assumed that it is not safe to extract this total volume of water because some quantity is required to recharge deeper aquifer zones. All ground water discharged to surface water is not available for use because some portion is required to maintain a minimum base-flow to protect fisheries and wildlife in streams and protect downstream senior surface water rights.

Assuming average rainfall and that only 50 percent of the water flowing out of the study area is available for use, an estimated 813 acre-feet/year (0.725 MGD) of ground water would be available for new development. Based on these figures, and until additional data can be obtained to refine the ground water budget, it may not be prudent to develop significant new water sources in the Redmond-Bear Creek Ground Water Management Area. Since the hydrologic budget for the Redmond-Bear Creek Ground Water Management Area is based predominately on data collected through indirect sources (e.g., census data to estimate ground water consumption rates) or data that represents a snapshot in time (e.g., stream flow measurements), the calculated recharge/discharge values should be viewed as estimates only. It is imperative that future data collection efforts attempt to refine the hydrologic budget with more accurate and refined data. Therefore, until further data are available, the only safe alternatives for acquiring additional water sources are trading existing water sources (such as water rights) or implementing water conservation measures.

9.0 RECOMMENDATIONS

The Redmond-Bear Creek study has provided a framework for future protection and management of the ground water resource. This framework consists of new data collected over a 3-year period and an evaluation of existing data. Much of the new data collected for this study represents the first attempt to characterize the complex geologic and hydrologic conditions in the study area. This data, while sufficient to use for initial development of various ground water protection and management strategies, also identified many gaps and questions which require more data in order to be answered. The following recommendations summarize the future data collection activities needed to fill in gaps or help in development of long-term ground water protection strategies.

1) Long term water level data needs to be collected throughout the study area in all aquifer zones. Water levels should be collected twice a year (summer and winter) to evaluate fluctuations and trends. New monitoring wells should be surveyed for vertical elevation control.

2) Ground water chemistry data is virtually non-existent except in municipal and water district wells. A representative number of wells sampled for the RBC study should continue to be monitored at least annually. Efforts should focus on the shallow, uppermost aquifer zones if there is insufficient resources to monitor all zones.

3) Hydrostratigraphic information is very limited for parts of the basin, particularly along Avondale road and Cottage Lake. Additional test wells should be drilled in these areas to evaluate geologic and ground water conditions. Since all of this area is served by septic systems, an understanding of the subsurface conditions is critical to evaluating aquifer vulnerability.

4) In the area north of NE 116 St., depth and configuration of aquifers, aquitards, and aquicludes is largely unknown. Geophysical investigation should be integrated into a test well drilling program.

5) In order to develop an accurate water balance for the Redmond-Bear Creek Ground Water Management Area, additional stream gauging, precipitation, evapotranspiration, and water use data must be collected. Stream gauging needs to be accomplished at 2 locations (upper and lower reaches) of each continuous flowing stream. Gauging should also be done where two streams intersect and where Bear Creek and Daniel Creek enter the north end of the study area. The gauging should be done hourly for at least 10-15 years, or permanently.

6) Precipitation data should continue to be collected in Redmond, Woodinville, Sahalee, and Novelty Hill. An evapotranspiration station should be established, probably in Redmond.

7) The number and distribution of domestic wells should be determined. This would show areas most vulnerable to a reduction in ground water quality and quantity. Much of this work could be accomplished through use of assessor records (location and well existence) and correlation with existing well logs.

8) To better estimate future ground water use potential and to supply input into any numerical computer models, aquifer parameters such as hydraulic conductivity and transmissivity should be estimated for the various aquifer zones. This should be accomplished through pump testing of existing and new test wells. Pumping tests should be done for a minimum of 24 hours and up to 72 hours if possible. Again, priority should be given to the shallow aquifer zones in the valley and upland areas.

9) An aquifer vulnerability assessment that integrates physical susceptibility and land use activities would be useful for long term ground water protection planning. Specific information that would be needed includes land use zoning, septic tank density, underground storage tanks, transportation corridors, beneficial use of ground water, and known contamination sites.

The following recommendations were made as a result of EMCON's review of additional hydrogeologic information from *The Characterization and Protection of the Union Hill Aquifer System*, Carr/Associates, January 11, 1993. It is important to realize that proposed changes in land use activities on the Novelty/Union Hill Plateau could significantly impact both water quality and quantity. To improve the knowledge of ground water conditions on the Novelty/Union Hill Plateau and provide for a technically based evaluation of future potential land use impacts EMCON recommends that future collection activities should include:

- Drilling and installation of at least three deep monitoring wells to the elevation of sea level;
- Perform aquifer pump tests on at least 2 of the new deep monitoring wells (minimum 72 hour);
- Drill and install three to four additional shallow and intermediate depth monitoring wells;
- Perform aquifer pump test on two intermediate and two shallow depth monitoring wells;
- Drill and install two or three nested wells in the upland areas to evaluate vertical gradients in suspected recharge areas; and
- Develop a long-term ground water quality and water level monitoring network using both domestic and test wells.

Since the Union Hill Study was performed, additional information for the UPD sites became available. AGI Technologies prepared the *Review of Northridge Urban Planned Development (UPD) Draft Environmental Impact Statement King County Department of Development and Environmental Services, May 1995*, in July 7, 1995.
This report included a review of the groundwater section and Appendices B and E of the DEIS. The Review recommended that the following additional information be collected:

- Logs from drilling three deep (500 foot) monitoring wells on Northridge property;
- Detailed records of pumping tests conducted on one or more of the test wells, including water level interference between wells;
- Water level monitoring records from each aquifer, to be continued through build-out of the proposed project; and
- Water quality monitoring data for each aquifer, to be continued through build-out of the proposed project.

Subsequent to AGI Technologies review of the DEIS for the Northridge UPD, Associated Earth Sciences, Inc. prepared the *Hydrogeologic Impacts and Mitigation Evaluation, Northridge UPD, King County, Washington*, for the Quadrant Corporation in December 1995. The intent of this report was to better delineate the Vashon Advance Aquifer and underlying aquitard, provide a more detailed analysis of potential impacts of development to static ground water levels, and evaluate the effectiveness of proposed mitigation.

Four observation wells were drilled on the site in November 1995, terminating at depths ranging from 122 to 182 feet below ground surface. The information obtained was used to update their earlier report on geologic and hydrogeologic conditions, to refine their three dimensional ground water model of the effects of development on the ground water system beneath the site, and to identify potential impacts to ground water levels.

The information from this latest study addresses part of one of the 1993 EMCON and AGI recommended data collection items, to drill and install three additional shallow depth monitoring wells. However, the 1995 study did not include any deep wells. Other recommendations made by EMCON and AGI for data collection may be met by the monitoring plans required for the UPDs, with the exception of drilling and testing of deeper aquifer units. In response to King County's requirements for ground water quantity and quality monitoring, the consultants for the Northridge UPD proposed a draft monitoring plan (March 1996) which includes:

1. Groundwater Quality Monitoring
    a) Water quality in the shallow (Vashon Advance) aquifer will be monitored at five locations (a sixth point may be identified following further review).
    b) Nitrate and nitrite-nitrogen will be measured in ground water as an indicator of water quality degradation, and fecal coliforms will be measured as the most direct groundwater quality threat.
    c) Elevated levels of either nitrate, nitrite-nitrogen or fecal coliforms will trigger sampling for contaminants typical of stormwater runoff (total

phosphorous, soluble reactive phosphorus, total suspended solids, total nitrogen, ammonia, and water acidity).

d) Quarterly sampling for Nitrate and Nitrite-nitrogen and fecal coliforms.

2. Groundwater Quantity Monitoring

a) Monitoring of water levels in the shallow (Vashon advanced) aquifer to assess baseline conditions and subsequent impacts of the infiltration facilities.

b) Water level deviations from baseline conditions of 1.5 times or greater will be considered significant and initiate additional investigation (including assessment of rainfall records and impacts on water levels in shallow wells in the area).

The GWAC considered the recommendations under Section 9 when formulating the Data Collection List. The GWAC ranked the recommendations (high, medium, and low) according to their importance to groundwater management. The Data Collection and Management Program provides for including additional information, such as from these studies, in the database for the groundwater program. (The Redmond DCMP Data Collection List is available upon request).

References

Redmond-Bear Creek Valley
Ground Water Management Plan

February 1999

10.0 REFERENCES

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Glossary

Redmond-Bear Creek Valley Ground Water Management Plan

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11.0 GLOSSARY

ALLUVIAL. Pertaining to or composed of alluvium or deposited by a stream or running water.

ALLUVIUM. A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope.

AQUIFER. A soil or geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.

AQUIFER SYSTEM. A body of permeable and relatively impermeable materials that functions regionally as a water-yielding unit. It comprises two or more permeable units separate at least locally by confining units that impede ground-water movement but do not greatly affect the regional hydraulic continuity of the system. The permeable materials can include both saturated and unsaturated sections.

AQUIFER TEST. A test involving the withdrawal of measured quantities of water from or addition of water to a well, and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition, e.g., a bailer or pump test. (These are withdrawal tests)

AQUITARD. An essentially impermeable geologic formation, group of formations, or part of a formation through which virtually no water moves.

AREA OF INFLUENCE. Area surrounding a pumping well within which the water table or potentiometric surface has been changed due to the well's pumping or recharge.

ARTESIAN WELL. A well deriving its water from a confined aquifer in which the hydraulic water level stands above the ground surface; synonymous with flowing artesian well.

ATTENUATION. The general process of reducing the amount and concentration of contaminants in water. Includes physical, chemical and biological processes as well as dilution.

BASALT. A general term for dark-colored iron- and magnesium-rich igneous rocks. It is the principal rock type making up the ocean floor and is easily seen in exposed cliffs in Eastern Washington.

BASE FLOW. That part of stream discharge not attributable to direct runoff from precipitation or snowmelt, usually sustained by ground-water discharge.

BEDROCK. A general term for the rock, usually solid, that underlies soil or other unconsolidated material.

BENTONITE. A colloidal clay, largely made up of the mineral sodium montmorillonite, [a hydrated aluminum silicate] used in sealing the annular space to create a surface or sanitary seal.

CAPILLARY ACTION. The movement of water within the interstices of a porous medium due to the forces of adhesion, cohesion, and surface tension acting in a liquid that is in contact with a solid.

CAPILLARY FRINGE. The zone at the bottom of the vadose zone where groundwater is drawn upward by capillary force.

CARBONATE. A sediment formed by the organic of inorganic precipitation from aqueous solution of carbonates of calcium, magnesium, or iron.

CHLORIDE. A compound of chlorine with one other positive element or radical.

CLEAN WATER ACT. Basic federal legislation regulating surface water quality.

COLIFORM BACTERIA. Bacteria (*E. coli*) associated with human and warm-blooded animal waste.

CONE OF DEPRESSION. A depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a well from which water is being withdrawn. It defines the area of influence of a well.

CONFINED AQUIFER. A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

CONFINING BED. A geologic unit with low permeability (hydraulic conductivity) which restricts movement of water into or out of the aquifer. See also aquiclude, aquitard.

CONTAMINATION. The degradation of natural water quality as a result of anthropogenic activities.

CROSS-SECTION. A schematic representation of geologic layers as seen in a side view.

DISCHARGE. Ground water that flows out of an aquifer into an adjacent aquifer or to the surface into a spring or river.

DISCHARGE AREA. An area in which there are upward components of hydraulic head in the aquifer. In the discharge area ground water flows toward the surface, and may escape as a spring, seep, or base flow, or by evaporation and transpiration.

DISPERSION. The spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

DRAINAGE BASIN. The land area from which surface runoff drains into a stream channel or system of channels, or to a lake, reservoir, or other body of water.

DRAWDOWN. The distance between the static water level and the top surface of the cone of depression during pumping of a well.

DRILLERS LOG. A record of the geologic and aquifer conditions encountered by a driller during drilling of a water supply well. The State of Washington requires that a log be completed for each well.

DRINKING WATER STANDARDS. Federal or state water quality regulations that limit the contaminant levels of certain compounds for drinking water.

DYNAMIC EQUILIBRIUM. A condition of which the amount of recharge to an aquifer equals the amount of natural discharge.

EFFLUENT. Liquid waste discharged from a manufacturing or treatment process, in its natural state or partially or completely treated, that discharges into the environment.

EROSION. The general process or group of processes whereby the materials of the Earth's crust are moved from one place to another by running water (including rainfall), waves and currents, glacier ice, or wind.

EVAPOTRANSPIRATION. Loss of water from a land area through transpiration of plants and evaporation from the soil.

FLOODPLAIN. The surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river and covered with water when the river overflows its banks. It is built of alluvium carried by the river during floods and deposited in the sluggish water beyond the influence of the swiftest current.

FLOW LINES. On a hydraulic gradient diagram, the lines indicating the direction followed by groundwater toward points of discharge. Flow lines are perpendicular to equipotential lines.

FLOW RATE. The volume of flow per time (e.g., gallons per minute).

FLOWING ARTESIAN WELLS. Wells which tap confined aquifers which flow at ground surface without the necessity of pumping.

GEOLOGIC MAP. A map showing the aerial distribution of geologic units and the altitude or structure of those units.

GLACIAL DRIFT. A general term for unconsolidated sediment transported by glaciers and deposited directly on land or in the sea.

GLACIOFLUVIAL. Pertaining to the meltwater streams flowing from melting glacier ice and especially to the deposits and landforms produced by such streams.

GLACIOLACUSTRINE. Deposits created in lake environments from glacial silts and clays.

GROUND WATER. All water that is located below the ground surface; more specifically, subsurface water below the water table.

GROUND WATER DIVIDE. A ridge in the water table, or potentiometric surface, from which ground water moves away at right angles in both directions.

GROUND WATER MODEL. A simplified conceptual or mathematical image of a ground-water system, describing the feature essential to the purpose for which the model was developed and including various assumptions pertinent to the system. Mathematical ground-water models can include numerical and analytical models.

GROUND WATER TABLE. The surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

HARDNESS. A property of water causing formation of an insoluble residue when the water is used with soap. It is primarily caused by calcium and magnesium ions.

HAZARDOUS WASTE. Regulated waste that is ignitable, corrosive, reactive, or toxic.

HYDRAULIC CONDUCTIVITY. The rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature (gpd/ft).

HYDRAULIC CONNECTION. The condition in which two water-bearing layers or bodies may freely transmit water between them.

HYDROGEOLOGIC. Those factors that deal with subsurface waters and related geologic aspects of surface water.

HYDROLOGIC CYCLE. The cyclical movement of water from the oceans to atmosphere to the land and back to the oceans.

HYDROSPHERE. All waters of the Earth, as distinguished from the rocks (lithosphere), living things (biosphere), and the air (atmosphere).

HYDROSTRATIGRAPHY. The assemblage of layers of aquifers and aquitards.

IGNEOUS. A type of rock solidified from molten material.

IMPERMEABLE. An adjective used to describe rock, soils, or sediments that impede the flow of water.

INFILTRATION. The downward movement of rain water or surface water into soil.

LACUSTRINE. Referring to a lake environment.

LAMINATED. The layering or thin bedding in sedimentary rocks.

LANDFILL. A general term indicating a disposal site of refuse, and dirt from excavations.

LEACHATE. The liquid that has percolated through solid waste and dissolved soluble components.

MAXIMUM CONTAMINANT LEVEL (MCL). The maximum permissible level as required by the Safe Drinking Water Act regulations, of a contaminant in water that is delivered to the users of a public water system.

METAMORPHIC. A rock that has been physically and/or chemically changed from an original texture and/or composition, usually by very high temperatures or pressures below the earth's surface.

MG/L. Milligrams per liter; a unit of concentration in water equivalent to a part per million or 0.0001 percent.

MICROORGANISMS. Microscopic organisms such as any of the bacteria, protozoans, or viruses.

NITRATE. A compound commonly associated with domestic and agricultural waste, and formed by nitrogen.

OUTWASH. Stratified sand and gravel removed or washed out from a glacier by meltwater streams and deposited in front of or beyond the end moraine or the margin of an active glacier. The coarser material is deposited nearer to the ice.

OUTWASH PLAIN. A broad, gently sloping sheet of outwash.

PEAT. A non-compacted deposit of organic material commonly developed from bogs or swamps.

PERCOLATE. The act of water seeping or filtering through soil without a defined channel.

PERMEABILITY. The property or capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure.

pH. A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. Originally stood for "potential of hydrogen".

PLUME. A contaminated portion of an aquifer extending from the original contaminant source.

POLLUTION. When the contamination concentration levels restrict the potential use of groundwater.

POROSITY. The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

POTABILITY. Ability to be used as drinking water.

POTENTIOMETRIC SURFACE. The surface to which water will rise in an aquifer under hydrostatic pressure.

PPM. Parts/per million. A unit of concentration equivalent to 0.0001 percent.

RECHARGE. The addition of water to the zone of saturation; also, the amount of water added.

RECHARGE AREA. Area in which water reaches the zone of saturation by surface infiltration.

RUNOFF. That part of precipitation flowing overland to surface streams.

SANDSTONE. A sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

SEAWATER INTRUSION. The entry of seawater into a fresh water aquifer.

SEDIMENTARY ROCKS. Rocks resulting from the consolidation of loose sediment that has accumulated in layers.

SHALE. A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated structure and will not fall apart on wetting.

STORAGE COEFFICIENT. The volume of water released from storage per unit-volume of porous medium per unit change in head.

STRATIGRAPHIC. Pertaining to the composition and position of layers of rock or sediment.

TERTIARY. A period of earth's history estimated to have occurred between 65 and 2 million years ago.

TILL. Predominantly unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

TOPOGRAPHIC. Pertaining to the general configuration of a land surface.

TOTAL DISSOLVED SOLIDS (TDS). A term that expresses the quantity of dissolved material in a sample of water, either the residue on evaporation, dried at 356°F (180°C), or, for many waters that contain more than about 1,000 mg/l, the sum of the chemical constituents.

TRANSMISSIVITY. The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values are given in gallons per minutes through a vertical section of an aquifer one foot wide and extending the full saturated height of an aquifer under a hydraulic gradient of 1 in the English Engineering system; in the International System, transmissivity is given in cubic meters per day through a vertical section of an aquifer one meter wide and extending the full saturated height of an aquifer under a hydraulic gradient of 1.

TRANSPIRATION. The process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface.

TURBULENT FLOW. Water flow in which the flow lines are confused and heterogeneously mixed. It is typical of flow in surface-water bodies.

UNCONFINED AQUIFER. An aquifer where the water table is exposed to the atmosphere through openings in the overlying materials.

UNSATURATED ZONE. The subsurface zone containing both water and air. The lower part of the unsaturated zone (capillary fringe) does not actually contain air, but is saturated with water held by suction at less than atmospheric pressure.

VADOSE ZONE. The zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

VISCOSITY. The property of a substance to offer internal resistance to flow. Specifically, the ratio of the shear stress to the rate of shear strain.

WATER TABLE. The surface between the vadose zone and the groundwater, where the pressure is equal to that of the atmosphere.

WEATHERING. The destructive process(es) by which the atmosphere and surface water chemically change the character of a rock.

ZONE OF CONTRIBUTION. The area surrounding a pumping well that encompasses all areas or features that supply ground-water recharge to the well.

ZONE OF INFLUENCE. The area surrounding a pumping well within which the water table or potentiometric surfaces have been changed due to ground-water withdrawal.

Area Characterization

Tables

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Table 5.1. Potential Impacts to Ground Water Conditions from Land Use Activities

Activity	Impact
Residential, Commercial, and Industrial Activities	
Use of private supply water wells	Increases discharge and translocation of ground water
Use of onsite septic tank sewage disposal	Formation of shallow ground water recharge mounds, downslope surface eruptions of effluent
Construction of impermeable surface (roof tops, pavement, parking lots, drainage systems)	Increased runoff, decreased infiltration and recharge
Building excavations and slope cuts, filling and constructions	Altered percolation of ground water, interconnection of aquifer systems
Landscaping and alteration of vegetative cover and maintenance	Altered evapotranspiration, surface drainage, infiltration, and recharge, increased discharge for irrigation
Operation and maintenance of cemeteries	Altered percolation of ground water, increased discharge for irrigation
Operation and maintenance of commercial and industrial facilities	Water quality degradation due to accidental spills, discharges or leaks
Public and Utilities Services	
Activity	Impact
Excavations for utilities and pipelines	Altered percolation of ground water
Grounded bed borings for pipelines and structures	Interconnection of surface drainage and aquifer systems
Construction of streets and roads, highway interchanges, parking lots, facilities with impermeable surface and rooftops	Increased runoff, decreased infilitration and recharge, increased ponding and folding with possible erosion downstream from collection points
Mechanical and chemical vegetation control in right-of-ways	Increased runoff, decreased infiltration and recharge
Construction of storm drainage	Increased runoff, decreased infiltration and recharge, possible localized recharge mounds under storm detention storage and along grassed waterways
Construction of public water supply	Translocation of water
Construction, operation and closure of landfills	Altered infiltrations, surface drainages, and ground water percolation, aquifer interconnections, recharge mounding
Maintenance of vegetation along utility corridors and transportation right-of-ways	Varied evapotranspiration, runoff, infiltration, and recharge
Maintenance of parks, golf courses, and landscaping	Increased discharge of irrigation, translocation of water, varied evapotranspration, infiltration and recharge

Table 5.1. Potential Impacts to Ground Water Conditions from Land Use Activities

Activity	Impact
Agriculture	
High density animal husbandry	Increased surface runoff, decreased infiltration and recharge
Irrigation and stock watering	Translocation of ground and surface water, shallow recharge mounding
Field preparation and crop cultivation	Varied evapotranspiration, increased runoff, decreased infiltration and recharge
Sand and Gravel Mining	
Activity	Impact
Operations (removal of overburden, sand and gravel, excavation site dewatering)	Decreased physical aquifer capacity, increased discharge of ground water to surface, altered surface drainage, interconnected aquifer systems
Abandonment of operations	Varied local ground water recharge or discharge, translocation of aquifer water, altered surface drainage
Land Clearing	
Activity	Impact
Tree and vegetation removal	Increased runoff and varied distruption of evapotranspiration processes
Access road construction	Increased surface runoff, decreased infiltration and recharge

Table 5.2 Waste Water Characteristics [1]

Land Use	Total Nitrogen[2] (mg/l)	Chloride (mg/l)	Lead (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Mercury (mg/l)	Total Phenol (ug/l)	Benzene (ug/l)	Toluene (ug/l)	Chloroform (ug/l)	Trichloro-Ethylene (ug/l)	Tetrachloro-Ethylene (mg/l)
RESIDENTIAL												
Range	20-85a	0-400b	0.0063-0.96b	0.016-0.66b	0.00016-0.007b	0.0002-0.0023b	13-22a	2.3-2.4c	4.3-5.4c	0.7-5.3c	0-150b	2.6-100a
Mean[3]	40											
INDUSTRIAL - FOOD												
Range	Highly Variable	Highly Variable	0.001-0.31d	0.270-1.5	0.0001-0.0067d	0.0002-0.002d	6.0-60d	1.0-30.d	1.0-101.0d	2.0-140.0d	cd	1.0-6.0d
Mean			0.01	0.56	0.0006	0.0001	2.4	0.637	8.8	5.45	0	0.653
INDUSTRIAL - CHEMICALS												
Range	Highly Variable	2.0-57,00	0.001-2.4d	0.11-39	0.0001-1.09d	0.0001-0.23	5.0-1,400,000d	2.0-1,700.0	5.0-117,000	1.0-55,000d	1.0-78,000d	1.0-7,700d
Mean		44.0	0.08	0.70	0.0036	0.0008	134.0	5.3a	140.6	6.15	17.3	18.9
INDUSTRIAL - METALS												
Range	Highly Variable	4.0-150	0.0001-240.d	0.034-11.0d	0.001-0.22d	0.001-0.009	2.0-530d	2.0-110.0d	1.0-83.0d	1.0-46.0d	1.0-500	1.0-85d
Mean		2.6	0.08	0.37	0.01	0.0002	6.2	1.5	1.5	3.3	2.9	1.0
COMMERCIAL												
Range	Highly Variable	0-120b	0.01-0.05b	0.050-0.22b	0.0001-0.0096	0.0001-0.014b	0-150b	0-16b	0-110b	0-28.0b	0-335b	0-115b
SOLID WASTE (leachate)												
Range	Highly Variable	0-400e	0.0029-0.03e	0.035-19.0e	0.0001-0.016e	0.002-0.0027e	0-300e	0-45	0-600e	0-11e	0-181e	0-54e

Notes:
(1) Tacoma-Pierce County Health Department, 1990.
(2) The mean is provided when available.
(3) Nitrate, nitrite, and organic and ammonia nitrogen.
mg/l = milligram per liter = ppm
ug/l = microgram per liter = ppb

Comments:
(a) Metcalf & Eddy, Wastewater Engineering.
(b) Draft A.2 Report, Collection System Modeling, Metro, May 1983.
(c) Metro Toxicant Study Report No. 2.
(d) Unpublished summary report data, TPPS Study, August 1983.
(e) Kent and Cedar Hills Landfills, Metro TPPS Study data, 1983.

Table 5.3. Hazardous Waste Generators

Business Name	Address	Resource Conservation and Recovery Act Type
Lake Washington SD Redmond Jr. High School	10055 166th Ave. N.E. Redmond	Generator 1.
Texaco Station 63 232 0273	11520 Avondale Rd. N.E. Redmond	Generator 2.
Chevron USA Inc. Service Station 98795	16000 Redmond Way Redmond	Generator 2.
Goodyear Auto Service Center	16101 N.E. 87th St., Site. B Redmond	Generator 3.
Chevron USA Inc. Gary's	16760 Redmond Way Redmond	Generator 3.
Overlake Cleaners	16940 N.E. 79th St. Redmond	Generator 3.
Sign Pros.	17425 N.E. 70th Redmond	Generator 1.
Pacific Circuits Inc.	17550 N.E. 67th Ct. Redmond	Generator 1.
HO Sports Inc.	17622 N.E. 67th Ct. Redmond	Generator 3.
Petersen Precision Engineering	17642 N.E. 65th St. Redmond	Generator 2.
Guaranteed Auto Rebuild	17657 1/2 Redmond Fall City Rd., Redmond	Generator 2.
ARCO Tech. Redmond	17760 N.E. 67th Ct. Redmond	Generator 1.
Teijin Seiki America, Inc.	17770 N.E. 78th Pl. Redmond	Generator 2.
Brown Bear Car Wash Redmond	17809 Redmond-Fall City Rd., Redmond	Generator 3.
Redmond Transmission	17825 N.E. 65th St., Site. 110, Redmond	Generator 2.

Table 5.3. Hazardous Waste Generators

Business Name	Address	Resource Conservation and Recovery Act Type
Kasco Corp.	17830 N.E. 65th St. Redmond	Generator 2.
Super Rent, Inc.	17950 Redmond Way Redmond	Generator 2.
United Parcel Service Redmond	18001 N.E. Union Hill Rd. Redmond	Generator 2.
Ring & Pinion Service	18014 Redmond Way, Unit 2, Redmond	Generator 2.
Guaranteed Radiator Repair, Inc.	18014 Redmond Way Unit 45, Redmond	Generator 2.
City of Redmond of Maintenance Operations Center	18080 N.E. 76th (Maint. Oper. Ctr.), Redmond	Generator 2.
Sajasa Construction, Inc.	8124 N.E. 76th St. Redmond	Generator 2.
Redmond Automotive	18130 Redmond Fall City Rd. Redmond	Generator 2.
Bell Industries Illuminated Displays	18225 N.E. 76th St. Redmond	Generator 1.
Genie Ind.	18340 N.E. 76th St. Redmond	Generator 1.
Super Rent Inc.	18455 N.E. 76th St. Redmond	Generator 3.
Washington Department of Transportation	18816 N.E. 80th Redmond	Generator 2.
Osborne Construction Co.	19114 N.E. 84th Redmond	Generator 1.
Lakeside Ind. Lab.	6500 187th Ave. N.E. Redmond	Generator 2.
Genetic Systems Corp.	6565 185th Ave. N.E. Redmond	Generator 1.
Caremark Inc.	6645 185th Ave. N.E.	Generator 2.

Table 5.3. Hazardous Waste Generators

Business Name	Address	Resource Conservation and Recovery Act Type
	Site. 151, Redmond	
Trigon Packaging Corp.	6812 185th Ave N.E. Redmond	Generator 3.
Queen City Auto Rebuild Inc.	7502 159th Pl. N.E. Redmond	Generator 2.
Sterling Auto Body & Paint	7520 159th Pl. N.E. Redmond	Generator 3.
Fitting Collision Ctr.	7662 159th Pl. N.E. Redmond	Generator 3.
King Co. Soils & Materials Lab.	7733 Leary Way N.E. Redmond	Generator 3.
Askew Auto Repair	7903 170th Pl NE Redmond	Generator 2.
Eastside Import Auto Rebuild Ltd.	7927 159th Pl. N.E. Redmond	Generator 2.
Redmond Cleaners Inc.	7981 Leary Way N.E. Redmond	Generator 2.
Hallmark Custom Cleaners	8469 164th Ave. N.E. Redmond	Generator 3.
Redmond AAA Radiator Inc.	7740 159th Pl. N.E. Redmond	Generator 2.
ETC Northwest	6645 185th Ave. N.E. Redmond	Generator 1.
Vintage Racing Motors, Inc.	7509 159th Pl. N.E. Redmond	Generator 3.
RP Auto Service	7430 159th Pl. N.E. Redmond	Generator 2.
HFI Foods, Inc.	17360 N.E. 67th Ct. Redmond	Generator 2.
Whirlpool Factory Service	18047 N.E. 68th St., Site B100, Redmond	Generator 2.
Ecova Corp.	18640 N.E. 67th Ct.,	Generator 1.

Table 5.3. Hazardous Waste Generators

Business Name	Address	Resource Conservation and Recovery Act Type
	Site. 200, Redmond	
Washington Department of Ecology Northwest Regional Office	Hwy 202 & 244th Ave. N.E., Redmond	Generator 2.
Lake Washington SD 98	1035 244th Ave. N.E. Redmond	Generator 2.
Northwest Pipeline Corp. Redmond MS	22607 N.E. Union Hill Rd. Redmond	Generator 1.
Northwest Pipeline Corp Redmond Dist.	22821 Redmond Fall City Rd., Redmond	Generator 1.
Lake Washington SD Evergreen Jr. High	6900 208th Ave. N.E. Redmond	Generator 1.

Key: Generator of dangerous/hazardous waste
1 = Generates or accumulates >2,200 pounds
2 = Generates or accumulates <2,200 pounds but >220 pounds
3 = Generates or accumulates <220 pounds (small quantity generators

Source: Department of Ecology, Database, February 1994.

Table 5.4 Toxic Clean-Up Program

Site Name	Address	Affected Media	Contaminant Status	Site Status	Comments
A and A Foreign Auto Repair	8004 Avondale Rd. N.E., Redmond 98052	Ground Water Drinking Water Surface Water Soil Sediment	Suspected Suspected Suspected Confirmed Suspected	Awaiting assessment by Ecology.	
All Sessions Construction	8504 192nd Ave. N.E. Redmond 98053	Ground Water Surface Water Soil Sediment	Suspected Confirmed Confirmed Suspected	Awaiting assessment by Ecology.	
Dunkin and Busch Painting, Inc.	17301 N.E. 70th St., Redmond 98052	Ground Water Drinking Water Surface Water Soil Sediment Air	Suspected Suspected Confirmed Confirmed Suspected Confirmed	Awaiting assessment by Ecology.	
Hancock Redmond Drug Lab	2426 244th N.E. Redmond	Ground Water Drinking Water Surface Water Soil Air	Confirmed Confirmed Suspected Confirmed Suspected	Awaiting assessment by Ecology.	
Johnny's Wrecking Yard	16616 N.E. 185th St. Woodinville	Ground Water Surface Water Soil	Suspected Suspected Confirmed	Awaiting assessment by Ecology.	
Northwest Pipeline/Redmond	22607 N.E. Union Hill Rd. Redmond	Soil Sediment Air	Confirmed Suspected Suspected	Awaiting assessment by Ecology.	
Olympian Precast, Inc.	19150 Union Hill Rd. Redmond	Ground Water Drinking Water Surface Water Soil Sediment	Confirmed Suspected Suspected Confirmed Suspected	Independent remedial action.	Interim independent remedial action. Report received by Ecology.
Truss Span	19340 N.E. Union Hill Rd./N.E. 80th Redmond	Ground Water Drinking Water Surface Water Soil	Suspected Suspected Suspected Suspected	Awaiting assessment by Ecology.	
Unocal Redmond Bulk Plant	16631 Cleveland St. Redmond	Ground Water Drinking Water Surface Water Soil Sediment	Confirmed Suspected Suspected Confirmed	Independent remedial action.	Interim independent remedial action. Report received by Ecology.

Source: Department of Ecology, February 1994

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
Texaco Station 11520 Avondale Rd. Redmond	Unleaded Gas	10000-19999 gals	7	OPERAT
Texaco Station 11520 Avondale Rd. Redmond	Unleaded Gas	10000-19999 gals	7	OPERAT
Texaco Station 11520 Avondale Rd. Redmond	Leaded Gas	5000-9999 gals	7	OPERAT
Chevron 16000 Redmond Way Redmond	Unleaded Gas	10000-19999 gals	3	OPERAT
Chevron 16000 Redmond Way Redmond	Unleaded Gas	10000-19999 gals	3	OPERAT
Chevron 16000 Redmond Way Redmond	Leaded Gas	10000-19999 gals	3	OPERAT
Philips 66 Company Service Station #07 16401 Redmond Way Redmond	Used Oil	111-1100 gals	25	UNRESO
Philips 66 Company Service Station #07 16401 Redmond Way Redmond	Unleaded Gas	5000-9999 gals	25	UNRESO
Philips 66 Company Service Station #07 16401 Redmond Way Redmond		111-1100 gals	25	UNRESO
Philips 66 Company Service Station #07 16401 Redmond Way Redmond	Leaded Gas	5000-9999 gals	25	UNRESO
Jackpot #305 16757 Redmond Way N.E. Redmond	Leaded Gas	10000-19999 gals	22	OPERAT
Jackpot #305 16757 Redmond Way N.E. Redmond	Leaded Gas	5000-9999 gals	22	OPERAT
Jackpot #305	Leaded Gas	5000-9999 gals	22	OPERAT

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
16757 Redmond Wy NE				
Chevron 96388 16760 Redmond Way Redmond	Used oil	5000-9999 gals	11	OPERAT
Chevron 96388 16760 Redmond Way Redmond	Unleaded gas	5000-9999 gals	11	OPERAT
Chevron 96388 16760 Redmond Way Redmond	Unleaded gas	5000-9999 gals	11	OPERAT
Chevron 96388 16760 Redmond Way Redmond	Leaded gas	5000-9999 gals	11	OPERAT
Minit-Lube #1109 17015 Avondale Way N.E. Redmond	Used oil	111-1100 gals	15	OPERAT
Minit-Lube #1109 17015 Avondale Way N.E. Redmond	Other	2001-4999 gals	11	OPERAT
Organizational Maintenance 17230 N.E. 95th Redmond	Unleaded Gas	10000-19999 gals	39	OPERAT
Brown Bear Car Wash 17809 Redmond Way Redmond	Leaded gas	5000-9999 gals	29	OPERAT
Brown Bear Car Wash 17809 Redmond Way Redmond	Diesel Fuel	5000-9999 gals	29	OPERAT
Brown Bear Car Wash 17809 Redmond Way Redmond	Unleaded gas	10000-19999 gals	29	OPERAT
Brown Bear Car Wash 17809 Redmond Way Redmond	Unleaded gas	10000-19999 gals	29	OPERAT
Super Rent Inc. 17950 Redmond Way Redmond	Kerosene	2001-4999	11	OPERAT
Super Rent Inc. 17950 Redmond Way Redmond	Unleaded gas	2001-4999	11	OPERAT

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
Super Rent Inc. 17950 Redmond Way Redmond	Diesel Fuel	2001-4999	11	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Diesel Fuel	10000-19999 gals	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Diesel Fuel	10000-19999 gallons	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Used oil	111-1100 gals	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Hazardous	111-1100 gals	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Hazardous	111-1100 gals	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Unleaded gas	10000-19999 gals	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Unleaded gas	10000-19999 gals	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill Rd. Redmond	Diesel Fuel	10000-19999 gals	5	OPERAT
United Parcel Service-Red 18001 N.E. Union Hill	Other	111-1100 gals	5	OPERAT

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
Rd. Redmond				
Sammamish Point Texaco 18065 Redmond Way Redmond	Unleaded Gas	5000-9999 gals	20	OPERAT
Sammamish Point Texaco 18065 Redmond Way Redmond	Leaded gas	10000-19999 gals	11	OPERAT
Sammamish Point Texaco 18065 Redmond Way Redmond	Unleaded gas	5000-9999 gals	20	OPERAT
Sammamish Point Texaco 18065 Redmond Way Redmond	Unleaded gas	5000-9999 gals	20	OPERAT
Sammamish Point Texaco 18065 Redmond Way Redmond	Diesel Fuel	5000-9999 gals	15	OPERAT
City Shops 18080 NE 76th Redmond	Used oil	111-1100 gals	15	OPERAT
City Shops 18080 NE 76th Redmond	Unleaded Gas	5000-9999 gals	15	OPERAT
City Shops 18080 NE 76th Redmond	Diesel Fuel	5000-9999 gals	15	OPERAT
City Shops 18080 NE 76th Redmond	Leaded gas	5000-9999 gals	15	OPERAT
Redmond Science Ctr (2562) 18120 NE 68th St. Redmond	Diesel Fuel	111-1100 gals	2	OPERAT
Hos Bros. Construction 18120 NE 76th St. Redmond		111-1100 gals	25	TEMP 0
Hos Bros. Construction 18120 NE 76th St. Redmond			20	TEMP 0

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
Redmond				
Hos Bros. Construction 18120 N.E. 76th St. Redmond			20	TEMP 0
Hos Bros. Construction, 18120 N.E. 76th St. Redmond	Diesel Fuel	10000-19999 gals	3	OPERAT
Hos Bros. Construction 18120 N.E. 76th St. Redmond	Used oil	111-1100 gals	25	OPERAT
Redmond Service Center 18150 Red-Fall City Hwy Redmond	Used oil	111-1100 gals	15	OPERAT
Redmond Service Center 18150 Red-Fall City Hwy. Redmond	Diesel Fuel	10000-19999 gals	15	OPERAT
Redmond Service Center 18150 Red-Fall City Hwy Redmond	Unleaded Gas	111-1100 gals	15	OPERAT
Cadman Gravel Company 18816 N.E. 80th Redmond	Diesel Fuel	10000-19999 gals	15	OPERAT
Cadman Gravel Company 18816 N.E. 80th Redmond	Diesel Fuel	10000-19999 gals	15	OPERAT
Cadman Gravel Company 18816 N.E. 80th Redmond	Leaded Gas	111-1100 gals	15	OPERAT
Cadman Gravel Company 18816 N.E. 80th Redmond	Other	111-1100 gals	15	OPERAT
Cadman Gravel Company 18816 N.E. 80th Redmond	Diesel Fuel	1101-2000 gals	20	OPERAT
Cadman Gravel Company 18816 N.E. 80th	Diesel Fuel	10000-19999 gals	20	OPERAT

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
Redmond				
Cadman Gravel Company 18816 N.E. 80th Redmond	Used Oil	111-1100 gals	15	OPERAT
Cadman Gravel Company 18816 N.E. 80th Redmond	Other	111-1100 gals	15	OPERAT
Cadman Gravel Company 18816 N.E. 80th Redmond	Diesel Fuel	10000-19999 gals	20	OPERAT
The Overlake School 20301 NE 108th Redmond	Leaded Gas	1101-2000 gals	20	OPERAT
King County Fire District 4200 228th Ave NE Redmond	Diesel Fuel	111-1100 gals	2	OPERAT
PDQ Oil Co. #1120 5040 148th Ave NE Redmond	Unleaded Gas	10000-19999 gals	3	OPERAT
Marymoor Park 6046 West Lake Sammamish Redmond	Unleaded Gas	111-1100 gals	2	OPERAT
Jackpot #304 7725 159th Pl NE Redmond	Unleaded Gas	5000-9999 gals	10	OPERAT
Jackpot #304 7725 159th Pl NE Redmond	Leaded Gas	10000-19999 gals	10	OPERAT
Jackpot #304 7725 159th Pl NE Redmond	Unleaded Gas	10000-19999 gals	10	OPERAT
A & G Leasing 7740 159th Pl NE Redmond	Used Oil	111-1100 gals	20	TEMP O
Shultz Distributing Inc. 7822 180th Ave NE Redmond	Leaded Gas	20000-29999 gals	29	OPERAT
Shultz Distributing Inc.	Unleaded Gas	20000-29999 gals	29	OPERAT

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
7822 180th Ave NE Redmond				
Shultz Distributing Inc. 7822 180th Ave NE Redmond	Unleaded Gas	20000-29999 gals	29	OPERAT
ARCO 6067 8009 164th Ave NE Redmond	Unleaded Gas	10000-19999 gals	8	OPERAT
ARCO 6067 8009 164th Ave NE Redmond	Unleaded Gas	10000-19999 gals	8	OPERAT
ARCO 6067 8009 164th Ave NE Redmond	Used Oil	111-1100 gals	26	OPERAT
ARCO 6067 8009 164th Ave NE Redmond	Leaded Gas	10000-19999 gals	8	OPERAT
City of Redmond Fire Dept 8450 161st Ave NE Redmond	Unleaded gas	1101-2000 gals	11	OPERAT
City of Redmond Fire Dept 8450 161st Ave NE Redmond	Diesel Fuel	1101-2000 gals	11	OPERAT
City of Redmond Fire Dept 8450 161st Ave NE Redmond	Unleaded Gas	1101-2000 gals	11	OPERAT
Lake Washington School Dist 9426 195th Ave NE Redmond	Heating Fuel		32	UNRESO
Lake Washington School Dist 9426 195th Ave NE Redmond	Heating Fuel		32	UNRESO
Lake Washington School Dist 9426 195th Ave NE Redmond	Heating Fuel	111-1100 gals	32	UNRESO
Lake Washington School Dist	Heating Fuel		32	UNRESO

Table 5.5. Underground Storage Tanks Reported in the Redmond-Bear Creek Ground Water Management Area

Site/Address	Substance	Size	Age(yr)	Status
9426 195th Ave NE Redmond				
Lake Washington School Dist 9426 195th Ave NE Redmond	Heating Fuel	111-1100 gals	32	UNRESO

OPERAT = Underground storage tanks in operation/use
TEMPO = Underground storage tanks temporary out of service (tank emptied but not removed, or closed in place).
UNRESO = Ecology is unaware of what is going on at the site. Ecology has or will correspond with the site owner.

Table 5.6. Age of Underground Storage Tanks in Operation in the Redmond-Bear Creek Valley Ground Water Management Area

Age (years)	Number of Tanks	Percentage of Total
1-2	3	4.1
3-5	14	19.2
6-10	9	12.3
11-15	27	36.9
16-20	7	9.6
21-30	12	16.4
Greater than 30	1	1.4
TOTAL	73	100.0

Source: Department of Ecology, 1994.

Table 5.7. Substances Contained in Underground Storage Tanks in Operation in the Redmond-Bear Creek Valley Ground Water Management Area

Substance	Number of Tanks	Percentage of Total
Leaded Gas	13	17.8
Unleaded Gas	28	38.4
Diesel Fuel	17	23.3
Kerosene	1	1.4
Used/Waste/Oil	8	10.9
Unknown	6	8.2
TOTAL	73	100.0

Source: Department of Ecology, 1994.

Table 5.8. Size of Underground Storage Tanks in Operation in the Redmond-Bear Creek Valley Ground Water Management Area

Size (gallons)	Number of Tanks	Percentage of Total
111-1100	18	24.7
1101-2000	5	6.9
2001-4999	4	5.5
5000-9999	16	21.9
10000-19999	27	36.9
20000-29999	3	4.1
TOTAL	73	100.00

Source: Department of Ecology, 1994.

Table 5.9. Department of Ecology Current and Former Contaminated Underground Storage Tank Sites

Site Name	Address	City	Clean-up Status	Media
Lake Washington School Mann El	17001 NE 104	Redmond	In progress	D
McEachern Property	19805 NE Novelty Hill Rd	Redmond	Conducted	D
WA State Military Army Nat'l G	17230 NE 95th	Redmond	Conducted	D
A & A Auto	8004 Avondale Rd	Redmond	In Progress	D
UPS Redmond	18001 NE Union Hill Rd	Redmond	In Progress	D
Arco Station #6067	8009 164th Ave NE	Redmond	In Progress	D
Kelly Realty	16450 Redmond Way	Redmond	Conducted	D
Chevron Station #9-6388	16760 Redmond Way	Redmond	In Progress	A
Unocal Station #4870	16909 Redmond Way	Redmond	In Progress	A,D
Car Wash Enterprises Redmond	17809 Redmond Way	Redmond	In Progress	A,D
Schultz Dist Plant Redmond	7822 180th Ave NE	Redmond	In Progress	A,D
Down to Earth Bulldozing	20840 NE 89th	Redmond	Conducted	D

Media
A = Ground Water
D = Soil

Cleanup Status
Conducted = Ecology received final independent action cleanup report - no further action.
In-Progress = Site cleanup in progress/ongoing.

Table 5.10. Ranges of Suspended Solids and Heavy Metals Detected in Storm Water, National Urban Runoff Program

Constituent	Concentration Range (mg/l)
Total Suspended Solids	180 - 548
Total Copper	43 - 118
Total Lead	182- 443
Total Zinc	202 - 633
Pesticides	<0.05
Nitrates	<1.0-6.0

Table 5.11. Vehicle Accident Summary

Roadway Location	1993 Average Daily Traffic Total Roadway # of vehicles	1993 Total Accidents	Estimated Number of Hazardous Waste Accidents (Per Year)
Avondale Road (Redmond)	28,000	28	<1
Union Hill Road (Redmond)	17,000	12	<1
Highway 202	23,900	76	<1

Source: City of Redmond, February 1994.

Table 5.12 City of Redmond Truck Accidents

YEAR	TRUCK ACCIDENTS	TRUCK ACCIDENTS INVOLVING HAZARDOUS MATERIALS
1991	33	0
1990	45	1
1989	34	1

Source: Washington Utilities and Transportation Commission, March 1994.

Note: Information unavailable prior to 1989.

Table 6.1. Existing Water Rights for Group A Public Water Systems for the Redmond-Bear Creek Valley Ground Water Management Area

Purveyor	Permit Number	Existing Instantaneous Right	Existing Annual Right
Union Hill Water Assoc.	G1-22756P	1300 GPM	2080 AF/YR
NE Sammamish Water & Sewer District	G1-09644C	230	335
	G1-22777C	250	200
	G1-23133C	300	150
	G1-23488C	350	300
	G1-23685C	400	315
	G1-25234C	350	504
	G1-25408C	350	480
City of Redmond	1313	200	
	G1-00130C	700	
	3420	500	
	6675	480	
	G1-22608C	800	
	G1-24204P	1000	
	249 (Surface Water - Sidel Creek)	-	3600
	250 (Surface Water)	-	33
	TOTAL GROUND WATER RIGHTS	7210	2817

Table 6.2. Projected Future Water Usage for Redmond-Bear Creek Ground Water Management Area (RBCGWMA)

		Projected Increases	
	Current Use	2000 (%)	2040 (%)
East King County	65-67 mgd	77-84 mgd (16-27)	134-185mgd (103-180)
Redmond-Bear Creek Ground Water Management Area	8 mgd	9.3-10.1 mgd (16-27)	16.6-22.4 mgd (103-180)

Table 6.3. Population Forecasts Using SAZ

GWMA	Acreage	Jurisdiction	Est. Growth	Current Pop.[a]	Est.Future Pop.
Redmond B.C.	27,766	King County	9276 (1990-2012)	12,749 (1993)	22,025 (2012)
		City of Redmond	12,760 (1995-2010)[b]	8,517 (1995)[b]	21,277 (2010)
		Total:	22,036	21,266	43,302

[a] - Population in households

[b] Current population estimated to occur within GWMA boundaries is 50 percent of the 1995 population of Redmond. Growth estimates assume that all of the growth that will occur within the city of Redmond will occur within GWMA boundaries.

Table 7.1. Delineation of Wells by Aquifer Zone

Alluvial Aquifers		Local Upland Aquifers		Sea Level Aquifers		Regional Aquifers	
Well ID	Approximate Intake Elevation	Well ID	Approximate Intake Elevation	Well ID	Approximate Intake Elevation	Well ID	Approximate Intake Elevation
8	68	1	292	6	54	14	-156
9	64	2	210	15	-124	16	-175
23	-59	3	216	26		34	-278
24		4	219	27		35	-224
33	-9	5	171	28	-31	36	-224
37	22	7	171	29		75	-631
40	-66	10	187	30	44	79	-205
41	12	11	161	31	-15		
42	-10	12	231	32	51		
43	50	13	186	68			
44	-10	17	172	74			
45	4	18	227	77	-2		
46	23	19	272	78			
47	24	20	251	79			
48		21	184	80	49		
50	15	22					
51	-37	69	424				
52	-23	71					
53	-23	72	388				
54	10	82					
55	10						
56	-8						
57	2						
58							
59	23						
60	10						
62	-1						
63	6						
64	-73						
65	60						
66	-31						
67	40						
70	-9						
73	-54						
76	8						
81	-129						
NOTE: 1 Elevation = feet above or below sea level							

Table 7.2. Susceptibility Ranking of NRCS Soil Units

NRCS Map Symbol	NRCS Soil Unit Name	Relative Physical Susceptibility
EvB	Everett	high
EvC	Everett	high
EvD	Everett	high
InA	Indianola	high
InC	Indianola	high
Pc	Pilchuck	high
RdC	Ragnar-Indianola	high
Re	Renton	high
AgC	Alderwood	moderate
AgD	Alderwood	moderate
AkF	Alderwood	moderate
AmC	Arents	moderate
Br	Briscot	moderate
Ea	Earlmont	moderate
KpB	Kitsap	moderate
KpD	Kitsap	moderate
No	Norma	moderate
Os	Oridia	moderate
So	Snohomish	moderate
Su	Sultan	moderate
Sk	Seattle muck	moderate
Tu	Tuckwila muck	moderate
Bh	Bellingham	low
Pu	Puget	low

Table 7.3. Susceptibility Ranking of USGS Geologic Units

Geologic Symbol	Geologic Unit Name	Relative Physical Susceptibility
Qaf	Alluvial fan deposits	high
Qual	Older alluvium	high
Qvr	Recessional outwash	high
Qvrb	Recessional outwash	high
Qvrd	Redmond Delta	high
Qvro	Older recessional outwash	high
Qvry	Recessional outwash	high
Qc	Colluvium	moderate
Qls	Landslide deposits	moderate
Qmw	Mass wasting deposits	moderate
Qob	Olympia beds	moderate
Qva	Advance outwash	moderate
Qyal	Younger alluvium	moderate
Qsw	Swamp deposits	low
Qtb	Transitional beds	low
Qvrc	Clay	low
Qvt	Glacial till	low

Table 7.4. Susceptibility Ranking for Depth to Water Criteria

DEPTH TO WATER Depth Below Ground Surface (feet)	Relative Physical Susceptibility
0-25	high
25-75	moderate
>75	low

Table 7.5. Typical Resistivity Values of Materials

Material Description	Resistivity
Silt/clay mixture (full to partial saturation)	10 to 100
Sandy silts and clays and possible sandstone/shale bedrock (full to partial saturation)	50 to 150 shale
Silty sand and saturated sand/gravel	100 to 500
Sand to gravel (fine to course)	200 to 1,500
Gravel (full to partial saturation)	1,000 to 2,000
Gravel (dry)	1,500 and above

Table 7.6. Vertical Electrical Sounding (VES) Interpretation

Depth (feet)	Resistivity (in ohm meters)	Geologic Interpretation
VES-37		
0 to 11	300+	Silty sandy gravel
11 to 17	173	
17 to 24	91	
24 to 35	75	Sandy silt and gravel layers
35 to 78	84	Silty sand and gravel
78 to 115	65	Fine to coarse sand
115 to 171	51	Fine sand
171 to 254	64	Silty sand and gravel and layers of silt
254 to 366	116	Gray fine sand, silt and clay
366 to 546	69	
546 to 600 +/-	low	Gray water-bearing silty fine sand
VES-40		
0 to 4	5,000+	Coarse dry sand and gravel
4 to 6	3,275	
6 to 8	771	Siltier material
8 to 11	149	Water table
11 to 14	33	Silty layer
14 to 24	261	Coarse sand and gravel
36 to 93	250	Interpreted top of rock at 36 feet
93 to 142	390	Sandstone

Table 7.7 Summary of Well Drilling and Aquifer Testing Data

					Pump Testing Results			
Test Well Site	Total Depth of Hole (ft)	Depth of Well(s) (ft)	Screened Intervals (ft)	Well Casing Diameter (mhos)	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Potential Yield (gpm)	Transmissivity (gpd/ft)
Woodinville	490	85	75-85	6	200	18	1200	80,000
Redmond	500	75	65-75	2	NA	NA	NA	NA
Lower Evans Creek	160	153	143-153	6	150	6	700	20,000
Upper Evans Creek	237	160/200	140-160/ 180-200	2	NA	NA	NA	NA
Marymoor	170	161	151-161	6	100	4	100	5,000

NOTE: NA Not applicable.

Table 7.8. Monthly Precipitation Data

YEAR	MONTH	STATION						
		Woodinville	Union Hill	Sahalee	Redmond	Hollywood	North Ridge	Blakely Ridge
1989	Jan	ND	ND	5.85	2.72	3.97	5.81	ND
	Feb	ND	ND	3.07	1.11	3.34	4.46	ND
	Mar	5.09	ND	6.85	3.04	5.56	6.79	ND
	Apr	1.47	2.00	2.45	0.97	1.32	2.30	ND
	May	3.33	3.78	3.95	3.81	3.54	4.28	ND
	June	1.58	1.36	1.72	1.20	1.21	1.45	ND
	July	0.19	ND	1.07	0.54	0.73	0.80	ND
	Aug	ND	1.37	1.05	ND	0.87	1.21	ND
	Sept	ND	0.37	0.35	0.13	0.38	0.42	ND
	Oct	ND	4.17	4.40	3.51	4.19	4.48	4.48
	Nov	ND	5.59	7.05	4.29	4.36	5.86	5.86
	Dec	ND	5.73	5.60	4.28	4.60	5.97	5.97
	total	11.66	24.37	43.41	25.60	34.07	43.83	16.31
1990	Jan	ND	9.02	9.70	7.68	8.02	9.99	9.99
	Feb	3.83	4.66	3.15	2.89	2.91	3.88	3.88
	Mar	3.02	3.89	3.50	3.11	3.92	4.14	4.14
	Apr	3.40	3.66	2.75	2.32	3.58	3.91	3.91
	May	2.52	3.42	2.35	1.81	2.50	2.78	2.78
	June	3.34	3.78	4.10	2.82	3.13	3.97	3.73
	July	0.77	0.98	1.20	0.74	0.74	1.09	0.86
	Aug	1.06	1.66	1.75	0.87	0.72	1.35	1.29
	Sept	0.08	0.04	ND	0.02	0.11	0.21	0.41
	Oct	7.03	8.38	7.85	5.80	6.87	8.30	8.76
	Nov	8.04	8.05	7.95	6.29	6.91	6.06	6.83
	Dec	4.86	4.39	5.35	4.02	5.10	4.34	5.29
	total	37.95	51.93	49.65	38.37	44.51	50.02	51.87
1991	Jan	3.82	4.86	5.00	3.72	3.68	5.02	4.60
	Feb	5.98	5.08	5.15	4.38	5.51	5.26	5.86
	Mar	5.04	5.82	6.05	4.24	4.79	7.27	6.52
	Apr	5.83	6.57	6.40	5.35	5.46	6.41	5.87
	May	ND	2.63	2.45	1.28	1.73	2.55	2.10
	June	ND	2.79	2.75	1.58	2.16	2.78	2.54
	July	ND	0.08	0.30	0.36	0.39	0.42	0.04
	Aug	ND	ND	1.80	1.41	1.62	1.75	1.83
	Sept	ND	ND	0.00	0.44	0.33	0.38	0.36
	Oct	ND	ND	1.70	1.64	ND	ND	ND
	Nov	ND	ND	2.38	ND	ND	ND	ND
	Dec	ND	ND	0.00	ND	ND	ND	ND
	total	20.67	27.83	33.98	24.40	25.67	31.84	29.72

ND - No Data Available

Table 7.9. Ground Water Monitoring Sites

Well Identification	Well Owner	Use	Monitoring Type
1	Dought, Lee	D	WL/WQ
2	Woodinville Water	D	WL/WQ
3	Paradise Park	D	WL/WQ
4	Bondo, Paul	D	WL/WQ
5	Odegard, David	D	WL/WQ
6	Kloepfer, Ryan	D	WL/WQ
7	Hosey #1	D	WL/WQ
8	Morgan, James	D	WL
9	Rigger Assoc.	D	WL
10	Tainter, Gordon	D	WL/WQ
11	Smith, Don	D	WL
12	Sharp, Grant	D	WL/WQ
13	Nelson, Gordon	D	WL/WQ
14	Thenos Dairy	D	WL/WQ
15	Thompson, Steve	D	WL
16	Ulrich Meats	D	WL/WQ
17	Heller, Charles	D	WL
18	Whyte, Myrna	D	WL
19	O'Leary, Chris	D	WL
20	Weide, Mike	D	WL/WQ
21	Stern, William	D	WL/WQ
22	Fischer, Leo	D	WL
23	Lien, William	D	WL/WQ
24	Larson (Stetler)	D	WL
25	Tollfeldt, Harvey	D	WL
26	Bauman, John	D	WL
27	Webster, Walt	D	WL/WQ
28	Sorenson	D	WL
29	Goss, Gordon	D	WL/WQ
30	Hutchinson, Ron	D	WL
31	Macklin	D	WL
32	McGlothlin, Del	D	WL
33	Home Port Farm	D	WL/WQ
34	Patterson, Stan	D	WL/WQ

Table 7.9. Ground Water Monitoring Sites

Well Identification	Well Owner	Use	Monitoring Type
35	Bowman, Carl	D	WL/WQ
36	Loveless (Stensland)	D	WL
37	Redmond Well #3	P	WL/WQ
38	McClan, Robert	D	WL/WQ
39	Keller Dairy	D	WL
40	Olympian Precast	I	WL/WQ
41	King County Shops	I	WL/WQ
42	Eastside Masonary	I	WL
43	Barrett, Del	D	WL/WQ
44	Redmond GWMA Test Well	MW	WL/WQ
45	Lacher	D	WL
46	Science Park B-1	MW	WL
47	Science Park B-2	MW	WL
48	Redmond Well #5	P	WL/WQ
49	Redmond Test Well #5	MW	WL
50	Redmond Cemetary	II	WL
51	Cedar Lawns Cemetary	PP	WL/WQ
52	Redmond Well #1	MW	WL/WQ
53	Redmond Well #2	MW	WL/WQ
54	Redmond Oil Co. #1	MW	WL
55	Redmond Oil Co. #2	MW	WL
56	Town Center I	I	WL
57	Washington Voc-Tech	I	WL
58	Gateway Piezometer #1	MW	WL
59	Gateway Piezometer #2/3		
60	Redmoor Corporation	I	WL
61	Campton Community	D	WQ
62	Sportsman Park	I	WL/WQ
63	Welcome	D	WL
64	Evans Creek Test Well 1	MW	WL/WQ
65	Turpsmith	D	WL
66	Ingalls, Robert	D	WL
67	Zimmerman, Margret	D	WL
68	Ramsey	D	WL
69	Tutko Landscape	D	WL/WQ

Table 7.9. Ground Water Monitoring Sites

Well Identification	Well Owner	Use	Monitoring Type
70	NEL Samm #6	P	WL
71	Varney	D	WL
72	Robretson, Richard	D	WL
73	Union Hill	P	WL/WQ
74	Evans Creek Test Well 2	MW	WL/WQ
75	NELS Test Well #1	MW	WL/WQ
76	NE L. SamPm #2	P	WL/WQ
76	NE L. Samm #2R	MW	WL
77	NE L. Samm #4	P	WL/WQ
78	NE L. Samm #5	P	WL
79	NE L. Samm #3	P	WQ
80	Sahalee	I	WL
81	Marymoor	MW	WL/WQ
82	Flippen	D	WL

Table 7.10. Constituents Tested at Monitoring Wells

Well Identification		Analyses Performed	
Well #	Well Owner	December 1989 Sampling	May 1990 Sampling
1	Dought, Lee	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
3	Paradise Park	PDW, SDW, GWC, TOX	PDW, SDW, GWC
4	Bondo, Paul	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
5	Odegard, David	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
6	Kloepfer, Ryan	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
7	Hosey #1	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
10	Tainter, Gordon	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
12	Sharp, Grant	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
13	Nelson, Gordon	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
14	Thenos Dairy	PDW, SDW, GWC, TOX	PDW, SDW, GWC,Others
16	Ulrich Meats	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
20	Weide, Mike	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
21	Stern, William	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
23	Lien, William	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
27	Webster, Walt	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
29	Goss, Gordon	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
33	Home Port Farm	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
34	Patterson, Stan	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
35	Bowman, Carl	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
38	McClan, Robert	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
40	Olympian Precast	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
41	King County Shops	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
43	Barrett, Del	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
48	Redmond Well #5	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
51	Cedar Lawns Cemetary	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
53	Redmond Well #2	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
61	Campton Community	PDW, SDW, GWC, TOX	PDW, SDW, GWC, Others
62	Sportsman Park	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
64	Evans Creek Test Well 1	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
69	Tutko Landscape	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
73	Union Hill	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
74	Evans Creek Test Well 2	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
76	NE L. SamPm #2	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
77	NE L. Samm #4	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX
79	NE L. Samm #3	PDW, SDW, GWC, TOX	PDW, SDW, GWC,TOX

NOTES:
PDW = Primary Drinking Water Analytes
SDW = Secondary Drinking Water Analytes
GWC = Ground Water Characteristic constituents
TOX = Total Organic Halogen
Others = Cyanide, phenol, volatile and semivolatile organic compound, chlorinated pesticides, PCVs, antimony, beryllium, nickel, and thallium.

Table 7.11. Normal Abundance of Inorganic Dissolved Solids in Ground Water

Category	Normal Concentration Range[a]	Analytes Examined for this Study
Major constituents	1.0 to 1000 mg/L	Bicarbonate, calcium, chloride, magnesium, silica, sodium, sulfate
Secondary constituents	0.01 to 10.0 mg/L	Carbonate, iron, fluoride, nitrate, potassium
Minor constituents	0.0001 to 0.1 mg/L	Antimony, arsenic, barium, cadmium, chromium, copper, lead, manganese, nickel, phosphate, selenium, zinc
Trace constituents	<0.001 mg/L	Beryllium, silver, thallium

[a] Modified from Davis and DeWiest,1966

Table 7.12 Summary of Ground Water Quality Analytical Results

Well ID (map)	Sample Number	Well Name	Sampling Date	Total Coliforms (MPN/100ml)	Fecal Coliforms (MPN/100ml)	TDS (mg/l)	Total Hardness (mg/l as CaCO3)	Total Alkalinity (mg/l as CaCO3)	Carbonate Alkalinity (mg/l as CaCO3)	Bicarbonate Alkalinity (mg/l as CaCO3)	Hydroxide Alkalinity (mg/l as CaCO3)	TOX (ug/l)	Calcium (mg/l)	Iron (mg/l)	Manganese (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Silica (mg/l)	Zinc (mg/l)
41	D-30	KING C. SHOPS DUPL	05/14/90	1 L	1 L	168	87	74	1 L	74	1 L		18	0.05	0.002 L	9.5	1.7	6.3	28	0.1
6	R-7	KLOEPFER, RYAN	05/14/90	1 L	1 L	104	48	48	1 L	48	1 L		7.5	0.25	0.003	7.2	0.69	5.2	30	0.27
61	R-16	CAMPTON COMMUNITY	05/14/90	1 L	1 L	178	94	72	1 L	72	1 L		21	0.01 L	0.005	10	1.4	8.8	28	0.02 L
51	R-17	CEDAR LAWNS	05/14/90	1 L	1 L	136	71	62	1 L	62	1 L		16	0.74	0.005	7.5	0.17	9.9	23	0.2
41	R-30	KING C. SHOPS	05/14/90	1 L	1 L	166	90	74	1 L	74	1 L		20	0.03	0.002 L	8.7	1.7	8.8	30	0.1
	5-11	TRIP BLANKS	05/14/90	1 L	1 L	6	1 L	2	1 L	2	1 L		0.01 L	0.01 L	0.002 L	0.01 L	1 L	0.02 L	11	0.02 L
29	R-5	GOSS, GORDON	05/14/90	1 L	1 L	264	31	131	1 L	131	1 L	5 L	8.4	0.03	0.015	2.5	2.2	44	23	0.03
13	R-9	NELSON, GORDON	05/14/90	1 L	1 L	134	73	70	1 L	70	1 L	5 L	11	0.03	0.002 L	11	1.9	6.5	34	0.02
10	R-11	TAINTER, GORDON	05/14/90	1 L	1 L	82	39	50	1 L	50	1 L	5 L	8.2	0.72	0.061	4.5	0.51	5.2	28	0.22
20	R-13	WEIDE, MIKE	05/14/90	1 L	1 L	110	55	53	1 L	53	1 L	5 L	9	9.1	0.03	7.9	1.5	5	30	0.21
16	R-24	ULRICH MEATS	05/14/90	2	1 L	448	68	293	1 L	293	1 L	5 L	12	11	0.21	9.3	6.6	110	51	0.12
3	D-4	PARADISE PARK DUPL	05/15/90	1 L	1 L	114	65	62	1 L	62	1 L		13	0.1	0.161	5.5	1.3	6.9	30	0.02 L
1	R-3	DOUGHTY, LEE	05/15/90	7	1 L	110	57	60	1 L	60	1 L		6.9	0.01	0.002 L	8.4	1	5.6	23	0.01
3	R-4	PARADISE PARK	05/15/90	1 L	1 L	114	54	60	1 L	60	1 L		13	0.11	0.151	5.2	1.2	6.6	30	0.45
4	R-1	BONDO, PAUL	05/15/90	1 L	1 L	66	41	42	1 L	42	1 L		7.7	0.02	0.002 L	5.3	0.67	5.3	23.	0.12
12	R-21	SHARP, GRANT	05/15/90	6	1 L	220	124	122	1 L	122	1 L		20	0.48	0.023	18	1.5	9.2	28	0.37
7	R-06	HOSEY #1	05/15/90	1 L	1 L	120	65	44	1 L	44	1 L	5 L	9.2	0.19	0.03	7.6	0.92	5	23	0.15
5	R-10	ODEGARD, DAVID	05/15/90	5	1 L	92	38	40	1 L	40	1 L	5 L	10	0.08	0.02	3.3	0.63	5.6	23	0.03
27	R-14	WEBSTER, WALT	05/15/90	1 L	1 L	196	51	130	1 L	130	1 L	5 L	13	0.31	0.07	4.4	4.2	34	30	0.03
34	R-20	PATTERSON, STAN	05/15/90	1 L	1 L	142	54	64	1 L	64	1 L	5 L	14	0.16	0.043	4.7	2.7	13	28	0.05
21	R-23	STERN, WILLIAM	05/15/90	1 L	1 L	132	58	62	1 L	62	1 L	5 L	12	0.04	0.114	6.9	2	5	28	0.01
77	D-27	NE SAMMAMISH #4 DUPL	05/16/90	1 L	1 L	110	63	66	1 L	66	1 L	5 L	19	0.03	0.049	3.8	0.72	6.1	26	0.02 L
23	R-8	LEIN, WILLIAM	05/16/90	1 L	1 L	180	33	31	1 L	31	1 L	5 L	6.7	0.1	0.047	3.9	5.4	26	32	0.02 L
35	R-15	BOWMAN, CARL	05/16/90	1 L	1 L	140	61	74	1 L	74	1 L	5 L	15	7.1	0.065	5.7	2.4	7.6	32	0.66
33	R-18	HOME PORT FARM	05/16/90	1 L	1 L	194	72	110	1 L	110	1 L	5 L	18	0.11	0.057	6.5	4	17	30	0.02
62	R-22	SPORTSMAN PARK	05/16/90	6	1 L	250	92	76	1 L	76	1 L	5 L	17	1.2	0.068	12	2.4	7.7	20	0.06
76	R-25	NE SAMMAMISH #2	05/16/90	1 L	1 L	110	61	56	1 L	56	1 L	5 L	11	1.3	0.045	5.8	0.72	5.7	26	0.04
79	R-26	NE SAMMAMISH #3	05/16/90	1 L	1 L	120	63	64	1 L	64	1 L	5 L	20	0.03	0.041	3.1	0.84	7.7	21	0.02 L
77	R-27	NE SAMMAMISH #4	05/16/90	1 L	1 L	102	59	70	1 L	70	1 L	5 L	18	0.01 L	0.042	3.5	0.61	5.5	23	0.02 L
48	R-35	REDMOND WELL #5	05/16/90	2	1 L	180	89	70	1 L	70	1 L	5 L	20	0.01 L	0.012	9.5	2.4	12	26	0.02 L
53	R-37	REDMOND WELL #2	05/16/90	1 L	1 L	196	63	68	1 L	68	1 L	5 L	15	0.01 L	0.025	11	1.6	9.5	26	0.02
40	D-32	OLYMPIAN PRECAST	05/17/90	1 L	1 L	138	48	98	1 L	98	1 L	5 L	13	0.05	0.069	3.4	2.6	26	34	0.06
43	R-26	BARRET, DEL	05/17/90	1 L	1 L	122	54	62	1 L	62	1 L	5 L	12	0.17	0.111	5.8	1.3	9.6	30	0.03
38	R-31	McCLAN, ROBERT	05/17/90	1 L	1 L	106	48	56	1 L	56	1 L	5 L	8.7	0.04	0.066	5.6	1.6	3.5	41	0.02
69	D-33	TUTKO LANDSCAPE	05/17/90	1 L	1 L	260	100	100	1 L	100	1 L	5 L	21	0.15	0.057	12	1.1	13	30	0.02 L
73	R-34	UNION HILL	05/17/90	1 L	1 L	65	46	60	1 L	60	1 L	5 L	10	0.11	0.095	5.6	1.1	6.2	32	0.02
74	D-50	EVANS CREEK WELL #2	05/17/90	17	1 L	92	65	52	1 L	52	1 L	5 L	11	28	0.374	9.2	2	5.9	56	0.06
64	R-51	EVANS CREEK WELL #1	05/17/90	110	1 L	220	2300	170	1 L	170	1 L	23	260	1000	13	400	135	100	300	3.2
14	R-12	THENOS DAIRY	05/17/90	1 L	1 L	590	47	300	1 L	300	1 L		7.6	0.46	0.06	6.7	12	130	47	0.03
40	R-32	OLYMPIAN PRECAST	05/17/90	1 L	1 L	180	50	100	1 L	100	1 L		14	0.11	0.084	3.6	2.3	28	36	0.02
43	R-28	BARRETT, DEL	12/06/89	1 L	1 L	166	59	68	1 L	68	1 L	5 L	13	0.71	0.078	8.4	2.6	9.3	24	0.054
4	R-1	BONDO, PAUL	12/06/89	1 L	1 L	120	42	39	1 L	39	1 L	5 L	7.6	0.01 L	0.002 L	5.5	1.3	4.6	24	0.12
29	RD-5	GOSS, GORDON DUPL	12/06/89	1 L	1 L	74	42	40	1 L	40	1 L	16	7.7	0.04	0.002 L	5.6	1.2	4.7	24	0.121
38	RD-73	McCLAN, ROBERT DUPL	12/06/89	1 L	1 L	178	48	52	1 L	52	1 L	5 L	9.5	0.29	0.049	5.8	2.3	4.6	32	0.374

Table 7.12 Summary of Ground Water Quality Analytical Results

Well ID (map)	Sample Number	Well Name	Sampling Date	Total Coliforms (MPN/100ml)	Fecal Coliforms (MPN/100ml)	TDS (mg/l)	Total Hardness (mg/l as CaCO3)	Total Alkalinity (mg/l as CaCO3)	Carbonate Alkalinity (mg/l as CaCO3)	Bicarbonate Alkalinity (mg/l as CaCO3)	Hydroxide Alkalinity (mg/l as CaCO3)	TOX (ug/l)	Calcium (mg/l)	Iron (mg/l)	Manganese (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Silica (mg/l)	Zinc (mg/l)
69	R-33	TUTKO LANDSCAPE	12/06/89	1 L	1 L	160	63	68	1 L	68	1 L	5 L	19	0.32	0.012	11	1.9	9.6	26	0.032
73	R-34	UNION HILL	12/06/89	1 L	1 L	148	48	58	1 L	58	1 L	5 L	10	0.15	0.077	5.6	1.8	5.1	24	0.021
51	RD-17	CEDAR LAWNS DUPL	12/05/89	1 L	1 L	66	84	56	1 L	56	1 L	11	19	2	0.068	8.8	1.5	10	21	0.139
33	R-18	HOME PORT FARM	12/05/89	1 L	1 L	78	73	107	1 L	107	1 L	5 L	18	0.16	0.065	6.8	4.1	17	26	0.014
23	R-8	LEIN, WILLIAM	12/05/89	1 L	1 L	144	33	103	1 L	103	1 L	5 L	6.7	0.1	0.025	3.9	5.6	26	30	0.018
79	RD-67	NE SAMMAMISH #3 DUPL	12/05/89	1 L	1 L	100	66	63	1 L	63	1 L	5 L	21	0.01 L	0.021	3.3	1.2	6	18	0.014
76	R-25	NE SAMMAMISH #2	12/05/89	1 L	1 L	80	48	56	1 L	56	1 L	5 L	9.8	0.14	0.003	5.8	1.7	4.6	21	0.016
62	R-22	SPORTSMAN PARK	12/05/89	19	1 L	96	66	76	1 L	76	1 L	5 L	16	1.4	0.065	13	2.9	7.3	14	0.055
29	R-5	GOSS, GORDON	12/04/89	11	1 L	202	32	131	1 L	131	1 L	5 L	6.6	0.01 L	0.019	2.5	2.9	48	17	0.006
10	R-11	TAINTER, GORDON	12/04/89	1	1 L	114	42	49	1 L	49	1 L	5 L	6.7	0.18	0.062	4.9	1.1	5.3	21	0.14
13	R-9	NELSON, GORDON	12/04/89	1 L	1 L	156	70	60	1 L	60	1 L	5 L	10	0.04	0.002 L	11	2.2	6.2	30	0.106
13	RD-9	NELSON, GORDON DUPL	12/04/89	1 L	1 L	166	70	60	1 L	60	1 L	5 L	10	0.01 L	0.002 L	11	2.3	6.2	15	0.14
12	R-21	SHARPE, GRANT	12/04/89	116	1 L	182	128	114	1 L	114	1 L	14	20	2.1	0.055	19	2.8	8.1	15	0.246
14	R-12	THENOS DAIRY	12/04/89	1 L	1 L	346	42	268	1 L	268	1 L	7	6.6	0.28	0.044	6	12	110	19	0.018
7	R-6	HOSEY #1	12/04/89	1 L	1 L	91	56	52	1 L	52	1 L	5 L	9.5	0.64	0.017	6.3	1 L	5	23	0.215
6	R-7	KLOEPFER, RYAN	12/04/89	1 L	1 L	105	52	56	1 L	56	1 L	13	8	0.47	0.002 L	7.8	1.2	5.2	28	0.316
5	R-10	ODEGARD, DAVID	12/04/89	21	1 L	80	32	36	1 L	36	1 L	5 L	7.6	0.17	0.002 L	3.1	1 L	4.5	23	0.067
27	R-14	WEBSTER, WALT	12/04/89	1 L	1 L	141	51	128	1 L	128	1 L	5 L	13	0.14	0.056	4.5	4.4	34	32	0.013
53	R-37	REDMOND WELL #2	12/04/89	1 L	1 L	129	69	64	1 L	64	1 L	5 L	16	0.01 L	0.003	12	2.1	6.3	20	0.022
48	R-35	REDMOND WELL #5	12/04/89	1	1 L	114	86	68	1 L	68	1 L	6	19	0.01 L	0.002 L	9.3	2.3	13	23	0.02
35	R-16	BOWMAN, CARL	12/04/89	1 L	1 L	89	62	74	1 L	74	1 L	5 L	15	0.31	0.038	6	2.3	7.6	25	0.066
77	R-27	NE SAMMAMISH #4	12/05/89	1 L	1 L	90	63	65	1 L	65	1 L	5 L	19	0.01 L	0.025	3.7	1 L	5.4	19	0.01
79	R-26	NE SAMMAMISH #3	12/05/89	1 L	1 L	88	66	62	1 L	82	1 L	5 L	21	0.01 L	0.02	3.4	1.2	6	16	0.011
61	R-19	CAMPTON COMMUNITY	12/05/89	1 L	1 L	166	100	71	1 L	71	1 L	15	22	0.01 L	0.004	11	2.2	9.1	22	0.016
51	R-17	CEDAR LAWNS	12/05/89	1 L	1 L	120	84	56	1 L	56	1 L	5 L	19	2	0.069	6.8	1.9	10	21	0.145
34	R-20	PATTERSON, STAN	12/05/89	1 L	1 L	96	55	62	1 L	62	1 L	5 L	14	0.19	0.032	4.9	2.9	13	26	0.027
21	R-23	STERN, WILLIAM	12/05/89	1 L	1 L	66	59	61	1 L	61	1 L	5 L	12	0.11	0.105	7.1	2.5	4.6	30	0.059
16	R-24	ULRICH MEATS	12/05/89	1 L	1 L	185	32	265	1 L	265	1 L	5 L	4.7	0.27	0.037	4.8	9.4	110	39	0.019
20	R-13	WEIDE, MIKE	12/06/89	1 L	1 L	92	55	62	1 L	62	1 L	5 L	8.7	0.65	0.036	8.1	2.7	4.9	24	0.018
40	R-32	OLYMPIAN PRECAST	12/06/89	1 L	1 L	210	47	100	1 L	100	1 L	5 L	13	0.01 L	0.055	3.6	3.4	23	26	0.017
41	R-30	KING C. SHOPS	12/06/89	1 L	1 L	196	63	72	1 L	72	1 L	20	14	0.01 L	0.002 L	6.6	2.7	9	22	0.052
36	R-31	McCLAN, ROBERT	12/06/89	1 L	1 L	136	47	60	1 L	60	1 L	5 L	9.3	0.14	0.047	5.7	2.8	4.6	32	0.304
1	R-3	DOUGHTY, LEE	12/07/89	1 L	1 L	92	61	56	1 L	56	1 L	5 L	9.6	0.01 L	0.002 L	9.1	1.6	6.4	26	0.0004 ???
3	R-4	PARADISE PARK	12/12/89	1 L	1 L	130	55	60	1 L	60	1 L	5 L	13	0.31	0.167	5.5	2.1	10	34	0.04

Table 7.12 Summary of Ground Water Quality Analytical Results

Well ID (MAP)	Sample Number	Well Name	Sampling Date	Silver (mg/l)	Selenium (mg/l)	Mercury (mg/l)	Barium (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Lead (mg/l)	Chromium (mg/l)	Arsenic (mg/l)	Chloride (mg/l)	Nitrite (mg/l)	Sulfate (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	Antimony (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Thallium (mg/l)	Cyanide (mg/l)	Phenol (mg/l)
41	D-30	KING C. SHOPS DUPL	05/14/90	0.01 L	0.001 L	0.0002 L	0.007	0.062	0.002 L	0.001	0.006 L	0.002	8.1	0.5 L	24	3.1	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
6	R-7	KLOEPFER, RYAN	05/14/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.005	0.006 L	0.002	3.7	0.5 L	8.4	0.85	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
61	R-16	CAMPTON COMMUNITY	05/14/90	0.01 L	0.001 L	0.0002 L	0.009	0.002 L	0.002 L	0.001	0.006 L	0.001	8.5	0.5 L	42	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
51	R-17	CEDAR LAWNS	05/14/90	0.01 L	0.001 L	0.0002 L	0.009	0.017	0.002 L	0.009	0.006 L	0.001	7.6	0.5 L	30	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
41	R-30	KING C. SHOPS	05/14/90	0.01 L	0.001 L	0.0002 L	0.008	0.061	0.002 L	0.001	0.006 L	0.003	5.9	0.5 L	24	3.1	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
	S-11	TRIP BLANKS	05/14/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.001	0.5 L	0.5 L	0.5 L	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.003 L	0.005 L
29	R-5	GOSS, GORDON	05/14/90	0.01 L	0.001 L	0.0002 L	0.005	0.002 L	0.002 L	0.001	0.006 L	0.025	2	0.5 L	0.5 L	0.2 L	0.2 L						
13	R-9	NELSON, GORDON	05/14/90	0.01 L	0.001 L	0.0002 L	0.004	0.002 L	0.002 L	0.001	0.006 L	0.004	4.4	0.5 L	9.6	3.6	0.2 L						
10	R-11	TAINTER, GORDON	05/14/90	0.01 L	0.001 L	0.0002 L	0.004	0.003	0.002 L	0.008	0.006 L	0.008	2.1	0.5 L	1.8	0.2 L	0.2 L						
20	R-13	WEIDE, MIKE	05/14/90	0.01 L	0.001 L	0.0002 L	0.02	0.002 L	0.002 L	0.008	0.006 L	0.027	2.5	0.5 L	14	0.2 L	0.2 L						
18	R-24	ULRICH MEATS	05/14/90	0.01 L	0.001 L	0.0002 L	0.043	0.126	0.002 L	0.01	0.014	0.004	2.6	0.5 L	0.5 L	0.2 L	0.2 L						
3	D-4	PARADISE PARK DUPL	05/15/90	0.01 L	0.001 L	0.0002 L	0.016	0.002 L	0.002 L	0.001	0.006 L	0.001	3.9	0.5 L	4.6	0.2 L	0.2 L						
1	R-3	DOUGHTY, LEE	05/15/90	0.01 L	0.001 L	0.0002 L	0.004	0.002 L	0.002 L	0.001	0.006 L	0.002	3.6	0.5 L	5.1	1.3	0.2 L						
3	R-4	PARADISE PARK	05/15/90	0.01 L	0.001 L	0.0002 L	0.016	0.002 L	0.002 L	0.015	0.006 L	0.001	3.7	0.5 L	4.4	0.2 L	0.2 L						
4	R-1	BONDO, PAUL	05/15/90	0.01 L	0.001 L	0.0002 L	0.008	0.002 L	0.002 L	0.001	0.006 L	0.005	10	0.5 L	75	1.3	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
12	R-21	SHARP, GRANT	05/15/90	0.01 L	0.001 L	0.0002 L	0.015	0.004	0.002 L	0.13	0.014	0.007	7.9	0.5 L	8.1	3.6	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
7	R-08	HOSEY #1	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.005	0.002 L	0.008	0.006 L	0.002	2.9	0.5 L	8.3	1.6	0.2 L						
5	R-10	ODEGARD, DAVID	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.005	0.002 L	0.002	0.006 L	0.001 L	2.9	0.5 L	3.5	2.6	0.2 L						
27	R-14	WEBSTER, WALT	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.01	0.002 L	0.002	0.006 L	0.004	1.8	0.5 L	0.5 L	0.2 L	0.2 L						
34	R-20	PATTERSON, STAN	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.001 L	1.9	0.5 L	2.9	0.2 L	0.2 L						
21	R-23	STERN, WILLIAM	05/15/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.001	2.2	0.5 L	9	0.2 L	0.2 L						
77	D-27	NE SAMMAMISH #4 DUPL	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.002	0.006 L	0.009	2	0.5 L	2.2	0.2 L	0.2 L						
23	R-6	LEIN, WILLIAM	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.002	0.006 L	0.001 L	1.3	0.5 L	0.5 L	0.2 L	0.2 L						
35	R-15	BOWMAN, CARL	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.016	0.005 L	0.001	2	0.5 L	4	0.2 L	0.2 L						
33	R-18	HOME PORT FARM	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.023	2.6	0.5 L	2.4	0.2 L	0.2 L						
62	R-22	SPORTSMAN PARK	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.001	0.006 L	0.003	10	0.5 L	23	0.2 L	0.2 L						
78	R-25	NE SAMMAMISH #2	05/16/90	0.01 L	0.001 L	0.0002 L	0.059	0.008	0.002 L	0.017	0.006 L	0.003	2.5	0.5 L	2.3	0.2	0.2 L						
79	R-26	NE SAMMAMISH #3	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.003	0.002 L	0.001	0.006 L	0.01	2	0.5 L	0.8	0.2 L	0.2 L						
77	R-27	NE SAMMAMISH #4	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.002	0.006 L	0.009	2	0.5 L	2.2	0.2 L	0.2 L						
48	R-35	REDMOND WELL #5	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.008	0.002 L	0.001	0.006 L	0.002	1.7	0.5 L	1.4	0.4	0.2 L						
53	R-37	REDMOND WELL #2	05/16/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.017	0.002 L	0.003	0.006 L	0.001	10	0.5 L	9	2	0.2 L						
40	D-32	OLYMPIAN PRECAST	05/17/90	0.01 L	0.001	0.0002 L	0.003 L	0.002 L	0.002 L	0.003	0.006 L	0.005	1.8	0.5 L	1.8	0.2 L	0.2 L						
43	R-26	BARRET, DEL	05/17/90	0.01 L	0.001	0.0002 L	0.003 L	0.002 L	0.002 L	0.008	0.006 L	0.001	3.9	0.5 L	6.5	0.31	0.2 L						
38	R-31	McCLAN, ROBERT	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.003	0.006 L	0.012	1.3	0.5 L	4.6	0.2 L	0.2 L						
69	D-33	TUTKO LANDSCAPE	05/17/90	0.01 L	0.001 L	0.0002	0.003 L	0.004	0.002 L	0.001	0.006 L	0.001	15	0.5 L	22	0.59	0.2 L						
73	R-34	UNION HILL	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.005	1.7	0.5 L	7.3	0.2 L	0.2 L						
74	D-50	EVANS CREEK WELL #2	05/17/90	0.01 L	0.001 L	0.0002 L	0.1	0.055	0.002 L	0.026	0.022	0.016	2.1	0.5 L	7.7	0.2 L	0.2 L						
84	R-51	EVANS CREEK WELL #1	05/17/90	0.01 L	0.008	0.0026	5.4	1.5	0.002 L	0.31	1.3	0.43	10	0.5 L	40	0.2 L	0.2 L						
14	R-12	THENOS DAIRY	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.008	0.002 L	0.001 L	0.006 L	0.003	6.3	0.5 L	6.6	0.2 L	0.2 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
40	R-32	OLYMPIAN PRECAST	05/17/90	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.001	0.006 L	0.005	2.7	0.1 L	1.8	0.1 L	0.1 L	0.02 L	0.005 L	0.01 L	0.001 L	0.005 L	0.005 L
43	R-28	BARRETT, DEL	12/06/89	0.01	0.001 L	0.0002 L	0.012	0.002 L	0.002 L	0.005	0.013	0.001	6.68	0.1 L	5.7	0.369	0.1 L						
4	R-1	BONDO, PAUL	12/06/89	0.01 L	0.001 L	0.0002 L	0.008	0.002 L	0.002 L	0.001	0.015	0.003	3.21	0.1 L	7.76	0.77	0.1 L						
29	RD-5	GOSS, GORDON DUPL	12/06/89	0.01 L	0.001 L	0.0002 L	0.008	0.002 L	0.002 L	0.001	0.014	0.003	7.29	0.1 L	7.48	0.77	0.1 L						
38	RD-73	McCLAN, ROBERT DUPL	12/06/89	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.002	0.011	0.009	2.4	0.1 L	3.8	0.1 L	0.1 L						

Table 7.12 Summary of Ground Water Quality Analytical Results

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Well ID (MAP)	Sample Number	Well Name	Sampling Date	Silver (mg/l)	Selenium (mg/l)	Mercury (mg/l)	Barium (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Lead (mg/l)	Chromium (mg/l)	Arsenic (mg/l)	Chloride (mg/l)	Nitrite (mg/l)	Sulfate (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)	Antimony (mg/l)	Beryllium (mg/l)	Nickel (mg/l)	Thallium (mg/l)	Cyanide (mg/l)	Phenol (mg/l)
69	R-33	TUTKO LANDSCAPE	12/08/89	0.01 L	0.001 L	0.0002 L	0.006	0.014	0.002 L	0.002	0.015	0.001 L	16	0.1 L	9.9	3.5	0.1 L						
73	R-34	UNION HILL	12/08/89	0.01	0.001 L	0.0002 L	0.007	0.002 L	0.002 L	0.002	0.012	0.004	3.4	0.1 L	6.1	0.1 L	0.1 L						
51	RD-17	CEDAR LAWNS DUPL	12/05/89	0.01 L	0.001 L	0.0002 L	0.009	0.108	0.002 L	0.005	0.009	0.001	10	0.1 L	67	1 L	1 L						
33	R-18	HOME PORT FARM	12/05/89	0.01 L	0.001 L	0.0002 L	0.017	0.018	0.002 L	0.001 L	0.009	0.024	4.2	0.1 L	3.9	1 L	1 L						
23	R-6	LEIN, WILLIAM	12/05/89	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001 L	0.007	0.001 L	2.1	0.26	0.2 L	0.1 L	0.1 L						
79	RD-67	NE SAMMAMISH #3 DUPL	12/05/89	0.01 L	0.001 L	0.0002 L	0.006	0.007	0.002 L	0.001 L	0.006	0.003	2	0.33	1.5	0.1 L	0.1 L						
76	R-25	NE SAMMAMISH #2	12/05/89	0.01	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.003	0.012	0.003	2.3	0.1 L	3.6	0.32	0.1 L						
62	R-22	SPORTSMAN PARK	12/05/89	0.01 L	0.001 L	0.0002 L	0.016	0.005	0.002 L	0.002	0.012	0.003	2.4	0.1 L	52	1.7	1 L						
29	R-5	GOSS, GORDON	12/04/89	0.01 L	0.001 L	0.0002 L	0.005	0.002 L	0.002 L	0.001 L	0.008 L	0.027	2	0.1 L	0.46	0.1 L	0.1 L						
10	R-11	TAINTER, GORDON	12/04/89	0.01 L	0.001	0.0002	0.003	0.006	0.002 L	0.001	0.009 L	0.005	2.1	0.1 L	2.7	0.1 L	0.1 L						
13	R-9	NELSON, GORDON	12/04/89	0.01 L	0.001 L	0.0002	0.004	0.004	0.002 L	0.001 L	0.01	0.004	5.9	0.1 L	10	2.7	0.1 L						
13	RD-9	NELSON, GORDON DUPL	12/04/89	0.01 L	0.001 L	0.0002 L	0.004	0.002 L	0.002 L	0.001	0.006 L	0.004	5.8	0.1 L	10	2.7	0.1 L						
12	R-21	SHARPE, GRANT	12/04/89	0.01 L	0.001 L	0.0003	0.02	0.031	0.002 L	0.33	0.042	0.011	8.8	0.1 L	13	3.8	0.1 L						
14	R-12	THENOS DAIRY	12/04/89	0.01 L	0.001 L	0.0002 L	0.007	0.02	0.002 L	0.004	0.006 L	0.002	4.7	0.1 L	0.2 L	0.1 L	0.1 L						
7	R-8	HOSEY #1	12/04/88	0.01 L	0.001 L	0.0002 L	0.003 L	0.002 L	0.002 L	0.005	0.01	0.002	3.5	0.1 L	7.7	1.4	0.1 L						
6	R-7	KLOEPFER, RYAN	12/04/89	0.01 L	0.001 L	0.0002	0.003	0.01	0.002 L	0.002	0.014	0.003	4	0.1 L	8.5	1	0.1 L						
5	R-10	ODEGARD, DAVID	12/04/89	0.01 L	0.001 L	0.0002 L	0.004	0.006	0.002 L	0.001	0.006	0.001 L	2.9	0.1 L	4.1	0.67	0.1 L						
27	R-14	WEBSTER, WALT	12/04/88	0.01 L	0.001 L	0.0002 L	0.006	0.01	0.002 L	0.001	0.01	0.003	1.9	0.1 L	1.5	0.1 L	0.1 L						
53	R-37	REDMOND WELL #2	12/04/88	0.01 L	0.001 L	0.0002 L	0.009	0.013	0.002 L	0.002	0.006	0.001	6.7	0.1 L	12	1.5	0.1 L						
46	R-35	REDMOND WELL #5	12/04/89	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001	0.006	0.002	12	0.1 L	12	1.3	0.1 L						
35	R-15	BOWMAN, CARL	12/04/89	0.01 L	0.001 L	0.0003	0.011	0.002 L	0.002 L	0.001	0.006 L	0.001	2.5	0.1 L	5.6	0.1 L	0.1 L						
77	R-27	NE SAMMAMISH #4	12/05/89	0.01 L	0.001 L	0.0002 L	0.004	0.007	0.002 L	0.002	0.011	0.008	2.3	0.33	0.1 L	0.1 L	0.1 L						
79	R-26	NE SAMMAMISH #3	12/05/89	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001	0.006	0.007	2	0.32	1.6	0.1 L	0.1 L						
61	R-16	CAMPTON COMMUNITY	12/05/89	0.01 L	0.001 L	0.0002 L	0.011	0.006	0.002 L	0.001 L	0.01	0.001 L	11	1 L	62	0.24	1 L						
51	R-17	CEDAR LAWNS	12/05/89	0.01 L	0.001 L	0.0002 L	0.006	0.119	0.002	0.006	0.011	0.001	11	1 L	41	0.65	1 L						
34	R-20	PATTERSON, STAN	12/05/89	0.01 L	0.001 L	0.0002 L	0.012	0.005	0.002 L	0.001 L	0.005	0.001 L	2.7	1 L	50	1 L	1 L						
21	R-23	STERN, WILLIAM	12/05/89	0.01 L	0.001 L	0.0002 L	0.006	0.002 L	0.002 L	0.001 L	0.009	0.002	2.5	1 L	12	1 L	1 L						
16	R-24	ULRICH MEATS	12/05/89	0.01 L	0.001 L	0.0002 L	0.005	0.017	0.002 L	0.001	0.007	0.003	3.3	0.6	0.1 L	0.1 L	0.45						
20	R-13	WEIDE, MIKE	12/08/89	0.01 L	0.001 L	0.0002 L	0.01	0.013	0.002 L	0.001 L	0.009	0.003	13	0.1 L	15	0.1 L	0.1 L						
40	R-32	OLYMPIAN PRECAST	12/06/89	0.01	0.001 L	0.0002 L	0.011	0.013	0.002 L	0.001 L	0.012	0.004	5.2	0.1 L	1.4	0.1 L	0.1 L						
41	R-30	KING C. SHOPS	12/06/89	0.01	0.001 L	0.0003	0.005	0.024	0.002 L	0.001 L	0.012	0.003	7.8	0.1 L	8.6	0.1 L	0.1 L						
36	R-31	McCLAN, ROBERT	12/06/89	0.01	0.001 L	0.0002 L	0.007	0.006	0.002 L	0.001	0.015	0.009	2.4	0.1 L	3.9	0.1 L	0.1 L						
1	R-3	DOUGHTY, LEE	12/07/89	0.01 L	0.001 L	0.0002 L	0.005	0.002 L	0.002 L	0.001	0.014	0.002	15	0.1 L	7.5	1.8	0.1 L						
3	R-4	PARADISE PARK	12/12/89	0.01 L	0.001 L	0.0002 L	0.017	0.002 L	0.002 L	0.002	0.006 L	0.001 L	2.6	0.1 L	7.5	0.1 L	0.1 L						

Note: Well number corresponds to numbers on map in Figure 5-1.
mg/l = milligrams per liter (parts per million).
L = laboratory method reporting limit.

Table 7.13 Analyte Classifications and Standards

Analyte	National Primary Drinking Water MCL[a] (mg/l)	National Secondary Drinking Water MCL[b] (mg/l)	Ground Water Characteristic Constituent	Priority Pollutant	Regulated Pollutant
Alkalinity					
Total	NR	NR	Yes	No	No
Bicarbonate	NR	NR	Yes	No	No
Carbonate	NR	NR	Yes	No	No
Hydroxide	NR	NR	Yes	No	No
Arsenic	0.05	NR	No	Yes	Yes
Barium	1	NR	No	No	Yes
Beryllium	NR	NR	No	Yes	No
Cadmium	0.010	NR	No	Yes	Yes
Calcium	NR	NR	Yes	No	No
Chloride	NR	250	Yes	No	No
Chlorinated Pesticides and PCBs	[c]	NR	Yes	No	Yes
Chromium	0.05	NR	No	Yes	Yes
Coliforms					
Total	1/100 ml	NR	No	No	Yes
Fecal	1/100 ml	NR	No	No	Yes
Copper	NR	1	No	Yes	No
Cyanide	NR	NR	No	Yes	No
Fluoride	4.0	2.0[d]	Yes	No	Yes
Iron	NR	0.3	Yes	No	No
Lead (at tap)	0.05	NR	No	Yes	Yes
Magnesium	NR	NR	Yes	No	No
Manganese	NR	0.05	No	No	No
Mercury	0.002	NR	No	Yes	Yes
Nickel	NR	NR	No	Yes	Yes
Nitrate (as N)	10	NR	Yes	No	Yes
Nitrite (as N)	NR	NR	No	No	Yes

Table 7.13 Analyte Classifications and Standards

Analyte	National Primary Drinking Water MCL[a] (mg/l)	National Secondary Drinking Water MCL[b] (mg/l)	Ground Water Characteristic Constituent	Priority Pollutant	Regulated Pollutant
Nitrate + Nitrite (as N)	NR	NR	No	No	Yes
Phenol	NR	NR	No	Yes	Yes
Potassium	0.01	NR	No	Yes	Yes
Selenium	NR	NR	Yes	No	No
Semivolatile Organic Compounds (BNAs)	[c]	NR	No	No	Yes
Silica	NR	NR	Yes	No	No
Silver	0.05	NR	No	Yes	Yes
Sodium	NR	NR	Yes	No	No
Sulfate	NR	250	Yes	No	No
Thallium	NR	NR	No	Yes	No
Total Dissolved Solids	NR	500	No	No	No
Total Hardness	NR	NR	Yes	No	No
Total Organic Halides (TOX)	NR[e]	NR	No	No	No[e]
Volatile Organic Compounds (VOCs)					
Acetone	NR	NR	No	No	Yes
Carbon Tetrachloride	0.005[f]	NR	No	No	Yes
Others	[c]	NR	No	No	Yes
Zinc	NR	5	No	Yes	No

NOTES:
- MCL Maximum Contaminant Level permitted under federal law.
- mg/l micrograms per liter (parts per million)
- NR Not Regulated

a These values are exactly aqual to the Washington State Primary Drinking Water Contaminant Criteria and Primary Ground Water Contaminant Criteria.
b These values are exactly equal to the Washington State Secondary Drinking Water Contaminant Criteria and Secondary Ground Water Contaminant Criteria unless otherwise noted.
c MCL depends upon specific analyte.
d Washington State has no secondary ground water contaminant criterion for fluoride.
e Although concentrations of TOX are not regulated as TOX, the concentrations of some individual organic halides which contribute to the total concentration are regulated under National Interim Primary Drinking Water Regulations.
f The Washington State ground water quality standard for carbon tetrachloride is 0.0003 mg/l.

Table 8.1 Hydrologic Budget for RBC-GWMA Study Area

Item	Recharge[a] (acre-feet/year)	Ground Water Loss[a] (acre-feet/year)
Precipitation - Average	112,000	--
Ground Water Extraction	--	--
City of Redmond	--	4,000
Rural Uppermost Aquifer Area	--	360
Water Loss to Surface Water	--	35,000
Evapotranspiration	--	64,000
Surface Runoff - Precipitation	--	13,300
Wastewater Recycling	--	--
Rural Uppermost Aquifer Area	1,465	--
Flux (ground water under flow)	--	--
Out of Uppermost Aquifer Area	--	1,626
Into Uppermost Aquifer Area	4,821	--
TOTAL	118,286	118,286

[a] Refer to sections 7.2 through 7.4 for discussion on value determination

Area Characterization

Figures

Redmond-Bear Creek Valley
Ground Water Management Plan

February 1999