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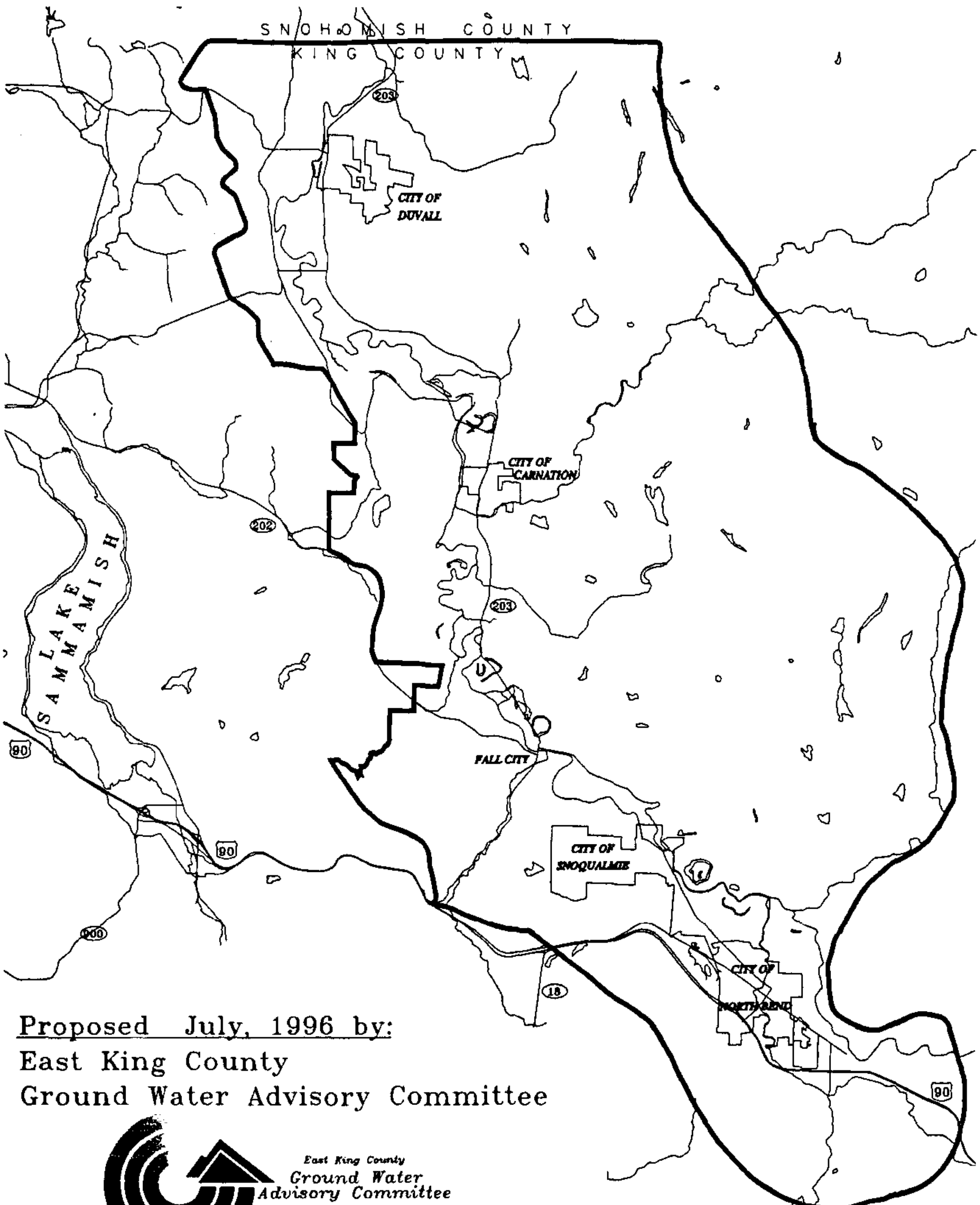
East King County Ground Water Management Plan
Supplement 1 - Area Characterization



Proposed July, 1996 by:
East King County
Ground Water Advisory Committee

East King County
Ground Water
Advisory Committee

98190982

Draft

East King County Ground Water Management Plan Supplement I

July 1996

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East King County Ground Water Advisory Committee

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Area Characterization

1.0 INTRODUCTION

This Area Characterization provides a description of the geology and hydrogeology in the East King County Ground Water Management Area (see Figure 1.1.). Also addressed in this report are issues pertaining to ground water quality, ground water supply and demand, purveyors of ground water, and impacts of land use on ground water. The Area Characterization is a compilation of information from previous ground water investigations in the East King County Ground Water Management Area and data collection activities included as part of this ground water planning program. The new data presented in this Area Characterization include summaries from the United States Geological Survey *Geohydrology and Ground-Water Quality of East King County* (1995) and field data collection completed subsequent to the U.S. Geological Survey work.

This introduction presents the boundaries of the East King County Ground Water Management Area and summarizes data collection activities conducted as part of this project. Section 2.0 identifies and describes the various federal, state, and local agencies which have political jurisdiction over the East King County Ground Water Management Area. Section 3.0 describes the physical geography such as climate, topography, and drainage. The plans and policies affecting the ground water resource, present and future land use impacts, and conclusions regarding the impacts of land use on ground water quality and quantity are discussed in Section 4.0. Section 5.0 addresses water applications including water use, water rights, services, and current and projected supply and demand. Section 6.0 discusses geology, hydrogeology, new wells drilled, geophysical surveys, data collection, ground water quality and conclusions. Also presented in Section 6.0 is a water balance for the area and recommendations for protecting the ground water resource. Background information and data are included as Appendices, some of which are available upon request.

1.1 Project Area

The East King County Ground Water Management Area, shown in Figure 1.1., encompasses approximately 225 square miles in the north central portion of King County. It is bounded on the north by the Snohomish county line; on the west by the Sammamish and Union Hill Plateaus (the eastern boundaries of the Redmond-Bear Creek and Issaquah Creek Valley Ground Water Management Areas); on the east by the Cascade mountain foothills; and on the south by Rattlesnake Mountain and the topographic divide between the Snoqualmie and Cedar River watersheds (see Figure 1.2.). Four small cities (Snoqualmie, North Bend, Carnation and Duvall), the incorporated communities of Fall City and Preston, low density rural areas, forestry and agriculture comprise most land use in the East King County Ground Water Management Area.

The boundaries of the East King County Ground Water Management Area were revised in March 1996 at the request of the Sammamish Plateau Water and Sewer District. As a result of the boundary change, the entire service area for the Sammamish Plateau Water and Sewer District was placed in the Issaquah Creek Valley Ground Water Management Area, and much of the Plateau area is no longer located within the East King boundary. It should be noted that data summarized from the 1995 U.S. Geological Survey report (*Geohydrology and Ground Water Quality of East King County*) include information from the Sammamish Plateau area.

Three distinct physiographic features lie within the area, the Snoqualmie River Valley, the very eastern portions of the Sammamish and Union Hill Plateaus, and the Cascade mountain foothills (see Figure 1.3.). The Snoqualmie River is a north-south trending river valley along a central corridor, supporting the majority of the East King County Ground Water Management Area population and commerce. The Sammamish and Union Hill Plateaus, of which the easternmost portions forms the western boundary of the East King County Ground Water Management Area, are upland areas located east of Lake Sammamish. The Cascade mountain foothills comprise the eastern portion of the study area from the Snohomish/King County border southward to the topographic divide between the South Fork of the Snoqualmie and Cedar River watersheds.

1.2 Data Collection Program

Due to the lack of available hydrogeologic data in the East King County study area, a primary focus of the East King County Ground Water Management Program was to collect appropriate information that would lead to a better understanding of the subsurface in this area. The Phase I data collection program involved collection of ground water quality and quantity, rainfall, and stream flow data. Phase II of the data collection program for the East King County Ground Water Management Area included continuation of some Phase I data collection activities, and also involved a geophysical study and a well drilling study, conducted to obtain a better understanding of the area hydrogeology in the vicinity of the Lower Snoqualmie River Valley.

1.2.1 Phase I Data Collection

The U.S. Geological Survey collected data from a network of public and privately owned water wells as part of Phase I data collection activities. These activities are described in the "Data Collection and Analysis Plan for East King County, Washington, Ground Water Management Area Study", dated July 1, 1991. This technical document specifies the types of data to be collected, the frequency of collection, the location of monitoring sites, and the rationale for collection of specific data. The data collection objectives as expressed in the Quality Assurance portion of this document are to:

- Describe and quantify the ground water system to the extent allowed using available data and readily collectable data. All data was to be collected and analyzed using standard U.S. Geological Survey procedures outlined in their Techniques of Water Resources Investigations manuals.

- Determine the general water chemistry of the significant aquifers, and describe regional patterns of pollution from on-site sewage systems, agriculture, and if they exist, from other sources.
- Evaluate the general potential for ground water development in terms of aquifer characteristics, interaction with surface water bodies, and recharge.
- Determine what additional data and analyses would be needed to quantify the ground water availability in the area.

The U.S. Geological Survey interpreted water quality and quantity information from a collection of 604 wells logs (approximately 20 percent of the total in the area) and six springs (an unknown number of springs exist in the area) in the East King County Ground Water Management Area. Of the 604 well locations, ground water levels were physically measured in 475 wells (340 wells were identified as being completed in one of four different aquifers). Following this initial inventory, 42 well locations were selected to be monitored monthly over a year and a half time period. Additionally, the U.S. Geological Survey tested the water quality of 121 wells and three springs during July and August, 1991. The results of these data collection activities are discussed in Section 6.7., Ground Water Quality.

The methodology used to obtain ground water quality and quantity data by the U.S. Geological Survey and the Seattle-King County Health Department was in accordance with the Washington State Department of Ecology Data Collection and Analysis Plan (DCAP) and Quality Assurance Plan (QAP).

1.2.2 Phase II Data Collection: Geophysical and Well Drilling Studies

The U.S. Geological Survey Technical Report (1995), prepared as part of Phase I of the East King County Ground Water Management Area program, presents a generalized conceptual model of the location of the aquifers, the ground water flow system, water use, ground water level fluctuations, and the water quality characteristics of the principal hydrogeologic units. The report identifies three areas where data gaps occur: the Lower Snoqualmie River Valley; the Sammamish Plateau; and the Cascade Foothills (Upper Snoqualmie Valley) (see Figure 1.3.). In order to address these data "gaps" identified in the U.S. Geological Survey Phase I study, the Phase II study assessed ground water quality and quantity using the following methods:

- Water Level Monitoring
- Water Quality Sampling
- Geophysical Testing
- Resource Protection Well Installation

Ground water levels continued to be measured monthly at a network of 40 well sites, and water quality samples were collected quarterly from 22 wells by the Seattle-King County Health Department personnel (see Figure 1.4.). The Seattle-King County Health

Department continued the data collection activities that were initiated by the U.S. Geological Survey. The water quality and quantity data collected by the Seattle-King County Health Department generated additional information required to understand seasonal ground water trends.

In addition to the water quality and quantity monitoring, the Seattle-King County Health Department coordinated a geophysical and well drilling study in the Carnation area (see Figure 1.5.). The geophysics and well drilling in the Carnation area expanded on the work completed by the U.S. Geological Survey in an attempt to more accurately characterize subsurface conditions. This subsurface investigation was part of Phase II of the Ground Water Management Area Program for East King County, funded under Centennial Clean Water Fund Grant Agreement TAX91048.

The geophysical assessment of the East King County Ground Water Management Area, conducted by Golder Associates, Inc., identified subsurface response to resistivity and involved the installation of one resource protection well in Carnation. The geologic borehole log obtained from the well installation was used to develop a correlation with geophysical logs, especially at depth, where the geologic conditions in the study area are relatively unknown. Time domain electromagnetics, and both marine and terrestrial seismic data were the geophysical tools employed for identifying types of unconsolidated sediments in the East King County Ground Water Management Area. The primary focus of this study was to characterize the unconsolidated sedimentary geologic units in the Carnation, Washington area. This information was used to provide the following:

- Potential ground water resource availability.
- Ground water storage capacity to delineate hydrostratigraphy.
- Depth to bedrock and stratigraphy which can be used for future planning purposes.
- Use as an aid to identify the location of resource protection well(s) for this study and any future study.

The Geophysical study is described in greater detail in Section 6.6, Water Resource Study. Generally, the work included:

- a geophysical plan based on the Quality Assurance Project Plan/Data Collection and Analysis Plan for Phase II;
- a drilling plan to complete the objectives listed in the Quality Assurance Project Plan/Data Collection and Analysis Plan For Phase II including the selection of a site from available lands in East King County; and
- development of a refined Area Characterization Report adding to and amending the March 1995 U.S. Geological Survey report (*Geohydrology and Ground Water Quality of East King County*).

2.0 JURISDICTIONS IN THE EAST KING COUNTY GROUND WATER MANAGEMENT AREA

This section discusses the role of public agencies with jurisdiction in the East King County Ground Water Management Area. The ground water related policies and activities of the agencies in the East King County Ground Water Management Area are organized below by federal, state, county and local agencies, respectively.

2.1 Federal Agencies

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

2.1.1 Environmental Protection Agency

The U.S. Environmental Protection Agency administers numerous programs that influence ground water management in the East King County Ground Water Management Area, 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 deals with water pollution, underground storage tanks, pesticide and herbicide use, liquid waste, landfills, hazardous waste management (including the Comprehensive Environmental Response, Compensation and Liability Act, Superfund Amendments Reauthorization Act of 1986 sites and generators), the Resource Conservation and Recovery Act and drinking water system management. As a support agency, the U.S. Environmental Protection Agency is involved with the regulation of sewage lagoons and holding ponds, sewage waste disposal, biosolids application, spill control and prevention, solid waste handling, storm water runoff, ground water, surface water, wetlands, wells and water rights. The U.S. Environmental Protection Agency administers the Sole Source Aquifer Program, the Pesticides in Ground Water Survey, and the Agricultural Chemical in Ground Water Strategy. The U.S. Environmental Protection Agency also administers the Safe Drinking Water Act which mandates the Washington State Wellhead Protection Program.

2.1.2 U. S. Department of Agriculture

The U.S. Department of Agriculture provides technical assistance to landowners and communities concerning livestock, crops, irrigation design, wildlife, municipal biosolids applications, 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.

Natural Resources Conservation Service

As part of the U.S. Department of Agriculture, the Natural Resources Conservation Service (formerly known as the Soil Conservation Service) provides technical assistance in soil erosion control, pasture management, manure application, and pesticide and herbicide use. It also plays a support role in agriculture, diking, and drainage, forestry, lagoons, surface water, and wetlands. The Natural Resources Conservation Service studies these natural land surface features to assess the physical characteristics of the feature and has completed technical documents regarding its findings.

2.1.3 United States Geological Survey

The United States Geological Survey (U.S. Geological Survey) is a non-regulatory branch of the U.S. Department of the Interior. The U.S. Geological Survey has the major responsibility within the Federal Government for assessing the water resources of the Nation. The availability of plentiful supplies of high quality water is an important consideration in all problems of managing this natural resource. As the largest water resources information agency in the Nation, the U.S. Geological Survey conducts investigations on lakes, streams, reservoirs, river basins, estuaries, aquifer systems, and glaciers. Investigations may include site specific or regional studies on the availability and uses of water and the impact of human activities on the hydrologic environment. In addition, emergency situations such as droughts or floods are monitored and analyzed. The information gathered by the U.S. Geological Survey and their expertise can be called on and has been called on for expert advise in explaining potential quality and quantity concerns. The growing and conflicting demands for water from a variety of users require planners and resource managers at Federal, State, and local levels to establish, and frequently reevaluate, priorities for use. Sound judgment in establishing such priorities depends on access to accurate hydrologic information.

In 1992, the U.S. Geological Survey entered into a cooperative agreement with the Seattle-King County Health Department to conduct a 2-year study of the ground water system in East King County for the East King County Ground Water Management Plan. The study had several objectives:

- describe and quantify the ground water system to the extent allowed using available and readily collectable data;
- describe the general water chemistry of the major hydrogeologic units and any regional patterns of contamination;
- evaluate the general potential for ground water development using aquifer characteristics, ground water interaction with surface water and ground water recharge; and
- determine what additional data are needed to further quantify ground water availability.

As a result of this study the U.S. Geological Survey produced a report entitled "*Geohydrology and Quantity of Ground Water in East King County, Washington*"(1995).

2.2 Washington State Agencies

The following agencies operate at the state level, but influence ground water management at a local level as well. The following discussion cites those state agencies that will influence the East King County Ground Water Management Area.

2.2.1 Washington State Department of Ecology (Ecology)

The Washington Department of Ecology activities and programs affect ground water management decisions in the East King County Ground Water Management Area both directly and indirectly. Funding for the development of the East King County Ground Water Management Plan comes from the Centennial Clean Water fund, a grant program administered by Ecology. Ecology issues waste discharge permits, performs compliance monitoring, enforces discharge regulations, and responds to pollution incidents and complaints. Ecology is the 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 the Resource Conservation Recovery Act facilities and state hazardous waste cleanup sites, and the regulation of underground storage tanks.

2.2.2 Washington State Department of Health, Office of Environmental Health Programs

The Washington State Department of Health is involved in a variety of programs that influence ground water management. As part of the Northwest Drinking Water Operations Programs, the Department of Health is responsible for approval and oversight of Group A public water supplies, including administration of the wellhead protection program, well site inspections and final system certificate of completion review, and compliance with required monitoring. 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 that exceeded the U.S. Environmental Protection Agency 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.

The Department of Health is responsible for enforcing the regulations that prescribe design and installation standards for on-site sewage systems (Chapter 248-96 WAC). These regulations are currently under revision to increase effectiveness in protecting public health and water quality. The Department of Health is also responsible for guideline development and performance review of alternative sewage disposal systems.

The Department of Health manages the Well Head Protection Program. The Well Head Protection Program requires ground water purveyors to delineate capture zones or areas of influence for each public drinking water well, identify land use within capture zones, and identifying potential sources of ground water and drinking water contamination.

2.2.3 Washington State Department of Natural Resources

As a proprietary agency, the Washington State Department of Natural Resources manages 5 million acres of state-owned forest, aquatic, agricultural, range and commercial lands. Of the total, 2.1 million acres are forest lands that produce income primarily through the sale of timber and other forest products. The Department of Natural Resources also manages 2 million acres of aquatic lands that include tidelands, shore lands, and the beds of all navigable lakes, streams and marine waters. As a regulator, the Department of Natural Resources is responsible for site permitting approval and enforcement of reclamation standards on public and private surface mines and quarries. The Department of Natural Resources is also responsible for enforcing the Forest Practices Act governing timber harvest, reforestation and water quality protection for forestry operations on state and private lands.

2.2.4 Washington State Department of Transportation

The Washington State Department of Transportation highway management activities in the East King County Ground Water Management Area include shoulder and ditch maintenance, as well as roadside spraying for plant control. Interstate 90 and State Routes 202, 203 and 18 are the only roads maintained by the Department of Transportation in the study area.

2.2.5 Washington State Department of Trade, Community and Economic Development

The Washington State Department of Trade, Community and Economic Development is responsible for implementing the Growth Management Act. The Growth Management Act affects the study area by requiring King County to establish urban and rural boundary lines and protection for critical aquifer recharge areas. The existing cities have urban growth boundaries designating centers for expected population growth as shown in the King County Comprehensive Plan. The intent of the Growth Management Act is to minimize human impacts on the native environment, limit urban sprawl, and plan for growth.

2.2.6 King Conservation District

The King Conservation District works with the 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 the county government nor an enforcement agency, rather a political subdivision of Washington State government authorized by Chapter 89.08 RCW. The organization is dedicated to the conservation and best uses of the natural resources of King County. Much of the technical assistance provided landowners and land users consists of helping them adopt conservation Best Management Practices (BMP). Conservation districts are being recognized increasingly as the logical focal point for coordinating local, state, and federal efforts to protect natural resources.

2.3 King County Agencies

The following King County agencies operate in the East King County Ground Water Management Area. Each of these agencies conducts activities that either directly or indirectly affect ground water management in the area.

2.3.1 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 King County Comprehensive Plan (1994) and the Community Plans for Snoqualmie River Valley (September 15, 1989).

2.3.2 Office of Strategic Planning

The King County Office of Strategic Planning is primarily involved in developing the King County Comprehensive Plan, sub-area land use plans (e.g., Community Plans for Snoqualmie Valley and East Sammamish), affordable housing, and economic development.

2.3.3 Department of Development and Environmental Services

The King County Department of Development and Environmental Services is responsible for the regulation and enforcement of land development and zoning in the East King County Ground Water Management Area. The specific duties of the Department of Development and Environmental Services include development control, commercial and residential permitting, sensitive area monitoring, and SEPA review. The Department of Development and Environmental Services also implements the Community Plans for Snoqualmie Valley and East Sammamish by issuing building permits and by administering rezones and plats.

Additionally, this Office is involved in coordinating the King County review of comprehensive plans for all water and sewer systems operating in unincorporated King County.

2.3.4 Seattle-King County Health Department, Environmental Health Division

The Seattle-King County Health Department is an advisory and regulatory agency involved in a wide variety of environmental health programs, including regulation of

Group B public water systems. The Seattle-King County Health Department was the lead agency for the East King County Ground Water Management Area through December of 1995. During that time, the Seattle-King County Health Department coordinated the activities necessary for the development of the ground water management plan including collecting ground water quality and quantity data, managing the ground water database and drafting technical issue papers for development of the East King County Ground Water Management Plan. On January 1, 1996, the King County Department of Natural Resources, Surface Water Management Division replaced the Seattle-King County Health Department as lead agency for completion and implementation of the East King County Ground Water Management Plan.

The Seattle-King County Health Department is responsible for evaluating soil quality and system design before permitting on-site sewage systems. The Seattle-King County Health Department also 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 Section of the Seattle-King County Health Department is responsible for permitting landfills, overseeing and permitting biosolids applications and sampling ground water in areas around existing or abandoned landfills. The Local Hazardous Waste Management Program of the Seattle-King County Health Department helps businesses discern if they have hazardous waste and then assists them in managing this waste properly. The program is oriented towards businesses that generate small amounts of waste.

The Seattle-King County Health Department, Solid Waste Section reviewed the closure of the Carnation Landfill and monitors the closed Duvall Landfill. The Seattle-King County Health Department, Solid Waste Section completed an Abandoned Landfill Study (1985) resulting in identification of two abandoned landfills. These landfills are discussed in further detail in Section 4.6. Landfills.

2.3.5 Department of Natural Resources

The following divisions of the King County Department of Natural Resources conduct the activities described below in the East King County Ground Water Management Plan.

<u>**Solid Waste Division**</u>

The Solid Waste Division is responsible for the solid waste facilities in the county. Within the East King County Ground Water Management Area no solid waste disposal facilities or transfer stations are currently in operation. However, the Cedar Falls Landfill has been monitored for releases to the ground water. Subsurface investigations are in process by the Solid Waste Division. The Cedar Falls Landfill is located south of the South Fork of the Snoqualmie River, southeast of the city of North Bend. The site is currently the location of a drop-box for recyclable materials. The Cedar Falls Landfill is addressed in further detail in Section 4.6. Landfills.

Surface Water Management Division

On January 1, 1996, the King County Surface Water Management Division became a part of the new King County Department of Natural Resources and assumed the lead agency role for the ground water program. Given the continuity between surface water and ground water in much of King County, the Surface Water Management Division management of surface water has a direct influence on the quantity and quality of water infiltrating to ground water.

Within the East King County Ground Water Management Area, Surface Water Management Division has completed the *King County Flood Hazard Reduction Plan*, November 1993, which analyzes flooding problems and potential solutions along the Snoqualmie River.

Water Pollution Control Division

The Water Pollution Control Division oversees regional sewage collection and treatment and is the designated regional water quality planning agency under the *1972 Clean Water Act.* The Water Pollution Control Division will be combined with the Surface Water Management Division to form the King County Department of Natural Resources, Water Resources Division in 1997.

Natural Resources Division

The Natural Resources Division is a new division created in 1995 as part of the King County consolidation effort. The purpose for forming this Division is to consolidate a wide array of existing natural resource programs into a single division for protection, acquisition, management and stewardship. The Natural Resource Division has two broad functions - Open Space and Resource Lands. The Office of Open Space is responsible for the acquisition of land. The Resource Lands Section is a new entity with staff and programs drawn from four former King County Departments who are responsible for land based and incentive programs. These programs focus on land-based resource uses such as open space, farmlands, forestry, wetlands and wildlife habitat. Many of these programs also enhance water quality throughout streams and wetlands.

2.3.6 King County Department of Transportation

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

Road Services Division

In addition to construction and maintenance of roads and associated drainage, the Road Services Division is responsible for vegetation control along the roadside. A current focus of the Road Services Division is to design better roads through the implementation of state of the art detention and infiltration facilities that facilitate the safe and efficient recharge of stormwater runoff (Tobiason, Personal Communication). The Road Services Division was responsible for the construction and installation of East King County Ground Water Management Area road signs. The road signs are located on major roadways in the Ground Water Management Area and indicates the Ground Water Management Area to vehicle occupants.

2.4 Local Agencies

The cities of Carnation, Duvall, North Bend and Snoqualmie are located within the East King County Ground Water Management Area (see Figure 1.1.). The responsibilities of these cities include: review and approval of proposed developments; review of the framework of future growth within the city limits; water and sewer system planning and administration; road maintenance including: plant control; stormwater facility maintenance and enhancement; and local water quality and quantity monitoring and protection.

2.4.1 City of Carnation

The City of Carnation is served by on-site sewage (septic) system for sewage disposal. The City is studying a proposed wastewater treatment facility (Carnation Comprehensive Plan, 1992). The Snoqualmie Valley Community Plan considers two areas for eventual city expansion to the west and northeast of the city. Most of the proposed expansion would be sited on the higher plateau northeast of the city. The updated their Comprehensive Water Plan in 1996 and is working with the Water Pollution Control Division of the King County Department of Natural Resources to develop waste treatment options (Morgan, personal communication).

2.4.2 City of Duvall

One hundred percent of the City of Duvall municipal water supply currently comes from surface water sources (the Seattle Water Department Tolt Reservoir). The City does have water rights for one shallow well that is currently used only by private well owners in the summer when their wells run dry. Although the city is not an active purveyor of ground water, activities that occur in Duvall can affect local ground water.

2.4.3 City of North Bend

The *City of North Bend 1993 Water System Plan* addresses the current and projected water supply and the vulnerability of North Bend's single source water supply. The City is currently investigating a deep aquifer in the Snoqualmie River Valley as additional drinking water supply. Other priorities for North Bend are to organize a storm water utility and a surface water management plan (Tissel, personal communication 1995).

2.4.4 City of Snoqualmie

The City of Snoqualmie completed a draft comprehensive water system plan in January of 1995. The City is also completing an Environmental Impact Statement for the expansion of their waste water treatment facility (B. Hansen, personal communication 1994). The City of Snoqualmie is working with developers of future golf courses and the communities of Snoqualmie Ridge Association and Falls Crossing.

3.0 PHYSICAL GEOGRAPHY

3.1 Geographic Setting

The 225 square mile area of the East King County Ground Water Management Area contains the Snoqualmie river valley lowlands and adjacent plateaus (see Figure 1.1) and a number of rivers, creeks and lakes which are east of metropolitan Seattle. The East King County Ground Water Management Area incorporates the Snoqualmie River which generally flows from the southeast to the northwest. The Snoqualmie River valley bisects the East King County Ground Water Management Area with the Cascade Mountain foothills to the east and the Sammamish and Union Hill Plateaus and the Redmond-Bear Creek and portions of the Issaquah Creek ValleyGround Water Management Areas to the west (see Figure 1.2.). The primary geographic river features include the Snoqualmie, Raging, and Tolt rivers, and Cherry, Griffin, Harris, and Patterson Creeks. The three largest lakes inside the East King County Ground Water Management Area boundary are Ames Lake, Lake Joy, and Lake Margaret.

The principal known aquifers in the area are the alluvium along the Snoqualmie River and its major tributaries, and the glacial deposits underlying the plateaus to the immediate east and west of the alluvial lowlands. The alluvial aquifer in the northern half of the area has relatively low permeability except where larger tributaries enter the Snoqualmie valley. The upper (southern) part of the valley above Snoqualmie Falls contains coarse alluvial material that is much more permeable than the lower valley, where more fine grained sediments have been deposited. The glacial deposits on the plateau and foothills east of the Snoqualmie River also appear to have poor capability of providing large ground water supplies. This area is near the eastern edge of glacial deposition and the deposits are thin and generally fine grained. The geologic section west of the Snoqualmie River contains moderately permeable sand and gravel deposits of glacial origin, and the total thickness of glacial deposits increases in that direction (U.S. Geological Survey, 1995).

3.2 Topography

Elevations in the East King County Ground Water Management Area rise steadily in an easterly direction and range from approximately 30 feet above mean sea level in the northern Snoqualmie River Valley to just over 2000 feet above mean sea level in the Cascade Mountain foothills.

3.3 Climate

Maritime air masses from the Pacific Ocean influence the climate of the East King County 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 surface. Precipitation is typically of light to moderate intensity and long duration. About 75 percent of the annual precipitation occurs during the period from October through March. In the spring and summer prevailing winds shift to the northwest. Summer is the dry season, with less than 5 percent of the annual rainfall occurring between July and September (U.S. Geological Survey, 1995).

The watersheds in the East King County Ground Water Management Area receive an average of 57 inches of rainfall annually (U.S. Geological Survey 1995), but precipitation ranges from less than 45 inches in the northwest part of the study area to more than 90 inches in the southeastern part of the study area. The month of January receives the greatest amount of precipitation and September receives the least amount of precipitation. The areas of greater precipitation result from the lifting and cooling of moist maritime air by relatively high land forms. Rainfall was usually greatest at the higher elevations along the eastern boundary of the East King County Ground Water Management Area and lowest in the broadest widths of the Snoqualmie River Valley.

Values of mean monthly precipitation and temperature (National Oceanic and Atmospheric Administration, 1982) are used to describe long-term climatic conditions in the study area for purposes of this report. Daily values of these parameters are used in the calculation of recharge and in the interpretation of streamflow quantity and fluctuations in ground water levels and lake stage.

4.0 LAND USE IMPACTS ON GROUND WATER

This section discusses land use plans, policies, and regulations; and the impacts of various land use activities on the ground water resource in the East King County Ground Water Management Area.

The most productive aquifers in the East King County Ground Water Management Area occur within highly permeable sand and gravel outwash deposits. Some of these aquifer systems are susceptible to land use impacts given the high permeability of the overlying soils and the shallow depth to ground water. As both agricultural and residential development increases, the risk of contamination to the ground water resource is likely to increase. Precipitation recharges the subsurface aquifer system. Various land uses can cause surface and/or shallow soil contamination, ultimately resulting in ground water contamination. Precipitation recharge can carry contaminants downward to ground water. Therefore, some land uses have the potential to cause ground water contamination, unless mitigating measures ensure recharge that is of adequate quantity and quality.

4.1 Existing and Proposed Land Use

Land use activities can have a significant impact on ground water quality and use. As area population grows, the 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 ground water resource contamination is likely to increase. Ground water reserves can also be reduced when development decreases the effective area of ground water recharge.

Based on population targets, the East King County Ground Water Management Area will experience a projected 60 percent increase in population between 1992 and 2012. The rural cities in the East King County Ground Water Management Area will experience substantially greater growth. Population projections for this area are addressed in Section 5.4.2. Along with the increased population, employment opportunities in the East King County Ground Water Management Area will expand in the cities as well. These two factors will have an impact on land uses in the area. These impacts will include an increase in residential housing densities and small hobby farms, and some growth of commercial and industrial activities.

4.1.1 Existing Land Use

The King County Comprehensive Plan specifies land use for the unincorporated portion of the East King County Ground Water Management Area which is shown on Figure 4.1. Land use zones are broken into eight general categories including: agricultural, commercial, industrial, forest, mining, rural area, rural residential, and urban reserve. The cities propose and adopt their own land use and zoning, so they are not included in this map. The Area is primarily in rural and resource land use. Urban uses are generally contained within the small cities of Duvall, Carnation, Snoqualmie and North Bend.

4.1.2 Proposed Land Use

The King County Comprehensive Plan specifies proposed future land use for the unincorporated portion of the East King County Ground Water Management Area which is shown on Figure 4.2. Under the Growth Management Act, the majority of the East King Ground Water Management Area, is designated as rural with low growth rates. Growth Targets have been developed for the cities in the East King Ground Water Management Area

Demographic indicators are helpful in estimating the amount and types of increased water demand predicted for the East King County Ground Water Management Area. Population and economic forecasts help King County, the cities, water, sewer and school districts and other agencies plan how to serve existing and new residents (King County Comprehensive Plan, 1994). In 1994, the State Office of Financial Management forecasted King County population to increase by 293,100 by the year 2012. The Office of Financial Management forecasts that the county will have 1,857,600 residents by 2012. Approximately 96 percent of the projected household growth from 1992 to 2012 is expected to locate within the Urban Growth Area, which makes up about one-fifth of King County land area. This includes Rural Area cities and their Urban Growth Areas. The remaining four (4) percent of growth would occur in the unincorporated Rural Area.

4.2 Plans and Policies Affecting Land Use

An understanding of existing land use activities and development trends in the East King County Ground Water Management Area requires a discussion of local and state land use policies influencing these factors. Summaries of the Growth Management Act, Countywide Planning Policies, King County Comprehensive Plan, Community Plans, and City Comprehensive Plans as they relate specifically to ground water management are included in this section.

As ground water management strategies are developed for the ground water management plan, it is proposed that 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.

4.2.1 Growth Management Act (GMA, Chapter 36.70A RCW)

The Growth Management Act 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 the policies and maps contained in the King County Comprehensive Plan are provided below.

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

The Countywide Planning Policies recognize that 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 in the Countywide Planning Policies are 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 areas 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.

4.2.3 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 Comprehensive 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.

Planning and Coordination

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 which 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.

4.2.4 King County Community Plans

Community Plans represent another legally binding policy document with jurisdiction in the East King County 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. With the adoption of the 1994 King County Comprehensive Plan some Community Plan policies may now be in conflict with the King County Comprehensive Plan. Where this occurs, the King County Comprehensive Plan policy takes precedence.

The King County Community Planning Area in the East King County Ground Water Management Area is governed by the Snoqualmie Valley Community Plan.

Snoqualmie Valley Community Plan

The Snoqualmie Valley Community Plan affects all of the East King County Ground Water Management Area. The effective date of the Snoqualmie Valley Community Plan was September 15, 1989. The Plan revolves around five themes:

- **Protect the Snoqualmie River** - this is a primary goal of the Plan.
- **Invest in Flood Protection Measures** - take steps to reduce dollars spent on flood damage including low density zoning in floodplain and commitments of valley cities to participate.
- **Preserve Rural Areas, Resource Lands and Sensitive Environments** - one home per 10 acres in sensitive areas, one home per five acres in non-sensitive areas, denser growth to the valley cities.
- **Promote the Economic Health of Valley Cities** - by down zoning rural areas and providing expansion areas for each town.
- **Keep the I-90 Corridor Scenic** - undeveloped interchanges have rural residential densities and limited signage and lighting visible from I-90.

The Snoqualmie Valley Community Planning area lies south of Snohomish County; east of the Bear Creek and the East Sammamish community planning areas; north of the forest areas of Tiger Mountain and Rattlesnake Ridge; and west of the crest of the Cascade Mountains. The land use in the Snoqualmie Valley Community Planning area is comprised primarily of forest production lands, agricultural lands, residential (one home per 10 acres, one home per five acres, one home per 2.5 acres), commercial and industrial, and quarrying/mining. The Snoqualmie Valley Community Planning area has numerous and varied surface water bodies providing a characteristic aesthetic quality. Of the 154 policies in the Snoqualmie Valley Community Plan, the following apply to ground water quality and quantity:

SQP 13 The demand for water to serve existing and future land uses should not exceed the capacity of the area's ground water resources. A ground water study determining recharge areas and their ability to support new development should be initiated.

SQP 14 Underground storage of gasoline, solvents, and other potential water pollutants should be stored in double-walled tanks with secondary containment and have technology for leak detection and off-site pollutant migration monitoring as required by the U.S. Environmental Protection Agency and Washington State Clean Water Legislation.

SQP 15 If the ground water study identifies significant impacts which cannot be mitigated, King County will initiate a plan amendment to the Snoqualmie Valley Community Plan to secure changes in land uses or densities.

4.2.5 Basin Plans

The King County Surface Water Management Division has not completed specific basin plans for the rural areas in the East King County Ground Water Management Area. The Surface Water Management Division is currently working with other public agencies in Snohomish County to develop a regional basin plan for the Snohomish River Basin, which will include the Snoqualmie River and the Skykomish River in King County.

4.2.6 City Comprehensive Plans

The Cities of Duvall, Carnation, Snoqualmie and North Bend all have comprehensive plans that provide policy direction for environmental review and future land use determinations in compliance with the Growth Management Act. Ground water related policies are included in the plans both directly and indirectly.

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 East King County Ground Water Management Area are discussed in Section 6.0, Hydrogeology. 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 contaminant(s);
- 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 the 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.

4.3 On-Site Sewage

On-site sewage systems are found throughout the East King County Ground Water Management Area. All on-site sewage systems are regulated by the Seattle-King County Health Department. New on-site sewage systems must conform to location and design guidelines established by the King County Board of Health Regulations Title 13.

4.3.1 Soils and Sewage Effluent

On-site sewage systems may be a source of non-point pollution to ground water in extremely permeable soils or within high recharge areas above ground water. However, properly designed, installed and maintained on-site sewage systems may be the preferred alternative to sewers because of lower water use and the infiltration of filtered wastewater to the ground.

According to the *Issaquah Creek Basin Current/Future Conditions and Source Identification Report*, King County Surface Water Management Division (October 1991), some soils, such as those in the Kitsap series, are more suitable for treating and absorbing sewage effluent than others. Clays and clay loams filter and attenuate contaminants favorably, but they do not absorb effluent adequately. Soils with a coarse texture, such as those in the Everett series, absorb effluent effectively, but do not remove contaminants because of their relative high permeability.

Soil depth is also important when determining the proper function of an on-site sewage system. At least three feet of unsaturated soil is required to protect potable ground water aquifers. If a design reviewed by Seattle-King County Health Department staff indicates that the soil depth and soil type on a proposed site are not appropriate for a conventional subsurface soil absorption system, an alternative type of system providing effluent pre-treatment, such as a mound system or sand filter, may be needed.

4.3.2 Areas of Concern and Future Information Needs

In 1990, the Seattle-King County Health Department reviewed on-site sewage system records, past field surveys, and a field survey of 192 on-site sewage systems in King County. The file review of 1,432 systems provided an estimated on-site sewage system failure rate of 5.5 percent; that is, 78 of the 1,432 systems were either currently failing or had failed in the past. The field survey indicated an overall nine percent failure rate. Roughly 32 percent of the systems reviewed were installed before 1970, when the focus was on design for disposal, not treatment of wastewater. "Lack of septic [on-site sewage] system maintenance (pumping) may contribute to an increase in the number of failures in the future as only 10 percent of all systems have records of being pumped in the last 20 years" (*Issaquah Creek Basin Current/Future Conditions and Source Identification Report*, King County Surface Water Management Division, October 1991).

Another research priority should be locating all on-site sewage systems, especially those with a history of failure and those located in potential ground water recharge zones. On-site sewage system drainage fields are a potential contributor of phosphates, nitrates, and synthetic organic chemicals to surface and ground water. More research is needed on the actual threat to ground water posed by drain fields in the study area.

4.4 Sewers

Currently three municipal sewer facilities serve the East King County Ground Water Management Area. The cities of Duvall, Snoqualmie and North Bend each operate a sewer facility consisting of a collection system and a treatment plant. The treated sewage (secondary treatment) from all three systems is discharged into the Snoqualmie River. The municipal systems do not serve surrounding unincorporated areas (Snoqualmie Valley Community Plan, 1989).

Information about existing sewered areas, capital improvement program areas, on-site sewage system areas within sewer utility areas, and non-sewered areas with the East King County Ground Water Management Area can be found in the Technical Appendices of the King County Comprehensive Plan.

4.5 Stormwater

4.5.1 Existing Conditions

Storm water is important to ground water management for two reasons. First, storm water has the potential to carry contaminants (e.g., oil and grease found along roadways and other impervious surfaces) to ground water recharge zones. In addition, stormwater management can effect ground water quantity if stormwater is directed to ground water recharge areas.

Potential contamination of ground water can occur from many sources. For example, runoff from parking lots and roadways carries oil and grease, asbestos from brake linings, and zinc from tires. Pesticides, herbicides, and fertilizers (nutrients for algae growth) are washed off from landscaped areas, and soils are washed away from construction sites. Anything found on the ground can end up in stormwater runoff such as oxygen demanding organisms, and fecal coliforms. The King County Surface Water Management Division will be completing an updated *Stormwater Design Manual in 1996.*

Stormwater can enter ground water by several means. In undeveloped areas, stormwater infiltrates through soils, pulled downward by gravity to the aquifers below. In developed areas, stormwater can be routed into drainage swales and infiltrated into the ground water, or is released to a surface water body. Another common past 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 ground. 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 soils that are effective in removing some contaminants, especially particulates, from stormwater. Infiltration of stormwater may provide direct contamination of the ground water with dissolved components of oils, greases, nitrates, and heavy metals often found in urban stormwater runoff.

Quantities of stormwater runoff generated within a given area 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 lot, 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, depending on the strength and duration of the storm event.

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, trichloroethene, 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 has detectable levels of heavy metals present. But, more typically, contains nitrates, pesticides, and coliform bacteria. Ranges of values for different constituents are presented in Table 4.1.

Certain areas of the East King County Ground Water Management Area contain rapidly percolating soils, swales, retention ponds, and dry well systems which are used to manage stormwater runoff. According to the King County Department of Natural Resources no drywells operate in the unincorporated portions of the county. However, retention ponds are used widely throughout the county areas for control of drainage along rights-of-way. Contaminant loading to the ground water from surface water runoff is therefore of concern for the East King County Ground Water Management Area particularly in areas where retention is used because of the potential degradation of ground water quality.

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

4.5.2 Future Data Collection Needs

Additional information needs relating to potential storm runoff impacts in the East King County Ground Water Management Area include:

- The number and location of stormwater retention basins in the East King County Ground Water Management Area.
- The monitoring of stormwater quality in retention ponds located in areas where ground water is highly susceptible to contamination or in recharge areas.

4.6 Landfills

Landfills are potential sources of ground water contamination, especially those constructed prior to implementation of new standards for construction of solid waste facilities. Within the East King County Ground Water Management Area, no active landfills exist. However, two abandoned landfills and three closed landfills do exist (see Figure 4.3.). Solid waste management is guided by the King County Comprehensive Solid Waste Management Plan (adopted by King County and the cities within King County in 1975), and by King County Comprehensive Plan policies F-321 through F-323:

- **F-321** King County adopts a goal of reducing and recycling 65 percent of its waste by the year 2000. King County should emphasize prevention and reduction of solid waste through education and incentive programs.
- **F-322** Solid waste management should be planned and disposal capacity provided on a regional basis.
- **F-323** Solid waste handling facilities should be dispersed throughout the County in an equitable manner.
  - the importance of handling solid waste in an environmentally responsible manner;
  - solid waste management is a regional effort;
  - encourage the use of recycling and energy/resource recovery systems to extend the life of landfills and regain useful materials; and
  - close and replace rural landfills, except the Vashon-Maury landfill, with transfer stations.

These plan policies are particularly important as a result of the expected development and the future increase in ground water demands with the unknown hydrogeologic environments in this area.

4.6.1 Cedar Falls Landfill

The Snoqualmie Valley Community Plan, dated September 15, 1989, states the Cedar Falls Landfill served the Snoqualmie Valley Community Plan area. The site was originally mined for aggregate during the 1930's and 1940's. The Seattle-King County Health Department officially opened the landfill, located near Brewster Lake, two miles south of North Bend, in the early 1950's (see Figure 4.3.). In 1958, the precursor of the Solid Waste Division, the Department of Sanitary Operations, took responsibility for this landfill. Currently, the King County Department of Natural Resources, Solid Waste Division, has responsibility for the Cedar Falls Landfill. The Snoqualmie Valley community disposed of their demolition, household, and municipal solid waste at the Cedar Falls landfill. The landfill was closed to solid waste disposal activities by April 1990. The Cedar Falls site is now maintained as a recyclable materials drop off point. Currently, solid waste collected in the East King County Ground Water Management Area is transported daily from transfer stations to the Cedar Hills landfill south of Issaquah

In 1982, the King County Solid Waste Division identified landfill leachate impacts on ground water at the Cedar Falls site, as evidenced by some springs discharging contaminated ground water. The Solid Waste Division responded by collecting the contaminated spring water, then pumping it untreated into the landfill. This did not remedy the environmental impacts and Ecology issued an enforcement order in 1984 requiring mitigation and site controls.

In 1986, after affected residences were connected to a public water supply provided by Sallal Water Association, a low permeability synthetic cap was installed over the eastern five acres while landfill operations continued immediately northwest of the closed area. Landfill operations continued until a drop box was constructed (between the fall of 1989 and April 1990). The last placement of material within the landfill boundaries was the installation of a low permeability synthetic cap and a passive, non-flared gas diffusion system in November 1990.

The Solid Waste Division monitors the ground water quality at Cedar Falls Landfill for trends, hydraulic gradient, and exceedances of U.S. Environmental Protection Agency water quality criteria. In July of 1993, the Solid Waste Division prepared an Evaluation of Ground Water Quality Data for the period of September 1986 through March 1992 (King County Solid Waste Division, March 1992). This analysis indicated that levels of iron and manganese were elevated above secondary standards and above levels found in the background ground water (Table 4.2). This analysis also indicated that standards for coliform were also exceeded. Certain volatile compounds were sporadically detected at levels near or below the ground water protection standards. This report concluded that certain wells appeared to be impacted by the landfill and others did not. On the basis of this finding, additional wells were installed to attempt to identify interconnections, if any, between the water encountered in the various wells. The water quality results from these new wells and the hydrogeologic data collected from these new wells will be used to better understand and evaluate the impacts of this site.

The water quality from the deep wells at this landfill suggests no significant influence from solid waste disposal activities. The shallow wells completed in perched ground water do indicate influence from solid waste activities (*Ground Water Geology/Quality Investigation for the Rural Landfills*, December 1984).

4.6.2 City of Carnation Landfill

The City of Carnation Landfill is located approximately 1.5 miles southeast of the city of Carnation on the south side of Northeast 24th Street (Langlois Road) approximately 0.5 miles east of the intersection of Northeast 24th Street and the Fall City-Duvall Road. The Landfill was operated by the City of Carnation. In April 1989, ECI Environmental Services, Inc. completed an assessment of the physical characteristics of the Carnation Landfill. Most of the Carnation residential sanitary solid waste accepted since the 1920's was burned until 1971. The dump site area is less than 2.0 acres on the 11.13 acre site with a total estimated volume of refuse was approximated to be 84,700 cubic yards (*Final Engineering Report for Closure Plan*, 1990). There have been no documented problems related to ground water.

The "As Built" indicates the closure details of the Carnation Landfill to be the following (from refuse to surface order): a 12 inch bedding/gas collection layer; a 60 mil geomembrane liner; a 12 inch drainage layer; a geotextile filter fabric; 12 inch vegetative layer; and six inches of topsoil. The final grading plan will include "a six foot high chain link fence around the perimeter of the 5.1 acre site to impede entry" (*Final Engineering Report for Closure Plan*, November 1990). The landfill officially closed March 13, 1995 and stopped receiving refuse approximately five years prior.

4.6.3 Duvall Landfill

The Duvall Landfill is located approximately two miles west of downtown Duvall. Refuse began to be placed in a sand and gravel borrow pit in the 1940's. The landfill was closed in 1981 with a two foot layer of soil covering an approximately 30 foot layer of landfilled material. In 1985, a three foot thick clay layer was placed over the two foot layer resulting in a five foot layer covering landfilled material. The King County Solid Waste Division was the agency responsible for the landfill.

Three wells were installed at the Duvall Landfill in 1983. Of the three wells only one has historically yielded sufficient water to allow sampling. Results from this well have not indicated any significant concerns. However, the Solid Waste Division has installed 15 new wells to better understand the stratigraphy beneath the site. The water quality results from these new wells and the hydrogeologic data collected will be used to better understand and evaluate the impacts of this site.

During closure of the site, perimeter drains were installed which collect surface water which may be impacted by leachate. These drains collect large volumes of water which is trucked from the site and disposed as wastewater in the Metropolitan King County Sewer System. Analysis of the ground water collected shows very low levels of leachate indicators. The cost of collecting and disposing of this ground water is significant and the Solid Waste Division is looking at whether some upstream diversion of ground water around the landfill is possible.

All the aforementioned landfills are monitored by King County Solid Waste and the Seattle-King County Health Department, Solid Waste Division. Ground water samples are obtained for analysis of various physical parameters and chemical constituents quarterly and annually depending on the analyte.

4.6.4 Abandoned Landfills

Two abandoned landfills are located in the East King County Ground Water Management Area in Fall City and North Bend. The Seattle-King County Health Department, Solid Waste Section has completed investigations of these sites. The study indicated relatively innocuous findings which the Seattle-King County Health Department hypothesized as resulting from non-industrial or residential waste disposal. The study included sampling for methane and non-specific trace gases in the subsurface. The parameters selected to identify surface leachate seepage include pH, temperature, dissolved oxygen, electrolytic conductivity and turbidity. Historical review of the site was completed to evaluate past and present uses, any engineering information, waste disposal practices, and known and suspected problems. Official records were few, so the Seattle-King County Health Department relied on personal recollections, historical documents and maps, newspaper clippings, environmental impact statements and specialized studies done for development purposes, or citizen's advisory committee reports.

The Fall City abandoned landfill is located on southeast 39th Place off the Fall City-Duvall Road. The site was located on Weyerhaeuser property and privately operated. The landfill operated for several years and was closed in the early 1960s. When it was closed, Weyerhaeuser was to clean the area up and close access. At the time of the site visit, there was no visual evidence that a landfill once operated on site. The site was observed to be overgrown with brush and tall grass and was vacant. No significant environmental health problems were observed at this site and no further study is warranted (Seattle-King County Department of Public Health; *Abandoned Landfill Study*, 1985).

The North Bend abandoned landfill at the time of the abandoned landfill study (1985) was a small clearing along the west side of the Middle Fork Road, about one mile north of the "Y" turn from Edgewick Road located on the east side of North Bend. The abandoned landfill is approximately two acres in size and the city of North Bend operated the landfill during the 1950s. On October 20, 1984, ten borings were tested at this site for methane and non-specific trace gases. Results of the testing were slightly positive for one methane and one non-specific organic/inorganic reading. No further study is warranted (warranted (Seattle-King County Department of Public Health; *Abandoned Landfill Study*, 1985).

4.7 Underground Storage Tanks

Underground storage of petroleum hydrocarbon and chemical substances represent a potential hazard to ground water. Faulty underground storage tank system components (failed piping and tank components) and poor facility management practices (bulk delivery over-fill incidents, and dispensing spills) are the most frequently cited causes of releases from underground storage tanks. An incidental release will become a greater environmental concern when underground storage tank operators fail to perform regular inventory checks and systems monitoring. Underground storage tank system components may fail from corrosion, however, failure from careless workmanship during installation and assembly is more common. Releases from underground storage tank systems are problematic in areas with shallow aquifers (if tank lies in a fluctuating ground water table) or where the release impacts private ground water and drinking water wells (Knowlton, 1994).

4.7.1 Regulation of Underground Storage Tanks

Ecology implements the Washington 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 of ground water (i.e., a pollution prevention program). The owner or operator of the underground storage tank system 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 was initiated when a federal law (Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act) was passed in 1984. The U.S. 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 U.S. 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).

State regulation requires that underground storage tanks be upgraded to include a leak detection system (water tanks are exempt). In 1989, the Washington State Legislature passed House Bill 1086 which was signed by the governor as Chapter 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 regulations. Ecology received final authority from the U.S. Environmental Protection Agency to implement its regulation in summer, 1993. The

Ecology regulations (Chapter 173-360 WAC) are similar, but not identical (more stringent) to the U.S. Environmental Protection Agency regulations.

In addition, 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 and releases 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.

As of December 1993, all regulated underground storage tank systems were required to employ an approved method of release detection for tanks and piping. The only exception is any underground storage tank used for emergency power generation that was installed between 1980 and 1988. The release compliance dates for these underground storage tank systems is December 1995 (Knowlton 1994).

Underground storage tanks without special leak containment or leak detection systems represent a potential threat to ground water quality. At some point during the active life of any underground storage tank without environmental controls, hazardous substances stored in ground water recharge zones will probably lead to some form of ground water contamination.

4.7.2 Underground Storage Tanks in East King County

Ecology maintains a list of underground storage tanks in the East King County Ground Water Management Area. Presently 159 registered underground storage tanks are operational in the East King County Ground Water Management Area (Table 4.3.). The total number of underground storage tanks in the East King County 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 1100 gallons) and many systems were emptied and taken out of service prior to the U.S. Environmental Protection Agency notification requirement, but still remain in place (Knowlton, 1994). These underground storage tanks range from less than two years old to greater than 30 years old. They vary in substance contained and size from 111 gallons to 20,000 gallons. The list represents the majority of regulated underground storage tank systems in the area, but not home heating oil tanks. Table 4.4. lists the age ranges of the underground storage tanks in the East King County Ground Water Management Area, and Table 4.5. lists the types of substances found in those underground storage tanks. Table 4.6. summarizes the sizes of these underground storage tanks.

In the East King County Ground Water Management Area, situations are diverse where regulated underground storage tanks occur. 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. Many unlikely establishments that own or operate regulated underground storage tanks have notified Ecology and are listed in Table 4.3.

4.7.3 Leaking Underground Storage Tanks

Since January 1989, Ecology has maintained a database of current and former leaking underground storage tanks. Table 4.7. (Ecology 1994) lists 15 sites in the East King County Ground Water Management Area where underground storage tank cleanups are in progress or have taken place (also see Figure 4.4.). Under the Model Toxics Control Act, underground storage tank owners are responsible for site cleanup and for sending the report to Ecology, which gives them a cleanup status.

Of the 15 leaking underground storage tank sites, six have completed remediation. As of the date of the Ecology report, eight sites were undergoing cleanup of ground water contamination. One site exists where Ecology is not aware of any remedial action and cleanup of ground water contamination is necessary. Staffing shortages have delayed assessment of these sites.

Although underground storage tanks represent a potential threat to ground water in the East King County Ground Water Management Area, some incidents are either unreported or undetected. Ecology does not regulate nor track information about underground home heating oil tanks (Knowlton 1994). The documentation of unregulated home heating oil tanks is difficult not only due to the hidden nature of the tanks, but also because not enough is known about the location, composition, and contents of many of the abandoned underground storage tanks in the area. Homes that once used or still rely upon fuel oil stored in underground storage tanks are common in western Washington. Home heating oil tanks are small (between 300 - 500 gallons) compared to most regulated underground storage tanks, but more common. Smaller tanks were typically constructed of thinner gauge steel and provide shorter service life than large, regulated systems. The average useful life of a 500 - gallon steel tank that does not have corrosion prevention (i.e. cathodic protection) has been estimated at about 20 years. Many underground home heating oil tanks in western Washington are older than 20 years and not cathodically protected.

4.7.4 Areas of Concern and Future Information Needs

A priority of future research should be the identification of underground storage tanks located in areas where significant recharge to aquifers occurs. Special guidelines may be designed for the location and monitoring of underground storage tanks in these recharge zones. Additional research should also try to locate smaller private underground storage tanks, especially residential heating oil tanks, in the East King County Ground Water Management Area. Home heating oil tanks that have not been permanently decommissioned, whether by removal or closure in-situ, may pose a serious threat to ground water resources in the East King County Ground Water Management Area.

Improperly closed heating oil tanks (i.e. those which still contain petroleum products or have not been secured from reuse) are the greatest concern (Knowlton 1994).

4.8 Sand and Gravel Quarries and Mines

Coal, peat, sand, and gravel resources are all found in the East King County Ground Water Management Area. Although coal mining drew most of the original settlers into the area in the late 1800s, in recent decades, sand-gravel and bulk-fill activities have been the primary surface mining industries (aside from Forestry) in the East King County Ground Water Management Area. King County contains valuable resources of coal, sand, rock, gravel, silica, peat, clay, metallic ores and potentially recoverable gas and oil (King County Comprehensive Plan, 1995). Sand, gravel, and crushed rock are literally the foundation for each community's infrastructure (*Washington Geology*, July 1994). Mining and processing these deposits is an important part of King County's economy. Many sand and gravel mining operation sites exist in the East King County Ground Water Management Area (Pierce, 1995 and King County Comprehensive Plan, 1995) listed in Table 4.8. and shown in Figure 4.5. The large sand and gravel deposits in East King County are related to Pleistocene continental ice sheets, which covered the northern third of the state as recently as 15,000 years ago (Booth and Goldstein, 1994).

Aggregate production temporarily obliterates entire mine-site ecosystems, but this loss can be mitigated with carefully sequenced reclamation (*Washington Geology*, July 1994). Furthermore, sand and gravel operations can potentially impact ground water quality and quantity. Sand and gravel mining/extraction operations can breach a confined aquifer, causing extensive flooding and lowering of the water table. Mining operations often leave portions of an aquifer directly exposed to surface water and contaminants from adjacent land use activities. These areas may be sited in significant ground water recharge zones. The removal of surficial sand and gravel results in excavations that historically were used as garbage dumps, such as at the Cedar Falls Landfill. Additionally, information regarding coal mining operations indicate historic coal mines were used for improper disposal of hazardous materials.

The Washington State Department of Natural Resources is responsible for site permitting approval, and reclamation of sand and gravel mines and quarries in the East King County Ground Water Management Area. 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 Resources' requirements.

A typical operation and reclamation plan might include (*Washington Geology*, December 1992):

- a map showing existing topography, hydrology, and details on how the site will be mined and whether it will be left wet or dry;

- information about subsequent use of the land, appropriate for the location of the quarry;
- an indication of the sequence of topsoil stripping, storage, and replacement on mined segments; and
- a map showing direction and sequence of excavation for prompt reclamation after mining on any segment and within the constraints of economically efficient mining.

Surface water and ground water quality is now addressed in a National Pollution Discharge and Elimination System (NPDES) General Permit written by the Washington State Department of Ecology (Ecology) that covers gravel mining (*Washington Geology*, July 1994).

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. The King County Comprehensive Plan states four main steps to maintain and enhance commercial mineral resource industries. First, mineral resource sites should be conserved through designation and zoning. Second, it is necessary to prevent or minimize land use conflicts between mining, processing and related operations and adjacent land uses. Third, operational practices are necessary that protect environmental quality, fisheries and wildlife, but are balanced with the needs of industry. Finally, mining areas need to be reclaimed in a timely and appropriate manner.

4.9 Agriculture

4.9.1 Discussion

Livestock keeping and crops are primary agricultural activities in the East King County Ground Water Management Area. The Snoqualmie River Valley is zoned for agriculture and is the primary location for all agricultural practices that occur in the study area. Small hobby farms and horse properties are sparsely located in the uplands. The background of the rural residents is varied and includes people from all professions and walks of life. A developing trend exists among landowners in the study area to harvest vegetables with certified organic practices (Fitch, 1995). The organic certification of these truck farms (thus named because their harvest can fit in a truck) results from the absence of pesticide or herbicide use in some areas. Historically, some landowners used their land as pasture (grass and hay growth) and only recently converted to growing vegetables. Initially, many of these land users do not have the necessary knowledge and skills that are needed to operate the truck or small farm (Fitch, 1995).

Agricultural activities causing nonpoint pollution (pollution from an unknown origin) can be divided into two groups: (1) practices associated with livestock keeping and (2) practices associated with crop production. Pollutants most identified with farming activities are sediment, nutrients, organic materials, pesticides and pathogens. Activities that can generate these pollutants in crop production are soil tillage, improper application of fertilizers and pesticides, irrigation, and manure holding ponds. Livestock owner activities that generate these pollutants include: animal confinement, overgrazing of pastures, unrestricted livestock access to streams, and improper application of fertilizers and pesticides (Henry, 1995).

Ecology is responsible for implementing federal and state water pollution control requirements. With the adoption of the Agricultural Compliance Memorandum of Agreement, Ecology shouldered the responsibility of investigating agricultural water quality complaints. During 1994, a Dairy Farm National Pollutant Discharge and Elimination System (NPDES) and Washington State Waste General Permits came into effect for dairy farms, thus moving them into a completely different process separate from this Memorandum of Agreement process. Therefore, all other animal waste issues are still handled under the Memorandum of Agreement process if water quality problems exist as a result of those facilities.

Ecology completes site confirmation of complaints. If the complaint is verified, then Ecology refers site owner to the local Conservation Districts for technical assistance. Invalid complaints are dismissed. A six month period is provided for the operator to voluntarily develop a farm plan that includes elements to correct the water quality problem. This is followed by an eighteen month period for the operator to voluntarily implement the plan. Alternatively, the operator may choose to develop and implement a farm plan, either by themselves or with help from a private consultant, as long as the U.S. Natural Resources Conservation Service (previously Soil Conservation Service of the U.S. Department of Agriculture) standards and technical specifications are followed (Hovde, personal communication, 1995). The landowner can operate as they please until a confirmed violation has been identified because the system in place is reactionary (Henry, personal communication, 1995).

Best management practices developed by the Conservation Service includes the following:

- a means of collecting stormwater runoff from roofs (gutters) to keep it separated from stormwater that lands on impervious ground surfaces;
- point source controls like curbs, diking, containment collection tank management, pasture seeding and pasture management;
- installing sprinklers, both stationary and mobile; and,
- assess soils and crops, condition of crops, to establish a rate and timing of nutrient and manure usage.

The Conservation Service indicates all dairy farmers in the East King County Ground Water Management Area have been assessed and technical assistance rendered (Henry, personal communication, 1995).

Rural residents often use their land for hobby farms, gardens, part-time farms and "alternative" farms. Initially, many of these land users did not have the necessary knowledge and skills that are needed to operate the so-called small farm. Virtually all of the water quality programs that are associated with livestock keeping and crop production can be prevented if the land users will take time to learn about and implement the skills needed to run their type of operation (Fitch, 1994).

The Washington State Department of Agriculture requires all commercial applicators, as well as all applicators applying restricted-use pesticides (includes all aquatic applications) to be licensed. As licensed applicators, they are required to keep records for seven years including the type of chemical applied, quantities, location of applications, and other such information. The Washington State Department of Agriculture can request records from anyone required to keep records. A general record call-in from a large land area, however, is financially unfeasible unless significant cause is present. Record availability outside the agency may be constrained by legal requirements also (Fitch, 1994).

Based on several hydrogeologic factors that influence the behavior and movement of contaminants in the ground, it is unlikely that the present livestock practices in the East King County Ground Water Management Area threaten ground water quality (Fitch, 1994). For example, very little use of fertilizers on pastures and/or hayfields occurs in the area. These hydrogeologic factors are: (1) the horizontal distance between the site and the point of water use; (2) slope of the land; (3) the depth to water table; (4) the vadose zone material; (5) the aquifer material; (6) soil depth; and (7) the attenuation potential of the soil. However, present livestock practices are a potential source of contaminants that may be an impact on surface water streams and ponds. The potential ground water threat from fertilizers is from truck crop farms (non-certified organic farms), nurseries, Christmas tree farms. Generally, this type of operation is commercial in nature. Fertilizer is generally applied once or twice a year and is applied in accordance with the requirements of the crop. When applied according to label directions there should not be a pollutant source.

4.9.2 Areas of Concern and Future Information Needs

Additional research is needed on the types and quantities of agricultural fertilizers and pesticides used in East King County Ground Water Management Area. This information would allow for a complete analysis of how agricultural activities affect ground water quality.

4.10 Transportation

Roads and highways are built in the most economic manner. The design of roadways must take into consideration the surficial geologic materials over which the roadway passes. As a result the long and winding road skirts unfavorable load bearing material but this does not preclude the construction over ground water recharge areas.

A ruptured fuel tank in an accident can potentially impact a shallow aquifer. Records from the Washington State Department of Transportation, Incident Response, stated records between 1993-1995 indicated there were 27 accidents on Routes 202, 203 and Interstate 90 in the East King County Ground Water Management Area. Sixteen accidents occurred on Route 202; six accidents on route 203; and five accidents on Interstate 90. Fuel was lost from vehicles tanks at six accidents. Eleven accidents involved tractor trailers and 34 accidents involved automobiles. The spilled fuel was eventually collected after clean-up by the Washington State Department of Transportation.

4.10.1 Roadside Spraying and Maintenance

Roadside maintenance programs usually attempt to accomplish one of four objectives: (1) to control excess weed growth; (2) to limit the spread of brush and trees; (3) to protect newly planted beds from disease and insects; and (4) to control insects and weeds at specific spots (Uyeda 1988). Pesticide spraying is a common method of roadside maintenance within the state of Washington. Labeling, distribution, transportation, application, use restrictions, and disposal of pesticides are governed by Chapter 16-288 WAC. The issuance and monitoring of statewide pesticide use permits is the responsibility of the Washington State Department of Agriculture.

Three different types of public agencies conduct roadside maintenance in the East King County Ground Water Management Area: the Washington State Department of Transportation, the King County Department of Transportation, Road Services Division, and the Departments of Public Works of various cities. Each of these agencies is required by law (Chapter 17.21 RCW) to record the details of each pesticide spraying event and to retain those records for a period of 7 years. Spraying records, showing specific quantities and locations of herbicidal applications in the East King County Ground Water Management Area, may be obtained from the Washington State Department of Transportation Bellevue office, from the Road Services Division in the King County Department of Transportation, and from the Departments of Public Works of the cities.

The Washington State Department of Transportation is responsible for vegetation control on Interstate 90 and State Routes 18, 202 and 203. The Washington State Department of Transportation chemically treats weeds appearing within two feet of roadside, around fire hydrants and manholes, and in drainage ditches. The amount of herbicide sprayed by the Washington State Department of Transportation fluctuates between four and five pounds per acre and the shipping concentration is heavily diluted with water before being applied. State roadsides in the East King County Ground Water Management Area are sprayed once a year, usually during the month of April, primarily using three herbicides: Karmex, Krovar, and Roundup (containing the herbicides diuron, bromacil and glyphosate respectively).

The Road Services Division of the King County Department of Transportation serves unincorporated portions of the East King County Ground Water Management Area. The Roads Services Division applies herbicides to control noxious weeds on rights-of-way and weed and grass growth on gravel shoulders and around guard rails. Either Escort or Garlon is used for broad leaf control. Oust or Roundup is used for the non-selective control on the shoulders. The use of the chemicals simazine and atrazine was discontinued after 1989 because they are water soluble and cannot be used in permeable soils. All herbicides, including those not on "restricted use," are applied by certified pesticide applicators (Matsuno 1994).

The Seattle-King County Health Department conducts ongoing soil and water monitoring to determine the residual levels of pesticides and monitors their degradation over time. According to the 1989 monitoring report, no herbicide residuals were found in surface water samples. As expected, low levels of herbicide residuals were found in soil samples taken at a depth of four inches. The results for Oust, Diuron, and Roundup indicate that roadside spraying of those herbicides did not appear to pose a significant threat to water quality. Further, the amount of herbicides applied has decreased over the years through improved application methods, such as dilution with water and overall decreased application volumes.

Potential Ground Water Impacts

The application of herbicides and pesticides for roadside plant control can threaten ground water quality in two ways. First, chemicals may be transported by stormwater into high ground water recharge areas. And second, pesticides may percolate into shallow aquifers through fissures or dry and sandy soils. Vegetation and clay soils that exist along roadside in the East King County Ground Water Management Area may act to effectively absorb some pesticides before they reach ground water. Particular attention should be paid to the quantity and type of chemical applied, especially if a chemical is likely to destroy or inhibit grass growth (Horner and Mar, 1982). However, the preferred method of vegetation control is the use of machinery or manual removal.

Area of Concern and Future Information Needs

Although ground water impacts from approved roadside chemical applications is statistically improbable, additional information is needed in four areas:

- the location of dry and sandy soils and exposed aquifers that may facilitate the contamination of ground water by chemicals applied at roadsides;
- the types of roadside chemicals most likely to percolate through soils to an aquifer as well as those which inhibit grass growth;
- the quantities and locations of chemical applications; and
- reports of any accidents or improper storage, handling or transport of pesticides and herbicides used for plant control in the East King County Ground Water Management Area.

4.10.2 Highway Runoff

As rain washes over a roadway, it carries oils and greases into soils and storm water systems. Runoff of this kind is likely to occur on highways and heavily traveled roads where frequent truck traffic is present (Horner and Mar 1982). Common contaminants found in stormwater runoff from roads include petroleum products, heavy metals, and soot. In areas where existing roads cross streams, untreated road runoff may be discharged directly to the streams.

Potential Ground Water Impacts

Ground water infiltration by highway runoff is possible in very porous earth and in areas of exposed aquifers. Studies of highway runoff in western Washington have shown that vegetation may effectively capture pollution in upper soil layers (Horner and Mar 1982). However, some channels are maintained with mechanical cutting that may clear soil and vegetation allowing highway runoff to infiltrate into ground water. The precise conditions under which runoff pollutants may be contained in surface soil is not yet known. Some highway runoff for Interstate 90 and other heavily traveled roads in the East King County Ground Water Management Area flows into vegetated channels in an effort to decrease the chance of ground water contamination.

Areas of Concern and Future Information Needs

The most comprehensive study of highway runoff in Washington State was conducted by the Washington State Department of Transportation between 1977 and 1982 (Horner and Mar 1982). Although these reports discuss the conditions under which runoff may lead to ground water contamination, the degree and impact of potential contamination is never quantified. Since the 1982 study no comprehensive studies of highway runoff have been conducted in Washington State. However, the Washington State Department of Transportation will be conducting a highway runoff characterization and Best Management Practices effectiveness monitoring program in King County for the National Pollutant Discharge Elimination System Permit Program, Chapter 173-270 WAC. Samples will be collected for a complete range of parameters including metals and priority pollutants (Schaftlein, 1994).

Additional research is necessary to determine the type and quantity of contaminants that flow from road surfaces. In addition, more information is needed on storm water drainage for major roads in the study area.

4.10.3 Hazardous Materials Spills

The term "hazardous material" refers to "hazardous waste" as well as "hazardous substances", both are generally defined as materials that pose a substantial present or potential threat to human health or the environment (Horner and Mar 1982). The majority of hazardous substances carried on East King County Ground Water Management Area roads are petroleum products. These products are most frequently transported in the East King County Ground Water Management Area along Interstate 90, State Routes 202 and 203 and Highway 18.

The Ecology Northwest Regional Office in Bellevue responds to reports of petroleum or other hazardous material spills in the East King County Ground Water Management Area. A spill response team is available on a 24-hour basis to implement and monitor cleanup operations for accidents that occur on highways or roads, at manufacturing plants, or any location in the East King County Ground Water Management Area. The Ecology procedure for responding to spills depends on the substance spilled, as well as the severity and location of the accident (Baker, 1990).

The goal of evaluating the risk of a hazardous material spill is to provide information to decision makers in the following areas:

- the location of accident zones where hazardous material spills are likely to occur;
- a description of sensitive areas where spills would threaten ground water quality; and,
- an estimation of the resources needed in any remediation effort resulting from a spill.

Areas of Concern and Future Information Needs

In order to complete this evaluation, the following research process may be followed:

- State traffic volume data will estimate the number of trucks that have used major roads in the East King County Ground Water Management Area in past years;
- Accident statistics will then help to determine the probability of a truck accident occurring on these roads;
- Additional data is then needed to determine the percentage of trucks carrying hazardous materials in order to locate principal accident zones and the likelihood of a hazardous material accident occurring;
- Further research will indicate the number of hazardous material accidents that result in spills as well as the quantity and substance of those spills; and,
- Research is needed to estimate the probability of spilled hazardous materials reaching and contaminating ground water.

The exact frequency and routes of hazardous material traffic is not yet known. Future research should determine the probability of a hazardous material accident occurring in the study area and the circumstances under which such an accident would threaten ground water quality.

4.11 Hazardous Waste

Hazardous waste, as defined in the Washington 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 number of ways. For hazardous waste generators regulated by the Resources Conservation and Recovery Act (RCRA) (U.S. Environmental Protection Agency), and potential small waste generators in the East King County Ground Water Management Area not served by a public sewer system, hazardous wastes may be discharged to on-site sewage systems through sinks, toilets, or floor drains. Inadvertent or intentional discharges to storm water disposal systems represent another release mechanism. Small quantities of hazardous wastes discarded along with normal solid waste refuse can be placed in landfills and contribute to leachate contamination of the 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 with precipitation into the ground water environment.

4.11.1 Hazardous Waste Disposal

Four sites are listed in the U.S. Environmental Protection Agency Superfund Program List or Comprehensive Environmental Response Compensation and Liability Information System (CERCLIS) within the East King County Ground Water Management Area. These sites have all undergone discovery and preliminary assessment action. However, the Cedar Falls Landfill is the only site listed to have completed site inspection, and site inspection prioritization. The following sites have been identified on the CERCLIS list but at this time deemed "no further remedial action required":

- Duvall Landfill located at 22905 Old Woodinville/Duvall Road;
- Cedar Falls Landfill located at 16901 Cedar Falls Road, Southeast;
- Washington State Fire Training Center located at 50810 Southeast Grouse Ridge Road; and
- Weyerhaeuser Company-Snoqualmie Plywood located at 7001 396th Avenue Southeast.

Section 4.6 further details specifics regarding the two aforementioned landfills. The Washington State Fire Training Center and Weyerhaeuser Company-Snoqualmie Plywood are also listed as large and conditionally exempt generators, respectively, under the Resource Conservation and Recovery Act.

4.11.2 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 per month of hazardous waste; transport dangerous/hazardous waste; treat, store or dispose of dangerous/hazardous waste; or burn or blend dangerous waste fuels or must have applied at some time for a permit to do so. Several commercial and industrial facilities located within the East King County Ground Water Management Area generate quantities of hazardous or extremely hazardous waste regulated under Resource Conservation and Recovery Act. The Washington State Department of 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 East King County Ground Water Management Area. The Federal Resource Conservation and Recovery Act maintains a record of regulated and other potential generators of hazardous waste in the East King County Ground Water Management Area. These lists are essentially the same and were generated by the facility as a result of permitting for disposal of hazardous substances. These facilities request permitting for various conditions such as:

- protective filer;
- one time generator;
- withdrawn identification number, no longer hazardous/dangerous; and,
- generators are classified as conditionally exempt (less than 100 kilograms/month), small quantity generator (100-1000 kilograms/month) and large quantity generator (greater than 1000 kilograms/month).

At least one type of hazardous material is associated with the normal operations of each type of Resource Conservation and Recovery Act regulated and potential hazardous waste generator listed in Table 4.9. 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.

Small quantity generators produce between 220 pounds and 2,200 pounds of hazardous waste each month. The Seattle-King County Health Department and the King County Department of Natural Resources, Water Pollution Control Division assess how these 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 still handle their waste properly according to Chapter 173-303 WAC and Title 10 of the King County Board of Health. To date, the Seattle-King County Health Department and the King County Water Pollution Control Division have been inspecting automotive repair, silk screening businesses, photo processing facilities, and other businesses in the County which are small quantity generators (Colville, G., personal communication, 1993).

The Washington State Department of Ecology, Toxics Cleanup Program conducts initial investigations of potentially contaminated sites. This is done within 90 days of learning about the site. If the initial investigation shows that further action is needed, the site will appear in the Confirmed and Suspected Contamination Report. Once remedial action has been completed, the Toxics Cleanup Program management determines the removal of a site from the Report. Listed in Table 4.10. are sites within the East King County Ground Water Management Area (Toxics Cleanup Program, December 1994).

A quantitative method for ranking hazardous waste sites has been developed for Washington state to satisfy the requirements of the Model Toxics Control Act). The model relies on information available from site hazard assessment efforts to assess the potential for risks posed by contaminated sites. The ranking of sites provides a basis for program planning and priority assessment for those sites identified as potential threats to human health or the environment. The ranking method provides information about the relative risks posed by a site. It provides individual exposure pathway scores and more general overall relative risk ranking. This information can be used by Ecology in setting its priorities for cleanup actions (from the Ecology Ranking Methods Scoring Manual, 1990).

4.12 Well Construction and Decommissioning

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. Proper well design and construction can prevent water quality problems of this nature.

An unknown number of wells may no longer be in use or may be decommissioned in the near future due to growth of centralized public water systems in the East King County Ground Water Management Area. Some 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.

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 well to Ecology. These reports describe the well's location, surface elevation, and the type of well construction. In addition, the report provides pertinent data concerning the geologic conditions encountered during construction and the characteristics of the aquifer.

Well construction reports serve as an important database for the evaluation and management of ground water resources within the East King County Ground Water

Management Area. Meeting present and future demands for drinking water in the East King County Ground Water Management Area may be dependent upon using ground water; thus, the accuracy and completeness of well reports is necessary to develop future water planning for the area.

Future data collection efforts should attempt to identify improperly decommissioned wells or wells that were improperly constructed and should be decommissioned in the East King County Ground Water Management Area. A data sort showing locations of wells which 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 wells, (dug wells), located in critical aquifer recharge areas.

4.13 Fertilizer/Pesticide Applications

Six public and three proposed golf courses are located in the East King County Ground Water Management Area: Carnation Golf Course (Carnation); Cascade Golf Course (Tanner); Mount Si Golf Course (Snoqualmie); Twin Rivers Golf Course (Fall City); and Snoqualmie Falls Golf Course (Snoqualmie); Tall Chief Golf Course (near Fall City); Ames Lake Golf Club (proposed by Ames Lake); Conifer Ridge Golf Course (proposed near Lake Joy); and Snoqualmie Ridge Golf Course (under construction in the Snoqualmie Ridge Development) (see Figure 4.6.).

Fertilizer is used in the East King County Ground Water Management Area by commercial agriculture, 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. Only a relatively small amount of phosphate is used by grasses and little of that is undesirable seed head growth, diminishing the aesthetic quality of the turf.

Fertilizing practices are essentially the same for most golf courses in western Washington. Nitrogen is applied to the fairways at relatively low rates, about two to 2.5 pounds per 1,000 square feet. The two to 2.5 pounds is split into two annual applications. The greens receive nitrogen at a much higher rate, about six 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. 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 four to six 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 East King County Ground Water Management Area is not documented. Presumably, the amount applied and the frequency of application varies widely. Pesticides/herbicides are applied to the forested area in the eastern portion of the study area for forest (timber production) management and rights-of-way maintenance.

Fertilizer use may not pose a significant threat to ground water in the East King County Ground Water Management Area. Future data collection efforts should focus on obtaining information on the types and quantities of fertilizers and pesticides used by golf courses and nurseries, and other non-agricultural businesses and monitoring ground water quality from wells in the vicinity of these establishments.

4.14 Ground Water Quantity

The amount of precipitation recharged to ground water is affected by land use, population growth, water use and weather patterns. Ground water recharge is affected by the amount of vegetation, soil conditions, and the topography of the potential recharge area. Vegetation decreases the velocity of runoff as water is diverted around plant stems and roots. This is a benefit to recharge because slowing the runoff increases the time available for infiltration and thereby increases infiltration. By clear-cutting the land and removing vegetation, ground water recharge can be diminished.

Soils composed of coarse-grained material such as sand and gravel are generally more porous and allow more recharge than those composed of fine-grained particles such as clay. Sealing over these recharge areas with parking lots, and residential and commercial buildings reduces the amount of ground water recharge (if impervious affects are not mitigated).

The slope of the surface upon which precipitation falls also affects the amount of precipitation that recharges into the ground. More rain tends to run off a steep slope than off a level plain because the precipitation does not have the time to infiltrate. Furthermore, the composition of the material that makes up steep slopes is likely to be less permeable (in total) than gently sloping terrain.

A corresponding increase in demand for water occurs with population growth. Ground water withdrawals from the aquifers, when combined with covering over of recharge areas, can lead to a diminished ground water supply for drinking water purposes. Because ground water and surface water are interconnected, surface water features such as lake levels and the low flow (base flows) periods of creeks are impacted by diminished ground water levels.

With the demands for more ground water, agencies and purveyors need to plan for methods to protect ground water as a valuable finite resource. A method to enhance recharge is to maintain portions of residential areas in their natural state or permit the planting of vegetation in these areas. Storm water facilities can be constructed to recharge ground water provided that the stormwater is first adequately treated so as not to contaminate ground water. Conservation methods are widely used: the use of low-use water figures in residential and commercial buildings and educating the public in water saving habits; and Ecology and the King County Department of Natural Resources, Water Pollution Control Division are currently investigating ways to treat and reuse gray and black wastewater.

4.15 Summary of Land Use Information Needs

From the aforementioned descriptions of land use activities in the East King County Ground Water Management Area, it is clear that the effects of existing and potential land use activities on ground water are still uncertain. This phase of the report presents information relevant to the East King County Ground Water Management Area and points to areas where additional information will provide decision makers with a complete picture of ground water management issues in the study area. The following discusses topics that future research priorities should address.

4.15.1 Ground Water Recharge Zones

Locating those surface areas where aquifers are most heavily recharged is important to every land use activity previously described, because 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 over by parking lots, buildings, or if other changes are made to the soil mantle.

A map of aquifer susceptibility to contamination based on three factors (surficial soils, surficial geology, and ground water depth (where available) is presented in Figure 4.7. Efforts to minimize the possibility of contaminants reaching these areas and to prevent the paving over of these areas should be undertaken. Land and water use activities described in this report will have the greatest impact on ground water when they take place in ground water recharge zones. Figure 4.7. should be further refined as more information becomes available from wellhead protection studies and hydrogeologic information provided as part of the State Environmental Policy Act (SEPA) reviews.

4.15.2 Future Development

A detailed analysis of existing land use activities in the East King County Ground Water Management Area, together with projected residential, commercial, and industrial development trends, is needed to assess land use activities that account for ground water contamination and to determine to what extent the demand for ground water is likely to increase in the future.

4.15.3 On-Site Sewage Systems

The threat to ground water quality from on-site sewage systems should be of particular concern whenever development occurs where sewer service is unavailable. The location of all on-site sewage systems, especially those with a history of failure and located in potential ground water recharge areas as identified in Well Head Protection Plans, should be tabulated and evaluated. Homeowners should be reminded to maintain their on-site sewage systems and to pump their on-site sewage tanks every three to five years, depending on use.

4.15.4 Sewers

Additional information is needed on existing and projected sewer quantities, and sewer line leaks. Also needed is a detailed account of future service options and system expansion plans.

4.15.5 Underground Storage Tanks

Without proper prevention or detection systems in place, a high risk of ground water contamination may be caused by a potential underground storage tank leak or accident. Additional information on appropriate commercial underground storage tank locations and safety measures is needed to minimize this risk. Underground storage tank research should also focus on smaller privately owned tanks, especially those installed to hold heating oil. Although no known record of these tanks exists, parallel studies in other areas may help to estimate potential ground water threats posed by residential underground storage tanks. An additional research priority should be to identify the extent and type of contamination from leaking underground storage tanks.

5.0 WATER APPLICATIONS

This section discusses water sources, water services, water rights, and existing and potential water demand. The withdrawal of water from an aquifer impacts quantity, availability, and may have reverberations on ground water quality. As area population grows, consumptive use of ground water will increase, particularly if alternative sources are not sufficient to meet demands.

5.1 Water Sources

With the exception of the areas serviced by the City of Duvall and King County Water District 119, nearly all the water used for private, municipal, recreational and industrial purposes in the East King County Ground Water Management Area is supplied by ground water. The U.S. Geological Survey *Geohydrology and Ground-Water Quality of East King County, Washington*, 1995, estimates 413,000 acre-feet of precipitation enters the ground water system as recharge. This study also estimates that 98,500 acre-feet of ground water discharges to the Snoqualmie River or Lake Sammamish each year. Of the remainder (300,700 acre-feet), 9560 acre-feet withdrawn from wells and springs was put to beneficial use (U.S. Geological Survey 1995).

According to the U.S. Geological Survey, ground water discharges to the major surface water features in the East King County Ground Water Management Area except the Raging, Tolt and a reach (between Carnation and Monroe) of the Snoqualmie River. The primary source of drinking water is stored precipitation recharged through permeable land forms to the subsurface ground water system.

The most productive aquifers in East King County Ground Water Management Area occur within highly permeable sand and gravel outwash deposits. Some of these aquifer systems are susceptible to land use impacts given the high permeability of the overlying soils and the shallow depth to ground water. Deeper aquifer systems are generally more difficult to characterize given the lack of deep subsurface information.

The Water Utility Coordinating Committee, in the East King County Coordinated Water System Plan (1989), identified three aquifer systems meriting consideration as sources of regional water supply within the East King County Ground Water Management Area. These include the Fall City Aquifer System, the Tolt Delta and the Cedar Falls Aquifer.

The Water Utility Coordinating Committee considers a regional water supply to include aquifer systems where individual well yields could exceed 700 gallons per minute (1.0 million gallons a day) and the total sustainable yield would be in excess of 5.0 million gallons a day. The Water Utility Coordinating Committee evaluated the Fall City aquifer system but the aquifer did not meet the 5 million gallon per day criterion when current use was subtracted from aquifer yield. The Tolt Delta met the 5 million gallon per day criterion, however, the Tolt Delta is remote from the current or near term regional transmission network. The Cedar Falls aquifer extends along the southern most portion of the East King County Ground Water Management Area and is actually associated with the Cedar River Watershed.

The East King County Coordinated Water System Plan, 1989 indicates two subregional aquifers that can supply water for the needs of local communities. Subregional supply systems have been identified within the Snoqualmie Flats and Snoqualmie Falls areas. The occurrence and characteristics of these systems will likely be delineated in more detail as additional deep exploratory drilling and testing occurs.

In 1992, CH2M Hill, under contract to the East King County Regional Water Association, conducted a feasibility study that identified three areas where a potential regional water source should be explored: the confluence of the three forks of the Snoqualmie River; the Middle Fork of the river; and the North Fork of the Snoqualmie. Golder Associates, under contract to the East King County Regional Water Association and the Seattle Water Department, conducted geophysical soundings to narrow the areas of exploration. The analysis of the soundings at the North Fork concluded that the potential in this area was only 5 million gallons per day. The decision was then made to concentrate on data collection efforts on the Middle Fork of the Snoqualmie. It has been estimated that the Snoqualmie Aquifer has the capacity to provide 20 million gallons per day of water. It is also possible that another 20 million gallons per day could be found where the North Fork converges with the other two forks of the river. This area has not been explored.

A well drilled in 1994 identified the Middle Fork of the Snoqualmie as an excellent source of water from the standpoint of both water quality and water quantity. Two additional wells were drilled in 1995 to collect data required by the Department of Ecology for a water right application. The deepest well was drilled over 700 feet, identifying an upper and lower aquifer beneath an embankment which is the recharge area. Golder Associates is now constructing a ground water model of this aquifer system. The model will show pumping impacts to the Middle Fork of the Snoqualmie River, and how much drawdown would occur given certain pumping schemes. Based on information from seepage measurements taken by the U.S. Geological Survey, there does not appear to be a connection between the Snoqualmie Aquifer and the Middle Fork of the Snoqualmie River.

This area near the Middle Fork of the Snoqualmie River is being pursued as a regional water supply source. The East King County Regional Water Association, a consortium of water purveyors, has applied to Ecology for water rights in this area.

5.2 Water Services

The boundaries for all water service areas in the East King County Ground Water Management Area are shown on Figure 5.1. The East King County Coordinated Water System Plan (August 1989) lists all the major water suppliers in the East King County Ground Water Management Area and the quantities of water drawn from these wells. The plan also describes future expansion plans for each water purveyor, water level depths of each Group A well (greater than 15 connections and/or greater than 25 customers), and the number of service connections for these wells.

Group B systems are those systems that service between two and 15 permanent connections. Approximately 215 Group B systems and an unknown number of private wells are located within the East King County Ground Water Management Area. A breakdown of Group A and Group B Water Systems in the East King County Ground Water Management Area is listed in Table 5.1.

5.2.1 Cities

City of Carnation

The City of Carnation owns and operates a municipal Group A water system with existing service connections under 1,000. The water system includes a reservoir, springs and one well, and is managed by the Carnation Public Works Department. The City of Carnation existing and future service areas lie within the current planning area boundaries established in the East King County Coordinated Water System Plan. This area extends beyond the city limits and encompasses approximately 21 square miles. Carnation has future plans to sell water to surrounding purveyors, including Water District 119, Water District 127 and Ames Lake Water Association. The Comprehensive Water System Plan was updated in 1996, and is required to be updated every six years.

During the early development of the city (known then as the Town of Tolt) the source of water was springs located on a 16± acre tract of the Weyerhaeuser Timber Company. The area was expanded to 80± acres and annexed to Carnation to protect the watershed. These 80± acres comprise the City's present watershed. The City of Carnation currently has water rights equal to 1.15 million gallons a day or 538 acre feet per year (East King County Coordinated Water System Plan, 1989).

The springs presently furnish 90 percent of the Carnation water supply. According to the Carnation 1996 Draft Comprehensive Water Plan, increasing spring intake capacity to a total of 600 gallons per minute would provide most of the water required to meet the future demands beyond the year 2015, allowing for the sale of water to outlying districts. Upgrading the springs intake from 380 to 600 gpm would maximize the allowable water rights of the springs and provide the water required to meet future demands. The City's ground water supply is averaged at 0.4 million gallons per day. The Draft Comprehensive Water Plan also recommends that the City should seek new water sources in anticipation of growth beyond the 20 year planning period due to the long lead time and effort required to obtain water rights.

City of Duvall

The City of Duvall potable water is supplied by the Seattle Water Department. Currently, one hundred percent of the Duvall water supply originates from surface water sources (the Tolt Reservoir). As of January 1988, the Seattle Water Department indicates 1,061 existing service connections (King County Comprehensive Plan, Technical Appendices, 1994). Duvall currently has water rights for one well of 0.09 million gallon per day and 36 acre feet per year, however, they are not using that right or the well at this time as a public purveyor.

City of North Bend

The City of North Bend currently relies on a single source of water, the Mt. Si spring, for its water supply. The city also has an emergency intertie with the Sallal Water Association. The watershed for the existing spring supply covers approximately 88 acres. It is estimated that the spring discharges an average of 5.8 million gallons per day. The City presently uses about 0.82 million gallons per day (maximum day demand), with a surface water-right certificate allowing expansion to up to 3.2 million gallons per day (1993 Interim Comprehensive Water System Plan).

The present capacity of the system can provide approximately 1.9 to 3.2 million gallons per day in the dry season (1993 Water System Plan). However, it is estimated that future requirements for water could exceed this capacity. The Water System Plan (December, 1993) estimates current maximum daily demand to be 0.82 million gallons per day, and 13 million gallons per day if full build-out occurs under existing land use plans. The infrastructure that is currently in place gives North Bend the current capacity of 1.4 million gallons per day. In an analysis projecting peak water demand based on historical growth patterns, projected demand exceeded current supply between 1999 and 2000 (1993 Water System Plan).

The single source of the North Bend water supply is quite vulnerable. First, if it were contaminated, the entire North Bend supply would be halted; second, the quantity of water the spring supplies is adequate for existing demands, but will not likely be adequate for future demands; and third, it does not follow the Washington State Department of Health recommendation that a water system have multiple sources. For these reasons, the City of North Bend is investigating a potential large aquifer under the Snoqualmie River Valley. A well has been drilled, and a preliminary application for water rights for this well was submitted to Ecology in 1995. However, the application will not be processed until pump tests have been conducted.

City of Snoqualmie

The City of Snoqualmie obtains its potable water supply from two spring sources and one deep well. The major source of supply is from Canyon Springs located 6 miles east of Snoqualmie on the North Fork of the Snoqualmie river. Two predominant springs were developed in this area. The City also maintains a well (well #1) adjacent to the Mt. Si High School within the Snoqualmie city limits. Currently, well No. 1 serves as a backup source and is used for summer supply. In addition, a second well (well #2) was drilled in the summer of 1995 and an application for supplemental water rights for this well is pending at the Washington State Department of Ecology.

Weyerhaeuser Real Estate Company is developing ground water sources in the deep aquifer in the north well field. This water source is being considered as a municipal supply for future development in the Snoqualmie Ridge expansion area. A water right application for 1650 gpm in this well field is pending. Snoqualmie holds water rights for four ground water sources. The allowable annual withdrawal from all four sources totals 1648 acre-feet.

The City of Snoqualmie submitted a draft of its comprehensive water system plan for review to the King County Utilities Technical Review Committee in 1995. The current average day demand for the city of Snoqualmie is 0.542 million gallons per day, and the current peak day demand is 0.929 million gallons per day. Canyon Springs is assumed to have a minimum reliable yield of 0.834 million gallons per day (based on low flow records over the last four years), and the average annual daily flow at the springs ranged between 1.2 to 1.35 million gallons per day over a four year period.

Two development scenarios have been examined in a water needs assessment for the City of Snoqualmie. For Scenario I (without development), the combined capacity of Canyon Springs and Well No. 1 greatly exceed projected peak day usage. For Scenario II (with development, assuming the city would provide water service within the boundaries of the urban growth area), sole use of the Canyon Springs service area indicated a supply deficit of 56 gallons per minute (gpm) in 2000 and 308 gpm in 2014. Other source areas would need to supply 1150 gpm of additional source capacity by the year 2000 and 2400gpm by the year 2014 to meet projected demand. This analysis indicates that the city must pursue additional sources of supply to accommodate growth.

5.2.2 Water Associations and Districts

Ames Lake Water Association

The Ames Lake Water Association completed a Draft Comprehensive Water System Plan in 1993. Approximately 680 existing service connections serve a population of 2,216 (Seattle-King County Health Department) and a current demand of 0.12 million gallons per day. With a supply of 0.2 million gallons per day, Ames Lake Water Associations forecasts their demand will exceed their supply by 0.04 million gallons per day by the year 2000 (King County Comprehensive Plan, Technical Appendices, 1994). Ames Lake Water Association has water rights equal to 0.41 million gallons per day or 340 acre feet per year. In addition, new rights were granted in January 1996. The source of their water is five ground water wells (East King County Coordinated Water System Plan, 1989).

The Association is a non-profit corporation committed to meet the regulations of local, state, and federal agencies and their related laws and regulations pertaining to providing a safe, adequate and reliable water distribution system in the Ames Lake area. The system is designed with the intent of intertying, for emergency purposes, with adjoining water purveyors.

Lake Margaret Community Purposes

From the Seattle-King County Health Department database, the Lake Margaret Community Purposes has 146 connections and services 436 people. It is also known that the system does not currently allow hook-up of new connections, because of a limited water supply. The East King County Coordinated Water System Plan states Lake Margaret has water rights equal to 0.29 million gallons per day or 135 acre feet per year.

King County Water District 119

One hundred percent of the water provided by Water District 119 originates from surface water sources. The water source for Water District 119 is the Tolt River Reservoir operated by the Seattle Water Department. The Water District plans to have interties with Carnation and Duvall (East King County Coordinated Water System Plan). The King County Water District 119 Comprehensive Water System Plan was completed by Engineering Consultants Northwest, Inc. in June 1994. The Plan stated that the growth in population experienced in the District warrants the planning of improvements to the water system. According to Engineering Consultants Northwest, Inc., the district currently has 910 service connections, of which four are commercial.

King County Water District 127

Water District 127 serves the unincorporated Fall City area (designated a "rural activity center") an area of over 15,000 acres of land, much of which is steep slope or floodplain. The current supply available to Water District 127 is 0.77 million gallons per day and their demand forecasts indicate that they will not exceed supply by the year 2020 (King County Comprehensive Plan, Technical Appendices, 1994). Water District 127 serves 900 customers and consists of over twenty-two miles of water mains. The Water District has two main wells less than 100 feet apart and screened in the same aquifer 200 feet below the land surface (King County Water District #127 Comprehensive Plan, 1995). The Water District currently holds water rights equal to 1.6 million gallons per day or 806 acre feet per year of water (East King County Coordinated Water System Plan, 1989).

Sallal Water Association

The Sallal Water Association completed a Comprehensive Water System Plan in 1992. The Plan states that three wells are in use with a combined installed capacity of 1700 gallons per minute, and a combined tested capacity of 3000 gallons per minute. The Sallal Water Association currently holds water rights equal to 2.3 million gallons per day or 696 acre feet per year of water (East King County Coordinated Water System Plan, 1989). At present, the Association has five storage tanks with total current capacity of 1.1 million gallons. A sixth storage facility is planned. The Association is intertied with the city of North Bend for water use in the case of emergency (fire or drought). It is expected that some of the service area will be annexed from King County to the city of North Bend, especially the North Bend Way Corridor. The neighboring water purveyors, Wilderness Rim and Riverbend, are within the service area of Sallal Water Association. Wilderness Rim has 577 customers served by the Association from the 0.2 million gallon Rattlesnake Ridge Tank. Riverbend serves 528 service connections from their own two wells. Future land use projections for this plan will be based on the Snoqualmie Valley Community Plan and the King County Comprehensive Plan (King County Comprehensive Plan, Technical Appendices, 1994).

5.2.3 Seattle Water Department

The Seattle Water Department provides drinking water to many of the residents in the East King County Ground Water Management Area. The residents of Duvall and customers within the King County Water District #119 are served by the Seattle Water Department (King County Comprehensive Plan, Technical Appendices, 1994). The Department serves the area via the Tolt River pipeline which comes from the Tolt Reservoir located east of the East King County Ground Water Management Area. The reservoir is fed by precipitation that falls on the Cascade mountains to the east and snow pack that accumulates during the high precipitation months (October to March).

5.2.4 Other Purveyors

In addition to the aforementioned purveyors, approximately 215 Group B water systems (less than 15 connections and less than 25 people) and an unknown number of individual wells exist in the East King County Ground Water Management Area (Cox, Personal Communication). Table 5.1. presents the Group A and Group B water systems by connection number, total number of connections, and population served.

5.2.5 Areas of Concern and Information Needs

The East King County Ground Water Management Area boundary line establishes a physical mappable feature which delineates it from other areas in the County. However, land use impacts in East King County Ground Water Management Area should not be thought of as limited only to East King County Ground Water Management Area land uses. The potential exists for land uses outside the East King County Ground Water Management Area to have a lasting impact on ground water resources within the East King County Ground Water Management Area. To complete the analysis of water users by public water purveyors and for conservation planning in the East King County Ground Water Management Area, additional research is needed as follows:

- For each of the major water suppliers, a current breakdown is needed of the type and percent of the water customers they service. Type of customer includes residential, industrial, commercial, agricultural. This may be included in update of their water comprehensive plans;
- Identify the key private wells in the basin. Key private wells will be those wells within 1, 5, and 10 year time of travel of the major Group A public water supplies, and those private wells in the most physically susceptible areas; and
- Identify where potential ground water issues extend outside the ground water management areas, and where ground water issues from other Ground Water Management Areas extend into the East King County Ground Water Management Area.

5.3 Water Rights

5.3.1 Discussion

A water right is a purveyor's permitted right to withdraw water. A water right can be 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 the well or aquifer capacity.

The State of Washington administers the water rights laws, which were enacted in 1891, 1917 and 1945, with subsequent laws and rules. The 1891 State Legislature put in place a process recognizing "first in time is first in right."

The Surface Water Code, Chapter 90.03 RCW, was enacted in 1917. It recognized and protected pre-existing rights, and provided a process for establishing rights to surface waters after that date and set up a procedure for acquiring water rights.

The Ground Water Code of 1945, Chapter 90.44 RCW, extends the provision of the 1917 Surface Water Code to ground water, with two differences. Withdrawals of less than 5,000 gpd were exempted from the permit requirement and a 5 year period was allowed for "declaring" ground water right existing before 1945. An application-certificate process was also provided with additional criterion for new applications for ground water permits. Chapter 90.44.070 RCW provided that "no permit shall be granted for the development or withdrawal of public ground waters beyond the capacity of the underground bed or formation in the given basin, district, or locality to yield such water within a reasonable or feasible pumping lift in case of pumping developments, or within a reasonable or feasible reduction of pressure in the case of artesian developments..."

Ecology controls new appropriations for ground water through the permitting process. It also has the authority and responsibility to regulate new uses to protect prior water rights. However, very little control exists over appropriations of ground water in amounts of 5,000 gpd or less, because they are exempted from permit requirements.

On each new application to appropriate ground water, Ecology considers the impacts of the proposed new withdrawal of ground water, not only on existing users with prior rights, but also on "protected surface waters." Also, they must guard against saltwater intrusion. Finally, their decision must be consistent with the purpose of the Water

Resources Act of 1971, "...to ensure that the waters of the State are protected and fully utilized for the greatest benefit to the people of the State..."

For clarification, it is noted that waters of the State are public waters. Water rights grant an authority to use certain amounts of those waters. So called ownership only occurs after the water is withdrawn from an aquifer and is in physical control of the appropriator. Utilities do not own aquifers or the waters within them, except in the case of artificially stored ground waters where ownership has been established in accordance with legal requirements (Chapter 90.44 RCW).

Of increasing importance in approving new appropriations is the site specific question of hydraulic continuity between ground water and surface water, and what degree of impact on the water source is acceptable. The use of guidelines for determining significant hydraulic continuity that were in place have been discontinued, and Ecology is formulating new criteria through the Water Resources Forum process. It is very important for the protection of base stream flows that the hydraulic continuity and level of acceptable impact be correctly established.

The Washington State Departments of Health and Ecology are responsible for water usage and water rights data. Technically and legally, water use should approximate water right totals. This is seldom the case due, in part, to the lack of a State-wide systematic water usage data management program and outdated water rights records. Staffing limitations and inefficient reporting frequently restrict staff efforts to priority areas experiencing significant problems. Consequently, estimates based on field inventory, random sampling, or personal contacts are frequently the best available figures (Wallace, 1990).

Subsequent regulations also affect issuance of water rights. Chapter 173-500 WAC *Water Resources Management Program Established Pursuant to the Water Resources Act of 1971* designates areas within the state as Water Resource Inventory Areas and provides for base flow. That is, where ground water appropriations will have a measurable effect on streams, any permits or certificates shall be appropriately conditioned to assure maintenance of said base flows. Two Water Resource Inventory Areas exist in King County, the Cedar-Sammamish Basin, and the Green-Duwamish River Basin (Chapter 173-508 WAC and Chapter 173-509 WAC, respectively.)

5.3.2 Water Rights in King County

In reviewing any listing of water rights, the reader should note that they do not reflect actual current use of the ground water resource. They only identify the maximum legal appropriations that can be made. Uncertainties are: certificates of water rights have either been issued in an amount greater than actually developed and used; numerous rights are still recorded and considered active although they are currently unused or totally abandoned and have never been formally relinquished; originally developed well capacities have permanently diminished to a point below the water rights amounts due to system deficiencies or source deterioration; new permits have been processed instead of changing ownership or point of withdrawal for an existing water right; and Ecology's permit listings reflect authorization to develop and use certain amounts of water, but the status of the development is not reflected on their water rights report (the well may not be drilled).

In reviewing water rights claims listing and a water rights printout, the reader should note that some individuals or entities may think they have listed a new water rights by filing a claim under the "Registration Claims Act" of 1969. In the case of ground water, uses of water initiated after June 6, 1945, in amounts greater than 5000 gallons per day, require a State permit or certificate of water right, not a filed claim (the previous discussion for water rights is from Wallace, et al, and Rolla, Smith, May 10, 1995 issue papers).

The only official source of water right records and water right claims is the registry at the Washington State Department of Ecology. Information on water rights in the East King County Ground Water Management Area will help to describe the relationship between a water purveyor's source capacity and the purveyor's permitted right to withdraw water. This information will help to determine the present and future allocation of ground water in the East King County Ground Water Management Area.

Currently, the State does not require a water rights claim for wells that withdraw less than 5,000 gallons per day. Therefore, some individual wells associated with rural residences are not accounted for by the quantities of water included in existing water rights.

An estimate of the total ground water withdrawal from wells without water rights will be necessary to allocate future ground water resources. Table 5.2. Summary of Ground Water Withdrawals lists water usages in the East King County Ground Water Management Area by category and sub-area in acre feet per year (U.S. Geological Survey, 1995).

5.3.3 Areas of Concern and Future Information Needs

Estimation of the capacity of the aquifer systems is necessary for comprehensive water rights analysis. A ground water model should be developed of the Snoqualmie River Valley in order to determine the capacity of the aquifer system.

5.4 Existing and Potential Water Demand

5.4.1 Major Suppliers and Water Demand

Existing and forecasted future water demand for major suppliers in the East King County Ground Water Management Area is reflected in the 1994 King County Comprehensive Plan. These data project an increase in water demand of 19 percent between the years 1995 and 2012. The 1989 Coordinated Water System Plan and preliminary findings from the latest demand forecast update of the Coordinated Water System Plan (1996) indicate that the East King County Critical Water Supply Service Area will required 75 to 100 million gallons per day (MGD) of new supply by the year 2040. The East King County

Critical Water Supply Service Area includes all of the East King County Ground Water Management Area as well as the area to the west (to Lake Washington), to the north (to the King/Snohomish County line), and to the south (south of the Cedar River and Lake Youngs).

5.4.2 Demographic Projections for the East King County Ground Water Management Area

Demographic indicators are helpful in estimating the amount and types of increased water demand predicted for the East King County Ground Water Management Area. A predictor of future population and development patterns in the study area is available through the adopted population targets in the King County Comprehensive Plan. The King County Comprehensive Plan states the Growth Management Act's Goals that affect land use impacts on ground water are: encouraging development in urban areas; reducing sprawl; encourage retention of open space and recreational areas; and a mandatory Land Use Element by providing for population densities, building densities, and estimates of future population growth. Most future growth and development is to occur within the Urban Growth Area to limit urban sprawl, enhance open space, protect rural areas and more efficiently use human services, transportation and utilities (King County Comprehensive Plan, 1994). Within the East King County Ground Water Management Area, the rural cities (Snoqualmie, North Bend, Carnation, Duvall) are planning for growth.

Adopted population targets were used to estimate growth in the East King County Ground Water Management Area (1994 King County Comprehensive Plan). Population targets for Small Area Zones used for transportation planning purposes were used to more accurately estimate growth in unincorporated areas specifically within the boundary of this Ground Water Management Area. For those Small Area Zones that lie on the boundary, a percentage of each zone was used in the forecasts. Small Area Zones projections are taken from the 1994 King County Comprehensive Plan, and are current as of February 1995. Population targets are also available for the cities of Duvall, Carnation, Snoqualmie and North Bend.

Adopted city population targets and Small Area Zones projections for unincorporated King County were used to estimate household growth between 1992 and 2012. Table 5.3. presents the current population, estimated growth, and estimated future population that is planned to occur between 1992 and 2012 in the East King County Ground Water Management Area. The data indicate that the total number of households requiring water in the East King County Ground Water Management Area is currently approximately 15,103 and projected to be 24,163 in the year 2012, reflecting a 60 percent increase in water service by the year 2012.

6.0 HYDROGEOLOGY

6.1 Introduction

This section discusses ground water occurrence in the East King County Ground Water Management Area and describes the site specific geology and ground water flow system in East King County as determined by the U.S. Geological Survey and by the review of historical data; and revised by Golder Associates after further field data collection (1995). The quality and quantity of ground water used for beneficial purposes, a water budget, and water level fluctuations are also discussed. Information from the Snoqualmie Ridge Project and other available geologic literature are also presented in the geologic and hydrogeologic area characterization. Most of the material that follows applies specifically to East King County, but the reader is referred to Freeze and Cherry (1979), Heath (1983), or Fetter (1994) for more comprehensive discussions of general ground water occurrence.

The U.S. Geological Survey work in the East King County Ground Water Management Area provides regional hydrogeologic information about the Snoqualmie Valley and the Sammamish Plateau (much of which is now incorporated into the Issaquah Creek Valley Ground Water Management Area as a result of a boundary change requested by the Sammamish Plateau Water and Sewer District). The U.S. Geological Survey study made use of existing information, along with new field information gathered about water levels and water quality. The U.S. Geological Survey entered into a cooperative agreement, in 1990, with the Seattle-King County Health Department to conduct a 2-year study of the ground water system in East King County. The U.S. Geological Survey described, with limited available hydrogeologic information, the physical and chemical characteristics of the ground water system (Washington Department of Ecology, 1988). The study had the following objectives:

- describe and quantify the ground water system to the extent allowed using available and readily collectable data;
- describe the general water chemistry of the major hydrogeologic units and any regional patterns of contamination;
- evaluate the potential for ground water development on the basis of aquifer characteristics, ground water interaction with surface water, and ground water recharge; and
- determine what additional data are needed to further quantify ground water availability.

The U.S. Geological Survey compiled the information gathered from the two year study into a report, titled *Geohydrology and Ground-Water Quality of East King County, Washington*, 1995.

The U.S. Geological Survey study identified additional technical information to be gathered in specific areas of the East King County Ground Water Management Area to clarify gaps in geological information. Golder Associates completed a geophysical investigation and well drilling as a follow up to the U.S. Geological Survey work (Golder Associates, *Geophysical and Hydrogeologic Investigation in the East King County Ground Water Management Area*, 1995). They investigated the Carnation area with the following objectives:

- obtain geophysical data in the Middle Snoqualmie River Valley;
- install a 1000 foot boring at Loutsis Park, Carnation, Washington;
- review and enhance the U.S. Geological Survey stratigraphy and geological model where new geophysical and well log information was collected; and
- develop from the new information cross-sections of their study area.

The Snoqualmie Ridge Project is located between Snoqualmie River, Lake Alice and Interstate 90, on the Lake Alice Plateau, contiguous with the northwest boundary of the City of Snoqualmie. This project includes residential development, a golf course, and construction of major arterials. The hydrogeologic investigation for this project was completed by Associated Earth Sciences, Inc. initially in May 1988 and finalized in February 1995. The report is presented in Appendix F of the Draft Supplemental Environmental Impact Statement for the project (Snoqualmie Ridge Project, April 1995), and contains a description of geology, hydrogeology, ground water modeling, and potential impacts and mitigations.

The Snoqualmie Ridge Project investigated ground water in four stages:

- All available records of wells on or within one mile radius of project boundaries were requested from sources (Ecology, Department of Social and Health Services (now the Washington State Department of Health), and the U.S. Geological Survey) and the most significant information was entered in a computer database.
- Seismic refraction surveys were completed to aid in determining location and extent of shallow bedrock.
- Three deep and two shallow exploratory borings; a pump test was completed on well EB-1 (most productive) and pump test completed on city of Snoqualmie backup water supply well located approximately 1.5 miles east of the site.
- A gravity survey was completed in the subsurface geologic units as an aid in the indication of the historical water courses of Snoqualmie River.

6.2 Geology

Many studies have contributed to the current understanding of the geologic framework of the East King County Ground Water Management Area. Detailed descriptions of geologic conditions in the study area, and the Puget Sound Lowland in general, are provided in Willis (1898), Bretz (1913), Mackin (1941), Liesch and others (1963), Crandell and others (1958,1965), Crandell (1965), Richardson and others (1968), Livingston (1971), Hall and Othberg (1974), Thorson (1980), Gower and others (1985), Blunt and others (1987), and Booth (1990).

6.2.1 Regional Geologic History

This section briefly describes the generalized geology and ground water occurrence in the East King County Ground Water Management Area. In the study area, the geologic record indicates tangible physical evidence of earth history since the early Tertiary period (approximately 60 million years ago). The composition of this evidence is categorized as geologic units that are characteristic of an intricate sequence of events.

The internal earth processes of volcanism (tectonics) and mountain building (orogeny) resulted in the surface bedrock exposures and topographic highs in the East King County Ground Water Management Area. As the finite water supply of earth became stored in the advancing glacial ice sheets, the ocean levels retreated out of the Puget Sound west of the Strait of Juan de Fuca. Rivers of melt water escaping from the leading edges of the advancing glaciers lanced deep into the surface of the earth in an effort to reach sea level. As a result of repeated glacial advances and retreats, some of these ancient river valleys are known to exist at elevations below present day sea level (Clayton, Geoff, personal communication, 1995). These valleys were subsequently buried by glacial and river sediment of varying permeability and composition.

Continental glacial ice sheets moved south into the study area from British Columbia several times during the Pleistocene Epoch (10,000 to 1,600,000 years before the present) incorporating rock chunks and sediment in their mass as they overrode the land surface (U.S. Geological Survey, 1995). This ice was part of the Cordilleran ice sheet of northwestern North America. The Cascade Mountain alpine glaciers ground downhill west and east towards the lowlands of the Puget Sound and eastern Washington. The varying characteristics and composition in the matrix of these glaciers resulted in the vertical and laterally changing nature of the subsurface sediments in the region. "Below an altitude of about 1,000 meters, nearly the entire land surface has been created or modified by glacial processes" (Booth, 1994). Resulting from the Vashon Stade of the Fraser Glaciation, the "massive proglacial infilling followed by subglacial scour" generated the geomorphic products found in the Puget Sound Lowland (Booth, 1994).

Repeated episodes of ice advance and retreat, called glaciations, resulted in thick accumulations of glacial and interglacial deposits throughout the region. These deposits consist of unconsolidated gravel, sand, silt, clay, and peat. The deposit identification of successive glaciations in the Puget Sound region is difficult because each glaciation eroded and disturbed the deposits from previous glaciations. Therefore our knowledge of all except the last major glaciation is limited.

This most recent glaciation, referred to as the Vashon Stade of the Fraser Glaciation, began about 15,000 years ago when the ice slowly advanced southward, blanketing the entire Puget Sound Lowland. Evidence of this glaciation is apparent throughout the lowland in the form of topographic features, as well as deposits called glacial drift. Although alpine glaciers extended westward from the Cascade Range foothills at the same time as the continental ice, those in the study area did not extend down the valleys far enough to merge with the continental ice during this last glaciation.

As the Vashon glacier advanced southward, rivers such as the Snoqualmie River that originally flowed northward were either diverted southward or dammed. Blocked drainages often resulted in extensive lakes fed by the rivers and the advancing glacier itself. Such lakes eventually breached or overtopped their enclosing basins. The Vashon glacier remained at its maximum extent for a relatively short period. As the climate warmed, beginning about 13,500 years ago, the glacier began to melt faster than it advanced, beginning the process of retreating. As the glacier retreated northward, the drainage to the north across the Puget Sound Lowland to the Strait of Juan de Fuca eventually was re-established. The Snoqualmie River, having regained its northerly course, subsequently formed a valley-wide floodplain graded to present-day sea level.

6.2.2 Stratigraphy

As a result of the Vashon and previous glaciations, much of the East King County Ground Water Management Area study area is covered by unconsolidated deposits that are both glacial and nonglacial in origin. These deposits tend to be mixed and may be missing or may not form a continuous layer in places. The variable topography of the study area further contributes to the complexity of the deposits. Beneath these unconsolidated deposits, which are thicker than 1,000 feet, are Tertiary and pre-Tertiary consolidated rocks, which are referred to in this section as bedrock. The various types of bedrock were not differentiated in this report section. The surficial extent of the geologic units illustrated by the U.S. Geological Survey is shown on Plate 1 of their report. The following is a detailed description of the geologic units identified by the U.S. Geological Survey in their technical report (1995). The units are in order of youngest to oldest and the units are described in percentage of surficial areal coverage in the East King County Ground Water Management Area.

The youngest geologic units in the study area are bog deposits (Qb), and alluvium (Qal). The bog deposits, which cover less than one percent of the study area (Plate 1, U.S. Geological Survey, 1995), consist of alluvium and peat that have accumulated in poorly drained depressions on the present day land surface. Because bog deposits occur to only a small extent, it is considered hydrogeologically insignificant for this study area. However, the bog deposits can perch or confine ground water locally.

The sediment deposited by rivers and streams (including intermittent streams) is known as alluvium. The alluvium consists mostly of the extensive deposits of the Snoqualmie River and its tributary streams and covers about 19 percent of the study area (U.S. Geological

Survey, 1995). Smaller amounts of alluvial fan deposits and landslide material are included in the unit. The Snoqualmie River alluvium consists of sand, silt, and clay downstream from Snoqualmie Falls, and sand and gravel upstream from the Falls. Alluvium from tributary streams generally consists of sand, gravel, and silt. Alluvium forms a highly productive, unconfined aquifer upstream of the Snoqualmie Falls. Downstream from the Snoqualmie Falls the matrix of alluvium becomes well-graded, resulting in lower permeability and aquifer productivity.

The youngest glacial unit in the study area is the Vashon recessional outwash (Qvr). About 22 percent of the study area is covered with Vashon recessional outwash (U.S. Geological Survey, 1995). Vashon recessional outwash consists of moderately- to well-sorted sand and gravel laid down by meltwater that has been discharged from the receding Vashon Stade of the Fraser Glaciation. Included in this unit are ice-contact deposits that accumulated along the margin of the ice in the eastern part of the study area. Associated with the recessional outwash, but mapped as a separate unit, is Vashon recessional lacustrine, a fine-grained deposit of ice-dammed lakes. These lacustrine deposits cover about one percent of the study area and is found in limited exposures along the margins of the Snoqualmie River and Patterson Creek Valleys. The lacustrine recessional deposits contain much more silt and clay than does the Vashon recessional outwash. The difference between lake sediment versus river sediment is that moving river water suspends the silt, clay and some sand-sized particles in the moving water. This sediment is deposited when the kinetic energy of the moving water decreases, such as when the water flows into a pond, lake or delta. The recessional outwash is an aquifer in areas where it is saturated. The ground water that occurs in it is mostly unconfined and perched conditions occur locally.

Glacial till, often referred to as hardpan or boulder clay, consists of a compact, unsorted mixture of sand, gravel, and boulders in a matrix of silt and clay. The Vashon till appears gray on fresh surfaces, is extremely dense, and will commonly stand in near-vertical cliffs (Snoqualmie Ridge Project, February 1995). Vashon till, (Qvt), owes its compact nature to the fact that it was deposited beneath and compacted by the heavy mass of the advancing Vashon Glacier. Vashon till is exposed at land surface over about 40 percent of the study area (see Plate 1, U.S. Geological Survey, 1995). The till is generally considered a confining unit but has produced water resulting from randomly occurring sand lenses.

As the Vashon glacier advanced southward, large quantities of stratified sand and gravel were deposited by meltwaters at the front and sides of the ice mass. These deposits, the Vashon advance outwash, are labeled on geologic maps as Vashon advance (Qva) and typically consist of well-graded gravelly sand to fine-grained sand. The Vashon advance coarsens upward through the sequence; in other words, the particle grain size is larger in the upper-part of the formation than in the bottom. The meltwater from the encroaching ice mass increased in velocity in the study area during the deposition of the Vashon advance. As a result, the formation is configured by a basal unit (lacustrine silt, clay, and very fine sand), a medium sand and sandy, cobbly gravel (characteristic of a high energy environment), and an ice marginal deposit (interbedded sands, silt, and gravels) (Snoqualmie Ridge Project, February 1995). The unit is exposed in the bluffs along the margins of the Snoqualmie River and tributary valleys (Plate 1, U.S. Geological Survey, 1995). These surficial exposures cover only three percent of the study area (U.S. Geological Survey, 1995). The advance outwash is a principal aquifer in terms of use in the East King County Ground Water Management Area and the ground water occurs mostly under confined conditions.

Beneath the Vashon advance is an extensive fine-grained assemblage of laminated clayey silt to clay with minor lenses of sand, gravel, peat, and wood. This unit, referred to as the transitional beds (Qtb), was deposited in standing water ponded by the advancing Vashon glacier. Surficial exposures of the unit, located mostly on the walls of the Snoqualmie Valley west of Duvall and Snoqualmie, cover about one percent of the East King County Ground Water Management Area.

The oldest unconsolidated deposits mapped in the East King County Ground Water Management Area are referred to as pre-Fraser deposits (Qpf). These include any unconsolidated material, regardless of origin, that was deposited prior to the Fraser glaciation. Surficial exposures of this unit are limited to less than one percent of the East King County Ground Water Management Area, and consist of either interglacial sand and gravel deposited by rivers between ice advances, or clay-rich till from earlier ice advances.

6.2.3 Pre-Vashon Deposits

The pre-Vashon deposits 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. The U.S. Geological Survey (1995) identifies five unconsolidated hydrogeologic units that are listed here in order of increasing geologic age:

- Upper fine-grained unit (Q(A)f);
- Upper coarse-grained unit (Q(A)c);
- Lower fine-grained unit (Q(B)f);
- Lower coarse-grained unit (Q(B)c); and
- Deepest unconsolidated and undifferentiated deposits (Q(C))[1].

Beneath the Vashon advance deposits are an extensive fine-grained assemblage of laminated clayey-silt to clay with minor lenses of sand, gravel, peat, and wood. This unit, referred to as the upper fine-grained unit (Q(A)f), includes transitional beds and local

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1 Names that refer to grain size and relative stratigraphic position were used to refer to older unconsolidated hydrogeologic units that are, in effect, subdivisions of the previously discussed geologic units. For example, Q(A)c is the upper (A) coarse-grained (c) hydrogeologic unit in the Quaternary (A) geologic units.

occurrences of till at the base of the unit. Surficial exposures of the unit, located mostly on the walls of the Snoqualmie Valley west of Duvall and Snoqualmie, cover about one percent of the study area. This confining unit can yield usable quantities of water for small public water systems (U.S. Geological Survey, 1995).

Underlying the upper-fine grained unit, but discontinuous in the study area, is the upper-coarse grained (Q(A)c). The U.S. Geological Survey (1995) describes this unit to be a principal aquifer in terms of use. Additionally, this unit consists of intraglacial deposits, including strongly oxidized sand and gravel. The ground water that occurs in this aquifer is confined.

The lower fine-grained unit (Q(B)f) consists of clay, silt, and till with some sand and gravel. This unit is a confining bed but can yield usable quantities of water. The unit is used rarely as a water source.

The lower coarse-grained unit (Q(B)c) consists of sand and gravel with minor percentages of clay and silt. The unit is an aquifer though saturated is rarely used as a ground water source. The ground water in this unit is probably confined.

The oldest unconsolidated deposits mapped in the East King County Ground Water Management Area are referred to as the deepest and undifferentiated deposits (Q(C)). These deposits include any unconsolidated material of unknown origin.

6.2.4 Bedrock

Underlying the previously mentioned stratigraphic and sedimentological features is the Tertiary age and older bedrock. Most of the consolidated rocks that make up the bedrock (Br) consist of andesite with minor amounts of basalt and diorite. However, sandstone, siltstone, and conglomerate are predominant southwest of the Snoqualmie River. Bedrock is exposed in about 13 percent of the study area, mostly in the east and southwest (Plate 1, U.S. Geological Survey, 1995). Drillers' logs indicate that the bedrock surface forms a southeast-to-northwest trending structural trough beneath the low-lying areas occupied by the Snoqualmie River Valley. The bedrock outcrop at Snoqualmie Falls represents a structural high that interrupts the otherwise continuous trough.

Two types of bedrock were encountered in the Snoqualmie Ridge Project area. The first type, the Tukwila Formation, consists of interbedded sandstone, basaltic siltstones, andesitic laval flows, and local occurrences of conglomerate and coal. The second bedrock type (Rattlesnake Mountain Rocks) generally consists of basalt with thin interbeds of sandstone. Tukwila Formation rocks were observed within the southern portion of the project area and Rattlesnake Mountain rocks were noted near Snoqualmie Falls and within Exploration Boring EB-1. According to Walsh (1984), the Tukwila Formation also occurs within the west bluff of the Raging River (City of Snoqualmie, May 1988).

6.2.5. Soils

Soils correspond to and are a direct result of the weathering and decomposition of the surficial geologic unit. Soils have been mapped by the U.S. Department of Agriculture, Soil Conservation Service, (now known as the National Resource Conservation Service). Soils maps in the area of man-made land developments are not useful because general construction practices remove the top three to five feet of the earth and alter natural conditions. A review of soils maps indicate the East King County Ground Water Management Area has been described to have 39 soil types covering the surficial three to five feet.

The Soil Survey of the King County Area, Washington, November 1973 and the Soil Survey of Snoqualmie Pass Area, Parts of King and Pierce Counties, Washington, April 1986 identify soils in the East King County Ground Water Management Area. The soil descriptions[2] for the East King County Ground Water Management Area were completed from aerial maps.

6.3 Hydrogeology

6.3.1 Ground Water Occurrence

The occurrence of ground water varies greatly, and is largely dependent on recharge and the permeability of the hydrogeologic unit, or the ability of the unit to transmit water. Water-saturated geologic units can be classified either as aquifers or as confining (or semiconfining) beds. An aquifer is a geologic unit that is at least partly saturated and is sufficiently permeable to yield water in significant quantities to a well or spring (Freeze and Cherry, 1979). A confining bed is a geologic unit having a much lower permeability than that of adjacent aquifers, thus restricting the movement of ground water into (recharge), or out of (discharge), those aquifers (see Figure 6.1.).

Ground water flow systems are commonly divided into local and regional systems (Tóth, 1963; Freeze and Cherry, 1979). Local flow systems have short flow paths, involve shallow aquifers, and are controlled chiefly by local topography. In contrast, regional flow systems have long flow paths, involve deep aquifers, and are controlled chiefly by large scale topographic features. A third kind of flow system, termed intermediate, commonly exists between the two extremes. In reality, the three flow systems are continuous rather than independent (U.S. Geological Survey, 1995). The idealized ground water flow pattern beneath an area of uniformly permeable material, as modified from Hubbert (1940), is shown on Figure 6.2. The primary control on the occurrence of flowing wells is not structure or stratigraphy, but topography (Freeze and Cherry, 1979).

2 Soil Survey of the Snoqualmie Pass included map numbers 1, 2, 9, 10, 17, 18, 24, 25, 31, 31, 36, 37, 44, 50. Soil Survey of King County included map numbers 3, 4, 7, 8.

Water is present in the pore spaces of soils and bedrock throughout the East King County Ground Water Management Area. This "ground water" is the part of the continuous hydrologic cycle (see Figure 6.3.) which, in the natural state, begins with infiltration of precipitation and runoff (recharge) and ends with discharge to springs, streams, and wetlands.

6.3.2 Principal Hydrogeologic Units

The geologic units described previously were differentiated into aquifers and confining beds based on lithologic and well-yield data from the 604 wells inventoried in the East King County Ground Water Management Area by the U.S. Geological Survey. The aquifers and confining beds thus defined are referred to as hydrogeologic units because the differentiation takes into account both the hydrologic and geologic characteristics of the unit. However, the heterogeneity of the units can result in local variations in hydrologic characteristics. For example, a glacial aquifer may be composed predominantly of sand and (or) gravel, but on a small scale it also may contain relatively thin and discontinuous lenses of clay or silt. Conversely, a confining layer, composed predominantly of silt and (or) clay, also may contain local lenses of sand or gravel. As a consequence, the general occurrence and movement of ground water may be influenced locally by these small scale variations in lithology (U.S. Geological Survey, 1995).

The relative importance of each of the hydrogeologic units as a source of ground water can be determined from a graph of the number of study wells finished in each unit (see Figure 6.4.). Analysis of this information indicates that alluvium, Vashon recessional, Vashon advance, the upper coarse-grained unit and bedrock are the principal sources of water for existing wells in East King County Ground Water Management Area. However, usable quantities of ground water also can be obtained from Vashon till, the upper fine-grained unit, the lower fine-grained unit and the lower coarse-grained unit.

Surficial and Alluvial Aquifer

The Quaternary alluvium, Qal, is present mostly in the floor of the Snoqualmie River Valley and its tributaries (Plate 2, U.S. Geological Survey, 1995). An average thickness of 100 feet and a maximum thickness of 250 feet in the upper Snoqualmie River Valley is shown on the hydrogeologic sections (Plate 1, U.S. Geological Survey, 1995). However, the thickness of the Qal is difficult to determine, because most wells do not penetrate the entire unit. Furthermore, Qal commonly overlies older but lithologically similar deposits. The altitude of the top of the unit ranges from less than 40 feet near the King County-Snohomish County boundary to 800 feet in the uppermost reaches of the Snoqualmie River tributaries (Plate 2, U.S. Geological Survey, 1995). The Qal is a highly productive aquifer, especially upstream of Snoqualmie Falls in and around the town of North Bend. Most of the 107 inventoried wells that tap this unit are located in this upper valley, where the North, Middle, and South Forks of the Snoqualmie River converge. Wells that tap Qal either downstream from the falls, in landslide deposits, or in alluvial fans have yields that tend to be smaller and somewhat less predictable than the wells in the upper valley. Wells that are on the lower valley floor are also subject to periodic flooding of the Snoqualmie River, so far fewer of them exist (U.S. Geological Survey, 1995).

Soil and sediments overlying glacial till are able to hold precipitation and serve as an aquifer because the rate of infiltration through the till is substantially lower than the rate of infiltration into this surficial layer. This structure usually results in a perched water table aquifer with limited use. Water table aquifers are very susceptible to anthropogenic effects and surficial use. Historically, most of the wells used by early farmers were from water table aquifers, usually large diameter hand dug wells.

Gravity pulls the water in surficial aquifers down, until it reaches the relatively impermeable till. Then, if the till is sloped, or hydraulic head is present, water will move down slope over the underlying till, discharging to streams and springs at the edge of the surficial unit, or into a wetland. Surficial aquifers occur in deposits of recessional glacial outwash and post-glacial alluvium washed into depressions on the till surface.

The Snoqualmie Ridge Association Report (1988) states that flow through the surficial aquifer is substantial, possibly amounting to recharge of two feet or more of rainfall, excluding infiltration consumed above the water table by plants. Most of this recharge is discharged to surface streams and springs, wetlands and lakes.

A fraction of the total recharge infiltrated to the surficial aquifer reaches deeper aquifers underlying the till. Where the till layer has been identified as missing in the geologic record, then infiltration is greater and direct recharge to deep aquifers is likely.

Vashon Recessional Outwash Aquifer

The U.S. Geological Survey (1995) reports the Vashon recessional outwash aquifer is present in a large part of the East King County Ground Water Management Area but is absent in the Snoqualmie Valley floor. A typical thickness of the unit is 60 feet, however, the unit can vary from a veneer overlying till to an accumulation greater than 300 feet. The altitude of the top of the unit varies from slightly less than 100 feet along the flanks of the lower Snoqualmie River to 1200 feet in the upper Snoqualmie River. This coarse-grained unit can be a productive aquifer in places where relatively thick sequences of sand and gravel are saturated. In areas where the unit is thin or lies above the water table, little water is available, such as east of the Snoqualmie River valley and the Sammamish Plateau. Most of the wells inventoried by the U.S. Geological Survey that are completed in the Vashon recessional outwash are east of Fall City, northeast of Snoqualmie or on the Sammamish Plateau. The aquifer is under water table conditions, and the wells produce moderate yields for domestic purposes.

Vashon Till Aquifer

The Vashon till (Qvt) is broadly distributed throughout a large part of the study area, but it is thin or absent in some areas where thick deposits of Vashon recessional outwash are present (Plate 2, U.S. Geological Survey, 1995). This implies that the till was probably eroded within the fluvial environment during the deposition of the Vashon recessional. Like the Vashon recessional, the Vashon till is also absent beneath the Snoqualmie Valley floor. Although the unit can be as much as 200 feet thick, a more typical thickness is 70 feet. The altitude of the top of the unit ranges from 100 to 1,400 feet above sea level. Vashon till generally produces low yields of water and is considered a confining bed. However, 37 inventoried wells tap thin layers of relatively clean sand and (or) gravel within the unit. In many places the upper part of the Vashon till is more permeable than the lower part. Therefore, the upper part can contain perched water bodies that will yield usable short-term quantities of water to shallow wells (Liesch and others, 1963). Because Vashon till is typically dense and unsorted, well yields from it are variable.

Vashon Advance Outwash Aquifer

The outwash aquifer receives essentially all its recharge via downward percolation from the surficial aquifer, and it discharges as springs and in streams. Seepage to deeper ground water zones also occurs. The Vashon advance outwash (Qva) is present throughout much of the study area, mostly in the subsurface (Plate 2, U.S. Geological Survey, 1995). Like Vashon recessional and Vashon till, it too is absent beneath the Snoqualmie River Valley floor and its extent east of the valley cannot be readily defined at this time due to a lack of data. A typical thickness of the unit is 200 feet. The top of the unit varies from slightly below sea level (Plate 2, U.S. Geological Survey, 1995) to 900 feet. Vashon advance aquifer is tapped by 124 of the inventoried wells and is one of the major aquifers of East King County. Ground water in this aquifer is usually confined by the overlying Qvt and the underlying Q(A)f.

Upper Fine-Grained Unit

The upper fine-grained unit (Q(A)f) consists primarily of all of the transitional beds (Qtb) and local occurrences of pre-Fraser till (Qpf). It is the youngest continuous unit beneath the alluvium of the Snoqualmie River Valley. The top of the unit ranges from 100 feet below to 800 feet above sea level (U.S. Geological Survey, 1995). The upper fine-grained unit has a typical thickness of 250 feet but can be as thick as 550 ft; it is the thickest unconsolidated unit in the study area. The upper fine-grained unit is not made up completely of fine-grained materials; 42 inventoried wells tap local, thin lenses of sand or gravel that yield relatively small quantities of water suitable for domestic use. The upper fine-grained unit generally acts as a confining bed between the coarse-grained deposits above and below it. Because of this, the upper fine-grained unit retards the percolation of ground water into upper coarse-grained unit and causes vertical head gradients between the Vashon advance outwash and the upper coarse-grained unit in places.

Upper Coarse-Grained Unit

The upper coarse-grained unit, Q(A)c, consists of interglacial sand and gravel from pre-Fraser (Qpf) unit and is extensive throughout the study area (Plate 2, U.S. Geological

Survey, 1995). The average thickness of the unit is approximately 140 feet (Plate 1, U.S. Geological Survey, 1995). The top of the unit varies from 300 feet below to 700 feet above sea level in the north-central part of the study area (Plate 2, U.S. Geological Survey, 1995). This unit may be present at even higher altitudes in the easternmost part of the study area where small exposures of pre-Fraser deposits have been mapped. Because of the lack of wells in that area, however, the hydrologic characteristics of the deposits are unknown and including them with the upper coarse-grained unit (Q(A)c) is not warranted. The upper coarse-grained unit (Q(A)c) is a major aquifer in the study area. Eighty-six inventoried wells tap this mostly confined unit.

Deepest Unconsolidated Units

The three deepest unconsolidated units in the study area are the lower fine-grained unit (Q(B)f), the lower coarse-grained unit (Q(B)c), and the deepest unconsolidated and undifferentiated deposits (Q(C)), all from pre-Fraser geologic unit (Qpf). On the basis of the few available drilling records, the lower fine-grained unit is a mostly fine-grained confining bed. Little information exists about the productivity and extent of the lower coarse-grained unit (Q(B)c) and the oldest unconsolidated units (Q(C)). Four inventoried wells are completed in the lower fine-grained unit (Q(B)f) and nine are completed in the lower coarse-grained unit (Q(B)c). No inventoried wells are completed in the oldest unconsolidated units (Q(C)).

Within the East King County Ground Water Management Area evidence exists of buried valleys from the ancient path of the Snoqualmie River. This evidence is from seismic refraction surveys and gravity analysis, and ground water gradients shown in water level measurements (Snoqualmie Ridge Project, 1987). Time domain electromagnetic results from the East King County Ground Water Management Area resource protection study indicates an aquifer in the vicinity of Carnation Farms has channel-like morphology. This feature may extend under Tolt Hill (Golder, *Geophysical and Hydrogeologic Investigations in East King County Ground Water Management Area*, 1995). Recharge to the deep aquifers is very slow in relation to the ability to draw water from them. The age of the water that is extracted is connate, probably as old as the sediment when deposited. If the deep aquifers were pumped for water supply purposes the time lag would be great between when ground water is removed and when surface aquifers that recharge them are impacted. However, once the deep aquifers are impacted from pumping the rate at which they will recover will be equally as slow or slower if they recharge at all (Turney, Gary personal communication, 1995).

Bedrock Aquifers

The consolidated Tertiary and pre-Tertiary rocks that constitute the bedrock (Br) contain small quantities of water in fractures and joints that are probably more numerous near the top of the unit. In general, however, the bedrock is an unreliable source of ground water, and many wells drilled into that unit yield insufficient or poor-quality water. Most of the 88 inventoried wells that tap bedrock are located in the southwestern and northeastern parts of the study area, and the wells supply water for domestic use. In areas where the aquifer used is bedrock, bedrock is either exposed at land surface or is covered by a thin, low water bearing layer of unconsolidated deposits. Because bedrock is the only source of water in some areas of the East King County Ground Water Management Area, water supplies in these areas (such as the northeastern portion of the study area) are often tenuous at best. In some areas northeast of Duvall, for example, wells in bedrock typically go dry in the summer. Where the bedrock is exposed at land surface, the ground water is likely to be under water-table conditions; where the bedrock is covered by a significant thickness of unconsolidated deposits, especially clays and silts, the ground water is likely to be confined.

6.3.3 Hydraulic Conductivity of Principal Units

Estimates of the horizontal hydraulic conductivity of the hydrogeologic units were used by the U.S. Geological Survey to help understand the availability and movement of ground water. Hydraulic conductivity is a measure of the ability of a hydrogeologic unit to transmit water. It is defined as the volume of water that will move in unit time through a unit cross-sectional area under a unit hydraulic gradient. For unconsolidated materials, hydraulic conductivity depends on the size, shape, and arrangement of the particles. Because these physical characteristics vary greatly within the glacial deposits of the study area, hydraulic conductivity values are also highly variable. Hydraulic conductivity data were statistically summarized so that differences between aquifers could be determined.

The median hydraulic conductivities are reasonable for all units except Qvt. The median hydraulic conductivities for the coarser grained units, Qal, Qvr, Qva, Q(A)c, and Q(B)c range from 34 to 130 ft/day and are the larger values observed. The median hydraulic conductivity of 130 ft/day for Qal is the largest of any unit. The median hydraulic conductivity of 51 ft/day for Qvt is somewhat anomalous because Qvt is relatively fine grained, and its hydraulic conductivity is larger than those determined for the coarse-grained Qva and Q(A)c. The median hydraulic conductivities for Q(A)f and Q(B)f are 9 ft/day and 15 ft/day, respectively, and are consistent with the fine-grained deposits present in those units. However, the median hydraulic conductivity for Q(B)f is based on only two samples. The lowest median hydraulic conductivity (0.88 ft/day) was for the Br unit. Because ground water in bedrock is present primarily in the fractures, a low median hydraulic conductivity suggests that the Br unit generally is not fractured enough to produce large quantities of water. This low hydraulic conductivity is the primary reason the bedrock is generally a poor source of water.

The relatively large median hydraulic conductivity of Qvt is likely a reflection of the presence of more permeable zones (U.S. Geological Survey, 1995). It is likely that most wells in this unit have been completed in sand and gravel lenses or in the upper part of the unit. Wells completed in the less-permeable zones either have been decommissioned or may not have produced enough water for a pump test to be practical. As a result, the data are biased toward the more productive zones in the unit and are not representative of Qvt as a whole. This bias is unavoidable when relying upon production well data; the bias probably exists for all of the units to various degrees, depending upon the heterogeneity of the unit. As a result, all of the median hydraulic conductivity values may be biased high. Because Qvt is probably the most heterogeneous of the units, the bias for it is probably the largest. The minimum hydraulic conductivities for the hydrogeologic units illustrate that poorly producing wells are present in each unit. Also, the range of hydraulic conductivities is at least three orders of magnitude for most units, indicating a substantial amount of heterogeneity.

No data were available to estimate the vertical hydraulic conductivity of aquifers or of confining layers between aquifers. Estimates made as part of other studies indicate that in glacial materials vertical hydraulic conductivity is commonly several orders of magnitude less than horizontal hydraulic conductivity.

6.4 Conceptual Model of the Ground Water System

Four coarse-grained major aquifers (Qal, Qvr, Qva, and Q(A)c) and two fine-grained confining layers (Qvt and Q(A)f) were identified. Beneath this assemblage and above the relatively impermeable bedrock are the older unconsolidated deposits (Q(B)f, Q(B)c, and Q(c)) that could contain significant quantities of water, but for which little data exist. The bedrock (Br) is not considered a principal source of water because it has relatively poor yields, as discussed previously. The resulting ground water flow system described for East King County is local to intermediate in scale and is controlled mostly by the relief between the upland foothills of the Cascade Range and the Snoqualmie River Valley.

Part of the precipitation that falls on and around the study area recharges the ground water system. Ground water in upland areas (such as the Sammamish Plateau and Cascade Range foothills) moves vertically downward and laterally to discharge points (such as Lake Sammamish and the Snoqualmie River). The amount of time required for an individual molecule of water to travel through the system is roughly proportional to the permeability of the unit and amount of precipitation that reaches the unit. Water molecules along a relatively short travel path from recharge point to discharge point may be in the ground water system for only a few months; molecules along relatively long flow paths may be in the system for years or centuries. Also, water may be withdrawn from any point in the system, creating an artificial discharge point.

Flow into and out of the study area can be qualitatively assessed by evaluating the ground water conditions along the study boundaries. Ground water flows out of the study area along the northern boundary. Along the eastern boundary, including the Snoqualmie River upstream of North Bend, and tributaries to the Snoqualmie such as Tokul Creek, Harris Creek, Griffin Creek and the Tolt River, ground water flows into the study area (Golder, 1995). All of the southwestern and western boundaries are along surface water drainage divides; shallow ground water likely flows neither into nor out of the study area along the divides. Confirmation of these hypotheses requires additional investigation and a phased approach to additional investigation is recommended.

6.4.1 Movement

After the hydrogeologic units were delineated and wells were assigned to one or more of the units, the U.S. Geological Survey (1995) created water level maps for the major aquifers. These maps were used to describe and interpret the horizontal and vertical components of the ground water flow system.

Water level maps were drawn for Qal, Qvr, Qva, and Q(A)c, the four major aquifers of East King County for which adequate data are available. For the purposes of showing ground water flow, Qal and Qvr were combined on one map because these two units are primarily surficial units and they have common boundaries. Flow is from areas of higher to lower hydraulic head, and is generally perpendicular to the contours of equal head. Because the units are heterogeneous and complex, local conditions may vary. Flow directions are also subject to the same conditions.

Ground water in the combined Qal-Qvr unit generally moves toward the Snoqualmie River, then northward along the Snoqualmie River Valley. The gradient is nearly flat in the lower valley; in some places it is 5 feet/mile or less. In the upper valley, the gradient is somewhat steeper with at least 10 feet/mile. In contrast, in the vicinity of Snoqualmie Falls, local gradients may exceed an estimated 1,000 feet/mile over short distances. Flow from the uplands to the valley is significant in areas north and east of Carnation and north of Snoqualmie. Driven by local topography, the gradient in these areas is relatively steep. Flow within this unit on the Sammamish Plateau is not well defined because of a lack of data points and because much of the unit is completely unsaturated there. Similarly, a lack of data points in the Cascade Range foothills and in the Cherry Creek Valley prevented the U.S. Geological Survey from inferring ground water movement in this area.

Ground water flow in Qva is discontinuous because the unit is divided by Qal in the Snoqualmie River Valley. Flow follows the general surface topography into the Snoqualmie River Valley. Ground water also flows toward Patterson Creek from the eastern Sammamish Plateau and Ames Lake areas. Flow from the western Sammamish Plateau is toward Lake Sammamish. The flatter gradients are less than 100 feet/mile in areas such as the Sammamish Plateau and southeast of Duvall. Steeper gradients in excess of 500 feet/mile are present along the slopes to the Snoqualmie River Valley and near Patterson Creek (U.S. Geological Survey, 1995).

In Q(A)c, ground water flow is also generally to the Snoqualmie River Valley, then northward down the valley. A ground water divide is present in the Sammamish Plateau, with ground water in the western part flowing to Lake Sammamish and ground water in the eastern part flowing ultimately toward the Snoqualmie River. Gradients are generally more gradual in this unit; some of the steeper gradients (200 to 300 feet/mile) are found between Snoqualmie Falls and Fall City. Gradients in the river valley and east of the Sammamish Plateau are less than 50 feet/mile in some places (U.S. Geological Survey, 1995).

Vertical flow directions are difficult to ascertain because the Qal-Qvr and Qva are discontinuous, and in some areas the heads are similar from one unit to the next. In general, vertical flow is downward in upland areas. The best evidence for upward vertical flow is in about 30 flowing wells located in lowlands and along valley floors near the base of uplands. Water-level altitude maps also show that heads in the lower Snoqualmie River Valley are less than 100 feet above sea level in Q(A)c, and heads in the overlying Qal-Qvr are less than 60 feet in some places. Although this difference does not confirm upward flow in the entire valley, it suggests that the upward flow is likely; the difference is also consistent with the existence of the flowing wells along the valley floors.

The presence of downward vertical flows indicates that some water may be moving into the deeper regional hydrogeologic system, possibly even the bedrock (U.S. Geological Survey, 1995). Although this water would probably tend to flow north and west also, it would flow within the deeper hydrogeologic units not mapped, such as Q(B)c, Qc, and possibly Br. The ground water in these units could easily flow beneath surface waters such as Lake Sammamish and the Snoqualmie River, and ultimately flow to surface water bodies (such as Puget Sound) outside the study area.

6.4.2 Recharge

The bulk of the recharge to the ground water system of the study area comes from precipitation. Recharge is present everywhere, with the possible exceptions of (1) areas of ground water discharge, such as along the Snoqualmie River, and (2) those areas covered by impermeable, man-made materials such as asphalt and concrete. Impermeable materials at the land surface delay and redistribute the recharge water where proper surface infiltration and detention facilities are installed. Precipitation that runs off of impermeable surfaces may seep into the ground as soon as it encounters natural permeable materials depending on precipitation rate. Where runoff from impermeable surfaces is channeled into sewer systems, recharge is lost to storm water discharge points. The largest quantity of recharge in the study area probably occurs from October to March, when precipitation is greatest. Data exhibiting the relationship between annual precipitation and ground water levels at Snoqualmie Falls is presented in Figure 6.5.

The quantity of recharge to the ground water system of East King County was estimated by the U.S. Geological Survey using precipitation/recharge relations derived from a study of southwest King County (Woodward and others, in press). The estimated recharge is shown in Figure 6.6. The precipitation/recharge relations used to develop Figure 6.6 are based on the application of a deep-percolation recharge model developed by Bauer and Vaccaro (1987). Regression equations determined from the southwest King County data showed that precipitation and surficial geology were the most significant independent variables in determining recharge. For the two predominant types of surficial geology in East King County, outwash (Qvr and Qva) and till (Qvt), curves were drawn relating precipitation to recharge based on the data from southwest King County. These curves were applied to East King County because the hydrogeologic units, climate, and vegetation in both areas are similar.

The U.S. Geological Survey made several observations and assumptions in the development of Figure 6.6. First, the percentage of precipitation becoming recharge increases with increasing precipitation. This is likely due to evapotranspiration, which decreases proportionally with increasing precipitation because of increased cloud cover. Second, data from southwest King County included only annual precipitation up to approximately 60 inches, whereas some areas of east King County receive almost 100 inches. To estimate recharge for areas receiving between 60 and 100 inches of annual precipitation, the percentage of precipitation that goes to recharge at 60 inches was assumed to be constant above 60 inches. Therefore, for precipitation values greater than 60 inches, recharge was calculated as 69 percent of precipitation for outwash, and 44 percent of precipitation for till. Because, as noted above, the effects of evapotranspiration decrease with increased precipitation, this was considered a somewhat conservative approach. Also, at 100 inches of precipitation, evapotranspiration is estimated to be 20 to 25 inches based on published values for the area (U.S. Department of Agriculture, 1973), leaving 75 to 80 inches for recharge and runoff. Because the calculated recharge for outwash is 69 inches for 100 inches of precipitation, the U.S. Geological Survey assumed that negligible runoff occurs on outwash in the higher precipitation areas. Outwash is generally quite permeable, and these high-precipitation areas tend to be densely vegetated, both of which are factors that contribute to the ability of the land to absorb precipitation as recharge, so runoff is indeed likely to be minimal. Finally, because data existed only for outwash and till, estimates needed to be made for other surficially exposed hydrogeologic units. The alluvium (Qal) was assumed to have lithologic and hydrologic characteristics similar to the outwash, so the outwash curve was used for Qal as well. Similarly, recharge into bedrock (Br) was estimated with the till curve, because exposed bedrock in the study area usually is weathered and is assumed to be less permeable than outwash and approximately equivalent to till. Units other than alluvium, till, outwash, and bedrock are not surficially exposed over a large enough area in East King County to affect the recharge estimates. These other units are the bog deposits (Qb), which were aggregated into whichever unit surrounded a given Qb exposure, and the transition beds (Qtb) and pre-Fraser deposits (Qpf), for which the till curve was used.

To determine the distribution of recharge, a detailed contour map of long-term precipitation rates was overlaid on the map of the surficial geologic units. Geographic information system (GIS) techniques were used to combine like units and calculate recharge. The results show higher recharge rates in the eastern and southeastern parts of the study area, where precipitation is highest. Large areas exist where recharge is 20 to 30 inches per year (in/yr) because of the aggregation of high-precipitation areas on till with lower-precipitation areas on outwash or alluvium. As a whole, the ground water system of the study area (East King County Ground Water Management Area only) receives 413,000 acre-feet, or about 31 inches, of recharge in a typical year, based on an area-weighted average (U.S. Geological Survey, 1995). This figure must be considered in light of the assumptions made, and may contain some degree of unquantifiable error.

No attempt was made to determine the fate of the recharge water in quantitative terms once it becomes part of the ground water system. Some of the recharge may immediately discharge to nearby streams, while some may enter the deeper regional flow system and not be discharged for many years. Such determinations would require a three-dimensional ground water flow model (U.S. Geological Survey, 1995).

County-wide Mapping of Physically Susceptible and Recharge Areas

Subsequent to the U.S. Geological Survey recharge study described above, a county-wide 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 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 East King County Ground Water Management Area, ranked by the physical susceptibility of the aquifer, is shown schematically in Figure 4.7. 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 county-wide map has been created using criteria specifying surficial geology, soils and depth to ground water. Each criteria was rated individually as high, moderate or low according to the protocols listed in Table 6.1 through Table 6.3. 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 6.1 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 6.2 indicates the susceptibility ranking of U.S. Geological Survey geologic units.

The data used to determine depth to groundwater was obtained from well logs from the Washington State 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 6.3.

Physically Susceptible Areas

Areas of high, medium and low susceptibility to ground water contamination were determined from the county-wide map discussed above. The areas which have the highest potential for infiltration, and hence are most physically susceptible in the East King County Ground Water Management Area, include most of the Snoqualmie River Valley.

Land use, both current and historic, influences actual recharge. Precipitation also affects the actual quantity of recharge. These effects were not included in determination of physically susceptible ground waters (see Figure 4.7). These criterion will be included in critical aquifer recharge maps for King County which are expected to be produced using the physical susceptibility maps in conjunction with land use information and precipitation data.

6.4.3 Discharge

Ground water in East King County discharges as seepage to lakes and streams, spring flow, seepage to valley walls, ground water flow out of the study area, and withdrawals from wells (see Figure 6.7.). Only a small part of discharge was quantified during this study; specifically, the quantity of water discharged to streams and springs and the quantity withdrawn from wells. Evapotranspiration is not thought of a discharge per se however, precipitation that transpires through plant metabolic processes has been documented to be a significant amount of the water budget (U.S. Geological Survey, 1995).

Ground water discharges to certain reaches of some of the rivers and streams and augments streamflow to produce what is usually referred to as a gaining reach. Ground water discharge also sustains the late summer flow of numerous streams in the study area, especially those not fed by glacial meltwater. Conversely, some river reaches may discharge water to the ground water system to produce a losing reach. The results of a seepage study conducted in September 1991 showed that the Snoqualmie River system generally gains ground water within the study area. The Snoqualmie River itself appeared to gain water along its entire length except for the reach from Carnation to Monroe. The two largest tributaries, the Raging River and Tolt River, lose water to the ground water system. The total net discharge of ground water to the river system was 133 $feet^3$/second. This should be considered a minimum value, however, because these discharges were determined during the dry summer period of low river flow. During wetter periods, larger quantities of ground water likely flow to the river because regional water levels are usually higher, increasing water level gradients. Also, interflow, which is water that enters the shallow water table and seeps directly and quickly to adjacent streams, can be large during wetter periods. Many small streams were not measured, but they may collectively receive a significant quantity of ground water discharge (U.S. Geological Survey, 1995).

The City of North Bend spring (24N/08E-35N01S) has by far the largest discharge of any spring in the study area, averaging 9.0 feet^3/second. The total spring discharge accounted for in this study is about 13.2 feet^3/second, or 9,540 acre-feet/year.

Ground water withdrawals from wells in the study area (East King County Ground Water Management Area only) in 1990 were an estimated 4,270 acre-feet of water. This quantity represents gross withdrawals (including wells on the Sammamish Plateau) and does not reflect the quantity of water returned to the ground water system through on-site sewage systems or excessive irrigation.

The quantity of ground water that discharges through plant transpiration, as seepage to valley walls, or as ground water flow out of the study area, was not determined by the U.S. Geological Survey, but probably constitutes the bulk of the discharge from the ground water system. The combined quantity was estimated by the U.S. Geological Survey (1995).

6.4.4 Ground Water Withdrawals

A summary of ground water withdrawals from the East King County Ground Water Management Area in 1990, compiled by water-use category, source (well or spring), and physiographic sub-area, is presented in Table 5.2. (U.S. Geological Survey, 1995). As shown, approximately 3,136 acre-feet of water was withdrawn from wells. Another 5,291 acre-feet of the water that discharges naturally through springs was put to beneficial use, for a total use of 8,427 acre-feet. The use of spring water is not a true withdrawal of the ground water resource because the spring would discharge anyway, regardless of the use. Nevertheless, water drawn from springs is discussed because it does represent a significant use of ground water. About 3,353 acre-feet (40 percent) of the total quantity of ground water withdrawn was used for public supply, and another 3,009 acre-feet (36 percent) was used for aquaculture (U.S. Geological Survey, 1995).

In 1990, approximately 48,100 (85%) of the estimated 56,500 people that reside in the study area obtained household water from Group A public supply systems. A total of 1,380 acre-feet of water was withdrawn from wells, and 1,973 acre-feet was drawn from springs to furnish these Group A public supply systems. The relatively large percentage (63 percent) drawn from springs reflects the fact that the Cities of North Bend, Snoqualmie, and Carnation use springs emanating from the Cascade Range foothills as their primary water supplies. Another 2,280 acre-feet, not shown in Table 5.2., was imported for public supply systems from water systems outside the study area. For example, the City of Duvall obtains its entire water supply from the City of Seattle water system. Although most of the water withdrawn for public supply is used for individual households, undetermined quantities are used for commercial, institutional, industrial, or municipal purposes and for some dairies. Also, a significant quantity of water can be lost through leakage from distribution systems. A marked seasonal variation in the demand for, and therefore withdrawal of, water for public supply purposes occurs. The greatest demand is in late summer and early fall, when temperatures are high, precipitation is at a minimum, and ground water levels are relatively low (U.S. Geological Survey, 1995).

The remaining 15 percent of the population (8,400 people) relied on either privately owned wells or water systems that supply between two and 15 households (Group B). An estimated 1,021 acre-feet of ground water was withdrawn from wells for domestic purposes. Most domestic withdrawals (958 acre-feet) were from the lower Snoqualmie Valley sub-area (U.S. Geological Survey, 1995).

Irrigation water use totaled an estimated 679 acre-feet in 1990. Because not all irrigators were contacted by the U.S. Geological Survey, this is probably a minimum value. About 529 acre-feet was used for irrigation of crops on truck farms, tree farms, nurseries, and pastures, all in the lower Snoqualmie Valley. About half of the crop irrigation water was drawn from springs. The remaining irrigation withdrawals, 146 acre-feet, were used for non-crop purposes, such as watering golf courses and school grounds. The quantity of water used to water residential lawns was accounted for in the domestic water category (U.S. Geological Survey, 1995).

Most of the water withdrawn for livestock usage went to dairies that are all located in the lower Snoqualmie Valley. About 274 acre-feet of water was withdrawn for these dairies, almost all from wells. A few dairies are situated in the upper Snoqualmie Valley, but their water comes from public supplies. The quantity of water withdrawn for other livestock is negligible (U.S. Geological Survey, 1995).

Of the 3,009 acre-feet of water used for aquaculture, or fish hatcheries, 2,350 acre-feet was used by a single hatchery in the upper Snoqualmie Valley. The source of the water is the City of North Bend spring and the water is taken from the excess that is not used by the city. The remaining 659 acre-feet was used in the lower Snoqualmie Valley, and of this, 645 acre-feet was used by a State fish hatchery near Tokul Creek. All of the aquaculture water is from springs and, as mentioned previously, does not constitute a real withdrawal from the ground water system. In addition, the use of spring water for fish propagation is nonconsumptive, although the quality of the water is probably altered slightly as a result (U.S. Geological Survey, 1995).

One industrial operation, a sand and gravel quarry located about a mile east of Snoqualmie Falls, accounted for the 82 acre-feet of ground water used for industrial purposes in the upper Snoqualmie Valley. This use also represents almost all of the industrial withdrawals in the study area. However, as mentioned previously, ground water is provided to some minor industrial concerns by public supply systems (U.S. Geological Survey, 1995).

The documentation of long-term trends in ground water withdrawal is difficult because of a lack of readily available data. Withdrawals have increased over time, at least with respect to public and domestic water supplies, because of the relatively steady growth in population in the study area (U.S. Geological Survey, 1995).

6.4.5 Water Budget of the Study Area

On a long-term basis, a hydrologic system is usually in a state of dynamic equilibrium; that is, inflow to the system is equal to outflow from the system and little or no change occurs in the quantity of water stored within the system. An approximate water budget, or distribution of precipitation, for an average year in the East King County Ground Water Management Area is presented in Table 6.4. The water budget was developed when the East King County Ground Water Management Area included the Sammamish Plateau and it's discharge area, Lake Sammamish. However, the boundaries of the East King County Ground Water Management Area were revised in March 1996 and no longer include the central and western Plateau areas.

The total recharge to the system (31 inches) is from the recharge calculations described in the Recharge section earlier. The value for evapotranspiration (23 inches) was calculated by averaging values reported for selected sites in and around the study area (U.S. Department of Agriculture, 1973). The value for runoff (3 inches) is a residual; that is, it represents the quantity that remains after recharge (31 inches and evapotranspiration (23 inches) are subtracted from precipitation (57 inches). Similarly, the value of 22.6 inches for ground water flow out of the study area also is a residual; it represents the remainder when the quantities known to be withdrawn by wells (0.3 inches), discharged to springs (0.7 inches), and discharged to rivers and lakes (7.4 inches), are subtracted from recharge (31 inches) (U.S. Geological Survey, 1995).

The water budget in Table 6.4. indicates that more than half of the precipitation (54 percent) falling on the study area recharges ground water. Of this recharge, only 1 percent is withdrawn from wells for use. The spring discharge represents another 2 percent of recharge, but only about half of this (5,290 acre-feet of 8,526 acre-feet, or 63 percent; see Table 5.2.) is put to beneficial use. The ground water extracted from the study area is, therefore, a small quantity of the total water present in the system (U.S. Geological Survey, 1995).

It would seem, then, that additional ground water may be withdrawn with little effect on the system. It appears from the water budget that 300,700 acre-feet, or 73 percent of the total recharge, simply flows as ground water north and west out of the study area and part could be available for additional withdrawal. This may not be the case, however (U.S. Geological Survey, 1995).

First, less than 300,700 acre-feet/yr is present as ground water flow, because this quantity includes unaccounted discharge to springs, rivers, and lakes, which may be significant. Second, any additional withdrawals from the ground water system may reduce flows to other discharge points. The U.S. Geological Survey stated citing Bredehoeft (1982), any additional withdrawal or discharge superimposed on a previously stable system must be balanced by an increase in recharge, a decrease in the discharge, a loss of storage within the aquifer (reflected by lower water levels), or by a combination of these factors. Considering the ground water system of East King County in particular, the possibility of increased natural recharge on a long-term basis appears remote. In fact, the trend of increased residential development will most likely result in decreased recharge. Additional withdrawals, therefore, would result in a loss of storage (with an attendant decline in water levels) or a decrease in discharge to springs, rivers, or lakes, or a decrease in ground water flow out of the study area. Discharged water used either directly or indirectly for streamflow maintenance, fish propagation, waste dilution, or supply would decrease also. The magnitude of potential ground water development, therefore, depends on the decrease in discharge that can be tolerated. Because it can take many years for a new equilibrium to become established, the effects of additional ground water development may not be immediately apparent (U.S. Geological Survey, 1995).

Also, the U.S. Geological Survey interpreted Bredehoeft (1982) to point out that the effects of additional development are independent of the magnitude of the original recharge and discharge and depend solely on how much of the original discharge can be diverted, or captured, without unwanted effects. Therefore, a water budget alone is of limited use in determining the magnitude of ground water available for development. Of much greater significance are the geometric boundaries and hydraulic properties of the aquifer system and the present uses of the discharged water that would be affected by pumping (U.S. Geological Survey, 1995).

6.5 Water Levels and Water Level Monitoring

The configuration of the water table or potentiometric surface of an aquifer is determined by (1) the overall geometry of the ground water system; (2) the hydraulic properties of the aquifer; and (3) the areal and temporal distribution of recharge and discharge. Where recharge exceeds discharge, the quantity of water stored will increase and water levels will rise; where discharge exceeds recharge, the quantity of water stored will decrease and water levels will fall (U.S. Geological Survey, 1995).

As stated previously, most of the recharge in the East King County Ground Water Management Area is from the infiltration of precipitation during the months of October through March. Previous studies in western Washington have shown that, in years of typical precipitation, ground water levels in shallow wells generally rise from October through March and fall from April through September. Water levels in deep wells generally respond more slowly, and usually with less change, than water levels in shallow wells. This happens because deeper wells are usually farther from the source of recharge, and any variability in recharge is dampened. Along rivers or lakes, water level fluctuations also are influenced by river or lake level changes; these fluctuations due to these surface water bodies are superimposed on the seasonal and long-term changes that are related to changing recharge-discharge relations (U.S. Geological Survey, 1995).

Water level fluctuations varied considerably through out the study area but generally followed the patterns described above. Hydrographs of water levels in six selected observation wells are shown in Figure 6.8. for the period May 1991 through December 1992. The water levels in well 23N/08E-03L03 probably exhibited the most month-to-month variability, but this well is in an alluvial aquifer less than a half mile from the Snoqualmie River, and the water levels closely reflect the discharge to the river (see Figure 6.9.). Likewise, the water levels in well 24N/06E-04K01 reflect a rapid response of the shallow ground water in the surficial aquifer, comprised of the Vashon recessional outwash, to variations in precipitation. Hydrographs of water levels in wells 24N/06E-11L01P1 and 25N/07E-34M01 (see Figure 6.8.) are much smoother and the maximums and minimums take place several months after those for precipitation. This is typical of the response in deeper, confined systems. The total fluctuation in well 24N/06E-11L01P1, which is in Vashon advance aquifer, is more than 10 ft, and the total fluctuation in 25N/07E-34M01, which is in the lower Upper coarse-grained unit, is only about 2 feet. Also, both hydrographs have a general downward trend, which is probably because annual precipitation in 1990 was 81 inch, much larger than normal, and water levels were declining from the resulting higher-than-normal levels. This trend was common to several wells monitored throughout the study area. In contrast, the hydrographs of wells 26N/06E-22K02, completed in an intermediate aquifer, comprised of the Vashon advance outwash, and 24N/07E-25N01, in the Upper coarse-grained unit (see Figure 6.8.), each exhibit about a foot of fluctuation, with no identifiable trend. The ground water fluctuations observed in the course of this study are seasonal and are probably not typical of the long-term average conditions; rather, the fluctuations are a reflection of recharge-discharge relations over a relatively short period (U.S. Geological Survey, 1995).

The homeowners in East King County that participated in this study were gracious in permitting the Seattle-King County Health Department access to their property so that their drinking water well could be monitored for ground water levels. The Seattle-King County Health Department continued the water level monitoring for an additional 2.5 years. Water level measurements from these well were plotted and graphed, the results are shown in Appendix D. The wells used in this study were in use and there were instances of monitoring episodes when a well was pumping or recently pumped which would result in (depending on the transmissivity rate of the well formation) an invalid static ground water level reported. The detection of long-term trends in ground water levels requires the plotting and analysis of water level versus precipitation data for many years.

In general, the results of water level monitoring indicate ground water fluctuates in response to seasonal variation in precipitation. Boring log static water level measurements indicate a few of the monitored well sites increased water levels over the study period. Most graphs of the monitored well sites showed a downward water level trend. It is likely that higher that normal precipitation values for the first year of monitoring were responsible for the apparent downward water level trend. However, an accurate corresponding precipitation data were recorded for these well sites.

Well site 25N/7E-34M1 showed considerable increase in ground water levels since February 1989. The initial static water level measurement for this well was 88 feet below land surface and on May 1995 the water level measured approximately 49 feet below land surface. The depth of the well is 296 feet deep (the well casing ends at 284 feet below land surface) with a surface elevation of 140 feet mean sea level. The U.S. Geological Survey indicates the well is obtaining water from the Q(A)c aquifer. Well 24N/08E-28E02 is screened in Vashon recessional outwash from 103 to 108 below land surface. The surface elevation at the well site is 630 feet mean sea level. The initial static water level measurement was approximately 64.5 feet below land surface in September 1982 and a February 1995 measurement indicated a ground water level approximately equal to 48 feet below land surface.

Ground water levels at most well sites did not exceed a maximum and minimum ground water depth of 20 feet. At many well sites ground water varied less than 10 feet seasonally. However, some well sites indicate decreases in static water levels such as 25N/7E15R02 and 25N/7E-17A01. These apparent ground water level decreases may result in dry wells.

6.6 Water Resource Study

In order to further define the hydrogeology in the East King County Ground Water Management Area, Golder Associates, as contracted by the Seattle-King County Health Department, began test well drilling and geophysical exploration in the Carnation area in May 1995. The information in this section is from the Golder Associates *Geophysical and Hydrogeologic Investigations in East King County Ground Water Management Area* (1995). The Carnation study area (shown in Figure 6.10.) comprises the Snoqualmie River valley, extending from two miles south to five miles north of the City of Carnation. This area was selected as a core area of interest in the Lower Snoqualmie River valley. Local geology consists of alluvium, glacial outwash, till, and glaciolacustrine sediments overlying volcanic and metamorphic bedrock. Bedrock has not been encountered in any of the existing borings within the survey area and depth to bedrock is unknown (Golder Associates, 1995).

The exploratory test well was located in Loutsis Park within the City of Carnation. The test well was drilled by Holt Drilling between June 26 and August 7, 1995. The well was logged by the Seattle-King County Health Department and Golder Associates Inc. personnel. The boring log of this well is located in Appendix D. The stratigraphic and conceptual geologic models were developed by Golder Associates Inc. and RH_2 Engineering.

The geophysical investigation consisted of a Time-Domain Electromagnetic (TDEM) survey, a walkaway seismic reflection test, and a marine seismic reflection survey on the Snoqualmie River. The marine seismic survey was conducted May 10 and 11, 1995, the TDEM surveys were conducted May 22-25 and September 27-30, 1995, and the terrestrial seismic reflection test was conducted September 7, 1995. The survey vessel and navigation control for the marine survey was provided by David Evans and Associates (DEA).

6.6.1 Exploratory Well Drilling

Over 600 inventoried wells (U.S. Geological Survey, 1995) exist in the East King County Ground Water Management Area. However, a regional geologic framework for the area is difficult to develop because of a general lack of deep wells. The few deep wells that are present in the area suggest productive aquifer materials exist at depths of 600 feet or more. The area around Carnation has been shown to contain both shallow and deep aquifers. A deep well (760 feet deep) at Carnation Research Farms has good water quality and produces more than 400 gallons per minute. The Carnation area was therefore selected as a core study area to collect additional hydrogeologic data and further the understanding of shallow and deep aquifer conditions. In addition to the geophysical data, a deep exploratory well was drilled in the town of Carnation, where deep hydrogeologic conditions were not known. Details of the exploratory drilling are presented in the following subsections. In general, the exploratory drilling confirmed the presence of a productive shallow aquifer, but was unsuccessful in reaching a deep aquifer.

Well Location

The well is located at the southern end of Loutsis Park in Carnation, Washington. This location was established and access approved prior to the completion of the geophysical survey. Preliminary interpretations of geophysical data (marine seismic and Time-Domain Electromagnetic surveys) indicated a deep geologic interface in the vicinity of Carnation. The depth to the interface varied in the study area. In some locations, the interface was clearly defined in the data and indicated a depth of 1,000 feet or less. In other locations, the resistive response was less clear. The nearest geophysical data to Loutsis Park was influenced somewhat by cultural interference and a clear indication of a deep interface was not observed. However, data from surrounding areas (within one-half mile) showed a deep interface, which was, by inference, interpreted to exist at the test well site.

Drilling Procedures

The borehole was drilled using a Speedstar 72 cable tool rig operated by Holt Drilling of Puyallup, Washington. The contract depth for the borehole was 800 feet, with an option for an additional 200 feet of drilling or a well completion. Pipe and materials for the drilling was provided by Tsubota Industrial Supply. The well was drilled at 12-inch diameter to a depth of 500 feet below ground surface. Subsequently, a 10-inch diameter casing was telescoped inside the 12-inch casing and advanced to a final depth of 1,000 feet. Grab samples were obtained at 5-foot intervals by the driller or on-site hydrogeologist. A hydrogeologist was on-site to log the borehole throughout the upper water-bearing section. Intermittent observations were made during drilling to the final depth. Observation of the drilling was carried out in accordance with Golder Associates Technical Procedure TP-1.2-3, Drillhole Logging for Rotary Cable Tool Drilling.

Drilling operations were generally satisfactory through the upper 500 feet. Below 500 feet, difficult drilling conditions were encountered, causing several mechanical malfunctions that caused delays.

Results

RH_2 Engineering and Golder Associates completed the geologic interpretation of the area based on the geophysical results, well logs in the study area around Carnation and geologic samples obtained from well drilling. Preliminary steps taken in the interpretation of geologic samples were to physically lay out bag samples and log the hole. Representative specimens comprised of coarse grained sand and gravels were separated from the geologic samples. To maintain the integrity of the sample interval, these specimens were washed to examine the soil matrix and then 100 pebbles were further separated from these specimens. These pebbles were then compared to known surface outcrops and rock formation in the Cascade and Canadian Rocky mountain ranges. This was done to determine the provenance of the pebbles found in that specific sample interval.

Knowledge of the provenance of the samples provides evidence for water or ice directional movement at the time of deposition. If an understanding of the water movement at the time of deposition is known then another piece of geologic history can be added to the puzzle. The new piece of information will be used to further the understanding of geology in combination with currently excepted geologic interpretation.

Coarse grained sand and gravel samples were also collected from points up river on the Tolt and Snoqualmie Rivers. This was done to determine the age and environment of deposition (glacial, fluvial, or lake bed), the lateral continuity with the region, and the presence of ground water movement through the formation.

The results of the drilling are summarized on the well log (see Appendix D). Coarse sand, gravel and cobbles were encountered from the ground surface to a depth of 295 feet. This is consistent with the interpretation of the geophysical sounding, which indicated a change at 300 feet (see Geophysical Survey Section). Two slightly silty zones were encountered above 150 feet, but in general the aquifer material is quite coarse and highly productive. Water levels in the upper aquifer ranged from 20 to 40 feet below ground surface during drilling, similar to a nearby shallow well (111 feet deep) in Loutsis Park. Specific conductance of the ground water is between 120 and 150 S/cm and the pH ranges from 6.9 to 7.2 standard units. Aquifer properties, hydraulic continuity, and maximum yields were not determined as part of this study. However, the well could be completed at 12-inch diameter between 255 and 275 feet with a probable transmitting capacity of up to 1,000 gpm. A pumping test will be required to determine long-term yield of the well.

Below 300 feet, a uniform stiff gray silty clay was encountered, which is also consistent with the geophysical sounding. The clay is present from a depth of 305 feet to 1,000 feet. Except for very minor changes in silt content and occasional pebble zones, the clay is very uniform. No significant ground water was encountered in the silty clay. The well was terminated at the contract depth of 1,000 feet. No screen was set and the drive shoe was left in place the casing. The well can be deepened at a later date.

6.6.2 Geophysical Survey

Overview

The geophysical investigation consisted of a Time-Domain Electromagnetic (TDEM) survey, a walkaway seismic reflection test, and a marine seismic reflection survey on the Snoqualmie River. A total of 23 TDEM soundings were collected (see Figure 6.10.). The initial phase of the TDEM survey consisted of seventeen soundings utilizing 100-meter loops and located throughout the survey area. These loops were located in areas with minimal cultural interference that provided good coverage of the survey area. A second phase of the TDEM survey consisted of six 300-meter loops. The larger loops were conducted to obtain information from deeper depths and were located in areas where there was suitable site access.

The terrestrial seismic reflection test was performed as a walkaway test at the test well site in Loutsis Park, Carnation (see Figure 6.10.). This test was performed after the test well had been drilled to a depth of 1,000 feet. The seismic test was performed in an effort to resolve geologic conditions below the bottom of the test well.

The marine seismic reflection survey consisted of one trackline run along the center of the Snoqualmie River. It covered approximately nine river miles from Pleasant Hill to Carnation Farms (see Figure 6.10.). Portions of the line were run in both downstream and upstream directions.

Time-Domain Electromagnetics

The time-domain electromagnetic (TDEM) technique utilizes differences in the electrical properties of the subsurface to map subsurface geology and conditions. An electric current is induced into the ground by a loop of wire laid on the ground surface. As these induced currents decay, they are increasingly influenced by the electrical properties of deeper layers in the subsurface. A series of measurements of a secondary magnetic field produced by the induced currents are used to model subsurface electrical properties as a function of depth. Changes in subsurface resistivity values can result from changes in lithology, water content, pore-water chemistry, and the presence of buried debris. A more detailed description of the TDEM methodology, limitations, instrumentation, field procedures, and data processing can be found in Appendix E.

The TDEM technique was selected for this survey because it provides several advantages over drilling and other geophysical techniques. The TDEM technique measures the electrical resistivity and also models the depth and thickness of subsurface layers. Empirical data has established a good correlation between resistivity values and the silt and clay concentration in sedimentary material. Clay and silt have low resistivity, while sand and gravel have relatively high resistivity. The distribution of silt and clay in subsurface material is important information for the development of hydrogeologic models. The TDEM also provides better vertical and lateral resolution compared to traditional DC resistivity techniques. The technique utilizes a relatively small survey area for the penetration depth achieved. This is advantageous for property access and avoiding cultural interference from fences, power lines, and other infrastructure. The TDEM technique is faster (2 to 5 large loop soundings per day) and less expensive than other geophysical techniques or exploratory drilling.

TDEM data are interpreted using a modeling approach. A model is generated, either by an iterative computer methodology (smooth model) or manually (discrete model). A smooth model is a numerically intensive approach where the resistivity of up to 19 layers, with fixed thickness, are varied until a TDEM response that best fits the data is achieved. The shape of this smooth model is used to guide the manual input of a discrete resistivity-depth model consisting of fewer (generally five or less) layers. This discrete model is submitted to an inversion process which adjusts the resistivity and thickness of the discrete layers until a "best fit" to the observed data is achieved. An equivalence analysis is run on the final discrete model to determine a set of equivalent resistivity-depth models that also fit the observed data within a 15% tolerance of the best-fit model. The scatter observed in the equivalence models represents the ability of the observed data to resolve a given layer or resistivity.

The overall quality of the TDEM data collected during this survey is considered good. High quality apparent-resistivity curves were recorded at nearly all the sites. Penetration depths of up to 800 feet were achieved with the 100-meter loops and up to 1,450 feet with the 300-meter loops. The fit of the modeled data to the observed data was generally better than 5 percent, resulting in generally well-resolved layers and resistivities.

Calibration to Boreholes

The TDEM resistivity-depth models were calibrated to deep wells at three locations within the survey area. The calibration sites were used to verify the depths calculated by the TDEM modeling and correlate the measured resistivity values with lithology.

Calibration Site 1 (Carnation Farms Well #3)

The first calibration correlates Carnation Farms Well #3 and sounding 2-15. Carnation Farms Well #3 is located on the western ridge behind Carnation Farms and sounding 2-15 is located on the flood plain of the Snoqualmie River (see Figure 6.10.). The well and

TDEM sounding are separated by approximately 3,500 feet with an elevation difference of about 100 feet.

Figure 6.11. shows the correlation between the discrete TDEM model and the geologic log for the Carnation Farms Well #3. The TDEM smooth model is also shown to illustrate the origin of the discrete model. The upper resistive layer (217 ohm-m) of the TDEM model generally correlates with the predominantly sand unit in the upper 200 feet of the well log (see Figure 6.11.). However, the TDEM layer extends to greater depth than the sandy unit on the well log. This discrepancy is interpreted to be the result of recent fluvial processes in the Snoqualmie River flood plain depositing a thicker sand sequence than exists on the western ridge where the well is located. The deeper layers on the TDEM model correlate very well with the well log. The conductive (20 ohm-m) second layer correlates with the clay and silt section of the well log. The resistive (157 ohm-m) third layer is in excellent correlation with the sand and gravel unit encountered on the bottom 250 feet of the well log. The TDEM detected a conductive basal layer approximately 425 feet below the bottom of the well. This suggests the coarse grained material encountered at the bottom of the well may extend several hundreds of feet below the bottom of the well.

Calibration Site 2 (Waide Property Well)

Figure 6.12. shows the geologic log for the Waide Property Well plotted with the smooth and discrete resistivity-depth models for sounding 1-16. The well site is located immediately off Carnation Farm Road south of 80th Street (see Figure 6.10.). The well and TDEM sounding are separated by approximately 300 feet with an insignificant elevation difference.

Good correlation is observed between the resistivity depth model and the well log. The moderately resistive (32 ohm-m) upper layer of the discrete model correlates with the sand and gravel layer in the upper 30 feet of the well log. The conductive (12 ohm-m) second layer correlates with a clay layer on the well log. The top of the resistive (254 ohm-m) third layer correlates with increased silt and sand content within the clay. The base of the third layer correlates with the base of the sand and gravel layers encountered to an elevation of about -550 feet. The two conductive (38 and 6 ohm-m) basal layers correlate with the increased silt and clay content observed in the bottom 50 feet of the well log.

Correlation of TDEM Sounding with Test Well Log (Loutsis Park)

Figure 6.13. shows the TDEM modeling results for the 300-meter loop sounding 2-2 plotted along with the test well geologic log (Loutsis Park, Carnation). Sounding 2-2 and the test well are separated by about 3,750 feet (see Figure 6.10.). Sounding 1-1 is closer to the test well, but is a 100-meter loop with shallower penetration. The modeling results of soundings 2-2 and 1-1 are similar. An excellent correlation exists between the upper resistive (1200 ohm-m) layer on the TDEM model and the upper layer of predominantly cobbles with gravel and sand on the well log. The relatively high resistivity values

measured for this upper layer are consistent with the very coarse grained material encountered in the upper 300 feet of the test well. The moderately conductive (31 ohm-m) second layer on the TDEM model correlates with the silty sand and silt layers between -190 and -315 feet elevation on the geologic log, but, the TDEM layer extends about 100 feet deeper. This minor discrepancy in thickness probably indicates differences in geology between the two sites. The conductive (5 to 11 ohm-m) bottom layers on the TDEM model correlate with the silty clay extending below -315 feet elevation to the bottom of the well.

There was good correlation between the TDEM results and the test well log. The TDEM penetration depth is effectively the same as the depth of the test well. Sounding 2-2 was a 300-meter loop and represents the largest loop (deepest penetration) that is logistically feasible in this area.

Geo-electric Cross-Sections

The resistivity-depth models for the TDEM soundings along four profile lines A-A', B-B', C-C' and D-D' (see Figure 6.10.) were plotted to create geo-electric cross-sections (see Figures 6.14. through 6.17.). The resistivity-depth models were plotted as stick diagrams, referenced to ground surface elevation, and plotted at the horizontal scale of the U.S. Geological Survey base map (1 inch = 2,000 feet). The cross-sections show a vertical exaggeration of 10:1.

Layers of similar resistivity were interpreted to represent similar lithology (e.g. clay, silt, sand, gravel) and correlated between soundings. The development of cross-sections from the resistivity values is based on the calibration soundings and the relative range of resistivities found within the cross-section. In general, material with resistivity less than 50 ohm-m is interpreted to consist predominantly of silt and clay and will likely act as an aquitard. Material with resistivity greater than 100 ohm-m is interpreted to consist predominantly of sand, gravel, or cobbles and will likely constitute an aquifer. Material with resistivities of 50-100 ohm-m is interpreted to be transition material consisting of silt or fine sand with possible interbeds of clay and gravel. At several locations material with transition material resistivities are included in interpreted aquifer or aquitard units based on continuity with adjacent soundings. These locations with marginal resistivity values may indicate localized facies changes within the unit or one unit becoming contiguous with another.

The resistivity of the basal layer on the TDEM models is generally the poorest resolved. This is due to a lack of data points beyond the end of the apparent resistivity curve. On soundings where little confidence exists in the modeled basal resistivity, the basal resistivity is left blank, and no attempt is made to correlate this basal layer to adjacent soundings.

The penetration depth varied between soundings depending on the loop size (100m or 300m) and the ambient noise level. Therefore, the cross-sections will show stick diagrams with varied maximum depth.

Geo-electric Cross-Section A-A'

Cross-section A-A' is a north-south trending section generally following the Snoqualmie River (see Figure 6.10.). Layers of similar resistivity were interpreted between soundings and form a geo-electric stratigraphy consisting of six units comprising an upper aquifer, an aquitard, a lower aquifer, and a deep aquitard (see Figure 6.15.). Note that sounding 1-8 is anomalous compared to the other soundings and may have been influenced by cultural interference from electric fencelines surrounding that site.

Upper Aquifer

An upper unit of relatively high resistivity (67-575 ohm-m), referred to as the upper aquifer (unit 2), is interpreted to consist predominantly of sand, gravel, and cobbles. This unit has the highest resistivities near the confluence of the Tolt River. This trend of increasing resistivity near the Tolt River may indicate a facies change within the unit from coarse grained materials deposited at the confluence of the Snoqualmie and Tolt Rivers to finer grained material northward as the influence of the Tolt River is reduced.

Aquitard

Two conductive units (units 3 and 5) separated by a transition zone (unit 4) are interpreted to comprise an aquitard separating the upper and lower aquifers.

A unit of relatively low resistivity (16-59 ohm-m), referred to as the upper zone (unit 3), underlies the upper aquifer. This unit is interpreted to consist predominantly of clay and silt and is regionally extensive. Resistivity values within this unit are laterally consistent suggesting lateral homogeneity within the unit. A moderate increase in resistivity is observed in the direction of the Tolt River and may indicate a slight coarsening of material near the confluence of the Snoqualmie and Tolt Rivers.

A unit of moderate resistivity (53-100 ohm-m), referred to as the transition zone (unit 4), underlies the upper zone of the aquitard. The unit is interpreted to consist predominantly of silt and fine sand with possibly some gravel and clay interbeds. The unit appears to pinch out at the southern end of the section, but possible cultural interference on sounding 1-8 makes this interpretation uncertain.

A unit of relatively low resistivity (15-32 ohm-m), referred to as the lower zone (unit 5), underlies the transition zone along the southern portion of the section. This unit is interpreted to consist predominantly of clay and silt and pinches out between soundings 1-4 and 1-6.

Lower Aquifer

A unit of relatively high resistivity (136-320 ohm-m), referred to as the lower aquifer (unit 6), was detected on three of the seven soundings comprising this section (see Figure 6.15.). The unit was detected in the middle portion of the section, but not on the north and south ends. This unit is interpreted to consist predominantly of sand and gravel. The top of this unit dips slightly to the south with an elevation change of about 200 feet across the section. Along this section, the thickness of the lower aquifer could be estimated only on the 300-meter sounding 2-8 and was modeled to be about 300 feet thick.

Deep Aquitard

A basal conductive (8-20 ohm-m) unit, referred to as the deep aquitard (unit 7), was detected on the 300-meter loop sounding (2-8). The penetration depth on the 100-meter loops was not great enough to detect this layer. The elevation of the top of this unit is modeled to be -1,070 feet and is consistent with the elevation of a similar basal unit detected under the northwest portion of the survey area shown on cross-sections B-B', and D-D'. This unit is interpreted to consist predominantly of silt and clay.

No bedrock is interpreted.

Plan-View Elevation Maps of Upper and Lower Aquifers

Plan-view elevation contour maps were produced for the base of the upper aquifer and the top of the lower aquifer (see Figures 6.18. and 6.19.).

Figure 6.18. shows contours of the base of the upper aquifer. The shape of these contours also reflects the thickness of the upper aquifer, since the elevation difference between soundings is nominal. The upper aquifer is deepest near the Tolt River reaching an elevation of -250 to -300 feet. Away from the Tolt River, the base of the upper aquifer maintains an elevation of -150 to -200 feet over much of the survey area and rises south of the Tolt River and in the direction of the east and west ridges. The aquifer pinches out at the base of the eastern ridge in the vicinity of geophysical soundings 1-9 and 1-12 and to the south of geophysical soundings 1-5 and 1-8.

Figure 6.19. shows contours of the top surface elevation of the lower aquifer. The surface of this unit dips to the east-southeast. This unit pinches out or interfingers with other units to the west at geophysical sounding 2-19 and to the east along the western margin of the present-day Snoqualmie River. The unit forms a channel-like feature that possibly extends beneath Tolt Hill. Additional soundings on Tolt Hill would be necessary to confirm the existence of this unit beneath the ridge. A deep aquitard was detected underlying this unit at an average elevation of about -1,050 feet on geophysical soundings 2-8, 2-15, and 2-18.

A map of the bedrock depth could not be prepared from the TDEM data because the sediments in the river valley are thicker than the maximum penetration depth for a standard TDEM survey. The larger loop sizes that would be necessary to investigate significantly deeper are not logistically feasible within the valley due to cultural development.

Terrestrial Seismic Reflection

Seismic reflection is a method of determining subsurface conditions based on the contrasting acoustical properties of the materials. A seismic shot (explosive charge) produces an acoustic pulse that travels through the underlying sediments or rock. At subsurface interfaces that have a change in acoustic properties, some of the transmitted energy is reflected back towards the surface. These acoustic reflections are received by a geophone, converted to an electrical signal, and recorded by the seismograph. This reflection test was performed as a walkaway test. A walkaway test is a term used to describe shooting multiple shots from increasing distance into a fixed spread of geophones. The records from each shot are combined to produce a time-distance plot that is used to identify and calculate depths to subsurface reflectors. The depth of subsurface penetration and resolution of strata is a function of the various properties of the materials (grain size, water content, density), background noise levels, and the characteristics of the seismic system (energy and frequency of the acoustic pulse). Detailed information on the methodology, instrumentation, field procedures and data processing can be found in Appendix E.

Three shots, ranging in size from 1/3 to 1 pound of Kinestik explosives were shot at the southern end of the spread. The data recorded from all shots contained a high level of 60-hertz interference from the power line adjacent to Loutsis Park. Post processing was performed using a 60-hertz notch filter to remove the 60-hertz noise, but no interpretable reflections were recovered at depth. The 60-hertz noise depleted the dynamic range of the seismograph and rendered this technique ineffective at the test well site.

Marine Seismic Reflection

Marine seismic reflection is identical in principal to terrestrial seismic reflection. The main differences are instrumentation (a waterborne seismic source replacing explosives and a hydrophone streamer replacing a fixed spread of geophones) and the ability to collect continuous data. The marine reflection system continuously transmits acoustic pulses that travel through the water column, and the underlying sediments or rock. Acoustic reflections are received by a hydrophone, converted to an electrical signal, and continuously displayed on a graphic recorder. The resulting display is a representative profile or cross-section of the underlying sediment strata. A detailed description of the methodology, instrumentation, field procedures, and data processing can be found in Appendix E.

The depth of subsurface penetration and resolution of strata is a function of the various properties of the materials (grain size, water content, density) and the characteristics of the seismic system (energy and frequency of the acoustic pulse). Subsurface penetration is reduced in areas where relatively large contrast in density exists between the water column and riverbed. This occurs where bedrock is exposed in the riverbed. The presence of biogenic gas in fine-grained sediments can also reduce the penetration of acoustic pulses. In areas where sand, gravel, or more consolidated surficial deposits occur, it is not unusual to obtain hundreds of feet of penetration.

One trackline was run along the Snoqualmie River from Carnation Farms to Pleasant Hill (see Figure 6.10.). Coherent reflectors were observed on the seismic reflection data to depths of 800-900 feet.

Reflectors observed on the seismic data were overlain on the TDEM models projected onto the seismic trackline to create the seismic cross-section E-E' (see Figure 6.20.). A seismic velocity of 6,000 feet/second was used to calculate the depth of reflectors. Coherent seismic reflectors were observed down to depths of 800 to 900 feet at the southern end of the section and about 450 feet at the northern end. This is consistent with the TDEM results that suggested the lower aquifer shallowing to the north and at a similar depth. The discontinuous nature of the seismic reflectors made it difficult to correlate specific reflectors with the geo-electric stratigraphy. This is likely the result of several factors, including lateral inhomogeneity within the sediments, gas charged near-surface sediments, acoustical noise created by water currents, and side echoes from the river banks. Figure 6.20. is an annotated cross-section showing seismic reflectors that are interpreted to correlate with the geo-electric stratigraphy. A strong correlation can be seen between the seismic reflectors plotted between TDEM soundings 1-7 and 1-5 and the geo-electric stratigraphy. This correlation both compliments and supports the TDEM interpretation.

The geophysical studies and exploratory well drilling conducted for this study provide the basis for a substantial revision of the conceptual geologic model of the central portion of the East King County Ground Water Management Area. The inferred depths to aquifers and bedrock in the Carnation area, as presented in several cross-sections in the *1995 U.S. Geological Survey Water Resources Investigations Report,* can be substantially revised with this new information. The following presentation of hydrogeologic information utilizes the following: 1) five existing deep well logs, 2) new geophysical exploration data, 3) the exploration well log, 4) the previous studies of the geologic history of the area, and 5) cross-sections of the unconsolidated sediments as presented in the *U.S. Geological Survey Report* (1995). The two most notable findings of this study are that 1) the Snoqualmie River Valley may be a fjord-like feature similar to Hood Canal, Puget Sound (off of Alki Point), Lake Washington, and Lake Sammamish, but the valley is filled with sediments carried from the north and northeast by ice marginal rivers; and 2) the Snoqualmie Valley may mark a deep (more than 500 feet below sea level) hydrogeologic boundary that blocks or terminates continuity between blankets of glacial drift underlying upland areas to the east and west.

6.6.3 Conceptual Geologic Model

A conceptual model of the regional geology of the central portion of the Snoqualmie Valley suggests that the plateaus east and west of the Valley are underlain by sequences of glacial drift representing as many as four glaciations of the Puget Lowland. The presence of two tills is common in the steep side sand valleys of these plateaus and locally three, and perhaps four, tills comprise the Quaternary section. However, the Snoqualmie Valley appears to represent a fjord-like arm or valley that is filled with glacial marine, glacial lacustrine, or post glacial lacustrine and alluvial deposits.

The Snoqualmie Valley lies subparallel to the Sammamish Valley and Lake Sammamish, Lake Washington and the main arm of Puget Sound. These roughly north-south trending troughs no doubt owe their origin largely to glacial scour, but glacial fluvial processes may have contributed to the erosion and certainly to the infill. The amount of sediment filling these troughs increases gradationally from east to west. The Snoqualmie Valley is now entirely filled due to catastrophic volumes of sediment from numerous meltwater channels including the bursting of the marginal embankments of the Middle and South Fork Snoqualmie Rivers and channelization of the North Fork Snoqualmie, Tokul Creek, Griffin Creek, the Tolt River, and others. This is in contrast to the Lake Sammamish trough which was filled only by erosion through the North Issaquah Creek spillway (forming the Issaquah Delta) and then flows down the Evans Creek channel (which built a gravel delta beneath the City of Redmond). Lake Washington appears to have received only minor ice marginal flows from the Cedar River Valley and perhaps through Totem Lake and Juanita Bay. Thus, the distribution of major Vashon recessional outwash deposits can be inferred based on the distribution of deep channels eroded by glacial meltwater.

The origin of the massive clay discovered in the exploratory well is problematic. It is too thick to be a glacial lacustrine deposit originating as the Vashon Glacier advanced because that would require the presence of a valley cut to nearly 900 feet below present day sea level. Fluvial erosion could not cut a valley more than 500 feet below sea level because 15,000-18,000 years ago worldwide glaciation caused sea levels to drop only about 400 feet. Even isostatic depression of 150 feet does not provide a channel with sufficient depth to accommodate the observed section. The clays observed in the exploration well may be glacial lacustrine sediments filling in a deeply scoured valley that perhaps resulted from the compression of ice in front of Tiger Mountain and confined flow of ice to the southeast through the Rattlesnake Lake divide. Alternatively, the clays may be lacustrine sediments accumulated in an environment like present day Lake Sammamish. Another possibility is that the clays are older than the Quaternary and represent the aggradation of marine sediments in the subsiding Puget Sound Basin. The presence of wood, peat and shells at about -500 feet implies a biologically active environment at depths far below present day sea level. Detailed examination of wood, peat, pollen, shells, foraminifera, and water characteristics are needed to date and characterize the deep aquifer found in the vicinity of Carnation Farms. Although glacial processes are capable of eroding and depositing extraordinary volumes of sediment, it appears that the clays of the exploratory well and the fossils of the Carnation Farms area wells are difficult to assign to the Quaternary section.

In conclusion, the geophysical and well drilling exploration have substantially revised our understanding of the hydrogeology of the Middle Snoqualmie Valley. The primary discoveries are that a fairly productive aquifer underlies portions of Section 6 and 5, but that this aquifer appears to pinch out to the east and west. This aquifer is overlain by a thick (approximately 400 feet) cap of fine-grained sediments and thus, appears well protected from potential contamination and hydraulic continuity with river streams or wetlands.

In the vicinity of Carnation, exploration for the deep aquifer was unproductive, but a model for the formation and distribution of favorable sands and gravels in the shallow aquifer was developed using 1) geophysical information 2) a reconstruction of the development of ice marginal channels and 3) a study of the lithology of pea gravels from selected sites in the Snoqualmie Valley. This leads to new conclusions about sites for future ground water exploration. The Tokul Creek delta at Snoqualmie Falls is considered an exposed or subareal model of deltas which likely exist at the mouth of the Raging River, Griffin Creek, Tokul Creek and possibly Harris Creek. Each of these deltas built outward from the valley wall, extended northward and grades into finer grained sediment within about two miles of the point of discharge of the river through the valley wall. However, these shallow aquifers could be subject to contamination by urban, agricultural, or on-site sewage systems.

6.7 Ground Water Quality

Water Quality Sampling Procedures

Sources for water quality data include samples collected by the U.S. Geological Survey staff in July and August 1991 and samples collected by the Seattle-King County Health Department staff from June 1994 through May 1995. Little long-term data exist for the area.

Data collection efforts were directed towards achieving:

- seasonal trends identification; and
- creation of a baseline database for inorganic and organic ground water chemistry for the project area.

The purpose of the monitoring network was to provide adequate background data to assess the impacts of land use activities on ground water quality. The type of land use activity can have a direct impact on water quality parameters found in ground water. For example, measuring a trend of increasing nitrate, chloride, or conductivity levels may indicate the failure of an on-site sewage treatment and disposal system. Likewise, detecting a pesticide in ground water quality samples may imply the possibility of agricultural activities.

The U.S. Geological Survey study included the one-time collection and analysis of samples from 121 wells and 3 springs during July and August 1991. The samples from all these sites were analyzed for bacteria, metals, inorganics, and physical characteristics. A subset of 11 sites were sampled for volatile organic compounds and another subset of 12 for selected pesticides. Other subsets were tested for boron, dissolved organic carbon, methylene blue active substances and radon.

Based on the U.S. Geological Survey recommendations, the Seattle-King County Health Department collected samples from a 23-well network. Five quarterly rounds of samples were collected, beginning in June 1994 and ending in May 1995. All these wells were tested for bacteria, metals, physical and inorganic parameters. A subset of nine wells were tested in June 1994 for volatiles and semi-volatiles. Eleven wells were sampled for pesticides, polychlorinated biphenyls, and herbicides in June and December 1994. The wells tested for organic compounds were selected based on location and potential for certain types of contamination. A list of these parameters is presented in Appendix A.

The criteria used by the Seattle-King County Health Department followed the U.S. Geological Survey criteria for site selection which included the following:

- availability and access permission by well owner;
- practicality and feasibility of collecting samples from wellhead;
- wells previously sampled by the U. S. Geological Survey that were out of compliance with Washington State Board of Health Drinking Water Quality Standards for arsenic, fecal coliform, and pesticides;
- wells where contamination is present from other sampling efforts;
- areas of potential contamination;
- wells that are used for municipal, irrigation and domestic purposes and that have been previously inventoried;
- areal distribution; and
- the hydrogeologic unit in which the well is completed.

Samples were collected in accordance with the procedures listed in the *East King County Ground Water Management Plan, Quality Assurance Project Plan/Data Collection and Analysis Plan*, December 1994 (Appendix B). Samples were analyzed by AmTest Laboratory which is certified by the Washington State Department of Health. Sample results and laboratory procedures were validated by the Seattle-King County Health Department.

Water quality data collected during the course of this study indicate that the ground water quality from the wells tested is generally excellent. With a few exceptions, notably iron, manganese, and arsenic, the ground water meets all Department of Health standards Chapter 246-290 WAC for public drinking water supplies.

Inorganic Compound Findings

The inorganic analyses showed the presence of ions characteristic to ground water in the Puget Sound region. These include inorganic compounds, such as iron, manganese, and arsenic, which can occur naturally in local ground water. Such metals are present in the soils and sediments of the basin and can be dissolved by contact with ground water. Key inorganic indicators that have been evaluated during this testing period include:

Total Dissolved Solids
Total Hardness
Sodium
Nitrate
Calcium
Chloride
Magnesium
Arsenic

These parameters represent some of the important ions and indicators of dissolved constituents. Total dissolved solids, hardness, calcium, and magnesium are indicators of the amount of time ground water has been in contact with the sediments. Sodium also can be an indicator of residence time, or contamination by on-site sewage system effluent. Nitrate and chloride can be indicators of effluent contamination. Certain analyzed constituents were consistently detected in East King County Ground Water Management Area wells. These constituents are discussed below.

Arsenic. Arsenic is ubiquitous in rocks and soil, generally occurring at concentrations ranging from one 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 parts per million), but greater concentrations can occur either naturally or due to contamination. The primary drinking water standard for total arsenic is 0.05 parts per million. Arsenic was consistently detected above the primary drinking water standard in one well near Duvall and averaged 0.073 parts per million for the first four rounds. Several methods of water treatment systems have been recommended to the well owner. Four other wells in or near Duvall showed high arsenic levels, with averages ranging from 0.022 to 0.041 parts per million. One additional well near Carnation indicated arsenic at an average of 0.026 parts per million. According to the U. S. Geological Survey, five of these wells are completed in the upper coarse-grained unit; the remaining one was completed in Vashon advance. In order to ascertain any trends and correlations, the data from wells with arsenic concentrations above 0.020 parts per million were analyzed. Recognizable trends for arsenic in four of these wells include concentrations decreasing between the September and December 1994 rounds and increasing between the December 1994 and March 1995 rounds. No correlation was detected between water level and arsenic level fluctuations.

Nitrate. Nitrogen occurs naturally in rocks and soils, generally at concentrations of 30 parts per million or lower. Two nitrate minerals; niter (potassium nitrate, or saltpeter), and soda niter (sodium nitrate) are present. These minerals are easily dissolved in water, and are, therefore, only found in arid climates. 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 parts per million. Only one well, a shallow, hand-dug well located on a farm, showed nitrate levels over the primary drinking water standard, which is 10 parts per million. The results from the first four rounds ranged from <0.01 to 19 parts per million. Results for one Fall City well, finished in Vashon till, averaged 4.6 parts per million. All other results were well below the standard. All of the wells with nitrate concentrations above 2.0 parts per million showed decreasing nitrate concentrations between the December 1994 and March 1995 rounds, and no consistent correlation was found between nitrate concentrations and water levels.

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 indicator 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. Although no fecal coliforms have been found in any of the samples, total coliforms have consistently been present in two wells. One well is completed in the upper coarse-grained unit and the second in the alluvial layer, (Qal).

Iron. Iron is an essential nutrient, and is one of the most abundant elements on earth. It occurs naturally at high concentrations (up to seven 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 parts per million and can exceed 50 parts per million. 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 parts per million. Iron concentrations were detected above the secondary drinking water standards in several wells in four different units. These wells are distributed throughout the project area. The maximum level was 9.4 parts per million. Analysis of data from wells with iron concentrations above 0.30 parts per million showed the iron levels in most of these well decreasing between the June and September 1994 rounds, when water levels were also decreasing. However, the same correlation was not found between the December 1994 and the March 1995 rounds, when water levels were rising in most of these wells.

Manganese. Manganese is an essential nutrient and is an abundant element. Manganese concentrations in rocks and soils generally range up to 6,700 parts per million. 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 manganese ion (Mn^{2+}). Manganese concentrations are usually less than 1 parts per million 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 parts per million. Manganese concentrations were detected above the secondary drinking water standard in ground water samples from many wells throughout the project area and in several different hydrogeologic units. The maximum level was 0.39 parts per million. Most of the sampled wells with manganese concentrations above 0.05 parts per million showed a decline in concentration between the June and September 1994 rounds; water levels also dropped during this period. From December 1994 to March 1995, when water levels were rising, manganese concentrations in many wells also increased. However, no statistical correlation could be made with the available data.

Organic Compound Findings

Of the 126 volatile and semi-volatile organic compounds analyzed, only one, methylene chloride, showed a concentration that was slightly above the detection limit. Reported concentrations near the detection limits are difficult to interpret because such results can be influenced by other sources, such as laboratory or other errors. Small concentrations of an herbicide were detected in four wells during the U.S. Geological Survey sampling round. Three of these wells are shallow and are located near agricultural activities. The real potential for similar, future incidents indicates a need for continued monitoring and analysis for organic compounds to provide relevant future data.

6.8 Conclusions and Recommendations

6.8.1 Water Quality Conclusions and Recommendations

Water quality data collection efforts should continue in the East King County Ground Water Management Area in order to identify long-term water quality characteristics. The results should be analyzed periodically to determine whether ground water contamination has occurred or is occurring. If any contamination is discovered, recommendations should be made for modifications to the monitoring system to further define the extent of contamination.

The water quality sampling network should include a minimum of 20 wells, distributed throughout the project area. These wells should be sampled quarterly for bacteria, nitrate, and arsenic. Twice a year, at highest and lowest water levels, samples should be analyzed for common ions and trace elements. Specific conductance, pH, dissolved oxygen, and temperature should be measured at the time of sampling. This monitoring would help identify long-term and seasonal changes in ground water chemistry.

Elevated arsenic levels have been detected in East King County wells. In order to understand exactly where the arsenic is coming from and why, a thorough geochemical study, investigating the mineralogy of the various units, water chemistry, and flow paths in relation to the arsenic concentrations, would provide some insight into the specific conditions under which arsenic occurs. This would also include a 1 to 2-year geochemical modeling effort.

A geochemical study similar to the one described for arsenic should be undertaken for iron and manganese. Excessive iron and manganese concentrations are probably the most widespread water quality problems in the project area. A geochemical study would help identify the conditions under which high iron and manganese concentrations occur and may help reduce the number of wells with related problems.

During the U.S. Geological Survey sampling event, pesticides were found in 4 of 12 wells sampled for these chemicals. No pesticides were detected in samples collected by the Seattle-King County Health Department. Sampling should continue every 2 years from the 11 wells sampled by the Seattle-King County Health Department and analyzed for concentrations of chlorophenoxy and triazine herbicides. These wells were chosen for pesticide sampling based on their proximity to agricultural areas.

Although no volatile organic compounds or semi-volatile organic compounds were detected by the U.S. Geological Survey or the Seattle-King County Health Department, samples should be collected every two years, from the network of nine wells established by the Seattle-King County Health Department, which are located in urban and commercial areas. This periodic monitoring would assist in detecting any future contamination in the wells.

6.8.2 Hydrogeology Conclusions and Recommendations

<u>Exploratory Drilling Conclusions</u>

An exploratory borehole was drilled at Loutsis Park in Carnation to a depth of 1,000 feet. The objective of the drilling was to obtain reconnaissance hydrogeologic data. Based on the results of the drilling, the following conclusions are drawn:

- A productive shallow aquifer exists at Loutsis Park that is likely capable of producing significant quantities of good quality ground water. Aquifer properties, hydraulic continuity, and maximum yields were not determined as part of this study. However, the well can be completed at 12-inch diameter, between 255 and

275 feet, with a probable transmitting capacity of up to 1,000 gpm. A pumping test will be required to determine long-term yield of the well.

- The deep aquifer observed in other locations in the valley is not present at the Loutsis Park site.
- A deeper aquifer may exist at the bedrock interface, but will require further deepening of the borehole.

Geophysical Surveys Conclusions

A geophysical investigation consisting of 23 TDEM soundings, a walkaway seismic reflection test, and 9 river miles of seismic reflection profiling was performed in the Lower Snoqualmie River valley near Carnation, Washington. The objective of this survey was to obtain reconnaissance hydrogeologic data and locate future test well locations. Based on the results of the geophysical investigation, the following conclusions are drawn:

- The overall quality of the TDEM data set is valid, and excellent correlation was observed between the TDEM results and two deep wells in the survey area. A good correlation was also observed between a large loop sounding and the test well at Loutsis Park. The quality of the TDEM data and the good correlation with the borehole data have shown that TDEM is an effective method of investigation in the river valley.
- The overall geo-electric stratigraphy is interpreted to show two aquifers separated by an aquitard. The aquitard is comprised of two conductive zones and a transition zone that interfinger with each other. The upper and lower aquifers have the highest resistivity and are interpreted to have a high water-bearing potential.
- The upper aquifer is extensive throughout the survey area and thins or pinches out to the south and at the topographical ridge to the east. The aquifer maintains a thickness of 200-300 feet over much of the survey area.
- The top of the lower aquifer is interpreted to dip to the east-southeast with an elevation change of about 350 feet from the northwest to southeast. The aquifer may be as thick as 625 feet near Carnation Farms. The aquifer pinches out to the east beneath the Snoqualmie River and west of Carnation Farms. The aquifer appears to have a channel-like morphology that may extend beneath Tolt Hill. The lower aquifer does not appear to be present at the test well location in the City of Carnation.
- The aquitard separating the upper and lower aquifers is extensive within the river valley. The conductive upper and lower zones and the more resistive transition zone that comprise the aquitard appear to interfinger with each other. The upper zone is extensive within the river valley while the lower zone exists in a narrow zone that pinches out northwest of Carnation and merges with the upper aquitard southeast of Carnation. A hydrologic connection may exist between the transition zone and the lower aquifer in the northwest part of the survey area. A possible

hydrological connection between the eastern ridge and the transition zone is also suggested by the TDEM data.

- A deep electrically conductive aquitard is present below the lower aquifer west and northwest of Carnation. The thickness and extent of the aquitard and the type of material underlying the aquitard cannot be determined using the geophysical data.
- Coherent reflectors were observed on the seismic reflection data that correlate with geo-electric stratigraphy interpreted from the TDEM data. This correlation supports the general stratigraphic model developed from the TDEM interpretation.
- The depth to bedrock cannot be resolved with traditional engineering geophysical methods, and is beyond the practical limitations for TDEM in the Snoqualmie Valley.

Regional Hydrogeology Conclusions

- The Snoqualmie Valley may be a fjord-like feature that has subsequently been filled with sediments from ice-marginal rivers during Vashon glaciation.
- Based on the thick occurrence of clay in the exploratory borehole, regional ground water flow may be complicated by a significant hydraulic boundary in the Snoqualmie Valley.
- Thick deltaic sediments have been identified in the exploratory borehole at the mouth of the Tolt River, and represent a viable and productive aquifer. These conditions may also exist at the mouths of Harris Creek and Griffin Creek.
- Productive aquifers exist at both shallow and deep depths and the prospects for future ground water exploration appear favorable for municipal and other uses.

Exploratory Drilling Recommendations

The exploratory borehole at Loutsis Park was terminated without completion to allow for subsequent deepening. The TDEM interpretation suggests that the deep aquifer encountered in other wells in the valley may be a channelized feature that is not present at the test well site. However, the exploratory borehole does provide the opportunity for further direct exploration of unresolved deep hydrogeologic conditions, particularly the depth to bedrock and the presence or absence of an aquifer at the bedrock interface. Neither of these conditions can be determined in the Carnation area using conventional TDEM methods.

The well can be deepened using cable-tool air-rotary, or mud-rotary methods. The 10-inch casing was easily advanced at the final depth of 1,000 feet and an additional 200 to 500 feet can be expected using cable tool or rotary methods.

Depending on the results of deepening (if pursued), the well should be completed in the shallow aquifer encountered above 300 feet. The 10-inch casing should be removed and the well completed at 12-inch diameter using a properly designed well screen. A pumping test should be performed, using the shallow well at the entrance to Loutsis Park as an observation well. Water quality samples should also be obtained during the test.

Geophysical Surveys Recommendations

Time Domain Electromagnetic (TDEM) Surveys

This study has shown that geophysical surveys, particularly TDEM, is effective in mapping the extent of potential aquifers to depths of over 1,000 feet. Golder Associates recommends additional TDEM soundings throughout the Snoqualmie Valley to further develop regional correlation of geophysical responses. In particular, Golder Associates recommends:

- Exploratory soundings with a minimum loop size of 300 meters on Tolt Hill. These soundings would be intended to better resolve whether the lower aquifer, with a channel-like appearance, extends beneath the western ridge. Interpolating elevations across the ridge, the top of the aquifer would be expected at a depth of about 1,000-1,200 feet. These depths would necessitate the use of large 300-meter loops.
- Reconnaissance soundings within the Snoqualmie Valley bottom, with a loop size of 100 meters between Carnation and Duvall and between Carnation and Fall City. These soundings would be intended to evaluate shallow and intermediate depths. Based on the results of the 100-meter soundings, 300-meter soundings would be performed in suitable areas and where warranted based on the shallow interpretation.
- Exploratory soundings with a minimum loop size of 300 meters on the eastern upland areas of the Snoqualmie Valley. These soundings would be intended to evaluate the presence or absence of deep aquifer materials and identify a bedrock interface, if possible.

Surface to Borehole Geophysical Testing

If the test well at Loutsis Park is deepened into bedrock, Golder Associates recommends conducting a series of geophysical tests to determine whether the bedrock surface can be imaged using geophysics. Two tests are proposed, consisting of a pole-dipole resistivity and "check-shot" seismic techniques. The pole-dipole resistivity test would consist of placing an electrode into the bedrock and cementing it in-place. The check-shot surveys would involve placing a geophone at the bedrock interface.

Gravity Surveys

The results of the TDEM survey suggest that the most practically feasible geophysical technique for estimating depth to bedrock in the vicinity of Carnation is gravity. Gravity profiles along the valley bottom and transverse to the valley can provide estimates of bedrock depths, but will not likely provide information on the thickness and distribution of Quaternary sediments.

Supplement I

Area Characterization

References

Draft

East King County
Ground Water Management Plan

July 1996

7.0 References

Ames Lake Water Association *Comprehensive Water System Plan,* Interlake Associates, May 13, 1993.

Baker, C. 1990. Department of Ecology, Redmond, Washington. Personal communication on Hazardous Material Spills. January 1990.

Bishop, Greg, 1995, Seattle-King County Health Department, Solid Waste Section. Information on abandoned landfills within the East King County Ground Water Management Area. Personal communication. February 1995.

Blunt, D.J., Easterbrook, D.J., and Rutter, N.W., 1987, *Chronology of Pleistocene Sediments in the Puget Lowland,* Washington: Washington Division of Geology and Earth Resources Bulletin 77, pp.321-353.

Booth, Derek B., 1990, *Surficial Geologic Map of the Skykomish and Snoqualmie Rivers Area, Snohomish and King Counties, Washington*: U.S. Geological Survey Miscellaneous Investigations Series Map I-1745, scale 1:50,000, 22 pp., 2 pls.

Booth, Derek B., August 1994, *Glaciofluvial Infilling and Scour of the Puget Lowland, Washington, During Ice-sheet Glaciation,* Geology, v. 22, pp. 695-698.

Booth, Derek B.; Goldstein, Barry, 1994, *Patterns and Processes of Landscape Development by the Puget Lobe Ice Sheet.* Lasmanis, Raymond, E.S. Cheney, convenors, Regional Geology of Washington State: Washington Division of Geology and Earth Resources Bulletin 80, pp. 207-218.

Booth, Derek B.; Hallet, Bernard, May 1993, *Channel Networks Carved by Subglacial Water: Observations and Reconstruction in the Eastern Puget Lowland of Washington,* Geological Society of America Bulletin, v. 105, pp. 671-683.

Braun, 1989. *Redmond-Bear Creek Ground Water Management Area Background Land and Water Use Report* prepared for the Seattle-King County Health Department July 1991 by Sweet-Edwards/EMCON, Inc., Adolfson Associates, Inc. and CWC-HDR.

Bredehoeft, J.D., Papadopolous, S.S., and Cooper, H.H., Jr., 1982, *Groundwater: the Water-budget Myth, in Studies in Geophysics, Scientific Basis of Water Resource Management*: National Academy Press, pp. 51-57.

Bretz, J.H., 1913, *Glaciation of the Puget Sound Region*: Washington Geological Survey Bulletin 8, 244 pp.

Chapman, Linda. City Planning, City of Duvall. Personal Communication. January 1995.

City of Carnation *Comprehensive Plan*, 1992.

City of Carnation *Final Draft Comprehensive Water Plan*. January 18, 1996.

City of Carnation *Landfill Health and Safety Plan, Ground Water Monitoring Well Installation and Ground Water Analysis Work Plan*. 1989. Prepared for the City of Carnation and Chandler Engineering by ECI Environmental Services, Inc.

City of North Bend *Interim Comprehensive Water System Plan*, December 1993. Prepared by RH2.

City of Snoqualmie *Comprehensive Water System Plan Operations Plan*, January 1995.

Clayton, Geoff., Personal communication on geology, June 1995.

Colville, G. 1993. Seattle-King County Health Department, Local Hazardous Waste Program. Personal communication on Small Quantity Generators. December 1993.

Cox, Gerald. Personal communication regarding water systems in East King County Ground Water Management Area, March 1995.

Crandall, D.R., 1965, *The Glacial History of Western Washington and Oregon*, in Wright, H.E., Jr., and Frey, D.G., eds., The Quaternary of the United States: Princeton, New Jersey, Princeton University Press, pp. 341-353.

Crandall, D.R., Mullineaux, D.R., and Waldron, H.H., 1958, *Pleistocene Sequence in the Southeastern Part of the Puget Sound Lowland, Washington*: American Journal of Science, v.256, pp.384-397.

Crandall, D.R., Mullineaux, D.R., and Waldron, H.H., 1965, *Age and Origin of the Puget Sound Trough in Western Washington*: U.S. Geological Survey Professional Paper 525-B, pp.B132-B136.

Draft Issaquah Creek Valley Ground Water Management Plan, Seattle-King County Health Department, December 1994.

Draft Redmond-Bear Creek Ground Water Management Plan, Seattle-King County Health Department, November 4, 1994.

East King County Coordinated Water System Plan, Economic and Engineering Services, Inc., October 1989.

East Sammamish Community Plan, King County Planning Division, September 15, 1989.

Evaluation of Ground Water Quality Data, 1986 through mid-1990. King County Solid Waste Division, by Sweet-Edwards EMCON, Inc., April 1991.

Evaluation of Ground Water Quality Data, 1986 through March 1992. King County Solid Waste Division, July 1993.

Fetter, C.W., 1994, *Applied Hydrogeology*, Third Edition, Macmillan College Publishing Company.

Final Engineering Report for Closure Plan, Carnation Landfill. November 1990, City of Carnation.

Fitch, Lyle. King Conservation District. Personal communication for agricultural information, 1994, and January 1995.

Flood Hazard Reduction Plan. King County Surface Water Management. November 1993.

Freeze, R.A., and Cherry, J.A., 1979, *Groundwater:* Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 604 p.

Geohydrology and Ground-Water Quality of East King County, Washington. United States Geological Survey, Water-Resources Investigations Report 94-4082, 1995.

Geophysical and Hydrogeologic Investigations in East King County Ground Water Management Area, for the Seattle/King County Health Department by Golder Associates, October 25, 1995.

Golder Associates, October 25, 1995, *Geophysical and Hydrogeologic Investigations in East King County Ground Water Management Area* for the Seattle-King County Health Department.

Gower, H.D., Yount, J.C., and Crosson, R.C., 1985, Seismotectonic map of the Puget Sound region, Washington: U.S. Geological Survey Miscellaneous Field Investigations Map I-1613, 15 p., 1 pl.

Ground Water Geology/Quality Investigations for the Rural Landfills. December 1984, King County Department of Public Works Solid Waste Division, by R.W. Beck and Associates and Sweet, Edwards & Associates.

Hall, J.B., and Othberg, K.L., 1974, Thickness of unconsolidated sediments, Puget Lowland, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-12, scale approximately 1:316,800, 3 p., 1 pl.

Hanson, Bob. City Planning, City of Snoqualmie, Personal Communication. January 1995.

Heath, R.C., 1983, Basic ground water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Henry, Joe., U.S. Natural Resources Conservation Service, U.S. Department of Agriculture. Personal communication on agricultural activities, March 1995.

Hickey, Joseph. Department of Ecology. Personal communication and information on leaking underground storage tanks, December 1994.

Holmes, Anne. King County Department of Public Works, Solid Waste Division. Personal communication, information on the Cedar Falls landfill, March 1995.

Horner, R., and Mar, B. 1982. Guide for water quality impact assessment of highway operations and maintenance. Washington State Department of Transportation. Report No. 14.

Hovde, Belinda. Washington State Department of Ecology. Personal communication, animal waste management. March 1995.

Hubbert, M.K., 1940, *The Theory of Ground-Water Motion*: Journal of Geology, v.48, no. 8, pt.1, pp. 785-944.

Hydrogeology and Ground Water Resource Impact Assessment of the Lake Alice Plateau. Snoqualmie Ridge Project, Snoqualmie. Prepared for Weyerhaeuser Real Estate Company by Associated Earth Sciences, Inc. February 1995.

Issaquah Creek Basin Current/Future Conditions and Source Identification Report, King County Surface Water Management Division. October 1991.

Jensen, Eric. City Planning, City of Carnation. Personal communication, January 1995.

King County Annual Growth Report. King County Planning Division, May 25, 1993.

King County Comprehensive Plan. King County Planning and Community Development, November 1994.

King County Department of Development and Environmental Services and the Seattle-King County Health Department. Mapping aquifer susceptibility to contamination in King County. August 23, 1995.

King County Flood Hazard Reduction Plan. King County Surface Water Management Division, November 1993.

King County Water District #127, *1995 Comprehensive Water System Plan Update*, March 7, 1995.

Knowlton, David. Department of Ecology. Personal communication and information on underground storage tanks, December 1994.

Komorita, John. King County Department of Public Works, Solid Waste Division. Information on the Cedar Falls landfill, personal communication, February 1995.

Liesch, B.A., Price, C.E., and Walters, K.L., 1963, *Geology and Ground Water Resources of Northwestern King County, Washington*: Washington Division of Water Resources, Water-Supply Bulletin no. 20, 241 pp., 3 pls.

Livingston, V.E., Jr., 1971, *Geology and Mineral Resources of King County*, Washington: U.S. Geological Survey Bulletin 63, 200 pp., 6 pls.

Mackin, J.H., 1941, *Glacial Geology of the Snoqualmie Cedar Area, Washington*: The Journal of Geology, v.49, no. 5, pp. 449-481.

Matsuno, R. King County Department of Public Works, Roads and Engineering Division. Personal communication of information on pesticide use on county right of ways and use of detentio facilities versus infiltration facilities, December 1994.

Morgan, Harold, Carnation City Engineer, Personal communication regarding ground water issues with Carnation, May 1995.

National Oceanic and Atmospheric Administration, Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1951-1980.

Phase I Hydrogeological Investigation, Closed Duvall Landfill, King County, Washington, February 1993, Department of Public Works, Solid Waste Division, prepared by Applied Geotechnology, Inc.

Phase Three, Section B Review of Existing Geological and Hydrogeological Data, Subsurface Conditions and Results of Groundwater Monitoring Program, City of Carnation Landfill, Carnation, Washington, April 17, 1989, Earth Consultants, Inc.

Phase I Hydrogeologic Investigation Cedar Falls Landfill, for the Department of Public Works, Solid Waste Division, by Applied Geotechnology, Inc., December 1992.

Pierce, Dave. Washington State Department of Natural Resources, Personal communication, sand and gravel quarries and mines, February 1995.

Richardson, Donald, Bingham, J.W., and Madison, R.J., 1968, *Water Resources of King County, Washington*: U.S. Geological Survey Water-Supply Paper 1852, 74 pp.

Schaftlein, S. State Department of Transportation. Personal communication, March 1995.

Seattle-King County Department of Public Health, April 30, 1985, *Abandoned Landfill Study in King County*.

Snoqualmie Ridge Project, *Soils, Geology, Geologic Hazards and Ground Water Hydrogeology*, November 1987, prepared for Snoqualmie Ridge Associates by Associated Earth Sciences, Inc., Appendix E in the *Draft Environmental Impact Statement for Snoqualmie Ridge Annexation and Master Plan*, City of Snoqualmie, May 1988.

Snoqualmie Ridge Project, *Hydrogeology and Ground Water Resource Impact Assessment of the Lake Alice Plateau*, February 1995, prepared for Weyerhaeuser Real Estate Company by Associated Earth Sciences, Inc., Appendix F in the *Draft Supplemental Environmental Impact Statement for Snoqualmie Ridge Mixed Use Final Plan*, City of Snoqualmie. April 1995.

Snoqualmie Valley Community Plan, King County Planning Division, September 15, 1989.

Stormwater Pollution Control Manual, Best Management Practices for Businesses. King County Surface Water Management, Draft January 1995.

Thorson, R.M., 1980, *Ice-sheet Glaciation of the Puget Lowland, Washington, During the Vashon Stade (Late Pleistocene)*: Quaternary Research, v. 13, pp. 303-321.

Tissel, Paul. City Planner for the City of North Bend. Personal communication, January 1995.

Tobiason, Scott. Personal Communication regarding current focus of the King County Roads Division, April 1995.

Tóth, J., 1963, *A theoretical analysis of groundwater flow in small drainage basins:* Journal of Geophysical Research, v.68, pp. 4,795-4,812.

Town of Carnation Reservoir Study, by CH_2M Hill, for the City of Carnation, May 31, 1983.

Turnberg, Wayne. *Seattle-King County Abandoned Landfill Toxicity/Hazard Assessment Project*, Seattle-King County Department of Public Health, December 31, 1986.

Turney, Gary, 1995, Personal communication regarding East King County Ground Water Management Area study findings and conclusions, February 1995.

U.S. Environmental Protection Agency. Nationwide Urban Runoff Program Priority Pollutant Monitoring Project: Summary of Findings. NTIS Report PB 84-175686. Washington, D.C. 1984

U.S. Geological Survey. *Geohydrology and Ground-Water Quality of East King County, Washington.* Water-Resources Investigations Report 94-4082. 1995

Wallace, Gene and Matlock, Dan, Pacific Groundwater Group and Krautkramer, Mike, Robinson and Noble. *Groundwater Resource Management Issue Paper, Draft #1.* Unpublished. Economic and Engineering Services, Inc., September, 1990.

Washington Geology, Vol. 20, No. 4, December 1992. Washington State Department of Natural Resources, pages 3-9.

Washington Geology, Vol. 22, No.2, July 1994. Washington State Department of Natural Resources, pages 36-45.

Washington State Department of Ecology, 1988. *Guidelines For Development of Ground Water Management Areas and Programs, Chapter 173-100 WAC.*

Washington State Department of Ecology. *The Washington Ranking Method Scoring Manual.* April, 1990.

Department of Ecology, Washington State; Toxic Cleanup Program, Site Information System. Legend for: Confirmed and Suspected Contaminated Sites Report. Revised May 9, 1994.

Willis, Bailey, 1898, *Drift Phenomena of Puget Sound*: Geological Society of America Bulletin, v. 9, pp.111-162.

Supplement I

Area Characterization

Glossary

Draft

East King County
Ground Water Management Plan

July 1996

GLOSSARY

ACUTE VALUE. Level which may result in injury or death to an organism as a result of short-term exposure.

ADVANCE OUTWASH. Outwash deposited during a time interval marked by the advance or general expansion of a glacier. See OUTWASH.

AEROBIC. Life or processes that require, or are not destroyed by, the presence of oxygen. For example, soil microorganisms which will degrade sewage effluent from septic systems need oxygen to function.

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.

ANOMALOUS. An adjective to describe a departure from the expected or normal.

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. See CONFINED AQUIFER, UNCONFINED AQUIFER.

AQUIFER SENSITIVE. Localities where rainfall replenishes an aquifer most efficiently.

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 groundwater 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. A geologic formation, group of formations, or part of a formation with low permeability through which only limited water flows or moves to or from an adjacent aquifer.

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

AREAL. An adjective indicating spatial distribution and horizontal extent.

ARSENIC. A native metallic element which, in sufficient concentrations, can be hazardous to human health. Arsenic can also accumulate in the tissues of aquatic organisms, though the nervous system of the organism is unaffected. Consumption of the organism, such as fish or shellfish, can cause acute illness in humans and other mammals.

ARTESIAN. An adjective referring to ground water confined under hydrostatic pressure, e.g., the hydrostatic pressure of ground water is generally due to the weight of water at higher levels in the zone of saturation.

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.

AUTO FACILITIES. Facilities which provide services to on-road motorized vehicles usually handling quantities of petroleum products, such as gasoline, diesel fuel, oil, antifreeze, etc.

BASAL LAYER. The geologic or hydrogeologic layer situated at and forming the base of the structure.

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.

BEST MANAGEMENT PRACTICE. A method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a water body. The term originated from the rules and regulations developed pursuant to Section 208 of the federal Clean Water Act (40 Codified Federal Register 130).

BIOLOGICAL OXYGEN DEMAND. A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the biological oxygen demand, the greater the degree of pollution. A major objective of conventional wastewater treatment is to reduce the biological oxygen demand so that the oxygen content of the water body will not be significantly reduced. Although biological oxygen demand is not a specific compound, it is defined as a conventional pollutant under the federal Clean Water Act.

BIOSOLIDS. Biosolids are municipal sewage sludge that is a primarily organic, semisolid product resulting from the wastewater treatment process, that can be beneficially recycled and meets all requirements under Chapter 70.95J RCW. Biosolids includes septic tank sludge, also known as septage, that can be beneficially recycled and meets all requirements of Chapter 70.95J RCW.

CADMIUM. A heavy metal element that accumulates in the environment and is toxic to human health.

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 ground water 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.

CATCH BASIN. A reservoir or basin into which surface water may drain, used to collect and retain material.

CENTENNIAL CLEAN WATER FUND, also known as the Water Quality Account. In 1986 legislation was passed creating the Water Quality Account in the Washington State treasury (RCW 70.146). The purpose of the account is to provide financing of water pollution control facilities and activities. The account receives revenue from a tax on tobacco products. Ecology, in adopting rules for administration of the account, has named it the Centennial Clean Water Fund.

CHEMICAL OXYGEN DEMAND. The amount of oxygen required for the oxidation of the organic matter in a water sample or a water body.

CHLORIDE. A compound of chlorine with one other positive element or radical; an indicator parameter for seawater contamination of ground water.

CHRONIC VALUE. Level that may result in injury or death to an organism as a result of repeated or constant exposure over an extended period.

CLAY. A term used in the U.S. and by the International Society of Soil Science for a rock or mineral particle in the soil, having a diameter less than 0.002 millimeters (2 microns).

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

COALESCING. Uniting as a whole.

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

COLLAPSE FEATURE. Any geologic structure resulting from the removal of support and consequent collapse by the force of gravity.

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. See AQUIFER.

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.

COMMERCIAL. Of or relating to the exchange or buying and selling of commodities on a large scale and involving transportation from place to place.

CONTACT LAYER. The point of contact between two types of deposits, e.g., between two types or ages of rocks, between two fluids, etc.

CONTAMINANT. Any physical, chemical, biological, or radiological substance or matter not naturally occurring in the environment or present in amounts that can, in sufficient concentration, adversely affect human health or the environment.

CONVENTIONAL INORGANIC CONTAMINANT. Statutorily listed inorganic contaminants, i.e., those substances of mineral origin, not of carbon-based structure.

CONVENTIONAL ORGANIC CONTAMINANT. Statutorily listed organic contaminants, i.e., those animal or plant-produced substances containing mainly carbon, hydrogen, and oxygen.

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

DATUM. Any numerical or geometric quantity or value that serves as a base or reference for other quantities or values; any fixed or assumed position or element (such as a point, line, or surface) in relation to which others are determined.

DEEP SEDIMENTS. Sediments extending to a depth greater than that typical of sediments in the vicinity.

DEMOGRAPHIC. Of or relating to the dynamic balance of a population, especially with regard to density and capacity for expansion or decline.

DEPTH TO WATER. The vertical distance from a specified datum to the top of a body of water.

DIAMICTON. A general term for unsorted, unstratified, and unconsolidated drift consisting of a heterogeneous mixture of clay, silt, and sand ranging widely in size and shape.

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.

DISSOLVED OXYGEN. The amount of oxygen, in parts per million by weight, dissolved in water. It is a critical factor for fish and other aquatic life, and for self-purification of a surface water body after inflow of oxygen-consuming pollutants.

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.

DRILLER'S LOG. See WELL LOG.

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

DRUMLINOID. A rock or drift deposit whose form approaches, but does not fully attain, the shape of a low, smoothly rounded, elongate oval hill, mound, or ridge of compact glacial till or other kinds of drift built under the margin of the ice and shaped by its flow. It usually has a blunt nose pointing in the direction from which the ice approached, and a gentler slope tapering in the other direction.

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.

ENVIRONMENTAL REVIEW. An assessment conducted by an organization for its own use to appraise the aggregate effect of social and physical activities that influence a community or ecosystem.

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.

FECAL COLIFORM. Those coliform bacteria found in the intestinal tracts of mammals. The presence of high numbers in a water body is considered the standard indicator parameter for drainfield effluent contamination and can indicate the recent release of untreated wastewater and/or the presence of animal feces. These microorganisms may also indicate the presence of pathogens that are harmful to humans. High numbers of fecal coliform bacteria, therefore, limit beneficial uses such as swimming and shellfish harvesting.

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.

FUNCTIONAL PLANS. A plan designed or developed chiefly from the point of view of use.

GEOHYDROLOGY. Synonomous with HYDROGEOLOGY.

GEOLOGY. The study of the planet Earth, the materials of which it is made, the processes that act on these materials, the products formed, and the history of the planet and it life forms since its origin, especially as recorded in rocks.

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

GEOMETRIC MEAN. The n^{th} root of the product of n numbers. Used particularly for evaluation of a few values that are very high or very low relative to the other values (skewed).

GLACIAL. Of or relating to the presence and activities of ice or glaciers. Pertaining to distinctive features and materials produced by or derived from glaciers and ice sheets.

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.

GRAVEL. An unconsolidated, natural accumulation of rounded rock fragments resulting from erosion, consisting predominantly of particles larger than sand (diameter greater than 1 millimeter, or 1/2 inch), such as boulders, cobbles, pebbles, granules, or any combination of these fragments.

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 SUBSTANCE. Generally, any material that poses a threat to human health and/or the environment. Typical hazardous substances are toxic, corrosive, ignitable, explosive, or chemically reactive. Also, any substance designated by the Environmental Protection Agency to be reported is a designated quantity of the substance is spilled in the waters of the United States or if otherwise emitted to the environment.

HAZARDOUS WASTE. Federally regulated man-made waste that is ignitable, corrosive, reactive, toxic, or listed as hazardous waste. Washington state law regulates additional wastes and identifies two categories: dangerous waste and extremely hazardous waste.

HOBBY FARM. A farm operated not for profit.

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 or adjusted for a temperature of 60°F. Expressed in units of gallons per day per foot (gpd/ft).

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

HYDRAULIC HEAD. The height of the free surface of a body of water above a given subsurface point.

HYDROGEOLOGY. The science that deals with subsurface waters and with related geologic aspects of surface waters. It is used interchangeably with GEOHYDROLOGY.

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

HYDROGRAPH. A graph showing stage, flow, velocity, or other characteristics of water with respect to time. A stream hydrograph commonly shows rate of flow; a ground water hydrograph commonly shows water level or hydraulic head.

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.

INDUSTRIAL. Of or relating to engaging in systematic labor for some useful purpose or the creation of something of value, especially a manufacturing activity.

INFILTRATION. The downward movement of rain water or surface water into soil, or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls.

INFILTRATION FACILITY. A facility constructed for the purpose of intercepting ground water and providing a perennial water supply to a man-made water source.

INTERBED. A bed, typically thin, of one kind of rock material occurring between or alternating with beds of another kind.

INTERCONNECTED. Mutually joined or related, such as having internal connections between the parts or elements.

INTERGLACIAL. Pertaining to or formed during the time interval between two successive glacial stages. The term implies both the melting of ice sheets to about their present level, and the maintenance of a warm climate for a sufficient length of time to permit certain vegetational changes to occur.

INTERTIDAL. Pertaining to the ocean environment exposed between low tide and during high tide. The alternate wetting and drying of this area makes the intertidal zone a transition between land and water and creates special environmental conditions and habitats.

KING COUNTY COMPREHENSIVE PLAN. The King County long-range, county-wide, comprehensive land use plan was published in 1985 and updated on November 18, 1994. The Plan establishes policies for ground water management throughout King County, including Vashon-Maury Island.

LAND USE. The way land is developed and used (e.g., agriculture, residences, industries, etc.). Certain types of pollution problems are often associated with particular land-use practices.

LACUSTRINE. Referring to a lake environment.

LAMINATED. The layering or thin bedding in sedimentary rocks.

LANDFILL. A general term indicating a land disposal site for refuse and/or dirt from excavations.

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

LEAD. A heavy metal that is hazardous to human health if breathed or swallowed. It can accumulate in organic and inorganic substances and in sufficient concentrations can cause acute illness in humans and other mammals.

LEAD AGENCY. The agency which acts or serves as the leader.

LENS. A geologic deposit bounded by converging surfaces, at least one of which is curved, thick in the middle and thinning out toward the edges, resembling a convex lens. Also a laterally disappearing stratum (layer).

MAGAZINE. A room in which powder or other explosives are kept in a military installation.

MANTLE. A general term for an outer covering of material.

MASS WASTING AREA. A general term for an area in which the dislodgement and downslope transport of soil and rock material occur under the direct application of gravitational body stresses. In contrast to other erosion processes, the debris removed by mass wasting is not carried within, on, or under another medium and includes slow displacement, such as creep, and rapid movements, such as rock slides.

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

MEAN. Same as average; the sum of a list of values divided by the number of items on the list.

METALS. A class of elements characterized as malleable, lustrous, and good conductors of heat and electricity. Metals, often found in rocks and minerals, are naturally released to the environment by erosion as well as generated by human activities. Certain metals, such as mercury, lead, nickel, zinc, and cadmium, are of environmental concern because they are released to the environment in excessive amounts by human activity. They are generally toxic to life at certain concentrations. Since metals are elements, they do not break down in the environment over time and can be incorporated into plant and animal tissue.

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.

MILLIGRAMS PER LITER (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.

MIGRATION. A broad term applied to the movement of organisms and chemical constituents from one place to another over long periods of time.

MITIGATE. To take measures to reduce the adverse impacts to the environment.

MODEL TOXICS CONTROL ACT. Law passed by the citizens of Washington state requiring cleanup of hazardous waste sites (Chapter 70.105D RCW), which became effective in March 1989. The Model Toxics Control Act is implemented through the Model Toxics Control Act Cleanup Regulation (Chapter 173-340 WAC).

MONITOR. To systematically and repeatedly measure conditions to track changes. For example, dissolved oxygen in a bay might be monitored over a period of several years to identify trends in concentration.

MONITORING WELL. A well drilled for the purpose of systematically and repeatedly collecting ground water samples for physical, chemical, or biological analysis to determine the amounts, types, and distribution of contaminants in the ground water beneath the site.

NITRATE. A compound containing nitrogen commonly associated with domestic and agricultural waste. Nitrates in water can cause severe illness in infants and cows.

NON-POINT SOURCE. A dispersed and uncontrolled source of pollutants, such as storm water runoff, that cannot be defined as a discrete point. Non-point sources (e.g., agriculture, forestry, urban, mining, construction, dams and channels, and land disposal) may contribute pathogens, suspended solids, and toxicants. While individual sources may be insignificant, the cumulative effects of nonpoint source pollution or contamination can be significant.

OUTFALL. The place where an effluent is discharged into receiving waters.

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.

PARALYTIC SHELLFISH POISONING. An illness, sometimes fatal to humans and other mammals, caused by a neuro-toxin produced by a type of plankton called Gonyaulax. During certain times of the year and at certain locations, these organisms proliferate in "blooms" (sometimes called red tides) and can be concentrated by clams, mussels, and other bivalves. The nervous system of shellfish is unaffected. Consumption of the shellfish can cause acute illness in humans and other mammals.

PARAMETER. Any of a set of physical properties whose values determine the characteristics or behavior of a system. For example, height, weight, sex, and hair color are all parameters that can be determined for humans. Water quality parameters include temperature, pH, salinity, dissolved oxygen concentration, and many others.

PARCEL. A tract or plot of land.

PATHOGENIC. Capable of causing disease.

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

PERCHED ZONE. An area of unconfined ground water separated from an underlying main body of ground water by an unsaturated zone.

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

PERENNIAL STREAM. A stream or reach of a stream that flows continuously through the year and whose upper surface generally stands lower than the water table in the region adjoining the stream.

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.

PESTICIDE. A general term used to describe chemical substances used to destroy or control pest organisms. Pesticides include herbicides, insecticides, algicides, fungicides, and others. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants or animals.

PETROLEUM PRODUCT. A substance produced by the distillation and removal of impurities from petroleum, a naturally occurring complex liquid hydrocarbon. The process yields a range of combustible fuels, petrochemicals, and lubricants in gaseous, solid, and liquid forms.

pH. A measure of the degree of alkalinity or acidity of a solution on a scale of 0 to 14, with a pH of 7.0 indicating neutral. A pH lower than 7.0 indicates an acidic condition and a higher pH indicates an alkaline or basic condition. The pH of water influences many of the types of chemical reactions that will occur in it. For instance, a slight decrease in pH may greatly increased the toxicity of substances such as cyanides, sulfides, and most metals. A slight increase may greatly increase the toxicity of pollutants such as ammonia. Originally stood for "potential of hydrogen".

PHENOLIC COMPOUNDS. Organic compounds that are by-products of petroleum refining, tanning, and textile, dye, and resin manufacturing. Low concentrations cause taste and odor problems in water; higher concentrations can kill aquatic life and humans.

PLAT. A diagram drawn to scale, showing boundaries and subdivisions of a tract of land as determined by survey, together with all essential data required for accurate identification and description of the various units shown and including one or more certificates indicating due approval.

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

POINT SOURCE. A stationery location or fixed source of pollutants. Also, any single identifiable source of pollution. For example, the discharge pipe of a sewage treatment plant or a factory is a point source.

POLICYMAKER. The person or agency which generates a policy.

POLLUTANT. A substance introduced into the environment that adversely alters the physical, chemical, or biological properties of the environment.

POLLUTION. The presence of a substance whose nature, location, or quantity produces undesirable environmental effects.

POLYCHLORINATED BIPHENYLS. A group of manufactured chemicals including about 70 different but closely related compounds made up of carbon, hydrogen, and chlorine. If released to the environment, they persist for long periods of time and can biomagnify in food chains because they have no natural usage in the food web. Polychlorinated biphenyls are suspected of causing cancer in humans. Polychlorinated biphenyls are an example of an organic toxicant.

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.

POTENTIAL RECHARGE. The maximum amount of water available under natural climatic conditions for absorption and addition to the zone of saturation in the subsurface.

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

PARTS PER MILLION (ppm). A unit of concentration equivalent to 0.0001 percent.

PRIMARY TREATMENT. A wastewater treatment method that uses settling, skimming, and (usually) chlorination to remove solids, floating materials, and pathogens from wastewater. Primary treatment typically removes about 30 percent of biological oxygen demand and less than half of the metals and toxic organic substances.

PRIORITY POLLUTANT. A substance listed by the Environmental Protection Agency under the federal Clean Water Act as toxic and having priority for regulatory controls. The list currently includes 13 metals, 2 inorganic compounds, and 111 natural and artificial organic compounds. The list of priority pollutants includes some substances that are not of immediate concern in Puget Sound, and it does not include all known harmful compounds.

PRIVATE WELL. A well that provides drinking water for consumption by a particular person or group.

PUBLIC WELL. A well that provides drinking water for consumption by all members of a community.

PUGET SOUND WATER QUALITY AUTHORITY. The state agency charged with the development and oversight of the Puget Sound Water Quality Management Plan (Chapter 90.70 RCW).

PUBLIC WATER SYSTEM. Any water supply system intended or used for human consumption or other domestic uses, including source, treatment, storage, transmission, and distribution facilities where water is furnished to any community or group of individuals, or is made available to the public for human consumption or domestic use, but excluding all water supply systems serving one single family residence.

RECESSIONAL OUTWASH. Outwash deposited during a time interval marked by the backward displacement or general decrease in the volume of a glacier. See OUTWASH.

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.

RED TIDE. See Paralytic Shellfish Poisoning.

REGULATION. An authoritative rule or order having the force of law issued by an executive authority of a government.

REGULATORY AGENCY. An administrative division of federal, state, or local government which controls or directs according to established regulations. A regulatory agency usually does not have the authority to determine policy.

RESIDENTIAL. Restricted to or occupied by dwellings used for living.

RESOURCE CONSERVATION AND RECOVERY ACT. The federal law that classifies and regulates solid and hazardous waste.

REVISED CODE OF WASHINGTON (RCW). The compilation of the laws of the state of Washington published by the Statute Law Committee.

REZONE. To alter the zoning of.

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

SALINITY. The total quantity of dissolved salts in water, measured by weight in parts per thousand. Salinity is usually computed from some other factor, such as the amount of chloride.

SAND. A rock fragment smaller than a granule and larger than a coarse silt grain, having a diameter in the range of 1/16 to 2 millimeters.

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.

SANDY GRAVEL. An unconsolidated sediment containing more particles of gravel size than of sand size, more than 10 percent sand, and less than 10 percent of all other finer sizes.

SCREEN. A metal or plastic slotted tube used to maintain the well opening in unconsolidated aquifer formations and to admit water being pumped from the aquifer.

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

SECONDARY TREATMENT. A wastewater treatment method that usually involves the addition of biological treatment to the settling, skimming, and disinfection provided by primary treatment. Secondary treatment may remove up to 90 percent of the biological oxygen demand and significantly more metals and toxic organics than primary treatment.

SEDIMENT. Material suspended in or settling to the bottom of a liquid, such as the sand and mud that make up much of the shorelines and bottom of Puget Sound.

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

SEEP. A place where ground water discharges naturally onto the land surface in quantities insufficient to form a stream of flowing water. See also, SPRING.

SEQUENCE. A succession of geologic events, processes, or rocks, arranged in chronologic order to show their relative position and age with respect to geologic history as a whole.

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.

SHELLFISH. An aquatic organism, such as a mollusk (clam or snail) or crustacean (crab or shrimp), having a shell or shell-like exoskeleton.

SILT. A rock fragment or particle smaller than a very fine sand grain and larger than coarse clay, having a diameter in the range of 1/256 to 1/16 millimeters.

SLOPE. The inclined surface of any part of the Earth's surface, as a hillslope.

SLUDGE. Semisolid residue resulting from the treatment of wastewater. Some of the contaminants (especially toxic metals) that were in the wastewater may remain in the sludge after treatment. Treated wastewater may be discharged into water, but sludge must be disposed of elsewhere. Sludge is usually at least partially dried before disposal and, if relatively uncontaminated, may be added to soil to increase plant growth.

SOLE SOURCE AQUIFER. The source of ground water providing at least 50 percent of the water for human use in any one area. Areas with a sole source aquifer have no other readily available source of ground water; any contamination to the aquifer could contaminate the entire water supply.

SOLID WASTE. Solid waste is all putrescible and nonputrescible solid and semisolid wastes including, but not limited to garbage, rubbish, ashes, industrial wastes, commercial wastes, swill, sewage sludge, demolition and construction wastes, abandoned vehicles or parts thereof, discarded commodities and recyclable materials.

SPECIAL PROTECTION AREAS. Areas of beneficial uses that require a level of ground water protection beyond that offered by the normal state standards.

SPECIFIC CONDUCTANCE. Electrical conductance of a body of unit length and unit cross section at a specified temperature, expressed as micromhos per centimeter; an indicator of the presence of charged ions in solution.

SPRING. A place where ground water discharges naturally onto the land surface in quantities sufficient to form a stream of flowing water. See also, SEEP.

STAFF GAUGE. A graduated scale or gauge on a staff, wall, pier, or other vertical surface, used in measuring water-surface height.

STATIC WATER LEVEL. That water level of a well that is not being affected by withdrawal of ground water.

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

STORM WATER. Water from rainfall and snowmelt that flows overland to surface streams.

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

STRATIGRAPHY. The arrangement of strata, especially as to geographic position and chronologic order of sequence. It is concerned not only with the original succession and age relationships of rock strata, but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties, and interpretation in terms of environment or mode of origin and geologic history.

STREAM BASE FLOW. See Base Flow.

STREAM DISCHARGE RATING CURVE. A graphic illustration of the relationship between gauge height and volume of flowing water, expressed as volume per unit of time.

STREAM FLOW. A type of channel flow, applied to that part of surface runoff traveling in a stream whether or not it is affected by diversion or regulation.

STREAM STAGE DATA. Stream height, as measured above an arbitrary datum.

SUPERVENED. The federal program operated that funds and carries out the Environmental Protection Agency solid waste emergency and long-term removal remedial activities. These activities include establishing the National Priority List, investigating sites for inclusion on the list, determining their priority level on the list, and conducting and/or supervising the ultimately determined cleanup and other remedial actions. Superfund is operated under the legislative authority of Comprehensive Environmental Response, Compensation, and Liability Act and Superfund Amendments and Reauthorization Act of 1986.

SURFACE DRAINAGE BASIN. A depressed area with no surface outlet which provides for the removal of unwanted water from the surface of the ground.

SURFACE WATER. All waters on the surface of the Earth, including fresh and salt water, ice and snow.

SURFICIAL. Pertaining to or occurring on a surface, especially the surface of the Earth.

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.

TOPOGRAPHY. The general configuration of a land surface or any part of the Earth's surface, including its relief and the position of its natural and man-made features.

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

TOTAL COLIFORMS. See COLIFORM BACTERIA.

TOTAL DISSOLVED SOLIDS. A term that expresses the quantity of dissolved organic and inorganic material in a sample of water. Excessive amounts make water unfit to drink or use in industrial processes.

TOTAL SUSPENDED SOLIDS. Particles, both mineral (clay and sand) and organic (algae and small pieces of decomposed plant and animal material), that are suspended in water.

TOXIC. Poisonous, carcinogenic, or otherwise directly harmful to living organisms.

TOXIC WASTE. Any unwanted material left over from a manufacturing process or refuse from places of human or animal habitation that are harmful to living organisms.

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.

U.S. ENVIRONMENTAL PROTECTION AGENCY. The federal agency which administers many federal environmental laws. Environmental Protection Agency Region 10 is headquartered in Seattle.

V-NOTCH WEIR. A device placed across a stream and used to measure the discharge. The v-notch weir structure used by King County in this study is 2 feet high by 8 feet long. The v-notch located in the center of the weir has a vertical depth of 12 inches to the center of the v on the weir crest plate. A small access door is mounted on one side of the v-notch for the removal of sediment and small debris. After the weir was placed across the streambed, sandbags were placed along the front edges and sides of the weir to offset erosion and structural stability problems. A staff gauge was mounted on the upstream side of the weir near the stream bank. The zero graduation mark was aligned with the lowest point of the v-notch crest plate.

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.

VASHON STADE. A substage of the Fraser glaciation glacial stage.

VINYL CHLORIDE. A chemical compound, used in producing some plastics, that is believed to be carcinogenic.

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.

VOLATILE ORGANIC COMPOUND. Any organic compound which participates in atmospheric photochemical reactions except for those organic compounds designated by the Environmental Protection Agency Administrator as having negligible photochemical reactivity.

WASHINGTON ADMINISTRATIVE CODE (WAC). The compilation of all state regulations adopted by state agencies through the rule-making process. For example, Chapter 173-201 WAC contains water quality standards.

WASHINGTON DEPARTMENT OF ECOLOGY (ECOLOGY). The state agency charged with developing, implementing, and enforcing many environmental protection laws and policies, including the state Water Pollution Control Act and the Model Toxics Control Act. Ecology is the preferred term for referring to the Department of Ecology, as the abbreviation DOE might be confused with the federal Department of Energy. Ecology's authority to develop water quality standards is granted by the Water Pollution Control Act.

WATER ELEVATION. The vertical distance from a datum to the water surface in relation to mean sea level.

WATER FLOW. The movement of water and the moving water itself; also, the rate of movement.

WATER LEVEL. The vertical distance from a datum to the water table.

WATER PURVEYOR. A person or group that supplies water as a matter of business.

> **GROUP A**. A community (residential) or noncommunity (school/business/industry) water system with 15 or more connections or serving an average of 25 people. Group A public water supply systems are regulated by the Washington State Department of Health.
>
> **GROUP B**. A public water system which is not a Group A water system. Group B public water supply systems are regulated by the Seattle-King County Health Department and presently consist of two to nine connections.

WATER QUALITY STANDARDS FOR GROUND WATERS OF THE STATE OF WASHINGTON. Regulation adopted by the State of Washington in October 1990 (Chapter 173-200 WAC) that establishes statewide ground water quality goals, defines criteria to measure water quality, and complies with the Water Pollution Control Act of Washington (Chapter 90.48 RCW).

WATERSHED. The geographic region within which water drains into a particular river, stream, or other body of water. A watershed includes hills, lowlands, and the body of water into which the land drains.

WATER TABLE. The surface between the vadose zone and the groundwater; the surface of a body of unconfined ground water 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.

WELLHEAD. The immediate area around the top of a well. Contamination of the aquifer may occur from surface water if the wellhead is not sealed to prevent flow down the well casing.

WELL 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.

WELL POINT. A screening device, equipped with a point on one end that is meant to be driven into the ground.

WETLANDS. An area that is regularly saturated by surface or ground water. Wetlands include tidal flats, shallow subtidal areas, swamps, marshes, wet meadows, bogs, and similar areas. Wetlands as defined by the Shoreline Management Act include all land within 200 feet of the ordinary high water mark, floodways, and floodplain areas.

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.

ZONING. To designate by ordinance areas of land reserved and regulated for different land uses

SOURCES

- Glossary of Environmental Terms and Acronym List, U.S. Environmental Protection Agency, August 1988.
- Groundwater Wells, Driscoll, F. Johnson Division, 1986.
- Groundwater Resource Protection, King County Planning Division/State of Washington/ Department of Ecology.
- Redmond-Bear Creek Ground Water Management Program Draft Hydrogeologic Characterization Report by EMCON Northwest, Inc., November 1992.
- Northern Thurston County Ground Water Management Plan, February, 1992.

Figures

Supplement I

Area Characterization

Figures

Draft

East King County
Ground Water Management Plan

July 1996

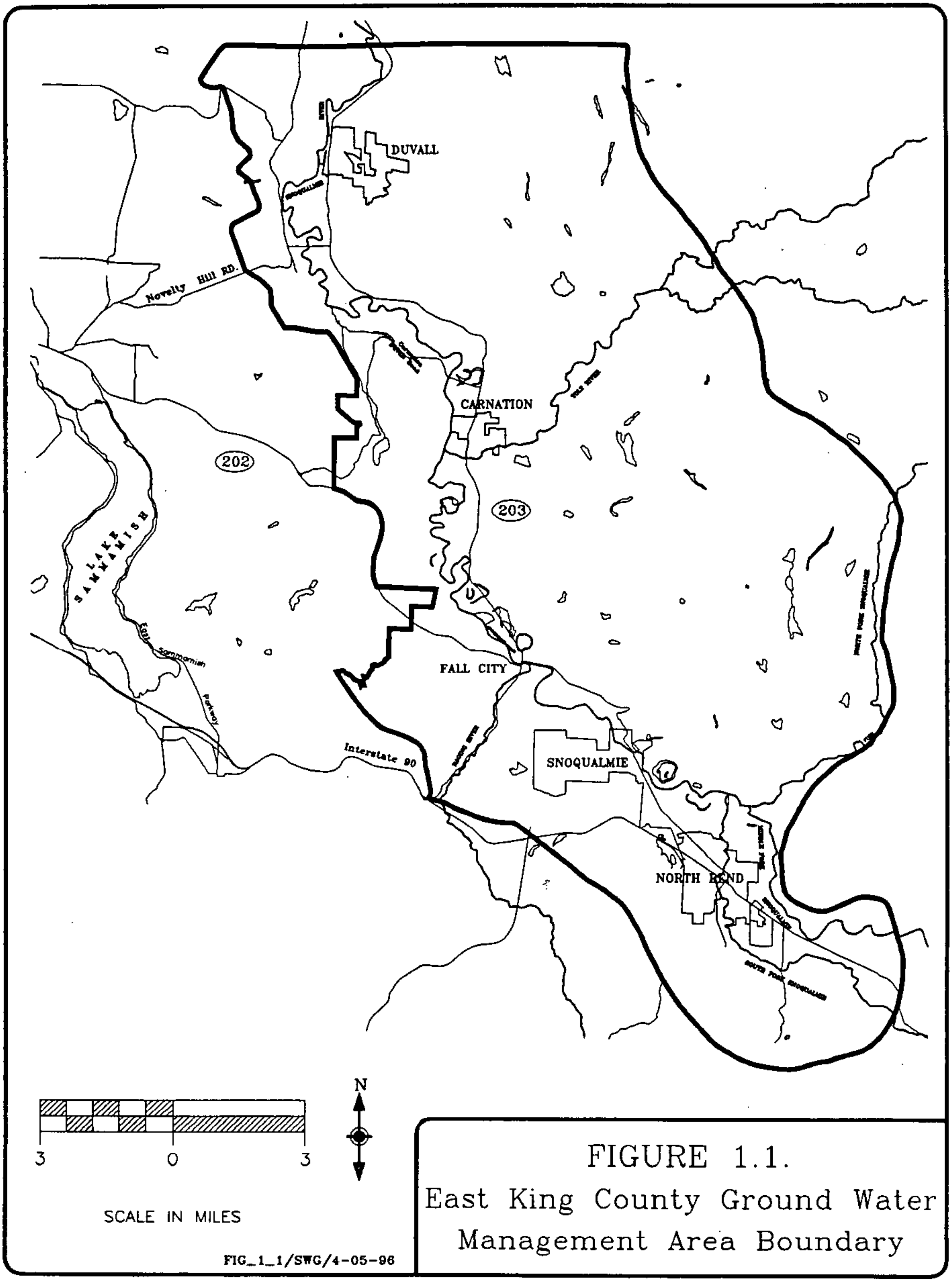


FIGURE 1.1.
East King County Ground Water Management Area Boundary

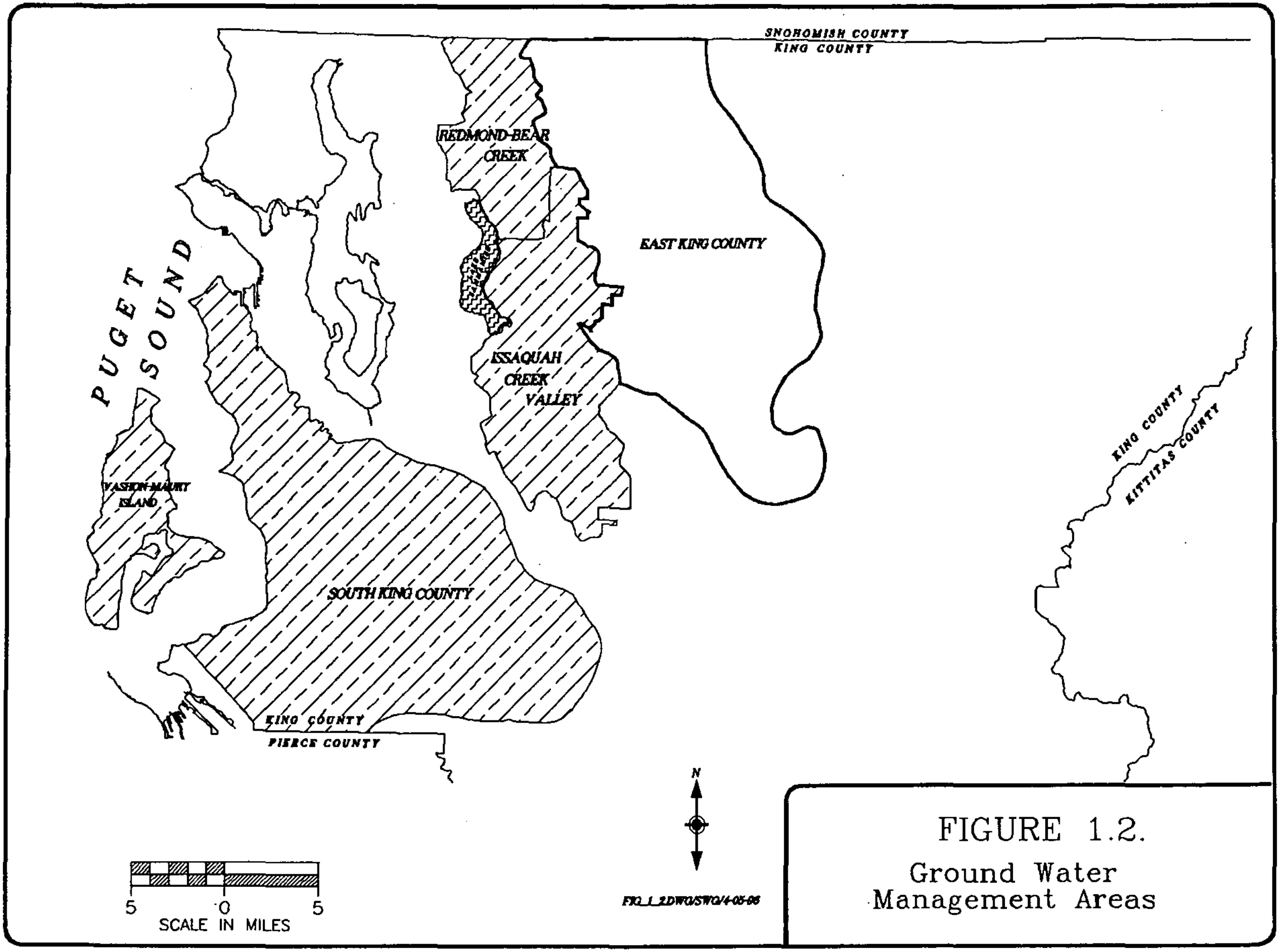


FIGURE 1.2.
Ground Water Management Areas

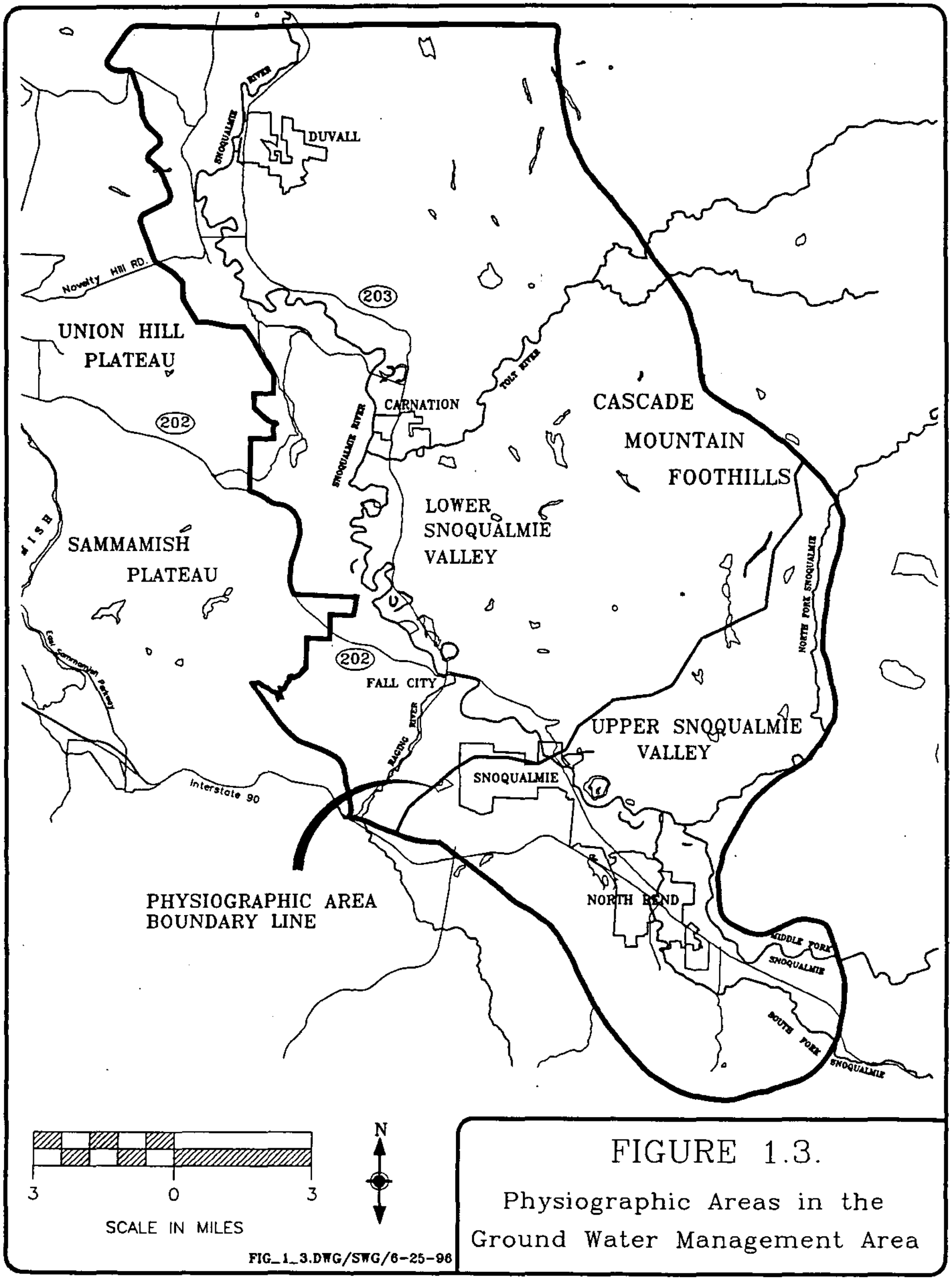


FIGURE 1.3.

Physiographic Areas in the Ground Water Management Area

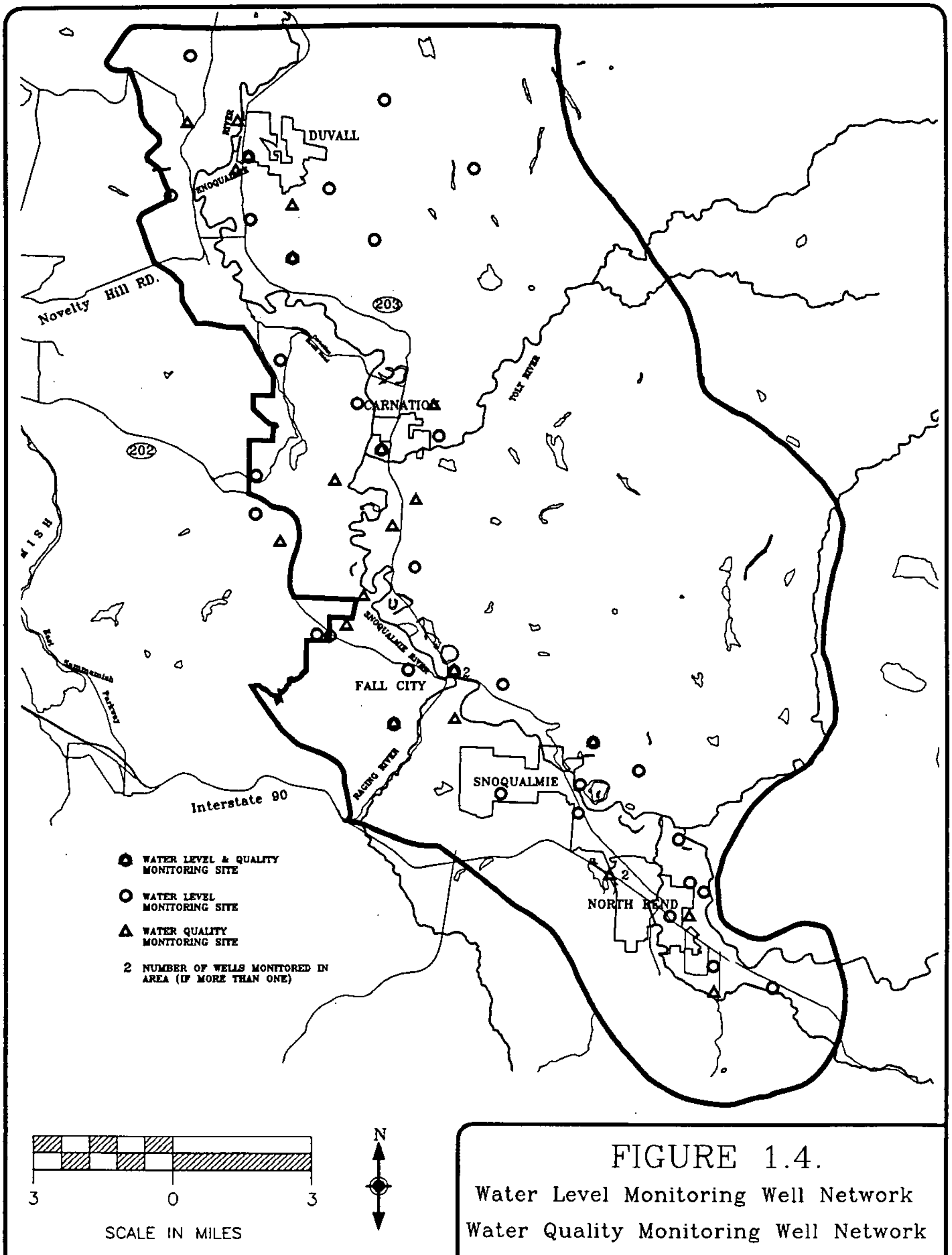


FIGURE 1.4.

Water Level Monitoring Well Network
Water Quality Monitoring Well Network

FIG_1_4.DWG/SWG/6-24-96

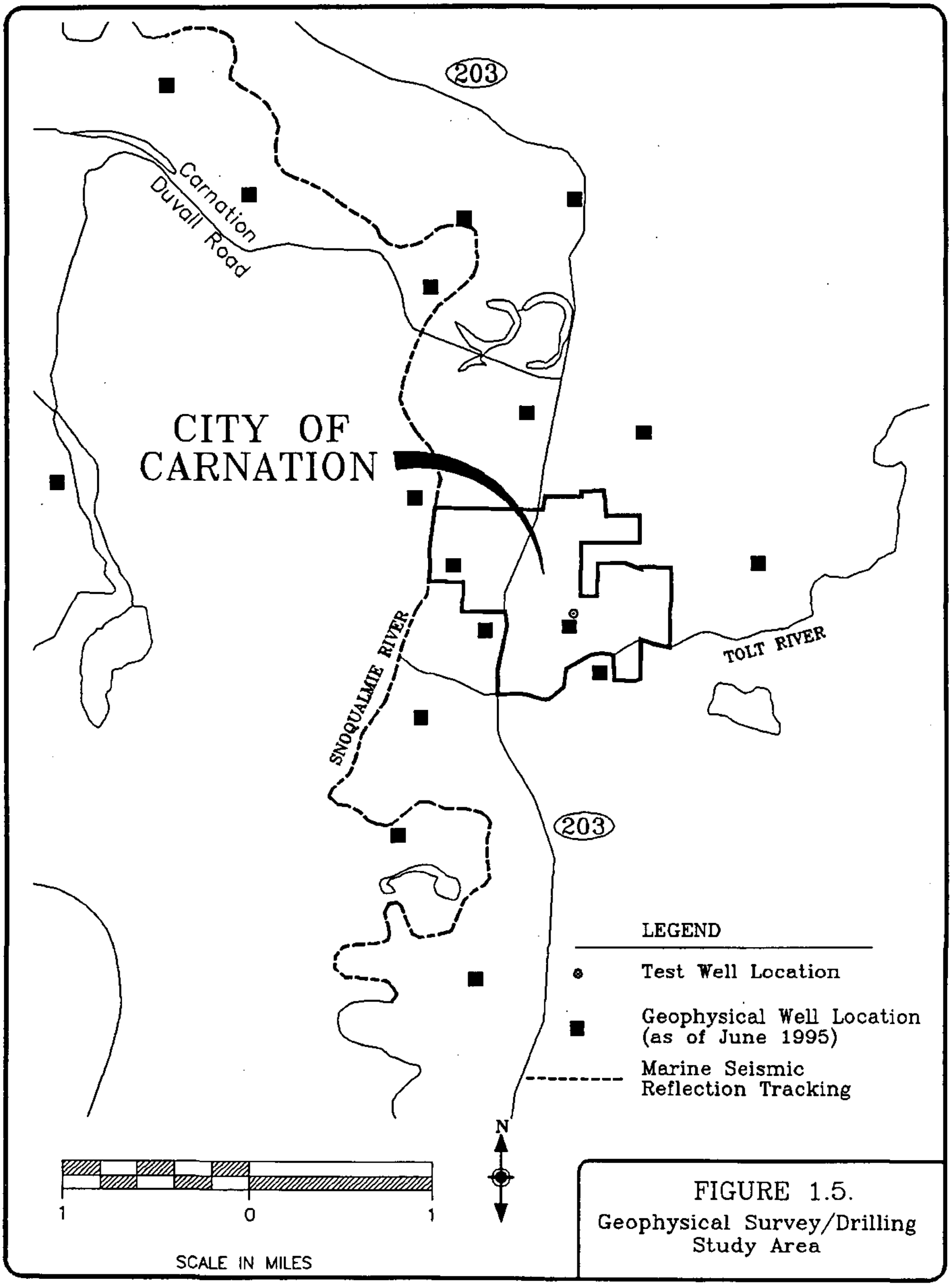


FIGURE 1.5.
Geophysical Survey/Drilling Study Area

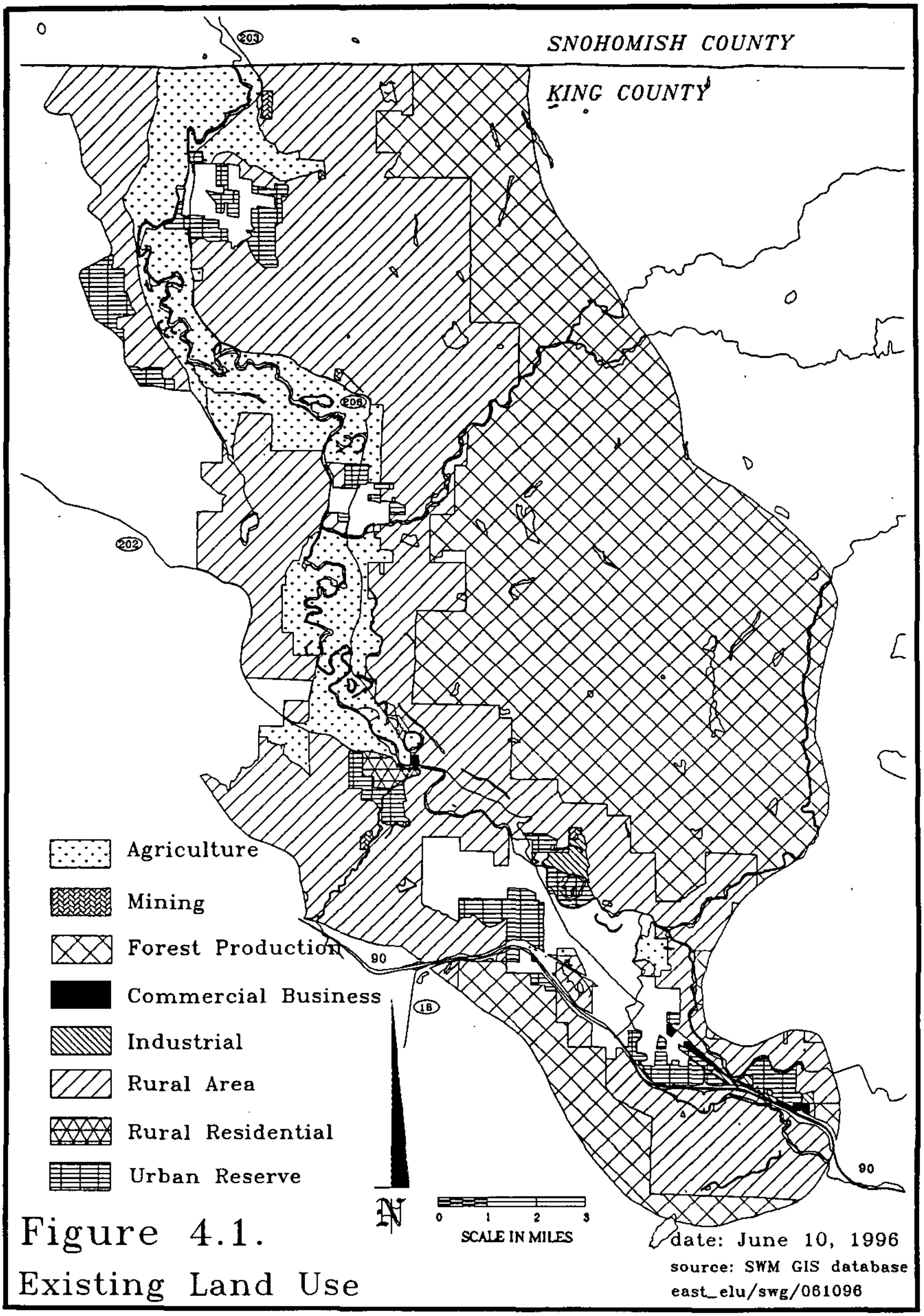
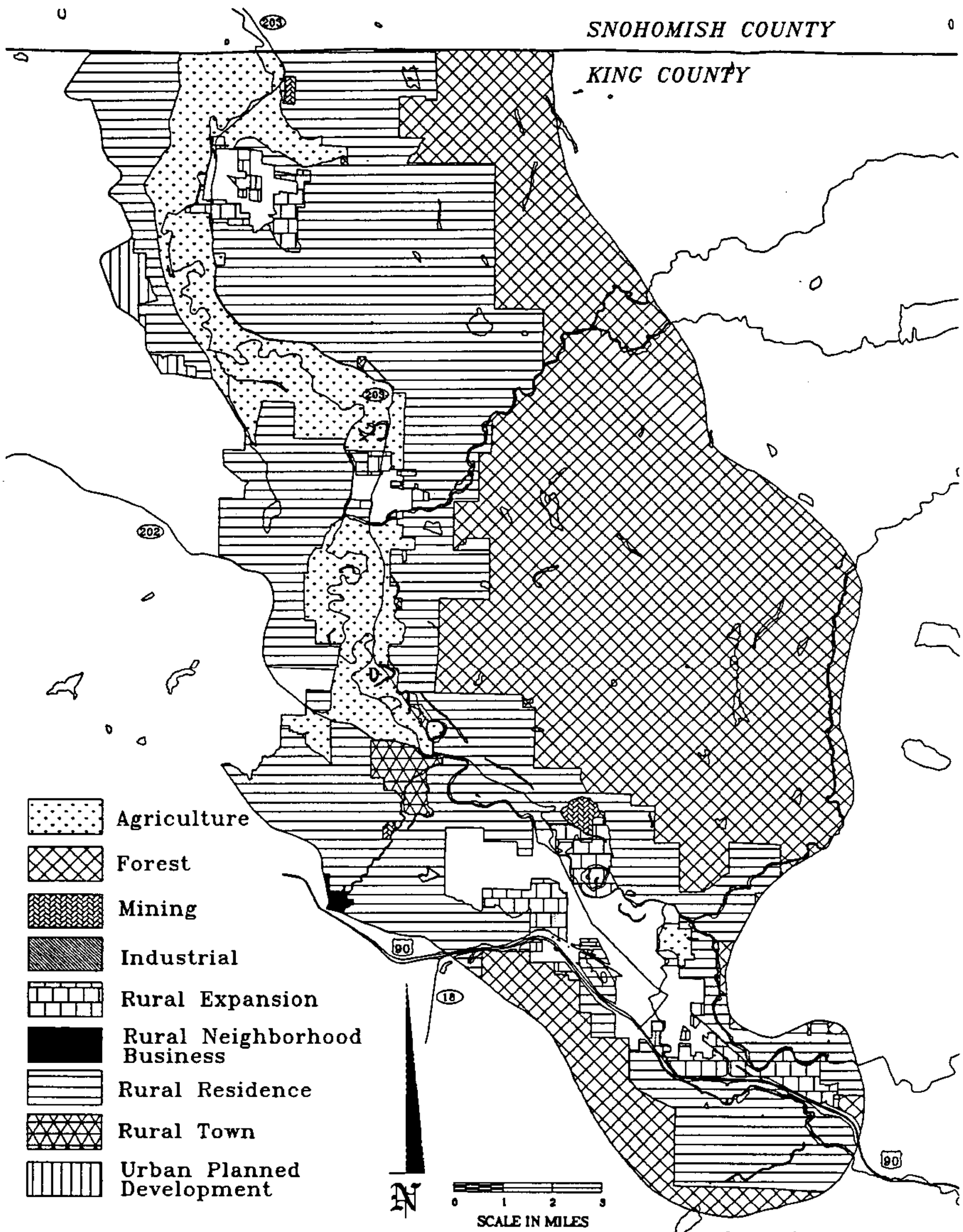


Figure 4.1.
Existing Land Use



date: June 10, 1996
source: SWM GIS database
east_flu/swg/061096

Figure 4.2.
Proposed Land Use

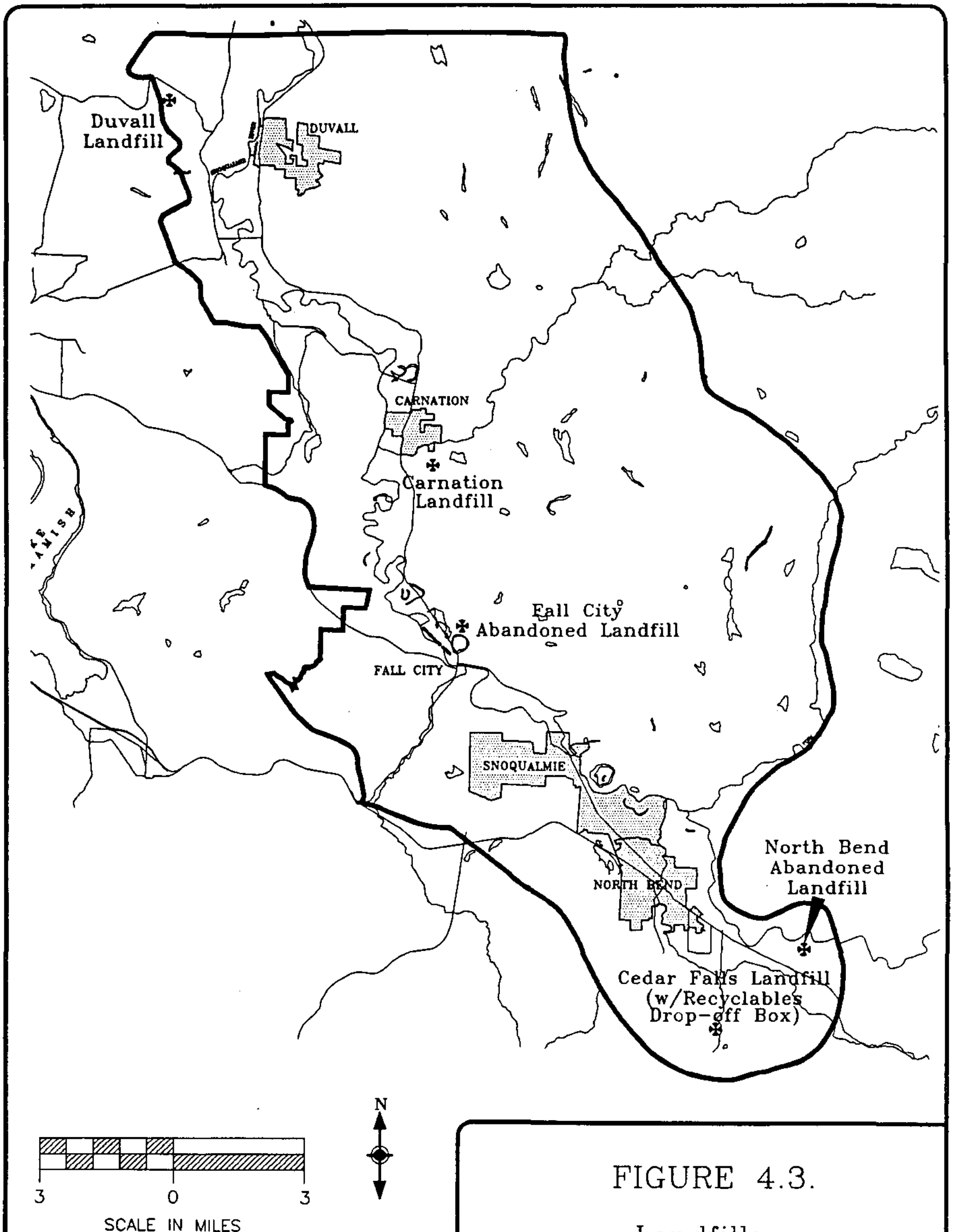


FIG_4_3.DWG/SWG/4-15-96

FIGURE 4.3.

Landfills

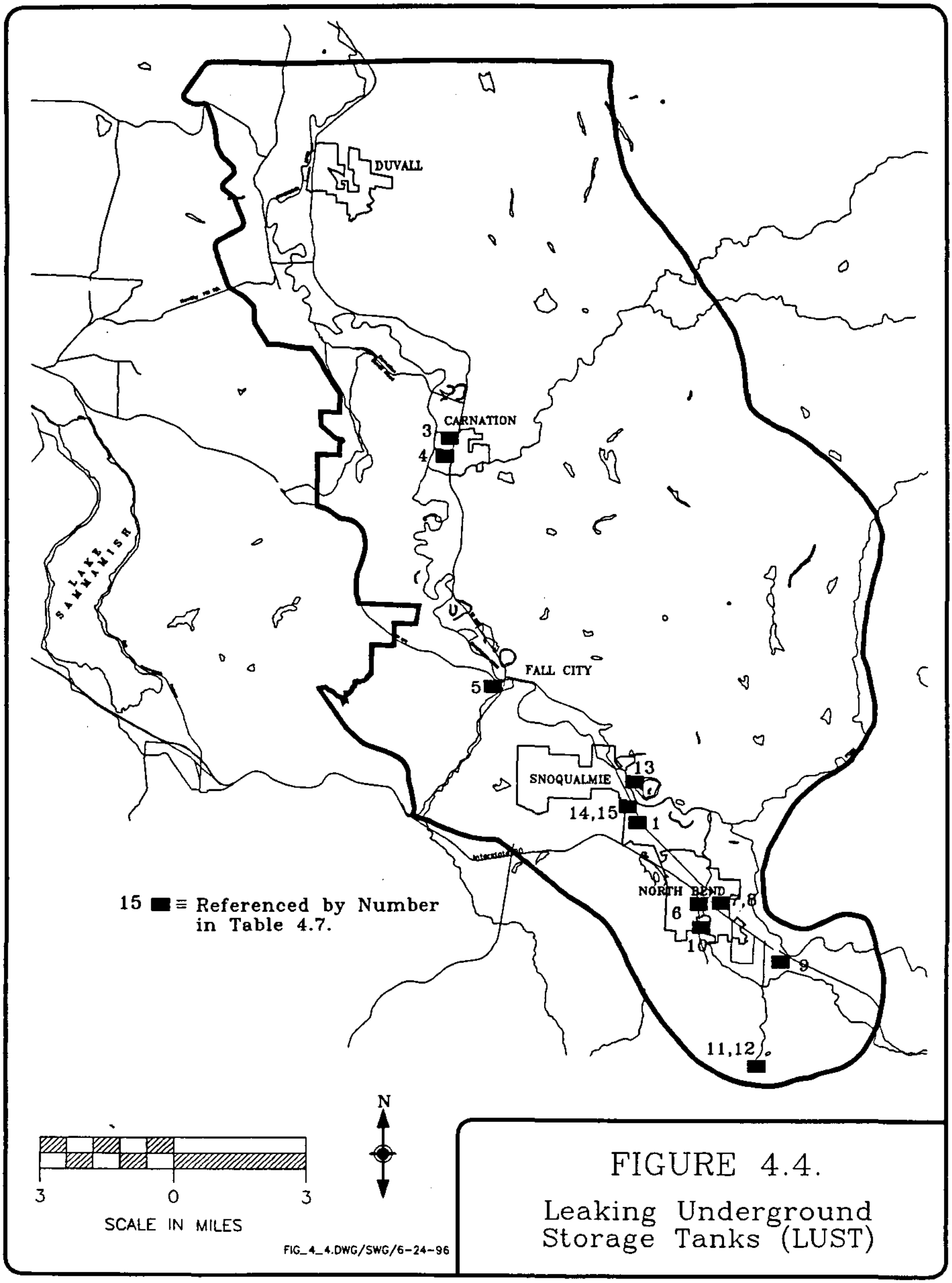


FIGURE 4.4.
Leaking Underground Storage Tanks (LUST)

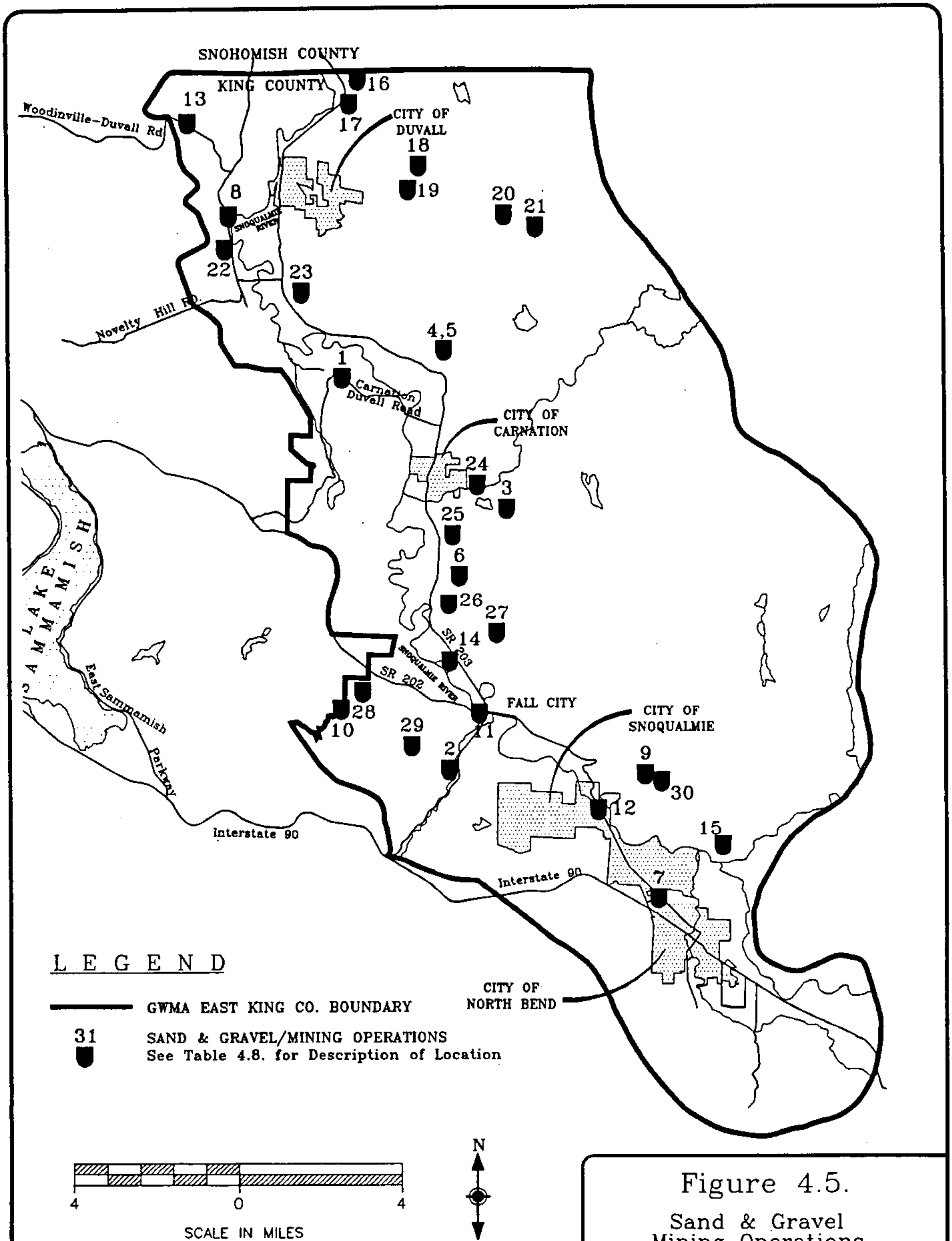


Figure 4.5.

Sand & Gravel Mining Operations

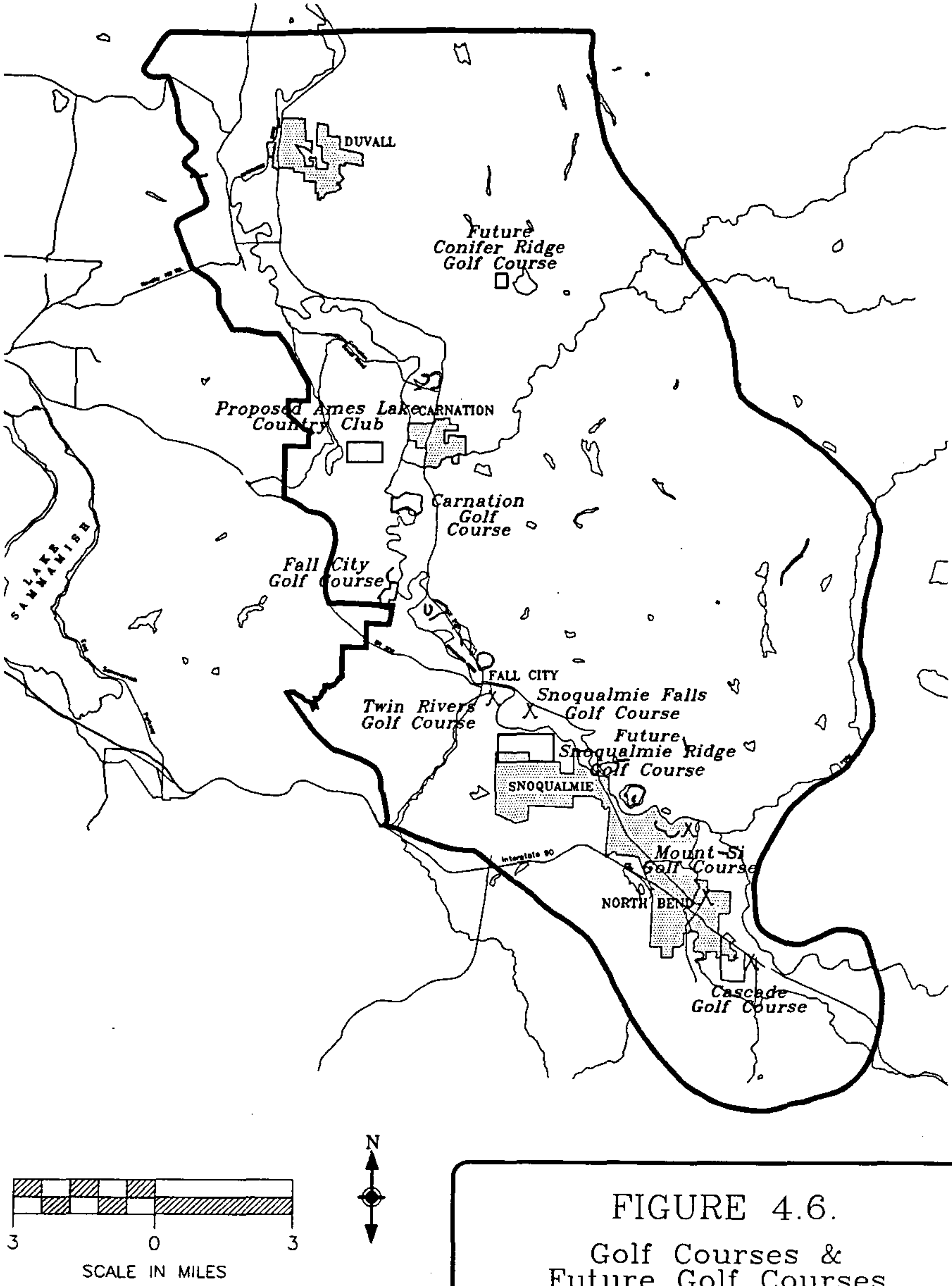


FIGURE 4.6.

Golf Courses & Future Golf Courses

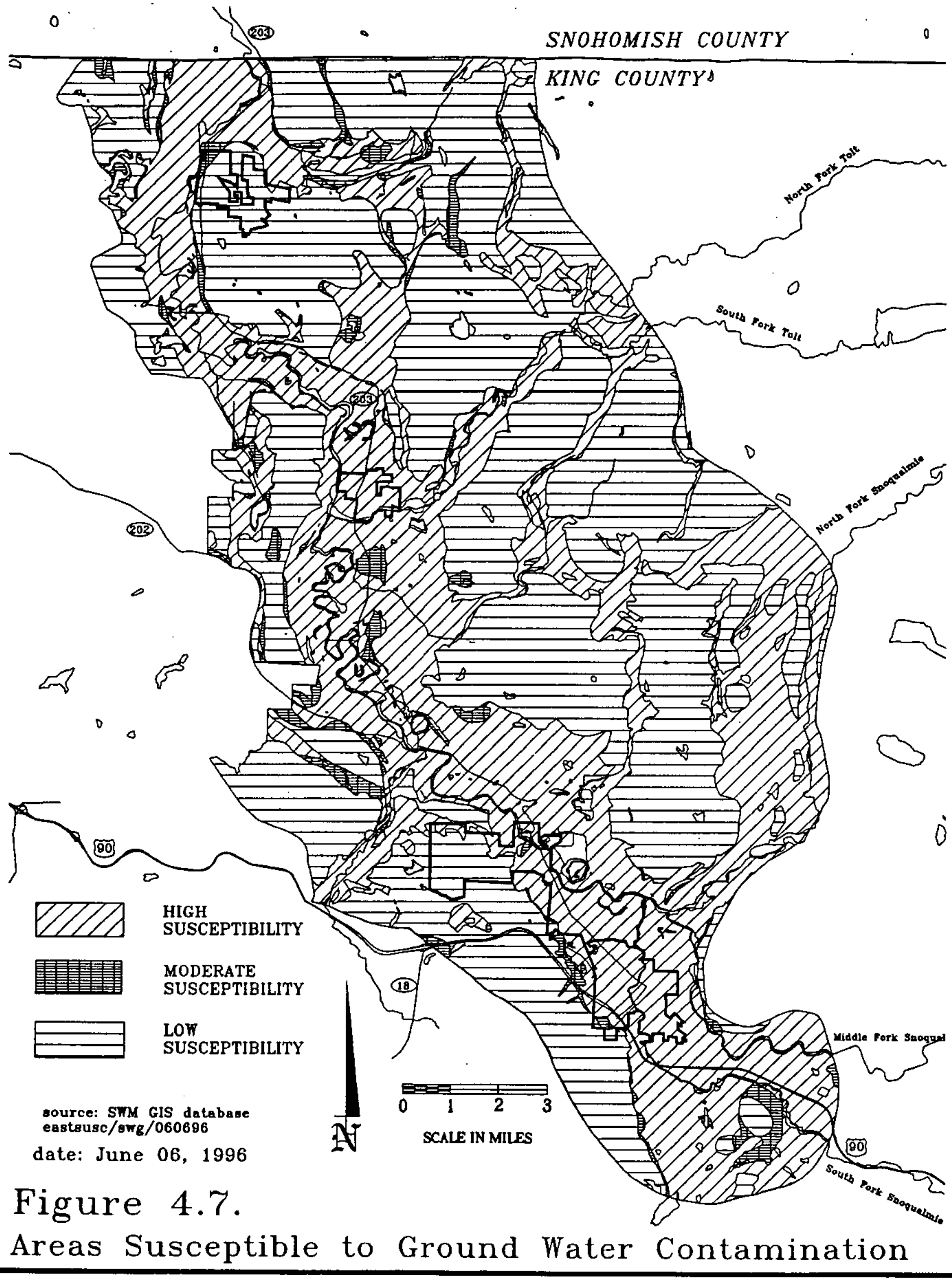


Figure 4.7.
Areas Susceptible to Ground Water Contamination

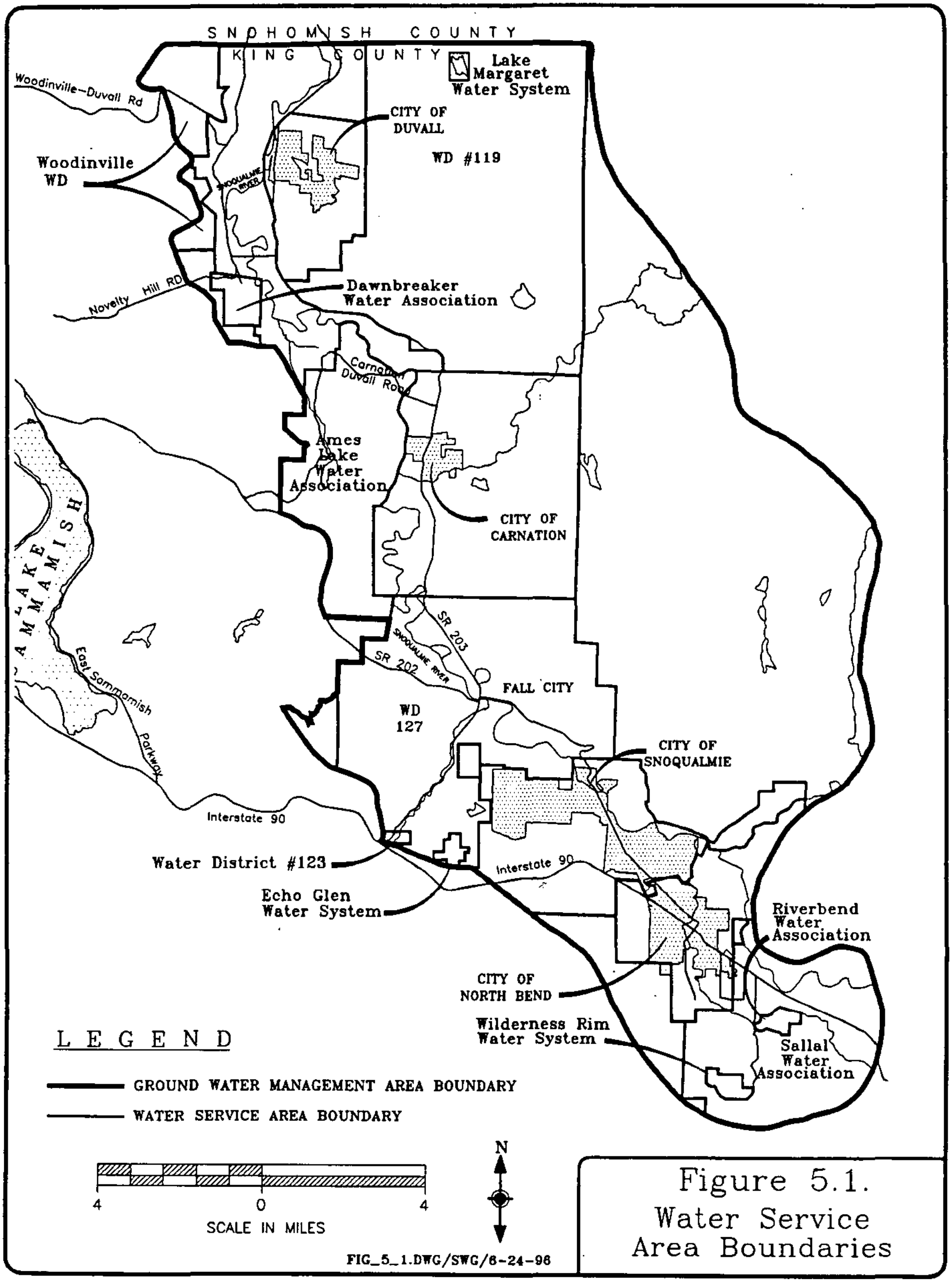


Figure 5.1.
Water Service Area Boundaries

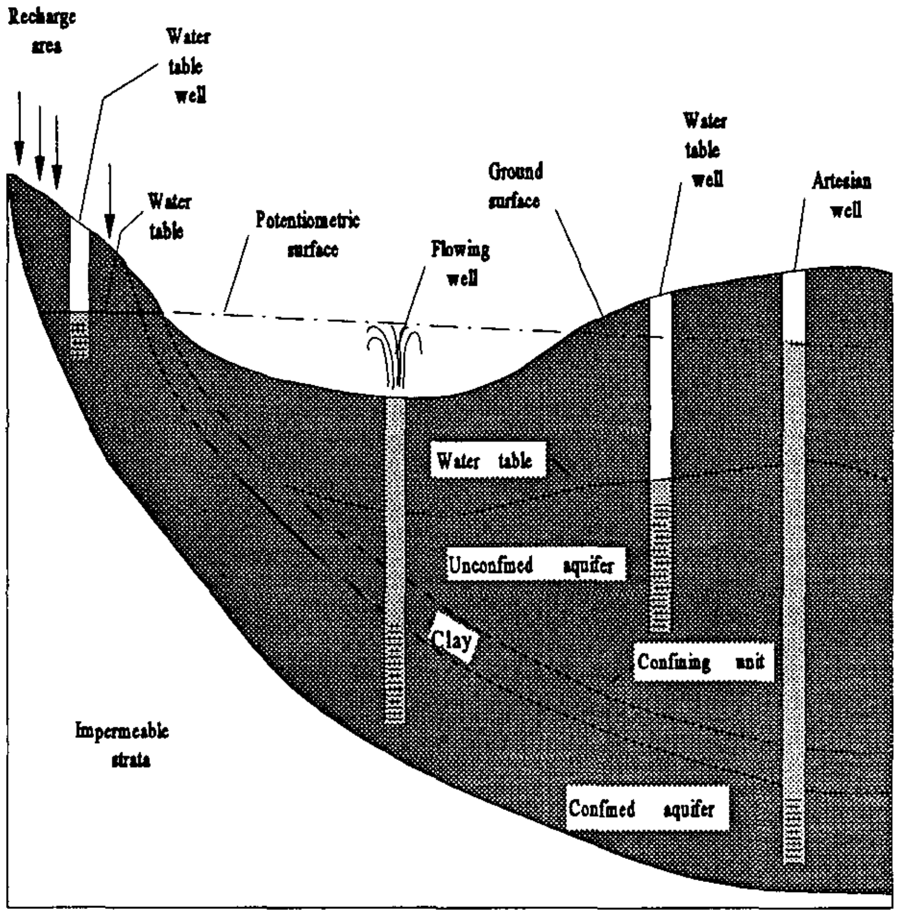


Figure 6.1. Features of unconfined and confined ground-water systems. (Modified from Todd, 1980.)

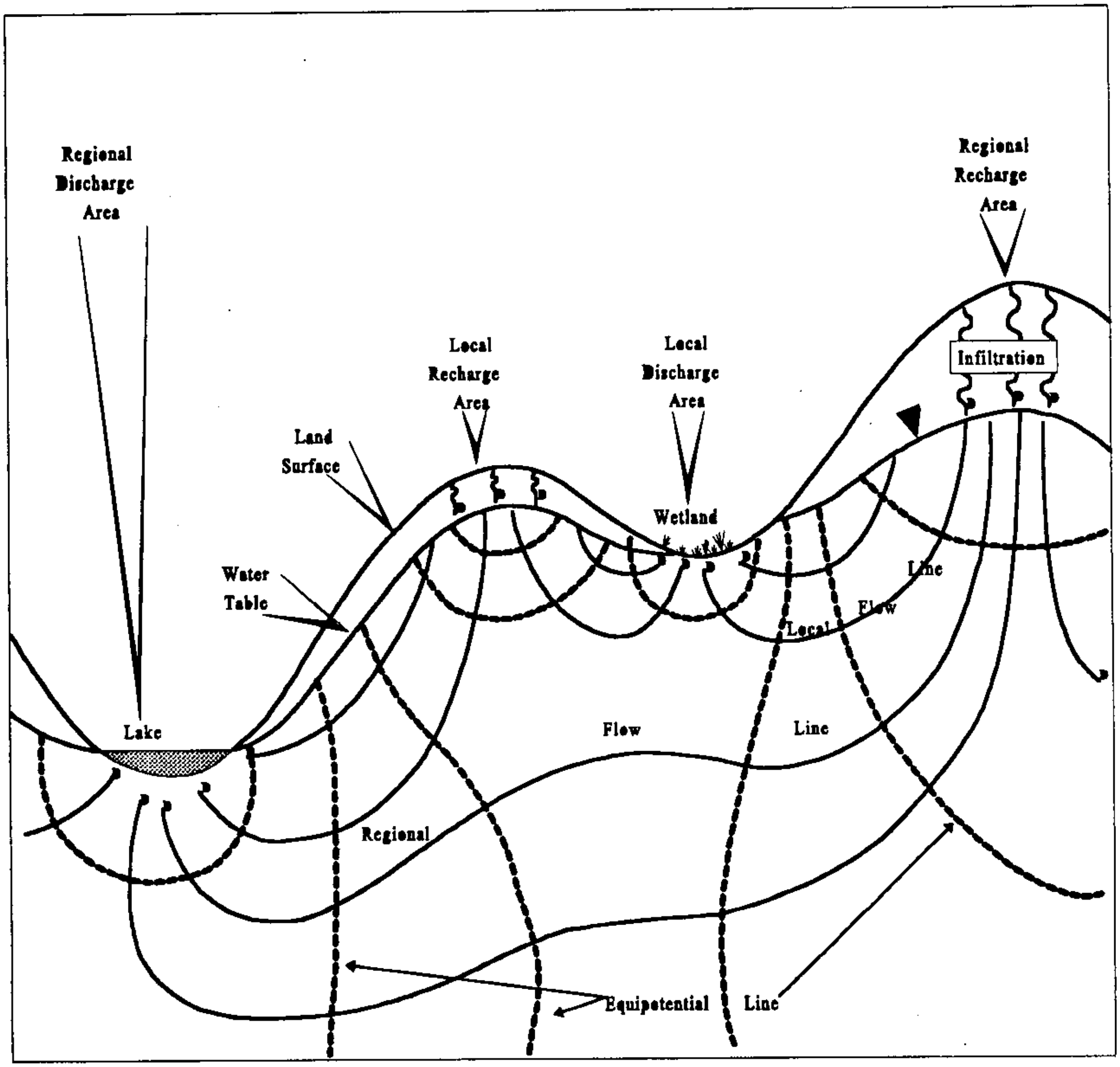


Figure 6.2. Idealized ground-water flow beneath an area of uniformly permeable material. (Modified from Hubbert, 1940).

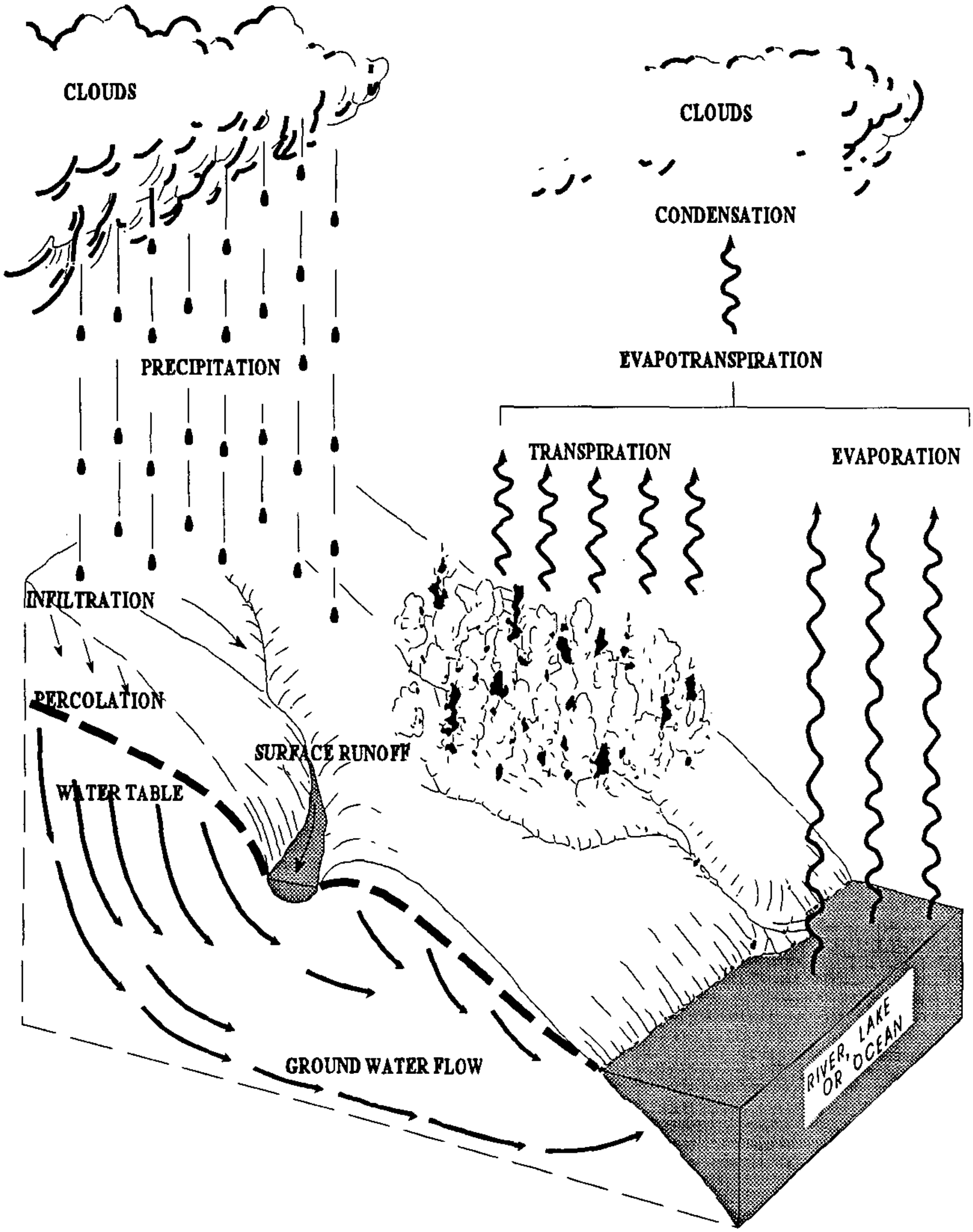


Figure 6.3. The hydrologic cycle.

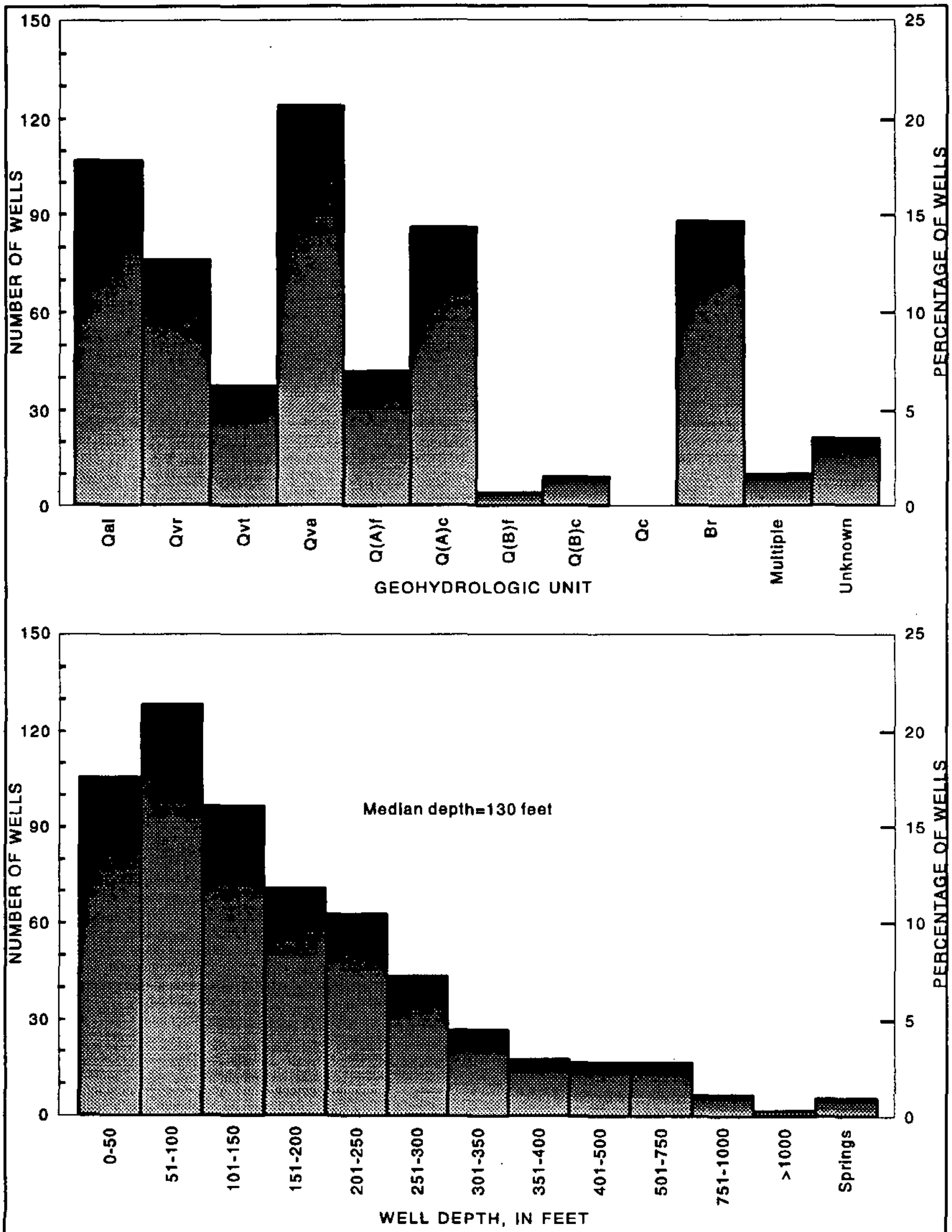


Figure 6.4. USGS selection of EKC-GWMA wells based on geohydrologic unit and well depth.

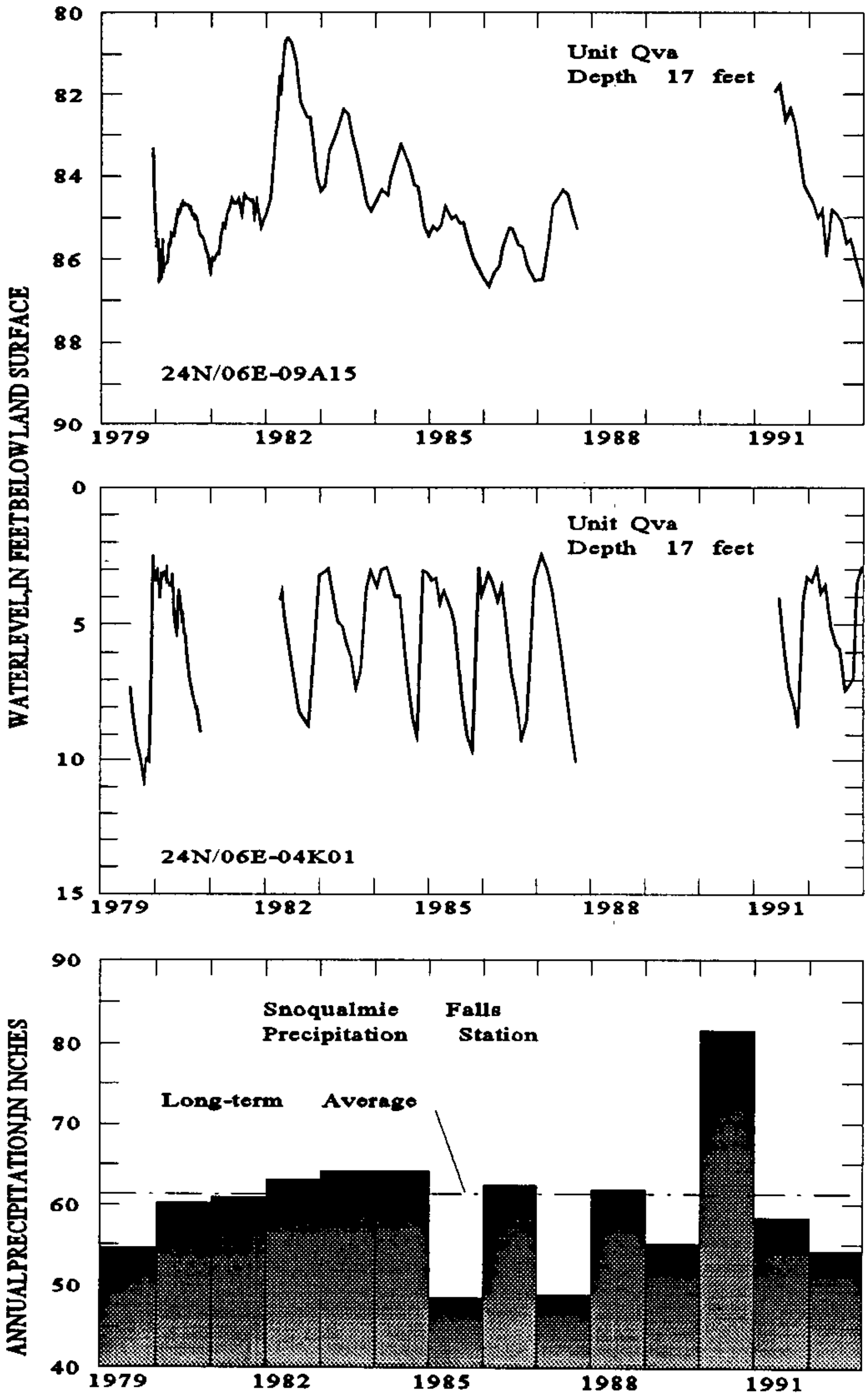


Figure 6.5. Water levels in wells 24N/06E-09A15 and 24N/06E-04K01 and annual precipitation at Snoqualmie Falls.

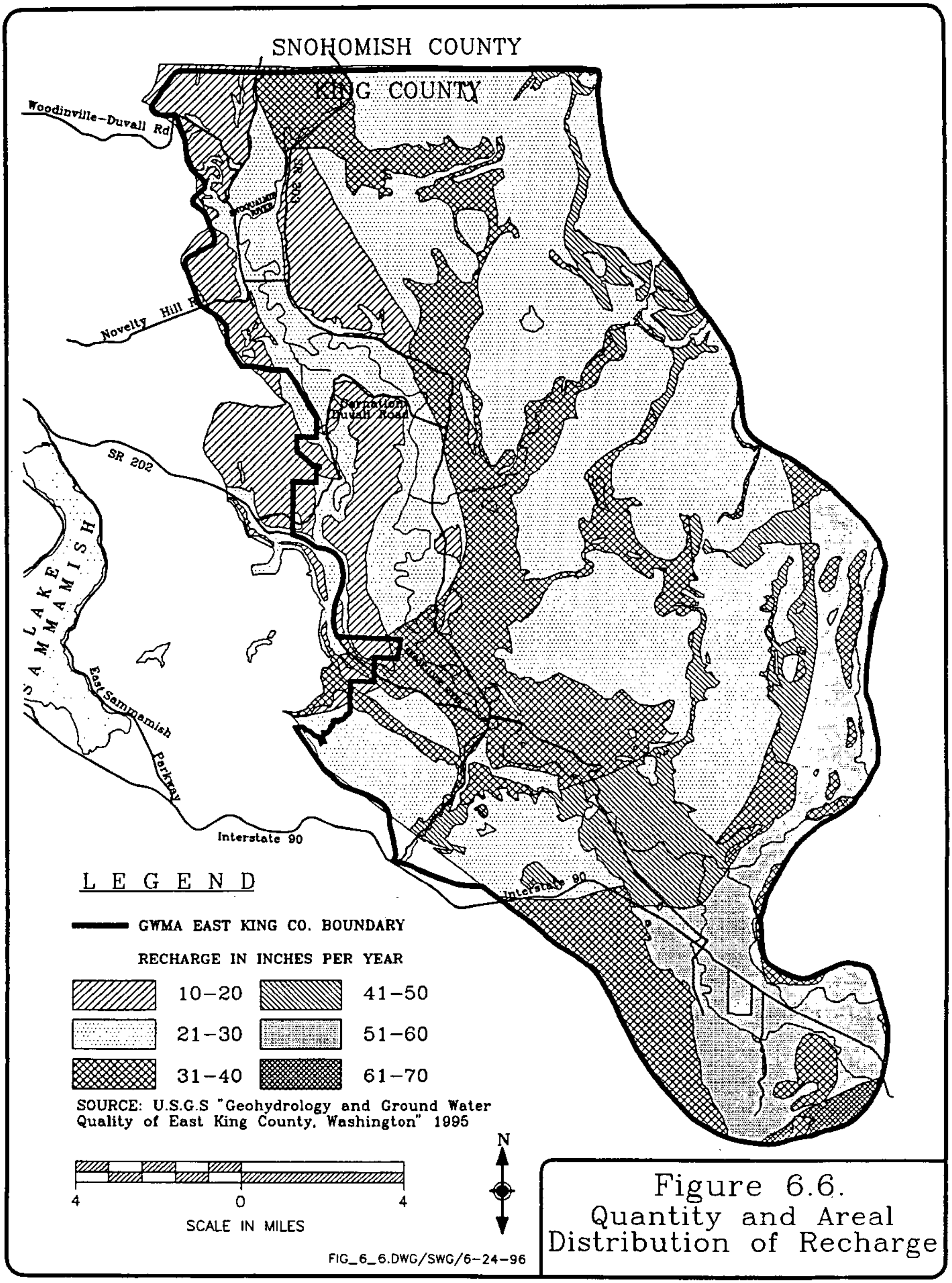


Figure 6.6.
Quantity and Areal Distribution of Recharge

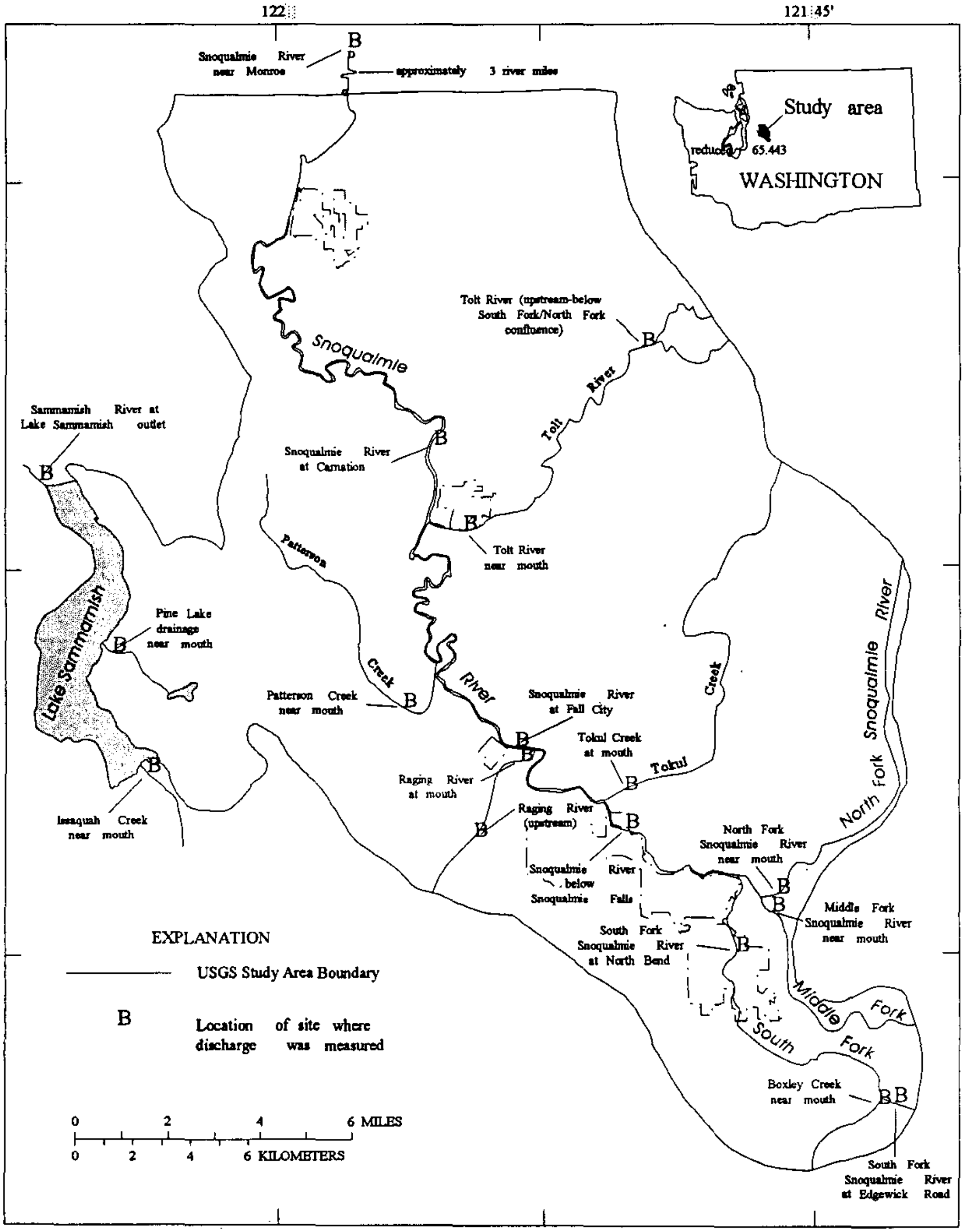


Figure 6.7. Locations of stream sites where discharge was measured to determine ground-water seepage by the U.S. Geological Survey.

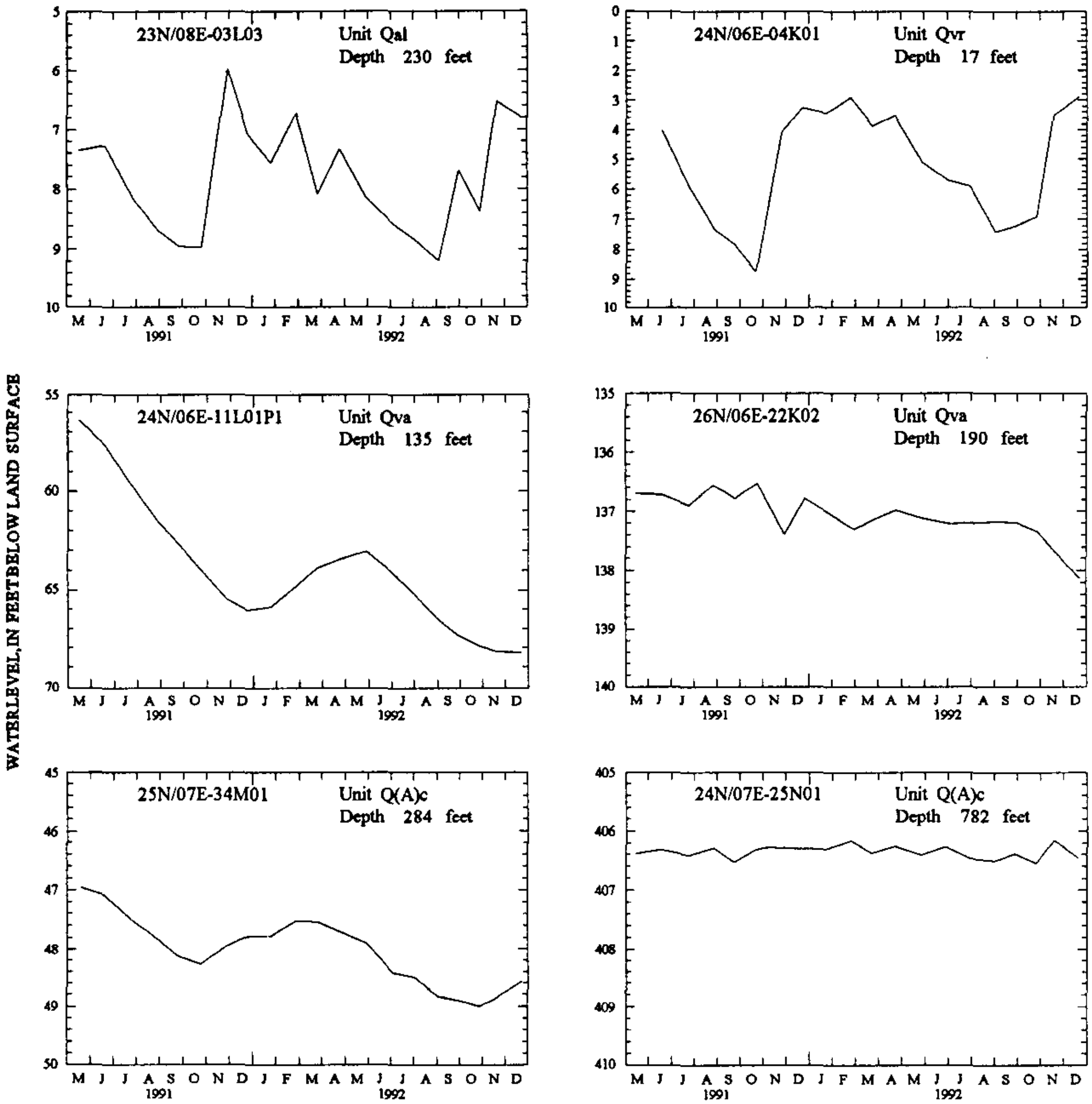


Figure 6.8. Water levels in selected wells in East King County

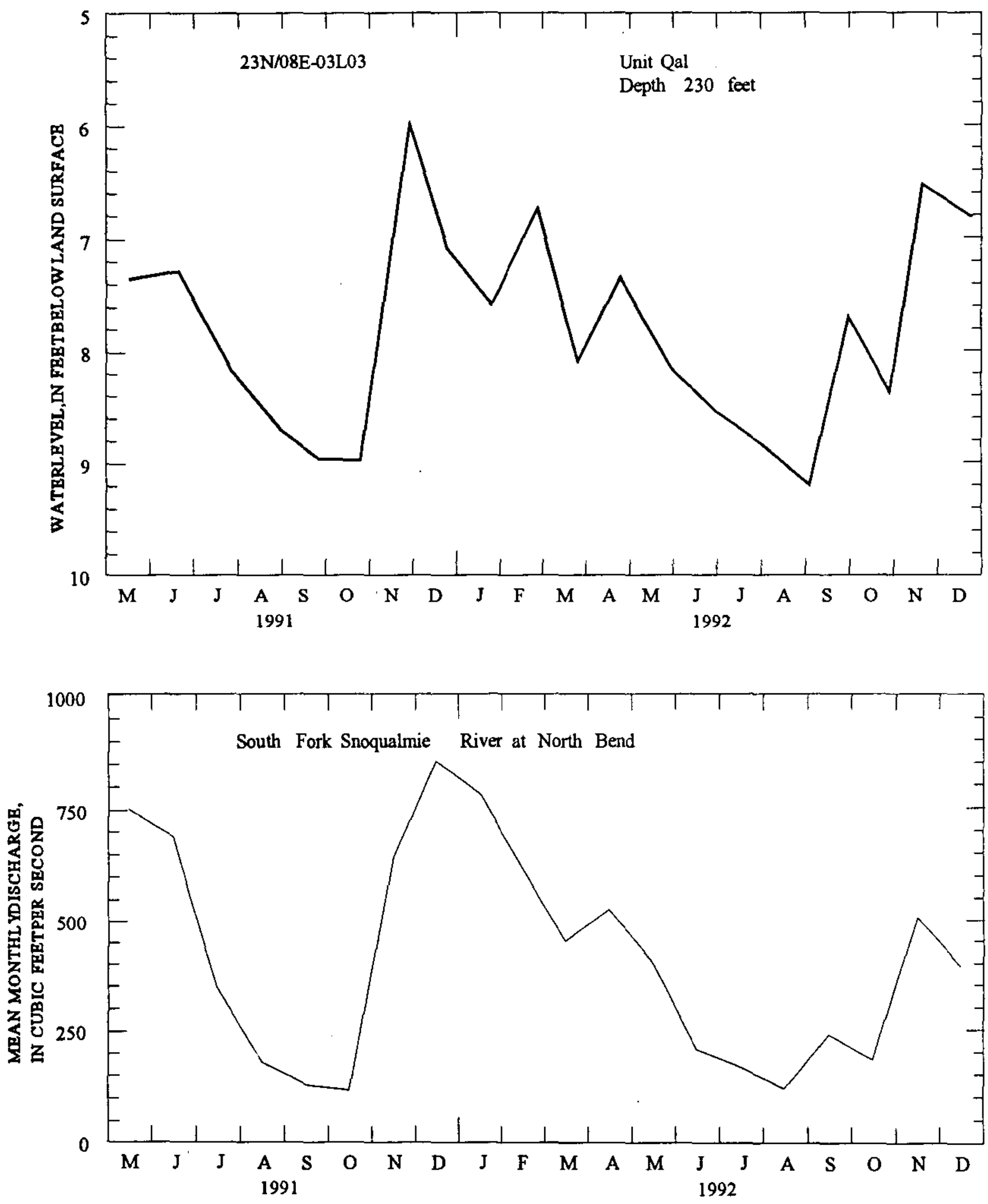
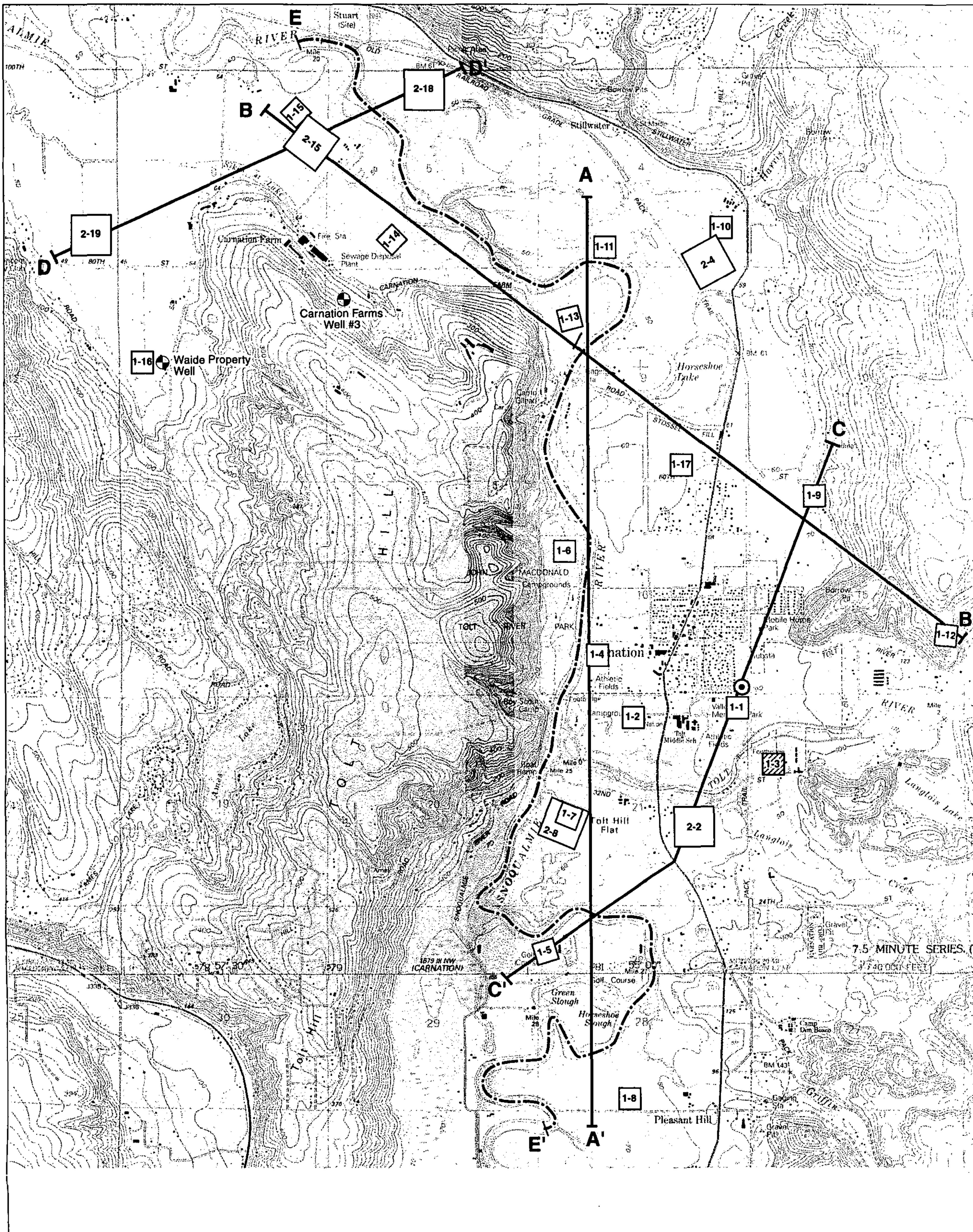


Figure 6.9. Water levels in well 23N/08E-03L03 and mean monthly discharge of the South Fork Snoqualmie River at North Bend.



LEGEND

A — A'	Geo-electric cross section
E — E'	Marine seismic reflection trackline
1-6	100-meter TDEM sounding location and number, square indicates loop orientation
1-3 (hatched)	Data on this sounding not usable due to cultural interference from power lines
2-2	300-meter TDEM sounding location and number, square indicates loop orientation
◐	Existing well used as calibration for TDEM soundings
⊙	Test well site (Loutsis Park, Carnation)

N

0 2500

FEET

FIGURE **6.10.**

BASEMAP WITH GEOPHYSICAL SURVEY LAYOUT
LOWER SNOQUALMIE RIVER VALLEY
CARNATION, WASHINGTON

EKC Figure 610.fh3 6/96 kjm

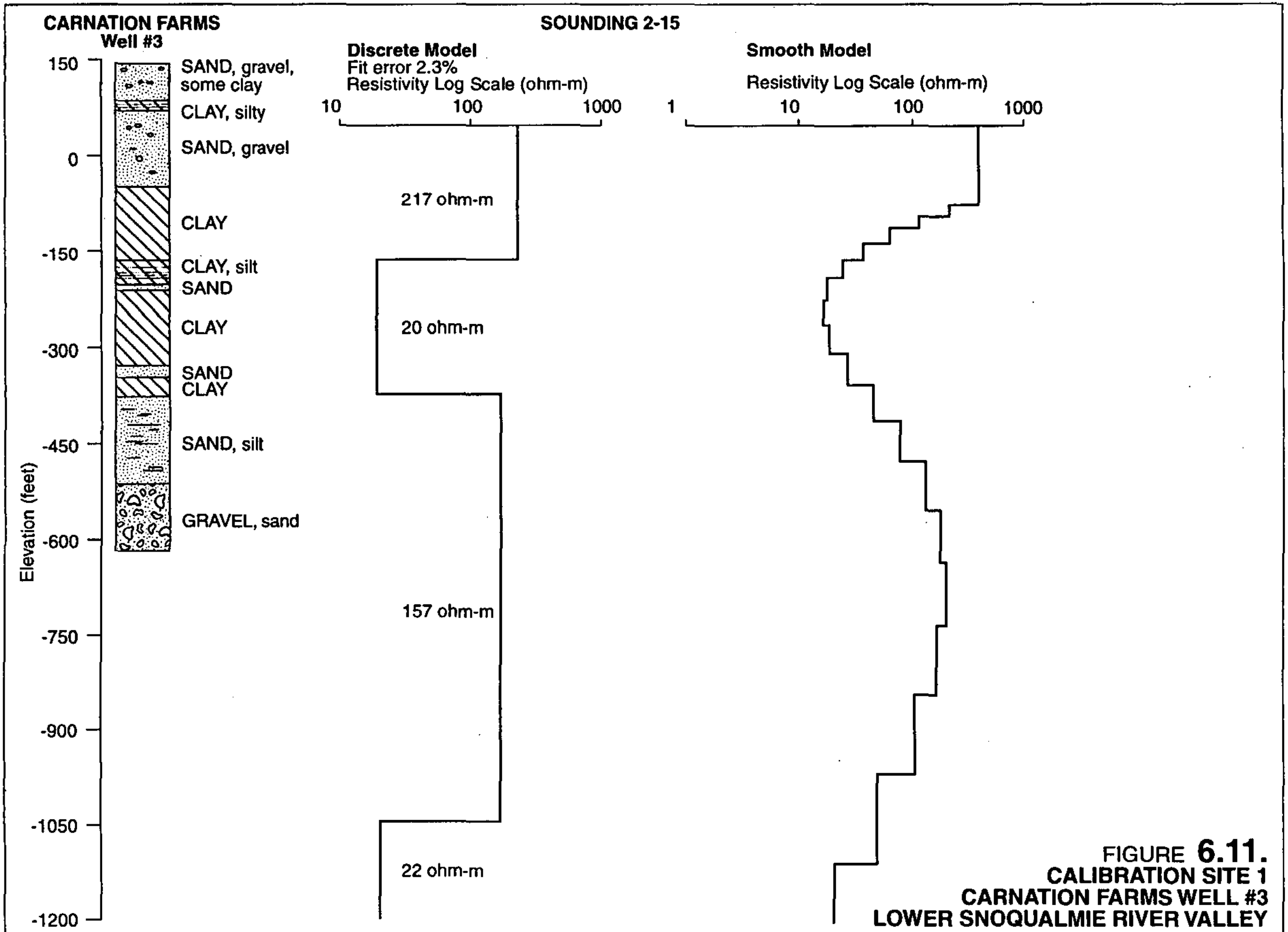


FIGURE **6.11.**
CALIBRATION SITE 1
CARNATION FARMS WELL #3
LOWER SNOQUALMIE RIVER VALLEY

EKC Figure 611.fh3 6/96 KJM

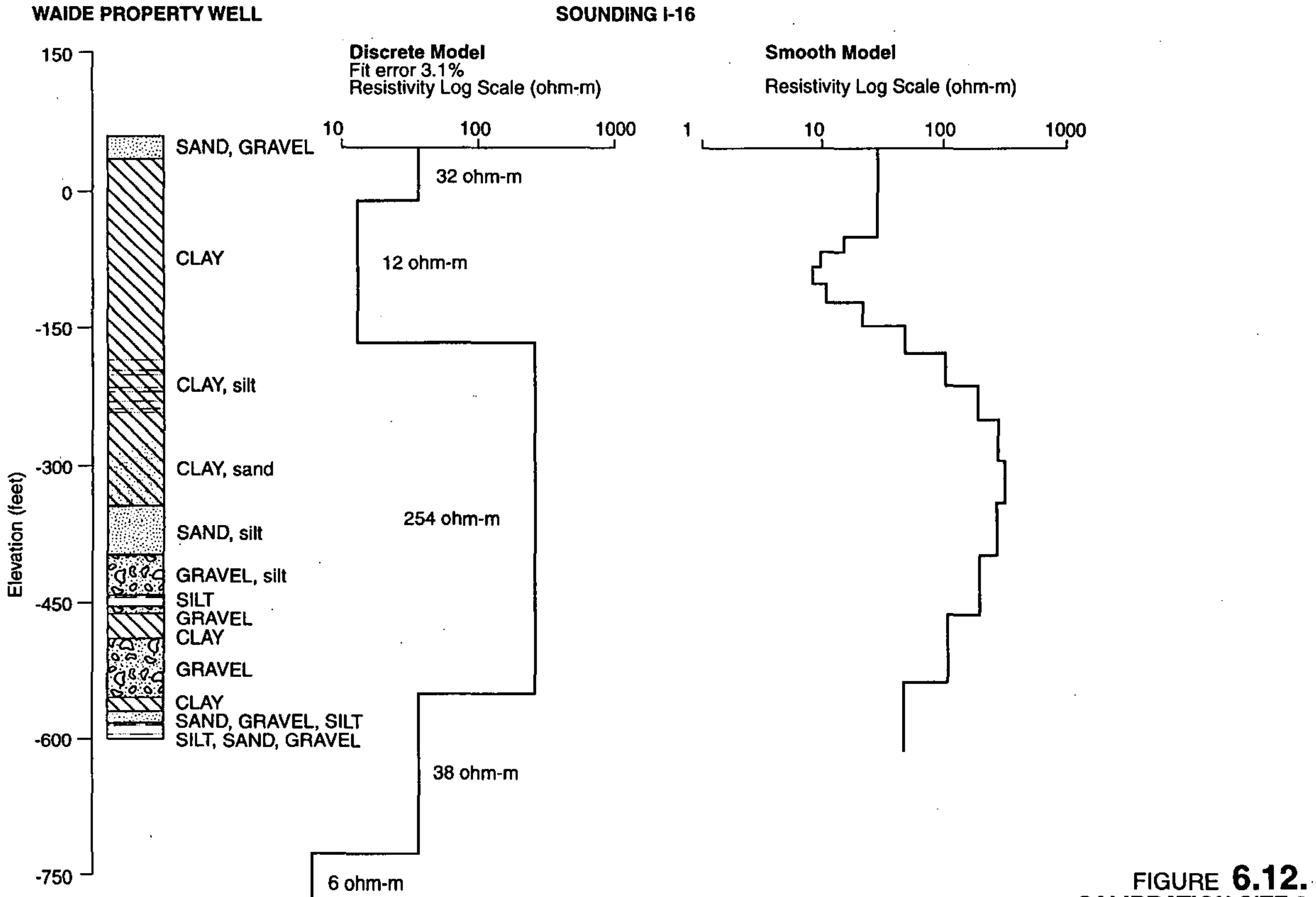


FIGURE **6.12.**
CALIBRATION SITE 2
WAIDE PROPERTY WELL
LOWER SNOQUALMIE RIVER VALLEY

EKC Figure 612.fh3 6/96 KJM

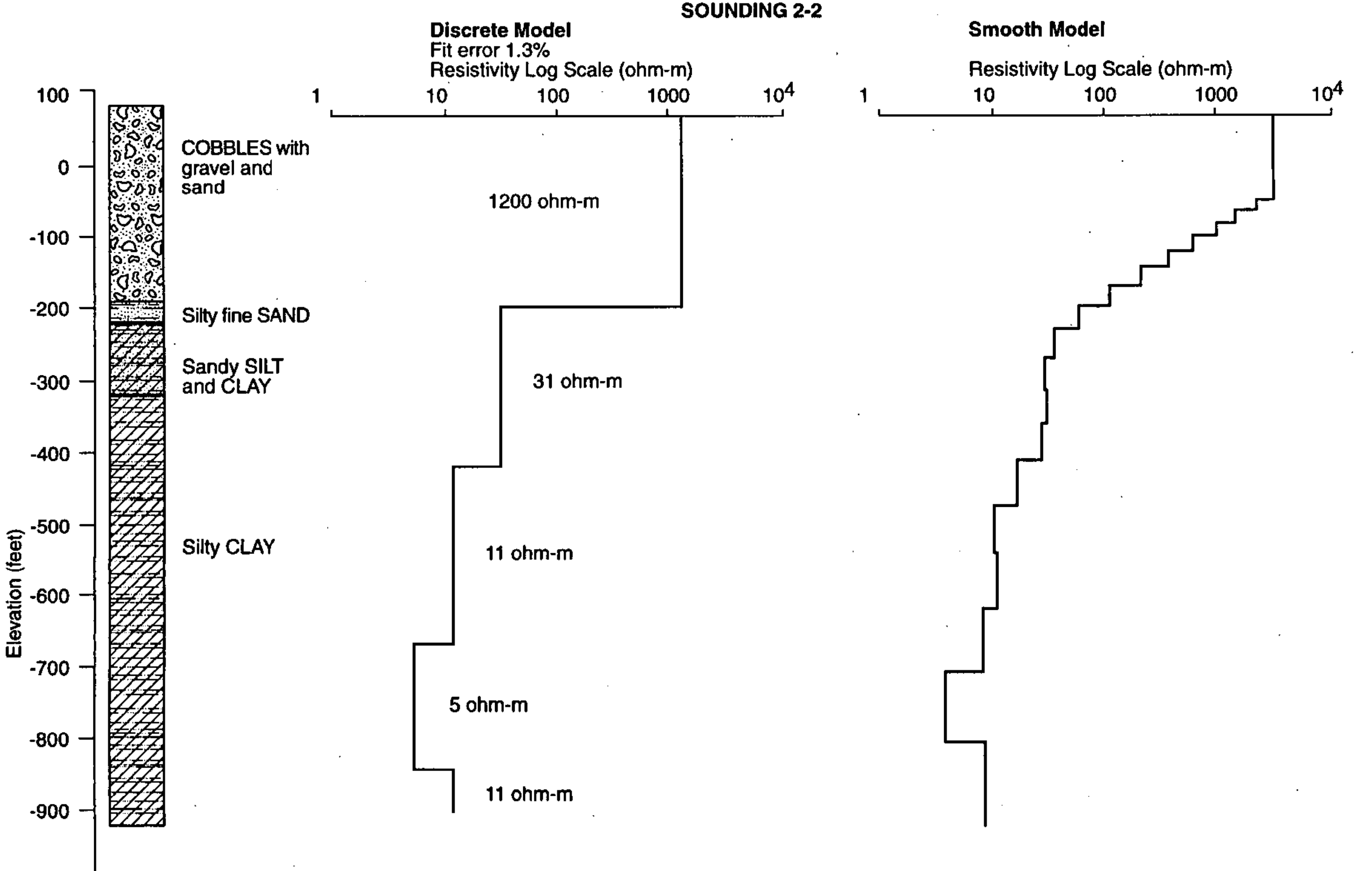


FIGURE **6.13.**
TEST WELL LOG WITH TDEM MODEL 2-2
LOWER SNOQUALMIE RIVER VALLEY
CARNATION, WASHINGTON

EKC Figure 613.fh3 6/96 KJM

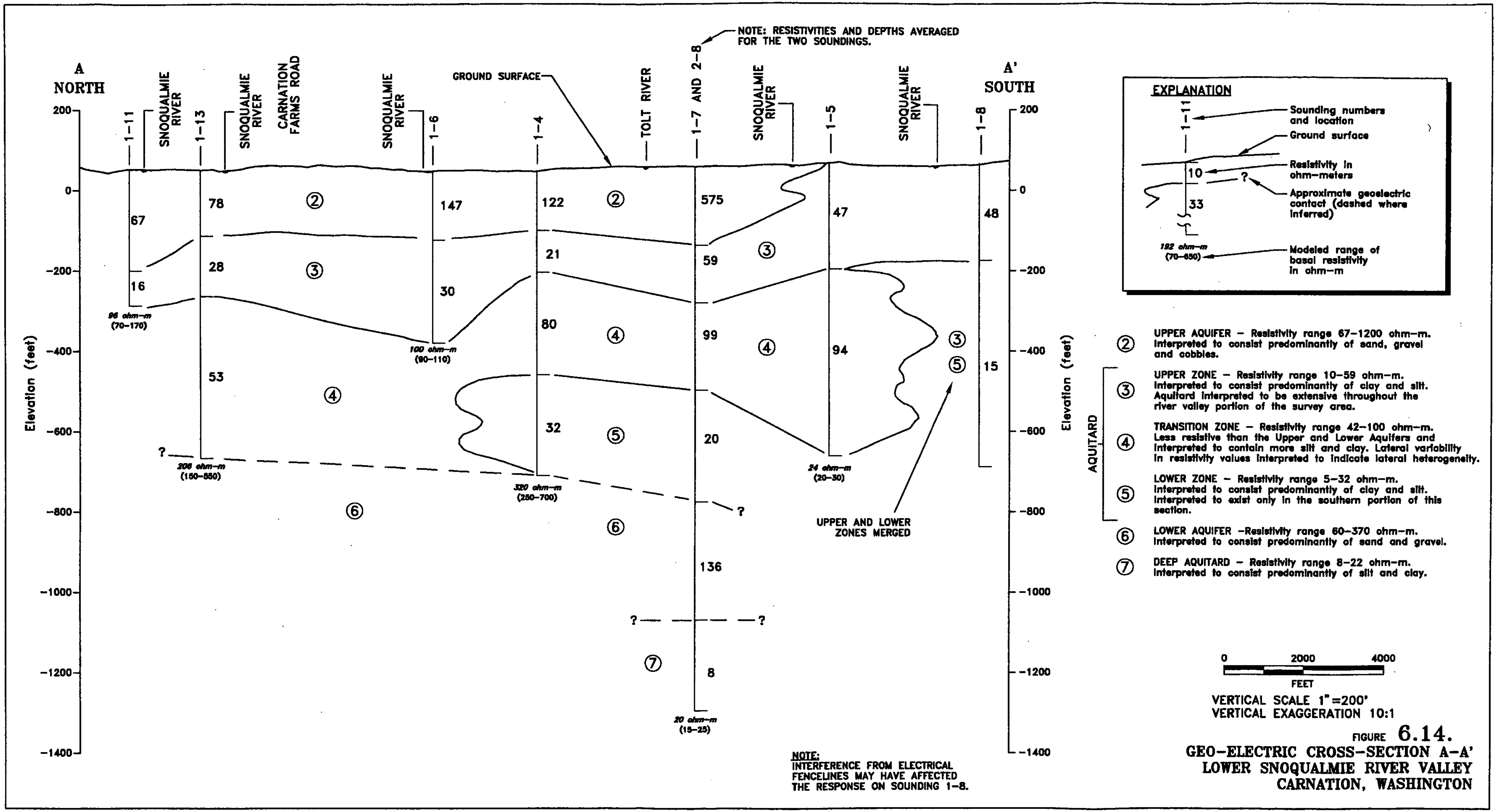


FIGURE 6.14.
GEO-ELECTRIC CROSS-SECTION A-A'
LOWER SNOQUALMIE RIVER VALLEY
CARNATION, WASHINGTON

C:\ADCADD\CIVIL\P\9531100\100\63544 10-24-95 15:49 xrf: NONE H:\GWMAMAPS\EAST\FIG_655

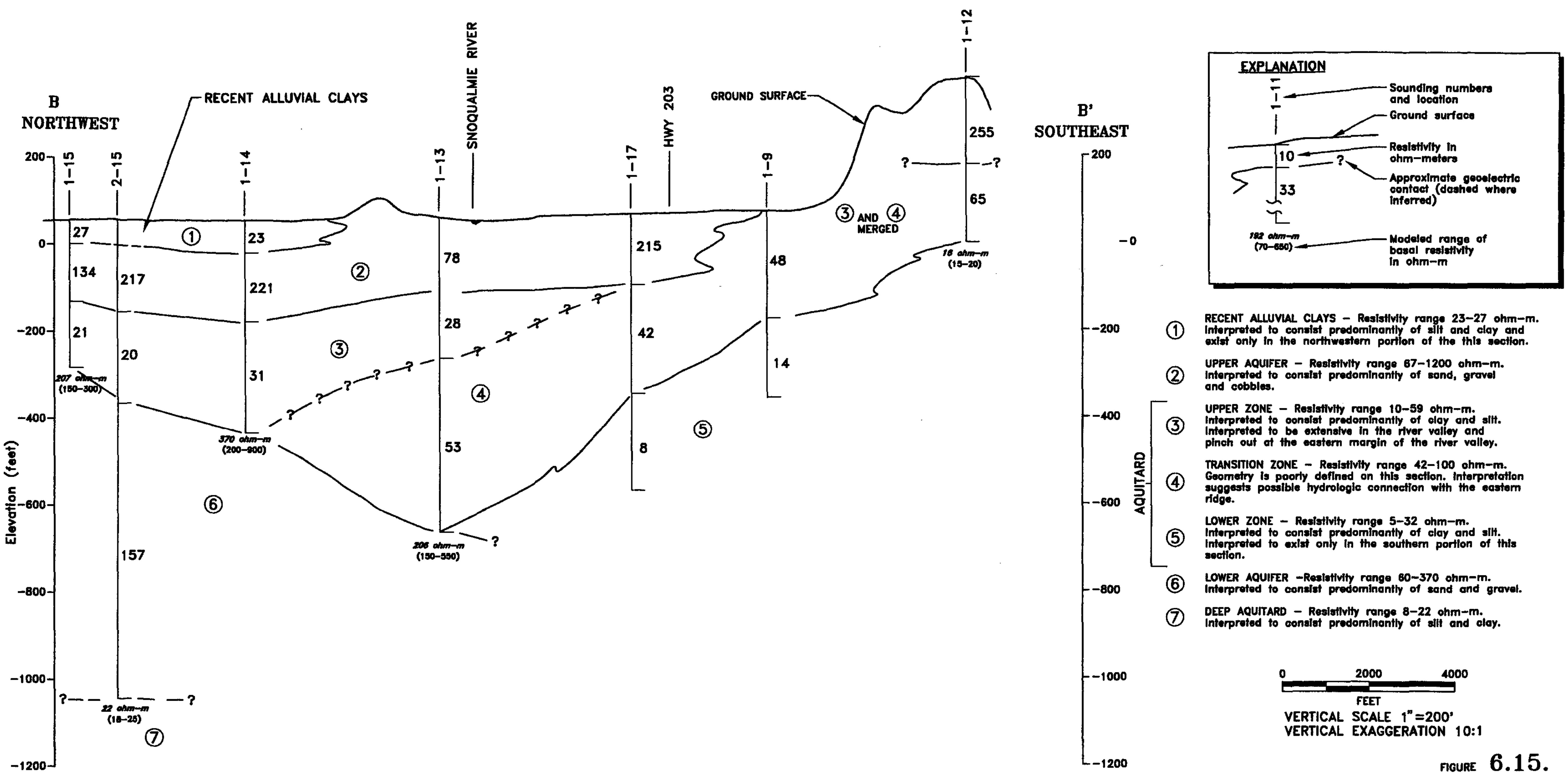


FIGURE 6.15.
GEO-ELECTRIC CROSS-SECTION B-B'
LOWER SNOQUALMIE RIVER VALLEY
CARNATION, WASHINGTON

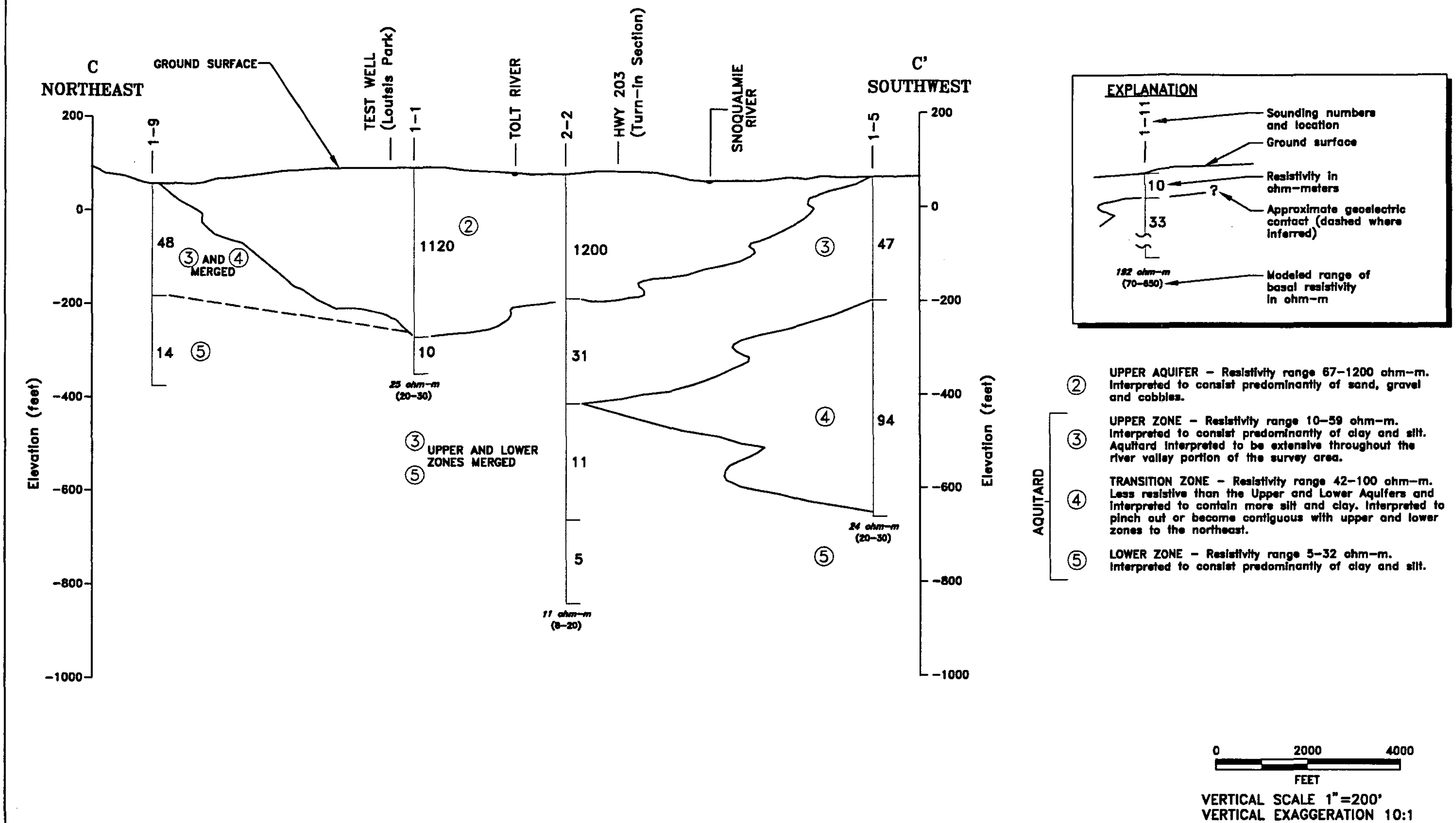


FIGURE 6.16.
GEO-ELECTRIC CROSS-SECTION C-C'
LOWER SNOQUALMIE RIVER VALLEY
CARNATION, WASHINGTON

C:\ADCADD\CIVIL\P\9531100\100\63546 10-24-95 16:53crf: NONE H:\GWMAMAPS\EAST\FIG 657

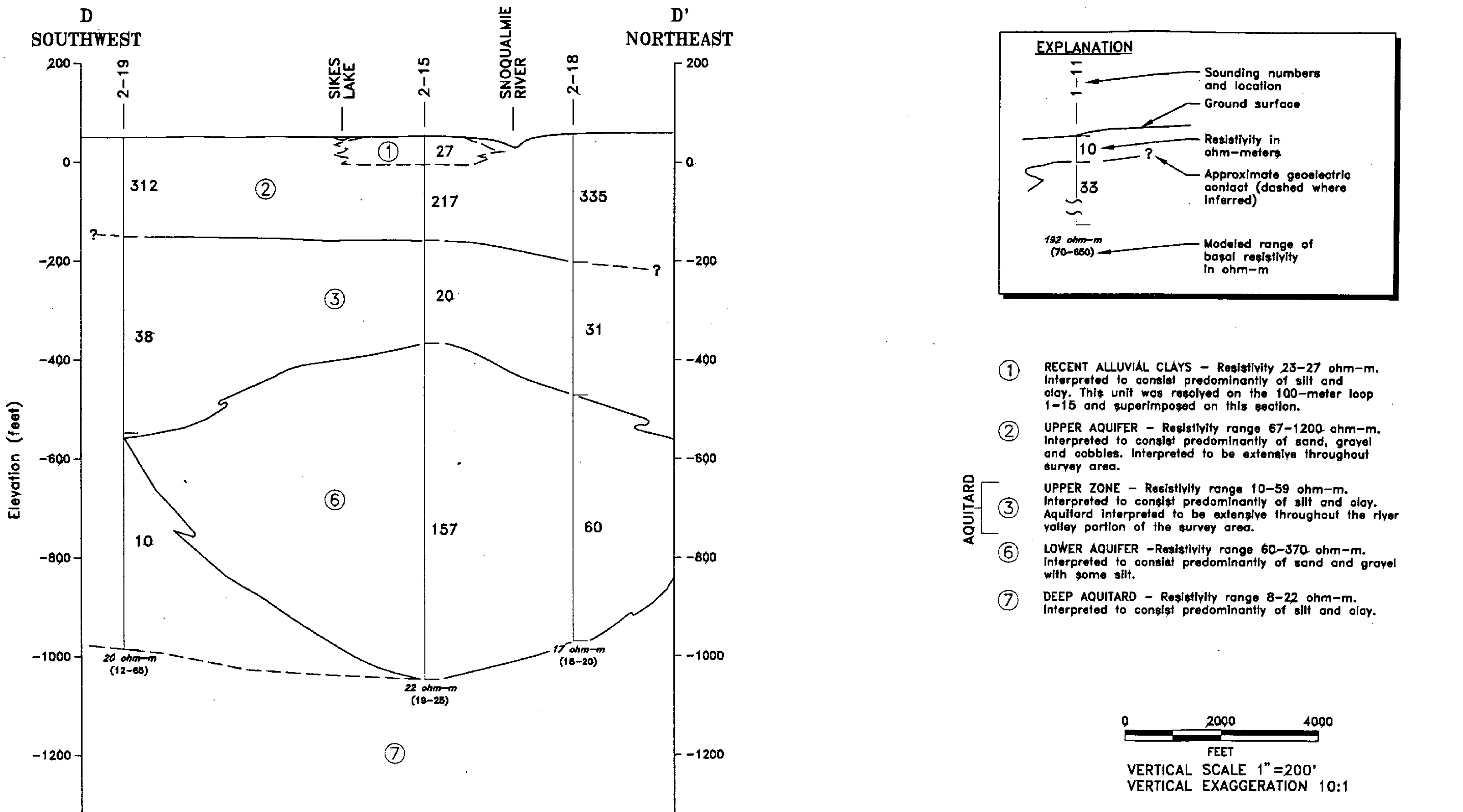
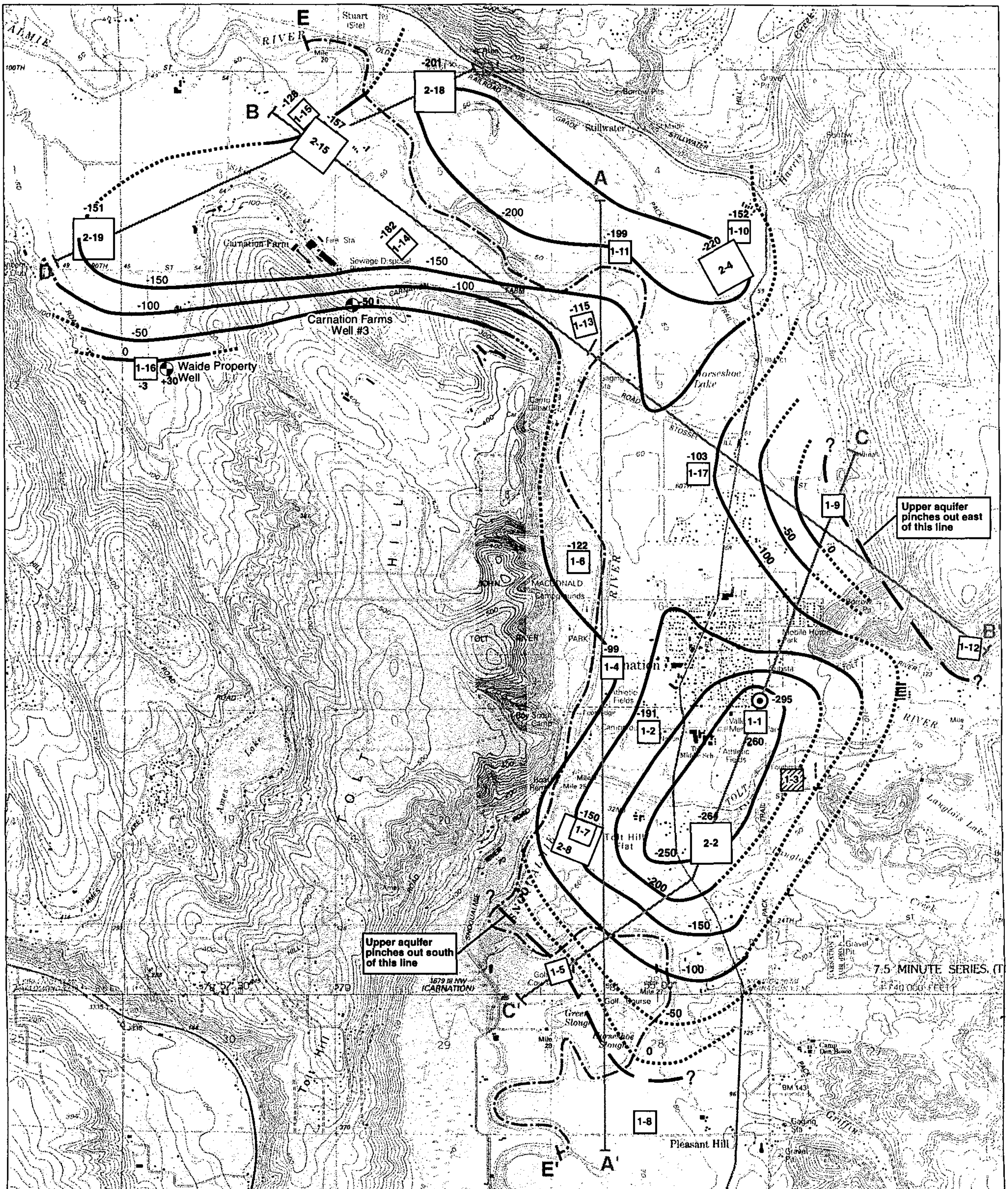


FIGURE 6.17.
GEO-ELECTRIC CROSS-SECTION D-D'
LOWER SNOQUALMIE RIVER VALLEY
CARNATION, WASHINGTON

C:\ADCADD\CIVIL\F\9531100\100\63547 10-24-95 16:54 xrf: NONE H:\GWMAMAPS\EAST\FIG_658



LEGEND

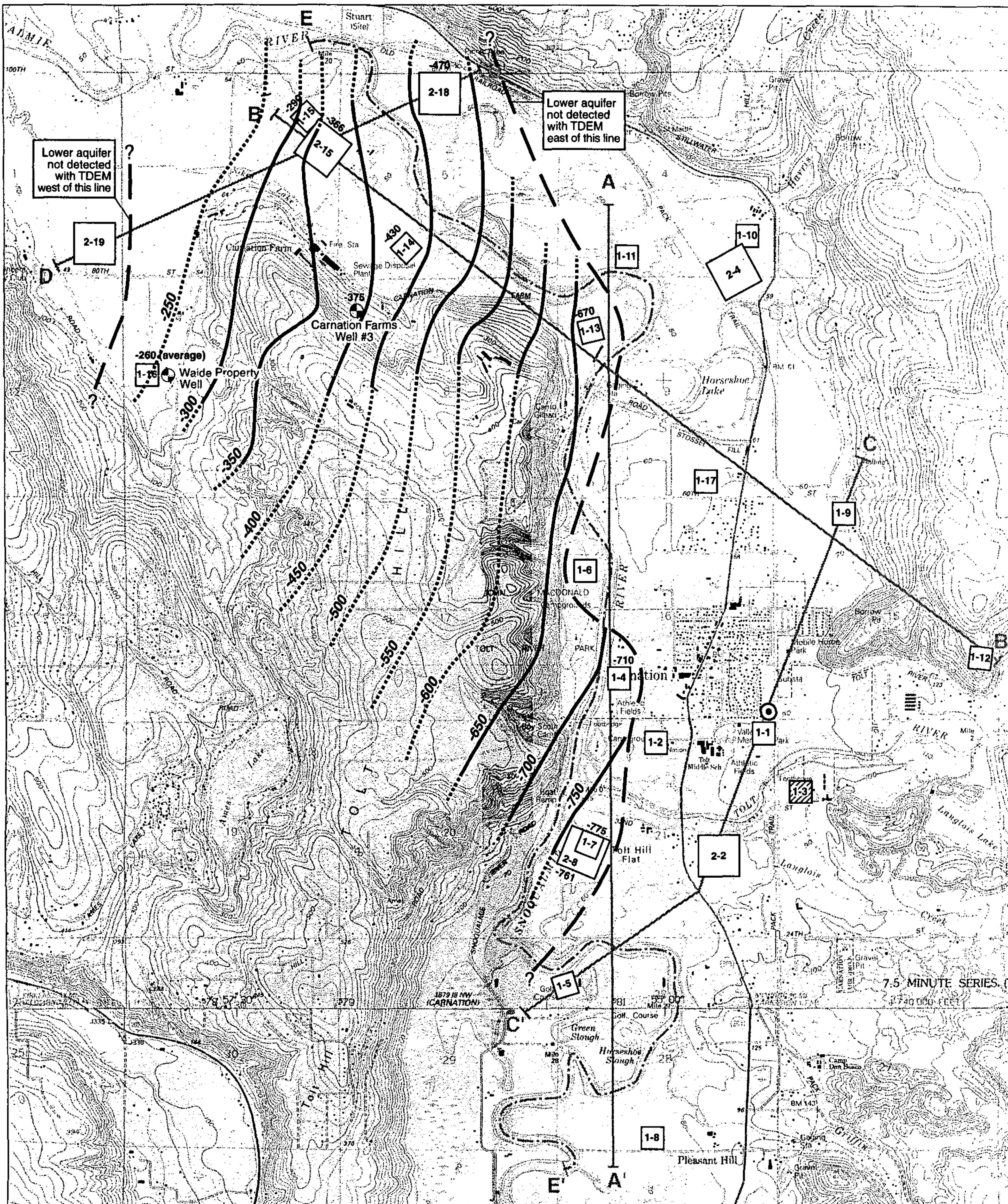
- A—A' Geo-electric cross section
- E—E' Marine seismic reflection trackline
- 1-6 100-meter TDEM sounding location and number, square indicates loop orientation
- 1-3 Data on this sounding not usable due to cultural interference from power lines
- 2-2 300-meter TDEM sounding location and number, square indicates loop orientation
- Existing well used as calibration for TDEM soundings
- Test well site (Loutsis Park, Carnation)
- 200 Elevation contour. Contour interval=50 ft. Dashed where inferred

NOTES

Numbers next to TDEM Loop symbols are elevations in feet above mean sea level for base of contoured unit.

0 2500
FEET

FIGURE **6.18.**
ELEVATION MAP OF BASE OF UPPER AQUIFER BASED ON TDEM SURVEY



LEGEND

- A — A' Geo-electric cross section
- E — E' Marine seismic reflection trackline
- 1-6 100-meter TDEM sounding location and number, square indicates loop orientation
- Data on this sounding not usable due to cultural interference from power lines
- 2-2 300-meter TDEM sounding location and number, square indicates loop orientation
- Existing well used as calibration for TDEM soundings
- Test well site (Loutsis Park, Carnation)
- 400 Elevation contour. Contour interval = 50 ft. Dashed where inferred.

NOTES

Numbers next to TDEM Loop symbols are elevations in feet above mean sea level for top of contoured unit.

0 2500
FEET

FIGURE **6.19.**
ELEVATION MAP OF TOP OF LOWER AQUIFER BASED ON TDEM SURVEY

EKC Figure 619.fh3 6/96 kjm

FIGURE 6.20.
INTERPRETED SEISMIC CROSS-SECTION E-E' WITH TDEM SOUNDINGS

C:\ADCADD\CIVIL\P\9531100\100\63548 10-24-95 18:56 xrf: NONE

Tables

Supplement I

Area Characterization

Tables

Draft

East King County
Ground Water Management Plan

July 1996

Table 4.1. Ranges of Suspended Solids and Heavy Metals Detected in Stormwater, 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

Source: National Urban Runoff Program

Table 4.2. Cedar Falls Landfill Ground Water Quality Sampling Results

Analyte	Site ID	Sample Date	Sample Value	Standard Exceeded	Standard Limit
Arsenic (mg/L)	MW-2	11/29/94	0.002	SGW	0.00005
	MW-4	12/1/94	0.003	SGW	0.00005
	MW-7	11/28/94	0.018	SGW	0.00005
Iron (mg/L)	MW-5	11/30/94	0.88	F2, SGW	
Manganese (mg/L)	MW-4	12/1/94	0.23	F2, SGW	
	MW-5	11/30/94	1.58	F2, SGW	
	MW-7	11/28/94	3.54	F2, SGW	
Acetone (ug/L)	MW-8A	11/28/94	8.12B		
	MW-MB	11/28/94	10.3		
Benzene (ug/L)	MW-4	12/1/94	0.2		1.0 ug/L SWG
	MW-7	11/28/94	0.4		
1,1-Dichloroethane (ug/L)	MW-5	11/30/94	0.24		1.0 ug/L SWG
	MW-7	11/28/94	0.39		
1,2-Dichloroethane (ug/L)	MW-2	11/29/94	0.22		0.5 ug/L SWG
	MW-5	11/30/94	0.32		
	MW-TRP	11/25/94	0.2		
cis1,2-Dichloroethene (ug/L)	MW-7	11/28/94	0.35		0.1mg/L SWG
Toluene (ug/L)	MW-4	12/1/94	0.96		1.0 mg/L SWG
	MW-7	11/28/94	0.21		
Xylenes, total (ug/L)	MW-4	12/1/94	0.54	SWG	12.8 ug/L

Table 4.3. Registered Operational Underground Storage Tanks in the East King County Ground Water Management Area by Washington Dept. of Ecology

Site Name/Address	Substance	Tank Size	Age
C.Y.O. Camp /Don Bosco 1401-327th Ave NE Carnation 98014-5905	Leaded Gas	111-1100 Gallons	20 Operational
Carnation Research Farm 28901 Carnation Farms Carnation 98014-8804	Unleaded Gas	2001-4999 Gallons	16 Operational
R.L.C. Timber Cutting Corp. 32317 NE 11th Carnation 98014-5901	Leaded Gas		12 Unresolved
Riverview School District 3805 Fall City-Carnation Carnation 98014-7502	Diesel Fuel Leaded Gas Leaded Gas Leaded Gas	10000-19999 Gallons 10000-19999 Gallons 111-1100 Gallons 111-1100 Gallons	13 Operational 13 Operational 13 Operational 13 Operational
Gehring Feed Co. 5721-320 NE Carnation 98014	Unleaded Gas Diesel Fuel	111-1100 Gallons 2001-4999 Gallons	15 Unresolved 15 Operational
Stillwater Store 9301 Carnation-Duvall Road Carnation 98014	Leaded Gas Unleaded Gas Unleaded Gas	10000-19999 Gallons 5000-9999 Gallons 5000-9999 Gallons	25 Operational 25 Operational 25 Operational
Texaco Food Mart Tolt Ave & Eugene Street Carnation 98014	Unleaded Gas Leaded Gas Unleaded Gas Diesel Fuel	10000-19999 Gallons 10000-19999 Gallons 10000-19999 Gallons 10000-19999 Gallons	3 Operational 3 Operational 3 Operational 3 Operational
Tolt Duvall Shops 13510 Carnation-Duvall Rd Duvall 98019-8208	Unleaded Gas	1101-2000 Gallons	32 Operational
Harding's Backhoe Bulldoz 14441 Carnation/Duvall Road Duvall 98019-8309	Unleaded Gas Diesel Fuel Used Oil/Waste	1101-2000 Gallons 1101-2000 Gallons 111-1100 Gallons	6 Operational 6 Operational 27 Exempt
Town Center Mini-Mart 15410 Main St. NE Duvall 98019-0000	Unleaded Gas Unleaded Gas Leaded Gas	10000-19999 Gallons 10000-19999 Gallons 10000-19999 Gallons	6 Operational 6 Operational 6 Operational
Duvall Central Office 15915 Snoqualmie Valley Duvall 98019	Diesel Fuel	1101-2000 Gallons	25 Operational
Eldon Neilson 19510 Monroe Rd NE Duvall 98019-9403	Diesel Fuel		11 Operational
Cottage Lake Rsu Bldg. Cottage Lake Duvall 98019	Diesel Fuel	111-1100 Gallons	8 Operational
Duvall Texaco 222 NW Main St. Duvall 98019	Leaded Gas Leaded Gas Kerosene Unleaded Gas Diesel Fuel Unleaded Gas	1101-2000 Gallons 1101-2000 Gallons 111-1100 Gallons 10000-19999 Gallons 10000-19999 Gallons 10000-19999 Gallons	15 Operational 15 Operational 15 Operational 15 Operational 15 Operational 15 Operational
Fall City Feed & Tack 33370 SE Fall City-Redmond Road Fall City 98024	Unleaded Gas Leaded Gas Unleaded Gas	111-1100 Gallons 111-1100 Gallons	29 Unresolved 29 Unresolved 29 Unresolved
Thomas M Berggren	Used Oil/Waste	111-1100 Gallons	11 Operational

Site Name/Address	Substance	Tank Size	Age
4211 Preston-Fall City Road	Leaded Gas	10000-19999 Gallons	15 Operational
Fall City 98024	Heating Fuel		11 Exempt
	Unleaded Gas	10000-19999 Gallons	11 Operational
	Unleaded Gas	10000-19999 Gallons	11 Operational
Fall City Market & Deli 3	Unleaded Gas	5000-9999 Gallons	16 Operational
4224 Preston-Fall City Rd	Unleaded Gas	5000-9999 Gallons	16 Operational
Fall City 98024	Unleaded Gas	10000-19999 Gallons	16 Operational
Fall City	Unleaded Gas	10000-19999 Gallons	20 Operational
4341 Preston-Fall City Road			32 Operational
Fall City 98024		111-1100 Gallons	32 Operational
	Diesel Fuel	10000-19999 Gallons	20 Operational
Campbell Air Field	Aviation Fuel		20 Exempt
Sec 13 T24N Rte W Fall City 98024	Aviation Fuel		20 Exempt
Camp Mason Maintenance Site	Unleaded Gas	10000-19999 Gallons	17 Operational
I90,Mp42.29,Southside	Unleaded Gas	10000-19999 Gallons	17 Operational
	Diesel Fuel	10000-19999 Gallons	17 Operational
A E Downs Manufacturing	Leaded Gas	111-1100 Gallons	14 Closed
10400 Meadowbrook-North Bend			
Floyd's Complete Services	Unleaded Gas	2001-4999 Gallons	20 Operational
106 E. North Bend Way	Leaded Gas	10000-19999 Gallons	20 Operational
North Bend 98045-0095	Used Oil/Waste	111-1100 Gallons	20 Operational
	Unleaded Gas	10000-19999 Gallons	20 Operational
Frank Padavich	Unleaded Gas	5000-9999 Gallons	16 Operational
1130 E North Bend Way	Leaded Gas	5000-9999 Gallons	16 Operational
North Bend 98045-9416	Used Oil/Waste	111-1100 Gallons	16 Operational
	Unleaded Gas	5000-9999 Gallons	16 Operational
	Unleaded Gas	2001-4999 Gallons	16 Operational
Cascade Autovon Company	Diesel Fuel	5000-9999 Gallons	1 Operational
12727 412th Av. SE			
North Bend 98045-9416			
Telephone Utilities of WA	Diesel Fuel	111-1100 Gallons	25 Operational
131 2nd St. East North Bend 98045			
Cascade Golf Course	Leaded Gas	111-1100 Gallons	11 Closure
14304 436 Ave SE			
North Bend 98045-9666			
Edgewick Village Gas & Deli	Unleaded Gas	10000-19999 Gallons	2 Operational
14420 468th SE	Diesel Fuel	10000-19999 Gallons	2 Operational
North Bend 98045-8762	Leaded Gas	10000-19999 Gallons	2 Operational
	Unleaded Gas	5000-9999 Gallons	2 Operational
Cedar Falls Headquarters	Diesel Fuel	1101-2000 Gallons	32 Operational
19901 Cedar Falls Rd SE	Unleaded Gas	1101-2000 Gallons	32 Operational
North Bend 98045-9681			
Alascom, Inc.	Heating Fuel	111-1100 Gallons	7 Operational
21209 SW 196th North Bend 98045			
George Wyrsch ARCO	Unleaded Gas	2001-4999 Gallons	20 Operational
225 E North Bend Way	Diesel Fuel	10000-19999 Gallons	8 Operational
North Bend 98045-0990	Diesel Fuel	10000-19999 Gallons	20 Operational
	Leaded Gas	10000-19999 Gallons	15 Operational
	Unleaded Gas	10000-19999 Gallons	8 Operational
	Unleaded Gas	2001-4999 Gallons	20 Operational
George Wyrsch ARCO (continued)	Unleaded Gas	10000-19999 Gallons	15 Operational

Site Name/Address	Substance	Tank Size	Age
	Leaded Gas	10000-19999 Gallons	15 Operational
	Used Oil/Waste	111-1100 Gallons	8 Operational
	Unleaded Gas	10000-19999 Gallons	15 Operational
North Bend Chevron	Unleaded Gas	10000-19999 Gallons	25 Operational
302 North Bend Way	Unleaded Gas	5000-9999 Gallons	25 Operational
North Bend 98045	Diesel Fuel	10000-19999 Gallons	25 Operational
	Leaded Gas	10000-19999 Gallons	25 Operational
City of North Bend	Diesel Fuel	111-1100 Gallons	15 Operational
400 Northbend Blvd. N. 98048			
Seattle East 76/Truck Tow	Diesel Fuel	10000-19999 Gallons	15 Operational
46600 SE North Bend Way	Diesel Fuel	5000-9999 Gallons	15 Operational
North Bend 98045-9730	Used Oil/Waste	1101-2000 Gallons	15 Operational
	Unleaded Gas	10000-19999 Gallons	15 Operational
	Diesel Fuel	10000-19999 Gallons	15 Operational
	Diesel Fuel	5000-9999 Gallons	15 Operational
	Unleaded Gas	5000-9999 Gallons	15 Operational
	Diesel Fuel	5000-9999 Gallons	15 Operational
	Unleaded Gas	10000-19999 Gallons	15 Operational
Dept. of Comm. Development	Unleaded Gas	5000-9999 Gallons	9 Operational
50810 Se Grouse Ridge Rd	Used Oil/Waste	10000-19999 Gallons	9 Operational
North Bend 98045-1273	Unleaded Gas	10000-19999 Gallons	9 Operational
	Used Oil/Waste	2001-4999 Gallons	6 Operational
	Unleaded Gas	5000-9999 Gallons	9 Operational
	Unleaded Gas	111-1100 Gallons	8 Operational
	Unleaded Gas	5000-9999 Gallons	9 Operational
	Diesel Fuel	2001-4999 Gallons	8 Operational
	Diesel Fuel	111-1100 Gallons	8 Operational
	Diesel Fuel	5000-9999 Gallons	6 Operational
Paul Bunyan Market	Unleaded Gas	5000-9999 Gallons	3 Operational
520 E North Bend	Unleaded Gas	10000-19999 Gallons	3 Operational
Way North Bend 98045	Leaded Gas	5000-9999 Gallons	3 Operational
George G Wyrsch	Unleaded Gas	10000-19999 Gallons	5 Operational
742 SW Mount Si Blvd.	Diesel Fuel	10000-19999 Gallons	4 Operational
North Bend 98045-0990	Unleaded Gas	10000-19999 Gallons	5 Operational
	Leaded Gas	10000-19999 Gallons	5 Operational
G & S Services	Unleaded Gas	10000-19999 Gallons	5 Operational
745 SW Mount Si Blvd.	Unleaded Gas	10000-19999 Gallons	5 Operational
North Bend 98045-0990	Diesel Fuel	10000-19999 Gallons	5 Operational
	Leaded Gas	10000-19999 Gallons	5 Operational
Mountain Tree Farm Co.	Diesel Fuel		37 Unresolved
T23N R/E Sec34 SE 1/4	Leaded Gas		37 Unresolved
North Bend 98045	Diesel Fuel		32 Unresolved
Town Pump and Grocery			32 Closed
122 Railroad Ave	Leaded Gas	10000-19999 Gallons	15 Operational
Snoqualmie 98065	Unleaded Gas	10000-19999 Gallons	15 Operational
		5000-9999 Gallons	32 Operational
	Unleaded Gas	5000-9999 Gallons	20 Operational
		5000-9999 Gallons	32 Operational
Snoqualmie Valley Hospital	Diesel Fuel	10000-19999 Gallons	11 Operational
1505 Meadowbrook Way Se			
Snoqualmie 98065-9535			

Site Name/Address	Substance	Tank Size	Age
City of Snoqualmie	Leaded Gas	5000-9999 Gallons	20 Temporary
208 Railroad Ave Snoqualmie 98065	Unleaded Gas	5000-9999 Gallons	20 Temporary
210 River St. Snoqualmie 98065	Unleaded Gas		11 Operational
	Diesel Fuel	111-1100 Gallons	8 Operational
Snoqualmie Valley School	Leaded Gas	10000-19999 Gallons	37 Closed
211 Silva Street	Diesel Fuel	111-1100 Gallons	25 Closure
Snoqualmie 98065	Used Oil/Waste	111-1100 Gallons	20 Closure
	Leaded Gas	111-1100 Gallons	25 Closure
DSHS Echo Glen Children's	Diesel Fuel	111-1100 Gallons	15 Deferred
33010 SE 99th St.	Diesel Fuel	111-1100 Gallons	26 Operational
Snoqualmie 98065-9797	Used Oil/Waste	111-1100 Gallons	15 Operational
	Unleaded Gas	5000-9999 Gallons	25 Operational
Mount Si Golf Course, Inc. 9010 Meadowbrook-North Bend Snoqualmie 98065-2020	Unleaded Gas	111-1100 Gallons	11 Operational
Shultz Distributing Inc. 9040 Meadowbrook Rd NE Snoqualmie 98065	Other	111-1100 Gallons	20 Temporary
Snoqualmie Summit Ski Area	Leaded Gas	1101-2000 Gallons	14 Operational
State Road 902 Snoqualmie 98068	Diesel Fuel	1101-2000 Gallons	14 Operational
	Diesel Fuel	111-1100 Gallons	24 Exempt
	Diesel Fuel	111-1100 Gallons	31 Exempt
	Diesel Fuel		19 Exempt
	Leaded Gas	2001-4999 Gallons	29 Operational
	Diesel Fuel	10000-19999 Gallons	19 Exempt
	Diesel Fuel	111-1100 Gallons	24 Exempt
	Diesel Fuel	2001-4999 Gallons	29 Operational
Preston Maintenance Facility	Unleaded Gas	2001-4999 Gallons	2 Operational
29726 SE Preston Way	Diesel Fuel	2001-4999 Gallons	2 Operational
Preston 98050	Diesel Fuel	2001-4999 Gallons	2 Operational
Preston General Store, Inc.	Leaded Gas	5000-9999 Gallons	6 Operational
30365 SE High Point	Diesel Fuel	5000-9999 Gallons	6 Operational
Way Preston 98050-9999	Unleaded Gas	10000-19999 Gallons	6 Operational
	Unleaded Gas	10000-19999 Gallons	6 Operational

Table 4.4. Age of Underground Storage Tanks in Operation in the East King County Ground Water Management Area.

Age of Tank (years)	Number of Tanks
1-2	9
3-5	15
6-10	25
11-15	43
16-20	32
21-30	22
Greater than 30	13
Total:	**159**

Source: Washington Department of Ecology 1994.

Table 4.5. Substances contained in Underground Storage Tanks in operation in the East King County Ground Water Management Area.

Substance	Number of Tanks
Leaded gas	30
Unleaded gas	61
Diesel fuel	45
Kerosene	1
Used/waste oil	10
Aviation Fuel	2
Heating Fuel	2
Unknown	8
Total	**159**

Source: Washington Department of Ecology 1994.

Table 4.6. Size of Underground Storage Tanks in the East King County Ground Water Management Area.

Size(gallons)	Number of Tanks
111-1,110	30
1,101-2,000	11
2,001-4,999	17
5,000-9,999	28
10,000-19,999	59
Unknown	14
Total:	**159**

Source: Washington State Department of Ecology 1994.

Table 4.7. The Washington State Department of Ecology Current and Former Contaminated Leaking Underground Storage Tank (LUST) Sites in East King County Ground Water Management Area, November 2, 1994.
(See Figure 4.4. for site location in the East King County Ground Water Management Area)

Site Name	Address	City	Zip	Cleanup Status[a]-Media[b]
1) WDOT Snoqualmie Right of Way	SR 202 & Meadowbrook Way	Snoqualmie		In Progress - A, D
2) WDOT Camp Mason Maintenance	I90,MP42.29,Southside	North Bend		In Progress - D
3) Fred's Automotive	4721 Tolt Ave	Carnation		In Progress - D
4) Gull Station # 0283	Tolt Avenue and Eugene Street	Carnation	98014	Conducted - D
5) Chevron Station # 9-0709	4211 Preston-Fall City Road	Fall City	98024	In Progress - A
6) Chevron Station North Bend	302 North Bend Way	North Bend	98045	In Progress - D
7) DNR North Bend	205 Ballaret	North Bend	98045	Conducted - D
8) Pacific Telecom	131 2nd Street East	North Bend	98045	Conducted - D
9) M C Anderson Trucking	44711 SE North Bend Way/P.O.	North Bend	98045-0354	Conducted - D
10) Cascade Autovon Co.	12727 412th Ave SE	North Bend	98045-9416	Conducted - D
11) Seattle Water Dept. Cedar Falls	19901 Cedar Falls Road SE	North Bend	98045-9681	In Progress - D
12) Seattle City Light N. Bend	20022 Cedar Falls Road SE	North Bend	98045-9681	In Progress - D
13) Weyerhaeuser Snoqualmie	38800 SE Millpond Road	Snoqualmie	98065	Awaiting - A,D
14) Snoqualmie City Hall	210 River Street	Snoqualmie	98065	In Progress - D
15) Snoqualmie Valley School District.	211 Silva Street	Snoqualmie	98065	Conducted - D

[a]Cleanup Status Legend:

Conducted = Ecology received final independent action cleanup report - no further action
Awaiting = Ecology not aware of any remedial action and cleanup necessary. Owner may have done cleanup but has not reported it to Ecology. Ecology prioritized these sites on priority (if impacts to human health and ground water).
Monitoring = Sites where cleanup has occurred and monitoring is ongoing. As the results are near cleanup levels, site is monitored for a year.
In Progress = Site cleanup in progress/on-going.

[b]Media Legend:

A = Ground Water
D = Soil

Table 4.8. Sand & Gravel Mining Operations in East King County Ground Water Management Area (See Figure 4.5. Sand and Gravel Mining Operations Sites)

	Permit Number/Parcel Number	Site Name, Taxpayer or Owner	Location/Size
1	10466	Novelty Hill, Jim Reid	Sec 6 T25N R7E
2	11047	Raging River-Cadman, Rod Shearer	Sec 22 T24N R7E, 46+ acres
3	11071	Cadman-Ben Jones, closed and reclamation proceeding	Sec 23 T25N R7E
4	11275, 0425078045, 0425079042	Cadman-Stillwater Pit-Gooch or Redmond Pit, King County Public	Sec 4 T25N R7E, 17.94 acres
5	11283	Cadman-Buse	Sec 4 T25N R7E
6	11319/3425073112	East Side Sand & Gravel, L.A. Welcome	Sec 34 T25N R7E, 23.67 acres
7	11310	Mt. Si Quarry-Tom Weber	Sec 5 T23N R8E
8	12490/2326069002	Horizon Trucking/Chapman Pit	Sec 23 T26N R6E, West of Duvall, 77.24 acres
9	12558/2024089017, 202489020, 20224089099, 1924089001, 2024089003, 2024089016, 2024089018, 2024089034, 2024089071, 2024089072, 2024089075, 2024089080, 2024089091, 2024089092, 2024089093, 2024089095	Weyerhaeuser Co. (Operator NW Aggregate), Leroy Gmazel, David M. Sims, Robert E+Florence B Vezzoni, Trina & Steve Parsons, Richard Charles, Heidi A Cox, Dixie L Quinn, Terrance Wilson	Sec 20 T24N R8E; approximately 665 acres current primary zoning RA5 with one RA10 and one MP and two IP
10	12662/0826079022 and 1726079027	DuMor S&G,	Sec 17, 18 T24N R7E/ 12.86 acres
11	1524079006	King County Public Works Pit No. 32	In town of Fall City off SE 44th Street
12	09230890xx	King County Public Works Pit No. 58	North Bend in town block 3, lot 2; Active Stockpile; Maintenance Facility
13		King County Public Works Pit No. 69	Old Woodinville-Duvall Rd NE 175th St. and 228th Ave NE
14	1024079027	King County Public Works Pit No. 77	10466
15		King County Public Works Pit No. 83	E. of N. Bend, M. Fork Rd.
16	0626079034	Edward W Hayes	8.3 ac. RA10, pot mine site
17	0626079032	Edward W Hayes	83.23 ac.zoned MP
18	826079020,1726079020	Robert Thompson+Amber D.	Pot. Mine, RA 10, 11.23 ac.

	Permit Number/Parcel Number	Site Name, Taxpayer or Owner	Location/Size
19	826079022,1726079027	Du Mor Sand & Gravel; Robert J. Thompson; owner: James Margan	12.86 zoned mine
20	1526079001	State of Washington	320 ac., RA 10 and RA 5, potential mine
21	2326079001	King County Public Works, Swan Quarry	75.55 ac., RA 5/RA 10, potential mine site
22	2226069004,2226069054	Alberg, Thomas A.	39.91 ac., RA 10P, a potential mine site
23	3126079007, 3126079008, 3126079011, 3126079039, 3126079040, 3626069013	Alberg, Thomas A.	117.2 ac., RA10/A35, potential mine site
24	2225079028	King County Public Works, Tolt River	Currently Inactive
25	3425079078	Welcome LA	4.52 ac., A10, pot. mine site
26	0224079001; 3224079001; 1124079001; 2625079010; 2725079003; 3425079008; 3425079012; 3425079014	Weyerhaeuser Co.	2077 ac.; parcels zoned potential mine 622 ac. currently forestry lands
27	1624079010	King County Public Works - Hoover	80 ac.; Active Stockpile; Grading Permit Pending; Approved NCU
28	2124079015	King County Public Works - Raging River	40 acres currently zoned RA10, potential mine site
29	1324079108, 1324079109, 1324089001, 1324089002, 1324089016, 1324089005, 1324089031	Micheal J & Sandra Riley, Lawrence H Everett, Weyerhaeuser Co., Robert F. Hamerly	370.5 acres currently zoned primarily RA10 and RA5 with two parcels UR, all are potential mine sites.

Source: the Department of Natural Resources and the King County Comprehensive Plan.

□

Table 4.9. U.S. Environmental Protection Agency Resource Conservation and Recovery Act Hazardous Waste Generators List (Submitted by Facility)

	Facility Name and Location	Generator Type
1	Carnation Farms 28901 NE Carnation Farms Rd Carnation, WA	Small Quantity Generator
2	Carnation Printing, Inc. 528 NW Main Duvall, WA	Small Quantity Generator/Transporter
3	Casey's Coachworks 164 Meadowbrook Avenue Snoqualmie	Small Quantity Generator
4	Echo Glen Children's Center 33010 SE 99th St. B19 thru B41 Snoqualmie	Small Quantity Generator
5	Gary's Magic Prolube 4721 Tolt Ave. Carnation, WA	Small Quantity Generator
6	King County Public Works Stossel Bridge NO NE Carnation Farm Rd. Carnation, WA	Small Quantity Generator
7	King County Public Works Shop 208 Railroad Ave. North Snoqualmie, WA	Conditionally Exempt
8	Loveland Chevrolet 106 Main St. North Bend, WA	Small Quantity Generator
9	Cty. Seattle, Watershed Mgmt. 19901 Cedar Falls Road SE North Bend	Large Quantity Generator
10	Shultz Dist., Inc., North Bend Bul 9120 Meadow Brook Rd SE North Bend	Small Quantity Generator
11	Snoqualmie Sand & Gravel 5601 396th Dr. SE Snoqualmie, WA	Conditionally Exempt
12	Snoqualmie Valley SD 46837 SE Middle Fork Rd. North Bend	Small Quantity Generator
13	Snoqualmie Valley SD Bus Garage 211 N. Silva Snoqualmie, WA	Small Quantity Generator
14	Tanner Electric COOP 45710 SE North Bend Way North Bend	Conditionally Exempt
15	Texaco Station 63 232 0274 Tolt & Eugene St. Carnation, WA	Small Quantity Generator
16	Tolt High/Middle School 3740 Tolt Ave. Carnation, WA	Small Quantity Generator
17	Tolt Regulating Basin T26N/R08E Sect.28 Duvall, WA	Small Quantity Generator
18	US Navy Undersea Warfare Eng. St. 50810 SE Grouse Ridge Rd North Bend	Large Quantity Generator
19	USWCOM North Bend Toll Office 12805 412th Ave. SE North Bend, WA	Large Quantity Generator
20	USWCOM Rattlesnake TD2 Radio 12 miles SW of Cty. North Bend, WA	Large Quantity Generator
21	Walmsley, Kevin E. T26N/R7E Sect. 16 Duvall, WA	Large Quantity Generator
22	Washington State Fire Training Center 50810 SE Grouse Ridge Rd. North Bend	Large Quantity Generator
23	WDOE NRO Ames Lake Road Waste 6412 Ames Lake Road Carnation, WA	Small Quantity Generator
24	WDOE NRO Carnation Drum 10909-298th Avenue NE Carnation, WA	Large Quantity Generator

	Facility Name and Location	Generator Type
25	WDOE NRO Duvall Dump Barrels 308th Avenue NE (left side 150 yards) Duvall, WA	Small Quantity Generator
26	WDOE NRO Echo Glen Drug Laboratory 200 yards south of intersection SE 96th Snoqualmie	Small Quantity Generator
27	WDOE NRO Fall City Drug Laboratory 5003 325th Place SE Fall City, WA	Large Quantity Generator
28	WDOE NRO Fall City Fire Department 4301 334th Place SE Fall City, WA	Conditionally Exempt
29	WDOE NRO North Bend Truck Stop NE Corner of intersection SE 146th St. North Bend	Small Quantity Generator
30	WDOE NRO Olympus Job 91 3593 S. Side 101st St. North Bend, WA	Not a UO Recycler, Verified
31	WDOE NRO Snoqualmie Falls Waste Bottom of Snoqualmie Falls Snoqualmie	Small Quantity Generator
32	WDOE NRO Tokul Wildlife Paint 37501 SE Fall City Fall City, WA	Conditionally Exempt
33	WDOE NRO 292nd Abandoned Drum Pub 292nd Ave NE 0.5 mi. N. of SE 8th Fall City	Small Quantity Generator
34	WDOE NRO 384th Street Drum 384th Street & HWY. 202 Snoqualmie	Small Quantity Generator
35	WDOT Camp Mason UST SR I-90 mile point 42.29	Small Quantity Generator
36	Weyerhaueser Co. Snoqualmie Plywood 7001 396th Avenue Southeast Snoqualmie	Conditionally Exempt

Table 4.10. Contaminated Sites Registered with the Washington State Department of Ecology

SITE NAME - ADDRESS	SITE TYPE - CONTAMINANTS
C and F Auto Wrecking 29017 NE Big Rock Road Duvall, WA 98019	Toxic Cleanup Program (TCP) Ranked, awaiting Remedial Action Soil, Sediment, Surface Water-Confirmed Air, Ground/Drinking Water-Suspected Confirmed Halogenated Organo Compounds Confirmed Petroleum Products Suspected Non Halogenated Solvents
Cedar Falls Landfill 16901 Cedar Falls Rd. SE North Bend, WA 98045	TCP site, Awaiting Assessment Confirmed Ground Water Contamination by Halogenated Organic Compounds, Organic Contaminants (BOD, COD, TOC), Inorganic Contaminants (Cl, S, N, pH, conductivity, Hardness, Alkalinity)
Dan's Auto Repair 9301 Carnation Duvall Rd NE Carnation, WA 98014-6706	TCP site, Awaiting Assessment Confirmed Soil, Suspected Ground Water, Sediment, and Surface Water Contamination. Halogenated Organic Compounds Suspected, Priority Pollutants (Sb, As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Tl, Zn, CN-), Petroleum Products, Non-Halogenated Organic.
Duvall Landfill 22905 Old Woodinville/Duvall Duvall, WA 98019	TCP site, Awaiting Assessment Surface Water-Confirmed, Ground Water. and Soil-Suspected Halogenated Organic Compounds, EPA P.P., Non-Halogenated Organic Solvents
Griffith Property 19 West Griffin Creek Rd Carnation, WA 98014-5707	TCP site, Awaiting Assessment Soil-Confirmed, Drinking/Ground Water-Suspected, Soil and Surface Water-Suspected, EPA P.P., Non-Halogenated Solvents Confirmed in Soil, Suspect in others.
Puget Sound Railway Hist. Kimball Creek/SR Hwy 202 Snoqualmie, WA 98065	TCP site, Independent Remedial Action As of July 13, 1995 the site remains on the TCP list because Ecology has not received a final closure report.
Shultz Distributing 9120 Meadowbrook Rd. SE	TCP site, Independent Remedial Action Ground Water-Confirmed, Drinking Water, Sediment, Soil, and Surface Water-Suspected Contamination Petroleum Products
Weyerhaueser/Snoqualmie Mill 7001 396th Dr. SE Snoqualmie, WA 98065	TCP site, Independent Remedial Action-Confirmed Sediment, Soil, Surface Water and Suspected Drinking Water and Ground Water Contamination: EPA Priority Pollutants, Petroleum Products, Non Halogenated Organic Solvents, BOD, COD, TOC

Table 5.1. Group A/Group B Breakdown from Drinking Water Database

SYSNAME	ST_ID_NUM	CURRENTCON	POPULATION
A B-C-D-E	00438D	4	10
ALDARRA FARMS	00885N	8	20
IRONS WATER	122517	3	8
ANDERSON WATER SYSTEM	130619	9	23
ANDERSON, DAVID	03593P	2	5
ANDERSON, WAYNE	150916	2	5
ANDERSON/BYNUM	445676	9	23
AYCOCK-WRIGHT (WICKHAM)	14557U	2	5
BAR-O	018591	3	8
BARKER-BURNITE	64831R	4	10
BARRON, L.	043838	7	18
BECKENBAUGH, L.	166027	4	10
BENDAWALD-FALL CITY	22299D	2	5
BEUTEL, T.J.	33197B	2	5
FOWLER/MONTY WATER	061243	2	5
BRAMMER	245632	4	10
BRIGGS BOYS COMMUNITY WATER	00143P	2	5
BRILL	13094L	3	8
BROOKSIDE COMMUNITY WELL	223013	6	15
BROWN, RANDY	08813B	5	13
BTH-LAKE ALICE WATER WORKS	20399D	3	8
BUSE, GENE	09870D	2	5
C.H.E.C.	23553Q	3	8
CAMPBELL-JOULE	17601R	2	5
CARLIN, H.	24666Q	3	8
EVERETT/CULLITON WATER	11164U	2	5
CARMEL WATER	64976H	2	5
CERNICK WATER SYSTEM	021723	3	8
CHERRY VALLEY RANCH WATER SYST	10928U	7	18
CHERRY VALLEY WATER ASSOCIATIO	57688K	8	20
CHOUINARD WATER ASSOCIATION	64268C	5	13
CHRISTMAS CREEK #1	618133	9	23
CIRCLE RIVER RANCH SUPPLY #1	03143W	6	15
CLARK-GRASSIT WATER SYSTEM	133415	3	8
CLEVELAND MEMORIAL FOREST	136509	1	5
CONNERS-CHERRY GARDENS	25526M	4	10
CORVINO	06714L	2	5
CORVINO, E.	336044	3	5
COYOTY POINT	36084L	6	15
CRITTENDEN-PRESTON II	159011	2	5
WINSTON WATER	26088M	3	8
DAVIS WATER SYSTEM	01495F	6	15
DAVIS, MAISIE	700300	6	15
DEEP ROCK	18395U	7	18
DENNEY, T.	18814W	2	5
DIAMOND R-FALL CITY COMMUNITY	00920N	2	5
DICKMAN WATER WORKS	42865D	3	8

Table 5.1. Group A/Group B Breakdown from Drinking Water Database (continued)

SYSNAME	ST ID NUM	CURRENTCON	POPULATION
DISTINCTIVE WATER SYSTEM	39767Q	4	10
DON BROWN WATER	64514D	2	5
DUMAS	00758A	2	5
DUVALL MEADOWS	24864Y	9	23
EADIE, GARY	571039	9	23
EAST LAKE ALICE WATER SYSTEM	19121R	9	23
EAST MITCHELL HILL	52489H	6	15
EBNER, JACK WATER	35094T	2	5
EDGEWATER WELL	061011	5	13
EDWARDS, S.	22570M	2	5
ELDERBERRY BEACH ESTATES	44821E	7	18
ERICH WATER SYSTEM	64301B	3	8
FAR OUT WATER SYSTEM	002976	5	13
FERN RIDGE ESTATES WATERWORKS	286515	6	15
FONG KOO WATER	14651V	6	15
FONS WATER SYSTEM	06746D	2	15
FREASE, M. (FOREST HILL)	26430Q	6	23
FURY WATER ASSOC.	26156Y	4	10
GARDEN HILL WATER	062669	8	20
GEHRING/EUSCHER	14647P	2	5
GEORGE, P.	160348	4	10
GEORGEFF, J.	27415V	3	8
PARKER, GLEN (GLENACRES)	66180R	9	23
GLENORA	44322A	4	10
GOLD HILL WATER SUPPLY	380647	3	8
GOOCH-DUVALL	360073	5	13
GOOCH-NE 155	45040F	6	15
GOOD NEIGHBORS COMMUNITY WELL	014013	4	10
GRANDRIDGE	28850W	3	8
GREENE, JACK	360643	2	5
PINORINI, H. WATER	30124T	6	15
GUNTHER	24647Q	2	5
HABAERKORN	21201W	2	2
HALL WATER SYSTEM-LAKE JOY	00970Y	5	8
HARDER WATER SYSTEM	645277	2	5
HARRIS CREEK	06305B	5	13
HARRIS WATER-FALL CITY	66123R	3	8
HAVEKOST WATER SYSTEM	311513	2	5
HEGGEN	322601	2	5
HENGTGEN #1	323858	8	20
STOSSEL CREEK COMMUNITY WATER ASS'N	32386R	9	23
HIGH VALLEY WELL	35090Q	3	8
HILLWOOD WATER SYSTEM	009741	3	8
HOLTZNER, B.	338999	4	10
HUMPHREY, R.	34858T	8	20
JOHNSON WELL-FALL CITY	17592F	2	5
JOHNSON, PETER COMMUNITY SYSTEM	12175N	8	20

Table 5.1. Group A/Group B Breakdown from Drinking Water Database (continued)

SYSNAME	ST_ID_NUM	CURRENTCON	POPULATION
KAHN, L.	23451K	2	5
KELLY ROAD WATER SYSTEM	37949C	4	10
KENYON, R.	005392	4	10
KISER #2 COMMUNITY WATER SYST	00017V	2	5
KLINT, W.	428302	4	10
LAKE JOY #1	53745V	4	10
KURTS WATERWORKS	006101	6	15
KUTZER-SNOQUALMIE	22764P	3	8
LAKE ALICE PLATEAU	37976L	8	20
LAKE ALICE WATER SYSTEM #1	21864R	5	13
LAKE CREEK	377518	3	8
LAKE JOY #2	64911C	6	15
LAKEY, B.	45560M	4	10
LAWRENCE, F.	463907	2	5
LEE WATER	20314R	5	13
LELAND & FINE	154716	2	5
GREY GHOST LAND TRUST WATER	47381J	3	8
LINK, D. WATER	10207W	6	15
LIVING WATER CO-OP	03361M	3	8
LYNCH, L.	33861C	6	15
MARSHALL	25933V	2	5
ADCOX & STODDARD	51880A	2	4
GELLNER-AINGE WATER	00421J	3	8
MASON-HAYWARD	05936B	2	5
MAYFAIR PLACE HOMEOWNERS	237216	8	20
MCCABE / ROLOSON	191311	9	23
MCCLOSKEY	02018H	4	10
MCFADDEN, F. WATER	523420	2	5
MCINTOSH	49940W	3	8
MCJUNKIN	64694L	2	5
MIDDLE FORK WOODLANDS	52886F	3	8
MITCHELL HILL NORTH	290561	4	10
MOON VALLEY	00651K	7	18
MAYFAIR WATER ASSOCIATION	35244R	6	15
MT. SI GYPSY COMMUNITY WATER	00570E	6	15
NELSON/SARGENT	004433	3	8
NIELSON COMMUNITY WATER	002195	2	5
NOVELTY HILL ESTATES	59264L	8	20
ORCHARD VIEW AUTO CAMP	641308	7	18
OUILLETTE	65038D	4	10
P.I.A.	00689F	2	5
PACECCA	25139X	3	8
PARK LAKE	66170H	9	23
PARK LAKE SPECIAL #1	618009	7	18
PECK #2	59051J	4	10
PECK, J.	310762	3	8
PLEASANT HILLS FARMS	678607	6	13

Table 5.1. Group A/Group B Breakdown from Drinking Water Database (continued)

SYSNAME	ST_ID_NUM	CURRENTCON	POPULATION
REED WATER SYSTEM	02168X	5	13
RENNAKER-EVANSON WELL	00565R	2	5
RESIDENT	31741L	7	18
REZNICK, G.	001550	2	5
RICE, WILLIAM R.	024015	2	5
JAMES, D. & D.	73157E	2	5
ROCK	61961F	2	5
ROCKY RIDGE	39754X	8	20
RUSSELL WATER SYSTEM	10601A	5	13
SAUVAGE	175405	3	8
SCHMELZER WATER SYSTEM	00973H	4	10
SCHNEIDER WATER SYSTEM	767309	3	8
SCHNEIDER, K.	76716V	2	5
SEAMAN C R	07815A	3	8
SHIVELY WATER SYSTEM	641770	2	5
SMITH & SMITH	000422	2	5
SMITH, ALGOT	01051V	2	5
SMITH-RUSNAK	35688C	3	8
SMITTY'S INC.	80770Y	4	10
SNOQUALMIE SAND AND GRAVEL	009192	1	5
SNOQUALMIE VALLEY LAND CO.	81073N	2	5
SOUTH FORK WATER SYSTEM	01245X	3	8
SPARKS, W.	304771	5	13
SPRING HILL II	64071R	8	20
STRUGAR, ROBERT	175761	3	8
SUNRISE ROAD & WATER ASSN.	093909	9	23
SUTTON WELL	61967K	4	10
SWAN, J.	01301Y	2	5
TARR/TUINSTRA	871860	3	8
TAYLOR, TAYLOR, VINEY-CASADY	00231J	3	5
THOMPSON-ROY WATER SYSTEM	00041J	2	5
TINELL WATER SYSTEM	14541F	4	10
TOKUL CREEK HATCHERY	886202	3	8
TOKUL PLATEAU	062793	4	13
TOLT RIVER CHALET TRACTS	88670B	9	23
TOLT RIVER ESTATES	576917	6	15
MASTENBROOK/HAFFORD	64501L	2	5
TOUCHSTONE, LEW	014390	2	2
TOVEY	29612P	2	5
TRAVIS, P.	213119	2	5
TREISMAN-CRUMBLEY	379310	4	10
UPLANDS II WATER	00809N	3	5
UPTON-LAKE ALICE	01586V	6	15
VALLEY VIEW-NORTH BEND	04276D	10	25
VAN OEVEREN	55076C	2	5
VENABLES WATER SYSTEM	119765	3	8
WADDINGTON PUBLIC SUPPLY, THE	619261	3	8

Table 5.1. Group A/Group B Breakdown from Drinking Water Database (continued)

SYSNAME	ST_ID_NUM	CURRENTCON	POPULATION
WADE WATER SYSTEM	64190W	6	15
WAKEFIELD/STILLWATER	30411C	3	8
WALKER, WALTER WATER WORKS	202767	6	15
WALLACE FARMS	014516	5	13
WAUGAMAN	93740D	2	5
WEPPLER	11981U	3	8
WEST LAKE ALICE WS #1	088898	9	23
WILSON-WILSON	17094V	2	5
WINGSNESS ACRES	00814B	5	13
WORLEY WATER SYSTEM	66126A	4	15
WOULF	53368D	2	5
WRIGHT WATER ASSOCIATION	38207F	4	10
ZUVER-SIMONSON	25479B	2	5
ZYLSTRA/LAMPAERT MEATS	999001	2	5
HOFFMAN WATER WORKS	06421X	7	23
SNOQUALMIE FALLS FOREST THEATER	25955D	1	2
		843	2,159

Table 5.2. Summary of Ground Water Withdrawals[1] in 1990 by Water Use Category, Source, and Sub-area.

Water Use Category	Withdrawals (acre-feet per year) Sub-area: Upper Snoqualmie River Valley	Lower Snoqualmie River Valley	Total
Public supply			
Wells	745	635	1,380
Springs	1,540	433	1,973
Domestic			
Wells	63	958	1,021
Springs	nr [2]	nr	nr
Crop irrigation			
Wells	nr	267	267
Springs	nr	262	262
Non-crop irrigation			
Wells	86	48	134
Springs	nr	12	12
Dairy livestock			
Wells	nr	243	243
Springs	nr	31	31
Other livestock			
Wells	.3	8.1	8
Springs	nr	4.0	4
Aquaculture			
Wells	nr	nr	nr
Springs	2,350	659	3,009
Industrial			
Wells	82	1.3	83
Springs	nr	nr	nr
Subtotal			
Wells	976	2,160	3,136
Springs	3,890	1,401	5,291
Total	**4,870**	**3,561**	**8,427**

Source: U.S. Geological Survey, 1995

1 Values are for the Ground Water Management Area (225 square miles), not the entire study area (259 square miles).

2 nr = no withdrawals reported

Table 5.3. Adopted Population Targets by Jurisdiction

Ground Water Mgmt Area	Acreage	Jurisdiction	Estimated Population Growth[a]	Current Population[a,b]	Estimated Future Population[a]
East King County	105,413	King County	2459 (1992-2012)[c]	11,811 (1993)	14,270 (2012)
		Duvall	1886 (1992-2012)[d]	1115	3001 (2012)
		Carnation	404 (1992-2012)[d]	505	909 (2012)
		North Bend/ Snoqualmie	4311 (1992-2012)[d]	1672	5983 (2012)
		TOTAL	9060	15,103	**24,163**

[a] Population in households

[b] Current population is the number of households in 1993, obtained from King County Annual Growth Report by Chandler Felt. These numbers were reduced by 5 % to account for occupancy rates.

[c] Estimated growth in unincorporated King County between 1992 and 2012 based on Small Area Zone (SAZ) numbers used in by the County for Transportation and Land Use Planning.

[d] Estimated growth in cities between 1992 and 2012 from 1994 King County Comprehensive Plan, Technical Appendices, Vol. 2, App. D.

Table 6.1. Susceptibility Ranking of Natural Resources Conservation Service (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 6.2. Susceptibility Ranking of U.S. Geological Survey 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 6.3. 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 6.4. Water Budget of the East King County Ground Water Management Area[1]

Water Budget Component	Quantity Inches[2] Per Year	Quantity Acre-feet[2] Per Year	Percent
Precipitation	57	760,000	100
Fate of precipitation:			
Runoff	3	40,000	6
Evapotranspiration	23	307,000	40
Recharge	31	413,000	54
Total	57	760,000	100
Recharge	31	413,000	54
Fate of recharge:			
Withdrawal from wells	.3	4,270	1
Discharge to springs[3]	.7	9,540	2
Discharge to rivers and lakes[3]	7.4	98,500	24
Ground water flow out of study area[4]	22.6	300,700	73
Total	31	413,00	100

Source: U.S. Geological Survey, 1995.

1 Values are for the entire US Geological Survey study area (259 square miles), not only the Ground Water Management Area (225 square miles).

2 Values are from the Ground Water Management Area. Precipitation values from a rain gauge at Snoqualmie Falls.

3 Figures reported from known measurements of springs, rivers, and lakes. These are likely minimum figures, due to unaccounted discharge to springs, rivers and lakes.

4 Also includes deep flow to the regional ground water system and any unaccounted discharge to springs, rivers or lakes.

Supplement I Area Characterization

Appendices

Appendix A: Ground Water Quality Parameters List

Appendix B: Quality Assurance Project Plan/Data Collection and Analysis Plan

Appendix C: Water Level Monitoring Graphs

Appendix D: Exploratory Well Log

Appendix E: Geophysical Methodology

Draft

East King County
Ground Water Management Plan

July 1996

Supplement I

Area Characterization

Appendix A

Ground Water Quality Parameters List

Draft

East King County
Ground Water Management Plan

July 1996

A.2: Sampling parameters

BIOLOGICAL/PHYSICAL/INORGANIC PARAMETERS

PARAMETER	UNIT	DETECTION LIMIT	PREFERRED METHOD
BIOLOGICAL			
Total Coliforms	Cellular Units/100ml	1	MF
Fecal Coliforms	Cellular Units/100ml	1	MF
PHYSICAL			
Total Dissolved Solids	mg/L	1	EPA 160.1
Total Hardness, $CaCO_3$	mg/L	1	EPA 130.2
Alkalinity			
Bicarbonate	mg/L	1	EPA 310.1
Carbonate	mg/L	1	EPA 310.1
INORGANIC			
Calcium	mg/L	0.10	EPA 200.7
Iron	mg/L	0.01	EPA 200.7
Manganese	mg/L	0.002	EPA 200.7
Magnesium	mg/L	0.10	EPA 200.7
Potassium	mg/L	1.0	EPA 200.7
Sodium	mg/L	0.5	EPA 200.7
Chloride	mg/L	1.0	EPA 325.2
Nitrate-N	mg/L	0.01	EPA 353.2
Silica	mg/L	0.1	EPA 200.7
Sulfate	mg/L	1.0	EPA 375.4
Zinc	mg/L	0.002	EPA 200.7
Silver	mg/L	0.01	EPA 200.7
Selenium	mg/L	0.001	EPA 270.2
Mercury	mg/L	0.0002	EPA 245.1
Fluoride	mg/L	0.02	EPA 340.2
Barium	mg/L	0.003	EPA 200.7
Copper	mg/L	0.002	EPA 200.7
Cadmium	mg/L	0.002	EPA 200.7
Lead	mg/L	0.001	EPA 239.2
Chromium	mg/L	0.006	EPA 200.7
Arsenic	mg/L	0.001	EPA 206.2

VOLATILE ORGANIC COMPOUNDS with MCLs
EPA METHOD 524.2

COMPOUND	DETECTION LIMIT µg/L	MCL µg/L
Vinyl Chloride	0.5	2
1,1-Dichloroethylene	0.5	7
1,1,1-Trichloroethane	0.5	200
Carbon Tetrachloride	0.5	5
Benzene	0.5	5
1,2-Dichloroethane	0.5	5
Trichloroethylene	0.5	5
p-Dichlorobenzene	0.5	75
Chlorobenzene	0.5	100
1,2-Dichlorobenzene	0.5	600
C-1,2-Dichloroethylene	0.5	70
T-1,2-Dichloroethylene	0.5	100
1,2-Dichloropropane	0.5	5
Ethylbenzene	0.5	700
Styrene	0.5	100
Tetrachloroethylene	0.5	5
Toluene	0.5	1000
Total Xylenes	0.5	10000
m + p-Xylenes	0.5	—
o-Xylenes	0.5	—
Ethylene Dibromide	0.5	0.05
1,2-Dibromo-3-Chloropropane	0.5	0.2
Methylene Chloride	0.5	5
1,2,4-Trichlorobenzene	0.5	70
1,1,2-Trichloroethane	0.5	5
Total Trihalomethanes	0.5	100
Chloroform (THM)	0.5	—
Bromodichloromethane (THM)	0.5	—
Chlorodibromomethane (THM)	0.5	—
Bromoform (THM)	0.5	—

MCL = Maximum Contaminant Level

VOLATILE ORGANIC COMPOUNDS without MCLs
EPA METHOD 524.2

COMPOUND	DETECTION LIMIT µg/L
Chloromethane	0.5
Bromomethane	0.5
Chloroethane	0.5
1,1-Dichloroethane	0.5
2,2-Dichloropropane	0.5
1,1-Dichloropropene	0.5
C-1,3-Dichloropropene	0.5
T-1,3-Dichloropropene	0.5
1,3-Dichloropropane	0.5
1,1,1,2-Tetrachloroethane	0.5
Bromobenzene	0.5
1,2,3-Trichloropropane	0.5
1,1,2,2-Tetrachloroethane	0.5
o-Chlorotoluene	0.5
p-Chlorotoluene	0.5
Dibromomethane	0.5
m-Dichlorobenzene	0.5
o-Dichlorobenzene	0.5
Dichlorodifluoromethane	0.5
Trichlorofluoromethane	0.5
Bromochloromethane	0.5
Isopropylbenzene	0.5
N-Propylbenzene	0.5
1,3,5-Trimethylbenzene	0.5
Tert-Butylbenzene	0.5
1,2,4-Trimethylbenzene	0.5
Sec-Butylbenzene	0.5
P-Isopropyltoluene	0.5
N-Butylbenzene	0.5
Napthalene	0.5
Hexachlorobutadiene	0.5
1,2,3-Trichlorobenzene	0.5

SEMI-VOLATILES BY GC/MS
EPA METHOD 625

COMPOUNDS	DETECTION LIMITS µg/L
N-Nitrosodimethylamine	5
Aniline	2
Phenol	2
bis(2-Chloroethyl)ether	2
2-Chlorophenol	2
1,3-Dichlorobenzene	2
1,4-Dichlorobenzene	2
Benzyl Alcohol	2
2-Methylphenol	2
bis(2-Chloroisopropyl)ether	2
4-Methylphenol	2
N-Nitroso-di-n-dipropylamine	2
Hexachloroethane	2
Nitrobenzene	2
Isophorone	2
2-Nitrophenol	5
2,4-Dimethylphenol	2
Benzoic Acid	5
bis(2-Chloroethoxy)methane	2
2,4-Dichlorophenol	2
1,2,4-Trichlorobenzene	2
Naphthalene	2
4-Chloroaniline	2
Hexachlorobutadiene	2
4-Chloro-3-Methylphenol	2
2-Methylnaphthalene	2
Hexachlorocyclopentadiene	5
2,4,6-Trichlorophenol	2
2,4,5-Trichlorophenol	2
2-Chloronaphthalene	2
2-Nitroaniline	5
Dimethylphthalate	2
Acenaphthylene	2
2,4-Dinitrotoluene	5

SEMI-VOLATILES (continued)

3-Nitroaniline	5
Acenaphthene	2
2,4-Dinitrophenol	10
4-Nitrophenol	5
Dibenzofuran	2
2,4-Dinitrotoluene	5
Diethylphthalate	2
4-Chlorophenyl-phenyl ether	2
Fluorene	2
4-Nitoaniline	5
4,6-Dinitro-2-methylphenol	5
N-Nitrosodiphenylamine	2
Azobenzene	2
4-Bromophenyl-phenyl ether	2
Hexachlorobenzene	2
Pentachlorophenol	5
Phenanthrene	2
Anthracene	2
Di-n-butylphthalate	2
Fluoranthene	2
Benzidine	50
Pyrene	2
Butylbenzylphthalate	2
3,3-Dichlorobenzidine	3
Benzo(a)anthracene	2
Chrysene	2
bis(2-Tehylhexyl)phthalate	2
Di-n-octylphthalate	2
Benzo(b)fluoranthene	2
Benzo(k)fluoranthene	2
Benzo(a)pyrene	2
Indeno(1,2,3-cd)pyrene	4
Dibenzo(a,hy)anthracene	4
Benzo(g,h,i)perylene	4

The above detection limits are based on "clean" samples. Dilution may be required for exceptionally dirty samples.

PESTICIDES/PCBs
EPA METHOD 508

CHLORINATED PESTICIDES	DETECTION LIMITS µg/L	MCL µg/L
Alachlor	0.05	
Aldrin	0.04	
Atrazine	0.6	
HCH-alpha	0.03	
HCH-beta	0.06	
HCH-delta (a)	0.09	
HCH-gamma (Lindane)	0.04	4
Butachlor	0.1	
Chlorobenzilate	Qualitative	
Chlordane Chlordane-alpha Chlordane-gamma	0.5	2
Chloroneb		
Chlorothalonil		
4,4-DDD	0.05	
4,4-DDE	0.04	
4,4-DDT	0.10	
Dieldrin	0.04	
Endosulfan II	0.05	
Endosulfan I	0.04	
Endosulfan Sulfate	0.08	
Endrin Aldehyde	0.1	
Endrin	0.05	0.2
Etridiazole		
Heptachlor Epoxide	0.03	0.2
Heptachlor	0.03	0.4
Hexachlorobenzene	0.004	
Hexachlorocyclo-pentadiene	0.004	
Methoxychlor	0.2	40
Metolachlor	0.1	
Metribuzin	0.01	
C-Permethrin		
T-Permethrin		
Propachlor	0.2	

PESTICIDES/PCBS (continued)

Simazine	1	
Toxaphene	5.0	5
Trifluralin		

<u>POLYCHLORINATED BIPHENYLS</u>

PCB-1016	0.5	0.5
PCB-1221	2.0	0.5
PCB-1232	0.5	0.5
PCB-1242	0.5	0.5
PCB-1248	0.5	0.5
PCB-1254	0.5	0.5
PCB-1260	0.5	0.5

HERBICIDES
EPA METHOD 515.1

COMPOUNDS	DETECTION LIMITS µg/L	MCL µg/L
2,4-D	0.1	70
2,4-DB		
2,4,5-T	0.1	
2,4,5-TP (Silvex)	0.1	50
3,5-Dichlorobenzoic Acid		
4-Nitrophenol		
Acifluorfen		
Bentazon		
Chloramben		
Dalapon	1	200
DCPA (Dacthal)	500	
5-Hydroxydicamba		
Dicamba	1	
Dichlorprop		
Dinoseb		7
Pentachlorophenol (PCP)		
Picloram		500
Tricamba	1	

Supplement I

Area Characterization

Appendix B

Quality Assurance Project Plan/Data Collection and Analysis Plan

December 1994

Available upon request from
King County Department of Natural Resources
Ground Water Management Program

Draft

East King County
Ground Water Management Plan

July 1996

Supplement I

Area Characterization

Appendix C

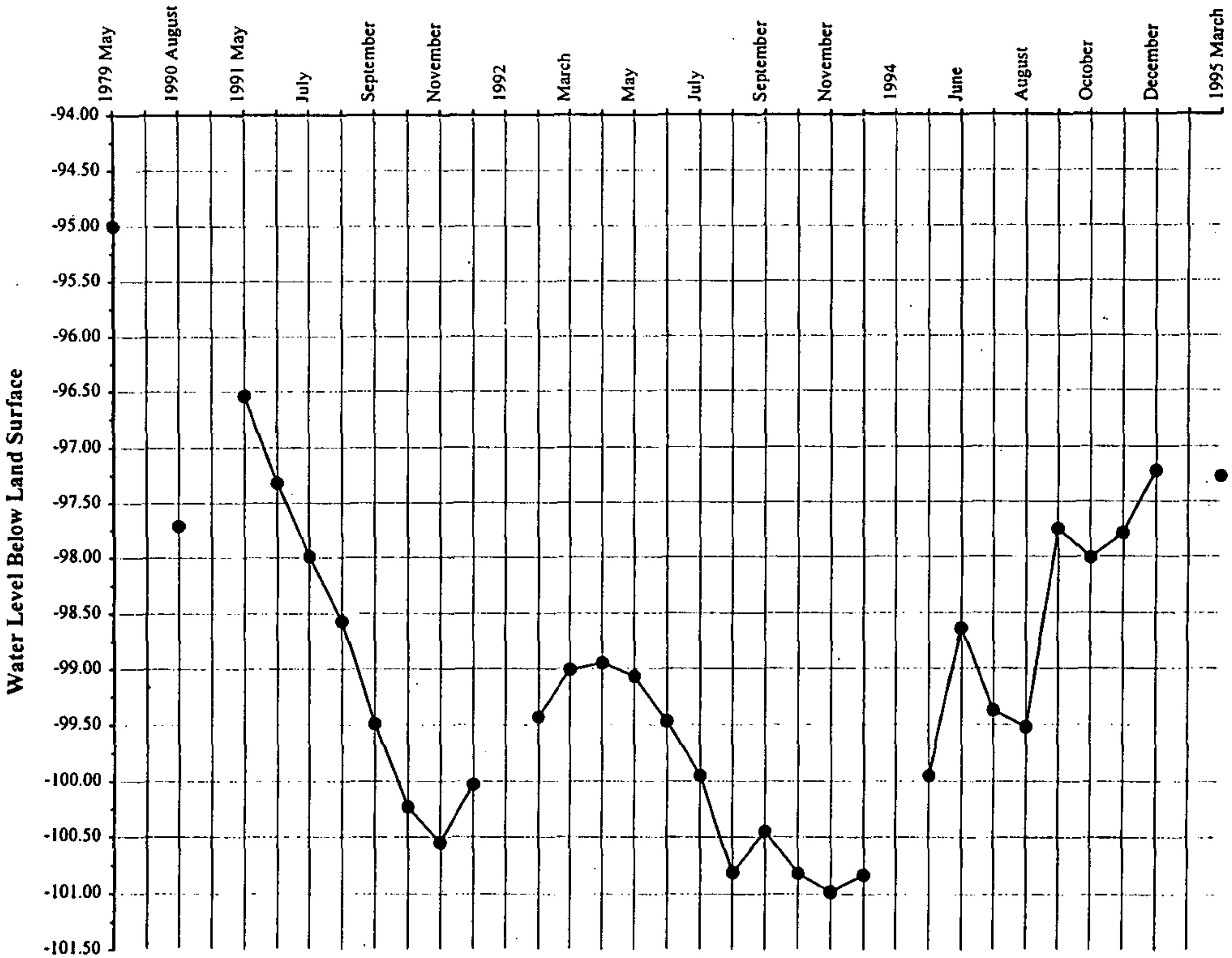
Water Level Monitoring Graphs

Draft

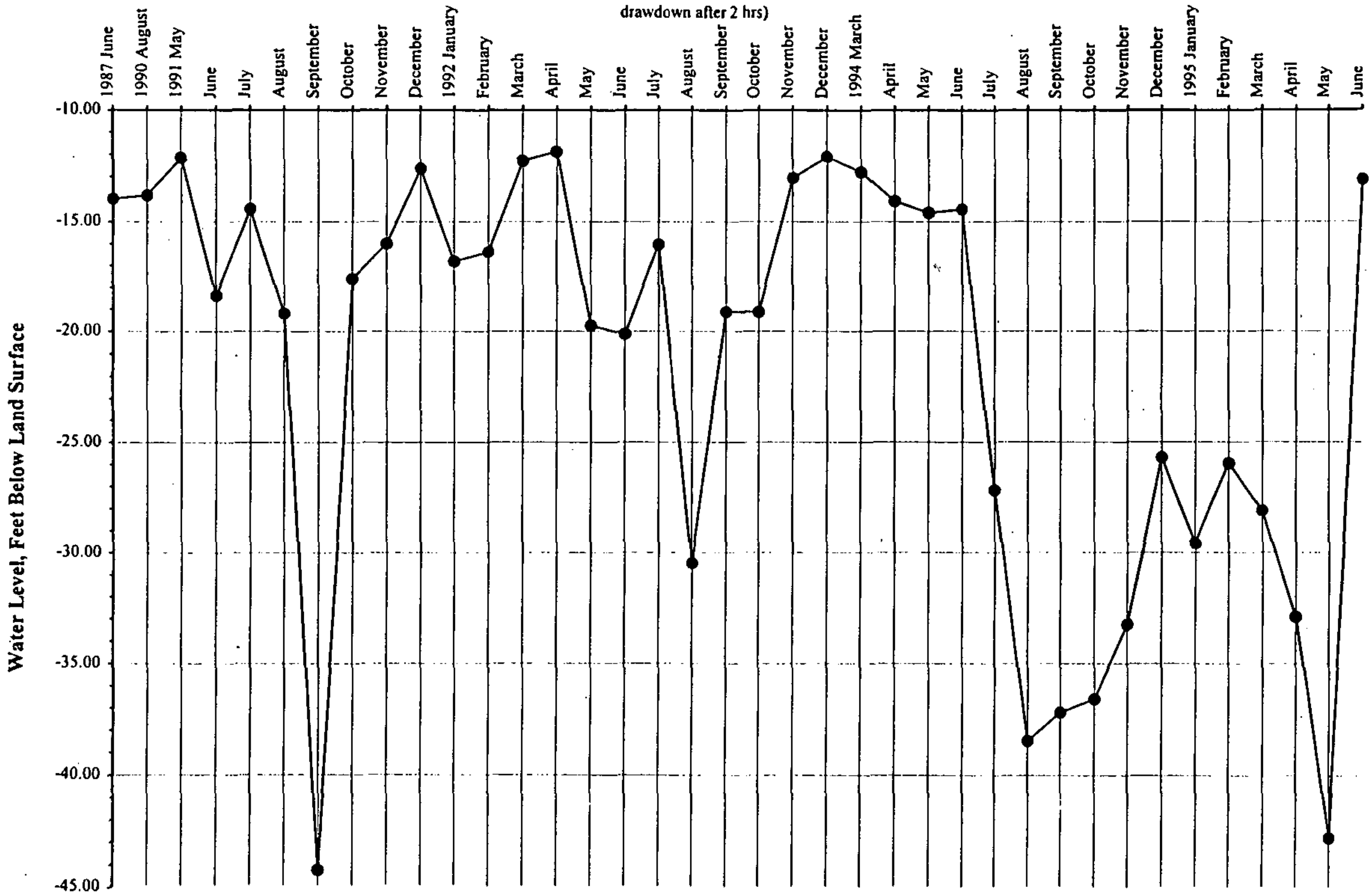
East King County
Ground Water Management Plan

July 1996

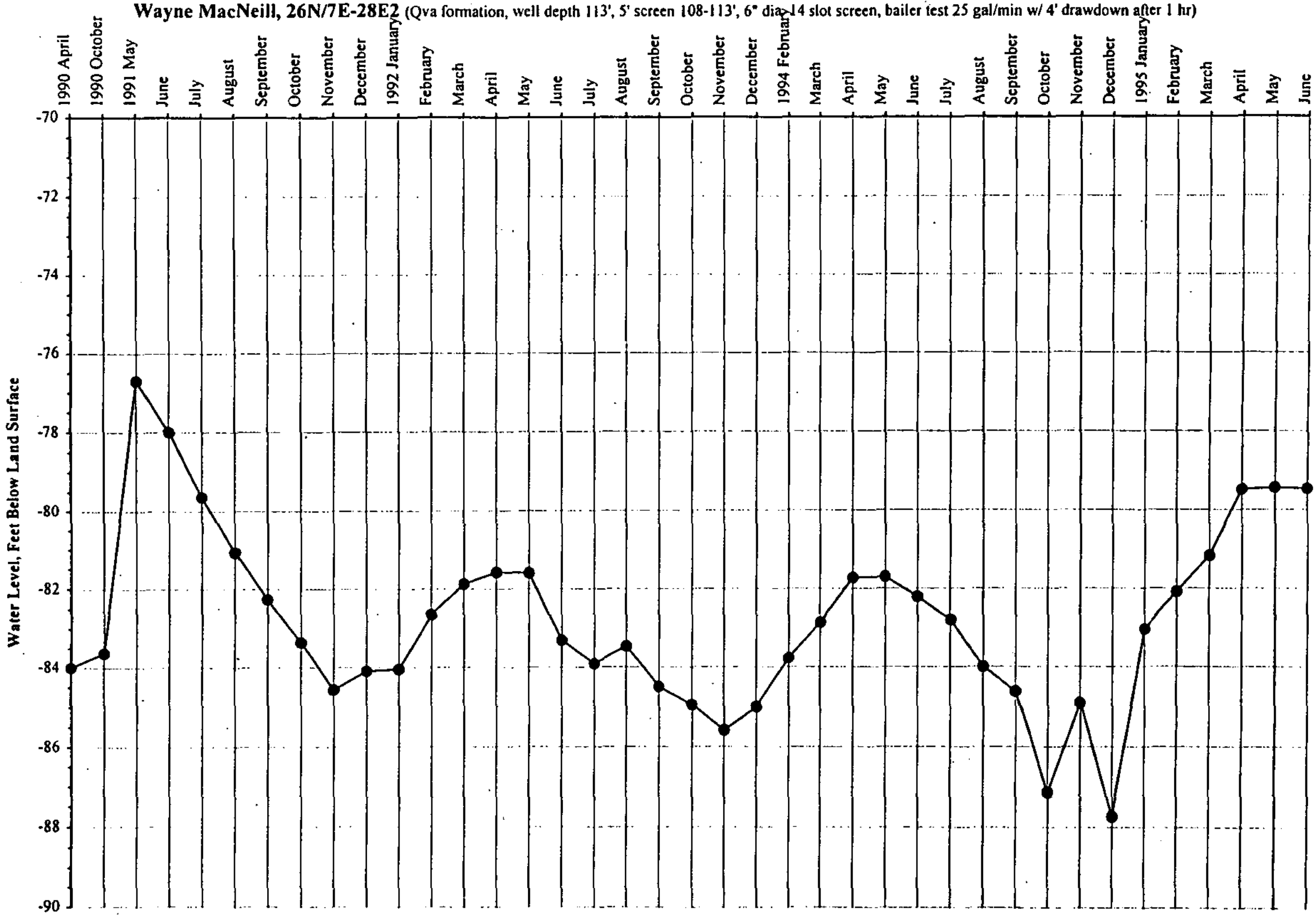
Mike Nodke-25N/06E-24K01(120 ft depth, 6 inch casing, no screen, Qvt formation, surface elevation ~420 ft msl, 7 gallons per minute with 22 ft drawdown after one hour)



Mr. and Mrs. Joe and Donna Pekara-24N/07E-21H01 (Sandstone and Shale strata, 118' depth, surface elevation ~490', bailer test 2.5 gal/min w/80' drawdown after 2 hrs)

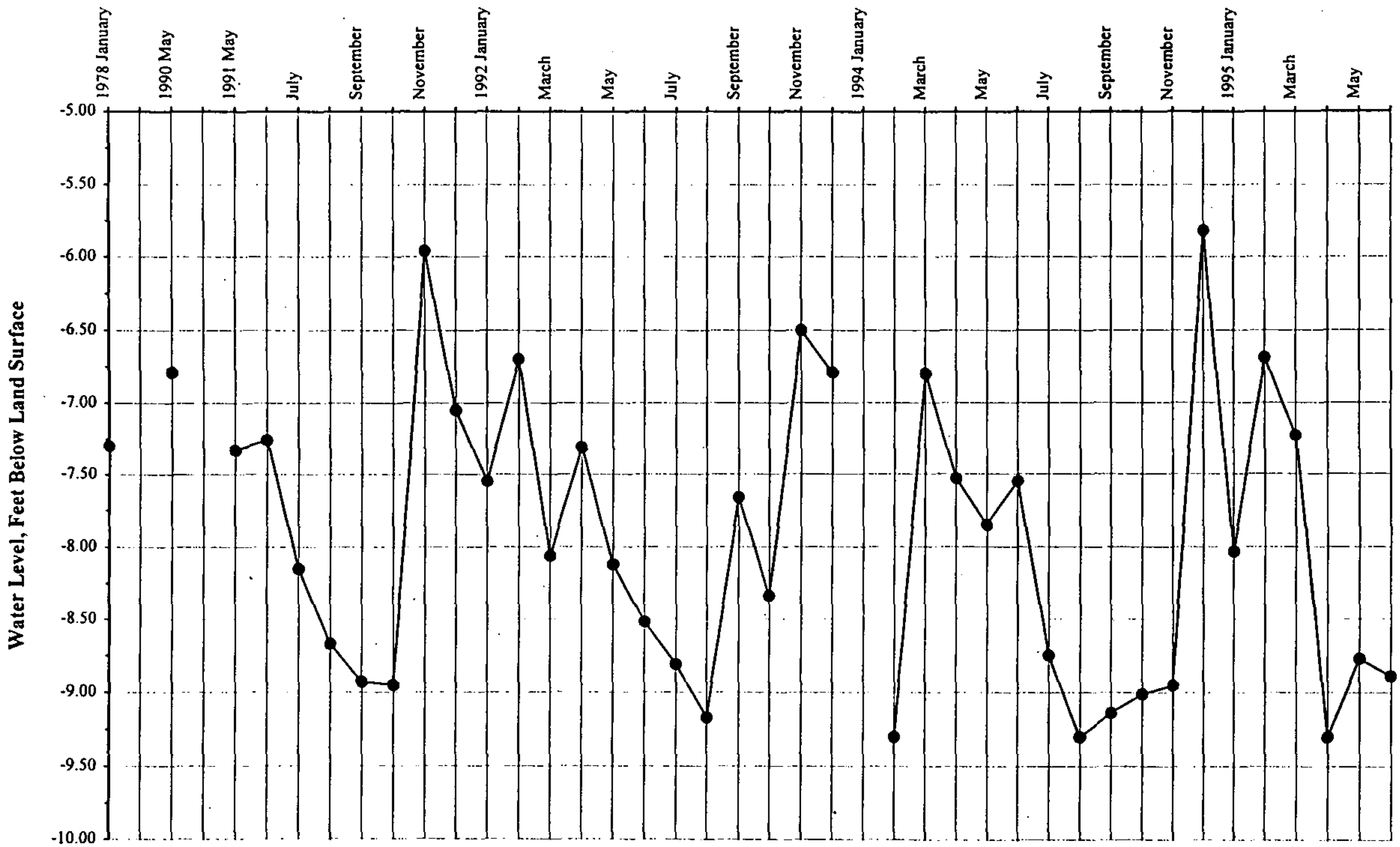


Wayne MacNeill, 26N/7E-28E2 (Qva formation, well depth 113', 5' screen 108-113', 6" dia. 14 slot screen, bailer test 25 gal/min w/ 4' drawdown after 1 hr)

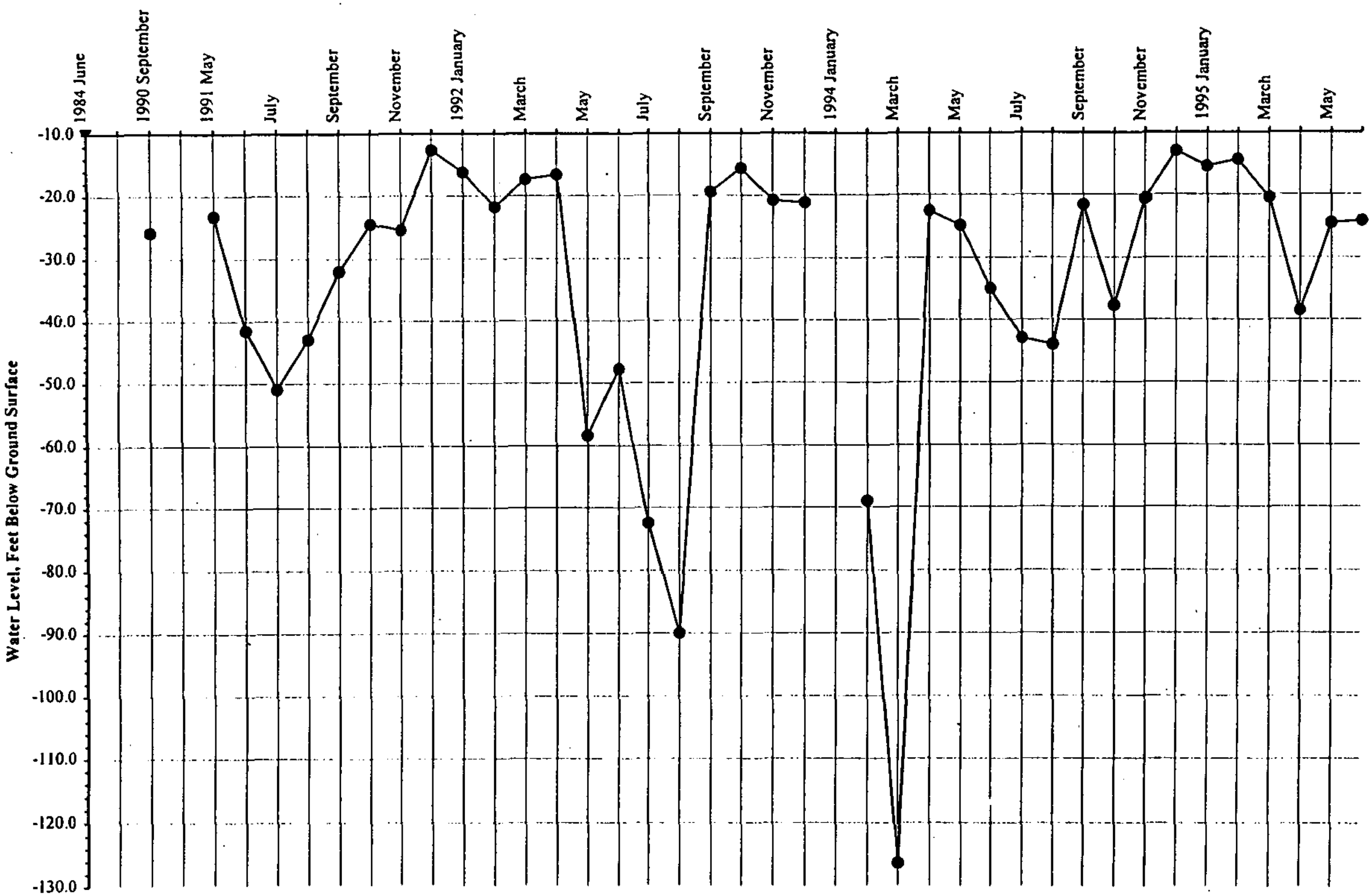


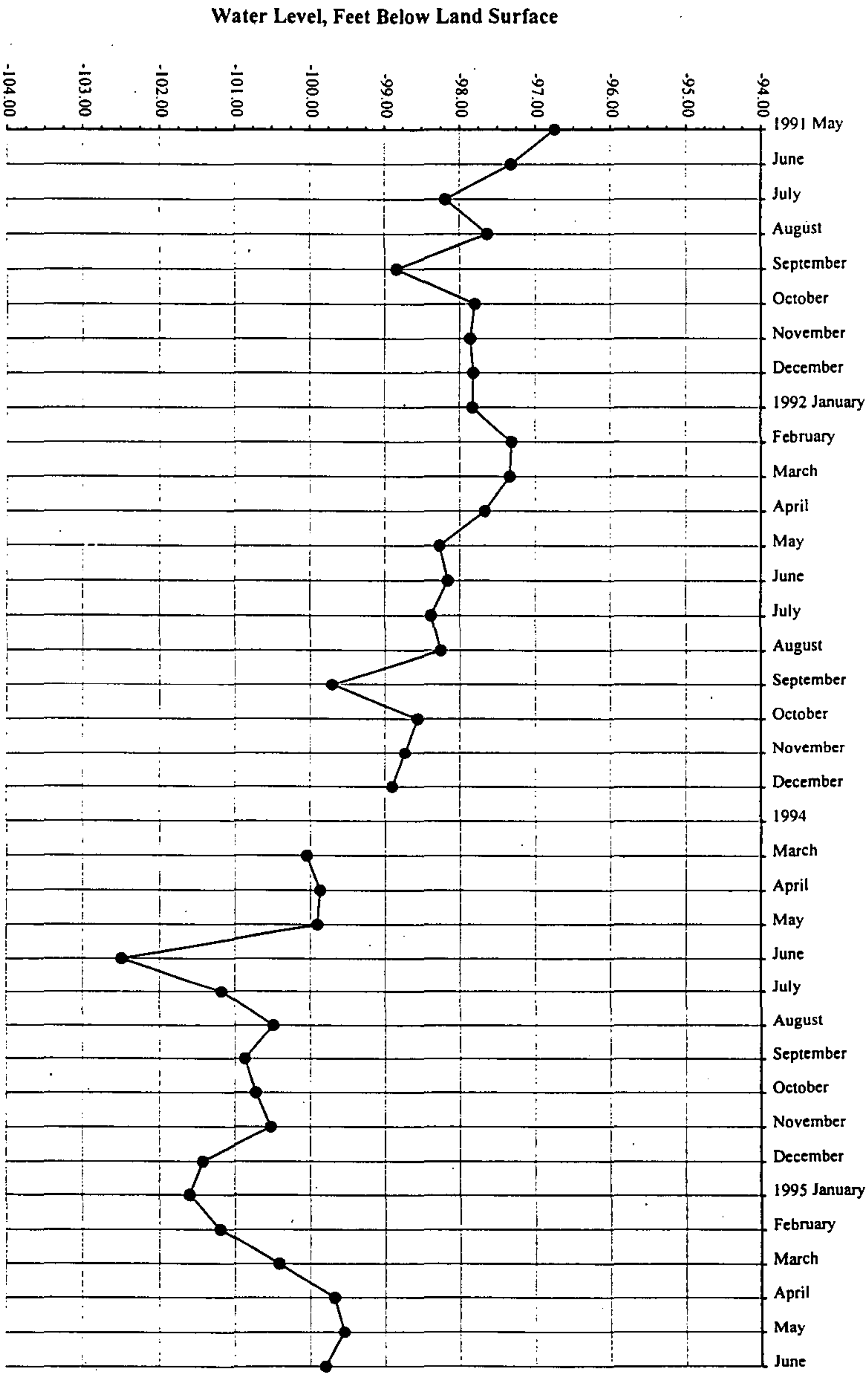
George Macris, 23N/8E-3L3

(well depth 230 ft bls; surface elevation 435 ft msl; Qal formation, 40 gallons per minute with 25 ft drawdown after 2.5 hours)



Mr. Rick La France-26N/07E-14P01 (Bedrock well, Shale from 15' to 130', bailer test resulted in 1gal/min with 90' drawdown after 1hr)

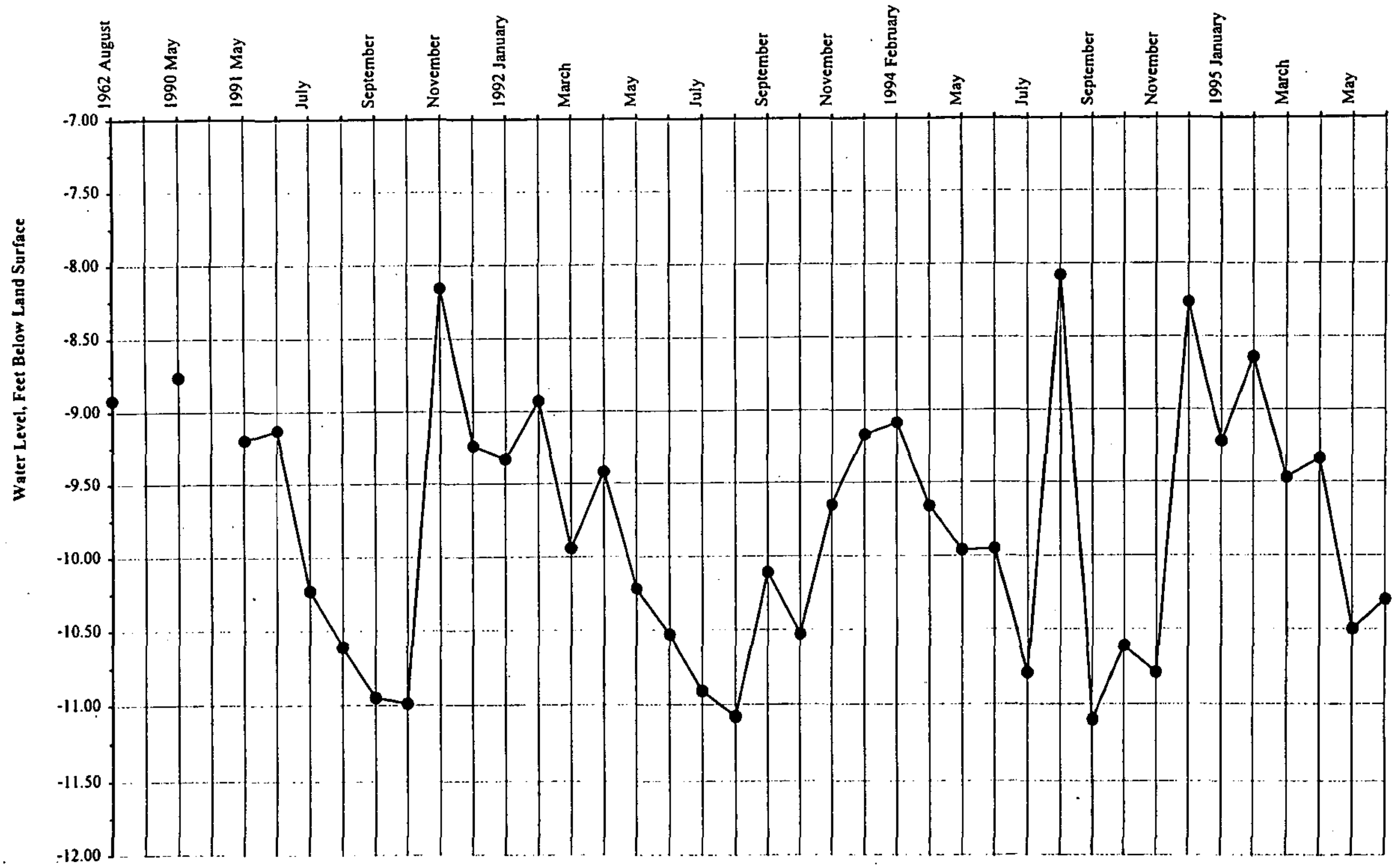


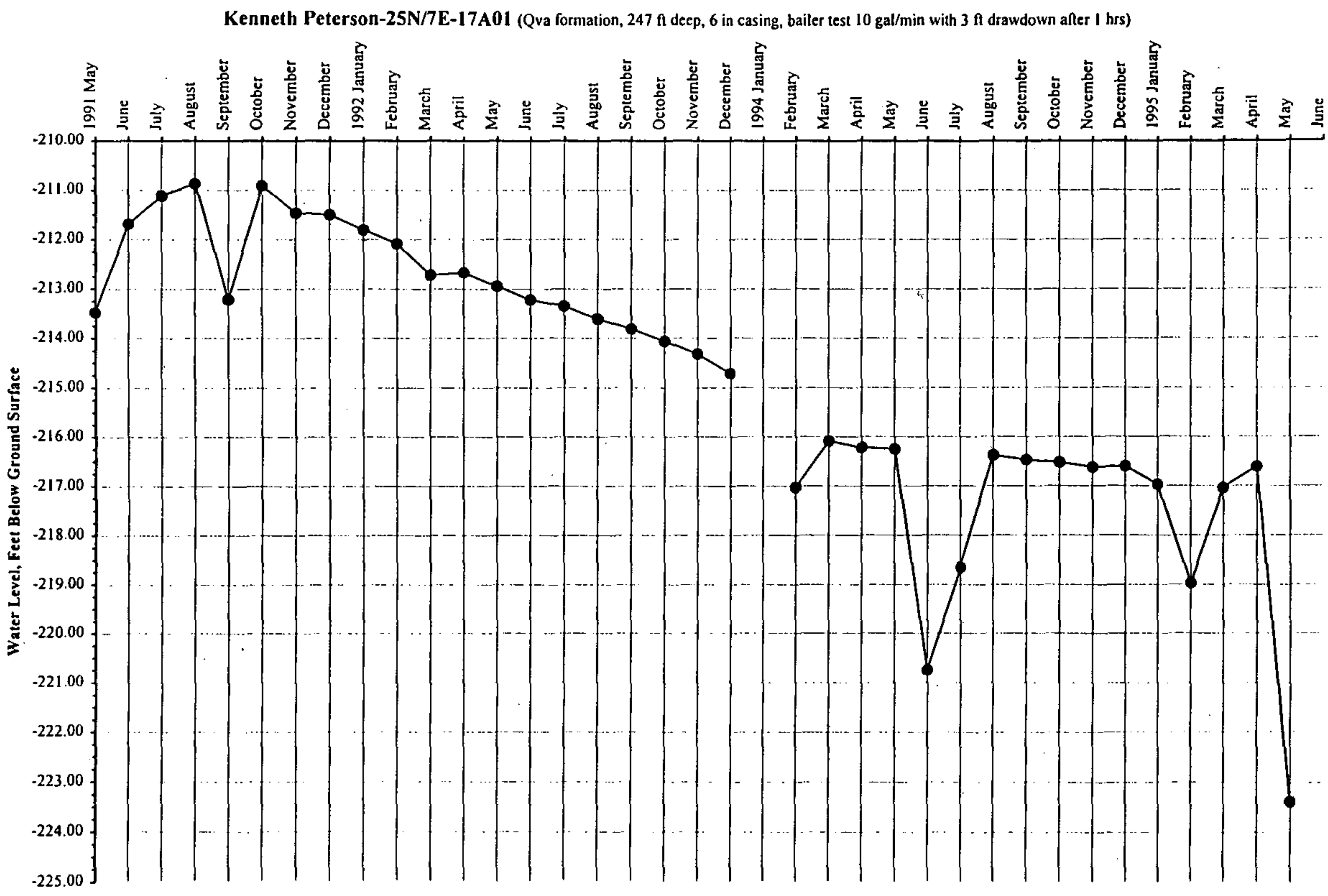


Lyle Pigort, 24N/6E-9N2 (6in casing, well depth 199ft bls, screen from 189-199 ft, Qvt formation, surface elevation ~420 ft)

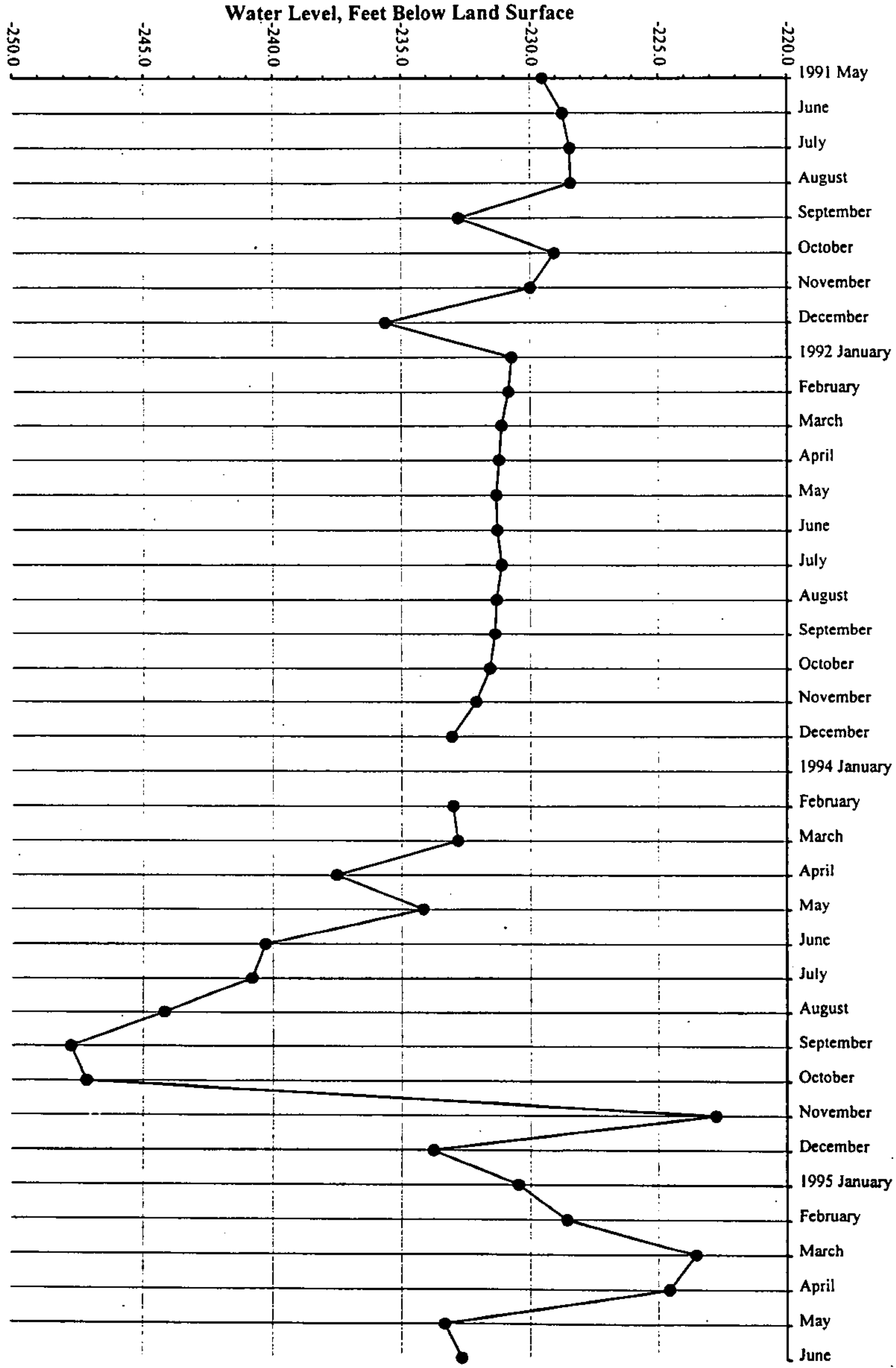
King County Parks Department, 23N/8E-9J1

(16 foot, 36 inch diameter hand dug well, sounded in 1962 at 13.1 feet, Qal formation)

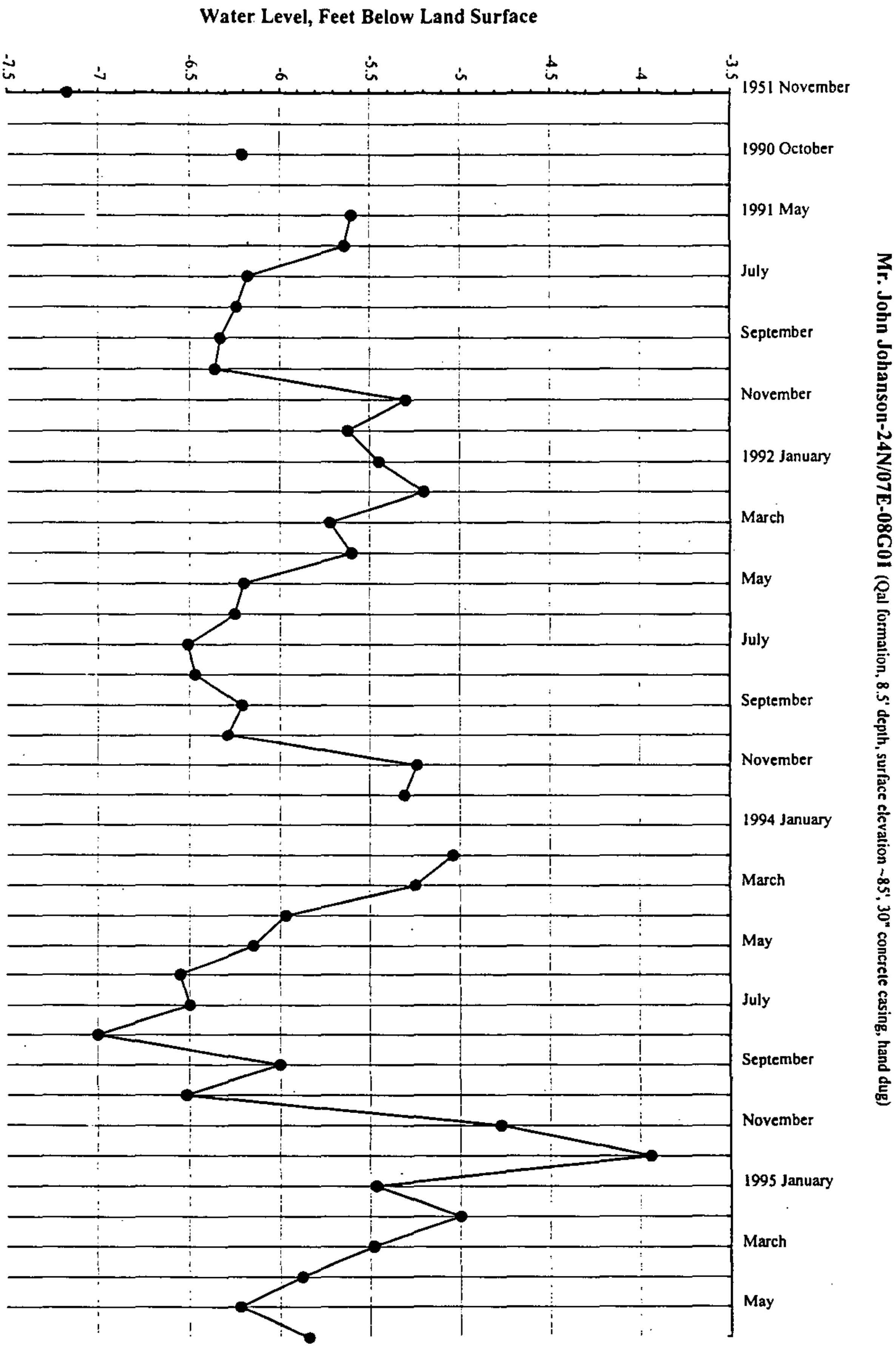


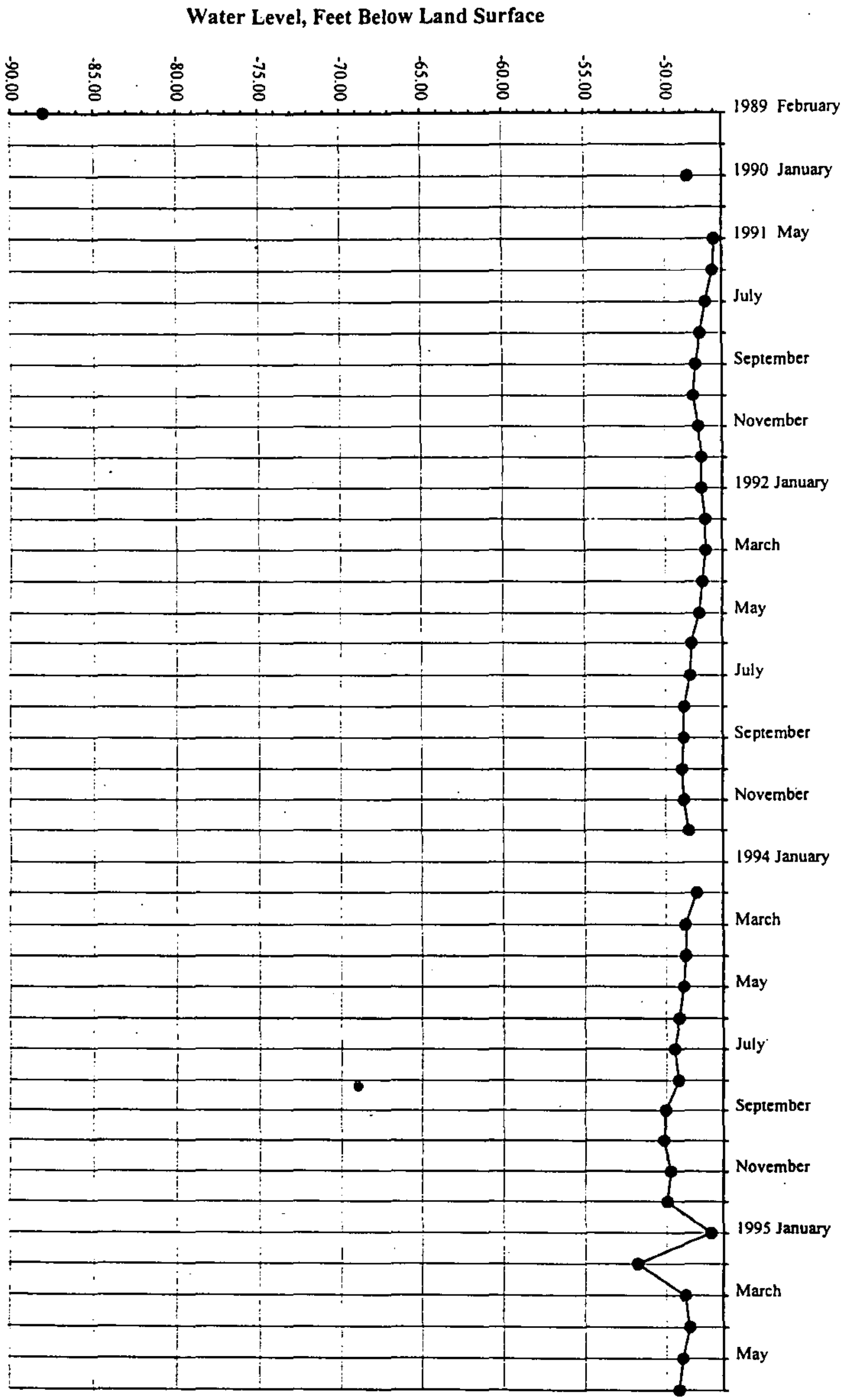


Kenneth Peterson-25N/7E-17A01 (Qva formation, 247 ft deep, 6 in casing, bailer test 10 gal/min with 3 ft drawdown after 1 hrs)
Water Level, Feet Below Ground Surface
-210.00
-211.00
-212.00
-213.00
-214.00
-215.00
-216.00
-217.00
-218.00
-219.00
-220.00
-221.00
-222.00
-223.00
-224.00
-225.00
1991 May
June
July
August
September
October
November
December
1992 January
February
March
April
May
June
July
August
September
October
November
December
1994 January
February
March
April
May
June
July
August
September
October
November
December
1995 January
February
March
April
May
June



Tom & Judy Worley-26N/07E-20E01 (Qva formation, 260' well depth, surface elevation ~485', bailer test 8 gal/min w/ 20' drawdown after 2 hrs)

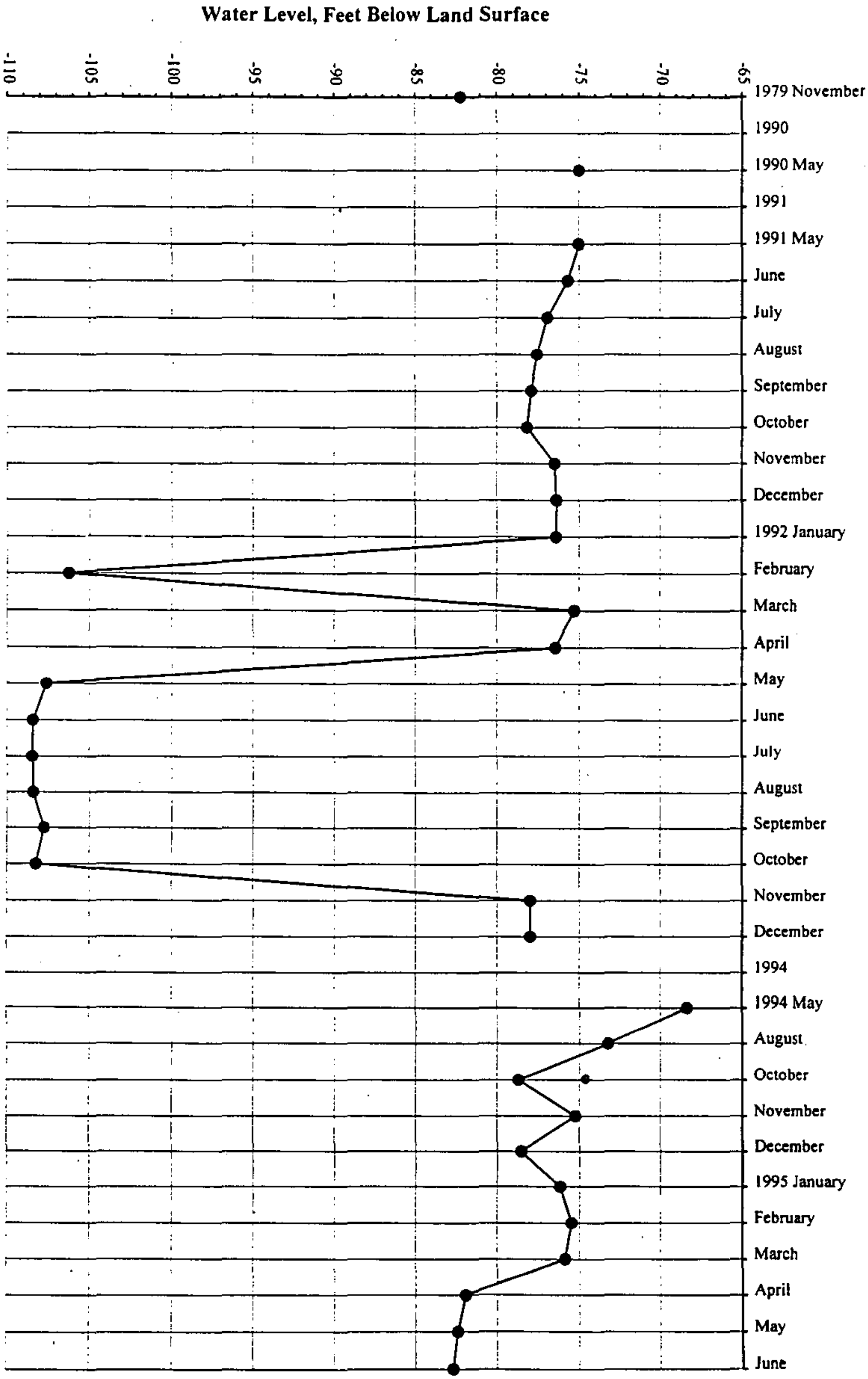

Water Level, Feet Below Land Surface
-7.5
-7
-6.5
-6
-5.5
-5
-4.5
-4
-3.5
1951 November
1990 October
1991 May
July
September
November
1992 January
March
May
July
September
November
1994 January
March
May
July
September
November
1995 January
March
May
Mr. John Johanson-24N/07E-08G01 (Qal formation, 8.5' depth, surface elevation ~85', 30" concrete casing, hand dug)

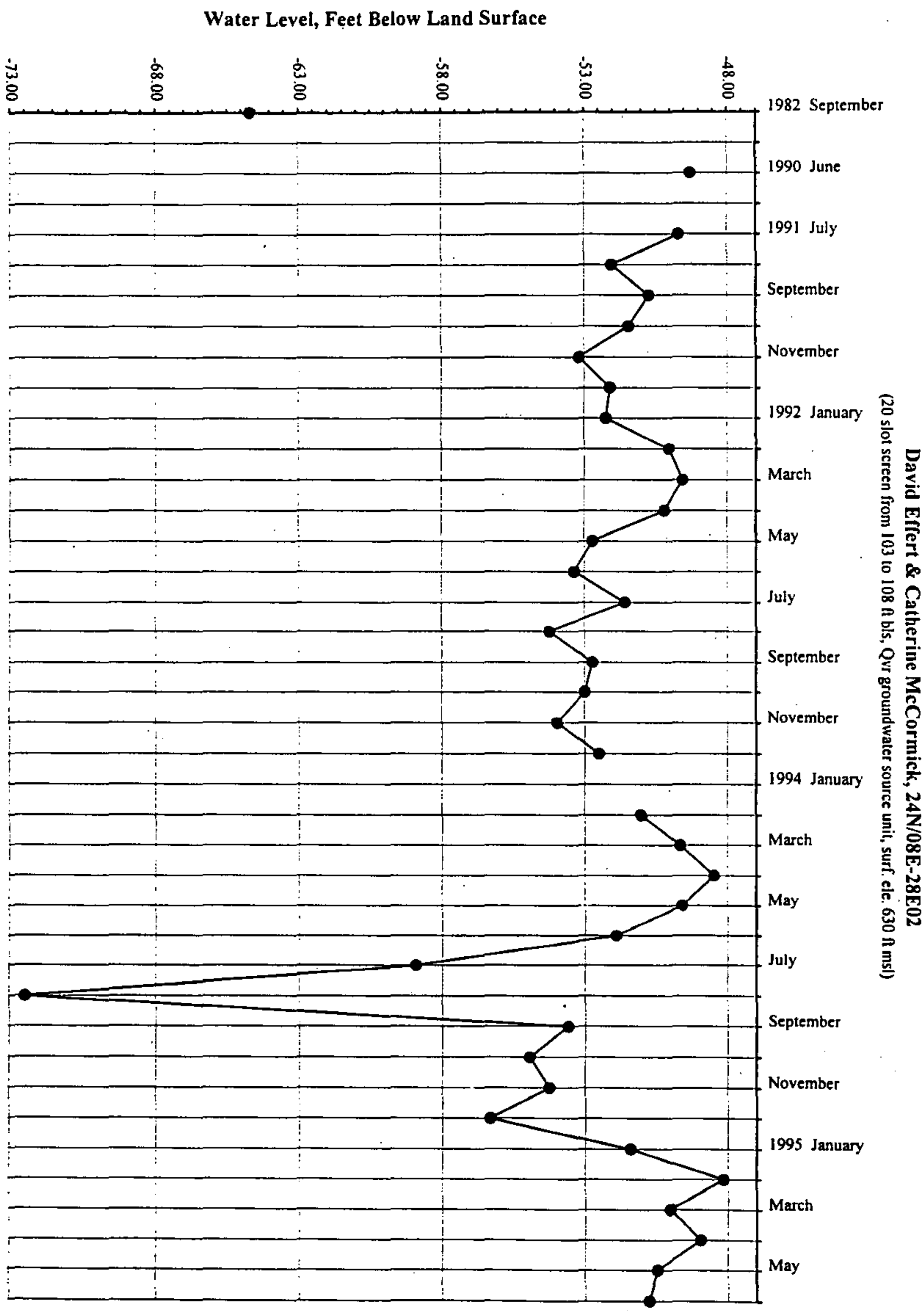


H. Michael Green, 25N/7E-34M1 (Q(A)c well drilled 296ft bls, casing ends 284ft bls, surface elevation 140 ft. msl, 2.5 gallons per minute with 104 ft drawdown after 2 hours)

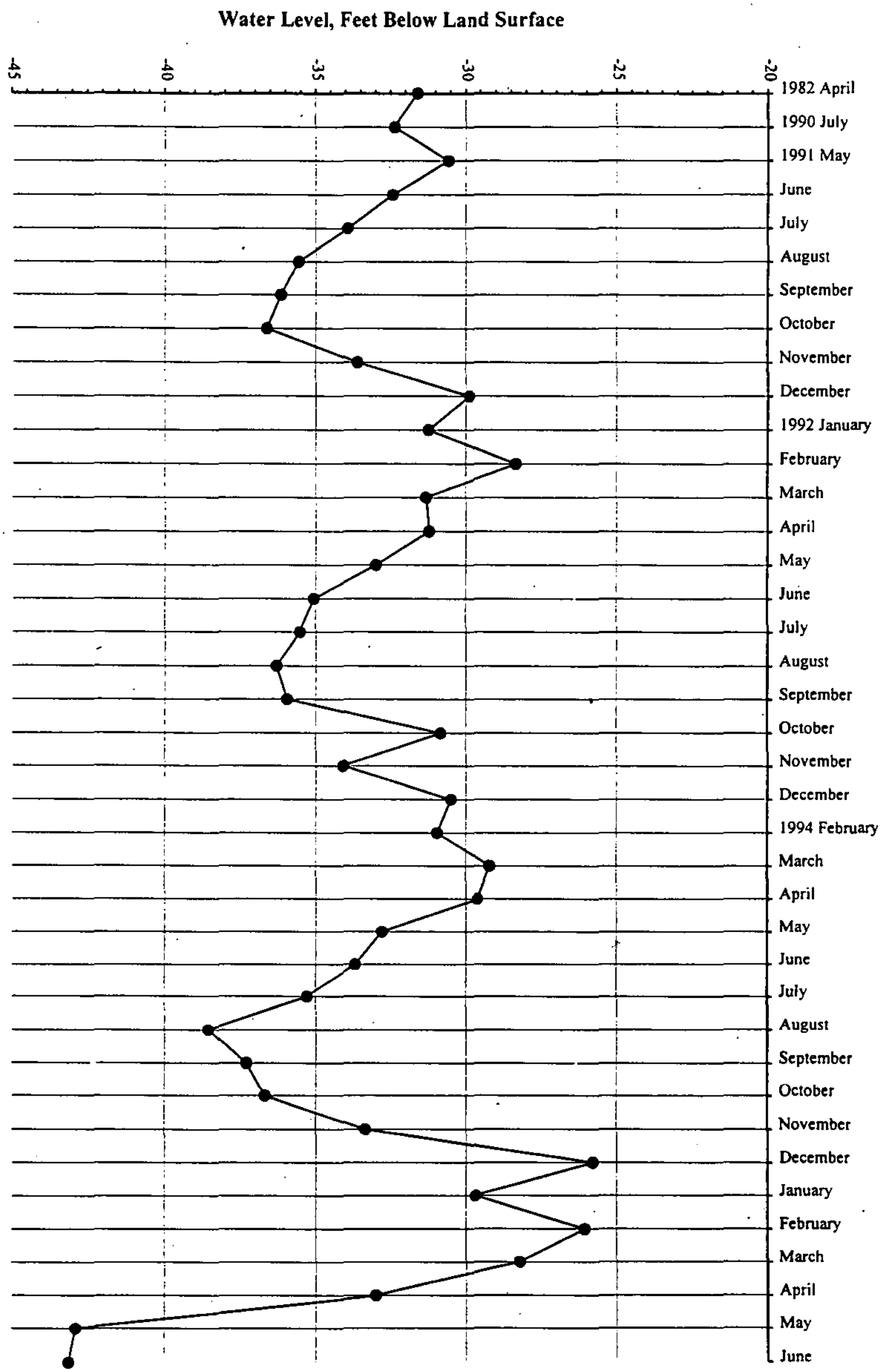
Highline School Dist #401, 23N/8E-13N1

(5ft well screen bottom at 194 ft bls; land elevation 595 ft msl; Qal formation; ~150 gallons per minute with 21 feet drawdown)



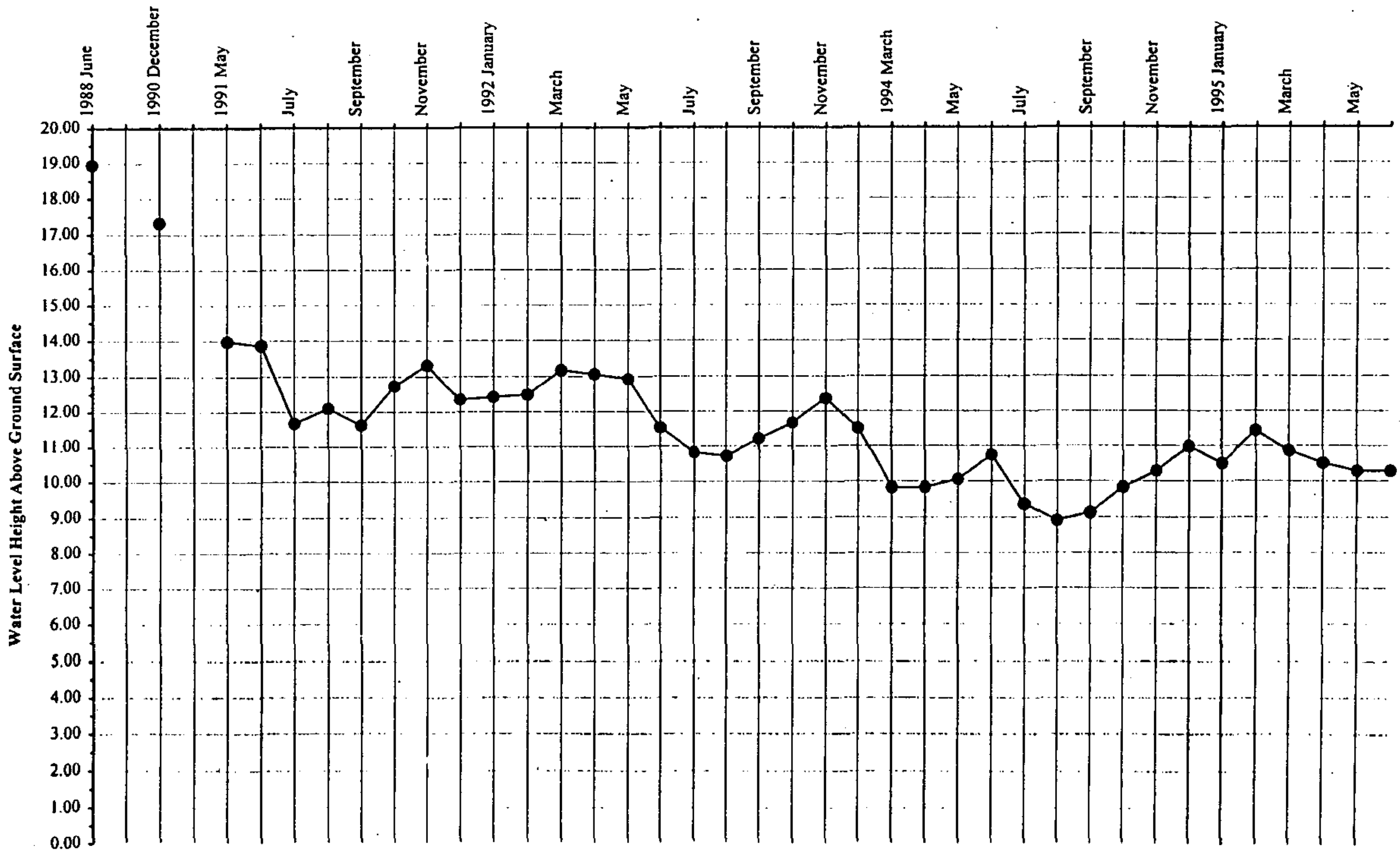


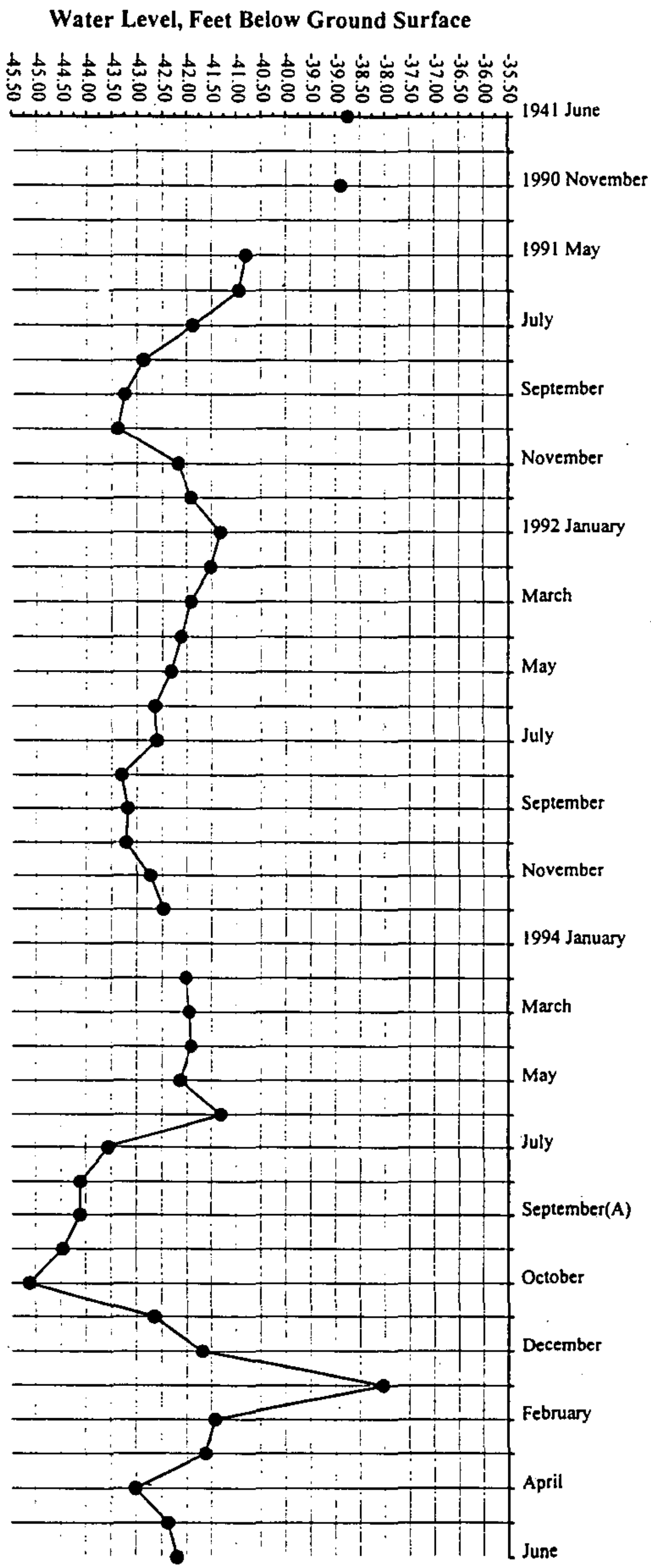
Water Level, Feet Below Land Surface
-73.00
-68.00
-63.00
-58.00
-53.00
-48.00
1982 September
1990 June
1991 July
September
November
1992 January
March
May
July
September
November
1994 January
March
May
July
September
November
1995 January
March
May
David Effert & Catherine McCormick, 24N/08E-28E02
(20 slot screen from 103 to 108 ft bls, Qvr groundwater source unit, surf. ele. 630 ft msl)



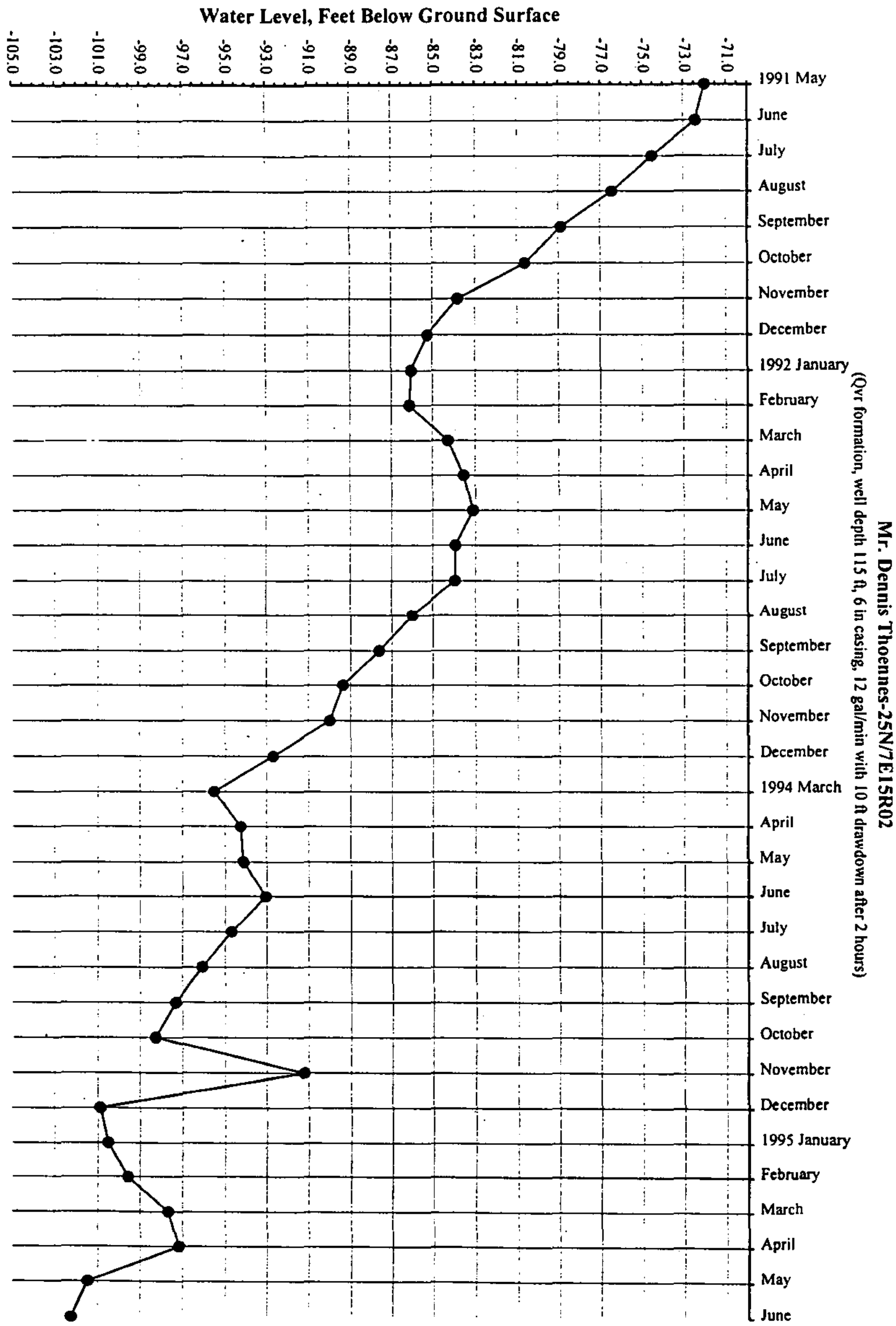
Mr. Wm L. Gnecchi 24N/07E-15D01 (Qal formation, well depth 49.5', surface elevation ~105', bailer test indicated 20 gal/min with 5' drawdown after 1hrs.)

Dale Waid-25N/07E-7E01(659' deep, 8" diameter, star perforator 1/4" by 1" from 565 to 595', Q(A)c formation, surface elevation ~55', 500 gallons per minute with 69 ft drawdown after 24 hours)

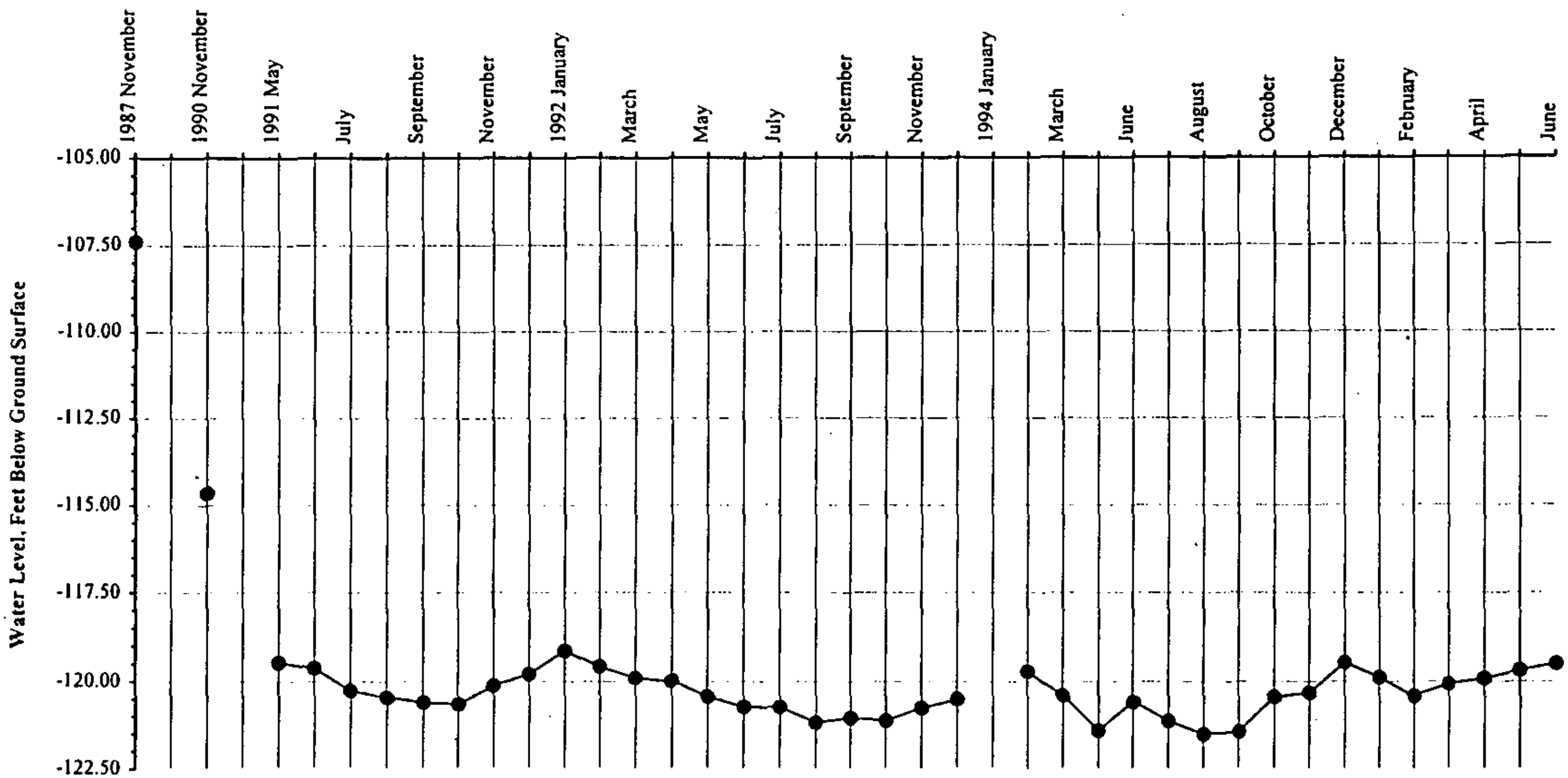




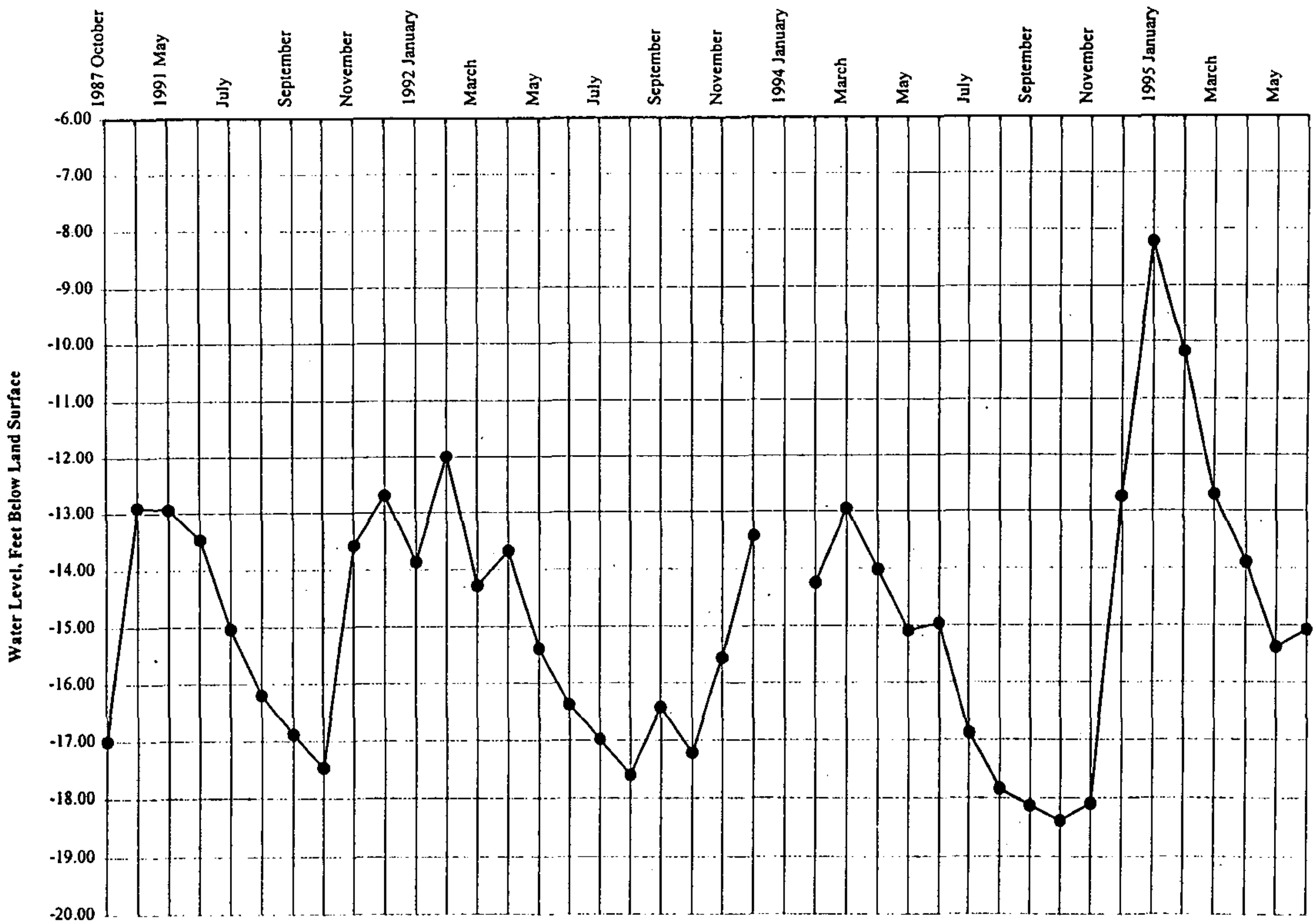
Mr. Dean Gibbs-26N/06E-13N01 (Q(A)c formation, 236' well depth, 6" casing, pump @~135')


Mr. Dennis Thoennes-25N/7E15R02
(Qvr formation, well depth 115 ft, 6 in casing, 12 gal/min with 10 ft drawdown after 2 hours)
Water Level, Feet Below Ground Surface
-105.0
-103.0
-101.0
-99.0
-97.0
-95.0
-93.0
-91.0
-89.0
-87.0
-85.0
-83.0
-81.0
-79.0
-77.0
-75.0
-73.0
-71.0
1991 May
June
July
August
September
October
November
December
1992 January
February
March
April
May
June
July
August
September
October
November
December
1994 March
April
May
June
July
August
September
October
November
December
1995 January
February
March
April
May
June

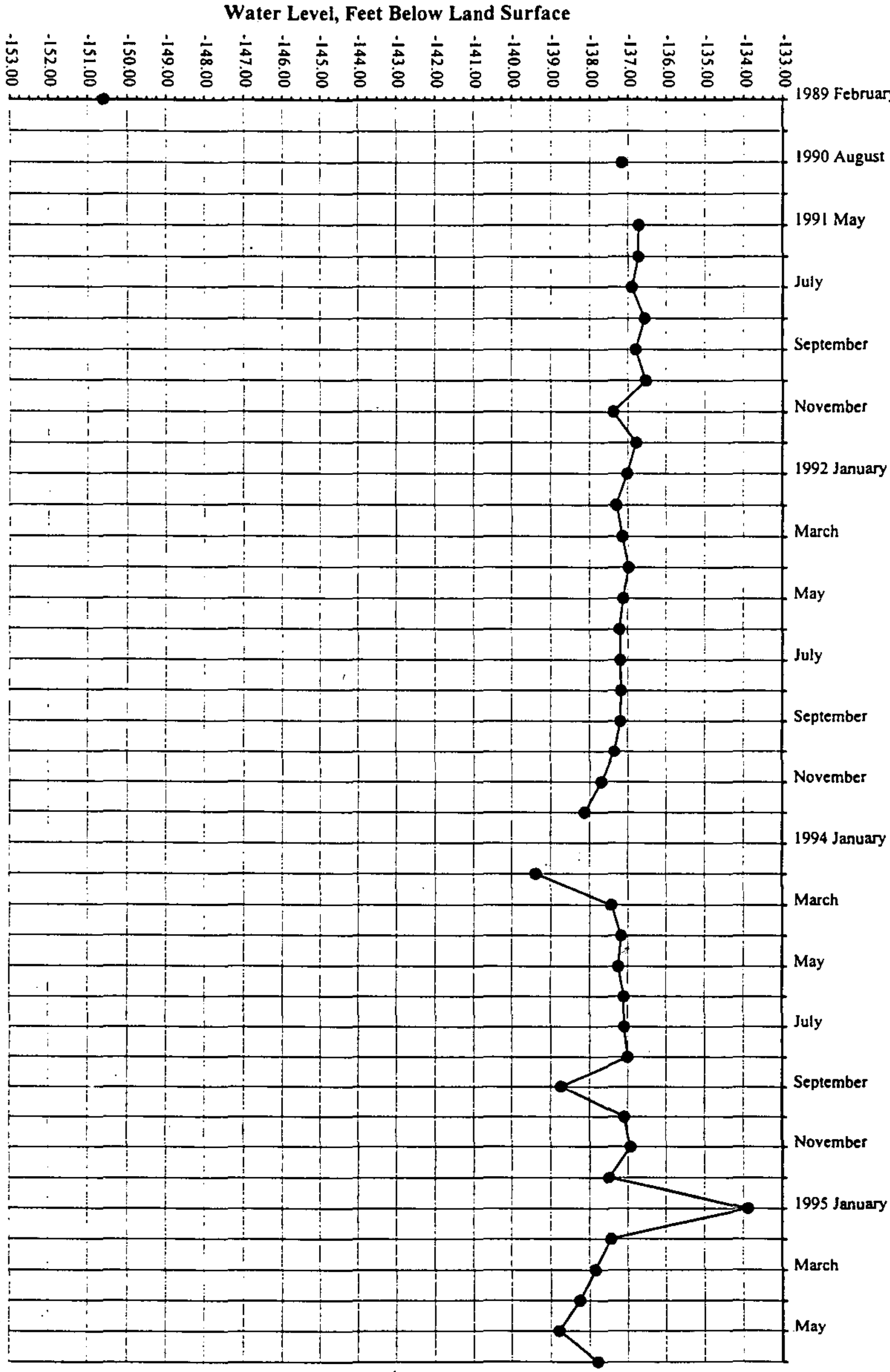
City of Seattle-26N/06E-25C02 (Q(B)c formation, 852' well depth, 12" casing to 500', 8" casing 800', 20' torch slotted 6" pipe, 5' of blank pipe)

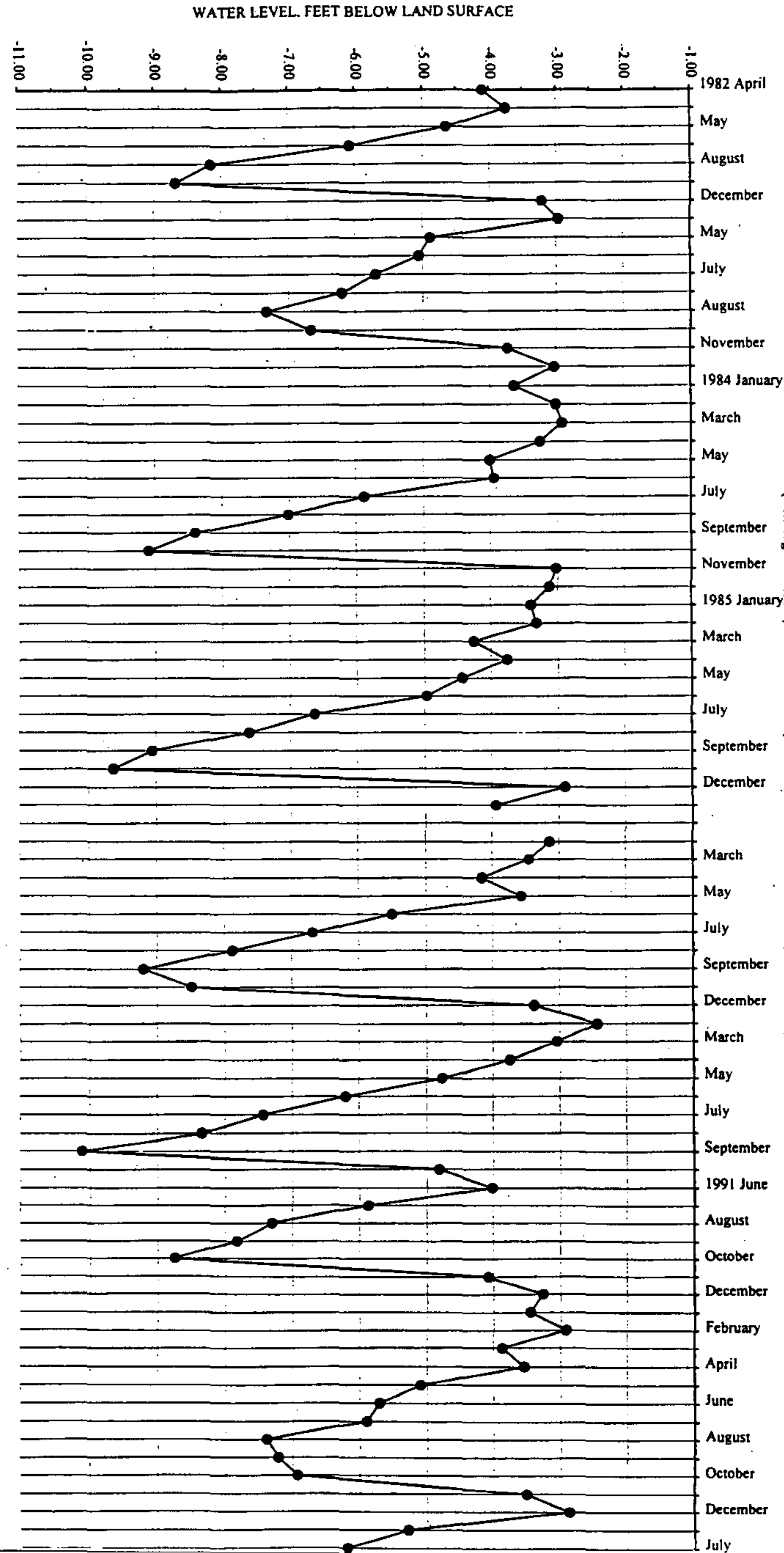


Eva Pierce, 23N/8E-15J6, (Qal formation, well depth 40', bottom of casing 40', bailer test indicate 25 gal/min with 4' drawdown after 1 hrs)



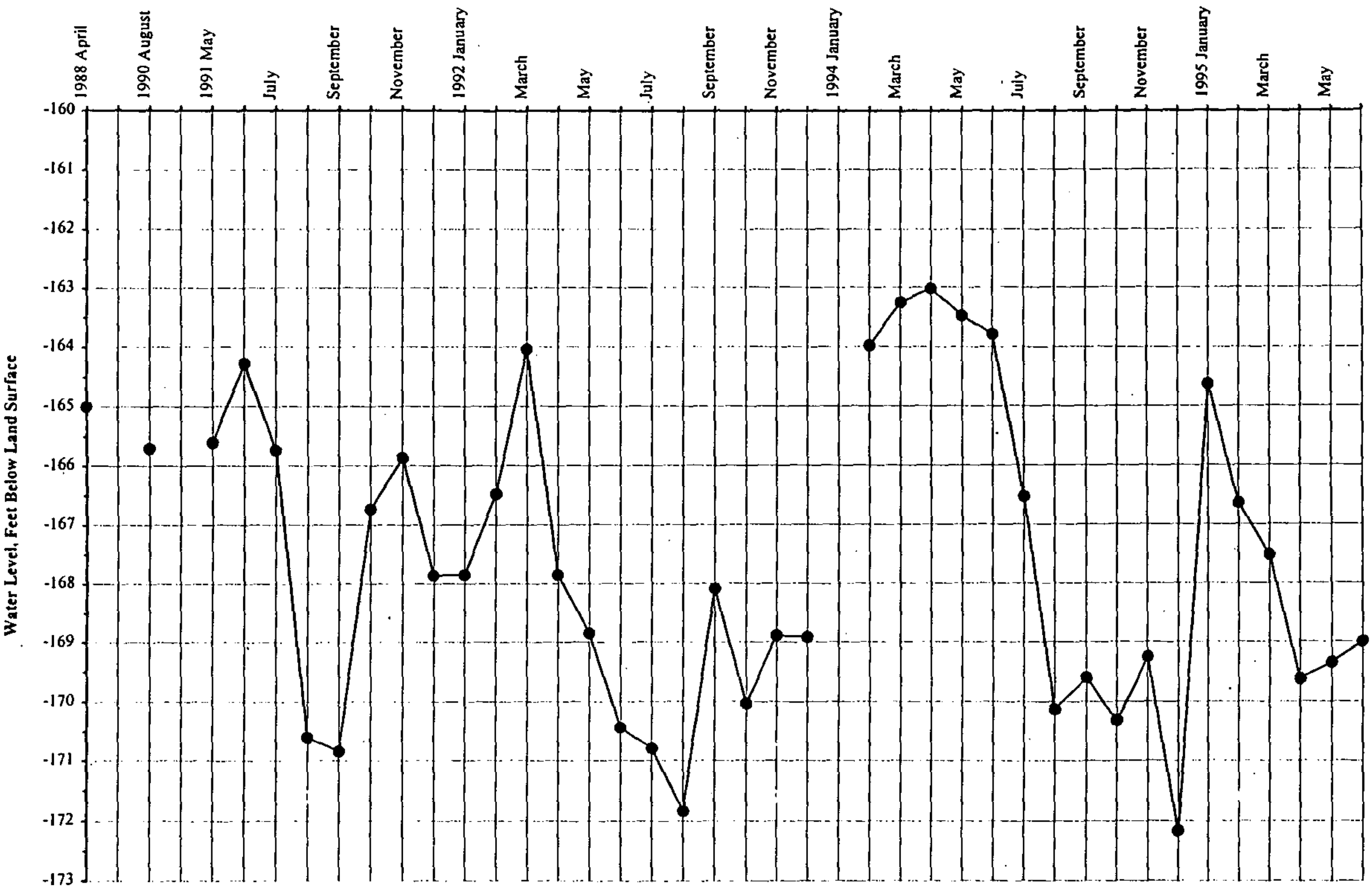
Rick Bell, 26N/6E-22K2 (well depth 190 ft, screened 160-170 ft. bls, 5 in. casing 170-190, Qva formation, surface elevation ~550 ft.)





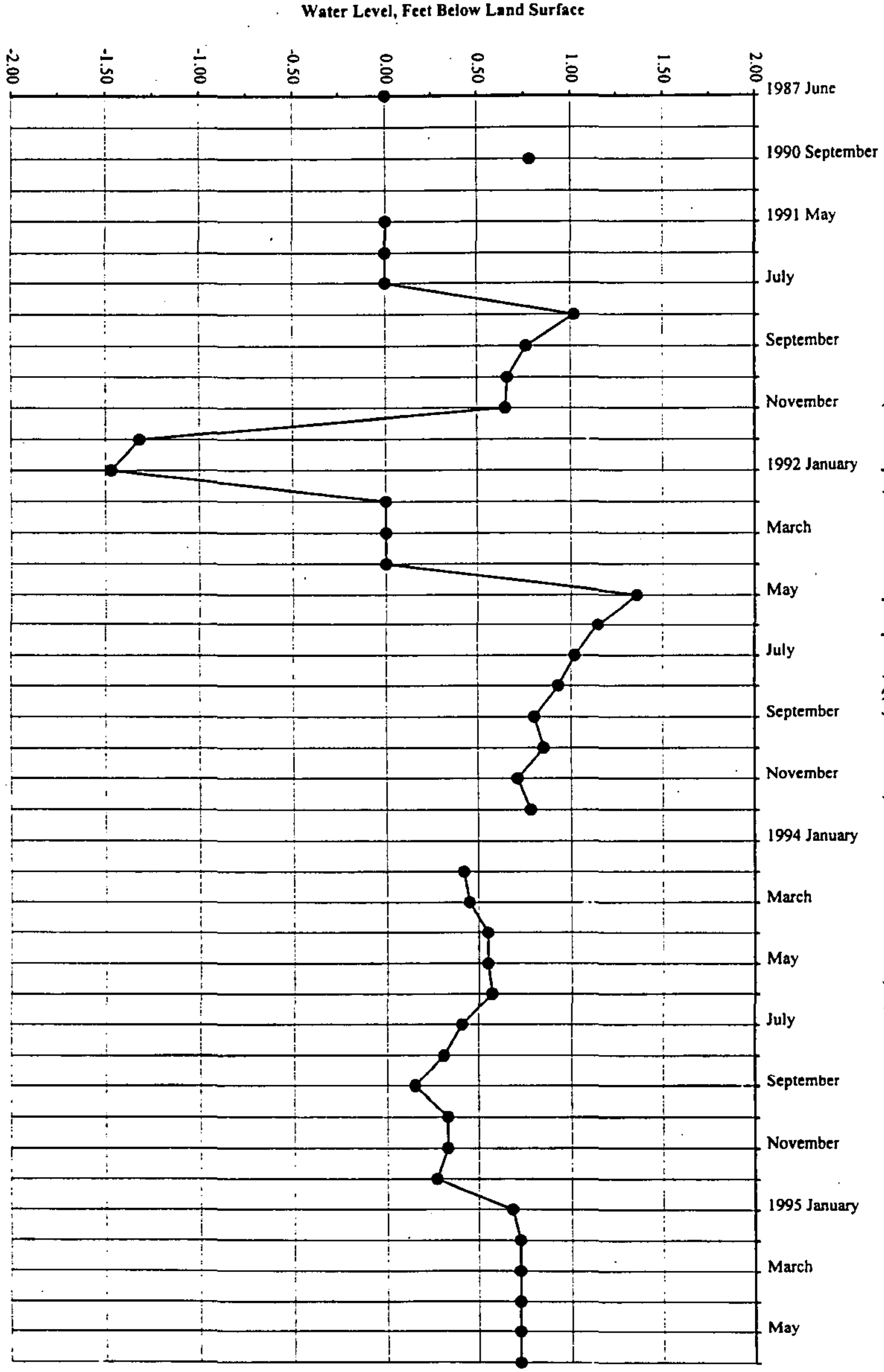
Robert Riggle, 24N/6E-4K1
(well dug to 17 ft bls, 60 inch diameter; surface elevation 426.77 ft msl; Qvr formation)

Robert Ranard 26N/6E-2M1 (well depth 229 ft bls, casing to 229 ft, Q(A)c formation, surface elevation ~490 ft)

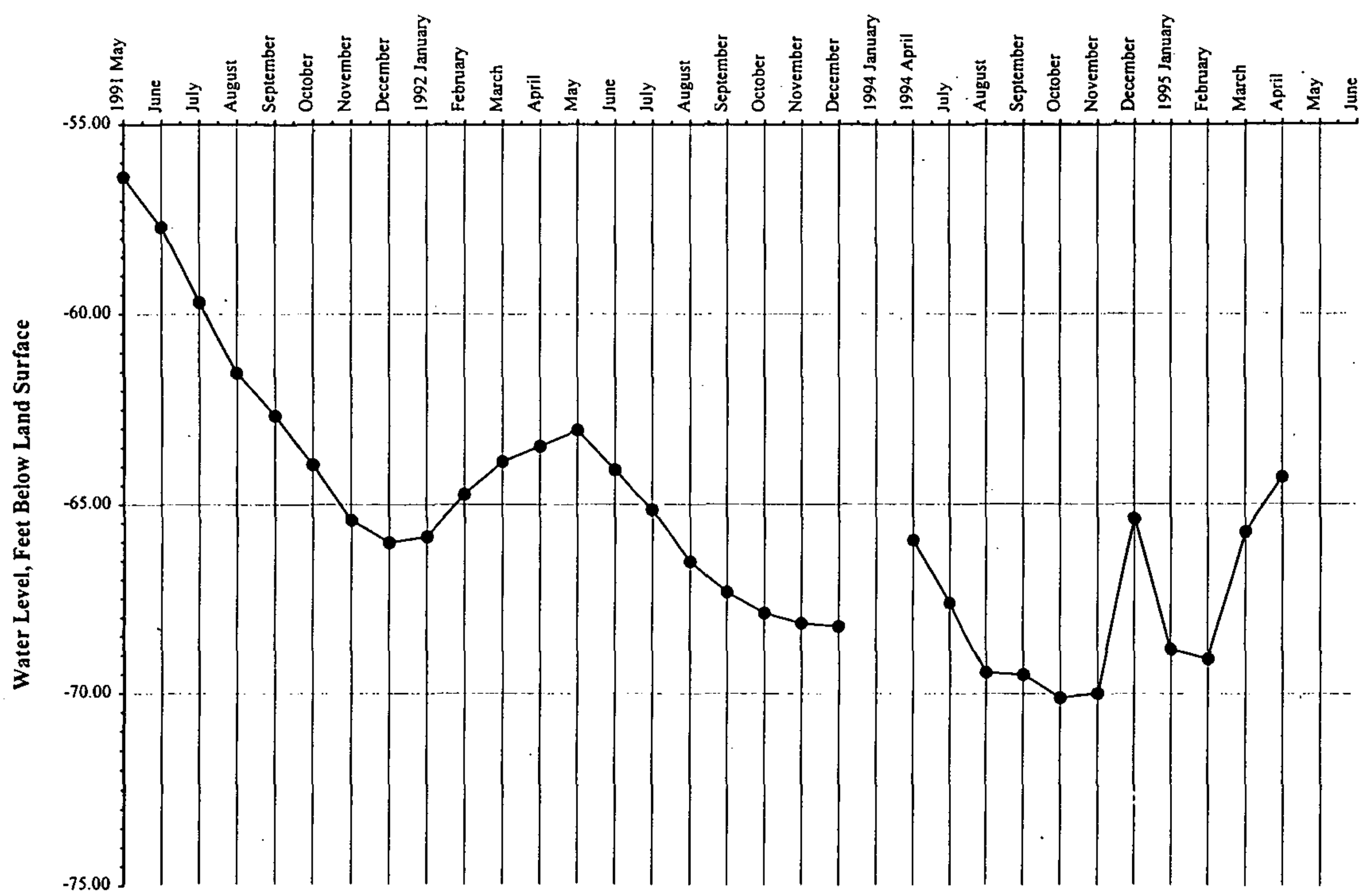


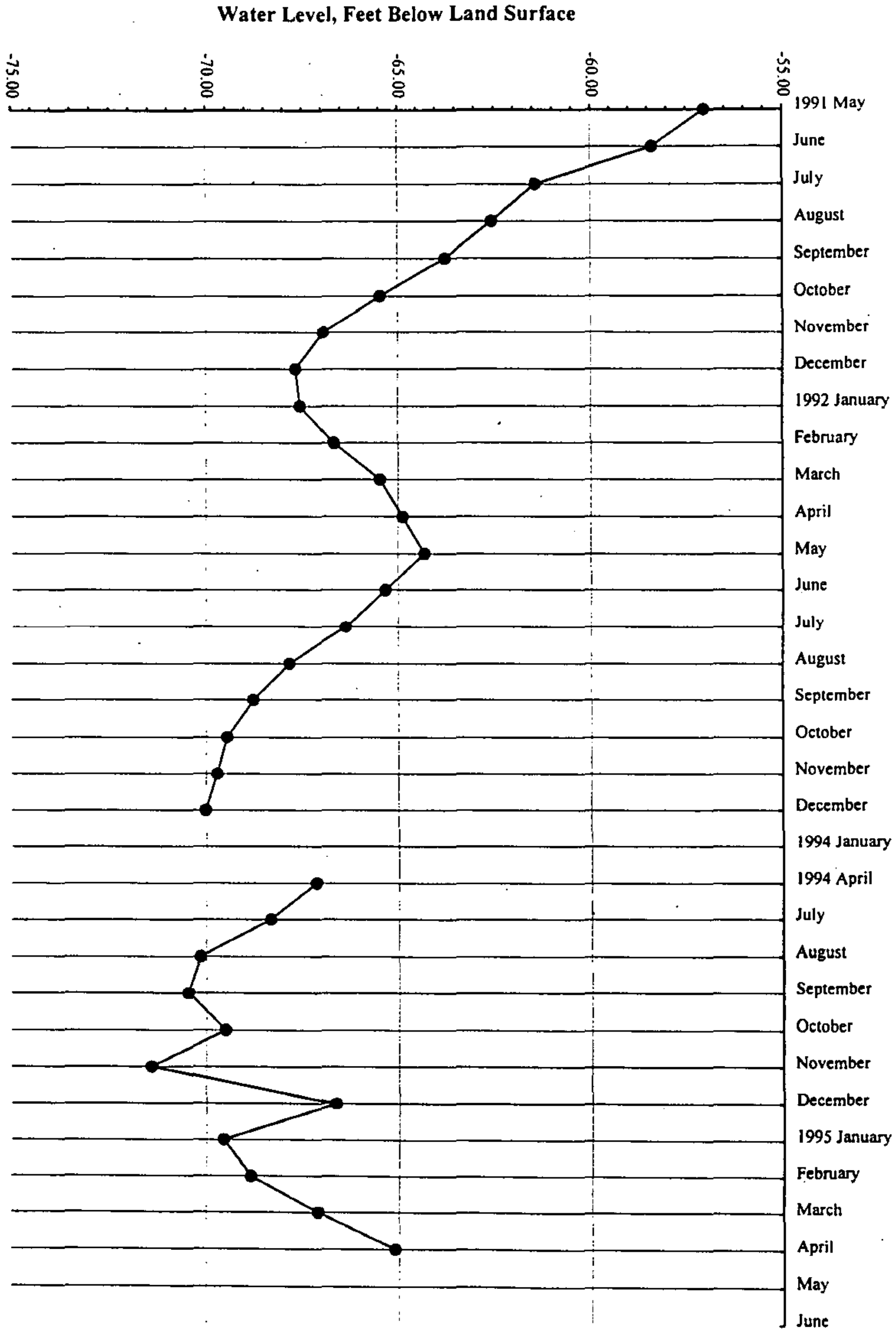
Sammamish Plateau Water & Sewer, 24N/7E-8F2

(888 ft depth, confined multiple aquifers, Q(B)c formation, surface elevation 90 ft msl)



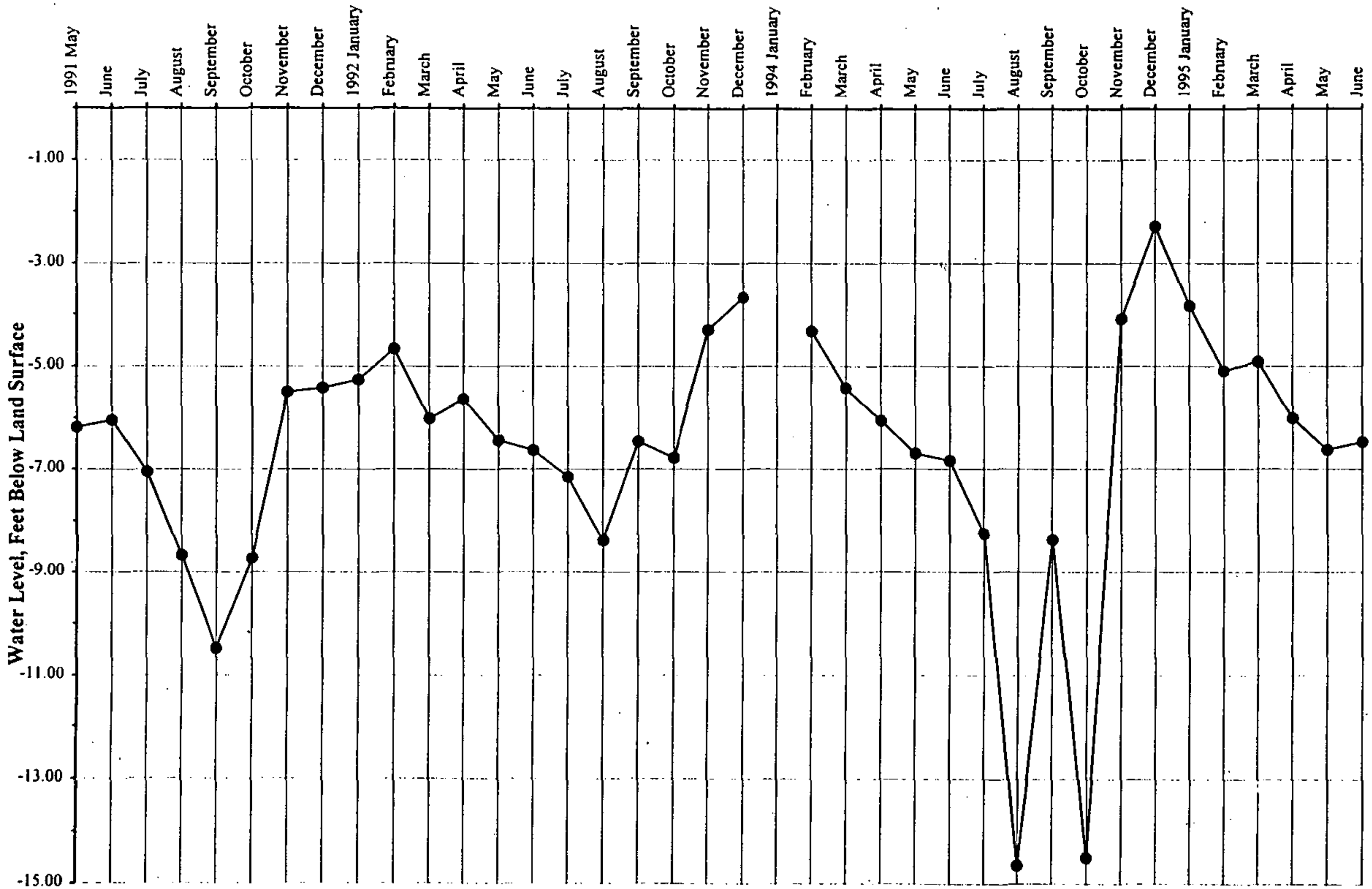
Sammamish Plateau Water & Sewer District, 24N/6E-11L1P01(Qva formation, well depth 135', 2" diameter PVC piezometer, screened from 125'-135', surface elevation ~420' msl)

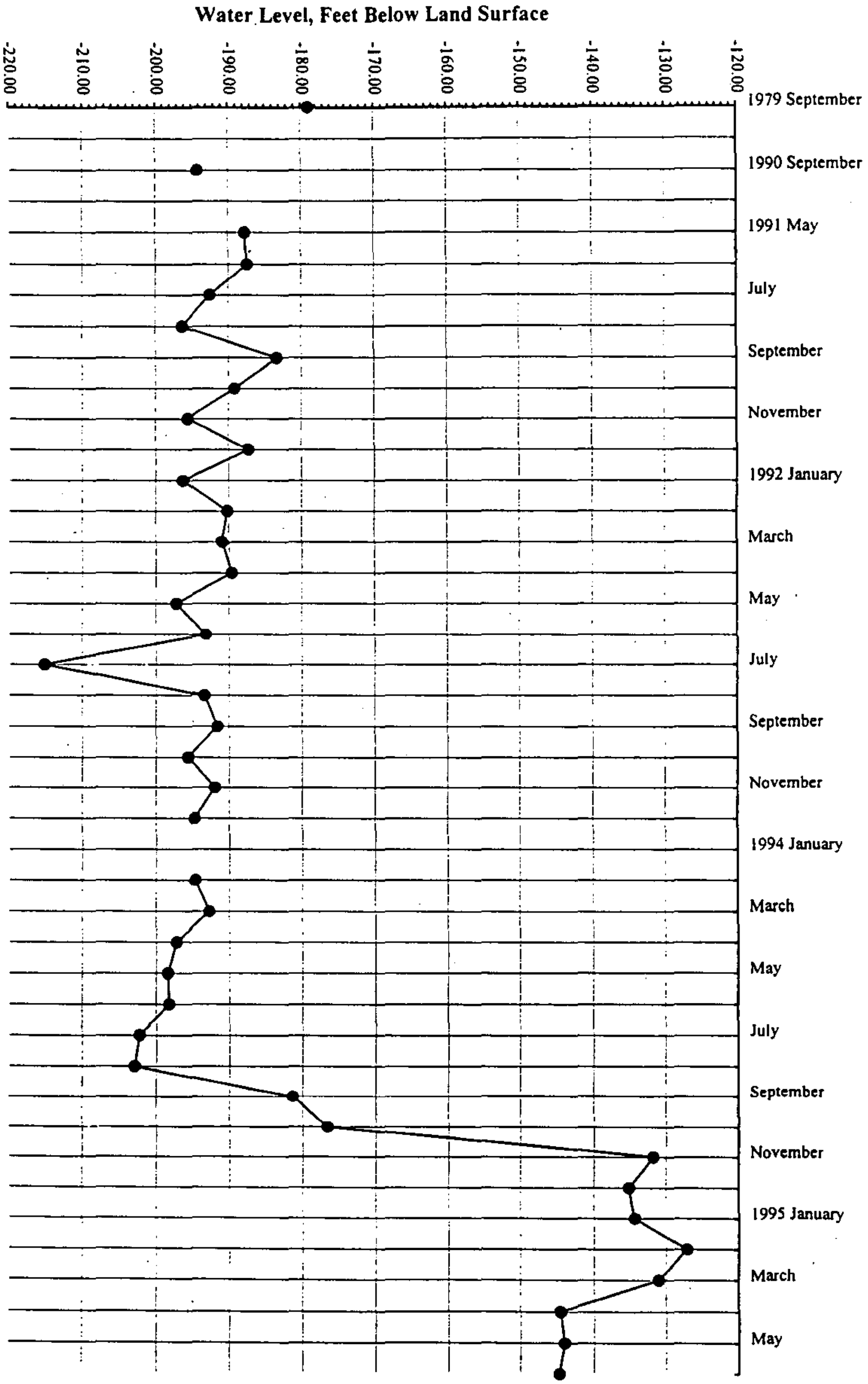




Sammamish Plateau Water & Sewer District, 24N/6E-11L1P02 (Qva formation, well depth 95', 2" diameter PVC piezometer, screened from 85'-95', surface elevation ~420' msl)

Art Schacklett, 26N/7E-9F2 (30 ft well, black shale, surface elevation ~295 ft, bailer test 3 gal/min with 25 ft drawdown after 1 hour)

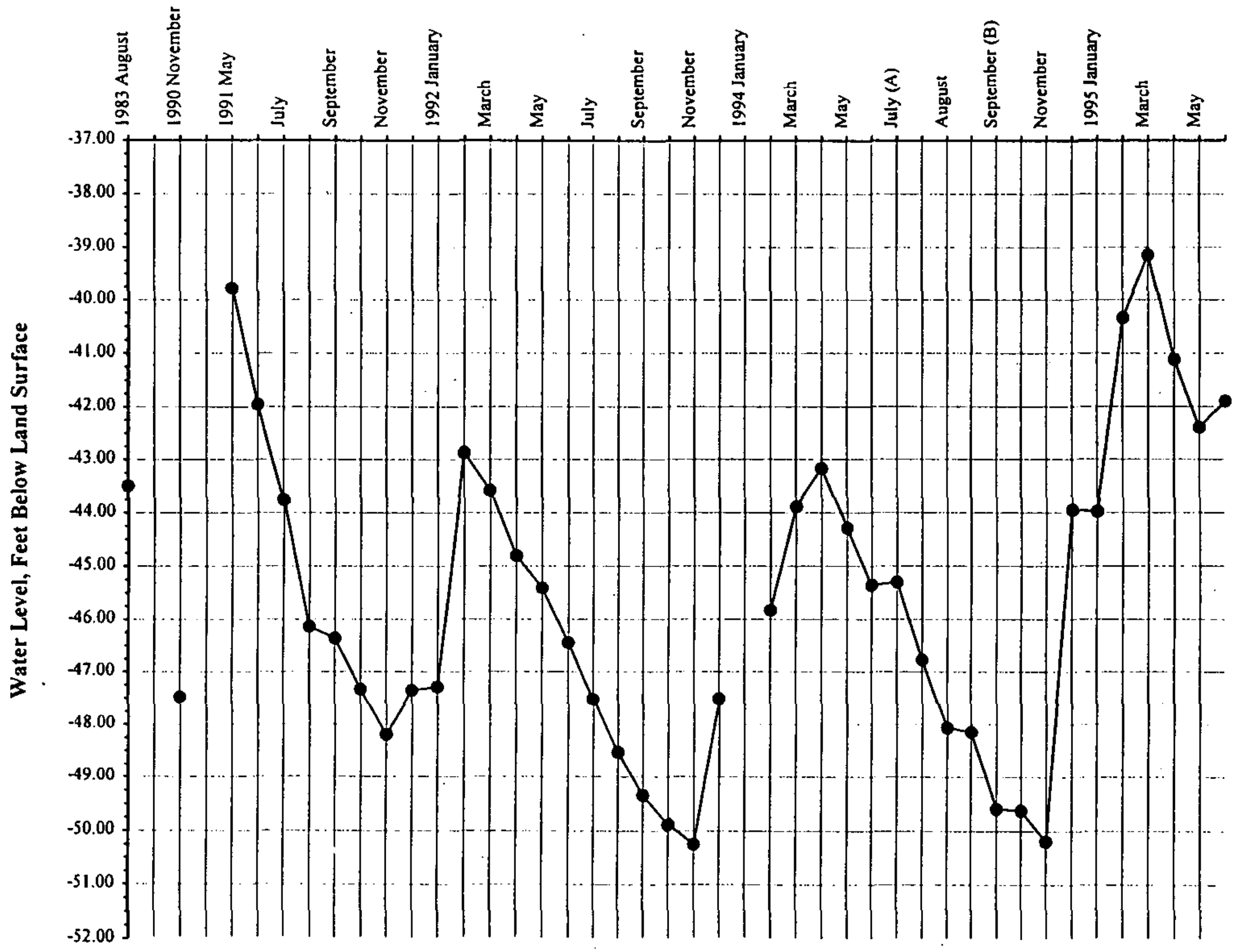




Ben Spiess, 24N/07E-13E01 (398 ft, 8 in. dia., 10 gallons per minute, surface elevation 295 ft msl, fractured basalt at 296 ft below land of casing)

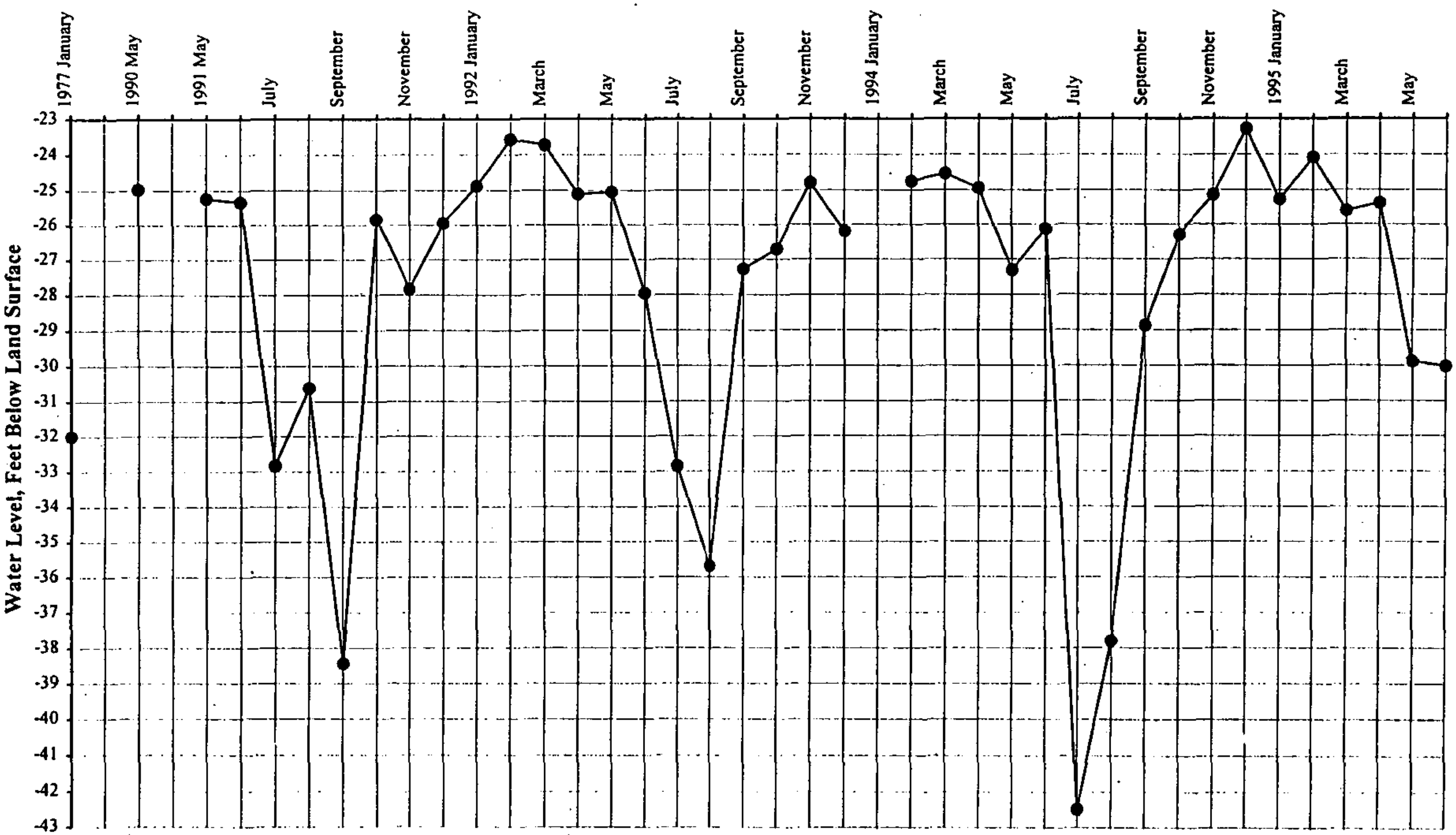
Mr. Stanley Cozad-26N/O7E-30P01

(Qvt formation, 60' depth, surface elevation ~410', bailer test indicated 15 gal/min w/ 2' drawdown after 2hrs)



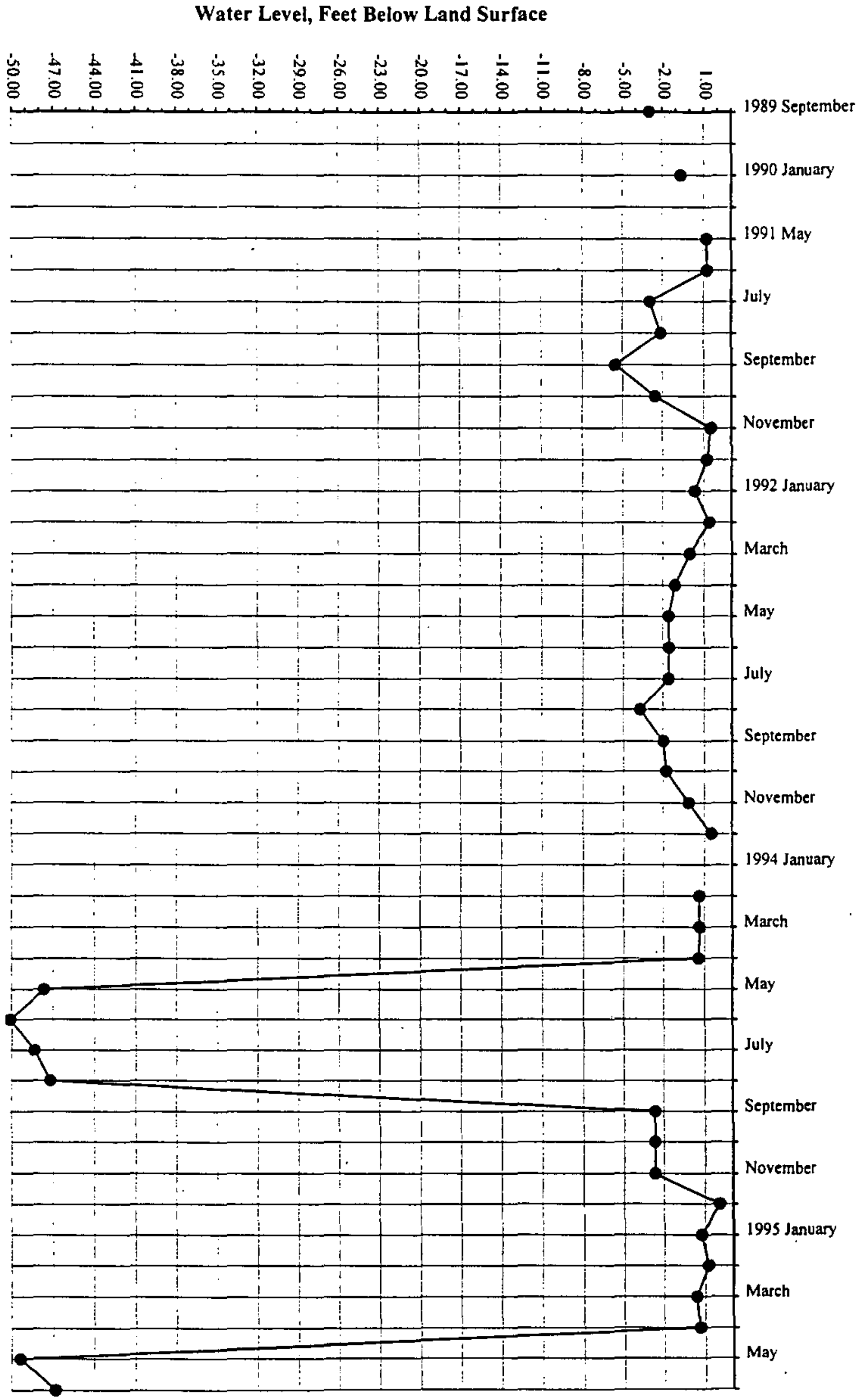
George Sutherland, 25N/6E-20E1

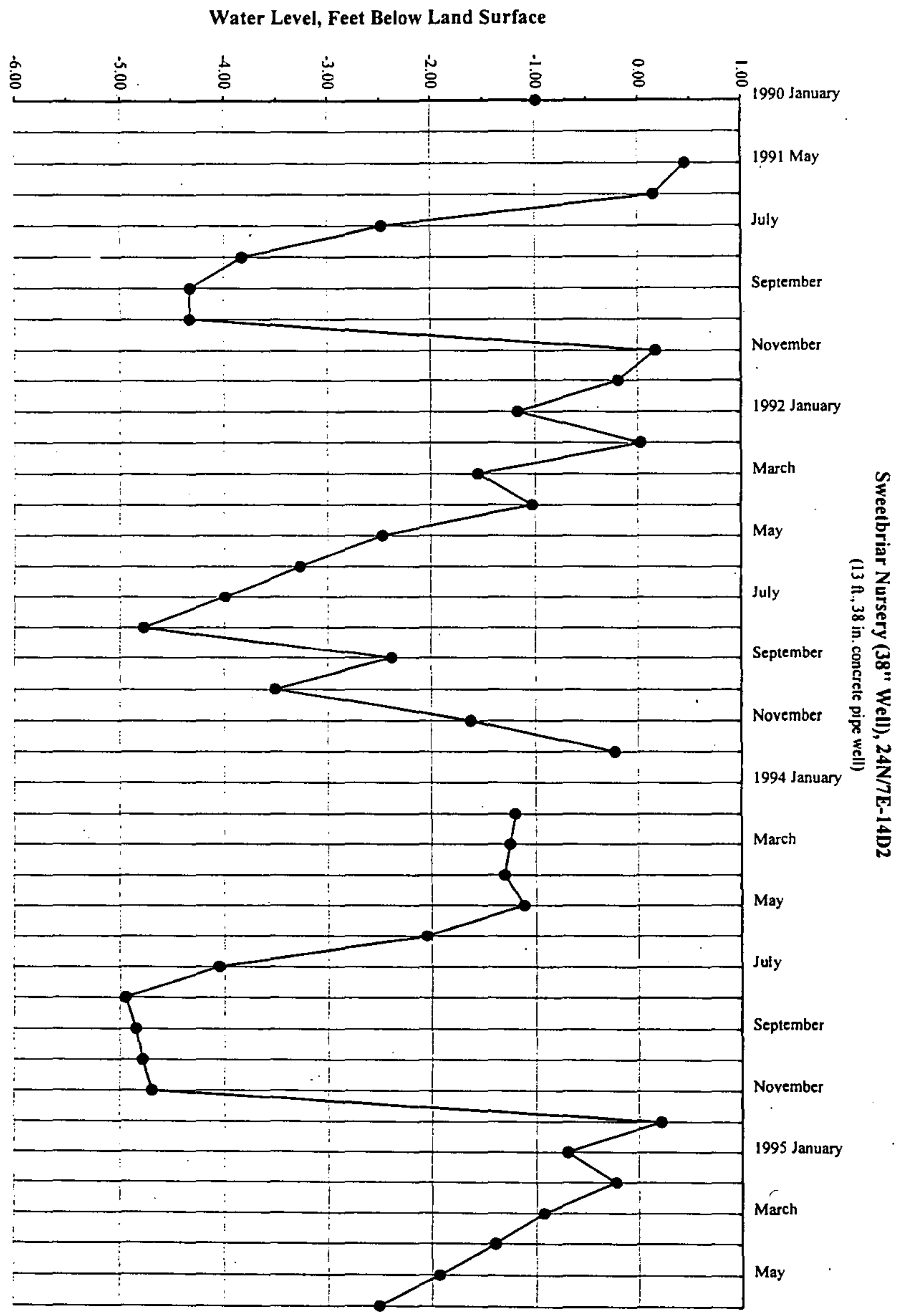
(20 slot screen from 112 to 117 ft bls, and 12 slot from 117 to 122 ft. bls, surface ele. 70 ft msl, Q(B)c formation, 45 gallons per minute with 24 ft drawdown after ? hours)



Sweetbriar Nursery (6" Well), 24N/7E-14D1

(well depth 150 ft., Alluvial Sediments, 5 in. diam. 12 slot screen from 135-150 ft bls)

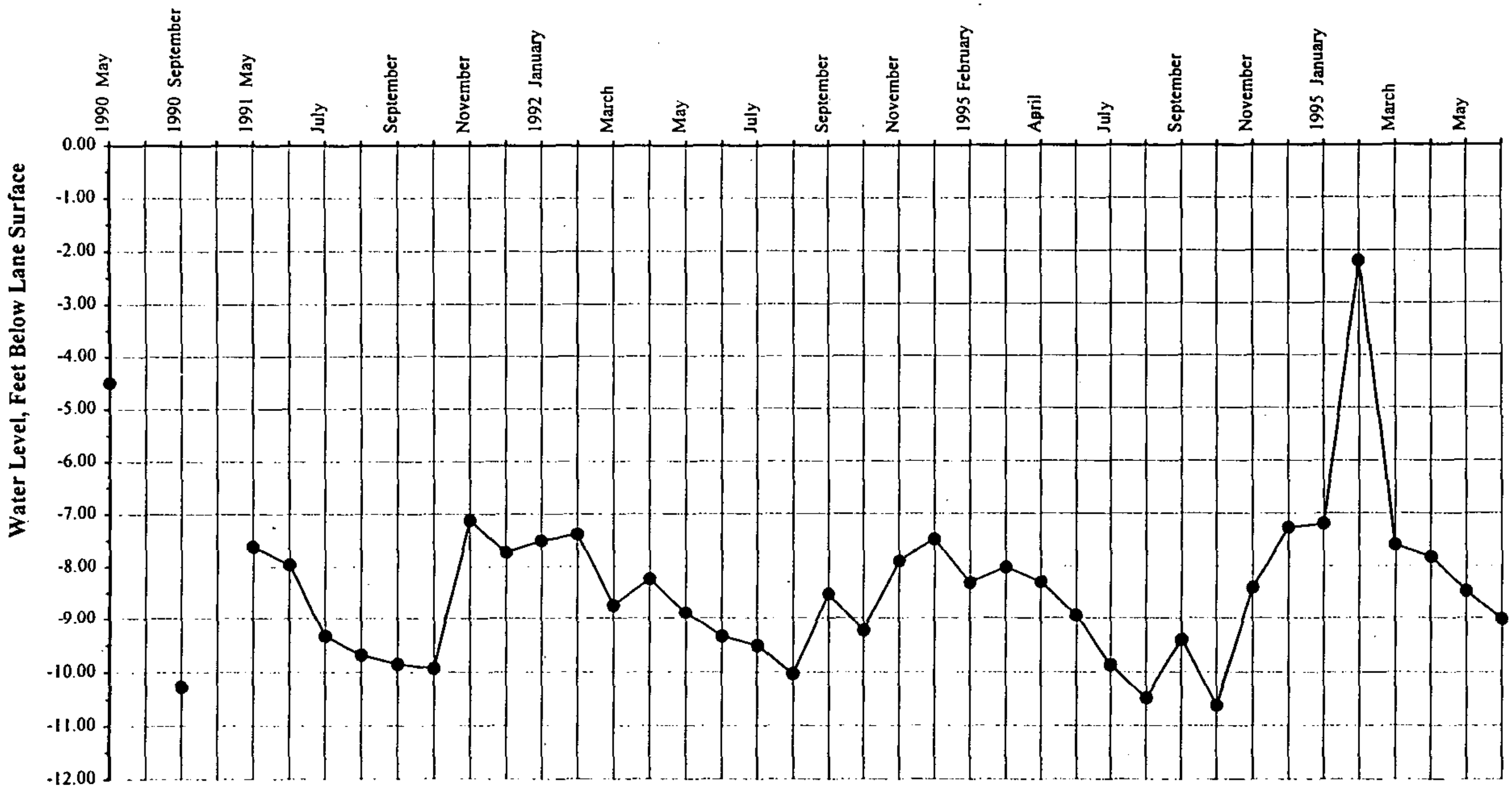


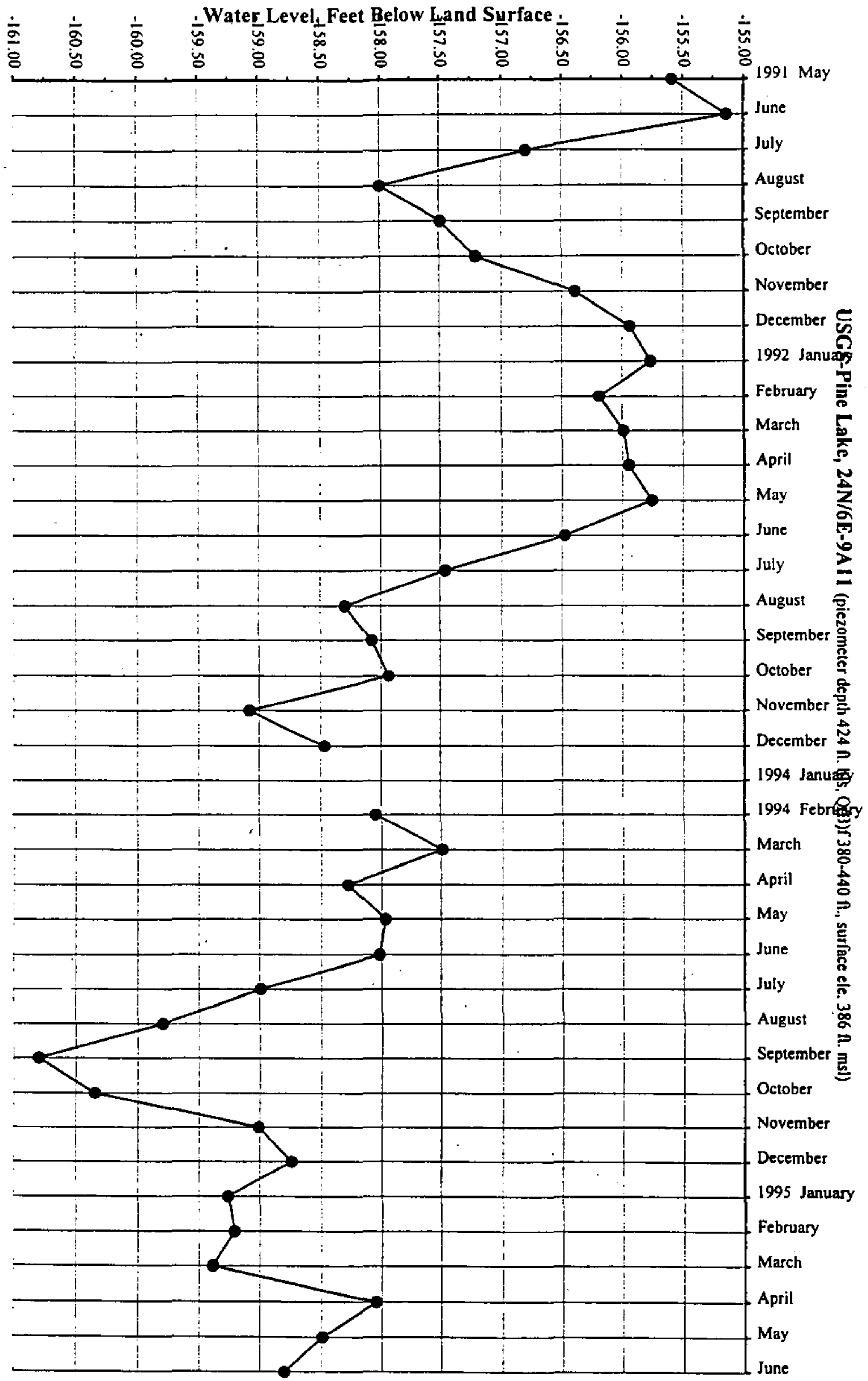


Water Level, Feet Below Land Surface
-6.00
-5.00
-4.00
-3.00
-2.00
-1.00
0.00
1.00
1990 January
1991 May
July
September
November
1992 January
March
May
July
September
November
1994 January
March
May
July
September
November
1995 January
March
May
Sweetbriar Nursery (38" Well), 24N/7E-14D2
(13 ft, 38 in. concrete pipe well)

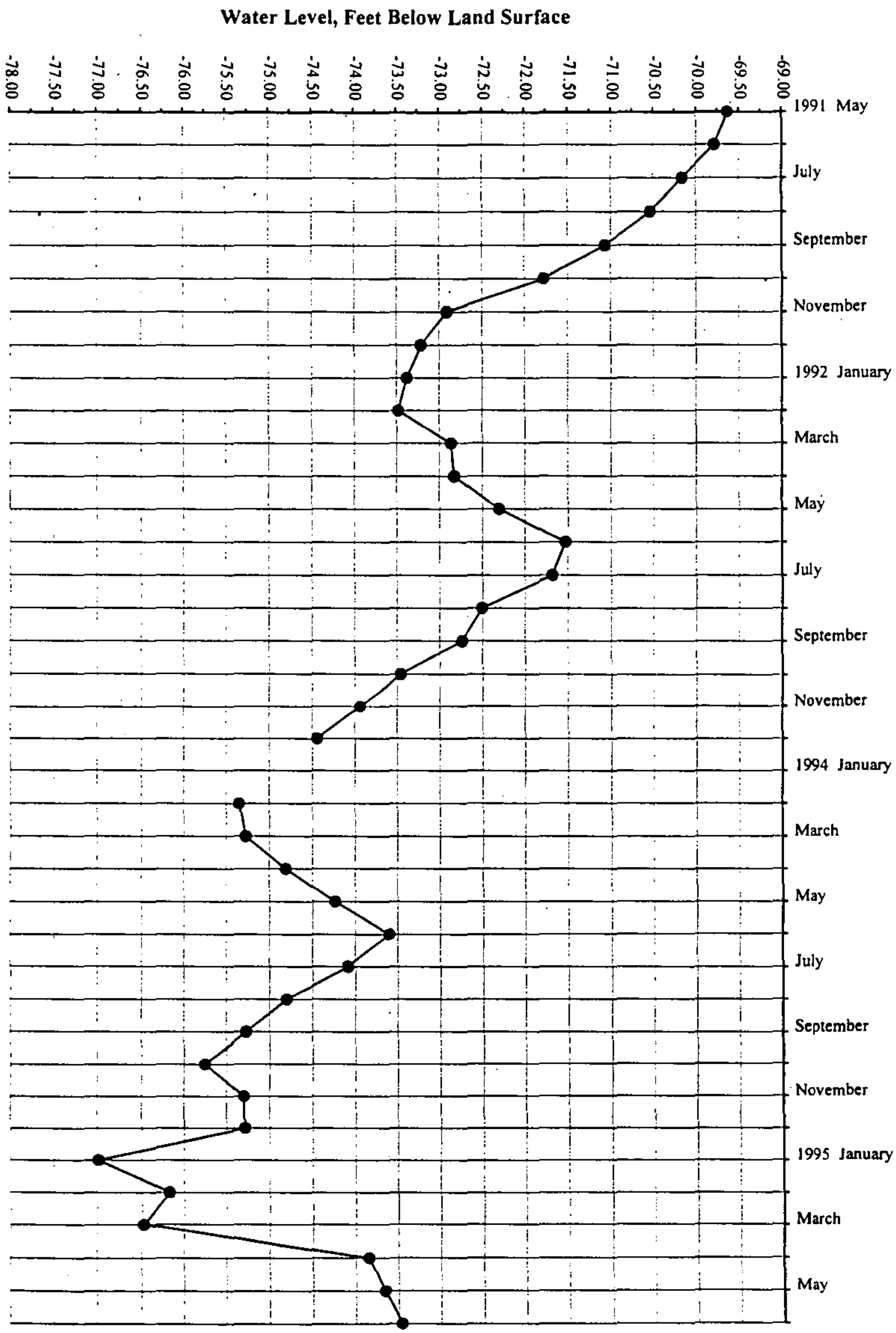
Roger Thorson, 25N/7E-21C1

(35ft., 6 inch casing, no screen, Qal formation, surface elevation 70 ft. msl, 30 gallons per minute with zero drawdown after one hour)

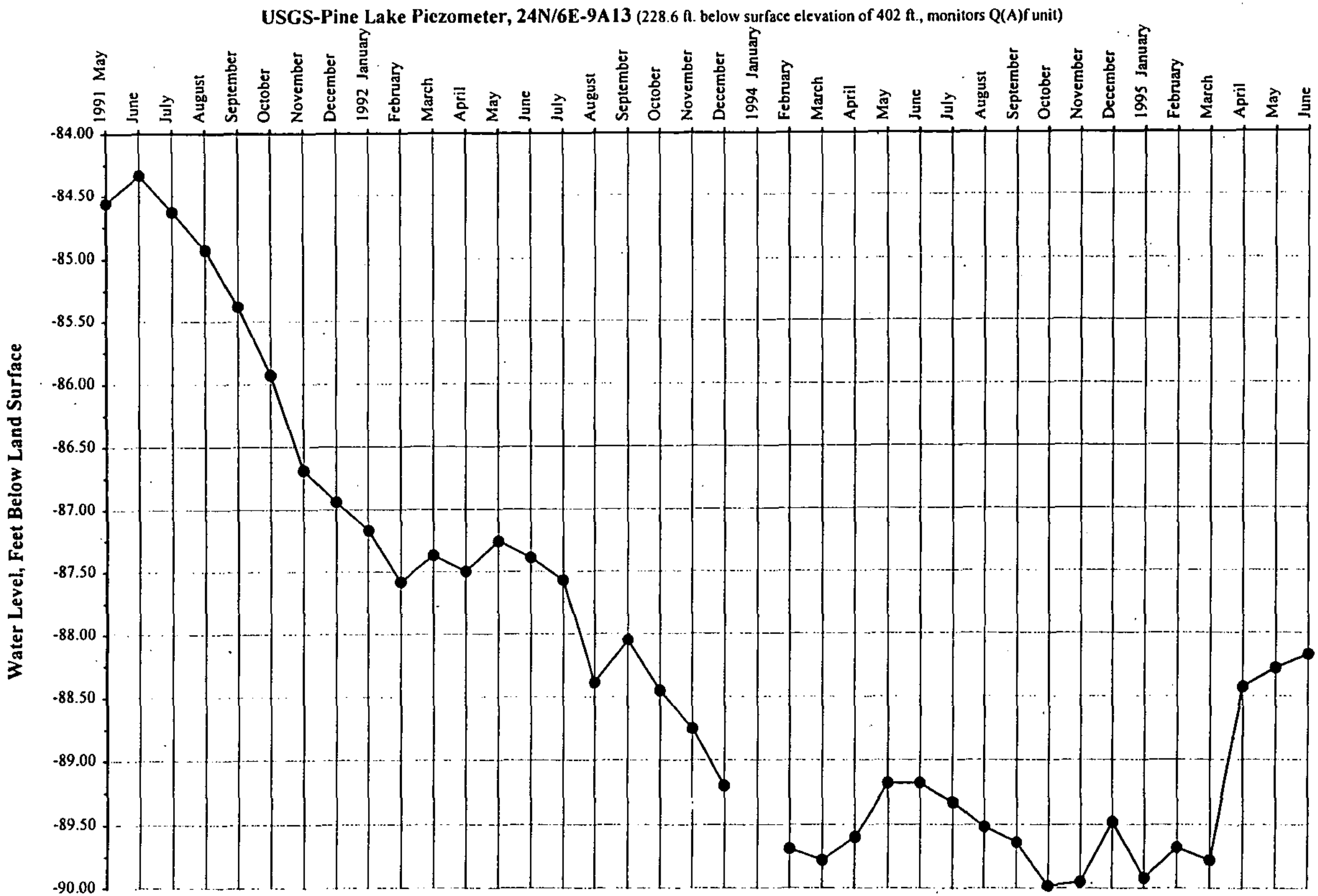


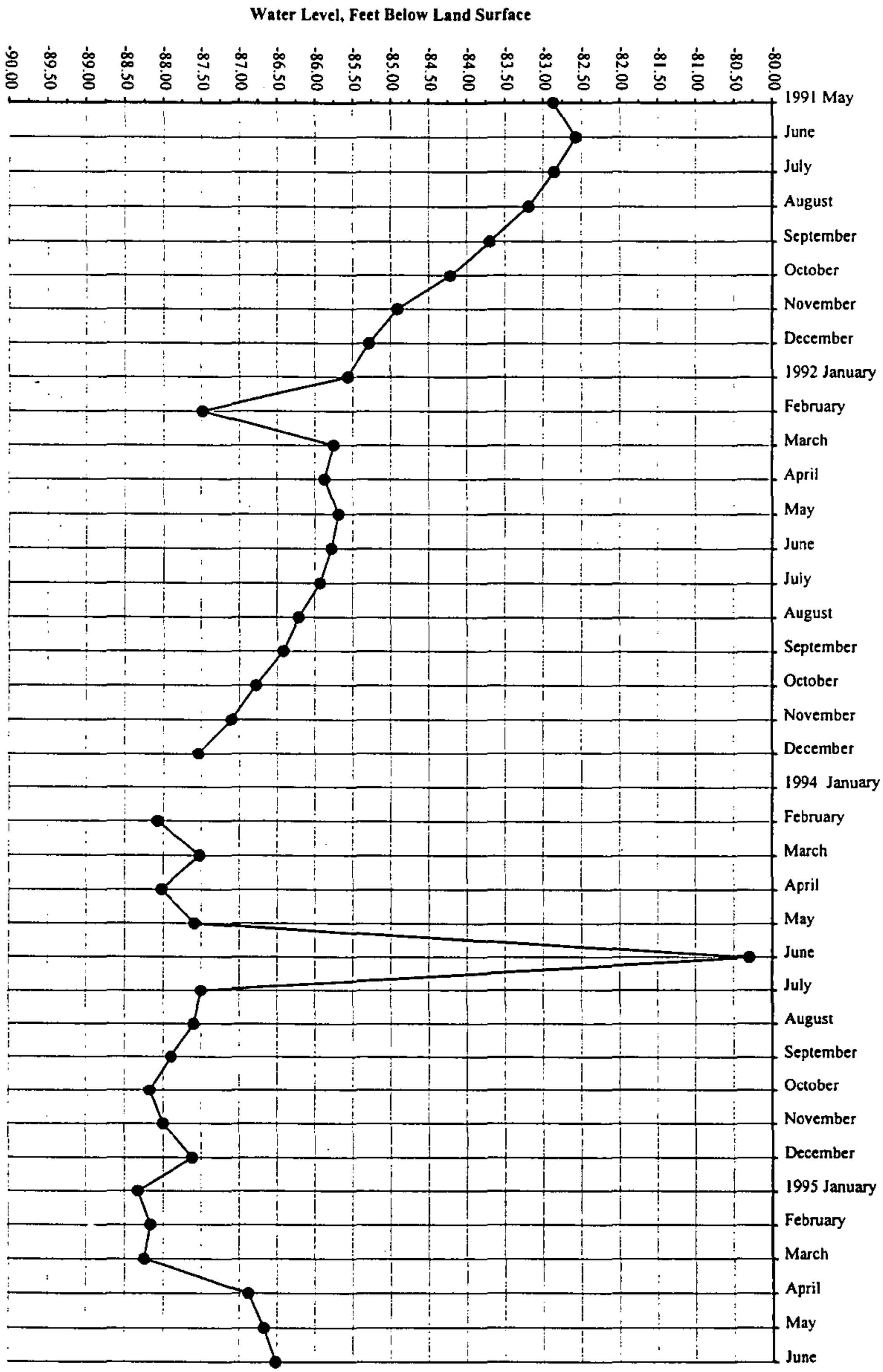


Water Level, Feet Below Land Surface
-161.00
-160.50
-160.00
-159.50
-159.00
-158.50
-158.00
-157.50
-157.00
-156.50
-156.00
-155.50
-155.00
1991 May
June
July
August
September
October
November
December
1992 January
February
March
April
May
June
July
August
September
October
November
December
1994 January
1994 February
March
April
May
June
July
August
September
October
November
December
1995 January
February
March
April
May
June
USGS-Pine Lake, 24N/6E-9A11 (piezometer depth 424 ft.
380-440 ft., surface ele. 386 ft. msl)



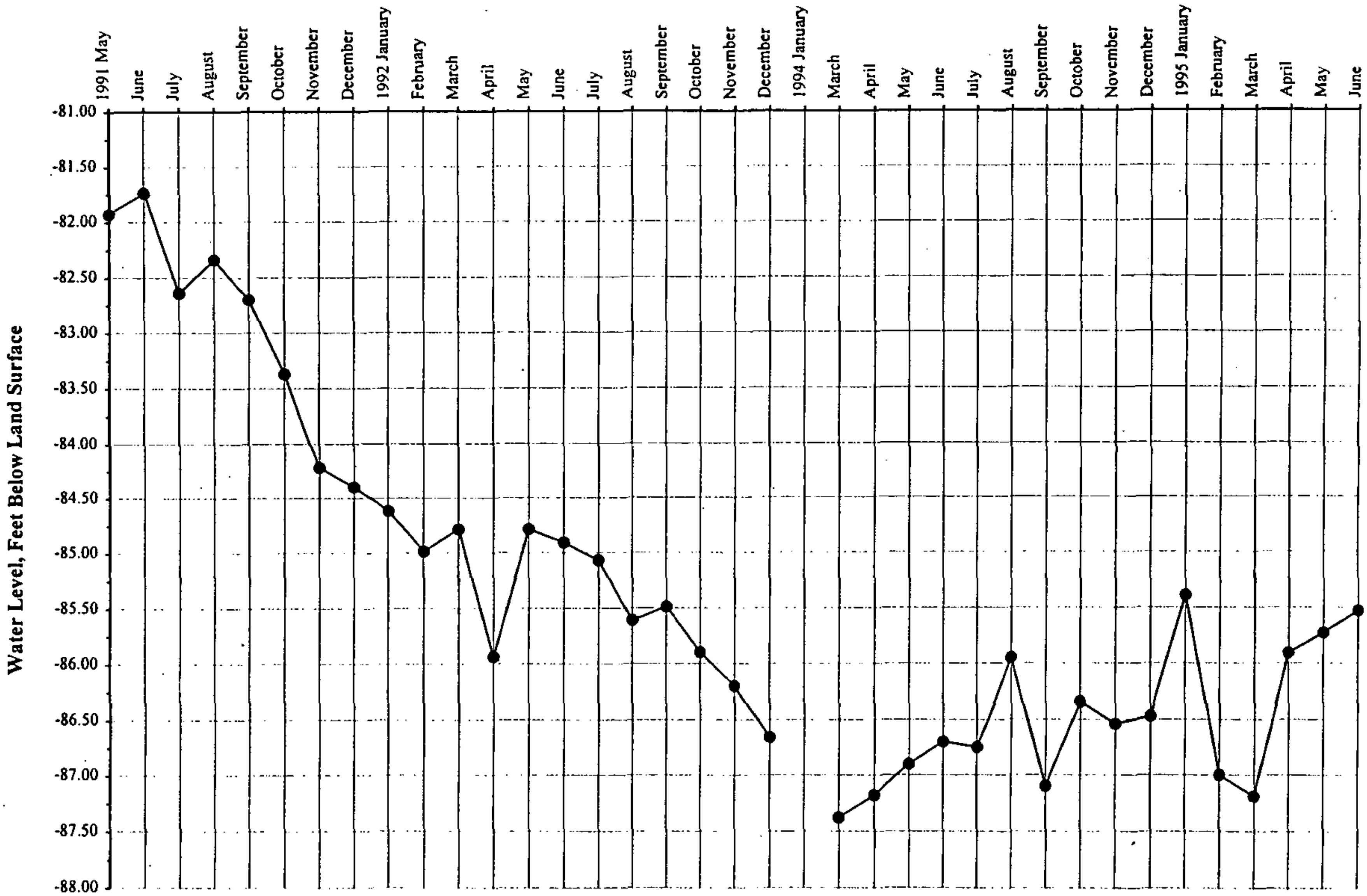
USGS-Pine Lake, 24N/6E-9A12 (piezometer 120.1 ft. below surface elevation of 402 ft msl, Qva formation)


USGS-Pine Lake Piezometer, 24N/6E-9A13 (228.6 ft. below surface elevation of 402 ft., monitors Q(A)f unit)
1991 May
June
July
August
September
October
November
December
1992 January
February
March
April
May
June
July
August
September
October
November
December
1994 January
February
March
April
May
June
July
August
September
October
November
December
1995 January
February
March
April
May
June
Water Level, Feet Below Land Surface
-84.00
-84.50
-85.00
-85.50
-86.00
-86.50
-87.00
-87.50
-88.00
-88.50
-89.00
-89.50
-90.00



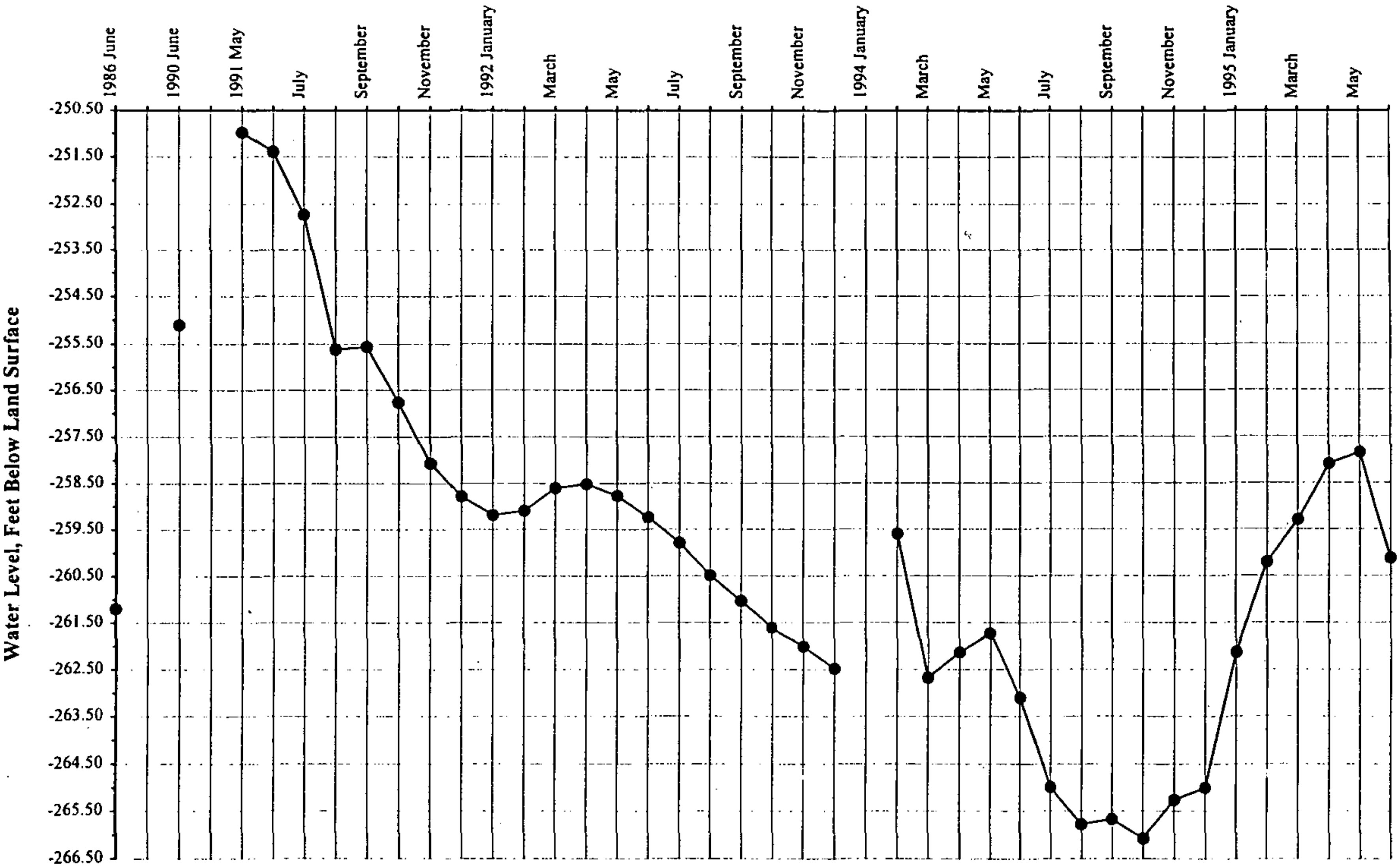
USGS-Pine Lake, 24N/6E-9A14 (piezo depth 203 ft, in the basal portion of Qva, surface elevation 402 ft msl)

USGS-Pine Lake, 24N/6E-9A15 (piezo depth 170 ft, in the median portion of the Qva unit, surface elevation 402 ft)



Robert Vezzoni, 24N/8E-20M1

(281 ft., 6 in. casing in Vashon recessional, 5 ft. 12 slot screen at 276 ft., surface ele. 560 ft.)



Supplement I

Area Characterization

Appendix D

Exploratory Well Log
(Loutsis Park)

Draft

East King County
Ground Water Management Plan

July 1996

RECORD OF WELL LOG GWMP-1

PROJECT: King County/Snoqualmie/WA
PROJECT NO: 953-1100.003
LOCATION: Carnation, WA

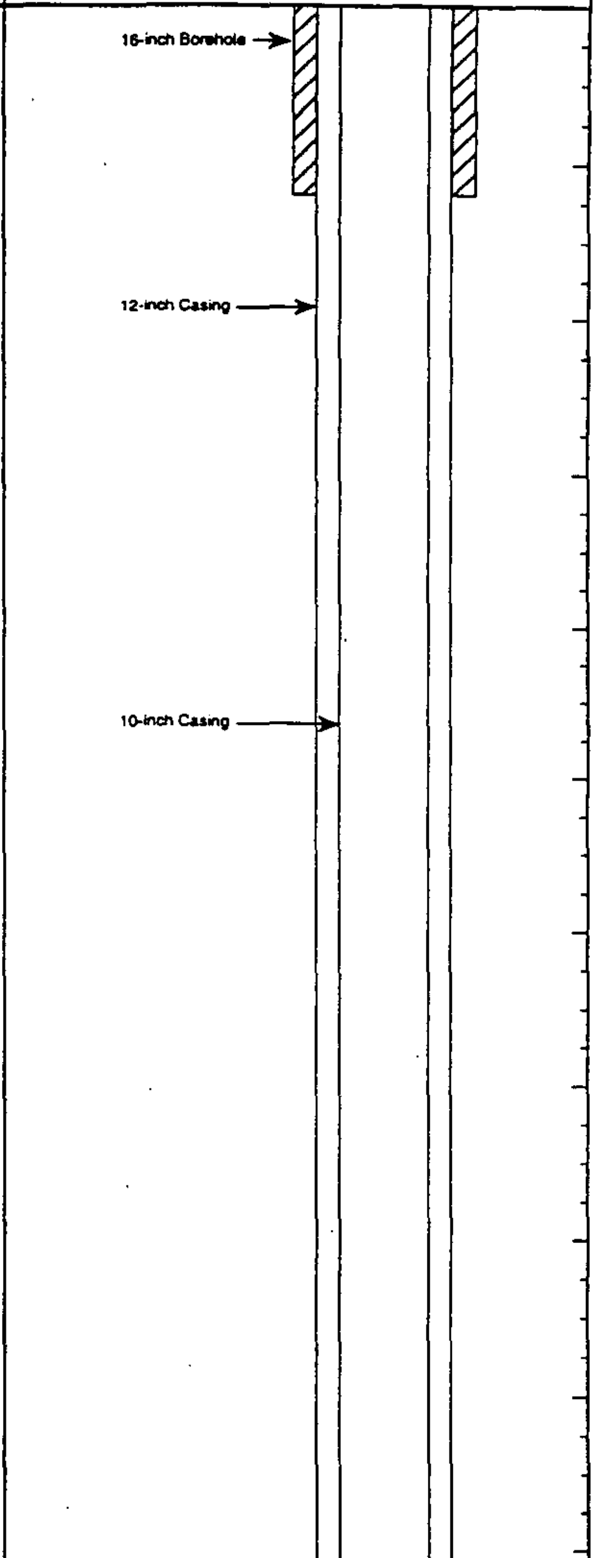
DRILLING DATE: July/August, 1995
DRILL RIG: Speedstar 72
ADDITIVES: Water

DATUM: MSL
COORDINATES N:
E:

COLLAR ELEV: NA
GROUND SURFACE: NA
INCLINATION: -90°

DEPTH (FEET)	ROCK TYPE – DESCRIPTION	SAMPLE NUMBER	SAMPLE TYPE	TEMPERATURE (°C)	CONDUCTANCE (µS/m)	Ph	WATER LEVELS
0	Compact, green-brown, rounded COBBLES and coarse SAND, trace silt		GRAB				
20		1-8					
	Compact, water bearing, dark gray, rounded COBBLES, coarse SAND and GRAVEL with some SILT						
40							
				13	132	7.4	45.5
60	Loose, dark gray, rounded COBBLES and GRAVEL with some SAND	8-16					
				15	150	6.9	
80				14	120	6.9	
	Loose, dark gray, rounded COBBLES and GRAVEL with some SILT						21.2
100		16-24		13	120	7.1	
120				13.5	110	7.0	
	Loose, dark gray, round to subround GRAVEL and SAND						
140		24-32		12.6	115	7.0	22.4
	Loose, gray, COBBLES and GRAVEL						
160				14.7	130	6.9	
							35.5
180	Tight	32-40					
200	Heaving Log continues			11.2	135	7.2	20.8

WELL COMPLETION



SCALE: 1" = 25'
DRILLING CONTRACTOR: Holt
DRILLER: R. Miller

LOGGED: M. Klisch/M. Amann/S. Groom
CHECKED: B. Anderson
DATE: 8/23/95

RECORD OF WELL LOG GWMP-1

PROJECT: King County/Snoqualmie/WA
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LOCATION: Carnation, WA

DRILLING DATE: July/August, 1995
DRILL RIG: Speedstar 72
ADDITIVES: Water

DATUM: MSL
COORDINATES N:
E:

COLLAR ELEV: NA
GROUND SURFACE: NA
INCLINATION: -90°

DEPTH (FEET)	ROCK TYPE / DESCRIPTION	SAMPLE NUMBER	SAMPLE TYPE	TEMPERATURE (°C)	CONDUCTANCE (µS/m)	Ph	WATER LEVELS	WELL COMPLETION
200	Loose, gray, COBBLES and GRAVEL		GRAB	13	135	7.2		
220		40-48		11.3	120	7.3	30.2	
240				11.7	113	7.2		12-inch Casing
260		48-56		11.8	130	7.2		
275	275 — Loose, silty fine SAND, trace to some GRAVEL and COBBLES							
280				11.8	130	7.2		
295	295 — Stiff, gray, sandy SILT and CLAY							10-inch Casing
300		56-64		12.5	130	7.5	104	
320								
340		64-72						
360								
380		72-80						
400	Log continues							

SCALE: 1" = 25'
DRILLING CONTRACTOR: Holt
DRILLER: R. Miller

LOGGED: S. Groom
CHECKED: B. Anderson
DATE: 8/23/95

RECORD OF WELL LOG GWMP-1

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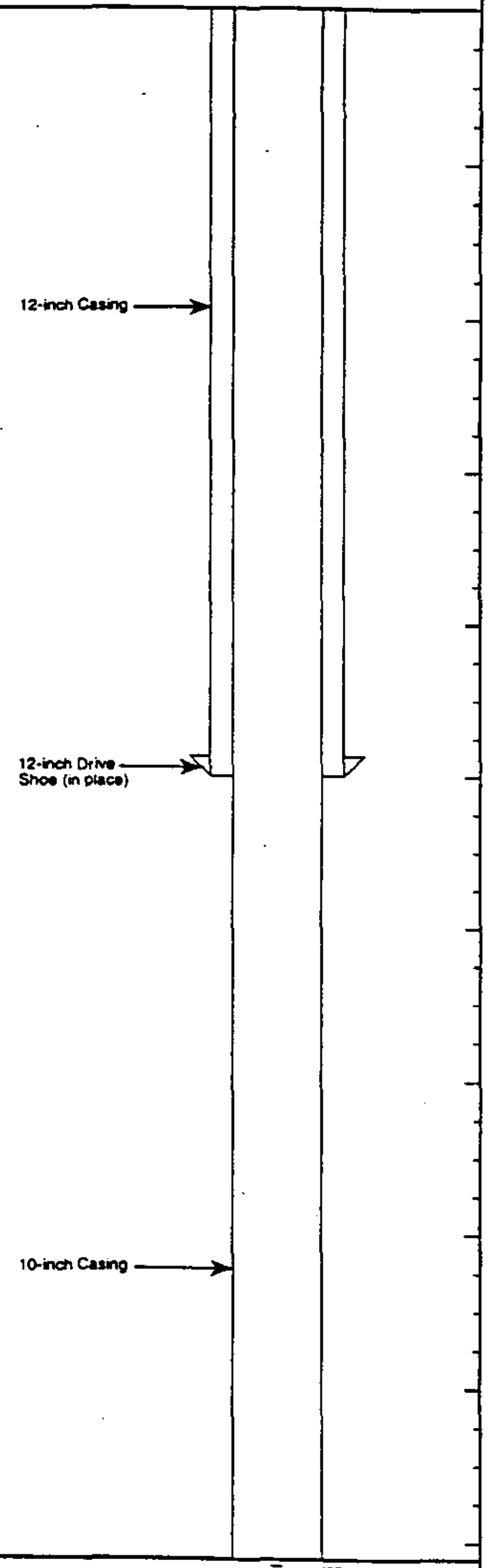
ADDITIVES: Water

DATUM: MSL
COORDINATES N:
E:

COLLAR ELEV: NA
GROUND SURFACE: NA
INCLINATION: -90°

DEPTH (FEET)	ROCK TYPE / DESCRIPTION	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	TEMPERATURE (°C)	CONDUCTANCE (µS/m)	Ph	WATER LEVELS
400	Stiff, gray, SILTY CLAY			GRAB				Dry
420			80-88					
440								
460			88-96					
480								
500			96-104					
520								
540			104-112					
560								
580			112-120					
600	Log continues							

WELL COMPLETION



SCALE: 1" = 25'
DRILLING CONTRACTOR: Holt
DRILLER: R. Miller

LOGGED:
CHECKED: B. Anderson
DATE: 8/23/95

RECORD OF WELL LOG GWMP-1

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PROJECT NO: 953-1100.003
LOCATION: Carnation, WA

DRILLING DATE: July/August, 1995
DRILL RIG: Speedstar 72
ADDITIVES: Water

DATUM: MSL
COORDINATES N:
E:

COLLAR ELEV: NA
GROUND SURFACE: NA
INCLINATION: -90°

DEPTH (FEET)	ROCK TYPE DESCRIPTION	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	TEMPERATURE (°C)	CONDUCTANCE (µS/m)	Ph	WATER LEVELS	WELL COMPLETION
600	Stiff, gray, SILTY CLAY			GRAB				Dry	
620			120-128						10-inch Casing →
640									
660			128-136						
680									
700			136-144						
720									
740			144-152						
760									
780			152-160						
800	Log continues								

SCALE: 1" = 25'
DRILLING CONTRACTOR: Holt
DRILLER: R. Miller

LOGGED:
CHECKED: B. Anderson
DATE: 8/23/95

RECORD OF WELL LOG GWMP-1

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COORDINATES N:
E:

COLLAR ELEV: NA
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INCLINATION: -90°

DEPTH (FEET)	ROCK TYPE / DESCRIPTION	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	TEMPERATURE (°C)	CONDUCTANCE (µS/m)	Ph	WATER LEVELS	WELL COMPLETION
800	Stiff, gray, SILTY CLAY			GRAB				Dry	
820			160-168						10-inch Casing
840									
860			168-176						
880									
900			176-184						
920									
940			184-192						
960									
980			192-200						
1000	End of Log								10-inch Drive Shoe (in place)

SCALE: 1" = 25'
DRILLING CONTRACTOR: Holt
DRILLER: R. Miller

LOGGED:
CHECKED: B. Anderson
DATE: 8/23/95

RECORD OF WELL LOG GWMP-1

PROJECT: King County/Snoqualmie/WA
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800	Stiff, gray, SILTY CLAY			GRAB				Dry	
820			160-168						10-inch Casing
840									
860			168-176						
880									
900			176-184						
920									
940			184-192						
960									
980			192-200						
1000	End of Log								10-inch Drive Shoe (in place)

SCALE: 1" = 25'
DRILLING CONTRACTOR: Holt
DRILLER: R. Miller

LOGGED:
CHECKED: B. Anderson
DATE: 8/23/95

Supplement I

Area Characterization

Appendix E

Geophysical Methodology

Draft

East King County
Ground Water Management Plan

July 1996

B1 TDEM SURVEY

The TDEM technique was selected because it provides several advantages over drilling and other geophysical techniques. TDEM measures electrical resistivity of the subsurface materials in addition to modeling depth and thickness of subsurface layers. The relative concentration of silt and clay in subsurface material is important for hydrologic investigations and empirical data has established a good correlation between resistivity values and the silt and clay concentration in sedimentary material. Clay and silt have low resistivity, while sand and gravel have relatively high resistivity. TDEM also provides better vertical and lateral resolution compared to traditional DC resistivity techniques. The technique utilizes a relatively small survey area which is advantageous for property access and avoiding cultural interference from fences, power lines, and other infrastructure. The TDEM technique is fast (2 to 5 large loop soundings per day) and less expensive than other geophysical techniques and exploratory drilling.

The initial phase of the TDEM survey consisted of seventeen 100-meter loops conducted throughout the survey area. These loops were located in areas with minimal cultural interference that provided good coverage of the survey area. A second phase of the TDEM survey consisted of six 300-meter loops. The larger loops were conducted in areas where there was suitable site access.

B1.1 TDEM Methodology

The TDEM method is a tool to determine subsurface conditions based on the contrasting electrical properties of the materials. The method measures the electrical conductivity of subsurface materials in ohm-meters. The TDEM system consists of a square transmitter loop (copper wire 20 to 500 meters on a side) laid on the ground surface and connected to a regulated current source. The receiver is a smaller multiple-turn coil in the center of the transmitter loop or a large loop coincident with the transmitter loop.

A current is run through the transmitter loop and cycled on and off in pulses of alternating polarity. The cycling of the transmitter current induces eddy currents that decay into the subsurface with time. As these eddy currents decay, they are increasingly influenced by the electrical properties of deeper layers in the subsurface. The eddy currents create a secondary magnetic field that is measured by the receiver and a decay curve is recorded. The decay curve is used to calculate a layered resistivity-depth model of the subsurface based on a best-fit to the observed data.

The depth of exploration varies, depending on the conductivity of the subsurface, the transmitter loop size, available power from the transmitter, and ambient noise levels. As a general rule, the depth of exploration is between one and three times the transmitter loop diameter.

B1.1.1 Limitations

The TDEM method assumes flat-lying and laterally homogeneous layers within the area under the transmitter loop. Dipping interfaces and lateral inhomogeneity within the footprint of the loop will be averaged together when calculating resistivities and depths. The ability to resolve a given layer is dependent on it having sufficient thickness and electrical contrast with the surrounding materials to create an inflection in the decay curve. As a general rule, the vertical resolution is limited to about one-fourth the transmitter loop size. Some uncertainty may result in the interpretation of TDEM data due to the wide range of resistivities that can be associated with a given rock type and the overlap of resistivity values for different rock types. This uncertainty can normally be reduced by a knowledge of the local geology.

B1.2 TDEM Instrumentation

The TDEM survey was conducted using Zonge Engineering and Research Organization instrumentation consisting of a GDP-16 receiver, NT-20 or GGT-10 transmitter, and TEM-3 receiver coil. Both 100-meter and 300-meter transmitter loops were utilized and consisted of 10-16 gauge stranded copper wire. The NT-20 transmitter and TEM-3 receiver coil were used in conjunction with the 100-meter loops and the GGT-10 transmitter and a coincident receiver loop were used in conjunction with the 300-meter loops. The system was powered by two 12-volt deep-cycle batteries.

B1.3 TDEM Data Collection

A total of 23 TDEM soundings were conducted throughout the core survey area (Figure 1). The TDEM survey consisted of seventeen soundings using a square 100-meter transmitter loop and 6 soundings were conducted using a square 300-meter transmitter loop.

The loop wire was premarked at 50-meter intervals and a brunton compass was used to square the loops. An 8-10 ampere current was applied to the transmitter loop and the each sounding was stacked (summed) 1024-2048 times to remove the effects of random noise. In addition, each sounding was recorded three times to assure repeatability of the results. An on-screen display of standard errors was monitored during acquisition to assess the quality of the data being collected. At the completion of each sounding the decay curve was displayed to insure that an adequate level of data quality was being obtained. The data were stored digitally in the memory of the instrument and later downloaded to a computer for processing. The location of the soundings were referenced to the local features and plotted on the 7.5 minute USGS base map.

B1.4 TDEM Data Processing

The TDEM data were downloaded to a personal computer and imported into the computer software package TEMIX-Z Version 3.16 by Interpex Limited. TDEM data are interpreted using a modeling approach. A model is generated, either by an iterative computer methodology (smooth model) or manually (discrete model). A smooth model is a numerically intensive approach where the resistivity of up to 19 layers, with fixed thickness, are varied to generate a TDEM response that best fits the data. The shape of this smooth model was used to guide the manual input of a discrete resistivity-depth model consisting of fewer (generally five or less) layers. This discrete model was submitted to a TEMIX-Z inversion process which adjusts the resistivity and thickness of the discrete layers until a "best fit" to the observed data is achieved. An equivalence analysis was run on the final discrete model to determine a set of equivalent resistivity-depth models that also fit the observed data within a 15% tolerance of the best-fit model. The scatter observed in the equivalence models represents the ability of the observed data to resolve a given layer or resistivity. A plot of the observed data, final resistivity-depth models, and equivalence analysis for each sounding can be found in Appendix C.