AQUIFER STORAGE AND RECOVERY
Hydrogeological Feasibility Study
of
Cooper Mountain Basalt Aquifer

Prepared for
Tualatin Valley Water District

Prepared by
CH2M HILL

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EXECUTIVE SUMMARY

The Tualatin Valley Water District (TVWD) and the City of Beaverton are jointly interested in Aquifer Storage and Recovery (ASR) as a new technology that will enable the agencies to delay expansion of water treatment, storage, and conveyance facilities to meet future peak demands for treated water. ASR involves storing treated drinking water in a suitable aquifer during a period of time when demand is low (winter months) and then recovering the water at a later time when demand is high (summer months). The aquifer penetrated by the ASR well essentially serves as an underground reservoir. The TVWD and Beaverton are interested in the feasibility of eventually developing up to a 10- to 15-million-gallon-per-day (mgd) ASR project in the basalt aquifer system underlying the northern flank of Cooper Mountain of the Tualatin Valley.

This report is a cumulation of data gathered for the TVWD and City of Beaverton. The two agencies share a common philosophy that providing reliable and effective water supply service is a regional issue and strive to work together to serve the regional water needs. Therefore, together they are interested in developing ASR within the Cooper Mountain basalt aquifer to augment current water supply during the peak-demand summer months. The TVWD will take the lead for the ASR permitting and pilot testing program in the northern portion of Cooper Mountain basalt aquifer. The City of Beaverton will proceed with pilot testing at its Hanson Road Well using the information gathered from these studies.

This ASR hydrogeologic feasibility study for the Cooper Mountain basalt aquifer has been prepared as technical documentation in support of the Oregon Water Resources Department (OWRD) ASR pilot study permit application to be filed by the TVWD. Technical issues and concerns that are addressed in the study include the study area's hydrogeologic conditions, storage capacity of the aquifer, potential rate of recharge and recovery, potential for loss of stored water, and water quality compatibility.

From a municipal water production and ASR perspective, the Columbia River Basalt is the most important aquifer within the Tualatin Valley. Basalt flows consist of dense lava flow interiors ranging from 5 to 100 feet thick, with interflow zones, which are typically scoriaceous, rubbly, and very permeable, sandwiched between the dense flow interiors. Groundwater within the basalt is stored and transmitted primarily in the interflow zones. Another physical characteristic of basalt aquifers that may affect groundwater conditions is geologic faults. Numerous fault zones have been identified within the study area, and these faults may have compartmentalized the regional basalt aquifer into smaller sub-units. Faults can influence groundwater flow either by being a conduit of groundwater flow or by acting as a hydraulic barrier.

The northern portion of the Cooper Mountain basalt aquifer has been selected as the site of the ASR pilot project because of its promising hydrogeologic conditions, existing large-capacity wells, and existing conveyance facilities. The TVWD is specifically interested in three wells that are completed in the valley's productive Cooper Mountain basalt aquifer as pilot test wells: the City of Beaverton's Hanson Road well and the TVWD's Schuepbach and

Grabhorn wells. Aquifer tests and borehole geophysical tests were completed on the Schuepbach and Hanson Road wells to further define the basalt aquifer hydrogeologic properties within the study area. Testing results indicate that:

- The aquifer is relatively productive.
- The aquifer has a potentially large storage capacity.
- The aquifer may sustain injection rates of greater than 700 gallons per minute (gpm).
- The groundwater quality in the study area is good.
- The existing wells are suitable for use as ASR wells.

The Schuepbach well will be the first well to be pilot tested. Recharge water for this ASR project can be supplied between November and May from two different sources that have excess treated drinking water supply during the winter: the JWC Fern Hill water treatment plant, which derives its water from the Trask and Tualatin Rivers, and the Portland Bull Run water supply. The first pilot test, at the Schuepbach well, will use Bull Run water for recharging the aquifer. At an estimated recharge rate of 1 million gallons per day, or 700 gpm, more than 120 million gallons of water could be stored in each well during a 4-month recharge period from December through March; this includes down time for maintenance and well redevelopment.

Using the estimated injection total of 100 million gallons of water for storage over a 4-month period, the distance that the recharge water would move from the injection well is estimated to be approximately 620 feet for the Hanson Road ASR well and 580 feet for the Schuepbach ASR well. These estimates indicate that, even with large storage volumes, the basalt aquifer would store the recharge water within a fairly short distance of the well.

Injection of recharge water into the aquifer would cause water levels to rise in the immediate vicinity of the injection well. Because the aquifer transmissivity is relatively high, the increase in water level near the injection well is not expected to be substantial; approximately 50 feet at the injection well (injecting at a rate of 700 gpm) and less than 1 foot within 1/2 mile of the injection well. The numerous faults in the basalt could also influence the rise in water levels by promoting an increase in head during recharge, if the faults create a barrier to groundwater flow. The significance of any nearby faults and the potential for unexpected head increases to affect ASR operation will be evaluated as part of the pilot testing and implementation phases of this project.

Loss of stored recharge water could occur through natural groundwater movement, interception by other pumping wells, or discharge to springs or surface water. CH2M HILL was unable to identify any large-capacity pumping wells or springs in the study area discharging from the basalt aquifer. Johnson Creek is the nearest surface water drainage. There is a potential for the creek to interact with (provide recharge to or receive water from) the uppermost basalt interflow zone. The potential for groundwater discharge to Johnson Creek will be further evaluated during the ASR pilot test. The potential for displacement and loss of native groundwater out of the aquifer system as a result of injection is not expected to be significant; the basalt aquifer that encompasses the Cooper Mountain area has a radius of 12,000 feet and contains approximately 35.5 billion gallons of water in its upper 400 feet. The 100 to 200 million gallons of water introduced and stored in the upper portion of the aquifer at each ASR well would represent less than 0.6 percent of the total volume, and is therefore not expected to have a significant (or possibly even measurable) effect.

For an ASR project, a thorough understanding of recharge (source) water quality and the geochemical interaction between the recharge water and the aquifer being recharged is necessary. Water quality analyses and geochemical modeling indicate that recharge will improve the existing groundwater quality and that chemical reactions resulting from mixing of the recharge and the native water are not expected to be significant. Some iron hydroxide precipitation (that is, iron going from a dissolved phase to a solid phase) is expected to occur as the oxygenated recharge water is injected into the relatively reducing groundwater environment. This precipitation is not expected to clog the well or aquifer because of the relatively large pore spaces present in the basalt aquifer. The final operation of the ASR system would be designed to control this circumstance. Chemical reactions are also not expected to degrade native groundwater quality or adversely affect the quality of the water recovered from the well. The quality of the recovered water is expected to meet all Oregon Health Division drinking water standards. Re-chlorination or pH adjustment may be necessary after the water is recovered and before it is pumped into the distribution system.

Details of the proposed pilot test project will be presented in a pilot study work plan. The plan will contain information regarding the proposed injection, storage, and recovery rates and schedule; engineering design details; and the monitoring program. The pilot study work plan will be submitted after the OWRD has had an opportunity to review this hydrogeologic feasibility report.

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ABBREVIATIONS AND ACRONYMS

ASR	Aquifer Storage and Recovery
bgs	below ground surface
cps	counts per second
DBPs	disinfection by-products
DEQ	Oregon Department of Environmental Quality
EPA	U.S. Environmental Protection Agency
gpd/ft	gallons per day per foot
gpm	gallons per minute
HAAs	haloacetic acids
JWC	Joint Water Commission
MCL	maximum contaminant level
mgd	million gallons per day
mg/L	milligrams per liter
MMLs	maximum measurable levels
msl	mean sea level
OAR	Oregon Administrative Rule
OHD	Oregon Health Division
OWRD	Oregon Water Resources Department
PHREEQE	pH Redox Equilibrium Equations (USGS geochemical model)
PVC	polyvinyl chloride
TDSs	total dissolved solids
THM	trihalomethane
TOC	total organic carbon
TSS	total suspended solids
TVWD	Tualatin Valley Water District
UGB	Urban Growth Boundary
USGS	U.S. Geological Survey

GLOSSARY

Activity–The measure of the reactivity of a substance; it is dependent on the ionic strength of the solution.

Anticline–A geologic term that describes large-scale structures associated with folded rock units. This term describes the portion of a fold that is generally concave downward, in which the middle of the folded terrain contains stratigraphically older rock.

Aquifer–Saturated rock or sediment that is permeable enough to transmit significant quantities of water to wells and/or springs.

Aquifer test–A test involving the withdrawal of measured quantities of water from, or the addition of water to, a well and the measurement of the resulting changes in head in the aquifer both during and after the period of discharge or addition.

ASR (Aquifer Storage and Recovery)–A water supply technique that involves storing drinking water in the ground. Drinking water is injected in a suitable aquifer during a period of time while the demand for drinking water is low (winter) and removed from the same well at a later time when seasonal demands for water are high (summer). Because ASR is not a source of water, but rather a storage mechanism, it can be used to balance peak and low demands on a water supply system.

Basalt interflow zone–A zone of rock and/or sediment occurring between individual basalt flows; typically scoriacious, rubbly, and very permeable.

Borehole geophysics–The use of one or more geophysical techniques, such as spinner logging, gamma logging, or caliper logging, to determine the physical characteristics of the borehole and the surrounding geology and hydrogeologic conditions.

Brackish water–Describes water conditions that are not appealing to the taste because of the high levels of salts (or dissolved compounds such as sodium or chloride).

Caliper log–A borehole geophysics technique that produces a continuous record of the hole diameter, made with a mechanical probe having one to six arms.

Drawdown–The distance between the static water level measured within a well and the water level created by the cone of depression developed during an aquifer test.

Fault–A geologic structure that is a fracture or zone of fractures along which there has been displacement of the sides relative to one another, parallel to the fracture.

Gamma log–A borehole geophysics technique that logs the natural radioactivity of the rocks penetrated by a drill hole.

Groundwater, confined–Water within an aquifer that is under greater-than-atmospheric pressure as a result of an overlying layer that has a low hydraulic conductivity.

Groundwater, unconfined–Water within an aquifer that has a water table.

Head–Energy stored in a water mass produced by elevation, pressure, or velocity.

Hydraulic conductivity–A measure of the ease with which an aquifer transmits water.

Hydraulic gradient–The change in head (groundwater elevation) divided by the change in distance in a given direction.

Leaky aquifer–A confined aquifer whose confining beds will conduct significant quantities of water into or out of the aquifer.

National Geodetic Vertical Datum of 1929 (NGVD)–A datum maintained by the U.S. Coast and Geodetic Survey. Replaces mean sea level.

Negative boundary–Description of a barrier that can be present within an aquifer system that restricts partial or total groundwater movement across that boundary (such as a fault, or the contact plane between a gravel unit and a crystalline rock mass).

Porosity–The void portion of an aquifer in which water is stored and through which groundwater flows.

Quaternary–The name for a period of time on the Geologic Time Scale that occurred beginning 2 to 3 million years ago and extends to the present day.

Recovery data–The aquifer test data set that is collected following the end of the withdrawal or addition of water to the aquifer system.

Reducing–An electrochemical process whereby a substance gains an electron (or it decreases in oxidation number); a reducing environment or condition is typically associated with a low-oxygen environment.

Saturation index–A ratio of the dissolved activities (concentrations) of chemical elements in a solution to the equilibrium constant. The saturation index provides a convenient means of evaluating whether, at equilibrium, a mineral will have a tendency to dissolve into the solution or precipitate from solution.

Semi-confining low-permeability layer–A layer or zone of generally low permeability underlying or overlying more permeable aquifer material that retards the movement of groundwater.

Spinner log–A borehole geophysics technique that logs the fluid velocity within the well under static or dynamic (pumping) conditions using an impeller flowmeter.

Stiff diagram–A graphical (visual) way of representing the general chemistry of a groundwater sample; is useful for comparing groundwater samples.

Storativity (coefficient of storage)–A term used to define an aquifer's hydraulic property representing the volume of water released from storage in a vertical column of 1.0 square foot when the water table (or piezometric surface) declines 1.0 foot. In an unconfined aquifer, it is approximately equal to the specific yield.

Syncline–A geologic term that describes large-scale structures associated with folded rock units. It describes the portion of a fold that is generally concave upward, in which the middle of the folded terrain contains stratigraphically younger rock.

Tertiary–The name for a period of time on the Geologic Time Scale that occurred spanning time from 65 million years ago to 2 or 3 million years ago.

Transmissivity–The product of hydraulic conductivity multiplied by aquifer thickness; a measure of the ability of an aquifer to produce water.

Unsaturated zone–The zone between the land surface and the water table, where the majority of the pore spaces are occupied by air.

Water table–The groundwater surface in an unconfined aquifer, the point at which groundwater occurs at atmospheric pressure.

Section 1
INTRODUCTION

This report presents the results of CH2M HILL's Aquifer Storage and Recovery (ASR) hydrogeologic feasibility study of the Cooper Mountain basalt aquifer located near Beaverton, Oregon. Cooper Mountain and the surrounding vicinity are shown in Figure 1-1. CH2M HILL has prepared this report for the Tualatin Valley Water District (TVWD) and City of Beaverton as the technical documentation to support an Oregon Water Resources Department (OWRD) ASR pilot study limited license application that will be filed by the TVWD.

This report is a cumulation of data gathered for the TVWD and the City of Beaverton. The two entities share a common philosophy that providing reliable and effective water supply service is a regional issue and strive to work together to serve the regional water needs. Therefore, together they are interested in developing ASR within the Cooper Mountain basalt aquifer to augment current water supply during the peak-demand summer months. The TVWD will take the lead for the ASR permitting and pilot testing program for the northern portion of the Cooper Mountain basalt aquifer ASR study area.

The general approach to the ASR project is to proceed in phases, beginning with the initial characterization of the aquifer and an evaluation of the feasibility of recharging treated drinking water into the subsurface. This report presents the initial characterization of the Cooper Mountain basalt aquifer, characterization of source and groundwater quality, and an evaluation of the chemical and physical processes that can affect the feasibility of recharge. In addition to the general evaluation of the basalt aquifer, this report also presents site-specific evaluation of the three pilot test wells.

Following this hydrogeologic study and issuance of a limited license by OWRD, the pilot testing of the three test wells will be conducted in phases. Results and experience obtained from each pilot test will be folded into the following testing phase. The first pilot test will be conducted at the TVWD Schuepbach well. An ASR pilot project work plan for the proposed ASR pilot testing of the study area is currently being prepared as a complementary document to this hydrogeologic study and will be submitted at a later date. The pilot project work plan will address the ASR pilot study injection rates and schedule, the injected water storage time(s), recovery rates and schedule, and the water quality sampling and water level monitoring program. The work plan will also include a testing report outline. Additional issues to be discussed in the pilot project work plan include legal land use, license duration, and water rights.

1.1 Project Background

The TVWD and City of Beaverton are interested in ASR as a technology that will help delay or minimize the necessary expansion of water treatment, storage, and conveyance facilities to meet future peak demands for treated water. ASR involves storing treated drinking water in a suitable aquifer during a period of time when demand is low and recovering water from the same well at a later time when demand is high. The aquifer penetrated by the ASR well essentially serves as an underground reservoir.

The TVWD and the City of Beaverton are interested in the feasibility of developing up to a 10- to 15-million-gallon-per-day (mgd) ASR project in the basalt aquifer system underlying the northern portion of the Cooper Mountain area of the Tualatin Valley. ASR in this area is discussed in the Phase 2 regional water supply plan prepared by the Water Providers of the Portland Metropolitan Area (1995). A preliminary evaluation of ASR potential in this area was prepared by Montgomery Watson (1994). This regional study area encompasses the Cooper Mountain-Bull Mountain Critical Groundwater Area.

The northern portion of the Cooper Mountain basalt aquifer has been selected as the site of the ASR pilot project because of its promising hydrogeologic conditions, existing large-capacity wells, and existing conveyance facilities. The ASR study area includes central and west Beaverton and the northern flank of Cooper Mountain (see Figure 1-2). The data generated from this initial pilot study will be used to augment future development of the ASR capacity of the basalt aquifer.

The TVWD and the City of Beaverton are specifically interested in three wells within the pilot test study area: the City of Beaverton's Hanson Road well and TVWD's Schuepbach and Grabhorn wells. These three wells are completed in the productive basalt aquifer. The Hanson Road well was operated in the past for municipal water supply; however, this well is currently not in use because of iron-rich and hard water conditions that make the water aesthetically objectionable without treatment. The Schuepbach well was a large-capacity private irrigation well that was purchased by TVWD. The well has been previously used as a back-up water source for municipal water supply; however, it is not currently in use. The Grabhorn well is operated occasionally for municipal water supply during peak demand. These wells were selected for eventual ASR pilot testing in the pilot test study area because they are large-capacity basalt wells, have suitable well construction, and are close to existing conveyance facilities. The TVWD Schuepbach well will be the first well to be tested.

1.2 ASR Study Scope

Most of the 50 successful ASR projects completed by CH2M HILL in the United States have a three-phased approach, as follows:

- Phase 1–Hydrogeologic feasibility study
- Phase 2–Pilot testing
- Phase 3–Implementation

The 1995 Oregon Legislature passed House Bill 3183, which simplifies the process for obtaining permits for ASR projects. The state has drafted regulations for ASR projects and defines the pilot test and full-scale ASR permit process (Oregon Administrative Rule [OAR] 537.534). The Oregon Water Resources Department (OWRD), Department of Environmental Quality (DEQ), and Health Division (OHD) are the regulatory agencies involved with developing the permitting process. However, unlike the previous permitting system, permitting for ASR projects will be done through OWRD with input from other agencies. This report is intended to present technical hydrogeologic information for the Cooper Mountain basalt aquifer study area that addresses issues and concerns of the regulatory agencies in order to facilitate the process of obtaining an ASR limited license pilot test permit.

Technical issues and concerns that are addressed in the study include hydrogeologic conditions in the study area, storage capacity of the aquifer, potential rate of recharge and recovery, potential for loss of stored water, and water quality compatibility.

This feasibility study presents findings regarding the following topics:

- Physical setting of the Cooper Mountain-Bull Mountain region
- Regional and local hydrogeology of the ASR study area
- Aquifer testing results for the ASR study area
- Conceptual hydrogeologic model of the ASR study area
- Storage capacity of the basalt aquifer
- Potential for loss of stored water
- Source water quality
- ASR study area groundwater quality
- Recovered water quality

Section 2

PHYSICAL SETTING OF THE COOPER MOUNTAIN-BULL MOUNTAIN REGION

This section summarizes the physical setting and hydrogeology of the basalt aquifer in the Cooper Mountain-Bull Mountain area. Information from the geologic literature was augmented by information from drillers' logs for water wells in the area. Characterization of the hydrogeology is important because of the need to identify target storage zones; to estimate injection and recovery rates; to identify locations (such as springs or wells) where stored water may be lost; and to identify water quality compatibility concerns. The results of this characterization, based on available information, are presented in the following subsections. Where applicable, data gaps are also identified.

2.1 Geography

The Cooper Mountain-Bull Mountain area is centered on the topographic highlands of the Cooper and Bull Mountains in the Tualatin Valley. Cooper Mountain is an elongated topographic high that reaches a maximum elevation of 770 feet. It is approximately 4 miles long and 2 miles wide, with the long axis trending northwest to southeast. Bull Mountain is located southeast of Cooper Mountain and is roughly circular in shape, with a maximum elevation of 720 feet. The surrounding land in the Tualatin Valley has an average elevation of 200 feet. The Tualatin River forms the approximate southern and western boundaries of the study area. A map showing regional features is presented in Figure 1-2.

2.2 Land Use

Land use designations for the Cooper Mountain-Bull Mountain area have been developed by Metro for Washington County. The northwest portion of the Cooper Mountain-Bull Mountain region lies within Metro's Urban Growth Boundary (UGB). The primary land use classification in the UGB is single-family residence. The majority of the land outside the UGB is classified as agricultural, with isolated areas of single-family residences.

2.3 Water Well Inventory

A water well inventory was compiled to identify wells that have already been completed in the basalt aquifer in the vicinity of the proposed ASR wells and that could be used as observation wells and/or water quality sampling points. Drillers' logs for water wells in the pilot test study area were obtained from OWRD files in Salem, Oregon. Wells that were completed in the basalt aquifer were identified and located, to the extent possible, on a map. Additional basalt wells in the pilot study area, not listed with OWRD, were located using a door-to-door survey. The well information was used to characterize the hydrogeology in the study area and to identify wells that could be affected by ASR operations or that could capture stored recharge water.

Information from the logs of wells completed in the basalt aquifer near the Hanson Road, Schuepbach, and Grabhorn wells, including well depth, well construction, well yield, and lithology, is presented in Table A-1 in Appendix A. Approximate locations of wells located near the proposed pilot test wells are shown in Figure 1-2.

The majority of the basalt wells identified in the study area are small-diameter wells associated with older farms. These wells were typically used for domestic and irrigation purposes. Most are no longer used as a primary source of drinking water because the area is served by a municipal water supplier. However, several wells completed in the basalt aquifer in the pilot test study area are large-diameter, large-capacity municipal or irrigation production wells. Characteristics of these large-capacity wells are summarized in Table 2-1, and representative wells of all types and depths are listed in Table A-1 in Appendix A. All the large-capacity wells identified in the basalt aquifer are reportedly capable of producing more than 425 gallons per minute (gpm).

2.4 Regional Hydrogeology

2.4.1 Geology

Geology and groundwater in the Tualatin Valley were described by Hart and Newcomb (1965) and Schlicker (1967) in the first comprehensive reports of the region. The Tualatin Valley is a broad synclinal basin trending northwest to southeast. It consists of extensive valley plains, adjacent slopes, and several northwest-trending anticlinal ridges, notably Chehalem Mountains and the Cooper Mountain-Bull Mountain area. The geology of the Tualatin Valley is shown in Figure 2-1 (map) and Figure 2-2 (cross sections).

The oldest and deepest rock unit known in the Tualatin Valley is Tertiary marine sedimentary rock consisting of sandstone, shale, and tuff; it is exposed in the western part of the valley near Fern Hill. The next oldest rock unit is the Columbia River Basalt Group, a sequence of basalt lava flows of Tertiary age. These basalt flows originated in eastern Oregon and Washington and spread over a low-lying, gently sloping plain consisting of the older sedimentary rock in the area of present-day Tualatin Valley. The older sedimentary rock and younger basalt are generally inclined toward the center of the Tualatin Valley, and are bowed upward in a broad fold at Cooper Mountain and Bull Mountain, as shown in Figure 2-2. The basalt ranges in thickness from zero in the northern Tualatin Valley to approximately 1,000 feet at Cooper Mountain and Fern Hill, where it is exposed at ground surface. Depth below ground surface to the top of the basalt increases from zero at Cooper Mountain and Fern Hill to more than 1,500 feet in the valley center near Hillsboro. Overlying the basalt in the Tualatin Valley study areas are younger sediments of Tertiary-Quaternary age, consisting primarily of silt, clay, and fine sand. Boring Lava, a Tertiary-Quaternary basalt that originated in local volcanoes, is present along the west flank of the Portland Hills in the eastern part of the valley, but it is not found within any of the ASR study areas.

The bedrock units of the Tualatin Valley also commonly contain faults that have displacements of greater than 1,000 feet. This faulting is present parallel to the flanks of the valley's northwest-trending anticlinal systems. Minor faults trending northeast to southwest are less common and are typically found perpendicular to the valley's major folds and faults.

2.4.2 Hydrogeology

From a municipal water production and ASR perspective, the Cooper Mountain-Bull Mountain Columbia River Basalt is the most important aquifer within the Tualatin Valley, while the younger sediments and the older marine sediments are less important aquifers. Most of the basalt thickness consists of dense lava flows ranging from 5 to 100 feet thick; these flow interiors yield only small quantities of groundwater. In contrast, interflow zones sandwiched between the dense flow interiors are typically scoriaceous, rubbly, and very permeable. Groundwater within the basalt is stored and transmitted primarily in the interflow zones. Interflow zones typically give the basalt aquifer a very high transmissivity, and drillers try to intersect at least a few of these productive water-bearing zones when drilling and constructing water wells in basalt.

All municipal and most other high-capacity wells in the area are completed in the basalt aquifer. These wells are typically deeper than 300 feet and yield from 300 to 1,000 gpm. Domestic wells are typically completed in the younger fine-grained sediments above the basalt to shallow depths and yield small quantities of water. These wells are usually less than 150 feet deep and yield less than 50 gpm. A smaller number of wells penetrate the older marine sedimentary rock, but groundwater within this formation is often brackish.

Groundwater within the basalt aquifer flows through the interflow zones from areas of recharge (for example, Cooper Mountain uplands) to wells or natural discharge locations. In most areas, the water table–meaning the surface where groundwater is at atmospheric pressure–is within 30 feet of the valley floor. The water table cuts across all rock units, including the valley fill sediments and basalt. It is shallow beneath the valley plain but relatively deep under Cooper Mountain. In areas where the water table (potentiometric surface) is in the basalt aquifer, such as Cooper Mountain, natural recharge water from precipitation percolates downward through the basalt (possibly as a result of increased fracture density around the folded/uplifted zone) and enters interflow zones. The water then flows downgradient from the recharge area and is progressively confined by the dense flow interiors (that likely have much lower vertical permeability away from folds and faults) that sandwich the interflow zones. This confinement results in groundwater levels in deeper wells that are higher than the local shallow water table. Where sufficient vertical permeability exists (possibly associated with faults, extensive vertical fractures, or uncased wells), groundwater may move from the confined zones upward into the shallow (water table) portion of the aquifer system.

2.5 Local Hydrogeology

2.5.1 Geology

The pilot test study area is roughly bounded by Cooper Mountain to the south, Highway 217 to the east, S.W. 229th to the west, and Farmington Road to the north (see Figure 1-2). Cooper Mountain is an anticlinal hill; the basalt layers incline downward from the summit on all sides and are buried by unconsolidated sediment on the flanks (see Figure 2-2). On the north and east flanks of Cooper Mountain, basalt is exposed from the summit down to approximately the 220-foot elevation.

There are numerous local faults in the Cooper Mountain-Bull Mountain area that follow the regional structural patterns of the valley. The northwest and northeast flanks of Cooper Mountain are intersected by two large fault zones: the Beaverton Fault Zone and an unnamed fault zone. These faults are inferred from the steep drop in the top of the basalt surface in these areas. The top of the basalt drops 100 meters (328 feet) in a narrow 500-foot-wide band along the north flank of Cooper Mountain. Elsewhere the depth to basalt increases more slowly as one moves away from Cooper Mountain. Contours depicting depth to the top of the basalt and the inferred location of local faults are shown on the geologic map, Figure 2-1.

Two additional northwest-trending faults have been identified on the flanks of Cooper Mountain: one southwest of Cooper Mountain and one between the northeast flank of Cooper Mountain and Sexton Mountain (see Figure 2-1). A minor fault has also been identified in the valley that separates Cooper and Bull Mountains. These regional and local fault structures have probably broken up the subsurface stratigraphy (and aquifers) into smaller isolated fault blocks, or compartments, within the Cooper Mountain basalt anticline. For example, the pilot ASR study area north of Sexton Mountain appears to be surrounded to the northwest, northeast, and southwest by faults. Additional unmapped faults may also be present in the basalt surrounding the region.

2.5.2 Hydrogeology

At least four municipal wells within the pilot test study area are completed in the basalt, in addition to other large-capacity wells used for irrigation. Characteristics of the large-capacity wells are summarized in Table 2-1, and representative basalt wells of all types and depths are listed in Table A-1 in Appendix A. The existing municipal wells penetrate only 20 to 60 percent of the available basalt formation that is approximately 1,000 feet thick. However, available data on the hydrogeologic properties of the deeper portions of the Cooper Mountain basalt formation are limited. Documented well yields range from 470 gpm for the TVWD 189th Street well to 1,250 gpm for the Grabhorn well.

Five of the municipal wells, in addition to the now-abandoned Cobb well, are shown as stratigraphic columns in Figure 2-3. The columns show the relative thickness of geologic units, elevations of the wellhead and static water levels, the portion of the boreholes open to the aquifer, and other features of the wells. The Hanson Road well has not been in use because it produced hard, iron-rich water during its most recent testing (Pippin, 1993). The park district well (No. 6a) penetrates a much smaller thickness of basalt, but it still produced more than 500 gpm at the time of construction. The Cobb well (No. 77) on Sexton Mountain was abandoned in 1992 to make way for a road widening (Norton, 1994). The Schuepbach well (No. 90) is a relatively large producer (reported to produce 1,100 gpm), from a modest thickness of basalt (300 feet). The TVWD 189th Street well (No. 143) was logged as having six interflow zones and shale at 700 feet below ground surface. The TVWD Grabhorn well (No. 132d) is a large-capacity well (approximately 1,250 gpm) that is exposed to a small thickness of basalt. Overall, the basalt aquifer near Cooper Mountain produces water efficiently and probably has the capacity to accept and release large quantities of water in ASR operation.

Information about the regional aquifer (the Cooper Mountain-Bull Mountain basalt aquifer) was obtained from OWRD records (Norton, 1994). Transmissivity values for the basalt aquifer in the vicinity of Cooper Mountain range from 9,300 gallons per day per foot (gpd/ft) to 340,000 gpd/ft. Storativity estimates ranged from 3×10^{-3} to 5×10^{-4}. Recorded drawdowns in observation wells during several pumping tests were less than 0.5 foot at a distance equal to or greater than 1,400 feet from the pumping wells. Although not a formal test, long-term pumping at approximately 1,000 gpm in Karban Quarry (see Figure 1-1) on the west side of Cooper Mountain caused water levels to decline in wells up to 1.5 miles away, illustrating the ability for a confined aquifer system to propagate head changes over a large area.

The wide range in transmissivity values and the existence of high values in shallow wells illustrate how variable the basalt aquifer can be. Transmissivity values on the order of several hundred thousand gpd/ft are common for basalt aquifers but very high compared with typical valley fill sediment. The storativity values are also typical of basalt aquifers and indicate confined conditions. Aquifer tests were performed at two wells as part of this hydrogeologic study for the pilot test study area, and the results are discussed in detail in Section 3 of this report.

The existing geologic information in the study area suggests that faulting probably has broken up the geologic units–and consequently the aquifer in the Cooper Mountain-Bull Mountain area–into sub-units or compartments. The effects of the faults on the hydrogeology of the area are not known and may vary from location to location. Faults can influence groundwater flow either by being a conduit of groundwater flow or by acting as a hydraulic barrier. Compartmentalization, or isolation, of fault blocks can create distinct hydrogeological blocks within the regional aquifer. A study of the effects of tectonic structures (faults) on groundwater systems in Columbia River basalt flows in the area around The Dalles, Oregon, (Newcomb, 1969) concluded that faults generally act as groundwater barriers. The study concluded that fault breccia are generally much less permeable than the productive interflow zones and that faulting could offset the water-bearing zone enough to create a barrier to groundwater movement.

Because insufficient data are available regarding the exact nature and location of faults within the study area, it is not known how faults affect the study area's groundwater system.

Section 3
HYDROGEOLOGY OF THE ASR STUDY AREA

This section provides additional geologic and hydrogeologic details for the basalt aquifer in the ASR study area, the northern portion of Cooper Mountain. Additional investigation was conducted in the ASR study area to further evaluate the feasibility of ASR within the basalt aquifer at the pilot test wells. The ASR pilot test area was selected because of the availability of existing large-capacity municipal wells for ASR testing and water conveyance systems to these wells. Two of the three wells identified as possible pilot test wells, the Schuepbach and Hanson Road wells, were examined for selection of the initial pilot test location. The Schuepbach well was recently selected for the initial ASR pilot testing. Following the initial pilot test, the other two wells (Hanson Road and Grabhorn wells) may also be further evaluated for ASR pilot testing. Initial data presented in this report and from pilot testing will be augmented by data obtained from testing conducted at each well considered for ASR.

This section summarizes the results of borehole geophysical logging, aquifer testing, and water quality analyses that were performed at the Schuepbach and Hanson Road wells. The purpose of the testing was to refine the current knowledge of existing hydrogeologic conditions, such as transmissivity and storativity, in the basalt aquifer at the potential ASR pilot test locations.

3.1 Hanson Road Well Aquifer Characterization

The Hanson Road well, owned by the City of Beaverton, is located at S.W. 136th Avenue and Hanson Road in Beaverton, Oregon (Figure 1-2). Borehole geophysical logging was performed on the well in December 1994, and a constant-rate aquifer test was performed during July 1994.

Stratigraphy at the Hanson Road well, based on the well log, consists of the following:

- Low-permeability clay and weathered bedrock from the surface to approximately 50 feet below ground surface
- Columbia River Basalt extending below the upper clay and weathered rock from 50 to at least 800 feet below ground surface

The elevation of the well is approximately 355 feet above mean sea level (msl). The static water level at the Hanson Road well is approximately 185 feet below ground surface (elevation = 170 feet).

3.1.1 Borehole Geophysics Results

Three geophysical test methods were used on the well: physical well survey, hydrologic survey, and geologic logging. Specific methods included the following:

- Video log
- Caliper log (physical survey)
- Spinner log (hydrologic survey)
- Natural gamma log (geologic logging)

Together, these logs are used to assess the well condition and to identify water-producing zones of the basalt aquifer (that is, interflow zones). A brief discussion of the methods and geophysical data and analyses is presented in Appendix B. The main features of the borehole identified in the geophysical analysis are presented in Figure 3-1.

Physical Well Survey

A video and caliper survey of the Hanson Road well were performed to evaluate the condition of the well and borehole. The results are summarized as follows:

- The well is cased with 16-inch-diameter casing from the surface to a depth of 63 feet. The metal casing appears to be in relatively good condition, with heavy rusting present on the casing from 42 to 63 feet below ground surface (bgs). No water seepage was observed at the bottom of the well casing. According to the well log, the casing is sealed with cement grout.

- The borehole penetrates basalt from a depth of 63 feet to 700 feet. The well log indicates that the well was drilled to 800 feet bgs, so it appears that the borehole has collapsed at 700 feet. The drilling log indicates a possible interflow zone at approximately 720 feet, near the top edge of the collapsed section. No debris or foreign material was observed at the base of the well.

- The geologic units penetrated by the borehole are layers of separate basalt flows with interflow zones. Columnar jointing was observed in a significant portion of the well with five distinctive interflow/breakout zones noted:

    - 138 to 168 feet bgs (30 feet thick)–zone located above the static water level in the well

    - 196 to 240 feet bgs (44 feet thick)–saturated zone

    - 260 to 310 feet bgs (50 feet thick)–saturated zone

    - 380 to 410 feet bgs (30 feet thick)–saturated zone

    - 445 to 465 feet bgs (20 feet thick)–saturated zone

    Video visibility tended to increase in the interflow zones, which probably indicates that water movement is occurring in those areas.

- Video visibility was extremely poor from 470 feet to 700 feet bgs, suggesting little water movement through the bottom portion of the borehole. The caliper log indicated that the well borehole diameter decreases from 16 to 12 inches at 470 feet bgs.

- The static water level was at 186 feet bgs.

Hydrologic Survey

Spinner log surveys were conducted under static and dynamic/pumping conditions to assess water movement in the borehole and to identify zones of water entry. Dynamic conditions were created by placing a submersible pump at 235 feet bgs and pumping at a rate of 260 gpm. The results of the static and dynamic spinner log tests are summarized as follows:

- The static spinner log survey indicated that very little, if any, vertical water movement is occurring within the borehole.
- The dynamic spinner log survey indicated four water entry zones in the well:
  - 210 to 225 feet bgs (Zone 1)–estimated (above intake of pump)
  - 370 to 380 feet bgs (Zone 2)
  - 430 to 470 feet bgs (Zone 3)
  - Bottom of the borehole (Zone 4)
- Percentages of water flow entering the well from each zone identified above are as follows:
  - Zone 1 = 42 to 44 percent
  - Zone 2 = 20 to 22 percent
  - Zone 3 = 30 to 34 percent
  - Zone 4 = 2 to 4 percent

Geologic Logging

Natural gamma ray logging was conducted to evaluate lithologic changes in the formations, such as the presence of clay minerals. Clay minerals are indicative of weathering or soil deposition between basalt flows and typically are associated with interflow zones. Note that the lack of gamma ray responses does not mean that no interflow zone is present.

Gamma ray counts were relatively constant throughout the length of the borehole with two exceptions: elevated gamma ray counts (which indicate the presence of an interflow zone) were noted between 140 and 160 feet bgs and between 360 and 375 feet bgs.

3.1.2 Aquifer Test Results

A constant-rate discharge test was conducted on the Hanson Road well to assess the localized characteristics of the regional basalt aquifer. The aquifer test data were collected in three distinct phases: a background water level collection period, a drawdown (pumping) period, and a recovery (post-pumping) period. Water level data collected from the three phases of the test were plotted as hydrographs, log-log plots, and semi-log plots and were used to evaluate the local aquifer characteristics.

The observation points used to monitor water levels during the aquifer testing included the Sage Place, Davies Lane, Beaverton Christian Church, and Schuepbach wells. The well locations are shown in Figure 1-2, and specific well information is summarized in Table 3-1. Water levels were collected manually with an electric water-level indicator at each well. Pressure transducers with automatic data loggers were used at the Hanson Road and Sage Place wells to monitor groundwater levels, temperature, and barometric pressure changes.

Background Data

Data were collected prior to the aquifer test to identify trends in groundwater level and barometric pressure. Without identifying pretest trends, it is difficult to attribute changes in groundwater levels observed during the pumping portion of the test to a specific influence, such as aquifer-wide water-level trends or drawdown that is a result of the pumping test. Background water level measurements were taken in all the observation wells and the Hanson Road well for 2 weeks prior to the start of the pumping test. Background water level fluctuations ranged from 0.1 foot in the Hanson Road well to 0.5 foot in the Sage Place well, with less than 0.5 foot in the remaining observation wells during non-pumping periods.

Barometric pressure changes also were monitored at the pumping well during background, pumping, and recovery phases of the test. Because barometric pressure fluctuations are small and did not correspond to the fluctuations of background water levels, the barometric response appears to be very minor and to be overshadowed by the other factors affecting the system. Therefore, barometric effects were not removed from the data sets.

Pumping and Recovery Test

A 24-hour constant-rate discharge test was conducted July 13 and 14, 1994, at the Hanson Road well. The average discharge rate during the test was 880 gpm. The Hanson Road well aquifer test data sets are included in Appendix C.

Hydrographs (time-drawdown plots) of the pumping and recovery test at the Hanson Road and Sage Place wells are presented in Figure 3-2. The maximum drawdowns in the Hanson Road and Sage Place wells were 32.2 and 1.2 feet, respectively. The Davies Lane well exhibited less than 0.1 foot of drawdown in response to Hanson Road pumping (the well was idle during the test). No response to Hanson Road well pumping was identified in the other wells.

Drawdown Data. A semi-log plot and a log-log plot for the Hanson Road and Sage Place wells are shown in Figures 3-3 and 3-4. The Hanson Road well drawdown data indicate two possible interpretations of aquifer conditions: (1) an unconfined aquifer with delayed yield, or (2) a confined or leaky confined aquifer with a negative boundary affecting the late data points. However, the Sage Place drawdown data clearly indicate that a negative hydrogeologic boundary is affecting the late time data. Because it limits the volume of water that can flow toward a pumping well, a negative boundary will increase the observed rate of drawdown in a well. This hydrogeologic boundary is observed in the Sage Place data set at approximately 500 minutes where the slope of the line on the semi-log plot increases significantly, indicating a faster rate of drawdown. Based on the evidence of a negative boundary in Sage Place drawdown data, it was concluded that the Hanson Road well data set most probably also reflects this negative boundary; therefore, Interpretation 2 was chosen to describe CH2M HILL's conceptual understanding of the aquifer conditions at the Hanson Road well. The boundary is observed in the Hanson Road data set at approximately 400 minutes, indicating that the Hanson Road well may be slightly closer to the negative boundary than the Sage Place well. (See Figures 3-3 and 3-4. Note that the graph scale for the drawdown axis on the Hanson Road graph is different from that on the Sage Place graph.)

A negative boundary condition is a hydrogeologic discontinuity that causes flow toward the well to be reduced. This discontinuity could be caused by a reduction in hydraulic conductivity (or transmissivity) of the water-bearing zones within the basalt, a potential pinching out of an interflow zone between basalt layers, or a fault zone within the basalt. The total drawdown in the pumping well at the end of the 24-hour pumping test was 32.2 feet.

Analysis of the drawdown data combined with the borehole geophysics data suggests that the basalt aquifer in the vicinity of the Hanson Road well is probably a combination of unconfined and confined systems. The uppermost interflow zone may be unconfined in the well vicinity under pumping conditions, and the deeper interflow zones in the aquifer are probably confined or leaky confined.

Recovery Data. The Hanson Road and Sage Place well recovery data are shown in Figures 3-5 and 3-6. The Sage Place recovery data began 10 minutes after pump shut-off. The Sage Place water level did not completely recover to the well's static water level within 24 hours; however, this may be attributable to the background water level fluctuations in the vicinity of the well.

Aquifer Parameter Estimates. Estimates of aquifer transmissivity and storativity are presented in Table 3-2. Aquifer transmissivity ranged from 88,000 to 790,000 gpd/ft, which is a typical range for basalt aquifers. These estimates were calculated using the Cooper-Jacob straight line solution method and Theis recovery solution methods. The large range in transmissivity is a result of the data being analyzed both before and after the boundary condition was encountered. The lower transmissivity values for each well correspond to analysis of the data after the aquifer boundary condition was encountered.

When a bounded aquifer system is pumped, water levels in the wells will initially decline solely as a result of the influence of the pumping well. When the cone of depression created by the pumping well reaches a negative boundary, the rate of the observed water level decline (the rate of drawdown) increases. These post-boundary data reflect apparent drawdown conditions that represent a combination of responses from the boundary and the aquifer material. Under these conditions, the early data that are unaffected by the boundary are used to determine the hydraulic properties of the aquifer. Thus, a representative transmissivity derived from the Hanson Road well test is 490,000 gpd/ft.

Storativity was also estimated from observation well data. Storativity ranged from 0.0015 to 2.3×10^{-7} for Sage Place. Storativities of 0.001 to 1×10^{-6} are typical of confined aquifers. A representative storativity value is 4.4×10^{-4}, estimated from Sage Place pumping data before the boundary effect.

3.2 Schuepbach Well Aquifer Characterization

The Schuepbach well is located at 160th and Division streets in Beaverton, Oregon, on the northern extension of Cooper Mountain (Figure 1-2). Borehole geophysics testing was performed on the well in May 1995, and a constant-rate discharge aquifer test was performed during April and May of 1995.

Stratigraphy at the Schuepbach well, based on the well log, consists of the following:

- Low-permeability clay from the surface to approximately 11 feet bgs
- Weathered basalt bedrock from 11 to approximately 167 feet bgs
- Columbia River Basalt extending below the upper clay and weathered rock from 167 to at least 414 feet bgs

The elevation of the well is approximately 272 feet above mean sea level. The static water level at the Schuepbach well is approximately 100 feet bgs (elevation = 172 feet).

3.2.1 Borehole Geophysics Results

Borehole geophysics testing was performed on the Schuepbach well on May 24, 1995. The same geophysical test methods were used on this well as were used on the Hanson Road well. A brief discussion of the methods and geophysical data and analyses is presented in Appendix B. The main features of the borehole identified in the geophysical analysis are presented in Figure 3-7.

Physical Well Survey

Video and caliper surveys of the Schuepbach well were performed to evaluate the condition of the well and borehole. The results are summarized as follows:

- The well is cased with 14-inch-diameter casing from the surface to a depth of 38 feet bgs. The metal casing appears to be in relatively good condition. No water seepage was observed at the bottom of the well casing. According to the well log, the casing is sealed with cement grout to a depth of 40 feet bgs.
- The borehole penetrates basalt from a depth of 38 feet to 362 feet. The well log indicates that the well was drilled to 414 feet bgs; therefore, it appears that the borehole walls have collapsed at 362 feet. The drilling log indicates a possible interflow zone at approximately 360 feet, near the top edge of the

collapsed section. No debris or foreign material was observed at the base of the well.

- The geologic units penetrated by the borehole are layers of separate basalt flows with interflow zones. Columnar jointing was observed in a significant portion of the well, with four distinctive interflow/breakout zones:

  - 94 to 109 feet bgs (15 feet thick)–zone straddles the current static water level in the well

  - 174 to 230 feet bgs (56 feet thick)–saturated zone

  - 280 to 314 feet bgs (34 feet thick)–saturated zone

  - 358 to 362 feet bgs (assumed 10 feet thick)–saturated zone

  Video visibility tended to increase in the interflow zones.

- The static water level was at 100 feet bgs.

Hydrologic Survey

Spinner log surveys were conducted under static and dynamic/pumping conditions to assess fluid movement in the borehole and to identify zones of water entry. Dynamic conditions were created by placing a submersible pump at 150 feet bgs and pumping 525 gpm. The results of the static and dynamic spinner log tests are summarized as follows:

- The static spinner log survey indicated that no vertical water movement is occurring within the borehole under non-pumping conditions.

- The dynamic spinner log survey indicated five water entry zones in the well:

  - 99 to 110 feet bgs (Zone 1)–estimated (above intake of pump)
  - 165 to 170 feet bgs (Zone 2)
  - 175 to 210 feet bgs (Zone 3)
  - 285 to 300 feet bgs (Zone 4)
  - Bottom of the borehole (Zone 5)

- Percentages of water flow entering the well from each zone identified above are as follows:

  - Zone 1 = Approximately 10 percent
  - Zone 2 = Approximately 10 percent
  - Zone 3 = 50 to 55 percent
  - Zone 4 = 8 to 10 percent
  - Zone 5 = 11 to 15 percent

Geologic Logging

Natural gamma ray logging was conducted to evaluate lithologic changes in the basalt, such as the presence of clay minerals. Clay minerals are indicative of weathering or soil deposition between basalt flows and typically are associated with interflow zones. Note that the lack of gamma ray response does not mean that no interflow zone is present.

Gamma ray counts were relatively constant throughout the length of the borehole with two exceptions: elevated gamma ray counts (which indicate the presence of an interflow zone) were noted between 94 and 99 feet bgs and between 180 and 220 feet bgs.

3.2.2 Aquifer Test Results

A constant-rate discharge test was conducted on the Schuepbach well to assess the localized characteristics of the regional basalt aquifer. Water level data collected during the background, pumping, and recovery phases of the aquifer test were plotted on log-log and semi-log plots.

The closest observation point used to monitor water levels during this aquifer test was the Dernbach well, located 2,400 feet from the Schuepbach well. The well locations are shown in Figure 1-2, and specific well information is summarized in Table 3-3.

Background Data

Background water level measurements were taken in the observation well and the Schuepbach well for 2 weeks prior to the start of the pumping test. Background water level fluctuations ranged from 0.5 foot at the Schuepbach well to 0.06 foot at the Dernbach well when not in use and 1.6 feet when the domestic well was pumping. The Dernbach well was not pumped during the pumping test.

Barometric pressure changes also were monitored at the pumping well during background, pumping, and recovery phases of the test. The barometric response appears to be very minor and to be overshadowed by the other factors affecting the system. Therefore, barometric effects were not removed from the data sets.

Pumping and Recovery Test

A 10-hour pumping test was conducted May 3, 1995, at the Schuepbach well. The test was planned to continue for 24 hours but was cut short after 10 hours (discharged water began to overwhelm the drainage system). The average discharge rate during the test was 770 gpm. The Schuepbach well aquifer test data sets are presented in Appendix C.

Hydrographs (time-drawdown plots) of the pumping and recovery test at the Schuepbach well are presented in Figure 3-8. The maximum drawdown recorded in the Schuepbach well was 39.9 feet. No water level changes at the Dernbach well were observed in response to pumping and recovery at the Schuepbach well.

Semi-log and log-log plots for the Schuepbach well pumping data are shown in Figures 3-9. As discussed in the Hanson Road well analysis, the Schuepbach well drawdown data indicate two possible interpretations of aquifer conditions: an unconfined aquifer with delayed yield, or a confined or leaky confined aquifer with a negative boundary affecting the late data points. No response was observed in the observation well to help clarify analysis of the data. However, based on the negative boundary associated with the Hanson Road well test and the location of fault zones in the basalt near this well (see Figures 1-2, 2-1, and 2-2), a negative boundary was assumed to be affecting the late data. Transmissivity was calculated from the late time water level data, corresponding to the period of maximum drawdown rate. The Schuepbach well recovery data are shown in Figure 3-10.

Aquifer Parameter Estimates. Estimates of aquifer transmissivity are presented in Table 3-4. Aquifer transmissivity ranged from 31,000 to 71,000 gpd/ft, typical for basalt aquifers. These estimates were calculated using the Cooper-Jacob straight line solution method on the late time drawdown data and Theis recovery solution methods. An aquifer transmissivity value representative of large-scale aquifer conditions at this location is an average of the two calculation methods, 51,000 gpd/ft. This transmissivity value is lower than the estimated conditions surrounding the Hanson Road well (490,000 gpd/ft).

Storativity could not be analyzed because no response was seen in the observation well. It is estimated that at least 24 hours would be needed to observe an effect in the Dernbach well in response to Schuepbach pumping. Anecdotal evidence from the owner of the Dernbach well suggests that over longer pumping periods at the Schuepbach well, water levels in the Dernbach well may be affected. The Dernbach well has been deepened twice in the past because it went dry, probably as a result of operation of the Schuepbach well.

3.3 Grabhorn Well Aquifer Characterization

The Grabhorn well is owned by the TVWD. The well is located on the northwestern flank of Cooper Mountain at the end of S.W. 209th Avenue (Figure 1-2).

Stratigraphy at the Grabhorn well, based on the well log, consists of the following:

- Low-permeability clay with intermittent broken rock layers from the surface to approximately 5 feet bgs
- Weathered basalt bedrock from 5 to approximately 89 feet bgs
- Columbia River Basalt extending below the upper clay and weathered rock from 89 to at least 858 feet bgs
- Marine shale is present below the basalt to the final exploration depth of 874 feet bgs.

The elevation of the well is approximately 375 feet above mean sea level. The static water level at the Grabhorn well is approximately 202 feet bgs (elevation = 173 feet). The main features of the borehole identified from the well log are presented in Figure 3-11.

A complete investigation of the well construction, location of interflow zones, and evaluation of the aquifer characteristics in the vicinity of the well will be completed at a later date.

3.4 Water Level Monitoring

This section summarizes groundwater level monitoring data for the pilot test study area. A groundwater level monitoring program was set up in a network of existing basalt wells that could be used to evaluate the groundwater conditions before and during ASR activities in the Schuepbach or Hanson Road wells. The monitoring program began in August 1995.

3.4.1 Study Area Monitoring Wells

The following wells were selected for the groundwater monitoring program to evaluate background water levels, water quality, and future ASR operations:

- Schuepbach well (potential ASR well)
- Hanson Road well (potential ASR well)
- Sage Place well
- Davies Road well
- Beaverton Christian Church well
- Dernbach well
- Blomquist well

The locations of the wells are shown in Figure 1-2. Available well construction information and approximate measuring point elevations for the wells are presented in Tables 3-1, 3-3, and 3-5. Sources of measuring point elevation data for these wells are limited to property owners' site plans, City of Beaverton 2-foot contour topographic maps, and U.S. Geological Survey (USGS) 7.5-minute topographic maps. None of the wellheads was surveyed.

3.4.2 Water Level Data

Water level measurements were obtained from selected wells in June 1994, April 1995, and August 1995 and are presented in Table 3-5. Groundwater elevations for August 30, 1995, are plotted in Figure 3-12. The limited data obtained to date indicate that the local groundwater flow direction in the ASR pilot test study area is toward the northeast. This suggests that Cooper Mountain is a recharge area for the regional basalt aquifer and that groundwater flows from this high point outward, away from the mountain into the valley.

The preliminary groundwater flow direction and gradient were calculated using the August 1995 data. However, because a majority of the existing basalt wells available for monitoring groundwater in this area are located southwest of the potential ASR wells (toward the topographic groundwater high under Cooper Mountain), the data may not accurately reflect gradients of the basalt aquifer in the vicinity of the ASR pilot test wells. Calculated gradients in the west part of the pilot test study area (the east flank of Cooper Mountain) are approximately 0.0025 foot per foot. Data in the vicinity of the Hanson Road well (the east portion of the study area) suggest that the groundwater gradient flattens to 0.001 foot per foot; this is similar to gradients reported to be typical in the regional basalt aquifer. Because of the lack of available observation wells in the vicinity of the Schuepbach well, it is unclear whether the local gradient in the basalt aquifer flattens out. This issue will be further addressed during the pilot test phase of the project.

3.5 Conceptual Hydrogeological Model

A conceptual hydrogeological model is a description of how the various components of the geologic framework affect the movement of groundwater. The conceptual groundwater flow model of the pilot test study area is described in the following subsections. A conceptual hydrogeological flow model is depicted in Figure 3-13.

3.5.1 Geologic Features of Basalt Aquifers

The basalt bedrock present in the pilot test study area consists of layers of individual dense basalt lava flows, ranging from 5 to 100 feet thick, stacked on top of one another. Each flow has a massive interior flow zone and a thin interflow zone. The massive flow interiors typically have columnar jointing structural features resulting from contraction during solidification of the formation and yield only small quantities of groundwater. In contrast, interflow zones sandwiched between the dense flow interiors are typically scoriaceous, rubbly, and very permeable. Groundwater within the basalt is stored and transmitted primarily in the interflow zones. Typical basalt aquifer structure is illustrated conceptually in Figure 3-14.

Interflow zones are relatively thin layers that consist of both the tops of older lava flows and the bottoms of younger flows. Vesicles (voids left by bubbling gas) and rubble are created at the top and bottom of a new lava flow by the rapid cooling and churning of the partially liquid basalt lava. Cooling of the lava flow causes additional fracturing of the rock. Later, weathering of the basalt surface may cause further breakdown of the rock and deposition of sediment; both processes provide additional water storage capacity in the rock. Vesicles, fractures, and void space between pieces of rock all contribute to the storage and transmissive qualities of the interflow zones. These horizontal interflow zones typically give basalt flows a higher permeability parallel to the lava flow top and significantly lower permeability perpendicular to the lava flows. As a result, most groundwater movement within the basalt is lateral (generally horizontal) through the interflow zones. Individual interflow zones are 1 to 10 feet thick, have very undulating and/or irregular surfaces, and are typically laterally extensive, such as on the order of a few square miles in the Tualatin Valley.

Vertical groundwater movement between interflow zones in the basalt aquifer is limited by the relatively massive lava flow interiors; however, vertical movement may occur via extensive columnar jointing, numerous fault zones, and fracture zones resulting from structural deformation present in the basalts of this area (Beeson, 1993). The total thickness of basalt that is interflow material probably varies between 5 and 30 percent of the total flow thickness and is highly variable in the region.

3.5.2 Groundwater Flow

Natural Recharge

Natural recharge in basalt aquifers occurs from infiltration of precipitation downward in the basalt through vertical stress fractures resulting from the formation of the anticline or weathered seams and enters interflow zones in the basalt. Cooper Mountain is a significant natural recharge area for the basalt aquifer system in the Tualatin Valley as precipitation infiltrates at higher topographic elevations. The groundwater elevations obtained for this study and from the Critical Groundwater Area study (OWRD, 1989) indicate that Cooper Mountain is a groundwater topographic high.

Groundwater Movement

Groundwater within the basalt aquifer flows laterally through the interflow zones. Interflow zones were identified in the pilot test area using borehole geophysics in the Hanson Road and Schuepbach wells and are described in Table 3-6. At least two of the individual interflow zones identified in each well appear to correlate to one another on the basis of similarity in elevation (for example, zones from elevation -15 to -25 and elevations -75 to -115 [Figure 3-13]). This suggests that some individual basalt interflow zones intersect both the proposed ASR wells in the pilot test study area, and that the zones are laterally extensive within the study area. In addition, two basalt interflow zones were identified in the Dernbach well drilling log (see Appendix A); this further suggests that some interflow zones in the study area are laterally extensive. The Grabhorn well has not been investigated to determine whether these interflow zones extend further to the west.

It is suspected that vertical groundwater movement in the study area is several orders of magnitude lower than horizontal flow because of the relatively massive lava flow interiors. However, vertical movement does occur, as seen by the percolation of recharge water downward from the surface to the interflow zones. It is also suspected that the faults present in the pilot test study area and the columnar jointing present in the massive interior flows between the interflow zones contribute to vertical movement of groundwater.

The fault structures identified in the pilot test study area may have an effect on groundwater movement. Faulting may compartmentalize the basalt aquifer into smaller groundwater units that are relatively isolated from one another. The effects of faults on the aquifer system will be evaluated further during the pilot testing phase of the project.

The available data suggest that the interflow zones present in the study area are vertically connected; however, vertical groundwater flow is believed to be insignificant compared with the horizontal flow component of the basalt aquifer (described in Section 3.4.1 of this report), and that vertical movement is not expected to be significant during ASR operations.

As groundwater flows downgradient from the recharge area, it becomes progressively confined by the dense flow interiors that sandwich the interflow zones. This confinement results in groundwater levels in wells that are above the level of the local water table present in the floor of the Tualatin Valley. Water level data from the ASR observation wells indicate a relatively flat groundwater gradient across the study area. Given these data and the borehole geophysics data, it appears that the basalt aquifer may be partially confined and that the degree of confinement varies spatially.

Natural Discharge

Natural discharge of groundwater from the basalt aquifer may occur as groundwater migrates from the confined zones back to the water table zone via natural conduits such as faults and vertical fractures, or via uncased wells. No natural discharge points from the basalt aquifer (such as springs or seeps) have been identified in the pilot test study area. However, potential discharge from or recharge to the uppermost interflow zone may be naturally occurring at Johnson Creek in the vicinity of the Schuepbach well. Johnson Creek is located 2,500 feet east of the Schuepbach well and has an approximate elevation of 175 to 200 feet.

The conceptual hydrogeologic flow model will be refined and updated as further data are gathered during the pilot test phase of the project.

Section 4

STORAGE CAPACITY OF THE BASALT AQUIFER

This section describes the physical characteristics of a basalt aquifer that determine its storage capacity. The three principal physical characteristics that determine an aquifer's capacity are its porosity, storativity, and transmissivity. Transmissivity (which is related to permeability) indicates how easily groundwater flows through the aquifer. Storativity indicates the amount of water that can be pumped from, or recharged to, an aquifer with a given change in head (that is, water level). Porosity is the percentage of the aquifer containing openings that can readily transmit water. Aquifers with high transmissivity, storativity, and porosity can accept, store, and yield large quantities of water. Aquifers with high transmissivity and low storativity, such as a basalt aquifer, are also suitable for recharging large quantities of water, but changes in head that are a result of recharge are likely to occur over longer distances than in aquifers with high storativity. Porosity in a basalt aquifer is generally limited to interflow zones and, to a lesser extent, fracture zones.

4.1 Conceptual ASR Storage Model

Conceptual operation of an ASR includes the injection of drinking water into an aquifer for storage and later recovery of that water for use. Storage of water in an aquifer will create changes in the natural hydrogeologic regime of the target aquifer. The injected water will displace in situ groundwater. To provide room for the injected water, the in situ water will be displaced outward. When water is injected, the pressure head in a confined system, or the water table in an unconfined system, will rise in the vicinity of the injection well. Because both confined and unconfined conditions exist in the regional study area, it is anticipated that the rise in water levels will be a result of the combined forces of pressure head increase and water table rise. Initially, these effects will decrease logarithmically with distance from the injection well. Over time, the rise in pressure head (or water levels) will be distributed laterally (theoretically, moving away from the well radially), and potentially reaching boundaries within the aquifer. If the water table rises to intercept the ground surface, increased discharge from seeps and springs may also be observed.

If an impermeable boundary is encountered (such as a fault zone containing cemented breccia), the radial movement of the pressure pulse is limited, increasing injection pressure at the pumping well and causing water levels or pressures to rise more rapidly in the aquifer. The amount and areal extent of water level or water pressure rise depends on the physical characteristics of the aquifer, such as transmissivity and storativity.

Groundwater storage in the basalt aquifer can be viewed conceptually as either unconfined or confined. When pore space in the basalt is filled during recharge or drained during pumping, the groundwater is said to be unconfined, or held in the aquifer under atmospheric pressure (water table conditions). Confined storage involves pressures greater than atmospheric pressure, leading to slight expansion of the aquifer matrix and compression of the water itself. Although these effects are very small, when they occur over a large portion of an aquifer, significant quantities of water can be stored. If the basalt pore space remains saturated during pumping, the water released to the well comes from compression of the aquifer matrix and expansion of the water. Such an aquifer is said to be confined because the water is held in the aquifer at a pressure that is greater than hydrostatic pressure. Aquifer tests and anecdotal evidence of groundwater response to pumping in the Tualatin Valley indicate that groundwater in the basalt aquifer is held primarily under confined to semi-confined conditions, although some groundwater is also stored under unconfined (water table) conditions. Storativity is much higher in unconfined aquifers than in confined aquifers; typically, it is several orders of magnitude higher. This means that a larger aquifer volume is needed to store water in a confined case than in an unconfined case. In the case of the confined portion of the basalt aquifer in the Tualatin Valley, this is not a serious limitation because the aquifer is laterally extensive except where faults have compartmentalized the aquifer. Even where compartmentalized, the basalt aquifer may be able to transmit a significant amount of water.

The combination of generally high transmissivity and low storativity in a basalt aquifer results in head changes over large areas in response to pumping and recharge of wells. Although water level changes may be noticed in neighboring wells up to a few miles away from an active, high-capacity pumping well, the water that is drawn into the well is derived from an area in the surrounding aquifer that is much closer to the well. Conversely, when recharge water is stored in the aquifer via an injection well, the distance that the recharge water moves away from the well is small contrasted with the areal extent of changes in head (water level). This effect occurs because changes in water levels involve pressure response rather than actual movement of groundwater. The simplified estimated distance that the recharge water in an unconfined aquifer travels from the ASR well depends on the porosity and cumulative thickness of the interflow zones and the degree of mixing. The greater the porosity and the larger the thickness of the interflow zones, the smaller the radial distance the injected water will move from the well. Degree of mixing is difficult to estimate from available information, but it could be examined in an ASR pilot test by calculating the ratio of recharge water to groundwater removed during the recovery period.

A simple conceptual model of ASR (the so-called "bubble model") in a basalt aquifer can be used to estimate how far water will travel from a well for a given total storage volume. The bubble model for visualizing ASR neglects mixing (a process caused by dispersion and flow through preferential pathways), but it does provide a starting point for quantifying ASR storage volume and area of effect. The ASR concept is graphically depicted in Figure 3-13. During the injection phase, recharge water displaces native groundwater away from the well in an assumed radial geometry, creating a "bubble" of recharge water. In a basalt aquifer, a number of tabular-shaped bubbles of recharge water are created in the interflow zones and are separated by the dense basalt flow interiors. The recharge water moves into confined and unconfined portions of the aquifer and into the unsaturated zone as the head increases.

Once established in the aquifer, the bubble of recharge water may migrate slowly away from the well during the storage period. The distance that the recharge bubble migrates away from the well is determined by the aquifer's natural hydraulic gradient and permeability, the effects of other nearby pumping wells, and the length of time the bubble is allowed to remain in the aquifer. Groundwater gradients in the study area basalt aquifer are discussed in Section 3.4 of this report. Although more detailed analysis needs to be completed in the ASR study area, the regional hydraulic gradient in Tualatin Valley appears to be relatively flat, and no high-capacity pumping wells that could have an effect on the ASR wells have been identified. Therefore, the recharge bubble is not expected to migrate an appreciable distance from the ASR well. If average observed values for transmissivity (50,000 gpd/ft) and gradient (0.0015) are used, the distance that groundwater might move during a typical 4-month storage period can be estimated to be approximately 100 feet.

The analysis in this study assumes that the basalt aquifer is confined, even though some field data suggest that the basalt aquifer in the pilot test study area may be under a combination of confined and unconfined conditions. Evaluating the ASR process using a confined aquifer scenario is a conservative approach because this method defines the largest area potentially affected by the ASR operations.

4.2 Estimated Aquifer Storage Capacity

The aquifer storage capacity can be roughly approximated by computing the volume of water that can be stored underground at a given well over a specified period. The volume of treated drinking water stored is governed by the quantity of treated water available for recharge, the rate of injection, and the duration of injection.

A typical example of an ASR yearly schedule includes the following:

- Four months of injection (in winter)
- Three to 4 months of storage time
- Three to 4 months of recovery (in summer)

For this preliminary evaluation of the ASR process, this generalized schedule will be used. A final ASR operating schedule will be developed based on the water supply needs of the TVWD and a complete evaluation of the pilot test.

Typically, water supply demands are low in the winter months and high in the summer months. Recharge water for this ASR project can be supplied between November and May from two different sources that have excess supply during the winter months: the JWC Fern Hill water treatment plant, which derives its water from the Trask and Tualatin Rivers, and the Portland Bull Run water supply.

From an operational point of view, the recharge rate should be established at approximately 75 percent of the pumping rate or less. The higher rate of pumping relative to the rate of recharge allows removal of sediment that might have been injected into the well during recharge. Pumping tests conducted on the proposed ASR wells when they were installed provide an indication of pumping and recovery rates. During past operations, the Hanson Road well was pumped at 950 gpm for an unknown amount of time, with a drawdown of 80 feet. The Schuepbach well was pumped at up to 1,089 gpm for up to 15 hours; its total drawdown was

83 feet. The Grabhorn well was pumped at 1,250 gpm for 12 hours with a drawdown of 78 feet.

At an estimated recharge rate of 1 million gallons per day, or 700 gpm, more than 120 million gallons of water could be stored in each well during a 4-month recharge period from December through March; this would include down time for maintenance and well redevelopment.

The maximum size of the recharge bubble depends on the total injected volume and the porosity and characteristics of the aquifer. The size of the conceptual bubble that displaces native groundwater is calculated using the following equation:

$$\text{radius of bubble} = \left(\frac{V}{7.48 \times \pi \times b \times n_e} \right)^{1/2}$$

where

V = volume of water injected (gallons)
π = pi
b = aquifer thickness (feet)
n_e = effective porosity

Table 4-1 presents the calculated sizes of a simplified recharge bubble created by injecting water for probable ranges of injected volume. Groundwater and recharge water mixing is neglected in these calculations. In the calculations, the cumulative thickness of the interflow zones obtained from borehole geophysics logs was used as the aquifer thickness (*b*). A median porosity of 0.15 for the interbeds is supported by the findings of LaSala and Doty (1971). Given a total injection volume of 120 million gallons of water over a 4-month period, the computed radius of the injection bubble is approximately 620 feet from the Hanson Road ASR well and 580 feet from the Schuepbach ASR well. These size estimates indicate that even with large storage volumes, the basalt aquifer will store most of the recharge water within a fairly short distance from the well. The total thickness of water-producing zones in the Grabhorn well is not known; therefore, the injection bubble radius was not calculated for this well.

This analysis does not consider the increase in head (water level) that would be accompanied by recharge or the effect of faults that may act as barriers to lateral groundwater movement. ASR could be limited if the head in the aquifer rises enough to promote groundwater discharge to springs or flow into unsaturated zones that is not recoverable. Faults are prevalent in the basalt and could promote increases in head during recharge, if the faults create a barrier to groundwater flow. The significance of these faults and coincident head increases on ASR operation cannot be evaluated with available information. Pilot testing and implementation of ASR in a phased manner will provide the needed information to further evaluate these issues.

4.3 Potential for Loss of Stored Water

Stored recharge water could be lost through natural groundwater movement, interception by other pumping wells, or discharge to springs or surface water. The available data suggest that the groundwater gradient within the aquifer across the pilot test study area is variable and needs to be evaluated on an area-by-area basis. Additional elevation controls will be required in the vicinity of the Schuepbach and Hanson Road wells to accurately determine the gradient in the local area and the rate of natural groundwater movement.

If water levels rise in the aquifer during or after recharge, some of this water could be lost to spring or surface water discharge. CH2M HILL was unable to identify any springs in the area discharging from the basalt aquifer. Johnson Creek is the nearest surface water drainage. The bottom elevation of the creek may be a source of discharge from the uppermost basalt interflow zone. The potential for groundwater discharge to Johnson Creek will be further evaluated during the ASR pilot test.

Potential displacement and loss of native groundwater out of the aquifer system is a concern during ASR operation. This would occur if the injected water pushed native groundwater out of the area at a rate faster than would naturally occur. The basalt aquifer that encompasses the Cooper Mountain area (with an assumed radius of 12,000 feet) contains approximately 35.5 billion gallons of water within the basalt aquifer's upper 400 feet (equivalent to an interflow zone thickness of approximately 70 feet). Introduction and storage of 100 to 200 million gallons of water into the aquifer at each ASR well will not affect the regional water budget. This volume represents less than 0.6 percent of the total calculated volume of groundwater present in the upper portion of the aquifer. Furthermore, substantial increases in groundwater gradient caused by injection are not expected in this highly permeable aquifer. Thus, displacement or loss of native groundwater outside the aquifer system is not a concern. Groundwater level monitoring will be conducted during the pilot tests to determine whether recharge is substantially increasing the gradient near the well.

4.4 Suitability of the Schuepbach, Hanson Road and Grabhorn Wells for ASR

The Schuepbach, Hanson Road and Grabhorn wells are existing large-capacity basalt wells located within the ASR study area. The wells were evaluated in terms of their suitability for ASR purposes using the following criteria:

- The well is located where it can be used in the distribution system.
- The well can provide a recharge capacity of at least 1 mgd.
- The well casing and seal are adequate to prevent potential downward movement of contaminants from the surface or shallow aquifer.
- The well does not promote commingling among aquifers.
- The well diameter is adequate to achieve the desired recharge rate.

- The recharge water source is close by.
- Redevelopment water can be discharged to a sanitary sewer or storm drain.
- The pump house is of adequate size to accommodate piping modifications.
- No known sources of contamination are in the area.

The Schuepbach, Hanson Road and Grabhorn wells meet all these criteria. Additional information about the wells and the associated distribution system is presented below.

4.4.1 Schuepbach Well

The Schuepbach well was constructed in 1959 to a depth of 414 feet; however, geophysical logging indicates that the open rock boring has collapsed near the base of the original well. The well is currently 362 feet deep. This well was originally a large-capacity private irrigation well; it is now owned by TVWD. The well has been used in the past as a backup water supply, although it is not in use now. Figure 3-7 illustrates the well construction, and the original well log is presented in Appendix A. The well is cased with 14-inch-diameter casing to a depth of 38 feet. From 38 feet to the total depth of 362 feet, the well is a 14-inch-diameter open borehole in basalt. The cased portion of the well is sealed with cement grout. The static water level in the well is 100 feet bgs (elevation 172). The well has a 60-horsepower turbine pump that was recently removed so that geophysical logging could be conducted on the well.

The pump house contains a manifold system that is directly connected to the existing water supply distribution system. The closest sanitary sewer or storm drain line is 300 feet away. No additional structures are currently present at the Schuepbach well site.

4.4.2 Hanson Road Well

The Hanson Road well is owned by the City of Beaverton and was constructed in 1945 to a depth of 800 feet; however, geophysical logging indicates that the open rock boring has collapsed to a depth of 700 feet. The well has periodically been used for water supply, but it is not currently in use because of high iron content and hardness, which make the water aesthetically objectionable. Figure 3-1 illustrates the well construction, and the original well log is presented in Appendix A. The well is cased with 16-inch-diameter casing to a depth of 63 feet. The well is a 15-inch-diameter open borehole in basalt from 63 feet to a depth of 450 feet and is 12 inches in diameter from 450 feet to the total depth of 700 feet. The cased portion of the well is sealed with cement grout. The static water level in the well is 185 feet bgs (elevation 170). The well has a 75-horsepower turbine pump that was recently removed so that geophysical logging could be conducted on the well.

The pump house contains a manifold system that is directly connected to the existing water supply distribution system. In addition, the Hanson Road well site has two 1-million-gallon concrete water storage tanks that can be used to store source water, recovered water, or redevelopment wastewater.

4.4.3 Grabhorn Well

The Grabhorn well is owned by TVWD and was constructed in 1965 to a depth of 874 feet. The well has periodically been used for water supply; however, currently it is not in use because of slightly elevated iron content of the water. The water quality from this well is quickly noticed by the high-tech manufacturing facility located near the well, who prefers the cleaner Bull Run water. Figure 3-11 illustrates the well construction, and the original well log is presented in Appendix A. The well is cased with 16-inch-diameter casing to a depth of 402 feet. The well is open borehole in basalt from 402 feet to a depth of 616 feet. A 12-inch casing is present from 616 to 728 feet. A 6-inch open borehole is present from 728 feet to the final depth of 874 feet below ground surface. The 16-inch cased portion of the well down to 406 feet is sealed with cement grout. The static water level in the well is 202 feet bgs (elevation 173).

The pump house contains a manifold system that is directly connected to the existing water supply distribution system. The size of the pump and additional details have not been fully researched at the Grabhorn well.

4.4.4 Aquifer Recharge Water Injection

Recharge water can be introduced into the wells using several methods: pump column, well annulus with ejector tubes, or well annulus without ejector tubes. The method of recharge (pump column or well annulus) depends on the diameter of the well casing and pump column and the desired recharge rate. The condition of the casing will also dictate whether annular recharge (without ejector tubes) is appropriate. Corrosion and scaling on the well casing can be a source of particulates that may be loosened during annular recharge and could promote clogging. According to well construction records for the Hanson Road and Schuepbach wells, there is insufficient room between the pump column and casing to do annular recharge. Recharge can be conducted down the pump column through the pump bowls. This method of recharge should produce enough head loss so that the pump column will remain full during recharge, minimizing entrainment of air into the formation, which can lead to clogging. It will be necessary to redevelop the well periodically to remove sediment that enters it during recharge.

Section 5
WATER QUALITY

5.1 Introduction

For an ASR project, a thorough understanding of recharge (source) water quality, the in situ groundwater quality, and the geochemical interaction between the recharge water and the aquifer being recharged is necessary. Undesirable reactions between the source water and the native aquifer can reduce the overall efficiency of the recharge well or affect the quality of the local groundwater. Water quality concerns relating to ASR projects include the following:

- Compatibility of the recharge water and the likelihood that the recharge water will degrade native groundwater quality.
- Chemical or physical clogging problems within the recharge well or the target aquifer; this can be caused by mixing recharge water with native groundwater.
- The potential for recharge water to leak out of the aquifer and affect surface water quality.
- The quality of the recovered water.

Each of these concerns is discussed below in terms of the proposed pilot project.

5.2 Recharge Water—Groundwater Quality Compatibility

This section provides a preliminary evaluation of the individual compatibility of the Joint Water Commission (JWC) water supply and the City of Portland public supply water with the basalt aquifer groundwater. In addition to evaluating the compatibility of the waters, the source and aquifer water are compared to the state-regulated water quality parameters. The evaluation is based on available water quality data collected from engineering reports, USGS reports (Hart and Newcomb, 1965), water quality analyses conducted on nearby wells, and data provided by the City of Beaverton and TVWD. The water quality assessment focused on comparing the general chemical character of the recharge water source and basalt groundwater, identifying constituents present in the recharge water that have higher concentrations than the native basalt groundwater, and identifying potential clogging problems that may result from mixing source water and groundwater.

The City of Portland water treatment plant (whose source is the Bull Run River) and the JWC water treatment plant (whose sources are the Trask and Tualatin Rivers) will be the sources of water for the project. Because of the proximity of existing water lines, the Schuepbach well pilot test will use water from the City of Portland, and the Hanson Road pilot test will use water from the JWC plant. The source water for the Grabhorn well pilot test will be determined following the initial pilot testing.

Groundwater samples were collected at several locations in the basalt aquifer to provide preliminary data regarding background water quality in the study area. Samples were collected from the Schuepbach well, Hanson Road well, Beaverton Christian Church well, Dernbach well, Davies Road well, and Kauppila well. The locations of these wells are shown in Figure 1-1.

5.2.1 Water Quality Characteristics

Tables 5-1 through 5-5 present the water quality data collected from the JWC and City of Portland ASR source water and the Schuepbach and Hanson Road wells. The test results are compared to the following water quality requirements:

- Oregon Health Division (OHD) regulated contaminants
- OHD unregulated contaminants
- Oregon Department of Environmental Quality (DEQ) maximum measurable levels
- Federal secondary standards
- OWRD additional constituents—ASR regulations

The Schuepbach and Hanson Road water quality analyses completed for this initial evaluation did not include all the water quality parameters currently required under the ASR rules. The tests were completed prior to the completion of the ASR rules and were intended to provide preliminary water quality analysis of the basalt aquifer. All constituents not analyzed but required by the new ASR rules are identified on the tables. The missing water quality parameters from the Schuepbach and Hanson Road wells will be analyzed and reported to WRD during background monitoring phase of the pilot test program.

The general water quality of the basalt aquifer was evaluated by analyzing water samples from the Beaverton Christian Church well, Dernbach well, Davis Road well and the Kauppila well. The analytical results are presented in Table 5-6.

Recharge Source Water Quality

The ASR source water locations are either the JWC Fern Hill treatment plant or the City of Portland Bull Run water. Portland's south shore wellfield water was not considered because that source is used for seasonal peaking demands (summer) and is unlikely to be online during the recharge period. The source water for the first pilot test at the Schuepbach well will be City of Portland water. The data for the proposed ASR source water represent a number of years of testing performed in compliance with OHD requirements (Oregon Revised Statute 448.273). The treated water is routinely tested for inorganic constituents (primarily metals) and organic constituents, including volatile organic compounds, semivolatile organic compounds, and pesticides. As indicated in Tables 5-1 through 5-5, the JWC and City of Portland source water quality is very good. Metals concentrations are very low or undetected. Organic compounds have not been detected, with the exception of low-level concentrations of disinfection by-products. Chlorine residuals are present in both source waters (at 0.5 to 5 milligrams per liter [mg/L]), and JWC-treated water is fluoridated.

All detected concentrations of constituents with drinking water standards or maximum measurable levels (MMLs) are substantially below 50 percent of the standards. Therefore, the water is acceptable for use as source water for an ASR project.

Basalt Aquifer Water Quality

Samples collected from selected basalt wells in the study area indicate that the basalt groundwater quality is generally good, with a few exceptions. The groundwater is considered hard and has elevated iron and manganese concentrations at some locations. As shown in Figure 5-2, the chemical signatures of the basalt water samples are similar. The Schuepbach and Beaverton Christian Church wells have somewhat elevated total dissolved solids (TDSs), indicating that groundwater in the vicinity of these wells may be affected by saline water, which has been documented elsewhere in the aquifer. No volatile organic compounds were detected and none of the constituents tested in groundwater exceed drinking water standards.

Groundwater in the basalt aquifer is reported to be somewhat geochemically reducing, or oxygen deficient. The degree to which the groundwater is reducing affects chemical reactions that could result in clogging of the injection well or dissolution of minerals in the aquifer. Dissolved oxygen measurements at the Schuepbach and Hanson Road wells ranged from 4.2 to 4.8 mg/L, indicating that the basalt groundwater is not substantially reducing at these locations (an unexpected result). Additional dissolved oxygen and redox potential information will be collected during the pilot study.

5.2.2 Groundwater Quality Degradation Potential

Stiff diagrams comparing the water quality signatures of the basalt aquifer and the treated water are presented in Figures 5-1 and 5-2. As shown in Figure 5-1, the treated JWC source water is quite different from the basalt groundwater in quality. The same is true of the City of Portland water. TDSs, which are a general indicator of overall water quality, are a factor of three to ten times lower in the JWC- and City of Portland-treated water than in the basalt aquifer groundwater. This indicates that recharge will result in an overall improvement of the existing water quality.

Although the concentrations of the majority of constituents with drinking water standards are substantially lower in the JWC source water than in basalt groundwater, the sulfate, fluoride, nitrate, residual chlorine, and trihalomethane (THM) concentrations in the JWC source water may be higher than natural background levels in the basalt aquifer. The measured sulfate concentration in the JWC source water is approximately 16 mg/L, contrasted with less than 5 mg/L in the basalt aquifer. Fluoride and nitrate concentrations in the JWC-treated water are higher than concentrations measured in some basalt aquifer wells and lower than other basalt wells. Fluoride is somewhat elevated because the JWC-treated water is fluoridated. With the exception of THMs, ammonia, and organic nitrogen, individual constituents present in the Portland treated water have lower concentrations than either the JWC-treated water or the typical basalt groundwater. Ammonia present in the Portland drinking water is a remnant of the treatment process, which uses chloramines to treat the water.

THMs and haloacetic acids (HAAs) are disinfection by-products (DBPs) formed during the chlorination of drinking water and are typically present in drinking water. For example, the total THM concentration in the JWC-treated water was measured at 0.0192 mg/L (see Table 5-1). These compounds are not naturally occurring in the aquifer. There is considerable controversy over the health effects of DBPs in drinking water. The maximum contaminant level (MCL) for total THM is currently 0.1 mg/L. It is anticipated that the U.S. Environmental Protection Agency (EPA) will set new MCLs at 0.08 and 0.06 mg/L for total THMs and HAAs, respectively. There are conflicting reports in the literature about the fate of DBPs when water is injected into and stored in the aquifer. Similarly, there has been uncertainty concerning the fate of DBP precursors (that is, compounds that promote the transformation of free chlorine into DBPs) present in the finished water when it is stored in the aquifer, and their effect on subsequent DBP formation when the recovered water is re-chlorinated before distribution.

The impact of ASR on DBPs was examined in a recently completed study funded by the American Water Works Association Research Foundation (Singer et al., 1993). Five operating ASR sites were investigated in the United States and England. The study concluded the following:

- Residual chlorine was not detected in recovered water at any of the ASR sites after 1 day of storage.
- THMs and HAAs are removed from chlorinated water during aquifer storage.
- HAA removal precedes THM removal; the more highly brominated THM species tend to be eliminated earliest.
- THMs appear to be broken down by dehalogenation under reducing conditions. A microbiological mechanism is suggested; however, adsorption of DBPs to the aquifer media may also have occurred.
- HAA removal is rapid and occurs while aerobic conditions are still prevalent in the aquifer.
- THM and HAA precursors are also removed to a significant degree during aquifer storage. This significantly reduces DBP formation potential during aquifer storage and after the water is recovered and re-chlorinated.

The significance of these findings is that residual chlorine and DBPs do not remain in the aquifer for an appreciable period of time. These compounds appear to break down rapidly and do not appear to degrade the existing groundwater quality. Additional testing for DBPs and DBP formation potential will be conducted during the pilot test to further evaluate the fate of DBPs in the basalt aquifer.

5.2.3 Impacts of Artificial Recharge on the ASR Well and Potential for Aquifer Clogging

Recharge of an aquifer by well injection can result in clogging of the well screen or intake zone, filter pack, or aquifer matrix. The major chemical and physical causes of clogging are well known. Most of these causes can be eliminated or controlled through proper investigation and design of the project. Causes that cannot be eliminated or controlled up front can sometimes be managed by monitoring and operational practices.

The following are the principal causes of well clogging during recharge operations (in the order they likely occur):

- Suspended solids clogging
- Biofouling
- Geochemical reactions causing insoluble precipitates to deposit
- Gas binding or air entrainment in the aquifer

These factors are discussed below.

Suspended Solids

Suspended solids clogging is the most common problem with ASR projects. Total suspended solids (TSS) concentrations in waters meeting turbidity standards for drinking water can have significant adverse effects upon wells with low hydraulic conductivity. Recharge waters with 2 mg/L TSS or above can significantly affect recharge wells (Pyne, 1995). Portland and JWC suspended solids concentrations are 1.5 and <0.01 mg/L, respectively; therefore, clogging by suspended solids is not expected to be a concern. Removal of suspended solids will be accomplished by periodic backflushing of the ASR wells on a routine basis. The required backflushing schedule will be determined in the field based on the results of the specific capacity (the drawdown in 24 hours divided by the pumping rate) or the specific injectivity (the rise in head over a 4-hour injection period divided by the recharge rate) testing. A baseline specific capacity and specific injectivity will be established for each well in the initial phases of recharge. The typical backflushing cycle occurs every 2 weeks, with six well surges lasting 20 minutes (depending on the pump manufacturers specifications). A discharge permit may be necessary before the redevelopment water is disposed of.

Biofouling

Biofouling is also not expected to be a concern for the JWC ASR project because of the existing low level of nutrients and high chlorine residual in JWC and Portland treated water. Temperatures between 20 and 40 degrees Celsius, pH between 7.8 and 8.6, total phosphorus exceeding 0.1 mg/L , nitrate exceeding 1 mg/L as N, or total iron exceeding 1 mg/L strongly enhance the biofouling potential (Pyne, 1995). Both of the recharge water sources (JWC and Portland) are below these limits (see Table 5-1). A chlorine residual may be maintained in the well during storage periods to control or eliminate the growth of bacteria at or near the well. This could be accomplished by using a trickle feed of chlorinated water during the storage period.

Chemical Reactions

A geochemical model was used to conduct a preliminary analysis of clogging potential and other chemical reactions that may result from mixing recharge water with native groundwater. The modeling was performed using a model written and distributed by USGS, titled PHREEQE (Parkhurst, Thorstenson, and Plummer, 1980). A geochemical model is a computer model that calculates the detailed chemical composition of a water sample and estimates the potential for precipitation or dissolution of mineral solids based on a general description of water quality. A more detailed description of the modeling process is provided in Appendix D.

The model was used to simulate mixing of two types of recharge water (JWC-treated water and Portland-treated water) with groundwater from two potential recharge wells (Beaverton's Hanson Road well and TVWD's Schuepbach well). Each mixing simulation evaluated mixing in three different proportions: 25 percent recharge water with 75 percent groundwater, 50 percent of each water type, and 75 percent recharge water with 25 percent groundwater. Each mixing proportion is indicative of a different zone within the envelope of recharge water that will surround the well during subsurface storage.

The primary goal of this geochemical modeling effort was to evaluate whether mixing within the aquifer would create chemical conditions conducive to precipitating solids that could lead to aquifer clogging or to dissolving minerals naturally present in the rock and bringing them into solution. These results are summarized in the form of a saturation index, which is the ratio between an equilibrium constant for the precipitation reaction of interest and the product of the activities (the activity roughly translates into concentration for this situation) of the compounds or ions participating in the reaction. Because the results can vary over many orders of magnitude, the logarithm of each value is used to simplify reporting. The mixed waters are considered to be oversaturated with respect to any mineral whose saturation index is greater than 1 (making the log saturation index greater than 0), and there will be a tendency for that mineral to precipitate from solution, assuming that equilibrium conditions apply.

It is apparent that a number of assumptions must be made for these modeling results to be directly applicable to the recharge scenarios simulated (for example, that equilibrium conditions exist between waters). Therefore, the primary utility of these results is to define the potential for chemical precipitation or mineral dissolution to occur and to evaluate whether the potential is great enough to be of concern in the ASR planning. For the geochemical model, CH2M HILL assumed that more reducing conditions exist in the basalt groundwater than the dissolved oxygen data may suggest, to provide a conservative analysis of possible mixing scenarios.

Iron hydroxide is commonly formed when oxygenated recharge water comes in contact with groundwater containing high iron concentrations in a reduced state. High iron and manganese concentrations have been noted in various locations within the basalt aquifer.

Assuming that the source water is oxidizing (pE = 5 to 6) and that the groundwater is reducing (pE = 0 to -2), the modeling results indicate that some iron precipitate is likely to form in the aquifer as result of mixing recharge and groundwater in the subsurface. The majority of these precipitation reactions will occur within the mixing zone of the ASR bubble, (which will be controlled during operation of the system). However, the amount of iron in the water is not sufficient to create significant clogging. It is anticipated that even if iron precipitation does occur, the relatively large pore spaces in the basalt will not plug easily. Other minerals that can precipitate quickly and potentially pose a clogging threat, such as calcium carbonate, calcium sulfate, and sodium chloride, are not likely to precipitate as a result of ASR activities. The concentrations of the ions that participate in these reactions are not sufficient for precipitation to occur.

Because the recharge water will be relatively oxidized, it may promote some dissolution of iron-bearing minerals, such as pyrite. Pyrite, a common iron sulfide mineral found associated with basalt rocks, may dissolve and produce iron and sulfate ions in solution when in contact with the recharge water. This reaction may also lower the pH slightly. Again, these reactions are not expected to substantially alter groundwater quality.

Air Entrainment

Air entrainment can cause clogging or a reduction in aquifer permeability. Air entrainment can occur when air bubbles are injected into the well with the recharge water or when air bubbles come out of solution after cool recharge water comes into contact with warmer groundwater. It is anticipated that the injection water will be colder than the native groundwater because the injection phase of the project will occur during the winter. Using measured temperature values for the groundwater and expected recharge water temperatures, the computed saturation indices for carbon dioxide and oxygen are less than one, suggesting that mixing in the subsurface should not create conditions conducive to the degassing and bubble formation that would cause clogging. Air entrainment caused by direct injection can be prevented or minimized by injecting the recharge water through a drop pipe or pump column (under full pipe flow) beneath the water level in the well, or by cascading recharge water down the well annulus or pump column under vacuum. These techniques for controlling air entrainment have been used at other ASR sites (Pyne, 1995).

5.2.4 Surface Water Quality Degradation Potential

Surface water quality could be affected by ASR operations if stored water leaks out of the aquifer and discharges into a stream or spring. If this were to occur to a large extent, the loss of stored water could make ASR impractical because OWRD would probably not allow full recovery of the stored water volume. Discharge of stored water containing elevated levels of metals (particularly copper) or chlorine could adversely affect aquatic life in a stream. The potential for loss of stored water to springs or surface water is not considered significant in the study area except possibly near Johnson Creek, where one of the basalt interflow zones may discharge groundwater naturally to the stream (refer to Section 4.3 of this report). The potential for loss of stored water to the creek will be evaluated during the pilot project. Even if some loss of stored water to the stream does occur, the stream would not be adversely affected because none of the constituents (including metals) in either the JWC or City of Portland water exceed federal ambient water quality criteria. In addition, residual chlorine will not be a concern because it is lost quickly after the water is injected into the aquifer (within 1 day).

5.2.5 Recovered Water Quality

The quality of the water recovered from the ASR well will be a function of several factors:

- The relative proportion of recharge water to native groundwater (mixing)
- Chemical reactions that occur when the two waters are mixed
- Chemical reactions that occur between the recharge water and basalt aquifer matrix
- The length of time the water is stored in the aquifer

The quality of the stored water near the well will be like that of the recharge water because the recharge water will displace the native groundwater. Some mixing of the stored water and native groundwater will occur progressively away from the well. As more recharge water is introduced into the aquifer, the mixing zone will be progressively farther away from the well. Mixing of the native groundwater and recharge water will also occur as a result of natural groundwater movement. Mixing caused by this phenomenon is not expected to be significant because groundwater movement is likely to be slow.

Depending on the amount of time that the water is stored in the aquifer, the concentration of DBPs may initially increase and then decrease again as the residual chlorine breaks down. During recovery and subsequent re-chlorination, as the water is introduced into the distribution system, DBPs will again form. The DBP concentration and rate of formation will depend on the concentrations of chlorine and total organic carbon (TOC) in the recovered water. TOC concentrations in the basalt aquifer and source water are low (see Table 5-1); thus, DBP formation potential is predicted to be low. The concentration of DBPs in the recovered water is not expected to exceed drinking water standards if the residual chlorine concentrations are maintained at current levels. Data will be collected during a pilot study so that DBP formation potential can be further evaluated.

As described previously, chemical reactions between the recharge water and native groundwater are not expected to significantly affect the overall quality of the recovered water, particularly as the storage zone in the aquifer becomes more developed and contains primarily treated source water. Because its pores are relatively large, the basalt aquifer has a relatively small surface area compared to a typical alluvial (sand and gravel) aquifer, so chemical reactions between the recharge water and aquifer matrix (basalt rock) are not expected to significantly affect the quality of the stored water, particularly because of the relatively short time the recharge water is stored in the aquifer. While these reactions are not expected to substantially affect the quality of the recovered water, they should be further assessed during a pilot recharge project.

As the stored water is recovered to meet peak demand later in the summer, the quality of the water produced from the ASR well will gradually become more like the native groundwater. Because the water produced by either the Schuepbach or Hanson Road wells has been objectionable to some local residents in the past, because of hardness, it is advisable to recharge enough water during the winter months so that some of the recharge water is left in the aquifer so that the recovered water quality is consistent. The need for re-chlorination or pH adjustment of the recovered water will be evaluated during the pilot test.

5.3 Water Quality Summary

In summary, the JWC- and City of Portland-treated water quality is good. Recharge of either treated water source is likely to result in overall improvement of the native basalt groundwater quality. Several constituents present in the JWC-treated water have slightly higher concentrations than those typically found in basalt groundwater. These constituents include sulfate, fluoride, nitrate, residual chlorine, and DBPs. Concentrations are significantly below drinking water standards and do not pose a health concern. In CH2M HILL's opinion, these constituents, found at the reported levels, will not degrade the native groundwater quality. When taken as a whole, recharge of JWC- or Portland-treated drinking water will result in a substantial improvement in the overall water quality in the aquifer.

Clogging caused by suspended solids or mineral precipitation when the recharge water and native groundwater are mixed during ASR is not expected to be a significant problem. Should clogging occur, it can be controlled during ASR operation with periodic backflushing and redevelopment.

Water quality in nearby streams should not be adversely affected if stored water is lost to the stream. The recovered water quality should meet all applicable drinking water standards. The need for re-chlorination and pH adjustment prior to directing the stored water into the distribution system will be further evaluated. Additional data collection is recommended during the pilot phase of the project to better characterize water quality compatibility, mixing, and recovered water quality.

Section 6
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Tables

Table 2-1
Municipal and Other Large-Capacity Wells
Pilot Test Study Area
TVWD ASR Hydrogeologic Feasibility Study

Well Inventory No.	Well Owner	Date Completed	Total Depth (ft bgs)	Ground Surface Elevation (feet)	Casing Diameter (inches)	Depth to Top of Basalt (ft bgs)	Saturated Thickness Open to Well (feet)	Well Yield or Capacity (gpm)	Permit (P) or Certificate (C) Number	Priority Date	Appropriation (gpm)
57	City of Beaverton Hanson Road well	1945	800	350	16" from 0 to 63 ft 15" from 63 to 450 ft 12" from 450 to 800 ft	54	630 ?	950	328 (P)	12/31/45	950 for public supply
64	Portland Golf Club	1951	500	220	8	410	40	1000	2021 &2022 (P)	12/31/23	Irrigation use
66	?	9/23/67	442	280	?	201	120	425	?		?
69	Tualatin Hills Parks and Recreation District	12/20/61	462	230	8	165	286	650	NA	NA	NA
90	Tualatin Valley Water District Schuepbach Well	5/17/59	414	270	14	11	305	1,089	44119 (C)	1/21/59	274 for irrigation 314 for public supply
132d	Tualatin Valley Water District Grabhorn Well	11/14/64	874	375	16" from 0 to 402 ft 12" from 616 to 728 ft	27?	210	1,250	36441 (C)	2/23/62	987 for public supply
143	Tualatin Valley Water District 189th Street Well	7/18/58	720	345	16" from 0 to 250 ft	45	450	470	36440 (C)	5/2/57	494 for public supply

Notes:
ft bgs = feet below ground surface.
gpm = gallons per minute. Yield value from pumping test rate after well completed.
Well inventory number is cross referenced to Table A-1. See this appendix table for additional information.
NA = not available.

Table 3-1
Hanson Road Well Aquifer Test
Pumping and Observation Well Characteristics
TVWD ASR Hydrogeologic Feasibility Study

	Hanson Road Well	Sage Place Well	Davies Road Well	BCC Well	Schuepbach Well
Owner	City of Beaverton	Dennis Peneyra	Homer Speer	Beaverton Christian Church	Tualatin Valley Water District
Well Address	136th Ave. and Salal Ct. Beaverton	7560 Sage Place Beaverton	13335 SW Davies Rd. Beaverton	13600 SW Allen Blvd. Beaverton	160th Ave. and Autumn Dr. Beaverton
Total Depth (ft)	800	395	300(?)	355	414
Ground Surface Elevation (ft)	355	291	299	223	272
Static Water Depth (ft) (8/30/95)	185	121	130	57	100
Static Water Elevation (ft)	170	170	169	166	172
Casing Diameter (inches)	16" from 0 to 63 ft	6	6	6	14
Depth to Top of Basalt (ft)	54	205	unknown	345	11
Saturated Thickness Open to Well (ft)	630?	175	unknown	10	305
Distance from Hanson Road Well (ft)	0	2,400	1,300	4,500	8,600
Type of Water Level Measurement	datalogger	datalogger	manual	manual	manual
Comments	Not in use	Former orchard irrigation well*	Used for lawn irrigation and stock watering*	Used for lawn irrigation*	Not in use*

Note:
ft = feet below ground surface.
* Not in use during test.

Table 3-2
Hanson Road Well Aquifer Test
Aquifer Parameter Estimates
TVWD ASR Hydrogeologic Feasibility Study

Well	Function	Test Phase	Solution Method	Transmissivity (gpd/ft)	Hydraulic Conductivity (ft/day)	Storativity	Specific Storage (1/ft)
Hanson Road	Pumping well	Pumping	Cooper-Jacob (before boundary)	150,000	260		
		Pumping	Cooper-Jacob (after boundary)	88,000	160		
		Recovery	Theis (early recovery)	150,000	270		
		Recovery	Theis (late recovery)	380,000	680		
Sage Place	Observation well	Pumping	Cooper-Jacob (before boundary)	630,000	1,130	4.4e-4	5.9e-6
		Pumping	Cooper-Jacob (after boundary)	130,000	230	1.5e-3	2.0e-5
		Recovery	Theis (late recovery)	790,000	1,400	2.3e-7	3.1e-9

Notes:
Aquifer thickness b = 75 feet (combined thickness of water-producing interflow zones identified in geophysics survey).
Transmissivity (T) in ft^2/min and storativity (unitless) were calculated using AQTESOLV software.
Hydraulic conductivity (K) is defined as K = T/b.
Specific storage (S_s) was calcaulated as S_s = S/b.
Conversion factor from gpd/ft to ft^2/day = divide by 7.48.

Table 3-3
Schuepbach Well Aquifer Test
Pumping and Observation Well Characteristics
TVWD ASR Hydrogeologic Feasibility Study

	Schuepbach Well	Dernbach Well
Owner	Tualatin Valley Water District	Margaret Dernbach
Well Address	160th St. and Autumn Dr. Beaverton	15820 SW Davis Rd. Beaverton
Total Depth (ft)	414	404
Ground Surface Elevation (ft)	272	466
Static Water Depth (ft)	100	290
Static Water Elevation (ft)	175	176
Casing Diameter (inches)	14	6
Depth to Top of Basalt (ft)	11	10
Saturated Thickness Open to Well (ft)	305	114
Distance from Schuepbach Well (ft)	0	2,400
Type of Water Level Measurement	datalogger	datalogger
Comments	Not in use	In use for domestic supply*

Note:
ft = feet below ground surface.
*Not in use during test.

Table 3-4
Schuepbach Well Aquifer Test
Aquifer Parameter Estimates

Well	Function	Test Phase	Solution Method	Transmissivity (ft^2/min)	Transmissivity (gpd/ft)	Hydraulic Conductivity (ft/day)
Schuepbach	Pumping well	Pumping	Cooper-Jacob (late data)	3	31,000	50
		Recovery	Theis straight-line recovery	7	71,000	110
Dernbach	Observation well	Pumping	No response to pumping observed			
		Recovery				

Notes:

Aquifer thickness b = 85 feet (combined thickness of water-producing interflow zones identified in geophysics survey).

Transmissivity (T) in ft^2/min was calculated using AQTESOLV software.

Hydraulic conductivity (K) is defined as K = T/b.

Table 3-5
Groundwater Depths and Elevations
TVWD ASR Hydrogeologic Feasibility Study

Date	Hanson Road Well	Schuepbach Well	Dernbach Well	Davies Road Well	Sage Place Well	Kauppila Well	Bloumquist Well	Beaverton Christian Church Well
*Measuring Point Elevation (feet)**								
	355	272	466	299	291	287	286	223
Depth to Water (feet)								
6/15/94	185.1	100.2	--	129.4	120.8	--	--	55.9
4/20/95	--	99.8	289.6	--	--	107.6	--	--
8/30/95	184.9	99.9	289.5	129.6	120.9	107.3	109.0	57.0
Water-Level Elevation (feet)								
6/15/94	170	172	--	170	170	--	--	167
4/20/95	--	172	176	--	--	179	--	--
8/30/95	170	172	177	169	170	180	177	166

Notes:

-- = not measured.

* Elevations obtained from City of Beaverton 2-foot contour maps.

Table 3-6
Identified Water-Producing Zone Elevation Comparisons
Hanson Road and Schuepbach Wells
TVWD ASR Hydrogeologic Feasibility Study

Well	Hanson Road Well	Schuepbach Well	Grabhorn Well
Wellhead Elevation	355 [a]	272 [a]	approximately 375
Depth to Interflow Zones (bgs) [b]	210 to 225	90 to 110	**
	370 to 380	165 to 170	**
	430 to 470	175 to 210	**
	flow from bottom of well	285 to 300	**
		352 to 362	**
Depth to Water	184.9 [c]	99.9 [c]	~202
Elevation of Interflow Zones	145 to 130	182 to 162	**
	-15 to -25	107 to 102	**
	-75 to -115	97 to 62	**
	flow from bottom of well	-13 to -28	**
		-80 to -90	**
Groundwater Elevations	170.1	172.1	~173

Notes:
bgs = below ground surface
[a] Elevations are from City of Beaverton 2-foot contoured topographic maps.
[b] Depths to interflow zones are based on borehole geophysical logs.
[c] Water level measurements obtained on August 30, 1995.
** Aquifer zone data to be collected following the successful completion of the first pilot test.

Table 4-1
Calculated Recharge Bubble Size
Hanson Road and Schuepbach Wells
TVWD ASR Hydrogeologic Feasibility Study

Well	Volume of Water Injected (V) (MG)	Total Thickness of Water-Producing Zone (b) (feet)	Porosity of Water-Producing Zone (n) (feet)	Radius of Recharge Bubble (r) (feet)
Hanson Road Well	125	75	0.15	690
	100	75	0.15	620
	75	75	0.15	530
	50	75	0.15	430
Schuepbach Well	125	85	0.15	650
	100	85	0.15	580
	75	85	0.15	500
	50	85	0.15	410
Grabhorn Well	125	? **	0.15	? **
	100	? **	0.15	? **
	75	? **	0.15	? **
	50	? **	0.15	? **

Notes:

MG = million gallons.

Thicknesses of water-producing zones are based on borehole geophysical logs.

The calculated recharge bubble size does not take into account mixing and ambient groundwater flow.

Radius = square root (V/7.48 x 3.14159 x b x n).

? ** Specific aquifer thickness data for the Grabhorn Well will be collected following the successful completion of the first pilot test.

TABLE 5-1
Regulated Contaminants for Drinking Water
Oregon Health Division
TVWD ASR Project

Category	Parameter	MCL Primary Standard (mg/L)	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
INORGANICS						
Physicals	Turbidity (NTU)	5	0.05	0.35	<0.1	0.14
	Asbestos (fibers per liter) [e]	7 million	<0.18	NA	NA	NA
Nutrient	Nitrite Nitrogen (NO2-N)	1	<0.01	<0.001	<0.01	<0.01
	Nitrite - Nitrate (Total N)	10	1.7	0.01	0.40	0.56
Metals	Antimony Total (Sb)	0.006	ND	<0.003	**	**
	Arsenic (As)	0.05	<0.002	<0.001	<0.002	<0.002
	Barium (Ba)	2	<0.025	<0.002	<0.1	<0.1
	Beryllium Total (Be)	0.004	ND	<0.0002	**	**
	Cadmium (Cd)	0.005	<0.005	<0.001	<0.0002	<0.0002
	Chromium (Cr)	0.1	<0.005	<0.001	<0.002	<0.002
	Copper (Cu)	1.3	0.001	0.004	<0.005	<0.005
	Cyanide (CN)	0.2	ND	<0.02	**	**
	Fluoride	4.0	ND	<0.05	<0.25	<0.25
	Lead (Pb)	0.015	<0.002	<0.001	0.002	<0.001
	Mercury (Hg)	0.002	<0.0003	<0.001	<0.0003	<0.0003
	Nickel (Ni)	0.1	ND	<0.001	**	**
	Selenium (Se)	0.05	<0.005	<0.001	<0.002	<0.002
	Thallium Total (Tl)	0.002	ND	<0.001	**	**
VOLATILE ORGANIC COMPOUNDS (VOCs)						
	1,1-Dichloroethylene	0.007	<0.0005	<0.0005	<0.0005	<0.0005
	1,1,1-Trichloroethane	0.2	<0.0005	<0.0005	<0.0005	<0.0005
	1,1,2-Trichloroethane	0.005	<0.0005	<0.0005	**	**
	1,2-Dichloropropane	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	1,2-Dichloroethane	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	1,2,4-Trichlorobenzene	0.07	<0.0005	<0.0005	**	**
	Benzene	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	Carbon tetrachloride	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	cis-1,2-Dichloroethylene	0.07	<0.0005	<0.0005	<0.0005	<0.0005
	Dichloromethane	0.005	<0.0005	<0.0005	**	**

TABLE 5-1
Regulated Contaminants for Drinking Water
Oregon Health Division
TVWD ASR Project

Category	Parameter	MCL Primary Standard (mg/L)	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
	Ethylbenzene	0.7	<0.0005	<0.0005	<0.0005	<0.0005
	Monochlorobenzene	0.1	<0.0005	<0.0005	<0.0005	<0.0005
	O-Dichlorobenzene (1,2-)	0.6	<0.0005	<0.0005	<0.0005	<0.0005
	P-Dichlorobenzene (1,4-)	0.075	<0.0005	<0.0005	<0.0005	<0.0005
	Styrene	0.1	<0.0005	<0.0005	<0.0005	<0.0005
	Tetrachloroethylene	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	Toluene	1.0	<0.0005	<0.0005	<0.0005	<0.0005
	Total Xylenes	10.0	<0.0005	<0.0005	<0.0005	<0.0005
	trans-1,2-Dichloroethylene	0.1	<0.0005	<0.0005	<0.0005	<0.0005
	Trichloroethylene	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	Vinyl chloride	0.002	<0.0005	<0.0005	<0.0005	<0.0005
SYNTHETIC ORGANIC COMPOUNDS (SOCs)						
	2, 4-D	0.07	<0.0013	<0.0002	<0.007	<0.007
	2, 4, 5-TP (Silvex)	0.05	<0.0009	<0.0004	<0.005	<0.005
	Adipates	0.4	<0.0027	<0.001	**	**
	Alachlor (Lasso)	0.002	<0.00016	<0.0004	<0.0004	<0.0004
	Atrazine	0.003	<0.0003	<0.0002	<0.0003	<0.0003
	Benzo(a)Pyrene	0.0002	<0.00004	<0.00004	**	**
	BHC-gamma (Lindane)	0.0002	<0.00002	<0.00002	<0.00002	<0.00002
	Carbofuran	0.04	<0.004	<0.001	<0.004	<0.004
	Chlordane	0.002	<0.0002	<0.002	<0.0004	<0.0004
	Dalapon	0.2	<0.0043	<0.02	**	**
	Dibromochloropropane (DBCP)	0.0002	<0.00001	<0.00002	<0.00002	<0.00002
	Dinoseb	0.007	<0.0002	<0.0004	**	**
	Dioxin (parts per trillion)	0.03	NA	<0.0007	**	**
	Diquat	0.02	<0.008	<0.0004	**	**
	Endothall	0.1	<0.017	<0.001	**	**
	Endrin	0.002	<0.00005	<0.00002	<0.00002	<0.00002
	Ethylene Dibromide (EDB)	0.00005	<0.00001	<0.00001	<0.00001	<0.00001
	Glyphosate	0.7	<0.025	<0.01	**	**

TABLE 5-1
Regulated Contaminants for Drinking Water
Oregon Health Division
TVWD ASR Project

Category	Parameter	MCL Primary Standard (mg/L)	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
	Heptachlor Epoxide	0.0002	<0.00010	<0.00002	<0.00002	<0.00002
	Heptachlor	0.0004	<0.00012	<0.00004	<0.00004	<0.00004
	Hexachlorobenzene	0.001	<0.00004	<0.0001	**	**
	Hexachlorocyclopentadiene	0.05	<0.00017	<0.0002	**	**
	Methoxychlor	0.04	<0.00015	<0.0002	<0.004	<0.004
	Pentachlorophenol	0.001	<0.00007	<0.00008	<0.0001	<0.0001
	Phthalates	0.006	<0.0010	<0.001	**	**
	Picloram	0.5	<0.025	<0.0002	**	**
	Polychlorinated Biphenyls (PCBs)	0.0005	<0.00020	<0.0002	<0.00025	<0.00025
	Simazine	0.004	<0.00008	<0.0001	**	**
	Toxaphene	0.003	<0.001	<0.001	<0.001	<0.001
	Vydate (Oxamyl)	0.2	<0.0013	<0.002	**	**
DISINFECTION BY-PRODUCTS NA						
	Total Trihalomethanes	0.1	0.0192	0.017	NT	NT
RADIONUCLIDES						
	Gross Alpha (pCi/L)[f]	15	0.0	0.0	0.233	0.211
BACTERIOLOGICAL						
	Total Coliform[g]	None	0	0 percent	<1	<1.1

Notes:
** = This analyte will be tested for in the baseline monitoring phase of the pilot test program.
[a]Dated January 15, 1997
[b]Dated February 4, 1997
[c]Sample collected May 3, 1995
[d]Sample collected July 14, 1994
[e]Source water asbestos sampling only applies in state designated risk areas.
[f]Detection of Gross Alpha requires further evaluation as specified in the OHD rules.
[g]Detection of Total Coliform requires further evaluation as specified in the OHD rules.
NA = analysis not applicable
NT = not tested for
ND = not detected at method detection limit

TABLE 5-2
Unregulated Contaminants for Drinking Water
Oregon Health Division
TVWD ASR Project

Category	Parameter	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
INORGANICS					
	Sodium (Na)	14	1.1	12.1	12.1
	Sulfate	0.5	0.5	<7.0	<7.0
SYNTHETIC ORGANIC COMPOUNDS (SOCs)					
	3-Hydroxycarbofuran	<0.0015	<0.004	**	**
	Aldicarb	<0.0015	<0.002	**	**
	Aldicarb Sulfone	<0.0016	<0.001	**	**
	Aldicarb Sulfoxide	<0.0015	<0.003	**	**
	Aldrin	<0.00009	<0.0001	**	**
	Butachlor	<0.00016	<0.001	**	**
	Carbaryl	<0.0016	<0.004	**	**
	Dicamba	<0.0002	<0.0005	**	**
	Dieldrin	<0.00013	<0.0001	**	**
	Methomyl	<0.0010	<0.004	**	**
	Metolachlor	<0.00020	<0.002	**	**
	Metribuzin	<0.00032	<0.001	**	**
	Propachlor	<0.00020	<0.001	**	**
VOLATILE ORGANIC COMPOUNDS (VOCs)					
	1,1-Dichloroethane	<0.0005	<0.0005	**	**
	1,1-Dichloropropene	<0.0005	<0.0005	**	**
	1,1,1,2-Tetrachloroethane	<0.0005	<0.0005	**	**
	1,1,2,2-Tetrachloroethane	<0.0005	<0.0005	**	**
	1,2,3-Trichloropropane	<0.0005	<0.0005	**	**
	1,3-Dichloropropane	<0.0005	<0.0005	**	**
	1,3-Dichloropropene	<0.0005	<0.0005	**	**
	2,2-Dichloropropane	<0.0005	<0.0005	**	**
	Bromobenzene	<0.0005	<0.0005	**	**
	Bromodichloromethane[e]	0.0026	0.017[e]	**	**

TABLE 5-2
Unregulated Contaminants for Drinking Water
Oregon Health Division
TVWD ASR Project

Category	Parameter	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
	Bromoform[e]	<0.0005	0.017[e]	**	**
	Bromomethane	<0.0005	<0.0005	**	**
	Chlorodibromomethane[e]	<0.0005	0.017[e]	**	**
	Chloroethane	<0.0005	<0.0005	**	**
	Chloroform[e]	0.0182	0.017[e]	**	**
	Chloromethane	<0.0005	<0.0005	**	**
	O-Chlorotoluene	<0.0005	<0.0005	**	**
	P-Chlorotoluene	<0.0005	<0.0005	**	**
	Dibromomethane	NT	<0.0005	**	**
	M-Dichlorobenzene	<0.0005	<0.0005	**	**

Notes:
** = This analyte will be tested for in the baseline monitoring phase of the pilot test program.
[a]Dated January 15, 1997
[b]Dated February 4, 1997
[c]Sample collected May 3, 1995
[d]Sample collected July 14, 1994
[e]This compound is one of the trihalomethanes. The result presented is a total of all four compounds added together.
NT = not tested for

TABLE 5-3
MAXIMUM MEASURABLE LEVELS (MML)
Department of Environmental Quality Groundwater Quality Protection
TVWD ASR Project

Category	Parameter	DEQ MML (mg/L)	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
INORGANIC						
	Arsenic (As)	0.05	<0.002	<0.001	<0.002	<0.002
	Barium (Ba)	1	<0.025	<0.002	<0.01	<0.1
	Cadmium (Cd)	0.010	<0.005	<0.001	<0.0002	<0.0002
	Chromium (Cr)	0.05	<0.005	<0.001	<0.002	<0.002
	Fluoride	4.0	ND	<0.05	<0.50	<0.25
	Lead (Pb)	0.05	<0.002	<0.001	0.002	<0.001
	Mercury (Hg)	0.002	<0.0003	<0.001	<0.0003	<0.0003
	Nitrate - N	10	0.4	0.03	0.40	0.56
	Selenium (Se)	0.01	<0.005	<0.001	<0.002	<0.002
	Silver	0.05	<0.005	<0.001	**	**
ORGANIC COMPOUNDS						
	Benzene	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	Carbon tetrachloride	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	P-Dichlorobenzene (1,4-)	0.075	<0.0005	<0.0005	<0.0005	<0.0005
	1,2-Dichloroethane	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	1,1-Dichloroethylene	0.007	<0.0005	<0.0005	<0.0005	<0.0005
	1,1,1-Trichloroethane	0.2	<0.0005	<0.0005	<0.0005	<0.0005
	Trichloroethylene	0.005	<0.0005	<0.0005	<0.0005	<0.0005
	Total Trihalomethanes	0.1	0.0192	0.017	NT	NT
	Vinyl chloride	0.002	<0.0005	<0.0005	<0.0005	<0.0005
	2, 4-D	0.10	<0.0013	<0.0002	<0.0007	<0.0007
	Endrin	0.0002	<0.00005	0.0002	<0.0002	<0.0002
	BHC-gamma (Lindane)	0.004	<0.00005	<0.00002	<0.00002	<0.00002
	Methoxychlor	0.10	<0.00015	<0.0002	<0.004	<0.004
	Toxaphene	0.005	<0.001	<0.001	<0.001	<0.001
	2, 4, 5-TP (Silvex)	0.01	<0.0009	<0.0004	<0.005	<0.005
RADIOACTIVE SUBSTANCES						
	Gross Alpha (pCi/L)[e]	15	0.0	0.0	0.233	0.211
	Gross Beta (pCi/L)	50	NT	1.8	3.24	2.70

TABLE 5-3
MAXIMUM MEASURABLE LEVELS (MML)
Department of Environmental Quality Groundwater Quality Protection
TVWD ASR Project

Category	Parameter	DEQ MML (mg/L)	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
BACTERIOLOGICAL						
	Coliform Bacteria[g]	<1/100 mL	0	0	<1	<1.1
TURBIDITY						
	Turbidity	1 NTU	0.05	0.35	<0.1	0.14

Notes:
** = This analyte will be tested for in the baseline monitoring phase of the pilot test program.
[a]Dated January 15, 1997
[B]Dated February 4, 1997
[c]Sample collected May 3, 1995
[d]Sample collected July 14, 1994
[e]Detection of Gross Alpha requires further evaluation as specified in the OHD rules.
[f]Detection of Total Coliform requires further evaluation as specified in the OHD rules.
NT = not tested for

TABLE 5-4
SECONDARY MAXIMUM CONTAMINANT LEVELS (SMCL)
Federal Regulations
TVWD ASR Project

Category	Parameter	Secondary Standard SMCL (mg/L	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
PHYSICALS						
	pH (standard units)	6-8.5	7.62	6.8	6.82	6.88
	Color (standard units)	15	ND	<5	NT	NT
	Hardness (as $CaCO_3$)	250	32.0	8.8	180	140
	Odor (threshold odor #s)	3	NT	1	NT	NT
	Total Dissolved Solids	500	72	20	290	245
INORGANICS						
Anions & Cations	Fluoride (F)	2.0	ND	<0.05	<0.50	<0.25
	Sulfate (SO_4)	250	10	<0.5	<7.0	<7.0
Metals	Aluminum (Al)	0.05-0.20	0.007	0.089	0.02	<0.1
	Chloride	250	4.7	2.0	68	47.5
	Iron (Fe)	0.3	ND	0.037	<0.03	<0.03
	Manganese (Mn)	0.05	0.005	0.004	0.019	0.019
	Silver	0.1	ND	1.1	NT	NT
	Sodium	20	14	<0.001	12.1	12.1
	Sulfate	250	10	NA	<7.0	<7.0
	Zinc	5	0.008	<0.001	NT	NT
Miscellaneous	Methylene Blue Active Substance (foaming agent)	0.5	0.01	0.15	NT	NT
	Corrosivity	Non-corrosive	NT	NT	NT	NT

Notes:
[a]Dated January 15, 1997
[b]Dated February 4, 1997
[c]Sample collected May 3, 1995
[d]Sample collected July 14, 1994
NT = not tested for
ND = not detected at method detection limit

TABLE 5-5
Additional Geochemical Parameters
TVWD ASR Project

Category	Parameter	JWC Water Analytical Results[a] (mg/L)	Bull Run Water Analytical Results[b] (mg/L)	Schuepbach Well Analytical Results[c] (mg/L)	Hanson Road Well Analytical Results[d] (mg/L)
Anions/Cations	Alkalinity as $CaCO_3$	41	4.2	194	110
	Carbonate	ND	<0.1	NA	NA
	Bicarbonate	41	4.2	194	110
	Potassium	ND	0.2	3.8	2.6
	Magnesium	2.3	0.58	19	19
	Calcium	6.8	1.5	47	36
	Sodium	14	1.1	12.1	12.1
	Iron				
	Total	ND	0.037	<0.03	<0.03
	Dissolved	--	--	--	--
	Manganese				
	Total	0.005	0.004	0.019	0.019
	Dissolved	--	--	--	--
	Chloride	4.7	2.0	68	47.5
	Sulfate	10	<0.5	<7.0	<7.0
	Silica	19.2	4.0	NA	NA
Miscellaneous	TSS (total suspended solids)	--	--	--	--
	TDS (total dissolved solids)	72	20	290	245
	TOC (total organic carbon)	0.90	1.05	<1.0	0.7
	pH	7.62	6.8	6.82	6.88
	ORP (oxidation/reduction potential)	**	**	**	**
	Temperature °C	NT	5 to 15	NT	NT

Notes:
** This analyte will be tested for in the baseline monitoring phase of the pilot test program.
[a]Dated January 15, 1997
[b]Dated February 4, 1997
[c]Sample collected May 3, 1995
[d]Sample collected July 14, 1994
NT = not tested for
ND = not detected at method detection limit

TABLE 5-6
Cooper Mountain Basalt Aquifer
Water Quality Summary
TVWD ASR Project

Parameter	Drinking Water Standard (1)	Typical Basalt Well in Tualatin Valley (USGS Report) (2)	Beaverton Christian Church Well (3)	Dernbach Well (4)	Davis Road Well (5)	Kauppila Well (6)
PHYSICAL						
Turbidity	1	--	85 (NTU)	0.5 (NTU)	2.5 (NTU)	125 (NTU)*
pH	6.5-8.5	7.7	6.58	6.79	6.47	5.94
Conductivity (μmohms/cm)		427	300	240	170	200
Total dissolved solids	500	200	222	175	146	116
Suspended solids		--	164	<1.0	<1.0	32
Total solids		--	–	–	–	–
Temperature (°C)		--	16.3	15.0	11.8	12.4
NUTRIENTS						
Ammonia (NH_3-N)	--	--	<0.1	<0.1	<0.1	<0.1
Nitrate (NO_3-N)	10	0.1	<0.25	<0.25	<0.25	<0.25
Nitrogen, organic (N)		--	--	--	--	--
Phosphorus, total (P)		--	--	--	--	--
Total organic carbon (TOC)		--	<1	<1	<1	<1
Dissolved oxygen	--	--	--	--	--	--
ANIONS/CATIONS						
Alkalinity ($CaCO_3$)		--	180	140	130	90
Bicarbonate (as $CaCO_3$)		156	180	140	130	90
Chloride (Cl)	250	15	31.5	7.0	2.0	5.0
Fluoride (F)	2	0.2	<0.25	<0.25	<0.25	<0.25
Sulfate (SO_4)	250	1.6	<7.0	<7	<7	<7
Calcium (Ca)		24	33	23	19	16
Magnesium (Mg)		15	12	18	16	13
Potassium (K)		5.3	3.2	3.0	2.1	1.6
Sodium (Na)		12	34	15.6	13.6	9.5
METALS						
Aluminum (total) (Al)	0.05-0.2	--	0.88	0.008	0.02	<0.01
Aluminum (dissolved)	–	--	0.09	<0.01	0.02	<0.01
Arsenic (As)	0.05	--	<0.002	<0.002	<0.002	<0.002
Barium (Ba)	1.0	--	<0.1	<0.1	<0.1	<0.1
Cadmium (Cd)	0.01	--	<0.0002	0.0002	<0.0002	0.0002
Chromium (Cr)	0.05	--	<0.002	<0.002	<0.002	0.002

TABLE 5-6
Cooper Mountain Basalt Aquifer
Water Quality Summary

TVWD ASR Project

Parameter	Drinking Water Standard (1)	Typical Basalt Well in Tualatin Valley (USGS Report) (2)	Beaverton Christian Church Well (3)	Dernbach Well (4)	Davis Road Well (5)	Kauppila Well (6)
Lead (Pb)	0.015	--	<0.001	<0.001	0.004	0.004
Mercury (Hg)	0.002	--	<0.0003	<0.0003	<0.0003	<0.0003
Selenium (Se)	0.01	--	0.002	<0.002	<0.002	<0.002
Silver (Ag)	0.05	--	–	–	–	–
Iron (Fe)	0.3	0.43	3.4♦	0.07	0.04	7.9♦
Manganese (Mn)	0.05	--	0.67	<0.01	<0.01	<0.01
Zinc (Zn)	5	--	--	--	--	--
Copper (Cu)	1.0	--	<0.01	<0.01	<0.01	0.03
ORGANICS						
THMs (total)	0.1	--	--	--	--	--
Haloacetic acid (HAAs)	--	--	--	--	--	--
VOCs		--	ND	ND	ND	ND
MISCELLANEOUS						
Chlorine residual	--	--	--	--	--	--
Total cyanide (CN)	0.2	--	--	--	--	--
Hardness (as $CaCO_3$)	250	50	116	108	96	76
Silica		--	--	--	--	--

Notes:

-- = Analyte not tested for.

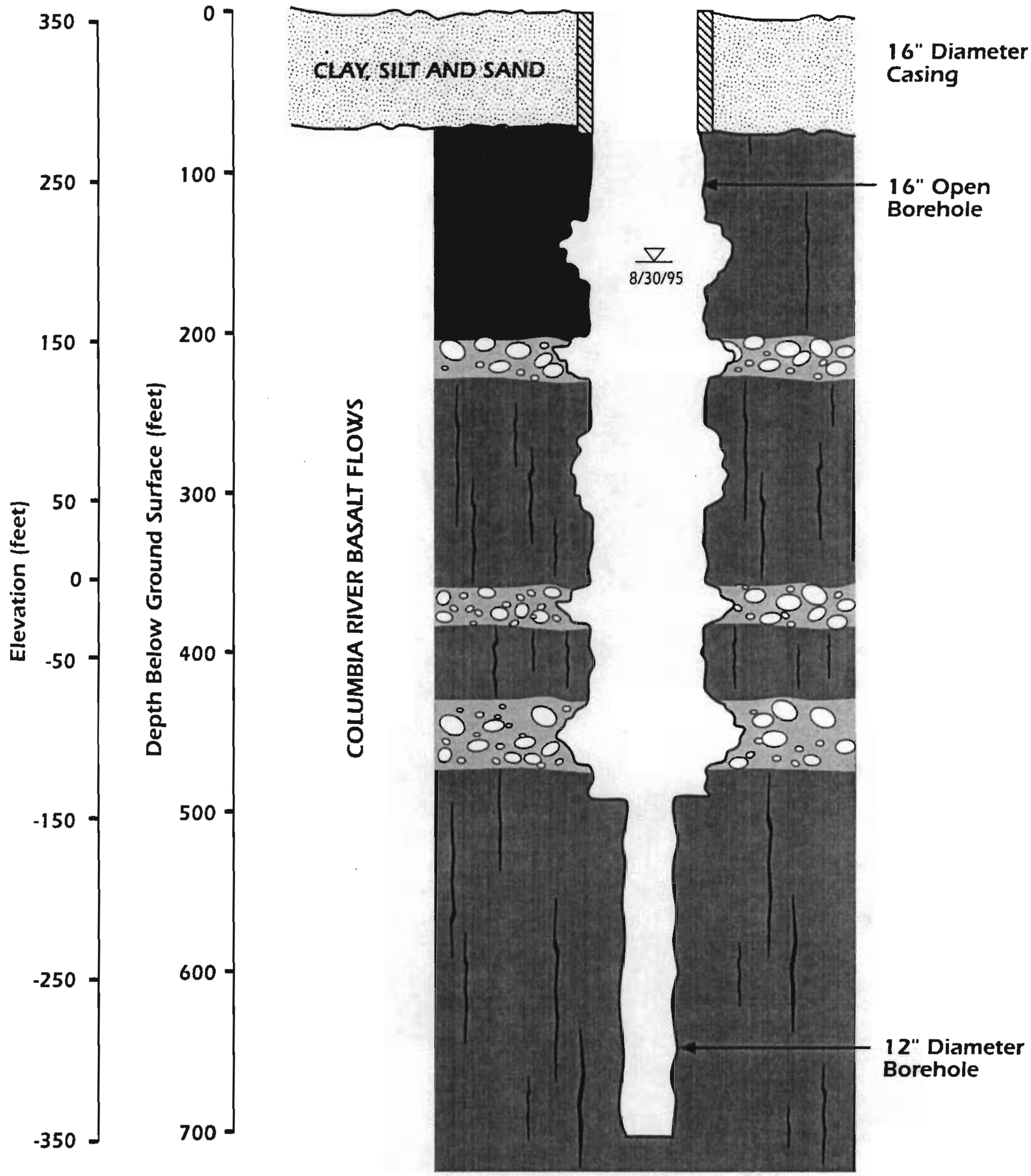
ND = Not detected.

♦ = Well owner noted the holding tank is rusty, and the rusty-colored, cloudy water clears up after approximately 45 minutes of using the well.

References:

1. Drinking water standards based on the most conservative value identified by EPA, DEQ, and Oregon Health Division standards.
2. Typical basalt well in the Tualatin basin (T1S, R2W, 31C1 well); sample collected on May 15, 1951; USGS Water Supply Paper 1697.
3. pH, conductivity, and temperature for BCC well collected on 8/30/95 (after 110 gallons purged).
4. pH, conductivity, and temperature for Dernbach well collected on 8/30/95 (after 150 gallons purged).
5. pH, conductivity, and temperature for Speer well collected on 8/30/95 (after 300 gallons purged).
6. pH, conductivity, and temperature for Kauppila well collected on 8/30/95 (after 180 gallons purged).

Figures



Note: Well drilled in 1945.

LEGEND

Static Water-Level Measurement

Clay, Silt, and Sand

Basalt

– Water-producing interflow zones

– Massive interior flow zones with columnar jointing

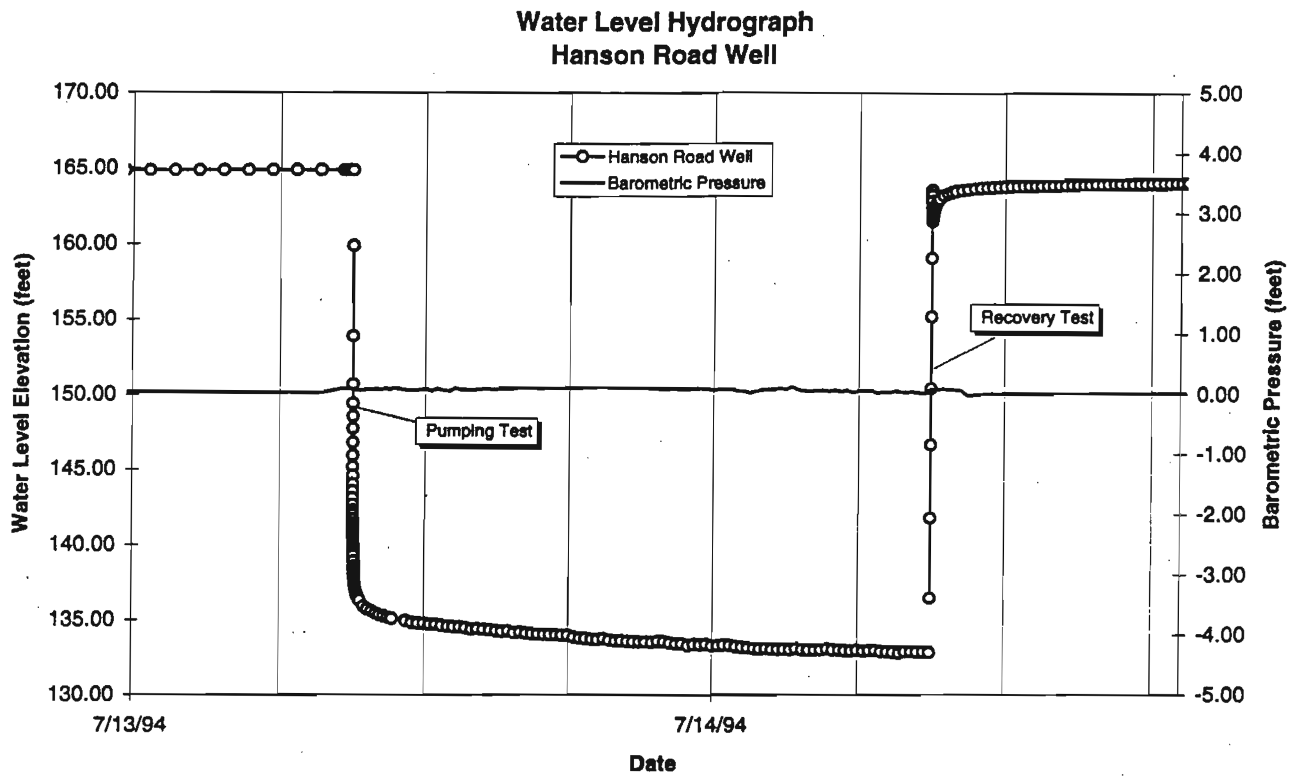
FIGURE 3-1

Hanson Road Well

Construction Details and Geologic Log

TUALATIN VALLEY WATER DISTRICT

ASR HYDROGEOLOGIC FEASIBILITY STUDY



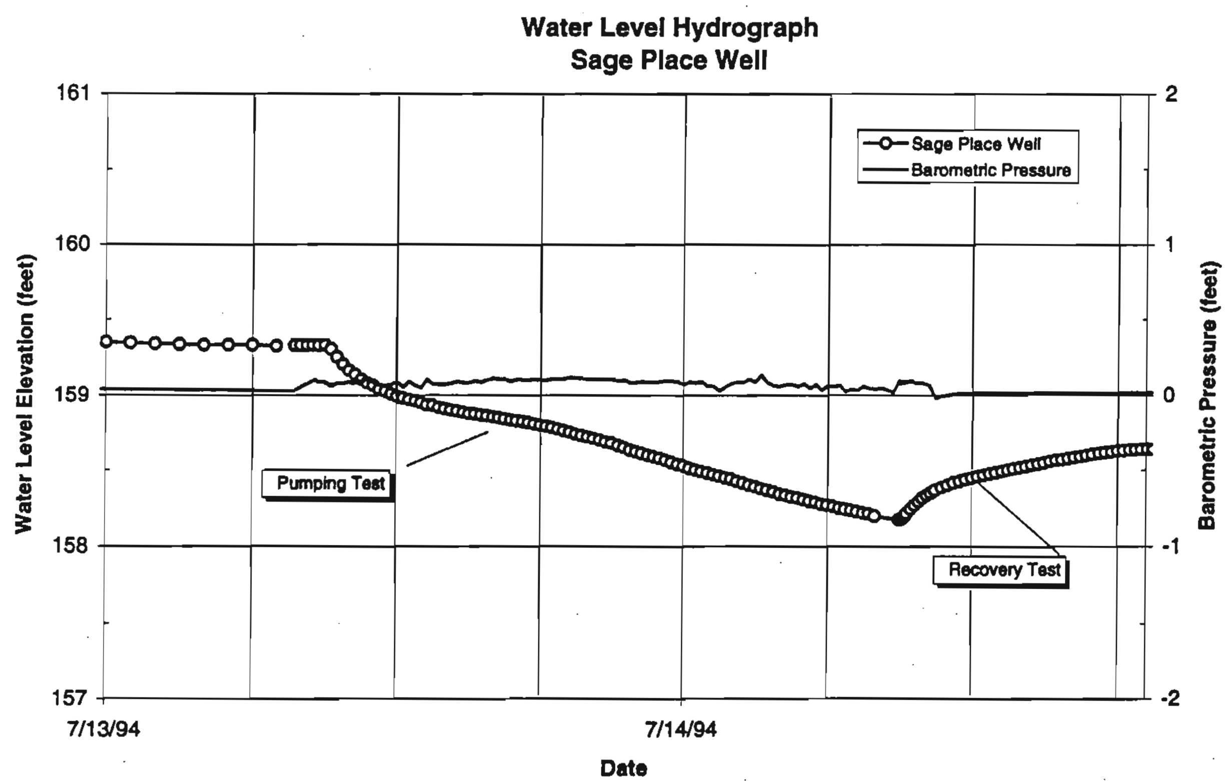
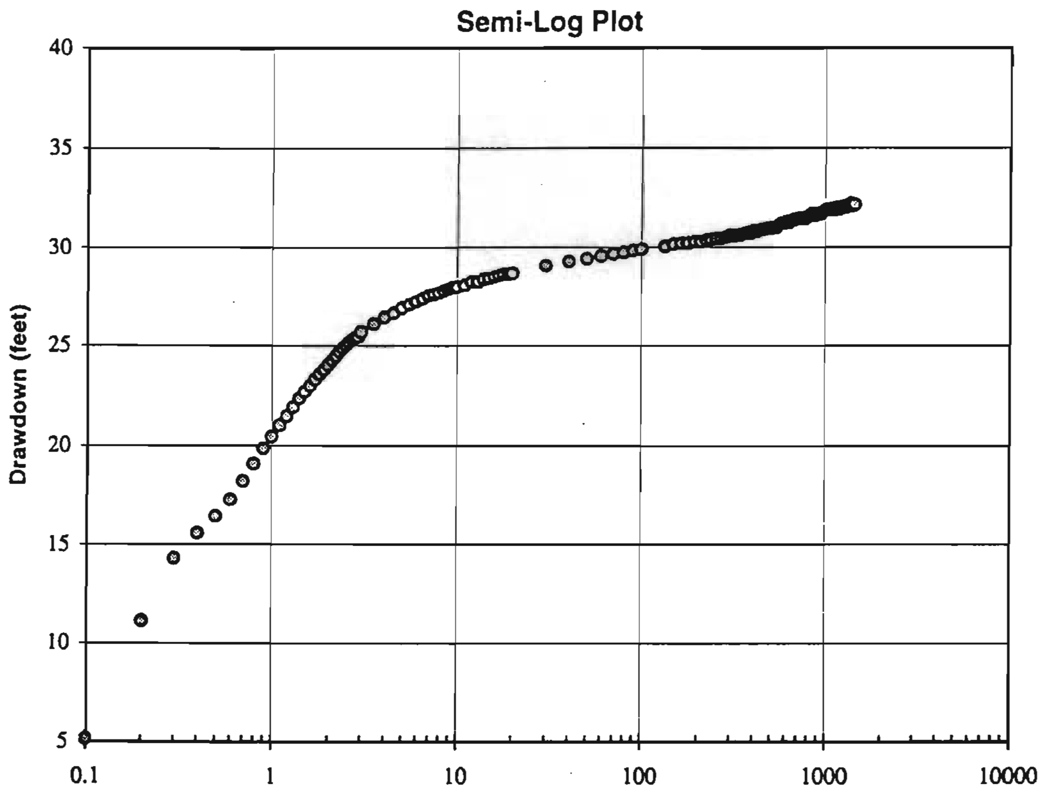


FIGURE 3-2

Hanson Road Aquifer Test
Hanson Road/Sage Place Hydrographs

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY



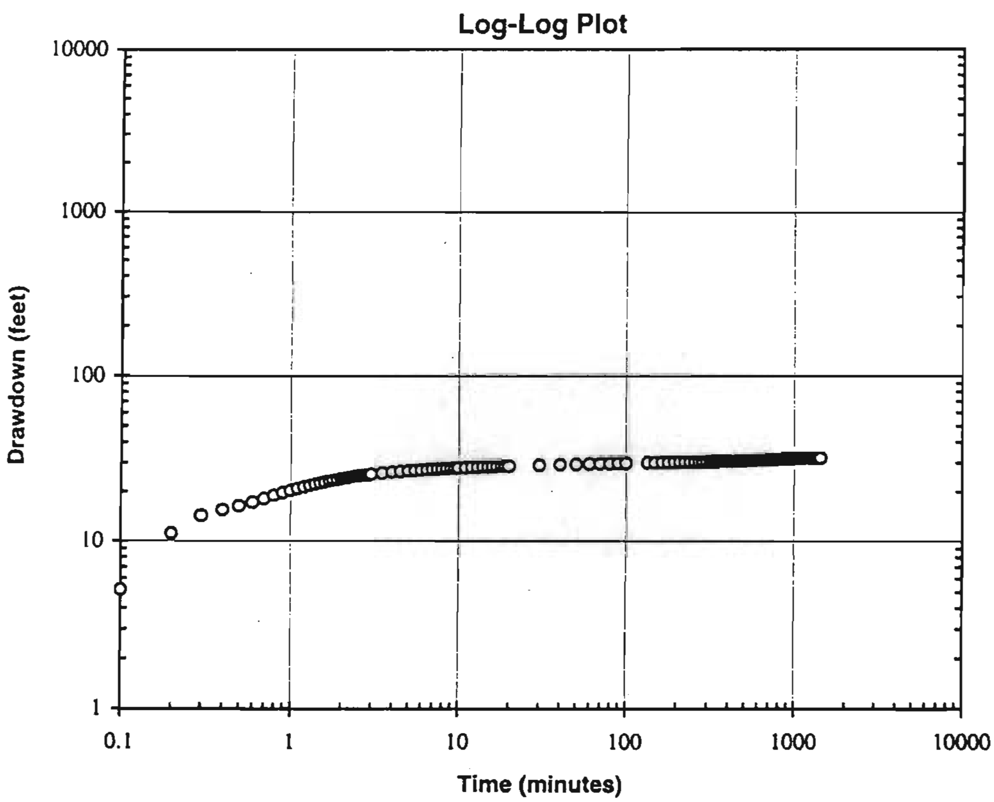
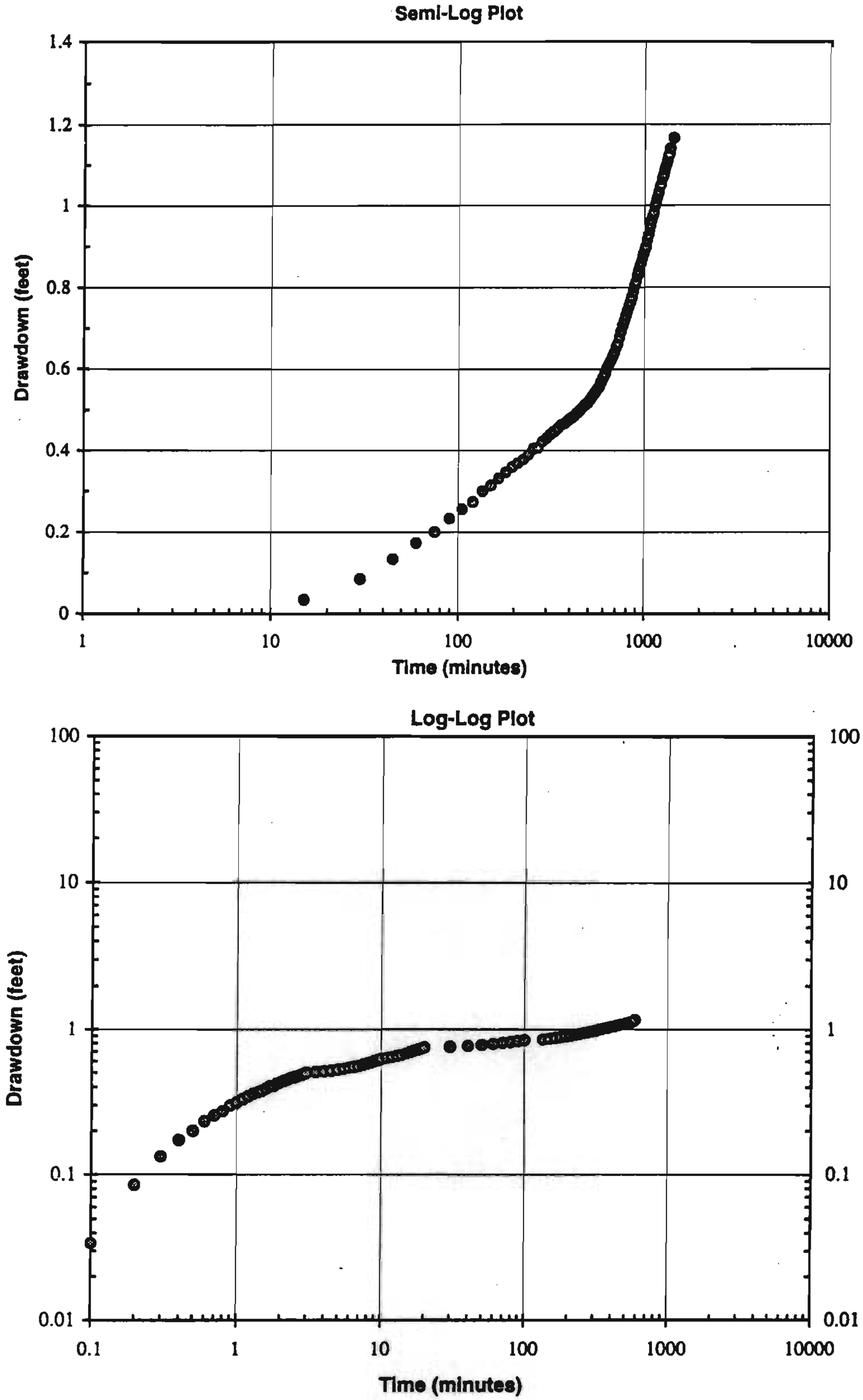


FIGURE 3-3

Hanson Road Aquifer Test
Hanson Road Well: Pumping Well Drawdown Data

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

Note: Q = 880 gpm
The scale for the Hanson Road well drawdown axis is different from the scale for the Sage Place well (observation well, Figure 3-4) drawdown axis.



Note: Q = 880 gpm at Hanson Road well
The scale for the Sage Place well drawdown axis is different from the scale for the Hanson Road well (pumping well, Figure 3-3) drawdown axis.

FIGURE 3-4
Hanson Road Aquifer Test
Sage Place Well: Observation Well Drawdown Data

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

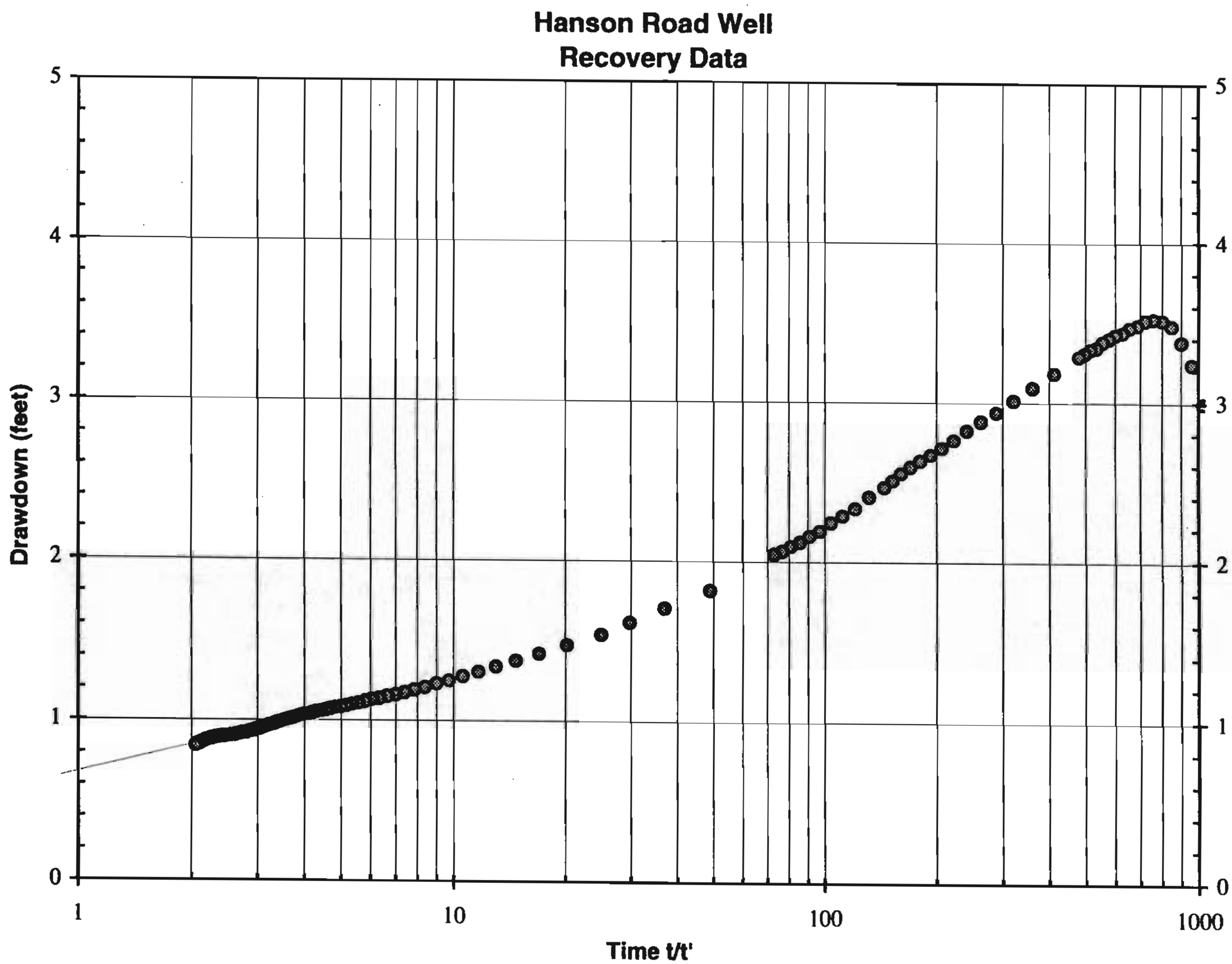


FIGURE 3-5
Hanson Road Aquifer Test
Hanson Road Well: Recovery Data

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

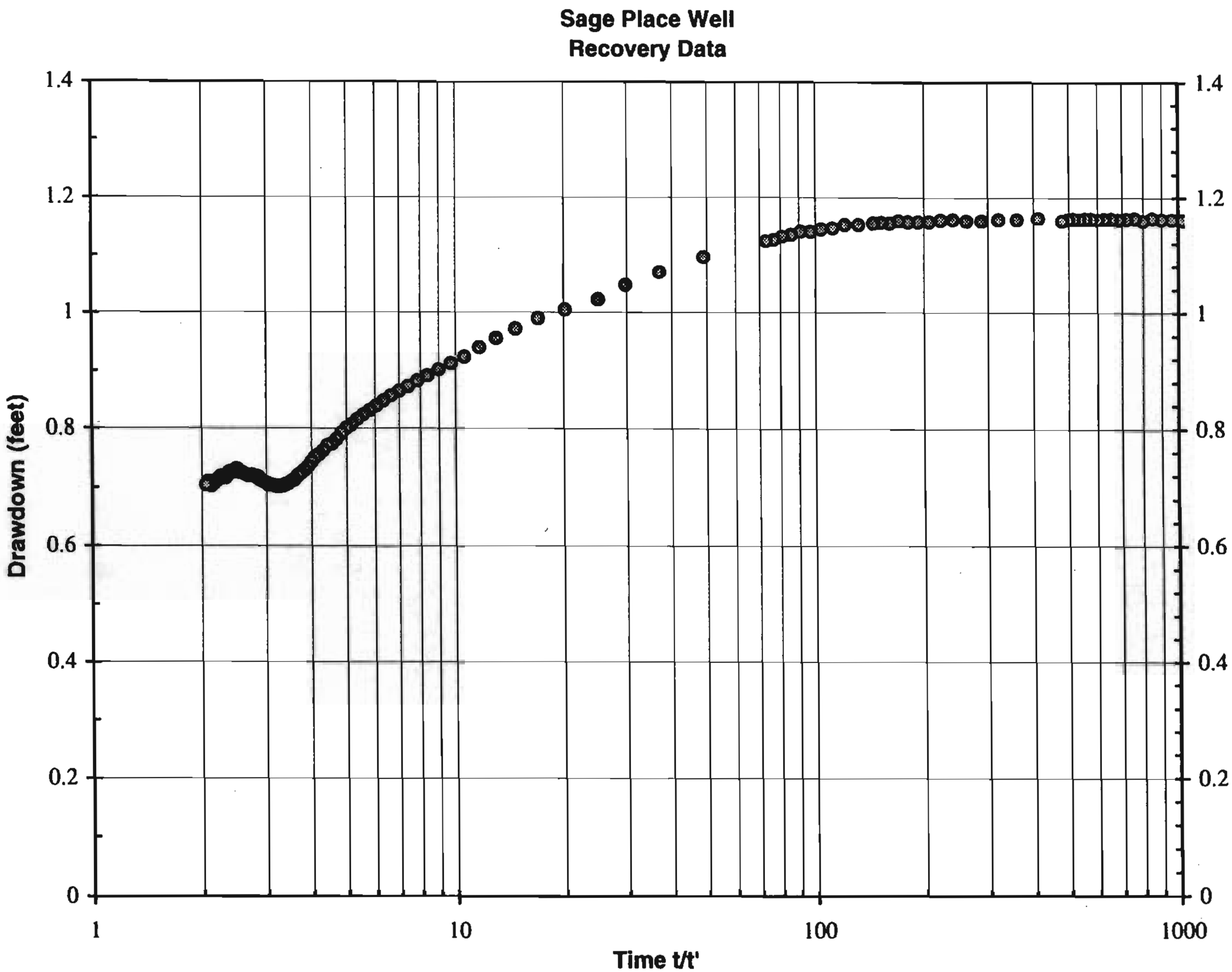
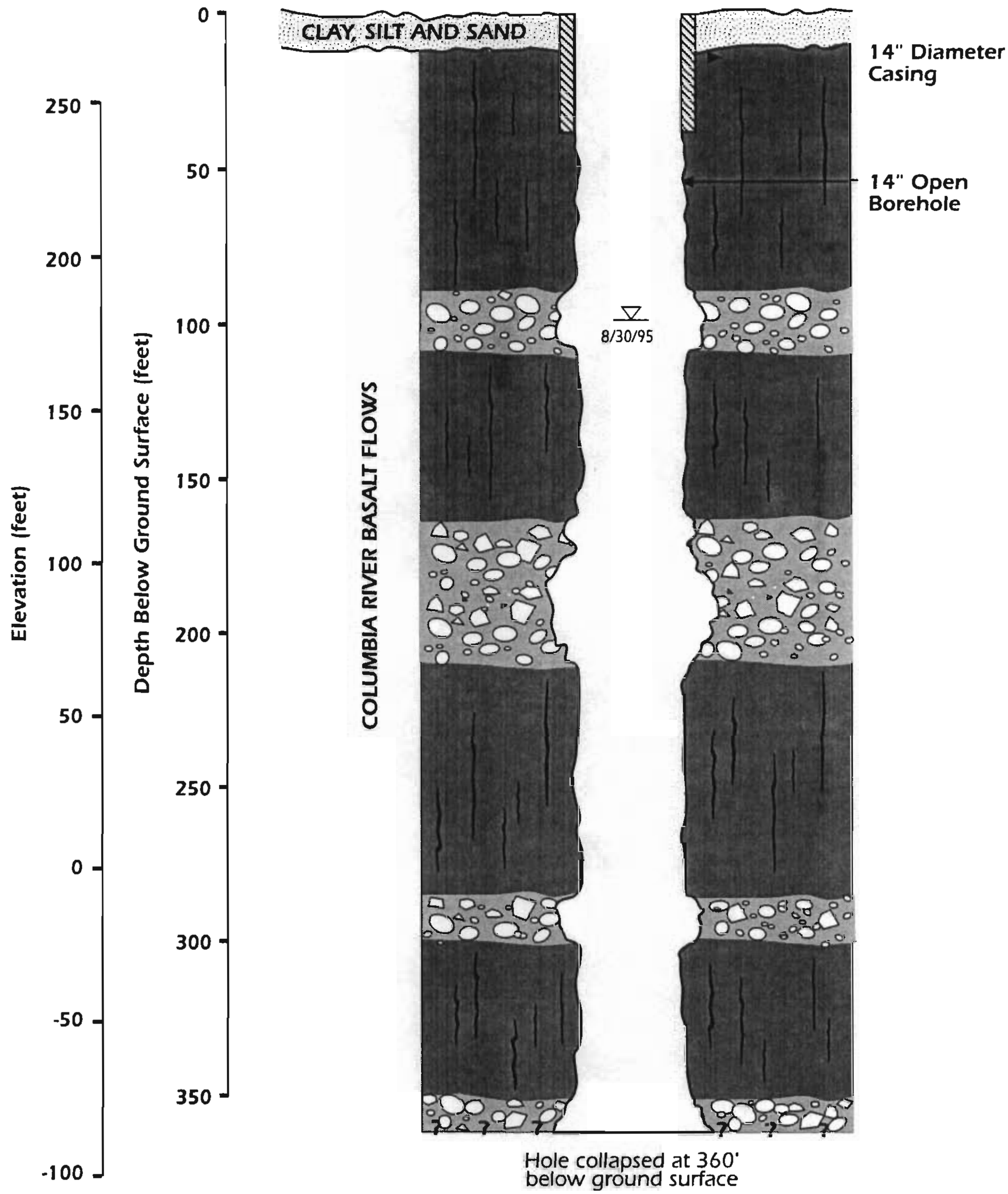


FIGURE 3-6
Hanson Road Aquifer Test
Sage Place Well: Recovery Data

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY



Note: Well drilled in May 1959.

LEGEND

Static Water-Level Measurement

Clay, Silt, and Sand

Basalt

– Water-producing interflow zones

– Massive interior flow zones with columnar jointing

FIGURE 3-7

Schuepbach Well
Construction Details and Geologic Log

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

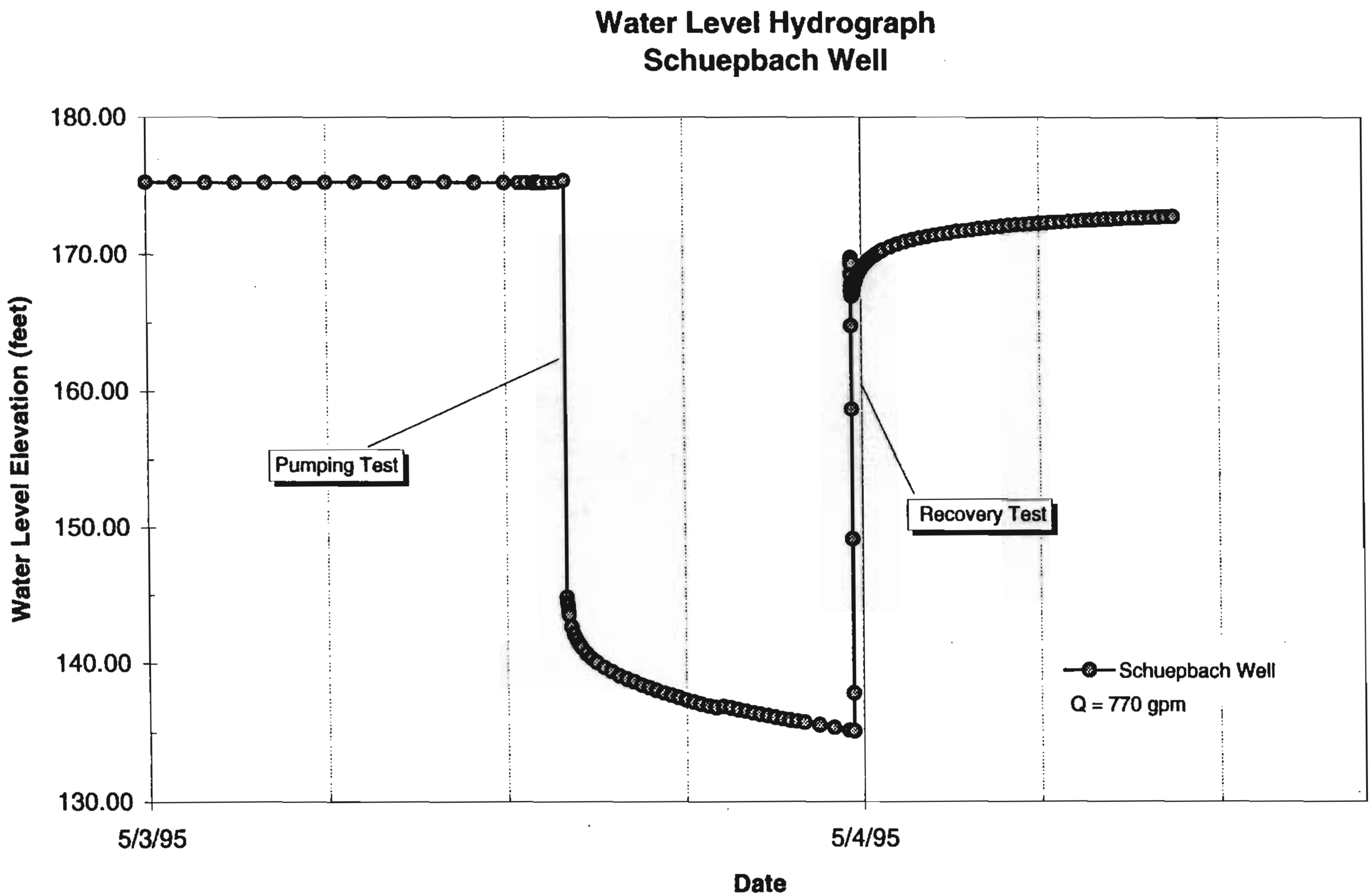
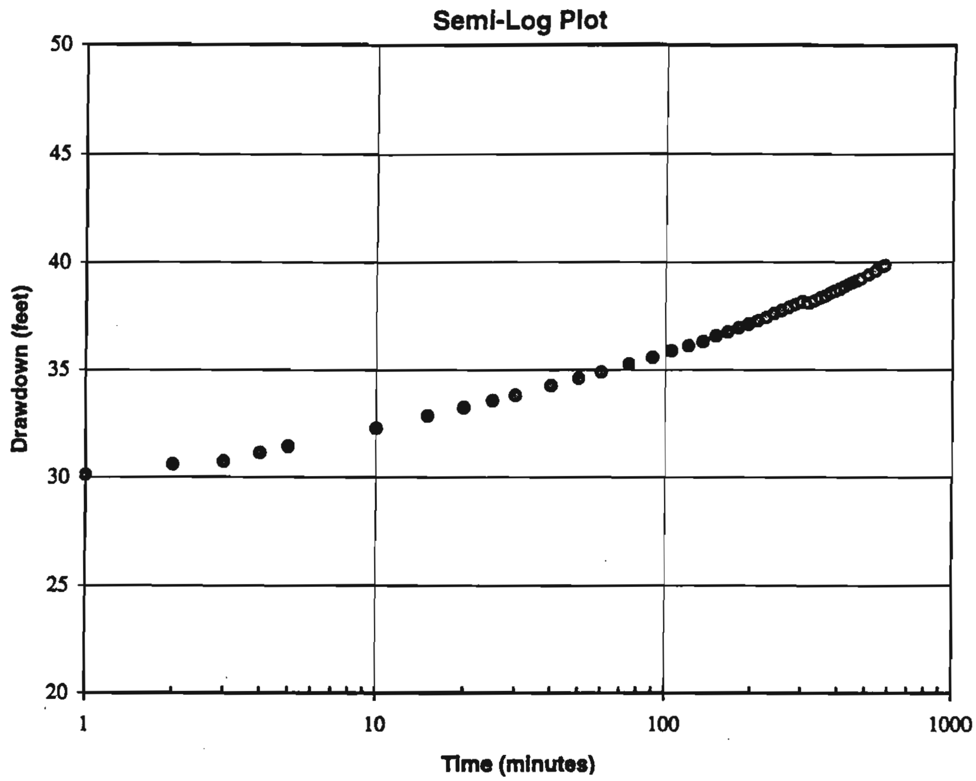
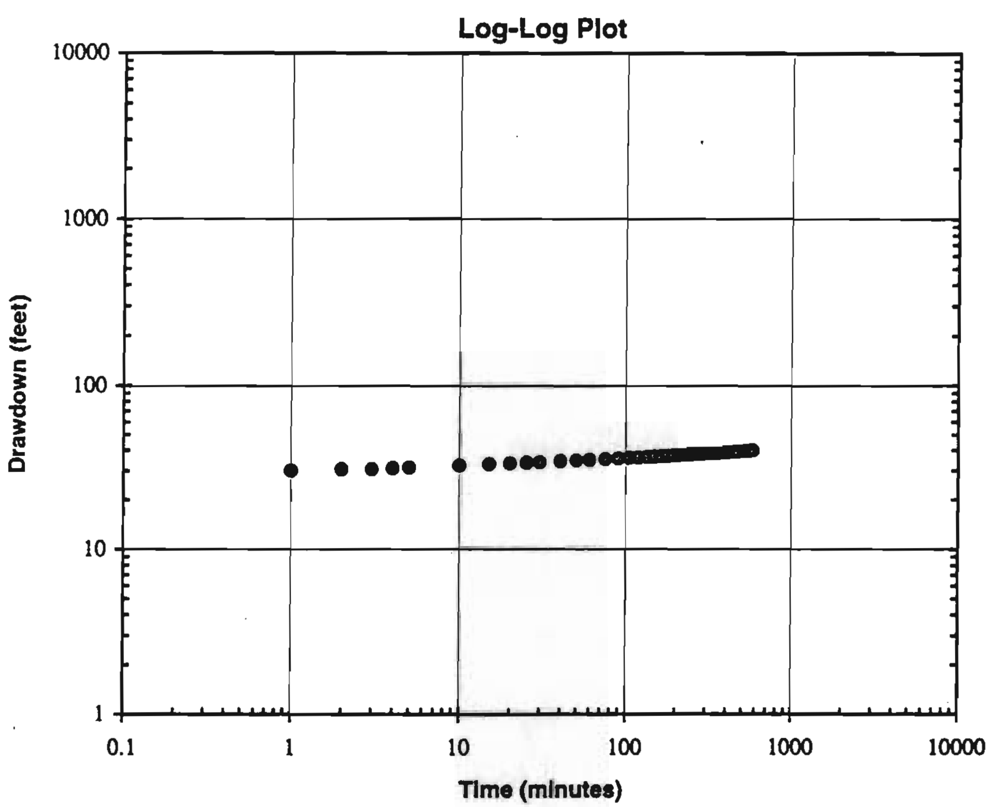


FIGURE 3-8
Schuepbach Well Aquifer Test
Schuepbach Well Hydrograph
TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

Note: Q = 770 gpm





Note: Q = 770 gpm

FIGURE 3-9
Schuepbach Well Aquifer Test
Schuepbach Well: Drawdown Data

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

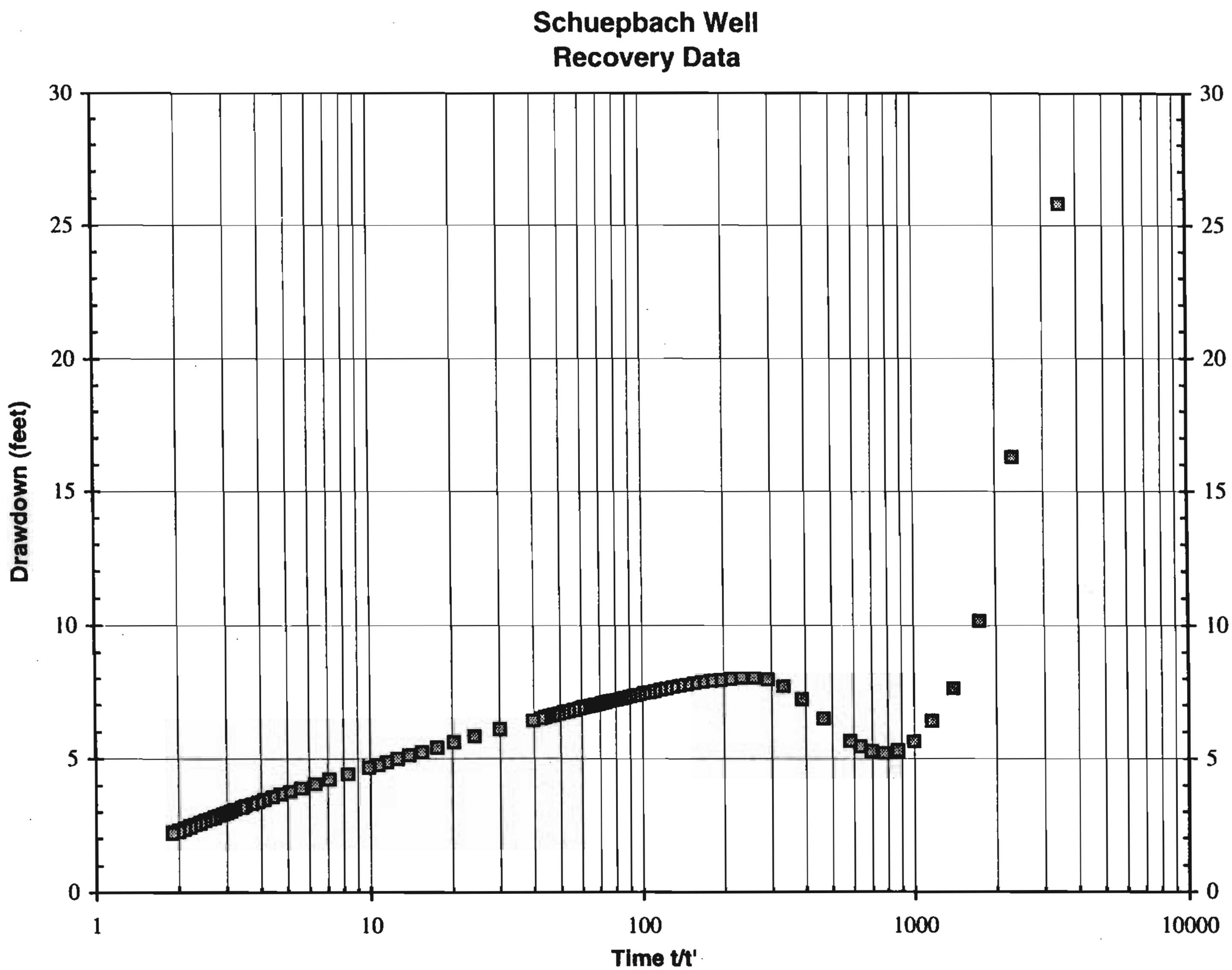


FIGURE 3-10
Schuepbach Well Aquifer Test
Schuepbach Well Recovery Data

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

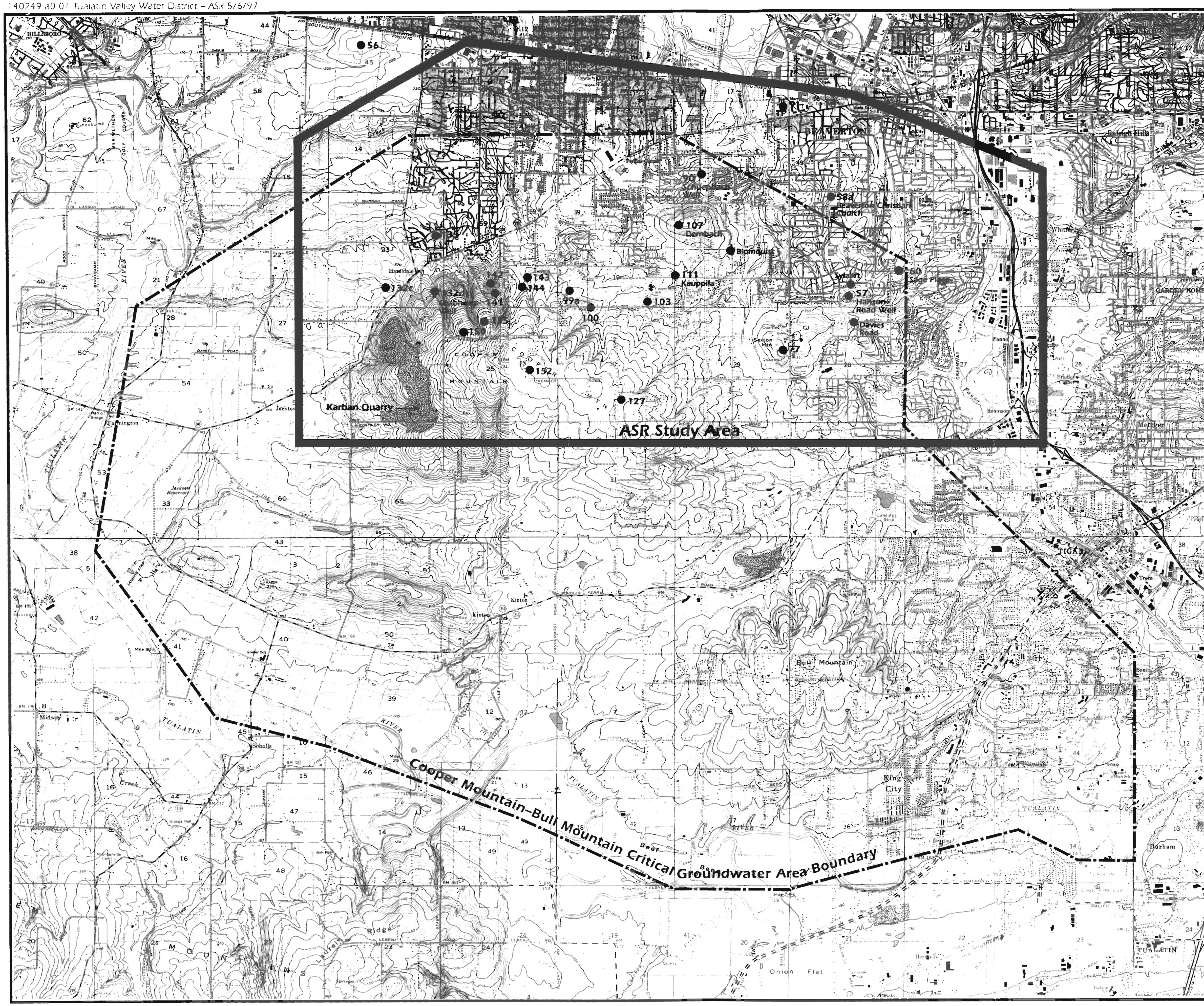
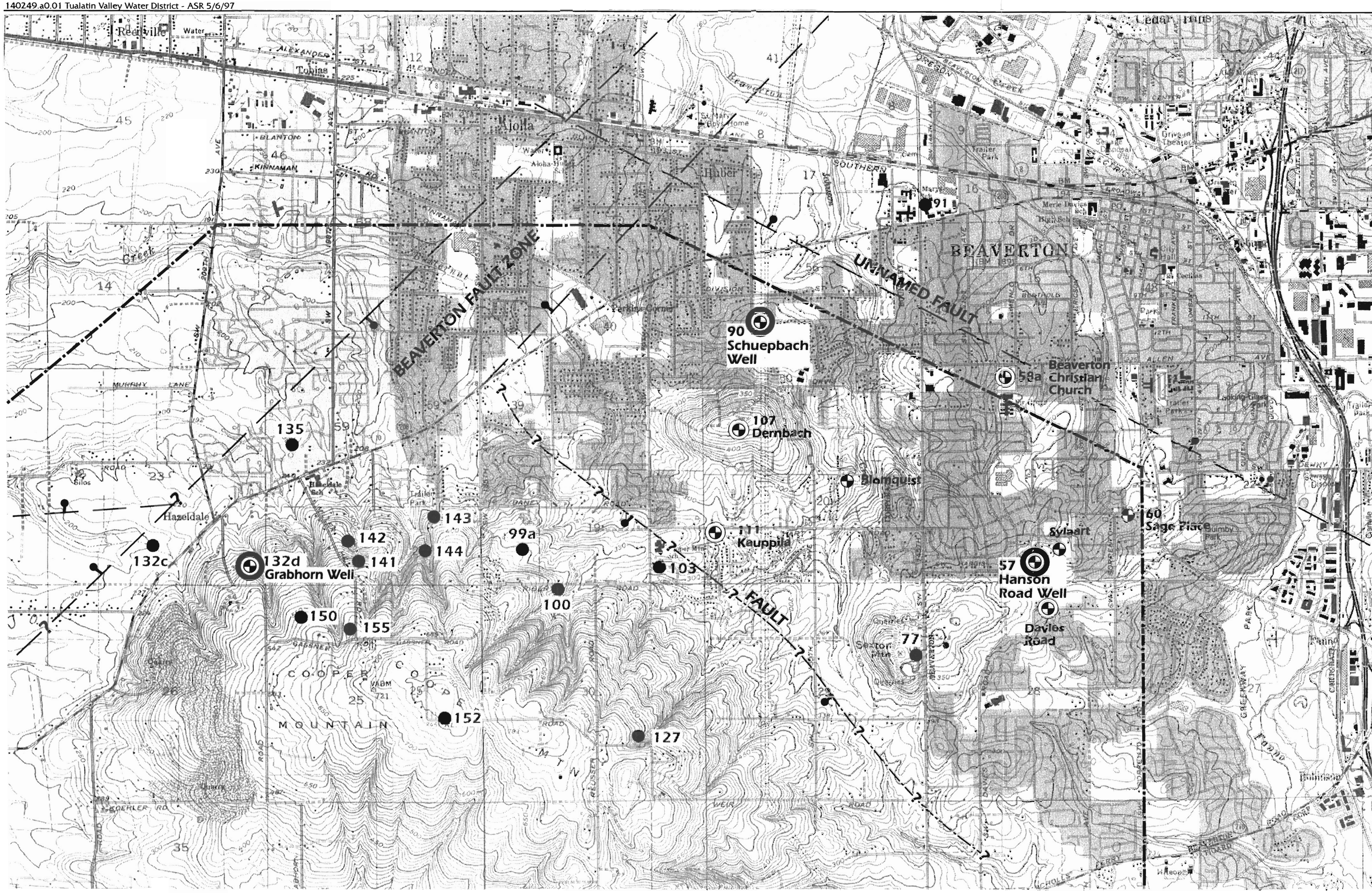


FIGURE 1-1
ASR Hydrogeologic Feasibility Study Location Map

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

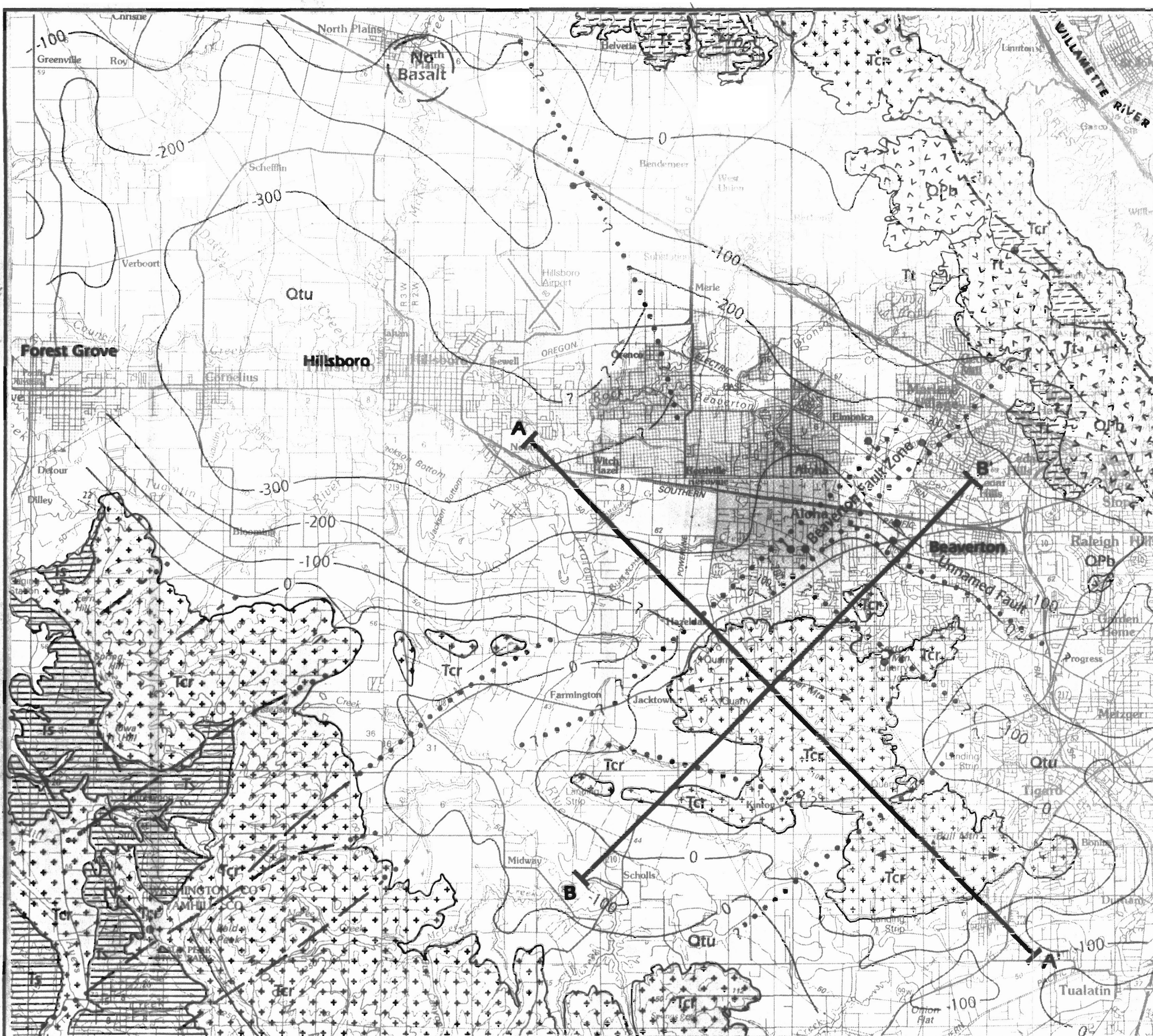
CH2M HILL



LEGEND

—·—·—	Cooper Mountain-Bull Mountain critical groundwater area boundary	111 Kauppila	ASR study area water quality sampling wells		ASR pilot test wells
● 143	Approximate well location and well inventory number corresponding to Tables 2-1 and A-1	60 Sage Place	ASR study area test observation wells		Fault; ball and bar on downthrown side

FIGURE 1-2
ASR Study Area
TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY



LEGEND

Geologic Units:

- Qtu — Undivided nonmarine deposits. Unconsolidated gravel, sand, and silt of fluvial and lacustrine origin.
- Qls — Landslide deposits.
- QTb — Basalts and basaltic andesites - Olivine basalt and basaltic andesite, and some pyroclastic material of local extents, corresponds to the Boring Lavas.
- Tt — Fluvial and lacustrine sediments - clay, silt, sand, and gravel. Largely fluvial, but may contain some lacustrine sediment. Correlates to Sandy River Mudstone and Troutdale.
- Tcr — Columbia River Basalt Group. Sub-aerial basalt flows, in places, separated by baked tuffaceous sedimentary rocks.
- Ts — Marine sedimentary rocks. Tuffaceous siltstone and sandstone.

Geologic Symbols:

- Inferred elevation (meters) of top of Columbia River Basalts relative to sea level.
- Concealed fault; dashed dots where location is uncertain; ball and bar on downthrown side.
- Strike and dip of bedding.
- Anticline - with fold axis plunge directions (large arrow).
- Cross-sectional location line.

NORTH

0 4,000 8,000 Feet
Approximate Scale

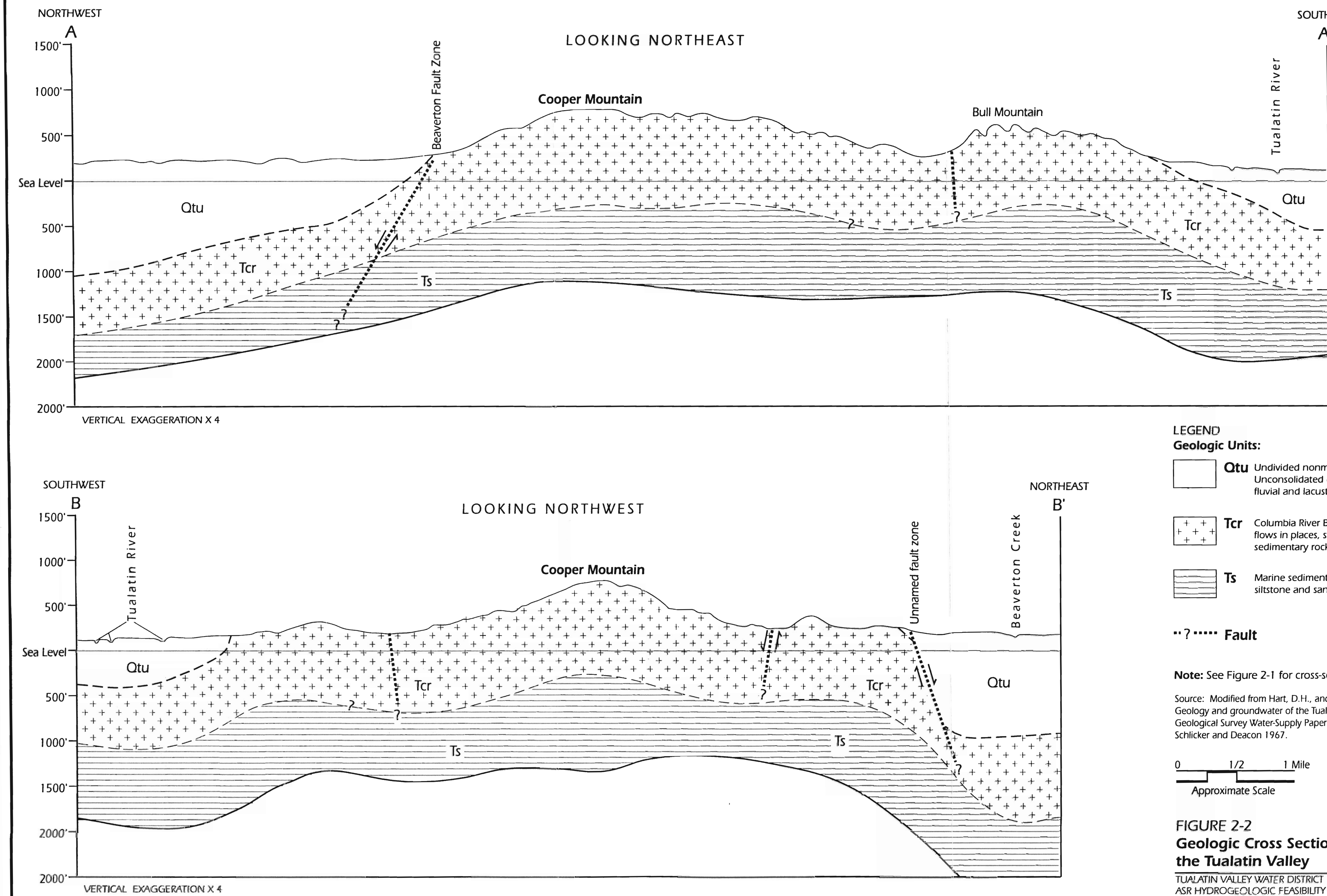
Source:
Modified from Yeats, Robert S., et al., 1991. Tectonics of the Willamette Valley, Oregon. United States Department of the Interior Geological Survey. Open File Report 91-441-P, 18 pp.

FIGURE 2-1

Geologic Map of the Tualatin Valley

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

CH2M HILL



LEGEND

Geologic Units:

Qtu Undivided nonmarine deposits. Unconsolidated gravel, sand, and silt of fluvial and lacustrine origin.

Tcr Columbia River Basalt Group. Subaerial basalt flows in places, separated by baked tuffaceous sedimentary rocks.

Ts Marine sedimentary rocks. Tuffaceous siltstone and sandstone.

··?····· **Fault**

Note: See Figure 2-1 for cross-sectional location lines.

Source: Modified from Hart, D.H., and Newcomb, R.C., 1965, Geology and groundwater of the Tualatin Valley, Oregon: U.S. Geological Survey Water-Supply Paper 1697, 172 p., and Schlicker and Deacon 1967.

0 1/2 1 Mile

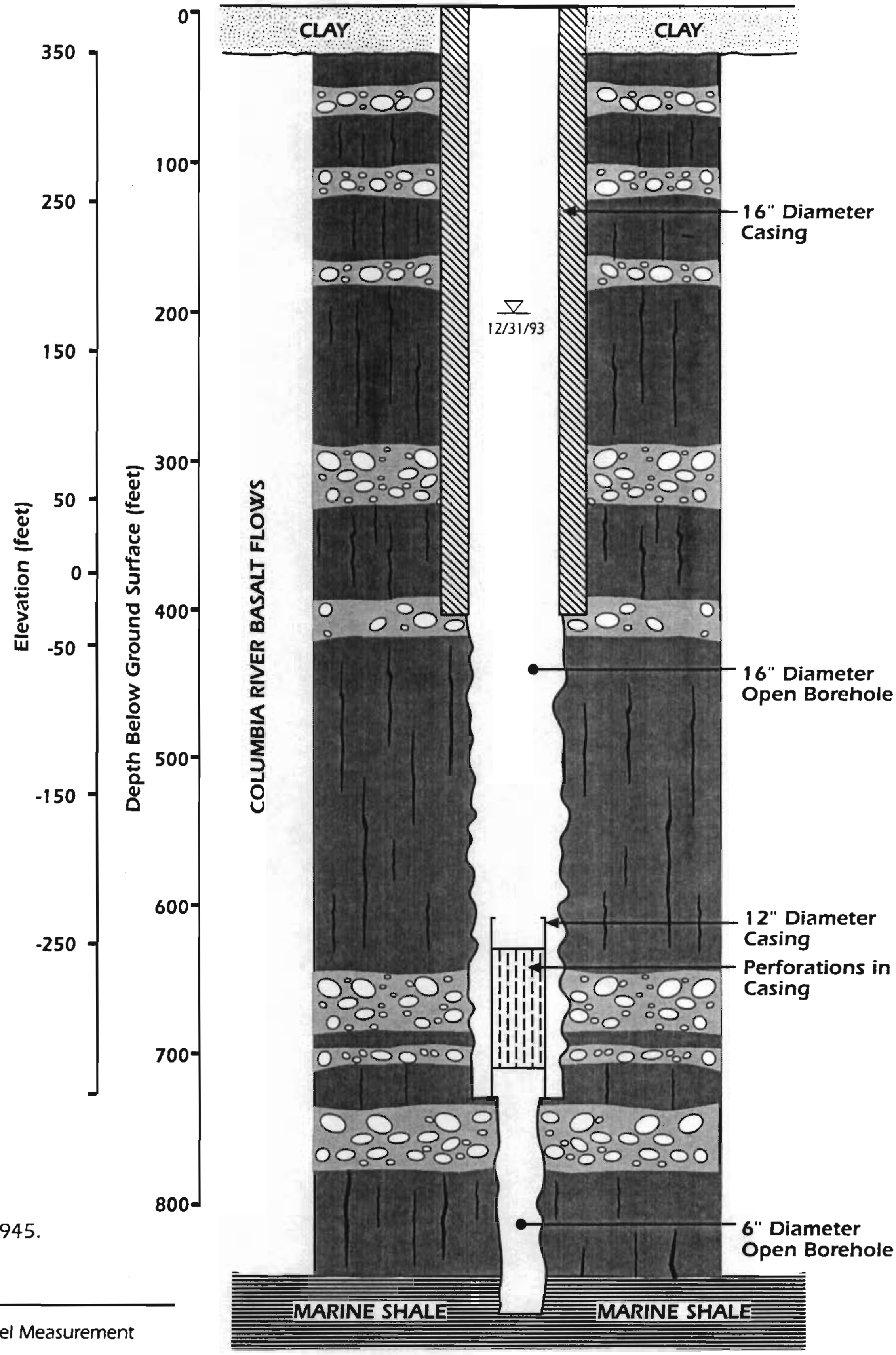
Approximate Scale

FIGURE 2-2

Geologic Cross Sections of the Tualatin Valley

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

CH2M HILL

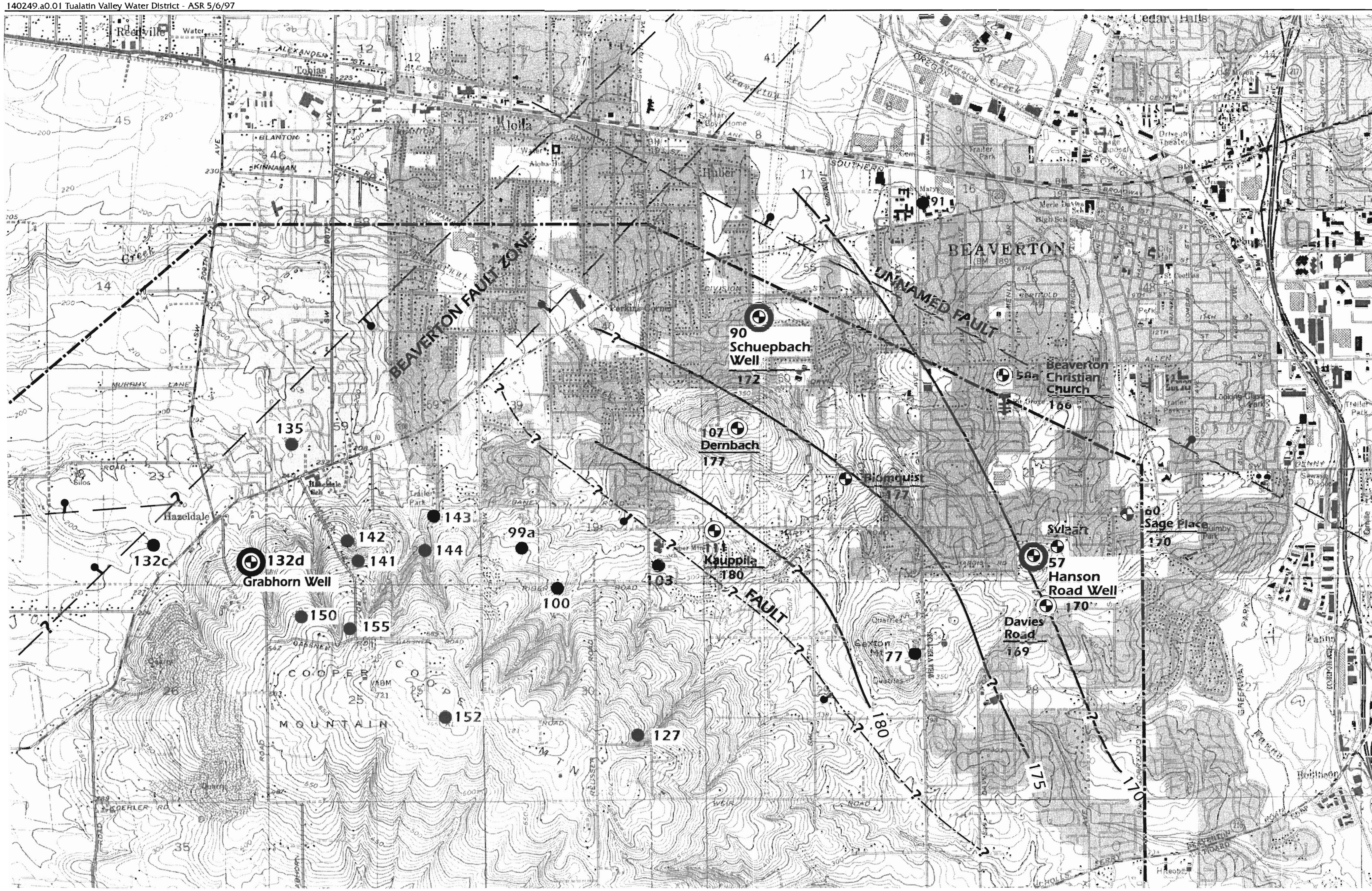


Note: Well drilled in 1945.

LEGEND

- Static Water-Level Measurement
- Clay, Silt, and Sand
- Basalt
  - *Water-producing interflow zones*
  - *Massive interior flow zones with columnar jointing*
- Marine shale deposits

FIGURE 3-11
Grabhorn Well
Construction Details and Geologic Log
TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY



NORTH

Base Maps: USGS 7.5 minute Washington Co. Quadrangles, Beaverton and Scholls, Oregon, photorevised 1984 and 1985, respectively.

0 1000 2000 Feet

Approximate Scale

LEGEND

Cooper Mountain-Bull Mountain critical groundwater area boundary

143 Approximate well location and well inventory number corresponding to Tables 2-1 and A-1

Kauppila 180 ASR study area water quality sampling wells with groundwater elevation

Sage Place 170 ASR study area observation wells with groundwater elevation

ASR pilot test wells

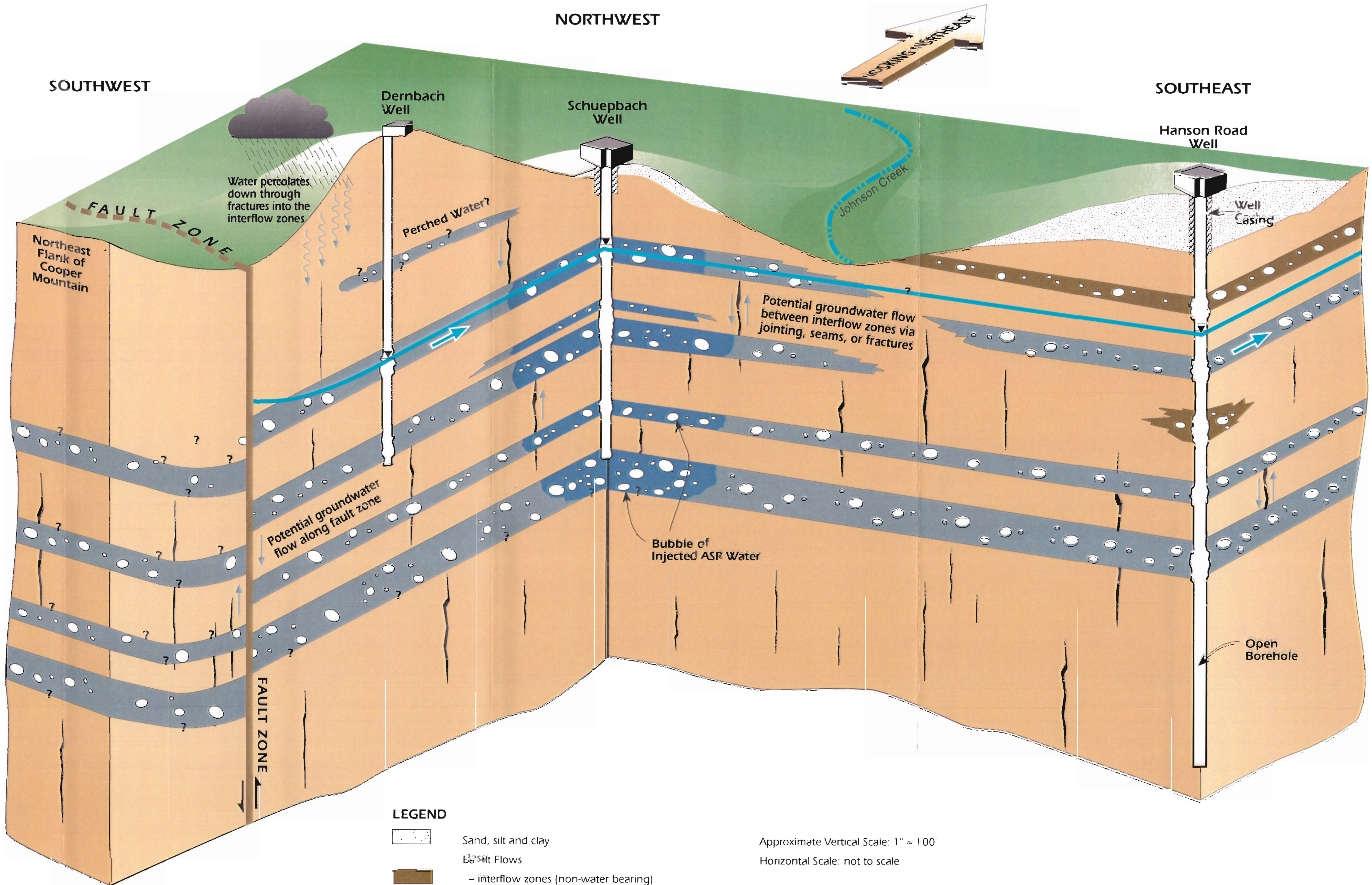
Fault; ball and bar on downthrown side

180 Groundwater elevation contour map (contour elevation = 5 feet)

General groundwater flow direction

FIGURE 3-12
ASR Study Area
Groundwater Elevation Contour Map
August 1995

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY



LEGEND

- Sand, silt and clay
- Basalt Flows
  - interflow zones (non-water bearing)
  - Water bearing interflow zones
  - massive interior flow zones with columnar jointing
- Static water level (8/30/95)

Approximate Vertical Scale: 1" ≈ 100'

Horizontal Scale: not to scale

NOTES

Refer to Figure 1-2 for locations of wells

FIGURE 3-13
Conceptual Hydrogeological Model

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

CH2M HILL

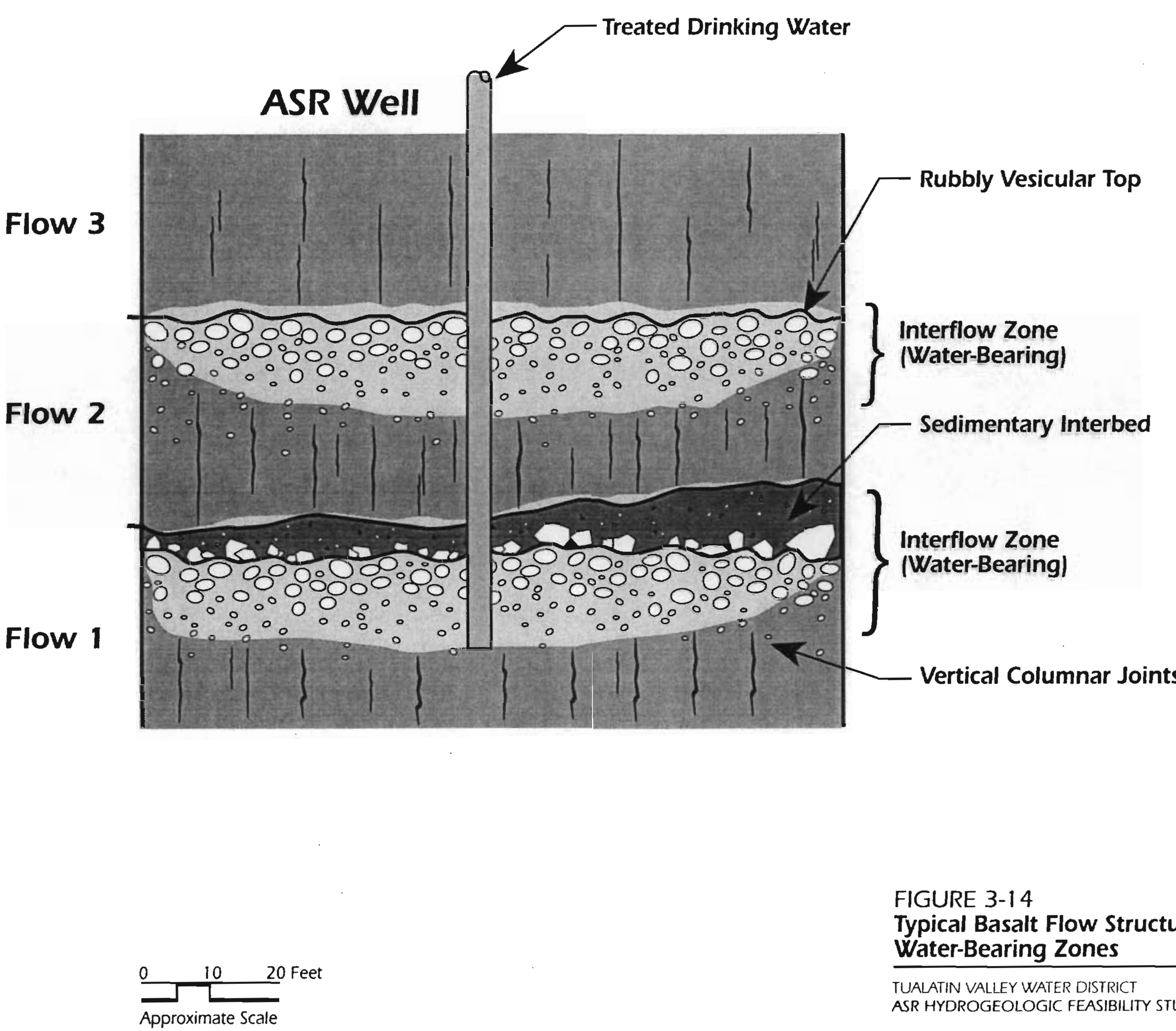


FIGURE 3-14
Typical Basalt Flow Structures and Water-Bearing Zones

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

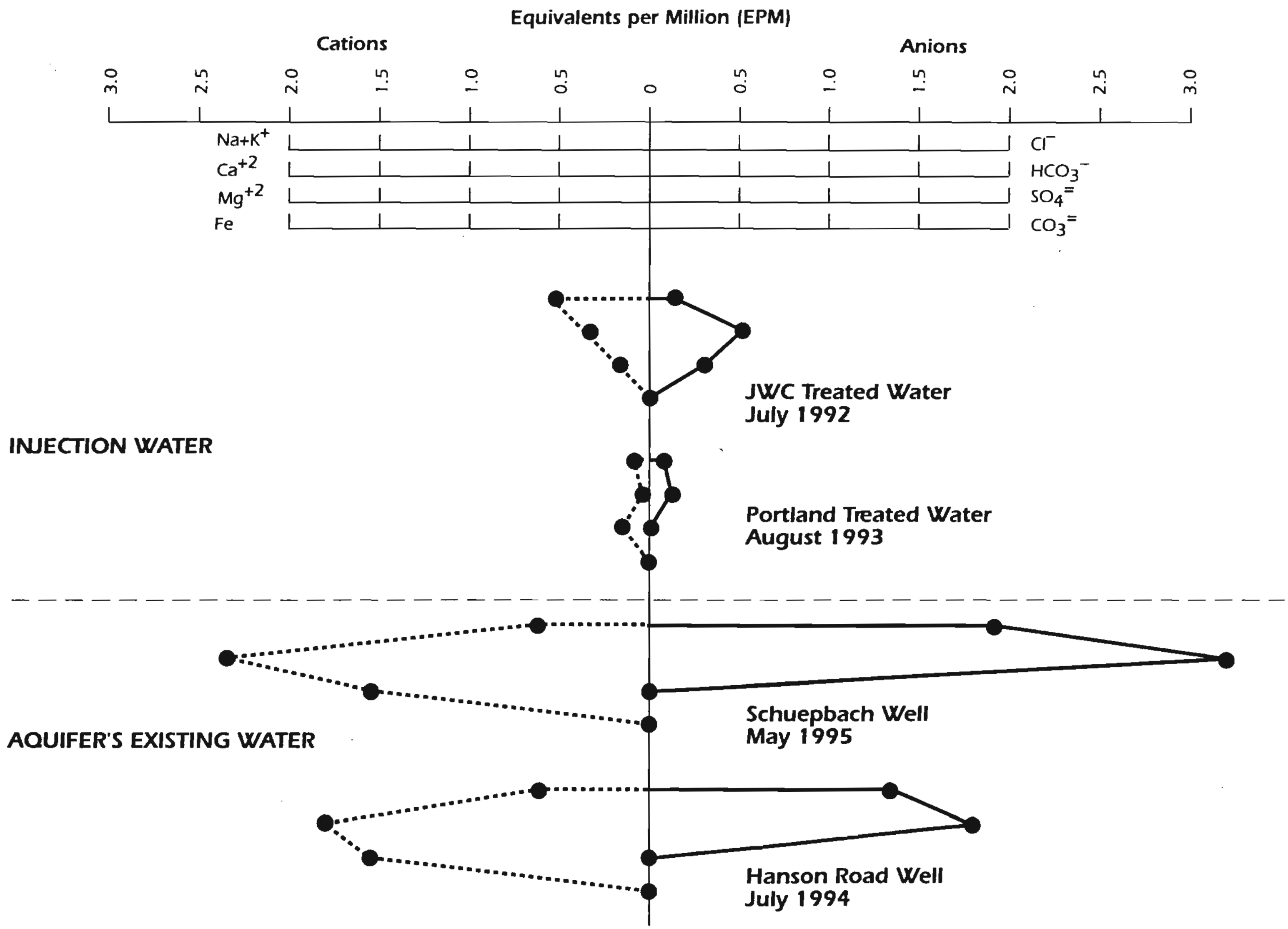


FIGURE 5-1
Stiff Diagram Representing Water Quality Signatures Injection Water and Existing Water

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

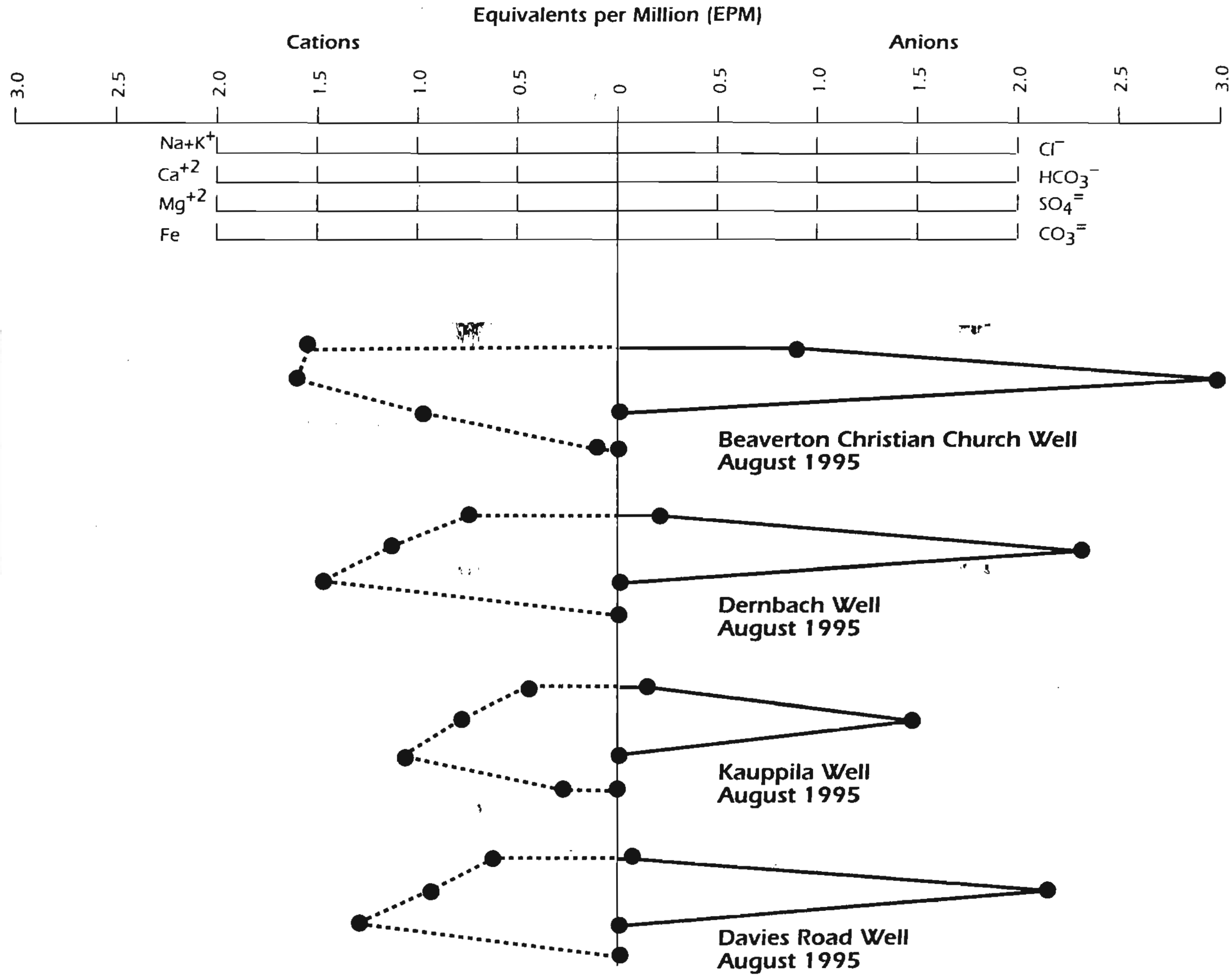


FIGURE 5-2
Stiff Diagram Representing Basalt Aquifer Water Quality

TUALATIN VALLEY WATER DISTRICT
ASR HYDROGEOLOGIC FEASIBILITY STUDY

Appendix A

Inventory of Representative Wells in the Beaverton-Cooper Mountain Study Area

Table A-1
Inventory of Representative Wells
Tualatin Valley Water District ASR Hydrogologic Feasibility Study
Tualatin Valley, Oregon

Well Inventory No.	Well Location (by section)	Date Completed	Well Use (a)	Total Depth ft bgs (b)	Depth to Top of Basalt (ft bgs)	Saturated Thickness Open to Well (feet)	Depth of First Encountered Water in Basalt (ft bgs)	Well Yield gpm (c)	Specific Capacity (gpm/ft) (d)	Basalt Water Bearing Zone(s) Or Water Quality Comments
Beaverton - Cooper Mountain Study Area										
T1S, R1W, Section 17										
90	17cd TVWD "Schuepbach" Well	5/17/59	M	414	11	305	NR	1,089	13.1	Tualatin Valley Water District
91	17aa (St Mary's)	1953	none	1,507	1,239	bad water	1,268	80	.35 at 1,369' bgs	Water sample taken at 1,374' bgs. Chloride = 960 ppm. Dissolved Solids = 1,640 ppm.
92	17ad	4/15/66	D	112	12	26	86	10	0.67	
93	17c	4/18/60	NR	620	100	380 ?	150	25	NR	
94	17	8/6/60	NR	320	273?	10	310	9	NDD	Well deepened.
T1S, R1W, Section 19										
95	19ac	7/28/70	D	196	92 ?	37	159	12	0.31	Well deepened.
96	19bc	9/3/58	D	211	159	38	173	12	0.09	
97	19bd	8/4/62	D	125	77	6	119	15	0.75	Water-bearing zone from 119-125' bgs, beneath basalt. Log says sedimentary unit - Basalt interflow zone?
98	19c	5/7/73	D	308	170	113?	195	20	0.48	
99	19ca	8/8/58	D	114	12	54?	60	25	0.29	
99a	19cca	6/10/57	O	215	NR	NR	184.85	NR	NR	Aquifer Test. Transmissivity = 340,000 gpd/ft, Storativity = 0.0028
100	19cdc	10/53	I	292	75	82	210?	15	NR	
101	19da	7/9/65	D	308	170	13	295?	20	0.67	Water level record available.
102	19dac	7/12/46	I	253	70	NR	NR	10	0.18	
103	19dd	7/23/60	D	320	238?	22 ?	298	12	0.34	Well abandoned on 6/17/93. Water level record available.
104	19dd	12/23/57	D	380	180	NR	NR	11	0.30	Acid Water entering well between 296' and 340' bgs. Interval cemented off.
105	19ddb	8/2/54	I,Supply	459	290	159	300	50	0.46	3 gpm from 300' bgs.
T1S, R1W, Section 20										
106	20ab	8/6/56	D	90	68	22	68	6	0.08	
107	20bc	10/20/70	D	410	320?	90	320?	11	NDD	Well deepened.
108	20ca	7/16/72	D	252	15	15	237	10	0.43	Well Deepened.
109	20ca	11/13/90	D	264	6	39	140	17	NR	7 gpm from 140-188'; 10 gpm from 235-255' bgs.
110	20ca	7/11/60	D	155	95?	1	155	10	0.10	Well deepened.
111	20cb	1949	D	276	233	43	NR	14	NDD	Close to Schuepbach & Hansen Rd Wells. Water level record available. Owner - Barron
112	20cd	8/21/71	D	243	152?	3	240	12	1.5	Well deepened
113	20cd	2/7/68	D	160	45	100	45	20	0.77	
114	20db	9/20/62	D	167	15	2	165	10	0.28	
115	20db	6/20/70	D	180	22	15	165	12	0.37	
116	20	10/16/73	D	340	61	104	236	18	0.16	2 gpm from 236-244'; 6 gpm from 262-284'; 10 gpm from 296-321' bgs.
117	20	10/30/72	D	185	121?	47	138	15	0.56	Well deepened. 6 gpm from 138-142' & 9 gpm from 167-180' bgs.
118	20	5/8/73	D	335	197?	72	263	30	0.19	Well deepened. 9 gpm from 263-268', 12 gpm from 296-319', & 6 gpm from 331-335' bgs.
119	20	6/21/71	D	260	135?	82	178	24	0.61	Well deepened. 5 gpm from 178-184'; 18 gpm from 237-248'.
120	20	6/9/71	D	400	9	196	204	24	0.12	Interflow zones: 2 gpm from 204-214', 4 gpm from 321-338', 6 gpm from 371-382'; 10 gpm from 389-400' bgs.
T1S, R1W, Section 21										
57	21cdd (City of Beaverton)	1945	M (Well #2)	800	54	630 ?	90	950	NR	Hansen Road Well. Water quality results attached to well log info. package. Don't have perforated/screened interval information. Well cased to bottom. WSP 1697 Well No. 21P1.
58	21ac	10/13/58	D	172	36	56	116	24	0.45	
58a	21bab	9/11/71	O	355	265	40	NR	25	0.11	
59	21da	10/21/56	D	118	80	34	84	15	3.00	
60	21da	2/9/68	I	395	205	175 ?	NR	45	0.25	Water level record available. Close to Hansen Rd well.
61	21dc	NR	D	124	111?	13	111	NR	none	Well no. 49 of WSP 890.
62	21ddb	NR	S,D	141	NR	NR	NR	NR	NR	Hardness = 95, Chloride = 11. Units Unknown.
T1S, R1W, Section 24										
63	24aa	4/10/93	I	594	417	94	500	230	1.50	Water analysis exists according to log.
64	24bb (Portland Golf Club)	1951	I	500	410	40	410	1,000	5.30	Perforated from 410-430' and 460-500' bgs. WSP 1697, Well No. 24D3. Two shallow (20') piezometers constructed in 199, tested for TPH method 418.1.
65	24bdd(1)	1927	I	521	403	118	NR	380	76	Well owner has 3 wells, all similar depths. One of the wells contained iron. See WSP 890, Well No.52, Plate 33 for WL record.
66	24	9/23/67	I	442	201	120	NR	425	3.19	

Table A-1
Inventory of Representative Wells
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study
Tualatin Valley, Oregon

Well Inventory No.	Well Location (by section)	Date Completed	Well Use (a)	Total Depth ft bgs (b)	Depth to Top of Basalt (ft bgs)	Saturated Thickness Open to Well (feet)	Depth of First Encountered Water in Basalt (ft bgs)	Well Yield gpm (c)	Specific Capacity (gpm/ft) (d)	Basalt Water Bearing Zone(s) Or Water Quality Comments
67	24	9/30/67	D	252	241	5	241	20	0.15	
T1S, R1W, Section 25										
68	25cb	Apr 1949	I	240	88	4	236	50	0.28	Water Supply paper 890. Hardness = 152 ppm.
69	25bb	12/20/61	M	462	165	286 ?	NR	650	4.58	
T1S, R1W, Section 27										
70	27ba	1952	None	314	31	NA	72	none	none	Well plugged back for test of higher water-bearing zones. Chemical analysis includes Hardness = 1,485 ppm; Chloride = 1,839 ppm. WSP 1697, Well No. 27C1.
71	27dd	NR	D,S	124	120	4	120?	NR	NR	
T1S, R1W, Section 28										
72	28aa	NR	D	310	159	76	NR	NR	NR	Well No. 54 of WSP 890.
73	28ac	NR	D	126	35	91	NR	NR	NR	
74	28ca	4/14/92	O	400	110	NA	NA	NA	NA	Not a water well. Used for stratigraphy only.
75	28cb	1/5/63	D	237	180?	NR	225?	15	0.34	Well deepened.
76	28	10/7/59	D	195	155	4?	191?	4	0.07	Well deepened.
T1S, R1W, Section 29										
77	29ada	1/26/62	D,I,In	900	265	550	110	235	0.59	Well abandoned on 9/23/92. Water level record available.
78	29bc	4/20/70	D	230	72	15	215	45	0.48	
79	29bd	6/3/65	D	214	155	10	204	15	0.29	
80	29ca	11/10/83	D	180	58	70	110	9	0.20	6 gpm from 110-158'; 3 gpm from 158-160' bgs.
81	29cb	10/6/56	D	244	30	14	230	15	1.50	
82	29cd	4/20/73	D	345	30	5	340	12	NDD (g)	
83	29da	6/20/67	D	230	193	37	193	14	0.31	
84	29dbb	10/24/64	D	165	120	12	148	10	0.05	Water from 148-160' bgs.
85	29dc	11/1/72	D	260	60	NR	120	15	0.13	Well deepened
86	29d	4/25/78	D	160	75	25	135	12	0.24	Abandoned by order of WRD: Critical Area.
87	29dd	NR	D	294	279	15	279	3	0.02	Reported 279' of clay above aquifer.
88	29	7/7/75	D	234	4 ?	6	228	20	1.00	Owner had 1 other well 200' deep. Aband. "No Water-Not A Drop"
89	29	7/8/68	NR	233	38	NR	NR	15	0.23	Good well log for stratigraphy. Water zone info. poor.
T1S, R1W, Section 30										
121	30aa	9/25/67	D	375	90	123	252	10	NDD	Water from 252-255' and 365-375' bgs.
122	30ac	1/18/74	D	385	305?	60	325	2 to 18	0.27	Well deepened. 2 gpm from 325-345'; 18 gpm from 360-380' bgs.
123	30ba	12/3/60	D	368	80	68?	300?	10	0.03	
124	30ca	5/20/57	D	535	65	80	100	10	NR	
125	30ca	1/21/61	D	720	592?	NR	NR	5	0.05	Well deepened.
126	30db	5/5/69	D	600	60	85	515?	7	0.47	Water from 515-524' & 576-600' bgs.
127	30dbd	5/6/67	D,I	320	162?	NR	NR	75	0.60	Well deepened twice.
128	30dd	11/3/92	D	608	10	40	490	40	0.06	Good log for stratigraphy! Water analysis done. Results?
129	30	5/27/71	D	662	43	181	481	12	0.11	8 gpm from 481-501'; 4 gpm from 599-608' bgs.
130	30	6/20/69	D	338	23	NR	NR	35	0.30	Good log for stratigraphy.
131	30	12/63	D	760	14	NR	580 ?	7	0.23	
132	30	6/10/69	D	347	36	NR	161 ?	25	0.14	
T1S, R2W, Section 13										
132a	13dcd	8/9/38	I	930	762 ?	172	760 ?	50	NR	Water well record available.
T1S, R2W, Section 23										
132b	23acd	4/ /1962	D,M	805	725	212	NR	400	2.39	Water well record available.
132c	23dcb	10/14/52	I	227	93	20	141 ?	200	1.82	Water well record available.
132d	23ddd	11/17/64	M	874	27 ?	210	NR	1250	16	Owned by Tualatin Valley Water District - Grabhorn Well.
T1S, R2W, Section 24										
133	24aa	1952	I	255	152.6	NR	NR	17	NR	
134	24ad	NR	I	214	210	4	210	NR	NR	
135	24bc	1/14/76	T	375	195	120	255	75	0.21	
136	24bd	8/10/57	D	95	60	25	70	30	3.0	
137	24bd	11/26/56	D	145	113	17	128	20	0.21	
138	24bd	11/27/56	D	104	90	11	93?	15	0.17	
139	24ca	6/2/56	D	73	8	5	68	15	1.5	
140	24cb	3/25/57	D	110	42	50	60	10	0.20	Aquifer test: Transmissivity = 190,000 gpd/ft, Storativity = 0.00005.
141	24cd	4/21/58	D	296	25	36	260	10	0.42	3 gpm from 260 ' bgs.
142	24cd	5/11/56	D	382	17	12	370	10	NDD	

Table A-1
Inventory of Representative Wells
Tualatin Valley Water District ASR Hydrogologic Feasibility Study
Tualatin Valley, Oregon

Well Inventory No.	Well Location (by section)	Date Completed	Well Use (a)	Total Depth ft bgs (b)	Depth to Top of Basalt (ft bgs)	Saturated Thickness Open to Well (feet)	Depth of First Encountered Water in Basalt (ft bgs)	Well Yield gpm (c)	Specific Capacity (gpm/ft) (d)	Basalt Water Bearing Zone(s) Or Water Quality Comments
143	24dac (Tualatin Valley WD)	7/18/58	M	720	45	450	270	470	2.90	Originally Aloha-Huber Well - Municipal Well No. 1. AKA 189th Street well. Water level record available.
144	24da (Tualatin Valley WD)	4/18/57	T	416	45	318	98	350	3.68	(Aloha-Huber Test Well)
145	24dab	1937	D	140	130	10 ?	130?	NR	NR	Iron water, Hardness = 102 ppm, Chloride = 5 ppm.
146	24	3/30/73	D	340	212?	NR	237?	24	0.16	Well deepened. Interflow zones: 6 gpm from 237-248', 8 gpm from 307-321' & 6 gpm from 326-336' bgs.
147	24	7/15/71	D	485	--	68	417	20	0.27	Well deepened. Interflow zones: 5 gpm from 417-428'; 15 gpm from 466-481' bgs.
148	24	8/27/70	D	410	303 ?	62	348	30	0.37	Well deepened. Interflow zones: 10 gpm from 348-355'; 2 gpm from 355-374'; 18 gpm from 399-410' bgs.
T1S, R2W, Section 25										
149	25abd	10/10/67	D,I	566	40	NR	NR	10	NR	Well deepened twice.
150	25bb	12/30/64	D	756	45	30	560?	7	NDD	Well deepened twice. Water reported from 726-756' bgs.
151	25bd	8/22/69	D	487	362?	15	NR	15	0.27	Basalt from 444-459' bgs.
152	25da	1947	T	9,263	100	939	NR	NR	NR	Hackman - Oil Test well.
153	25db	7/1/58	D	662	27	102	560?	10	NR	
154	25	2/4/67	D	625	24	30?	595?	12	0.24	
155	25	6/30/70	D	508	361?	NR	441?	30	0.30	Well deepened. 7 gpm from 441-453'; 23 gpm from 491-503' bgs.
156	25	6/15/71	D	405	296?	NR	318?	45	0.34	Well deepened. 8 gpm from 318-327'; 36 gpm from 405' bgs.

NOTES:

(a) Well Use:

D = Domestic
O = Other
I = Irrigation
In = Industrial
M = Municipal
T = Test
S = Stock

(b) ft bgs = feet below ground surface.

(c) gpm = gallons per minute. Yield value from pumping test rate after well completed.

(d) Specific capacity units = gpm/ft of drawdown.

(d) Specific Capacity in gpm per feet of drawdown. Calculated from well log test data.

(e) NR = Information "Not Recorded" on well log or original well log not available.

(f) NA = not applicable.

(g) NDD = No drawdown during pumping test.

1. Well log information from Oregon Water Resources Department original Water Well Report forms.
2. Well owner and location was not field verified.
3. Saturated basalt thickness includes both interflow zones and unfractured rock below the water level in the well.

SCHUEPBACH WELL

OBSERVATION WELL (70) G-7331 (1)   cd

WATER WELL REPORT

STATE OF OREGON → G5265

State Well No. 1/1W-17P(A)

State Permit No.

(1) OWNER:

Name Schuepbach Brothers

Address Beaverton, Oregon

(2) LOCATION OF WELL:

County Wash.   Owner's number, if any—

¼ ¼ Section T. R. W.M.

Bearing and distance from section or subdivision corner

(3) TYPE OF WORK (check):

New Well ☑ Deepening ☐ Reconditioning ☐ Abandon ☐

If abandonment, describe material and procedure in Item 11.

(4) PROPOSED USE (check):

Domestic ☐ Industrial ☐ Municipal ☐

Irrigation ☑ Test Well ☐ Other ☐

(5) TYPE OF WELL:

Rotary ☐ Driven ☐

Cable ☑ Jetted ☐

Dug ☐ Bored ☐

(6) CASING INSTALLED: Threaded ☐ Welded ☑

14" Diam. from 0 ft. to 40 ft. Gage 3/8"

" Diam. from ft. to ft. Gage

" Diam. from ft. to ft. Gage

(7) PERFORATIONS: Perforated? ☐ Yes ☐ No

Type of perforator used

SIZE of perforations in. by in.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

(8) SCREENS: Well screen installed ☐ Yes ☐ No

Manufacturer's Name

Type Model No.

Diam. Slot size Set from ft. to ft.

Diam. Slot size Set from ft. to ft.

(9) CONSTRUCTION:

Was well gravel packed? ☐ Yes ☑ No Size of gravel:

Gravel placed from ft. to ft.

Was a surface seal provided? ☑ Yes ☐ No To what depth? 40 ft.

Material used in seal— Cement

Did any strata contain unusable water? ☐ Yes ☑ No

Type of water? Depth of strata

Method of sealing strata off

(10) WATER LEVELS:

Static level 109 ft. below land surface Date 5/17/59

Artesian pressure lbs. per square inch Date

Log Accepted by:

[Signed] Rudolph Schuepbach Jr. (Owner) June 8 1959

(11) WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☑ Yes ☐ No If yes, by whom? Harty Bros.

Yield: 744 gal./min. with 49 ft. drawdown after hrs.

" 975 " 18 "

" 1089 " 83 " 15 hrs All to

Bailer test — gal./min. with — ft. drawdown after — hrs.

Artesian flow g.p.m. Date

Temperature of water 54 Was a chemical analysis made? ☐ Yes ☑ No

(12) WELL LOG: Diameter of well 14 inches.

Depth drilled 414 ft. Depth of completed well 414 ft.

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.

MATERIAL	FROM	TO
Clay	0	11
Weathered Basalt	11	167
Black Basalt	167	268
Red Inner Flow	268	271
Black Basalt	271	309
Porous Honeycombed Rock Showing Rose Quartz	309	326
Black Basalt	326	393
Porous Basalt	393	397
Black Basalt	397	405
Porous Basalt	405	414

Work started 19 Completed 19

(13) PUMP:

Manufacturer's Name Johnston

Type: Turbine H.P. 100

Well Driller's Statement:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME Harty Bros.
(Person, firm or corporation) (Type or print)

Address 3340 S.W. Seymour

Driller's well number

[Signed] Glenn Harty (Well Driller)

License No. 168 Date 5/8/59, 19

(USE ADDITIONAL SHEETS IF NECESSARY)

HANSON ROAD WELL

page 1

Well Record

(57)

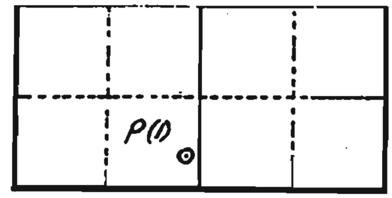
STATE WELL NO. 1/1W-21 l
COUNTY Washington
APPLICATION NO. GR-34

OWNER: City of Beaverton
MAILING ADDRESS: City Hall 21ca

LOCATION OF WELL: Owner's No. #2
CITY AND STATE: Beaverton, Oregon

SE ¼ SW ¼ Sec. 21 T. 1 S., R. 1 W., W.M.

Bearing and distance from section or subdivision corner 2500 feet east and 460 feet north from the SW corner of section 21,



Altitude at well 350 feet Interpolated

TYPE OF WELL: Drilled Date Constructed 1945

Depth drilled 800 Depth cased 800

Section 21

CASING RECORD:

16 — inch casing set from 0 to 63 feet.
15 — " " " " 63 to 450 feet.
12 — " " " " 450 to 800 feet.

FINISH:

none ?

AQUIFERS:

rock from 90 to 800 feet.

WATER LEVEL:

170 feet below land surface. Dec. 1945.

PUMPING EQUIPMENT: Type Fairbanks-Morse Turbine H.P. 60
Capacity 950 G.P.M.

WELL TESTS:
Drawdown 80 ft. after ______ hours pumping ? G.P.M.
Drawdown ______ ft. after ______ hours ______ G.P.M.

USE OF WATER Municipal 950 gpm Temp. ______ °F. ______, 19___
SOURCE OF INFORMATION Reg. Statement GR-343
DRILLER or DIGGER –
ADDITIONAL DATA:
Log Yes + Water Level Measurements ______ Chemical Analysis X Aquifer Test ______

REMARKS:

State Printing 00216

HANSON ROAD WELL

page 2

State Well No. 1/1W-21 P(
County Washington
Application No. GR-343

Well Log

Owner: City of Beaverton, Oregon   Owner's No. #2

Driller: —   Date Drilled 1945

CHARACTER OF MATERIAL	(Feet below land surface) From	To	Thickness (feet)
soil & clay	0	34	34
rock, soft, gray	34	38	4
clay, yellow	38	54	16
Columbia River Lava (basalt)	54	196	142
rock, soft gray - water bearing at 90-92			
rock, hard gray to blue	196	720 [redacted]	524
rock, hard blue with (seams)	720	735	15
rock, water bearing	736	736	1
rock, hard blue (with water)	736	800	64

GRABHORN WELL

page 1

#1320

WATER WELL REPORT
STATE OF OREGON
(Please type or print)

State Well No. 1/2w - 23R

State Permit No. G

(1) OWNER:

Name Aloha-Huber Water District #2

Address 17880 S. W. Blanton

Aloha, Oregon

(2) LOCATION OF WELL:

County Wash. Driller's well number

¼ ¼ Section 23 T. 1S R. 2W W.M.

Bearing and distance from section or subdivision corner

(3) TYPE OF WORK (check):

New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐

If abandonment, describe material and procedure in Item 12.

(4) PROPOSED USE (check):

Domestic ☐ Industrial ☐ Municipal ☒

Irrigation ☐ Test Well ☐ Other ☐

(5) TYPE OF WELL:

Rotary ☐ Driven ☐

Cable ☒ Jetted ☐

Dug ☐ Bored ☐

(6) CASING INSTALLED: Threaded ☐ Welded ☐

16 " Diam. from 0 ft. to 402 ft. Gage .330

12 " Diam. from 616'4" ft. to 728 ft. Gage .250

" Diam. from ft. to ft. Gage

(7) PERFORATIONS: Perforated? ☒ Yes ☐ No

Type of perforator used Torch

Size of perforations 3/16 in. by 12 in.

240 perforations from 630 ft. to 710 ft.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

(8) SCREENS: Well screen installed? ☐ Yes ☒ No

Manufacturer's Name

Type Model No.

Diam. Slot size Set from ft. to ft.

Diam. Slot size Set from ft. to ft.

(9) CONSTRUCTION:

Well seal—Material used in seal Cement

Depth of seal 403 ft. Was a packer used? No

Diameter of well bore to bottom of seal 24" in.

Were any loose strata cemented off? ☐ Yes ☒ No Depth

Was a drive shoe used? ☐ Yes ☒ No

Was well gravel packed? ☐ Yes ☒ No Size of gravel:

Gravel placed from ft. to ft.

Did any strata contain unusable water? ☐ Yes ☒ No

Type of water? depth of strata

Method of sealing strata off

(10) WATER LEVELS:

Static level 200 ft. below land surface Date 11-17-64

Artesian pressure lbs. per square inch Date

(11) WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☒ Yes ☐ No If yes, by whom?

Yield: 500 gal./min. with 38 ft. drawdown after 24 hrs.

" 900 " 58 " 24 "

" 1250 " 78 " 12 "

Bailer test gal./min. with ft. drawdown after hrs.

Artesian flow g.p.m. Date

Temperature of water 58 Was a chemical analysis made? ☒ Yes ☐ No

(12) WELL LOG: Diameter of well below casing 16

Depth drilled 874 ft. Depth of completed well 874 ft.

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.

MATERIAL	FROM	TO
See attached sheets		

Work started 19 . Completed 11-17 1964

Date well drilling machine moved off of well 11-20 1964

(13) PUMP:

Manufacturer's Name

Type: H.P.

Water Well Contractor's Certification:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME A. M. Jannsen Drilling Co.
(Person, firm or corporation) (Type or print)

Address 21075 S. W. Tualatin Valley Hwy., Aloha, Oregon

Drilling Machine Operator's License No. 164

[Signed] Edward M. Jannsen
(Water Well Contractor)

Contractor's License No. 79 Date 1-6-65, 19

Water Well Report

GRABHORN WELL
page 2

(12) WELL LOG:

Well #2

Material	From	To	
Clay	0	5	feet
Clay & rock - broken brown	5	24	
Clay & rock - broken red	24	27	
Rock & some clay - gray	27	49	
Rock, solid - gray	49	52	
Soft brown rock	52	69	
Brown rock - a little harder	69	89	
Light brown rock - hard	89	101	
Hard gray rock	104	107	
Broken gray rock	107	115	
Soft brown rock	115	122	
Hard gray rock	122	150	
Soft brown rock	150	152	
Hard brown rock	152	158	
Soft brown rock	158	162	
Hard brown rock	162	167	
Very soft brown rock	167	181	
Hard brown rock	181	211	
Soft brown rock	211	216	
Harder brown rock	216	255	
Hard gray rock	255	292	
Fairly soft gray rock	292	331	
Hard gray rock	331	394	
Fairly soft rock - gray - broken	394	403	
Hard gray rock	403	410	
Soft brown rock	410	420	
Hard gray rock	420	450	
Broken gray rock	450	467	
Hard gray rock	467	470	
Broken brown rock	470	485	
Very hard gray rock	485	523	
Broken rock with glay seams	523	528	
Gray rock	528	560	
Broken rock	560	576	
Gray rock	576	597	
Gray & white clay	597	601	
Gray rock	601	647	
Crevice - water bearing	647	651	
Hard gray rock	651	656	
Wormy rock - water bearing	656	667	
Broken rock - water bearing	667	682	
Brown & gray rock	682	698	

Cont. next page

GRABHORN WELL

Page 3

Material	From	To
Black Broken Rock - water	698	706
" " "	706	715
Black solid hard rock	715	720
Broken black rock	720	730
Gray hard rock	730	738
Softer rock	738	747
Hard gray rock	747	750
Softer gray rock	750	767
Hard gray rock	767	770
Clay & gray rock mixed	770	772
Gray soft rock	772	780
Medium hard gray rock	780	788
Very hard gray rock	788	802
Hard black rock	802	808
Broken black rock	808	817
Hard black rock, making water	817	820
Broken black rock, making water	820	833
Very hard black rock - crevices	833	852
Black rock - crevices - very heavy	852	855
Black rock	855	858
Shale, very hard	858	874

Total depth 874

(94)

File Original and First Copy with the STATE ENGINEER, SALEM, OREGON

WATER WELL REPORT
STATE OF OREGON

State Well No. 1/1w-17 20
State Permit No.

(1) OWNER:
Name C. J. Dernbach
Address 15820 S.W. Davis
Beaverton, Ore

(2) LOCATION OF WELL:
County Wash Owner's number, if any—
¼ ¼ Section 17 T. 1 S. R. 1 West W.M.
Bearing and distance from section or subdivision corner Well is located on D.L.C. No 50 in Sec. 17 T 1 S R. 1 W Washington County – 600 ft south of north line at entrance of Davis RD. and 700 West of east line 2½ mi southwest of Beaverton, Ore Washington Co. 15820 SW Davis

(3) TYPE OF WORK (check):
New Well ☐ Deepening ☒ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 11.

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐

(5) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☐ Jetted ☐
Dug ☐ Bored ☐

(6) CASING INSTALLED: Threaded ☐ Welded ☐
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(7) PERFORATIONS: Perforated? ☐ Yes ☐ No
Type of perforator used
SIZE of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(8) SCREENS: Well screen installed ☐ Yes ☐ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(9) CONSTRUCTION:
Was well gravel packed? ☐ Yes ☐ No Size of gravel:—
Gravel placed from ft. to ft.
Was a surface seal provided? ☐ Yes ☐ No To what depth? ft.
Material used in seal—
Did any strata contain unusable water? ☐ Yes ☐ No
Type of water? Depth of strata
Method of sealing strata off

(10) WATER LEVELS:
Static level 280 ft. below land surface Date 8/6/60
Artesian pressure lbs. per square inch Date

Log Accepted by:
[Signed] C J Dernbach (Owner) Sept 10 1960

(11) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom? -
Yield: gal./min. with ft. drawdown after hrs.
" " " "
" " " "
Bailer test 9 gal./min. with 0 ft. drawdown after 2 hrs.
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? ☐ Yes ☒ No

(12) WELL LOG: Diameter of well six inches.
Depth drilled 320 ft. Depth of completed well 320 ft.
Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.

MATERIAL	FROM	TO
Original depth – 273		
shale formation		
Rock – medium hard	273	285
Rock – medium heavy	285	296
Sandstone – porous	296	298
Rock – Hard	298	310
Rock – varying hardness containing water flow	310	320

Work started 7/30 1960 Completed 8/6 1960

(13) PUMP:
Manufacturer's Name Fairbanks Morse
Type: Lift – Cylinder H.P. 1

Well Driller's Statement:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME Jack Barron (Person, firm, or corporation) (Type or print)
Address 16425 S.W. Hart
Driller's well number 57
[Signed] Jack Barron (Well Driller)
License No. 59 Date 8/6 1960

(USE ADDITIONAL SHEETS IF NECESSARY)

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the
STATE ENGINEER, SALEM, OREGON 97310
within 30 days from the date of well completion.

RECEIVED
NOV 20 1970
STATE ENGINEER
SALEM, OREGON

WATER WELL REPORT
STATE OF OREGON
(Please type or print)
(Do not write above this line)

(107)

State Well No. 1/1W-20 bc
State Permit No. bc

(1) OWNER:
Name C. J. Dernbach
Address 15820 SW. Davis Rd. Beaverton, Oregon 97005

(2) TYPE OF WORK (check):
New Well ☐ Deepening ☒ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☒ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☒ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☐

(5) CASING INSTALLED: Threaded ☐ Welded ☐
None " Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS: Perforated? ☐ Yes ☒ No.
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WATER LEVEL: Completed well.
Static level 312 ft. below land surface Date 10/18/70
Artesian pressure lbs. per square inch Date

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☐ No If yes, by whom?
Yield: gal./min. with ft. drawdown after hrs.

Bailer test 11 gal./min. with 0 ft. drawdown after 1 hrs.
Artesian flow g.p.m. Date
Temperature of water 53° Was a chemical analysis made? ☐ Yes ☒ No

(10) CONSTRUCTION:
Well seal—Material used
Depth of seal ft.
Diameter of well bore to bottom of seal in.
Were any loose strata cemented off? ☐ Yes ☐ No Depth
Was a drive shoe used? ☐ Yes ☐ No
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☒ No Size of gravel:
Gravel placed from ft. to ft.

(11) LOCATION OF WELL:
County Washington Driller's well number 161
SW ¼ NW ¼ Section 20 T. 1 S. R. 1 W. W.M.
Bearing and distance from section or subdivision corner
1820' South and 480' East of North West corner of Sec. 20

(12) WELL LOG: Diameter of well below casing 6"
Depth drilled 410 ft. Depth of completed well 410 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level as drilling proceeds. Note drilling rates.

MATERIAL	From	To	SWL
Deepening - of original well in Rock from 320' to 410'			
original static level 312'			
Rock - brown	320	340	312'
Rock - gray	340	385	
Rock - soft	385	410	312'

Work started 10/6 1970 Completed 10/20 1970
Date well drilling machine moved off of well 10/21 1970

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] Jack Barron (Drilling Machine Operator) Date 11/9, 1970
Drilling Machine Operator's License No. 165

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
NAME Jack Barron (Person, firm or corporation) (Type or print)
Address 6425 SW. Hart, Beaverton, Oregon
[Signed] Jack Barron (Water Well Contractor)
Contractor's License No. 59 Date 11/9, 1970

(USE ADDITIONAL SHEETS IF NECESSARY)

NOTICE TO WATER WELL CONTRACTOR
The original and first copy of this report are to be filed with the STATE ENGINEER, SALEM, OREGON 97310 within 30 days from the date of well completion.

OBSERVATION WELL

(60)

WATER WELL REPORT
STATE OF OREGON
(Please type or print)
(Do not write above this line)

RECEIVED FEB 13 1968

State Well No. 1/1W-21J

State Permit No.

G-4379

(1) OWNER:
Name SAGE PLACE WELL
Address Rte. 1 Box 212 Beaverton, Ore.

(2) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:
Rotary ☒ Driven ☐
Cable ☐ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☒ Test Well ☐ Other ☐

(5) CASING INSTALLED: Threaded ☐ Welded ☒
6" Diam. from 0 ft. to 220 ft. Gage 17#
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(6) PERFORATIONS: Perforated? ☐ Yes ☒ No.
Type of perforator used
Size of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(7) SCREENS: Well screen installed? ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(8) WATER LEVEL: Completed well.
Static level 80 ft. ft. below land surface Date 2-9-68
Artesian pressure lbs. per square inch Date

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☐ Yes ☒ No If yes, by whom?
Yield: gal./min. with ft. drawdown after hrs.

Bailer test 45 gal./min. with 180 ft. drawdown after 1 hrs.
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? ☐ Yes ☒ No

(10) CONSTRUCTION:
Well seal—Material used sand and cement
Depth of seal 220 feet ft.
Diameter of well bore to bottom of seal 9 in.
Were any loose strata cemented off? ☐ Yes ☒ No Depth
Was a drive shoe used? ☐ Yes ☒ No
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? depth of strata
Method of sealing strata off
Was well gravel packed? ☐ Yes ☒ No Size of gravel:
Gravel placed from ft. to ft.

(11) LOCATION OF WELL:
County Washington Driller's well number
¼ S. E¼ Section 21 T. 1 S R. 1 W W.M.
Bearing and distance from section or subdivision corner

(12) WELL LOG: Diameter of well below casing 6 inch
Depth drilled 395 ft. Depth of completed well 395 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. Report each change in position of Static Water Level as drilling proceeds. Note drilling rates.

MATERIAL	From	To	SWL
Top soil	0	2	
Yellow clay	2	110	
Blue clay	110	165	
Brown clay	165	205	
Brown rock	205	210	
Brown soft rock	210	300	
Black med. rock	300	350	
Brown soft	350	380	
Brown med.	380	385	
Brown lava	385	395	

Work started Feb. 7 1968 Completed Feb. 9, 1968
Date well drilling machine moved off of well Feb. 9, 1968

Drilling Machine Operator's Certification:
This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.
[Signed] Ralph Turner (Drilling Machine Operator) Date 2/10, 1968
Drilling Machine Operator's License No. 254

Water Well Contractor's Certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
NAME Ralph Turner Drilling Co. (Person, firm or corporation) (Type or print)
Address Rte. 1 Box 141, Hillsboro, Ore.
[Signed] Ralph Turner (Water Well Contractor)
Contractor's License No. 247 Date Feb. 9, 1968

USE ADDITIONAL SHEETS IF NECESSARY

The original and first copy of this report are to be filed with the STATE ENGINEER, SALEM, OREGON within 30 days from the date of well completion.

SEP 17 1971
STATE ENGINEER
SALEM, OREGON

WATER WELL REPORT #58a

STATE OF OREGON

(Please type or print)

(Do not write above this line)

State Well No. 1/1W-21

State Permit No. ______

(1) OWNER:

Name Beaverton Christian Church

Address 13600 S. W. Allen Blvd. Beaverton, Ore.

(2) TYPE OF WORK (check):

New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐

If abandonment, describe material and procedure in Item 12.

(3) TYPE OF WELL:

Rotary ☒ Driven ☐
Cable ☐ Jetted ☐
Dug ☐ Bored ☐

(4) PROPOSED USE (check):

Domestic ☐ Industrial ☐ Municipal ☐
Irrigation ☐ Test Well ☐ Other ☒

CASING INSTALLED: Threaded ☐ Welded ☒

6 " Diam. from 0 ft. to 93 ft. Gage .280
5-9/16 " Diam. from 75 ft. to 355 ft. Gage 10 gage
______ " Diam. from ______ ft. to ______ ft. Gage ______

PERFORATIONS: Perforated? ☒ Yes ☐ No.

Type of perforator used torch

Size of perforations 1/8 in. by 6 in.

40 perforations from 315 ft. to 355 ft.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.

(7) SCREENS: Well screen installed? ☐ Yes ☒ No

Manufacturer's Name ______

Type ______ Model No. ______

Diam. ______ Slot size ______ Set from ______ ft. to ______ ft.
Diam. ______ Slot size ______ Set from ______ ft. to ______ ft.

(8) WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☒ No If yes, by whom?

Yield: ______ gal./min. with ______ ft. drawdown after ______ hrs.

air
Bailer test 25 gal./min. with 225 ft. drawdown after 1 hrs.

Artesian flow ______ g.p.m.

Temperature of water ______ Depth artesian flow encountered ______ ft.

(9) CONSTRUCTION:

Well seal—Material used Bentonite

Well sealed from land surface to 90 ft.

Diameter of well bore to bottom of seal 9 in.

Diameter of well bore below seal 6 in.

Number of sacks of cement used in well seal ______ sacks

Number of sacks of bentonite used in well seal 4 sacks

Brand name of bentonite National

Number of pounds of bentonite per 100 gallons of water 50 lbs./100 gals.

Was a drive shoe used? ☐ Yes ☒ No Plugs ______ Size: location ______ ft.

Did any strata contain unusable water? ☐ Yes ☒ No

Type of water? ______ depth of strata ______

Method of sealing strata off ______

Was well gravel packed? ☐ Yes ☒ No Size of gravel: ______

Gravel placed from ______ ft. to ______ ft.

(10) LOCATION OF WELL:

County Washington Driller's well number ______

¼ ¼ Section 21 T. 1-S R. 1-W W.M.

Bearing and distance from section or subdivision corner ______

(11) WATER LEVEL: Completed well.

Depth at which water was first found 145 ft.

Static level 80 ft. below land surface. Date 9-11-71

Artesian pressure ______ lbs. per square inch. Date ______

(12) WELL LOG: Diameter of well below casing 6

Depth drilled 355 ft. Depth of completed well 355 ft.

Formation: Describe color, texture, grain size and structure of materials; and show thickness and nature of each stratum and aquifer penetrated, with at least one entry for each change of formation. *Report each change in position of Static Water Level and indicate principal water-bearing strata.*

MATERIAL	From	To	SWL
Top soil	0	3	
Yellow clay	3	75	
Blue clay	75	115	
Blue sandy clay	115	145	
Brown clay	145	175	
Blue clay	175	225	
Blue sandy clay and wood	225	265	
Brown sandstone	265	345	
Brown broken rock	345	355	

Work started 9-10-71 19 Completed 9-11-71 19

Date well drilling machine moved off of well 9-11-71 19

Drilling Machine Operator's Certification:

This well was constructed under my direct supervision. Materials used and information reported above are true to my best knowledge and belief.

[Signed] Ralph Turner (Drilling Machine Operator) Date 9-15-, 19 71

Drilling Machine Operator's License No. 254

Water Well Contractor's Certification:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

Name Ralph Turner Drilling Co. (Person, firm or corporation) (Type or print)

Address Rte 1 Box 141 Hillsboro, Oregon

[Signed] Ralph Turner (Water Well Contractor)

Contractor's License No. 247 Date 9-15-71, 19

(USE ADDITIONAL SHEETS IF NECESSARY)

189th Street WELL
page 1

WATER WELL REPORT
STATE OF OREGON

143

State Well No. 1/2w-24 J(3)
State Permit No. G-588 24d

(1) OWNER:
189th Street well

Name Aloha-Huber Water District
Address 17880 S. W. Blanton
Aloha, Oregon

(2) LOCATION OF WELL:
County Washington Owner's number, if any— No. 1
NE ¼ SE ¼ Section 24 T. 1 S R. 2 W W.M.
Bearing and distance from section or subdivision corner
1520 ft. N 0°34'E; 990.3 Ft. N 89°41'W
from SE corner of Sec. 24, T1S, R2W

(3) TYPE OF WORK (check):
New Well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 11.

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☒
Irrigation ☐ Test Well ☐ Other ☐

(5) TYPE OF WELL:
Rotary ☐ Driven ☐
Cable ☒ Jetted ☐
Dug ☐ Bored ☐

(6) CASING INSTALLED:
Threaded ☐ Welded ☒
16" Diam. from 0 ft. to 250' 7" ft. Gage 3/8 wall
" Diam. from ft. to ft. Gage
" Diam. from ft. to ft. Gage

(7) PERFORATIONS:
Perforated? ☐ Yes ☒ No
Type of perforator used
SIZE of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

(8) SCREENS:
Well screen installed ☐ Yes ☒ No
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to ft.
Diam. Slot size Set from ft. to ft.

(9) CONSTRUCTION:
Was well gravel packed? ☐ Yes ☒ No Size of gravel:
Gravel placed from ft. to ft.
Was a surface seal provided? ☒ Yes ☐ No To what depth? Casing 250' 7" ft.
Material used in seal—200 sks cement grout
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? Depth of strata
Method of sealing strata off

(10) WATER LEVELS:
Static level 138' ft. below land surface Date 7-18-58
Artesian pressure lbs. per square inch Date

Log Accepted by:
[Signed] (Owner) Date , 19

(11) WELL TESTS:
Drawdown is amount water level is lowered below static level
Was a pump test made? ☒ Yes ☐ No If yes, by whom? Driller
Yield: 470 gal./min. with 162 ft. drawdown after 24 hrs.
" " " "
" " " "
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m. Date
Temperature of water 55° Was a chemical analysis made? ☒ Yes ☐ No

(12) WELL LOG:
Diameter of well 15¼" to 685' 10" on to 720' inches.
Depth drilled 720 ft. Depth of completed well 720 ft.

Formation: *Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.*

MATERIAL	FROM	TO
brown & yellow clay	0	15
red clay	15	45
green rock	45	55
black rock	55	85
decomposed rock	85	88
hard red rock	88	94
soft red rock	94	98
black rock	98	176
brown rock	176	178
hard grey basalt	178	210
black rock	210	240
grey rock	240	270
red & brown rock - water bearing	270	293
black rock	293	300
broken black rock - water bearing	300	312
hard grey basalt	312	358
black rock	358	378
brown rock - water bearing	378	404
hard grey rock	404	422
hard black rock	422	475
soft black rock - water bearing	475	481
hard black rock	481	499
soft black rock	499	504
hard black rock	504	528

-Continued on page two

Work started 19 Completed 19

(13) PUMP:
Manufacturer's Name
Type: H.P.

RECEIVED AUG 1958

Well Driller's Statement:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME (Person, firm, or corporation) (Type or print)
Address
Driller's well number
[Signed] (Well Driller)
License No. Date , 19

(USE ADDITIONAL SHEETS IF NECESSARY)

189th Street Well

WATER WELL REPORT
STATE OF OREGON

State Well No. 1/2W - 24 J/3

State Permit No.

(1) OWNER:
Name Aloha-Huber Water District -Continued

Address

(2) LOCATION OF WELL:
County Owner's number, if any—

¼ ¼ Section T. R. W.M.

Bearing and distance from section or subdivision corner

(3) TYPE OF WORK (check):
Well ☐ Deepening ☐ Reconditioning ☐ Abandon ☐

If abandonment, describe material and procedure in Item 11.

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☐ Irrigation ☐ Test Well ☐ Other ☐

(5) TYPE OF WELL:
Rotary ☐ Driven ☐ Cable ☐ Jetted ☐ Dug ☐ Bored ☐

(6) CASING INSTALLED:
Threaded ☐ Welded ☐

" Diam. from ft. to ft. Gage

" Diam. from ft. to ft. Gage

" Diam. from ft. to ft. Gage

(7) PERFORATIONS:
Perforated? ☐ Yes ☐ No

Type of perforator used

SIZE of perforations in. by in.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

perforations from ft. to ft.

(8) SCREENS:
Well screen installed ☐ Yes ☐ No

Manufacturer's Name

Type Model No.

Diam. Slot size Set from ft. to ft.

Diam. Slot size Set from ft. to ft.

(9) CONSTRUCTION:
Well gravel packed? ☐ Yes ☐ No Size of gravel:

Gravel placed from ft. to ft.

Was a surface seal provided? ☐ Yes ☐ No To what depth? ft.

Material used in seal—

Did any strata contain unusable water? ☐ Yes ☐ No

Type of water? Depth of strata

Method of sealing strata off

(10) WATER LEVELS:
Static level ft. below land surface Date

Artesian pressure lbs. per square inch Date

Log Accepted by:

[Signed] Eldon W. Carter (Owner) Date 19 August 1958

Engineer

(11) WELL TESTS:
Drawdown is amount water level is lowered below static level

Was a pump test made? ☐ Yes ☐ No If yes, by whom?

Yield: gal./min. with ft. drawdown after hrs.

Bailer test gal./min. with ft. drawdown after hrs.

Artesian flow g.p.m. Date

Temperature of water Was a chemical analysis made? ☐ Yes ☐ No

(12) WELL LOG:
Diameter of well inches.

Depth drilled ft. Depth of completed well ft.

Formation: *Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.*

MATERIAL	FROM	TO
hard grey rock	528	550
soft brown rock - water bearing	550	553
hard grey rock	553	624
soft black rock	624	629
hard grey rock	629	653
soft black rock possibly water bearing	653	657
XXX black rock	657	694
grey shale	694	720

Work started Jan. 13 1958. Completed July 18 1958

(13) PUMP:
RECEIVED

Manufacturer's Name

Type: H.P.

Well Driller's Statement:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME A. M. Jannsen Drilling Company (Person, firm, or corporation) (Type or print)

Address 21075 S. W. Tualatin Hiway - Aloha, Orego

Driller's well number

[Signed] Edward M. Jannsen (Well Driller) Edward M. Jannsen, Partner

License No. 79 Date 7-23-58, 19

(USE ADDITIONAL SHEETS IF NECESSARY)

Appendix B

Borehole Geophysics Survey

Appendix B

Borehole Geophysics Survey

Geophysical surveys at the Hanson Road and Schuepbach wells were conducted by Welenco, Inc., of Kennewick, Washington. For dynamic (pumping) surveys, a submersible pump was installed in the boreholes; the tools were lowered through a 4-inch-diameter polyvinyl chloride (PVC) protective access pipe installed to a depth below the base of the pump. Following are brief descriptions of each physical and geophysical survey method used at the Hanson Road and Schuepbach wells.

Video Survey

A reconfigured television camera was used to survey the boreholes visually from the surface to total depth to assess the mechanical condition of the casing, casing depth, fracture zones, and potential obstructions. The video is displayed in the logging truck and recorded on a VHS videocassette. The picture is viewed vertically downward, at a focal length of approximately 2 feet.

Caliper Survey

A caliper log was used to measure the average borehole diameter continuously over the total depth of the boreholes. The diameter was measured with three caliper arms connected to precision potentiometers in the tools base. Changes in borehole diameter are converted into electric pulses that are transmitted to the surface for recording. The log is presented as a single trace that displays the average borehole diameter in inches.

Static and Dynamic Flowmeter Surveys

A flowmeter (spinner) survey was used to identify the water-producing zones in the boreholes. This tool measures the rate of movement in the boreholes using a low-inertia impeller mounted on precision carbide bearings. The counts per second (cps, 12 per revolution) are recorded at the surface.

The flowmeter survey was conducted under both pumping and nonpumping conditions. The nonpumping (static) flowmeter survey was conducted to determine whether water is moving between aquifers because of a natural difference in hydraulic head. Because water movement under these conditions is slow enough that it is insufficient to initiate impeller rotation, the tool is lowered into and retrieved from the borehole at a constant speed. A difference in impeller speed between the two runs provides an indication of the direction of water movement in the borehole. For instance, if water were moving downward in the borehole, the down-run (when the tool is moving with the water) would indicate a slower fluid velocity (or fewer counts per second) than the up-run (when the tool is moving against the flow).

Once the cps resulting from the tool speed have been subtracted, the actual rate of water movement under non-pumping conditions can then be estimated.

A submersible pump was installed in the well to conduct a dynamic flowmeter survey to measure the contribution of each fluid entry point. The Hanson Road well was pumped at 260 gallons per minute (gpm) with the pump set at 235 feet below ground surface for this survey. The Schuepbach well was pumped at 525 gpm with the pump set at 150 feet below ground surface for this survey. Once the pumping rate was stabilized, the tool was lowered into the hole through the access pipe and a stop-check (that is, stationary) measurement was made in the casing above the first production zone. This allows the cps for the tool to be calibrated for a 100 percent response (the number of cps for the known discharge rate).

In addition to a stop-check dynamic flowmeter survey of the boreholes, three continuous flowmeter surveys (two down and one up) were conducted for the Hanson Road well, and four continuous flowmeter surveys (three down and one up) were conducted for the Schuepbach well. For actual flowrates to be derived from the flowmeter survey data, the measured cps need to be corrected for both line speed and borehole diameter. Variations in borehole configuration not measured by the caliper survey can lead to unexplained variations in the apparent fluid velocity.

Natural Gamma Logging

Gamma ray logging measures the naturally occurring gamma emissions from the formation surrounding the borehole. The emissions are electromagnetic radiation that is released by the decay of naturally radioactive elements. The gamma ray probe measures these emissions, calculates the average, and converts the averaged number to an electrical signal that is recorded at the surface. The most common unstable element found in geologic formations is potassium 40 (^{40}K). As the presence of ^{40}K increases in a formation, the gamma ray activity increases. In general, ^{40}K concentrations increase in finer-grained sedimentary materials such as clays and silts.

When metamorphic or low-permeability igneous rocks are being logged, the gamma ray response depends on the minerals contained within the rock. In some cases, gamma ray activity is heightened along open water-bearing fractures where either dissolved radioactive minerals (such as uranium) are encountered or where the host rock has been altered by the precipitation of radioactively enriched minerals along the fracture wall.

Gamma ray logging was conducted to provide a means of correlating porosity-related tools with entry-point surveys (flowmeter surveys). It should be noted that gamma energy is proportional to distance and therefore must be compared with the caliper log when correlations are attempted.

Hanson Road Well
Borehole Geophysics Survey
Raw Data

For a copy of:

Hanson Road Well Borehole Geophysics Survey Raw Data

Please Contact :

CH2M HILL
825 NE Multnomah
Portland Oregon, 97232
Jeff Barry

Schuepbach Well Survey
Borehole Geophysics Survey
Raw Data

For a copy of:

Schuepbach Well Survey
Borehole Geophysics Survey
Raw Data

Please Contact :

CH2M HILL
825 NE Multnomah
Portland Oregon, 97232
Jeff Barry

Appendix C

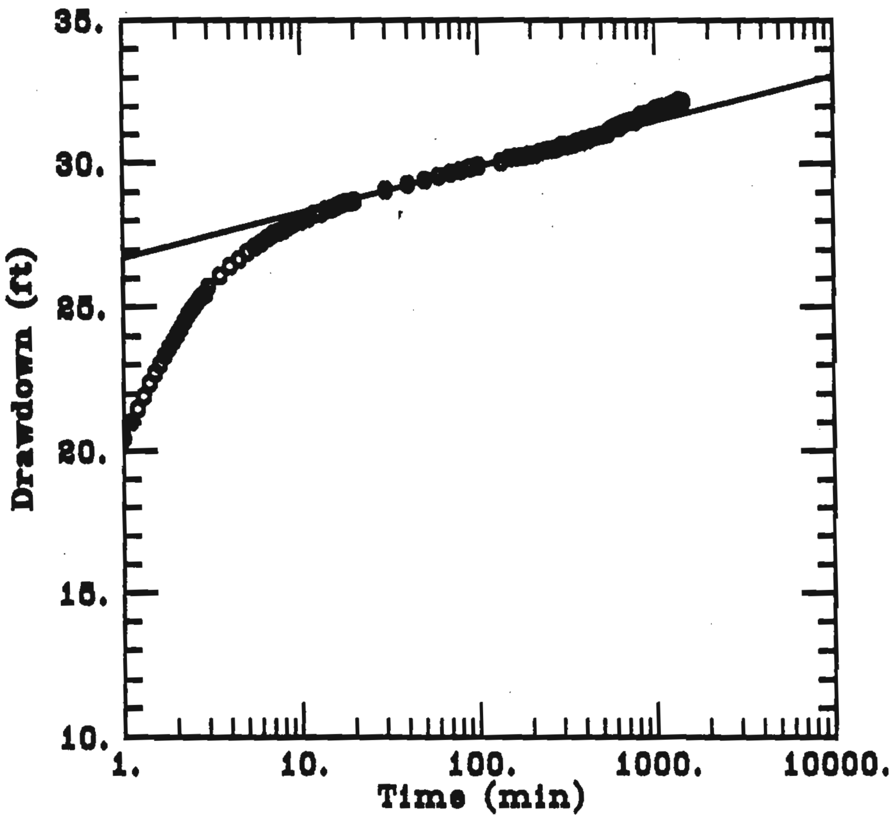
Aquifer Test Analysis

Hanson Road Well Aquifer Test
Data & Analyses

Hanson Road Well Aquifer Test Data							
Hanson Road Well - Pumping Data							
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study							
Pumping Started: July 13, 1994 @ 0900							
Time (min)	Drawdown (ft)		Time (min)	Drawdown (ft)		Time (min)	Drawdown (ft)
0.1	5.148		19	28.649		765	31.439
0.2	11.135		20	28.693		780	31.469
0.3	14.308		30	29.075		795	31.539
0.4	15.583		40	29.284		810	31.609
0.5	16.449		50	29.418		825	31.602
0.6	17.285		60	29.561		840	31.715
0.7	18.216		70	29.667		855	31.643
0.8	19.086		80	29.748		870	31.668
0.9	19.847		90	29.843		885	31.629
1	20.443		100	29.905		900	31.728
1.1	21.009		135	30.056		915	31.709
1.2	21.468		150	30.183		930	31.673
1.3	21.915		165	30.224		945	31.700
1.4	22.360		180	30.231		960	31.766
1.5	22.710		195	30.294		975	31.820
1.6	23.013		210	30.298		990	31.863
1.7	23.320		225	30.393		1005	31.898
1.8	23.588		240	30.431		1020	31.929
1.9	23.823		255	30.464		1035	31.905
2	24.051		270	30.463		1050	31.935
2.1	24.278		285	30.527		1065	31.952
2.2	24.491		300	30.635		1080	31.954
2.3	24.717		315	30.585		1095	31.975
2.4	24.893		330	30.628		1110	31.895
2.5	25.029		345	30.652		1125	31.971
2.6	25.178		360	30.728		1140	32.002
2.7	25.309		375	30.766		1155	32.003
2.8	25.418		390	30.735		1170	31.992
2.9	25.457		405	30.859		1185	31.921
3	25.708		420	30.813		1200	32.002
3.5	26.100		435	30.886		1215	32.020
4	26.430		450	30.923		1230	32.053
4.5	26.658		465	30.941		1245	32.060
5	26.915		480	30.962		1260	32.024
5.5	27.087		495	30.980		1275	32.094
6	27.238		510	30.986		1290	32.041
6.5	27.397		525	31.025		1305	32.045
7	27.542		540	31.022		1320	32.118
7.5	27.606		555	31.146		1335	32.124
8	27.675		570	31.222		1350	32.150
8.5	27.798		585	31.231		1365	32.221
9	27.880		600	31.294		1380	32.104
9.5	27.964		615	31.315		1395	32.117
10	27.984		630	31.241		1410	32.132
11	28.080		645	31.353		1425	32.132
12	28.251		660	31.405		1440	32.165
13	28.255		675	31.392			
14	28.399		690	31.441			
15	28.423		705	31.462			
16	28.511		720	31.472			
17	28.585		735	31.483			
18	28.646		750	31.508			

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Hanson Road Pumping Phase



DATA SET:
hanpump.dat
02/10/95

AQUIFER TYPE:
Confined

SOLUTION METHOD:
Cooper-Jacob

TEST DATE:
7/13/94

TEST WELL:
Hanson Rd.

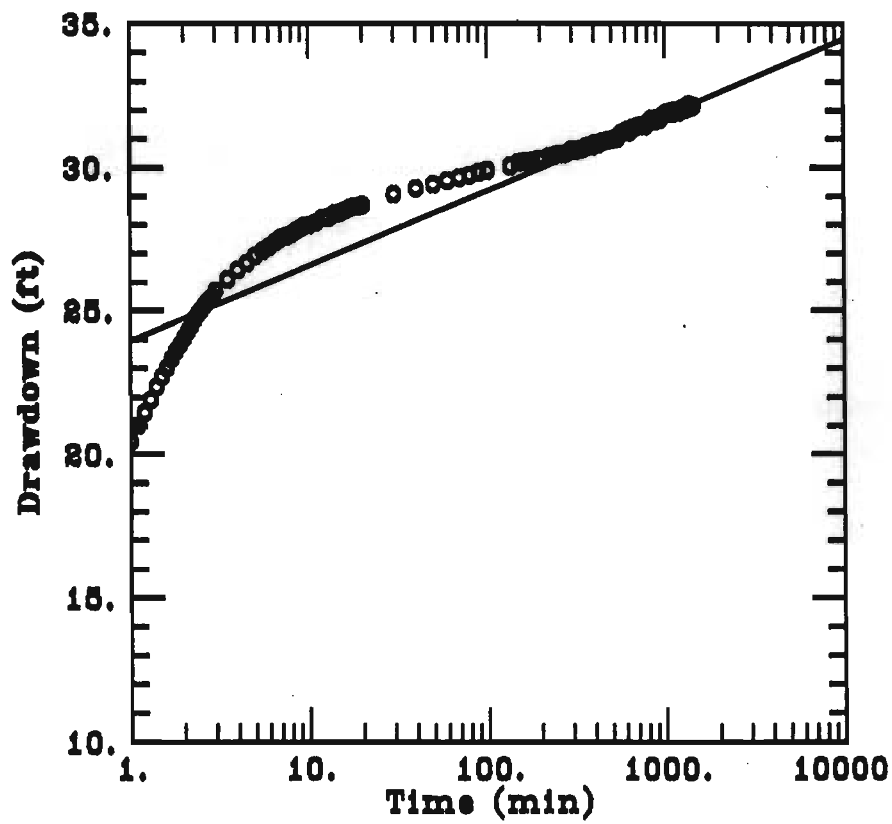
OBS. WELL:
Hanson Rd.

ESTIMATED PARAMETERS:
T = 13.58 ft^2/min
S = 4.4767E-16

TEST DATA:
Q = 117.6 ft^3/min
r = 1. ft

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Hanson Road Pumping Phase



DATA SET:
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02/10/95

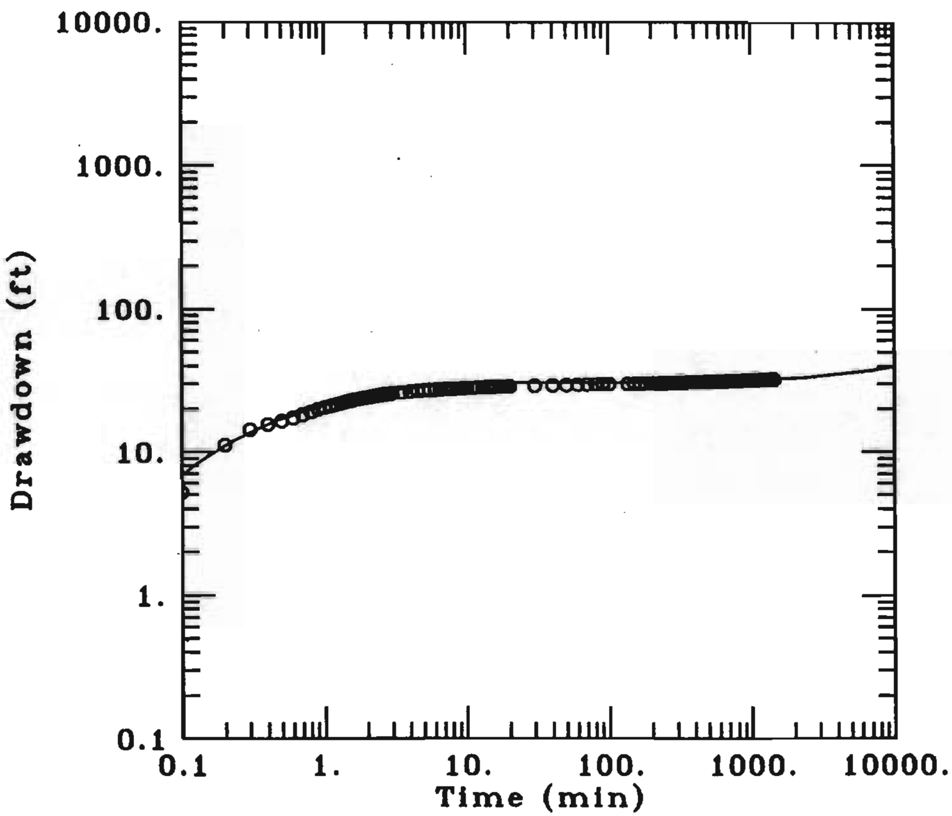
AQUIFER TYPE:
Confined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
7/13/94
TEST WELL:
Hanson Rd.
OBS. WELL:
Hanson Rd.

ESTIMATED PARAMETERS:
T = 8.195 ft^2/min
S = 1.4409E-08

TEST DATA:
Q = 117.5 ft^3/min
r = 1. ft

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Hanson Road Pumping Phase



DATA SET:
hanpump2.dat
09/23/94

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Neuman
TEST DATE:
7/13/94
TEST WELL:
Hanson Rd.
OBS. WELL:
Hanson Rd.

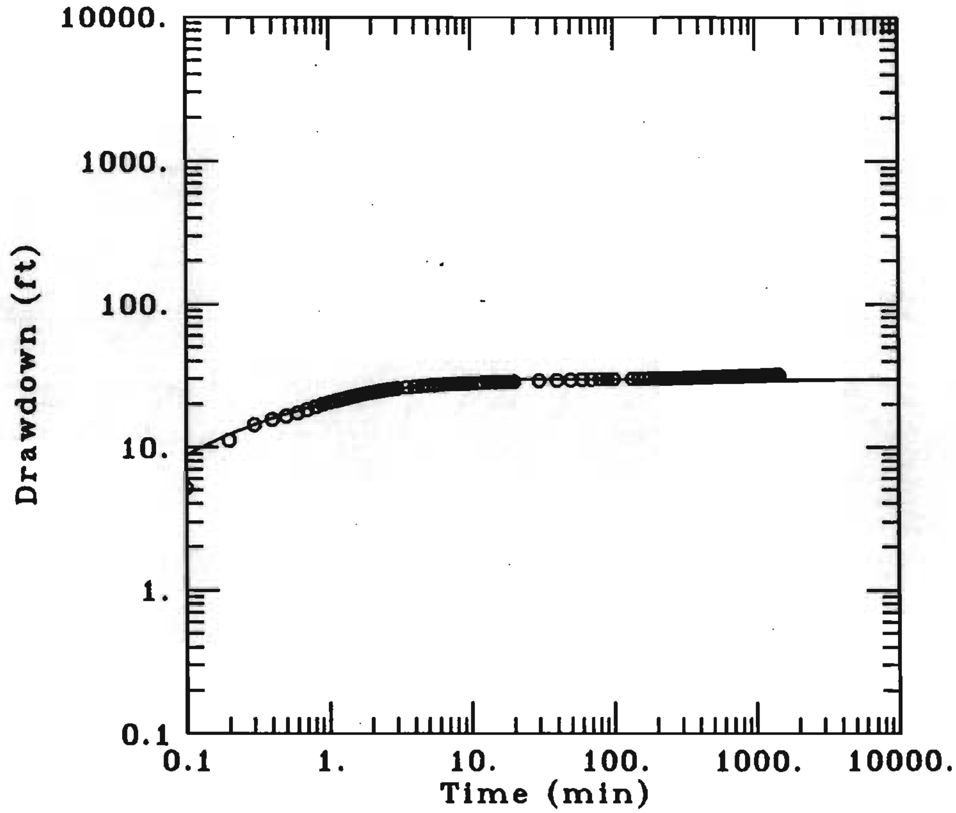
ESTIMATED PARAMETERS:
T = 1.058 ft^2/min
S = 0.1422
Sy = 366.
β = 0.01

TEST DATA:
Q = 117.6 ft^3/min
r = 1. ft
b = 615. ft

\hanpump2.wp

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Hanson Road Pumping Phase



DATA SET:
hanpump.dat
09/15/94

AQUIFER TYPE:
Leaky
SOLUTION METHOD:
Hantush
TEST DATE:
7/13/94
TEST WELL:
Hanson Rd.
OBS. WELL:
Hanson Rd.

ESTIMATED PARAMETERS:
T = 1.668 ft^2/min
S = 0.08819
r/B= 0.08

TEST DATA:
Q = 117.6 ft^3/min
r = 1. ft

\hanpmp2.wp

Hanson Road Well Aquifer Test Data

Hanson Road Well - Recovery Data

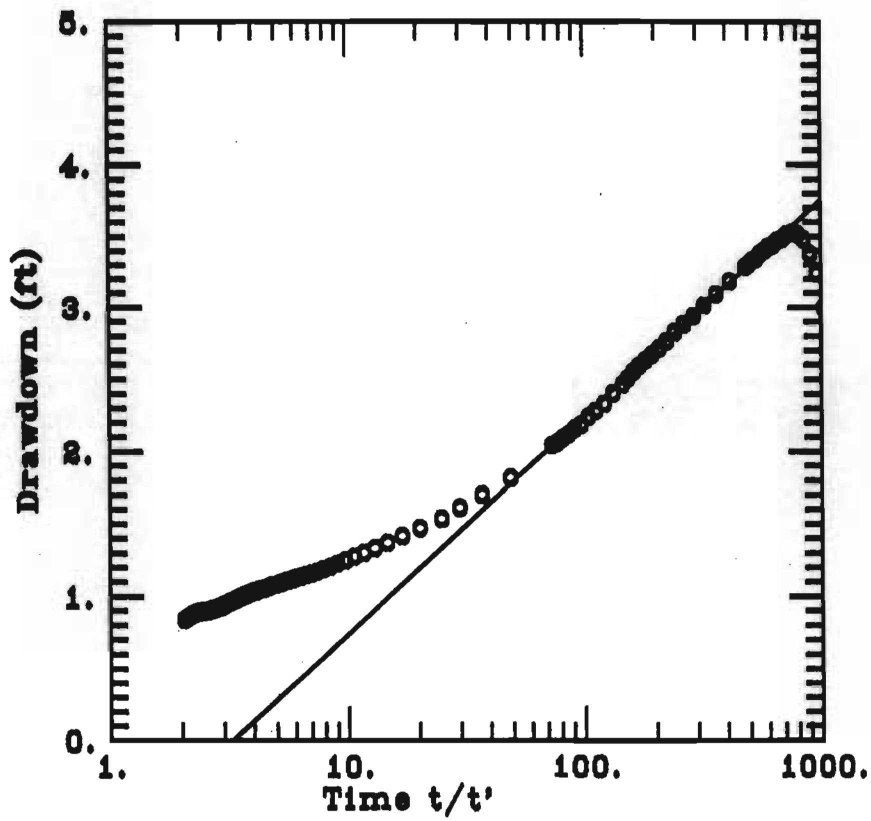
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study

Recovery Started: July 14, 1994 @ 0900

Time (t/t')	Drawdown (ft)	Time (t/t')	Drawdown (ft)	Time (t/t')	Drawdown (ft)
14401	28.529	91	2.156	3.13	0.956
7201	23.225	86	2.119	3.09	0.950
4801	18.374	81	2.091	3.04	0.944
3601	14.572	77	2.061	3.00	0.941
2881	9.843	73	2.043	2.96	0.938
2401	5.962	49	1.817	2.92	0.930
2058	3.109	37	1.702	2.88	0.929
1801	1.834	30	1.612	2.85	0.927
1601	1.449	25	1.537	2.81	0.921
1441	1.511	20	1.472	2.78	0.918
1310	1.816	17	1.417	2.75	0.918
1201	2.189	15	1.372	2.71	0.915
1109	2.612	13	1.335	2.68	0.911
1030	2.995	11.67	1.302	2.66	0.911
961	3.239	10.60	1.275	2.63	0.907
901	3.379	9.73	1.248	2.60	0.901
848	3.480	9.00	1.228	2.57	0.904
801	3.516	8.38	1.205	2.55	0.902
759	3.524	7.86	1.190	2.52	0.899
721	3.514	7.40	1.174	2.50	0.899
687	3.484	7.00	1.160	2.48	0.898
656	3.469	6.65	1.150	2.45	0.894
627	3.438	6.33	1.137	2.43	0.898
601	3.425	6.05	1.130	2.41	0.897
577	3.400	5.80	1.119	2.39	0.893
555	3.379	5.57	1.109	2.37	0.890
534	3.343	5.36	1.102	2.35	0.893
515	3.332	5.17	1.092	2.33	0.890
498	3.306	5.00	1.084	2.32	0.889
481	3.287	4.84	1.081	2.30	0.887
412	3.183	4.69	1.072	2.28	0.883
361	3.092	4.56	1.064	2.26	0.881
321	3.012	4.43	1.057	2.25	0.881
289	2.936	4.31	1.053	2.23	0.878
263	2.882	4.20	1.046	2.22	0.876
241	2.824	4.10	1.038	2.20	0.875
223	2.763	4.00	1.035	2.19	0.872
207	2.714	3.91	1.029	2.17	0.868
193	2.669	3.82	1.021	2.16	0.864
181	2.631	3.74	1.014	2.14	0.861
170	2.593	3.67	1.009	2.13	0.860
161	2.552	3.59	1.002	2.12	0.855
153	2.505	3.53	0.998	2.10	0.850
145	2.464	3.46	0.990	2.09	0.850
132	2.402	3.40	0.986	2.08	0.846
121	2.331	3.34	0.978	2.07	0.845
112	2.284	3.29	0.972	2.05	0.839
104	2.241	3.23	0.968		
97	2.187	3.18	0.961		

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Hanson Road Recovery Phase



DATA SET:
hanrec.dat
02/13/95

AQUIFER TYPE:
Confined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
7/13/94
TEST WELL:
Hanson Rd.
OBS. WELL:
Hanson Rd.

ESTIMATED PARAMETERS:
T = 14.31 ft^2/min
S = 103.5

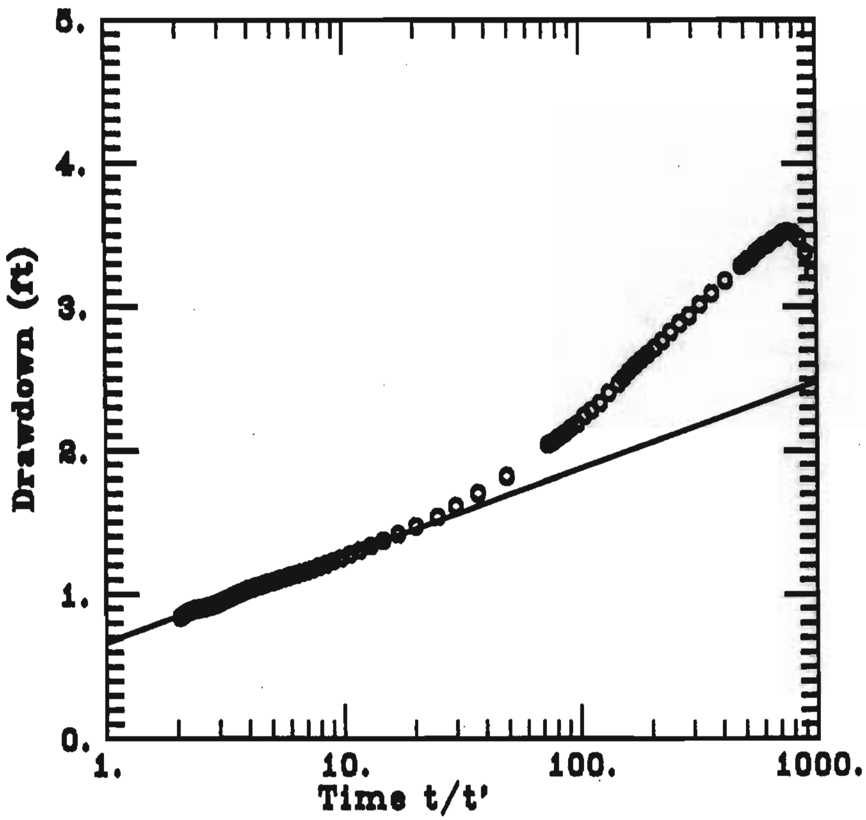
TEST DATA:
Q = 117.6 ft^3/min
r = 1. ft

\hanrec2.wp

7

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Hanson Road Recovery Phase



DATA SET:
hanrec.dat
02/13/95

AQUIFER TYPE:
Confined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
7/13/94
TEST WELL:
Hanson Rd.
OBS. WELL:
Hanson Rd.

ESTIMATED PARAMETERS:
T = 35.56 ft^2/min
S = 6.429

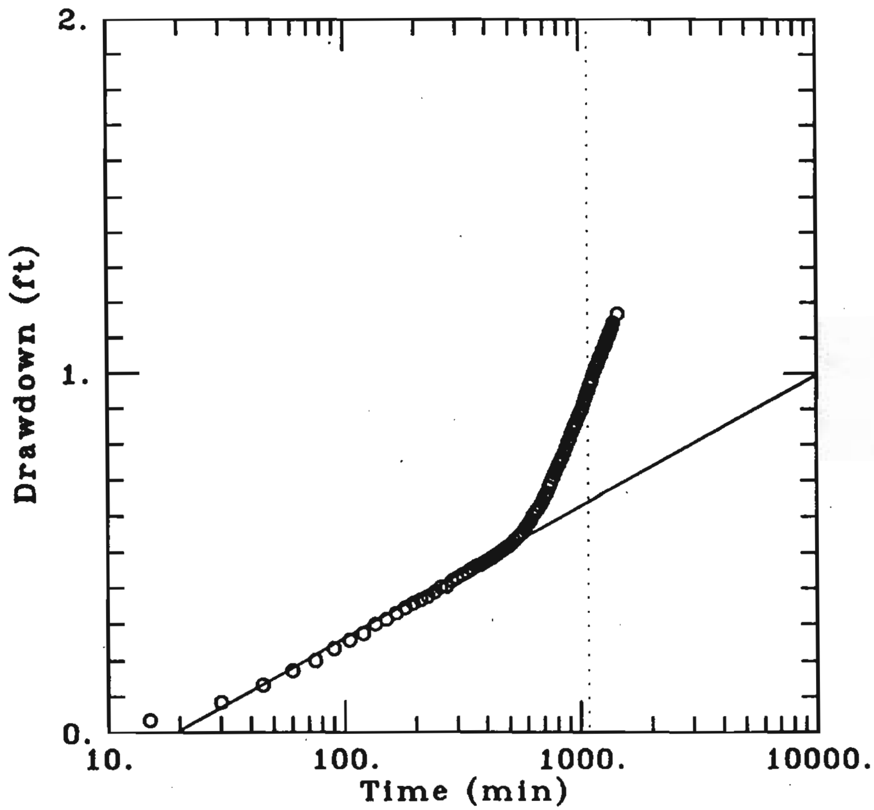
TEST DATA:
Q = 117.6 ft^3/min
r = 1. ft

\hanrec3.wp

Hanson Road Well Aquifer Test Data				
Sage Place Observation Well - Pumping Data				
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study				
Pumping Test Started: July 13, 1994 @ 0900				
Time (min)	Drawdown (ft)		Time (min)	Drawdown (ft)
0	0.007		720	0.663
15	0.034		735	0.679
30	0.085		750	0.693
45	0.133		765	0.708
60	0.173		780	0.720
75	0.200		795	0.732
90	0.233		810	0.744
105	0.256		825	0.754
120	0.274		840	0.764
135	0.300		855	0.776
150	0.314		870	0.790
165	0.331		885	0.804
180	0.346		900	0.814
195	0.359		915	0.829
210	0.369		930	0.840
225	0.378		945	0.851
240	0.390		960	0.860
255	0.404		975	0.872
270	0.406		990	0.882
285	0.422		1005	0.891
300	0.430		1020	0.899
315	0.439		1035	0.915
330	0.446		1050	0.927
345	0.454		1065	0.940
360	0.463		1080	0.951
375	0.466		1095	0.964
390	0.473		1110	0.974
405	0.479		1125	0.983
420	0.485		1140	0.999
435	0.492		1155	1.006
450	0.499		1170	1.018
465	0.506		1185	1.025
480	0.512		1200	1.035
495	0.517		1215	1.047
510	0.525		1230	1.052
525	0.533		1245	1.065
540	0.541		1260	1.071
555	0.549		1275	1.078
570	0.556		1290	1.089
585	0.568		1305	1.097
600	0.578		1320	1.104
615	0.588		1335	1.112
630	0.602		1350	1.121
645	0.612		1365	1.127
660	0.620		1380	1.141
675	0.630		1440	1.166
690	0.641			
705	0.654			

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Sage Place Pumping Phase



DATA SET:
sagpump.dat
09/23/94

AQUIFER TYPE:
Confined

SOLUTION METHOD:
Cooper-Jacob

TEST DATE:
7/13/94

TEST WELL:
Hanson Rd.

OBS. WELL:
Sage Place

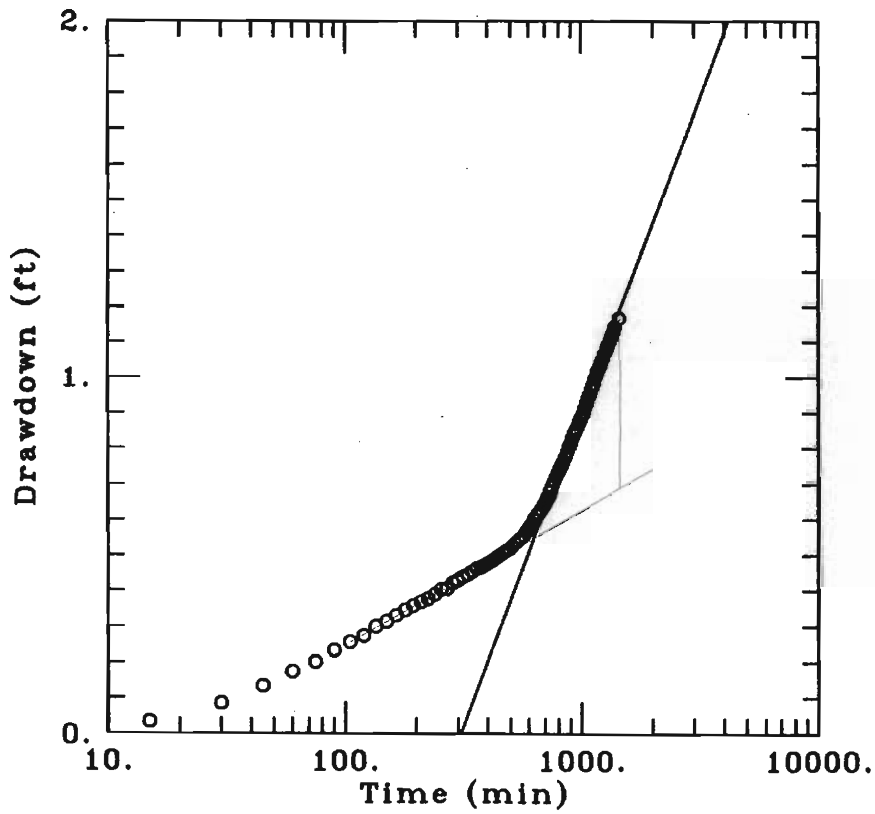
ESTIMATED PARAMETERS:
T = 58.81 ft^2/min
S = 0.0004414 ≈ 4.4×10^{-4}

TEST DATA:
Q = 117.6 ft^3/min
r = 2400. ft

\sagepmp2.wp

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Sage Place Pumping Phase



DATA SET:
sagpump.dat
09/23/94

AQUIFER TYPE:
Confined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
7/13/94
TEST WELL:
Hanson Rd.
OBS. WELL:
Sage Place

ESTIMATED PARAMETERS:
T = 12.22 ft^2/min
S = 0.001466

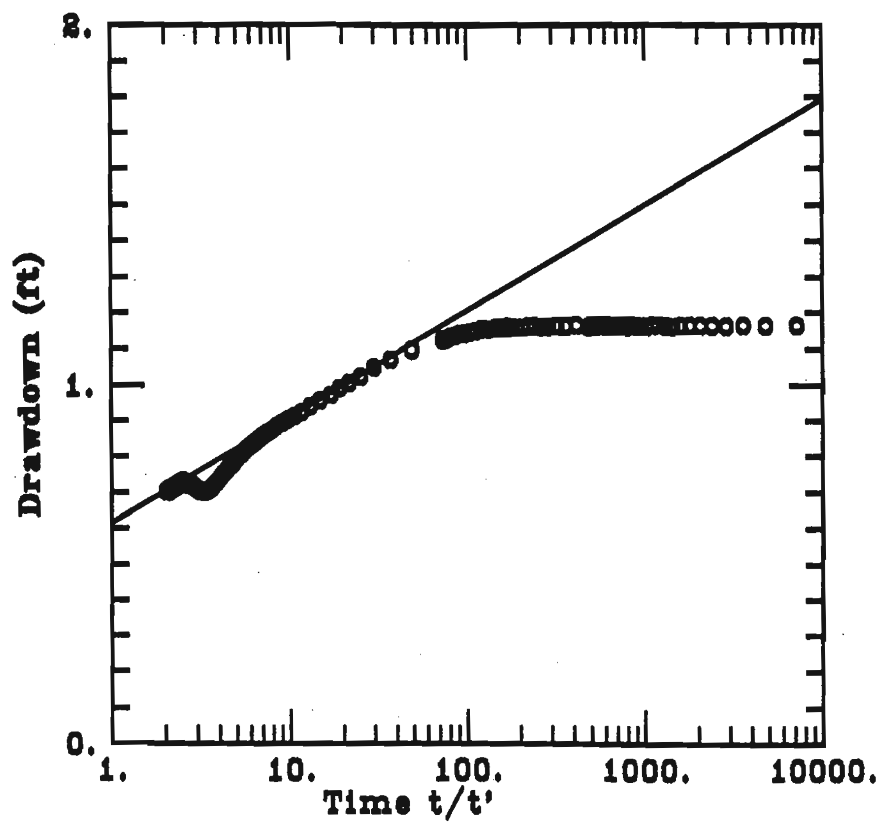
TEST DATA:
Q = 117.6 ft^3/min
r = 2400. ft

\sagepmp1.wp

Hanson Road Well Aquifer Test Data							
Sage Place Observation Well - Recovery Data							
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study							
Recovery Started: July 14, 1994 @ 0900							
Time (t/t')	Drawdown (ft)		Time (t/t')	Drawdown (ft)		Time (t/t')	Drawdown (ft)
14401	1.164		81	1.132		3.00	0.709
7201	1.164		77	1.126		2.96	0.711
4801	1.163		73	1.124		2.92	0.713
3601	1.164		49	1.096		2.88	0.718
2881	1.162		37	1.070		2.85	0.718
2401	1.163		30	1.048		2.81	0.719
2058	1.163		25	1.023		2.78	0.721
1801	1.163		22	1.005		2.75	0.720
1601	1.163		19	0.990		2.71	0.720
1441	1.161		17	0.972		2.68	0.721
1310	1.162		14.71	0.956		2.66	0.722
1201	1.164		13.00	0.940		2.63	0.724
1109	1.164		11.67	0.924		2.60	0.725
1030	1.161		10.60	0.913		2.57	0.727
961	1.162		9.73	0.902		2.55	0.726
901	1.162		9.00	0.892		2.52	0.731
848	1.164		8.38	0.883		2.50	0.731
801	1.160		7.86	0.873		2.48	0.729
759	1.164		7.40	0.865		2.45	0.728
721	1.163		7.00	0.857		2.43	0.725
687	1.162		6.65	0.848		2.41	0.726
656	1.163		6.33	0.839		2.39	0.726
627	1.163		6.05	0.831		2.37	0.721
601	1.162		5.80	0.824		2.35	0.718
577	1.163		5.57	0.816		2.33	0.716
555	1.163		5.36	0.807		2.32	0.716
534	1.162		5.17	0.801		2.30	0.716
515	1.163		5.00	0.792		2.28	0.716
498	1.162		4.84	0.782		2.26	0.719
481	1.160		4.69	0.774		2.25	0.715
412	1.164		4.56	0.771		2.23	0.715
361	1.162		4.43	0.762		2.22	0.712
321	1.162		4.31	0.756		2.20	0.711
289	1.160		4.20	0.751		2.19	0.711
263	1.160		4.10	0.743		2.17	0.707
241	1.162		4.00	0.735		2.16	0.709
223	1.161		3.91	0.729		2.14	0.707
207	1.158		3.82	0.724		2.13	0.703
193	1.158		3.74	0.720		2.12	0.706
181	1.158		3.67	0.713		2.10	0.707
170	1.160		3.59	0.711		2.09	0.710
161	1.156		3.53	0.707		2.08	0.707
153	1.157		3.46	0.705		2.07	0.705
145	1.156		3.40	0.703		2.05	0.704
132	1.153		3.34	0.702		2.04	0.702
121	1.153		3.29	0.702		2.03	0.705
112	1.147		3.23	0.702		2.02	0.702
104	1.145		3.18	0.704			
97	1.141		3.13	0.704			
91	1.141		3.09	0.704			
86	1.135		3.04	0.708			

CH2M HILL	Client: Tualatin Valley Water District
Project No.: 140249	Location: Beaverton, OR

Sage Place Recovery Phase



DATA SET:
sagerec.dat
02/13/95

AQUIFER TYPE:
Confined
SOLUTION METHOD:
Cooper-Jacob
TEST DATE:
7/13/94
TEST WELL:
Hanson Rd.
OBS. WELL:
Sage Place

ESTIMATED PARAMETERS:
T = 73.17 ft^2/min
S = 2.3021E-07

TEST DATA:
Q = 117.6 ft^3/min
r = 2400. ft

\sagerec1.wp

Hanson Road Well Aquifer Test Data
Manual Water Levels Measurements
Schuepbach, Beaverton Christian Church, and Davies Lane Wells
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study

Well	DATE	HOUR	MINUTE	DTW (FT)	WLE (FT)
Schuepbach Well (Elevation 272')	*Background*				
	06/30/94	15	35	100.15	172
	07/05/94	17	12	100.29	172
	07/07/94	12	25	100.18	172
	07/09/94	12	05	100.22	172
	07/11/94	17	30	100.24	172
	07/13/94	07	00	100.30	172
	Pumping Test				
	07/13/94	09	35	100.30	172
	07/13/94	11	10	100.28	172
	07/13/94	14	05	100.25	172
	07/13/94	15	50	100.22	172
	07/13/94	18	30	100.21	172
	07/13/94	23	13	100.25	172
	07/14/94	02	30	100.30	172
	07/14/94	05	18	100.32	172
	07/14/94	07	15	100.34	172
	DATE	HOUR	MINUTE	DTW (FT)	WLE (FT)
Beaverton Christian Church Well (Elevation 223')	*Background*				
	06/24/94	16	50	62.32	161
	06/27/94	16	50	52.12	171
	06/30/94	15	50	52.75	170
	07/07/94	10	20	66.86	156
	07/11/94	13	55	53.17	170
	07/13/94	07	50	53.15	170
	Pumping Test				
	07/13/94	09	45	52.84	170
	07/13/94	11	20	52.51	170
	07/13/94	13	50	52.72	170
	07/13/94	15	35	52.70	170
	07/13/94	18	40	96.68	126
	DATE	HOUR	MINUTE	DTW (FT)	WLE (FT)
Davies Lane Well (Elevation 299')	*Background*				
	06/16/94	15	45	129.38	170
	06/21/94	17	40	129.90	169
	06/24/94	19	30	132.55	166
	06/27/94	17	40	132.12	167
	06/30/94	16	25	129.67	169
	07/05/94	18	01	129.56	169
	07/07/94	11	55	139.34	160
	07/09/94	11	47	129.64	169
	07/11/94	17	44	129.60	169
	07/13/94	07	14	129.39	170
	Pumping Test				
	07/13/94	09	22	129.50	170
	07/13/94	10	10	129.51	169
	07/13/94	11	30	129.45	170
	07/13/94	13	30	129.52	169
	07/13/94	15	15	129.47	170
	07/13/94	15	17	129.51	169
	07/13/94	17	30	129.51	169
	07/13/94	20	17	129.52	169
	07/13/94	23	25	129.60	169
	07/14/94	02	15	129.56	169
	07/14/94	05	30	129.73	169
	07/14/94	07	58	129.64	169
	Recovery				
	07/14/94	09	40	129.73	169
	07/15/94	09	20	129.66	169

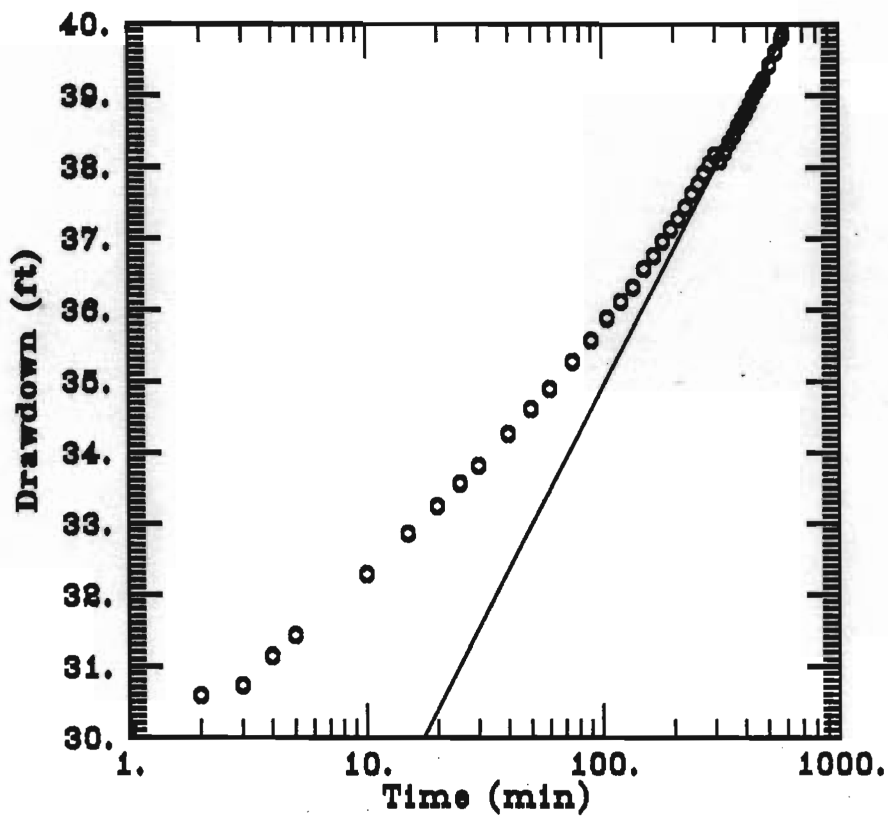
Note: DTW=Depth to water; WLE=Water level elevation (NGVD)

Schuepbach Well Aquifer Test
Data & Analyses

Schuepbach Well Aquifer Test Data	
Schuepbach Well - Pumping Data	
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study	
Pumping Started: May 3, 1995 @ 1400	
Time (min)	Drawdown (ft)
1	30.12
2	30.59
3	30.73
4	31.14
5	31.43
10	32.28
15	32.85
20	33.24
25	33.56
30	33.81
40	34.26
50	34.61
60	34.89
75	35.27
90	35.57
105	35.88
120	36.11
135	36.31
150	36.57
165	36.75
180	36.95
195	37.12
210	37.27
225	37.43
240	37.62
255	37.76
270	37.91
285	38.04
300	38.16
315	38.08
330	38.2
345	38.33
360	38.43
375	38.56
390	38.66
405	38.75
420	38.86
435	38.97
450	39.06
465	39.14
480	39.22
510	39.42
540	39.6
570	39.8
580	39.85

CH2M HILL	Client: Tualatin Valley Water Dist.
Project No.: 140249	Location: Beaverton, OR

Schuepbach Pumping Phase



DATA SET:
schpmp1.dat
05/08/95

AQUIFER TYPE:
Confined

SOLUTION METHOD:
Cooper-Jacob

TEST DATE:
May 3, 1995

TEST WELL:
Schuepbach

OBS. WELL:
Schuepbach

ESTIMATED PARAMETERS:
T = 2.926 ft^2/min
S = 0.002551

TEST DATA:
Q = 103. ft^3/min
r = 1. ft
rc = 0.58 ft
rw = 0.58 ft

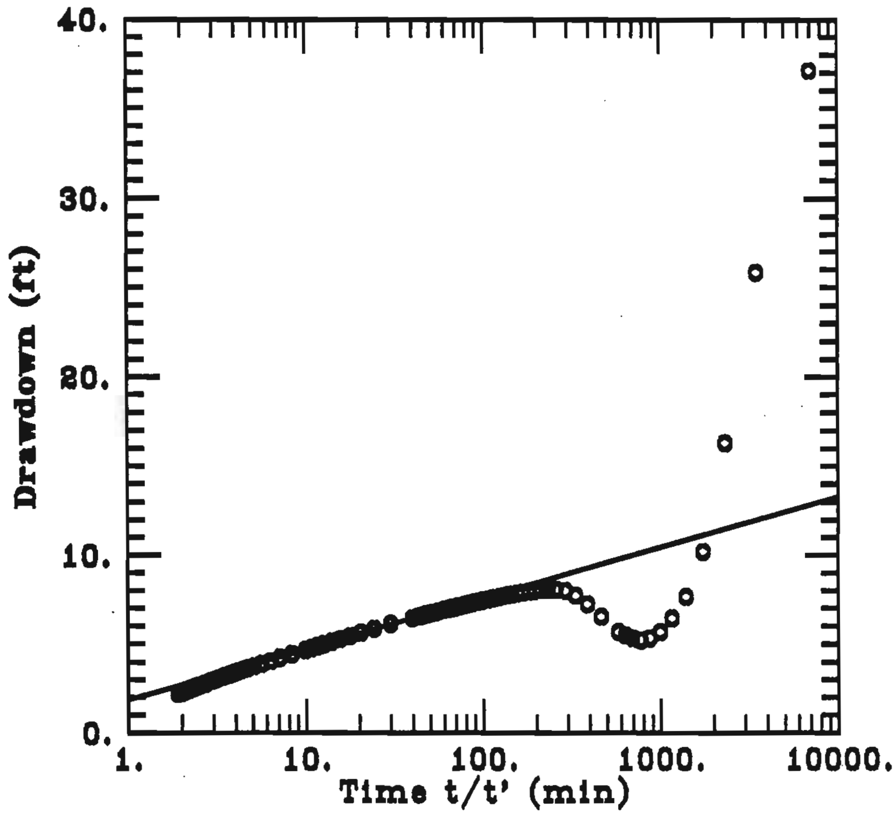
Schuepbach Well Aquifer Test Data
Schuepbach Well - Recovery Data
Tualatin Valley Water District ASR Hydrogeologic Feasibility Study

Recovery Started: May 3, 1995 @ 2340

Time (t/t')	Drawdown (ft)		Time (t/t')	Drawdown (ft)		Time (t/t')	Drawdown (ft)
6961	37.11		51.4	6.73		2	2.3
3481	25.82		49.3	6.68		2	2.27
2321	16.29		47.4	6.64		2	2.25
1741	10.18		45.6	6.6		1.9	2.23
1393	7.63		44	6.55		1.9	2.21
1161	6.42		42.4	6.51		1.9	2.19
995.3	5.65		39.7	6.43			
871	5.31		30	6.11			
774.3	5.21		24.2	5.84			
697	5.29		20.3	5.62			
633.7	5.46		17.6	5.42			
581	5.66		15.5	5.25			
465	6.51		13.9	5.13			
387.7	7.22		12.6	5			
332.4	7.71		11.5	4.88			
291	7.98		10.7	4.77			
258.8	8.04		9.9	4.67			
233	8.04		8.3	4.43			
211.9	8		7.1	4.23			
194.3	7.95		6.3	4.05			
179.5	7.92		5.6	3.9			
166.7	7.88		5.1	3.77			
155.7	7.83		4.7	3.67			
146	7.77		4.4	3.57			
137.5	7.73		4.1	3.47			
129.9	7.68		3.9	3.38			
123.1	7.62		3.7	3.3			
117	7.59		3.5	3.24			
111.5	7.53		3.4	3.17			
106.5	7.48		3.2	3.1			
101.9	7.47		3.1	3.03			
97.7	7.4		3	2.97			
93.8	7.37		2.9	2.92			
90.2	7.33		2.8	2.87			
86.9	7.29		2.7	2.82			
83.9	7.25		2.7	2.77			
81	7.21		2.6	2.73			
78.3	7.18		2.5	2.69			
75.8	7.15		2.5	2.66			
73.5	7.11		2.4	2.62			
71.3	7.08		2.4	2.58			
69.2	7.04		2.3	2.54			
67.3	7.02		2.3	2.51			
65.4	6.99		2.2	2.48			
63.7	6.97		2.2	2.45			
62.1	6.94		2.2	2.42			
60.5	6.92		2.1	2.4			
59	6.88		2.1	2.37			
56.2	6.83		2.1	2.34			
53.7	6.77		2	2.32			

CH2M HILL	Client: Tualatin Valley Water Dist.
Project No.: 140249	Location: Beaverton, OR

Schuepbach Recovery Phase



DATA SET:
schrec1.dat
05/08/95

AQUIFER TYPE:
Confined

SOLUTION METHOD:
Cooper-Jacob

TEST DATE:
May 3, 1995

TEST WELL:
Schuepbach

OBS. WELL:
Schuepbach

ESTIMATED PARAMETERS:
T = 6.598 ft^2/min
S = 3.318

TEST DATA:
Q = 103. ft^3/min
r = 1. ft
rc = 0.58 ft
rw = 0.58 ft

Appendix D
Geochemical Modeling

Appendix D
Geochemical Modeling

The Aquifer Storage and Recovery (ASR) process involves mixing recharge water and groundwater in the subsurface. The resulting change in the geochemical composition of the subsurface water within the recharge bubble may produce chemical reactions between the surrounding aquifer material and the recharge water. The geochemical model PHREEQE (Parkhurst, Thorstenson, and Plummer, 1980) was used to evaluate the compatibility of the injection water with the natural water present in the aquifer system. The geochemical computer model calculates the detailed chemical composition of water mixtures based on the general chemical composition of each water source. The model also estimates the potential for the precipitation-dissolution of solids in the mixed water zone.

Modeling Objectives

The geochemical model PHREEQE was used to simulate chemical processes initiated in the subsurface as a result of artificial recharge of the basalt aquifer. The model was used to make a preliminary assessment of the potential for clogging to occur as a result of introducing either Joint Water Commission (JWC) or City of Portland-treated water into the aquifer. Particular attention was paid to the precipitation of minerals and the release of gas from solution as a result of recharge and groundwater being mixed in the subsurface. Both mineral precipitation and degassing could reduce the effectiveness of recharging and withdrawing water from the wells in the basalt aquifer and could make the project infeasible. This effort is intended to provide an initial evaluation of whether the geochemical processes initiated by artificial recharge will have an adverse impact on the project.

The PHREEQE model was chosen for this application for three reasons. It is an established geochemical tool that has been successfully applied to a number of hydrogeologic situations. It contains a mixing option that simulates the physical processes of introducing recharge water through a well. Finally, it can be run using a personal computer with a minimum of set-up and input data. These features made PHREEQE the appropriate model because only existing water quality data were available as input. A more sophisticated model (such as EQ3) would not be appropriate for an initial assessment such as this because a more complete data set would be needed to justify the higher cost of operating the model.

Model Description

The PHREEQE model contains a library of thermodynamic equilibrium constants, atomic weights, and atomic numbers for many minerals and ions commonly found in natural waters. It uses these data in conjunction with concentrations in water that are input by the user to simulate three main types of reactions:

- The addition of reactants to a solution

- The mixing of two waters
- The titration of one solution with another

Each reaction type is described below to better illustrate the types of situations to which the model can be applied. An example is included in each description to illustrate a particular application.

The first reaction involves the addition of reactant to a solution. A simple example of this type of reaction is adding table salt to water. The concentrations of various dissolved ions of interest are input for the water and a specified amount of salt is added. The model calculates the changes in the concentrations of the dissolved chemical parameters that are the result of adding the salt. This includes a number of ion pairs that contain at least one of the components of the salt.

The second reaction simulates the mixing of two waters. As in the first option, the concentrations of various dissolved ions of interest are input for each of the two waters. The model mixes the two waters in specified ratios and calculates the beginning and final concentrations of various dissolved chemical species.

The third reaction simulated by the model involves titrating one solution with another. A titration is a procedure in which a solution of known concentration (called a standard solution) is slowly added to a second solution until a reaction between two solutes is complete (an example of a solute is table salt that has been dissolved in water). This procedure is useful in determining the concentration of a particular dissolved species in the second solution. The most commonly applied example is the procedure to determine alkalinity in a water sample.

The PHREEQE model's primary utility as a geochemical tool lies in its ability to relate the results of the simulated reaction to a number of minerals. It will calculate a parameter called the saturation index for all the applicable minerals in its library using the input data and reaction results. The saturation index is a ratio of the dissolved activities (concentrations) to the equilibrium constant. Therefore, the mixed waters are considered to be oversaturated with respect to any mineral whose saturation index is greater than 1 (making the log saturation index greater than 0) and there will be a tendency for that mineral to precipitate from solution. It provides a convenient means of evaluating whether, at equilibrium, a mineral will have a tendency to dissolve into the solution or precipitate from solution.

The model can calculate saturation indices for each reacting solution prior to simulating the reaction and then repeat the calculation for the final solution. This makes it possible to make "before" and "after" comparisons. Comparing the tendency of different minerals to precipitate as a result of artificially recharging an aquifer is the primary reason for using a geochemical model.

Model Application

The model was used to simulate mixing of two types of recharge water (JWC-treated water and City of Portland-treated water) with groundwater from two potential recharge wells (Beaverton's Hanson Road well and TVWD's Schuepbach well). Water quality data were obtained for each recharge source and the injection wells and used as input for the model. Model input files and results are attached to this appendix.

The mixing option was used to simulate artificial recharge through a well because it best approximates the actual system. Each mixing simulation evaluated mixing in three different proportions: 25 percent recharge water with 75 percent groundwater, 50 percent of each type of water, and 75 percent recharge water with 25 percent groundwater. Each mixing proportion is indicative of a different zone within the envelope of recharge water that will surround the well during subsurface storage. The rationale for choosing this approach to the mixing simulation can best be explained by considering the way in which the recharge water enters and is stored in the aquifer.

When recharge water is introduced into an aquifer through a well, it enters the aquifer at a much greater rate than the normal rate of groundwater flow. Therefore, it moves out into the formation as a slug of roughly cylindrical shape. The degree of mixing varies from very little near the well to a maximum at the outer edge of the slug. Therefore, a higher percentage of recharge water will be found in the zone near the well with an increasing proportion of native groundwater as the distance from the well increases.

Each of the three steps is intended to represent a different zone within this slug of recharge water. The first step simulated a mixture that was 75 percent groundwater and 25 percent recharge water. This represents the area on the outer edge of the expanding slug of recharge water where the two waters initially come into contact in the subsurface. The mixture in the second step was 50 percent groundwater and 50 percent recharge water, and the final simulation mixed 75 percent recharge water with 25 percent groundwater, representing the zone nearer the well where a small percentage of resident groundwater remains.

The results of the modeling effort are a list of saturation indices for all the minerals in the models library to which the input data apply. The saturation index relates the activity (concentration) of the dissolved constituents to the mineral's thermodynamic equilibrium constant. It is a convenient way of stating whether a mineral can precipitate from solution given the current measured concentrations. The results for the simulations performed for this study have been discussed in detail in the body of this report.

Attachment

Model Input Files and Results

Sample Input File

```
Portland Treated Water (August 1993) Mixed with Beaverton Hanson Road Well Water
(7/14/95)
001010000  3 0        .00000
ELEMENTS
C        10     50.04460

SOLUTION 1
Portland Treated Water (August 1993)
12 10 2      6.7000    8.0000   15.0000    1.0000
  11 .18000E+01  21 .74000E+00  19 .30000E+00  24 .16000E+01  17 .89000E-01
  22 .11000E-01  16 .25000E-01  13 .20000E+01  10 .75000E+01  23 .10000E-01
  29 .25000E+00
SOLUTION 2
Beaverton Hanson Road Well Water (7/14/95)
12 10 2      7.3200    -2.000   13.3000    1.0000
  11 .36000E+02  21 .19000E+02  19 .26000E+01  24 .12100E+02  17 .15000E-01
  22 .19000E-01  16 .12000E+00  13 .47500E+02  10 .11000E+03  23 .12000E+00
  29 .35000E+01
STEPS
   .250000   .500000   .750000
END
```

Geochemical Modeling Results

Several assumptions were made for geochemical modeling. These assumptions are as follows:

- assumed equilibrium conditions exist
- assumed that the temperature of the recharge water was 15 degrees C
- The pH for JWC recharge water is the same as the pH for Portland water (there were no data for the JWC recharge water.
- The value of 19 ppm Mn reported for both Schuepbach and Beaverton is actually 19 ppb
- artificially set the pE for recharge water at 5-6 (well oxygenated) and pE for groundwater at 0 for JWC and -2 for Beaverton. This placed the water within the Fe2+ stability field for the pH reported for Beaverton and undersaturated with respect to amorphous Fe(OH) so we could look at the effects of mixing oxygenated water with low DO groundwater. The DO data for the groundwater suggest that the pE condition for the groundwater is actually higher than the value used for the simulation, making these results conservative or tending to overestimate the potential for ppt Fe

JWC Treated Water Mixed with Beaverton Hanson Road Well Water

	Phase	Log IAP	Log KT	Log IAP/KT
JWC Recharge Water				
	Fe3(OH)8	42.9151	46.7987	-3.8836
	FeOH)2.7	16.0418	10.2444	5.7975
	Hematite	38.4101	23.3535	15.0566
	Goethite	19.2050	14.1527	5.0524
	Calcite	-10.8052	-8.4231	-2.3821
	Dolomite	-21.8651	-16.7891	-5.0760
	Gypsum	-7.7353	-4.8566	-2.8787
	Halite	-7.1753	1.5566	-8.7319
	Fe(OH)3S	19.2050	15.9544	3.2507
Beaverton Groundwater				
	Fe3(OH)8	34.4539	46.8888	-12.4349
	Fe(OH)2.7	10.1898	10.2894	-0.0996
	Hematite	26.5160	23.5823	2.9337

	Phase	Log IAP	Log KT	Log IAP/KT
Beaverton Groundwater				
	Goethite	13.2580	14.2629	-1.0049

Calcite	-9.0084	-8.4167	-0.5916
Dolomite	-18.0779	-16.7518	-1.3261
Gypsum	-7.8191	-4.8578	-2.9613
Halite	-6.2196	1.5525	-7.7720
Fe(OH)3S	13.2579	15.9994	-2.7414

25% Recharge Water and

75% Beaverton Groundwater

Fe3(OH)8	33.7746	46.8661	-13.0915
FeOH)2.7	9.9699	10.2781	-0.3082
Hematite	26.0800	23.5249	2.5551
Goethite	13.0400	14.2352	-1.1952
Calcite	-9.2710	-8.4182	-0.8528
Dolomite	-18.6120	-16.7612	-1.8508
Gypsum	-7.6094	-4.8575	-2.7519
Halite	-6.3310	1.5535	-7.8845
Fe(OH)3S	13.0399	15.9881	-2.9481

50% Recharge Water and

50% Beaverton Groundwater

Fe3(OH)8	33.0248	46.8436	-13.8188
FeOH)2.7	9.7319	10.2668	-0.5349
Hematite	25.6183	23.4676	2.1507
Goethite	12.8091	14.2076	-1.3985
Calcite	-9.6005	-8.4198	-1.1807
Dolomite	-19.2866	-16.7705	-2.5161
Gypsum	-7.5343	-4.8572	-2.6771
Halite	-6.4786	1.5545	-8.0332
Fe(OH)3S	12.8091	15.9768	-3.1677

75% Recharge Water and

25% Beaverton Groundwater

Fe3(OH)8	32.2507	46.8211	-14.5704
Fe(OH)2.7	9.5040	10.2556	-0.7516
Hematite	25.2027	23.4104	1.7923
Goethite	12.6014	14.1801	-1.5788
Calcite	-10.0461	-8.4214	-1.6246
Dolomite	-20.2118	-16.7798	-3.4319
Gypsum	-7.5556	-4.8569	-2.6987
Halite	-6.7008	1.5556	-8.2564
Fe(OH)3S	12.6013	15.9656	-3.3642

JWC Treated Water Mixed with TVWD Schuepbach Well Water

	Phase	Log IAP	Log KT	Log IAP/KT
JWC Recharge Water				
	Fe3(OH)8	42.9151	46.7987	-3.8836
	FeOH)2.7	16.0418	10.2444	5.7975
	Hematite	38.4101	23.3535	15.0566
	Goethite	19.2050	14.1527	5.0524
	Calcite	-10.8052	-8.4231	-2.3821
	Dolomite	-21.8651	-16.7891	-5.0760
	Gypsum	-7.7353	-4.8566	-2.8787
	Halite	-7.1753	1.5566	-8.7319
	Fe(OH)3S	19.2050	15.9544	3.2507
TVWD Schuepback Well Water				
	Fe3(OH)8	31.9569	46.9906	-15.0337
	Fe(OH)2.7	10.1259	10.3403	-0.2144
	Hematite	25.8713	23.8414	2.0300
	Goethite	12.9342	14.3876	-1.4533
	Calcite	-10.1229	-8.4104	-1.7125
	Dolomite	-20.3658	-16.7096	-3.6562
	Gypsum	-5.2510	-4.8591	-0.3919
	Halite	-6.0148	1.5478	-7.5626
	Fe(OH)3S	12.9313	16.0503	-3.1190
25% Recharge Water and 75% Beaverton Groundwater				
	Fe3(OH)8	32.0144	46.9422	-14.9278
	Fe(OH)2.7	10.1544	10.3161	-0.1617
	Hematite	25.9799	23.7182	2.2617
	Goethite	12.9889	14.3283	-1.3394
	Calcite	-10.3176	-8.4133	-1.9043
	Dolomite	-20.7609	-16.7297	-4.0313
	Gypsum	-5.3890	-4.8585	-0.5306
	Halite	-6.2244	1.5500	-7.7744
	Fe(OH)3S	12.9867	16.0261	-3.0394
50% Recharge Water and 50% Beaverton Groundwater				
	Fe3(OH)8	32.1889	46.8941	-14.7052
	Fe(OH)2.7	10.2268	10.2920	-0.0653
	Hematite	26.1981	23.5959	2.6022
	Goethite	13.0983	14.2694	-1.1711
	Calcite	-10.5513	-8.4164	-2.1350
	Dolomite	-21.2377	-16.7496	-4.4881

	Phase	Log IAP	Log KT	Log IAP/KT
50% Recharge Water and 50% Beaverton Groundwater				
	Gypsum	-5.5665	-4.8579	-0.7086
	Halite	-6.5046	1.5522	-8.0568
	Fe(OH)3S	13.0969	16.0020	-2.9051
75% Recharge Water and 25% Beaverton Groundwater				
	Fe3(OH)8	32.6674	46.8463	-14.1788
	Fe(OH)2.7	10.4134	10.2681	0.1453
	Hematite	26.6952	23.4743	3.2209
	Goethite	13.3472	14.2109	-0.8636
	Calcite	-10.8494	-8.4196	-2.4298
	Dolomite	-21.8525	-16.7694	-5.0831
	Gypsum	-5.8271	-4.8572	-0.9699
	Halite	-6.9433	1.5544	-8.4977
	Fe(OH)3S	13.3465	15.9781	-2.6316

Portland Treated Water (August 1993) Mixed with Beaverton Hanson Road Well Water

	Phase	Log IAP	Log KT	Log IAP/KT
Portland Treated Water				
	Fe3(OH)8	46.0839	46.7987	-0.7149
	Fe(OH)2.7	16.9741	10.2444	6.7298
	Hematite	40.5226	23.3535	17.1691
	Goethite	20.2613	14.1527	6.1086
	Calcite	-11.9449	-8.4231	-3.5218
	Dolomite	-24.0587	-16.7891	-7.2696
	Gypsum	-10.0056	-4.8566	-5.1490
	Halite	-8.4231	1.5566	-9.9797
	Fe(OH)3S	20.2613	15.9544	4.3069
Beaverton Groundwater				
	Fe3(OH)8	34.4539	46.8888	-12.4349
	Fe(OH)2.7	10.1898	10.2894	-0.0996
	Hematite	26.5160	23.5823	2.9337
	Goethite	13.2580	14.2629	-1.0049
	Calcite	-9.0084	-8.4167	-0.5916
	Dolomite	-18.0779	-16.7518	-1.3261
	Gypsum	-7.8191	-4.8578	-2.9613
	Halite	-6.2196	1.5525	-7.7720
	Fe(OH)3S	13.2579	15.9994	-2.7414
25% Recharge Water and 75% Beaverton Groundwater				
	Fe3(OH)8	35.5718	46.8661	-11.2944
	Fe(OH)2.7	10.5687	10.2781	0.2906
	Hemaitie	27.3261	23.5249	3.8012
	Goethite	13.6630	14.2352	-0.5722
	Calcite	-9.2436	-8.4182	-0.8254
	Dolomite	-18.5499	-16.7612	-1.7887
	Gypsum	-8.0099	-4.8575	-3.1524
	Halite	-6.4368	1.5535	-7.9903
	Fe(OH)3S	13.6630	15.9881	-2.3251
50% Recharge Water and 50% Beaverton Groundwater				
	Fe3(OH)8	36.1658	46.8436	-10.6778
	Fe(OH)2.7	10.7760	10.2668	0.5092
	Hematite	27.8075	23.4676	4.3399

	Phase	Log IAP	Log KT	Log IAP/KT
50% Recharge Water and 50% Beaverton Groundwater				
	Goethite	13.9037	14.2076	-0.3039
	Calcite	-9.5813	-8.4198	-1.1614
	Dolomite	-19.2280	-16.7705	-2.4574
	Gypsum	-8.2784	-4.8572	-3.4212
	Halite	-6.7325	1.5545	-8.2870
	Fe(OH)3S	13.9037	15.9768	-2.0731
75% Recharge Water and 25% Beaverton Groundwater				
	Fe3(OH)8	36.4061	46.8211	-10.4150
	Fe(OH)2.7	10.8746	10.2556	0.6191
	Hematite	28.0993	23.4104	4.6888
	Goethite	14.0496	14.1801	-0.1305
	Calcite	-10.1578	-8.4214	-1.7364
	Dolomite	-20.3890	-16.7798	-3.6092
	Gypsum	-8.7224	-4.8569	-3.8655
	Halite	-7.1973	1.5556	-8.7528
	Fe(OH)3S	14.0496	15.9656	-1.9160

Portland Treated Water (August 1993) Mixed with TVWD Schuepbach Well Water

	Phase	Log IAP	Log KT	Log IAP/KT
Portland Treated Water				
	Fe3(OH)8	46.0839	46.7987	-0.7149
	Fe(OH)2.7	16.9741	10.2444	6.7298
	Hematite	40.5226	23.3535	17.1691
	Goethite	20.2613	14.1527	6.1086
	Calcite	-11.9449	-8.4231	-3.5218
	Dolomite	-24.0587	-16.7891	-7.2696
	Gypsum	-10.0056	-4.8566	-5.1490
	Halite	-8.4231	1.5566	-9.9797
	Fe(OH)3S	20.2613	15.9544	4.3069
TVWD Schuepback Well Water				
	Fe3(OH)8	31.9569	46.9906	-15.0337
	Fe(OH)2.7	10.1259	10.3403	-0.2144
	Hematite	25.8713	23.8414	2.0300
	Goethite	12.9342	14.3876	-1.4533
	Calcite	-10.1229	-8.4104	-1.7125
	Dolomite	-20.3658	-16.7096	-3.6562
	Gypsum	-5.2510	-4.8591	-0.3919
	Halite	-6.0148	1.5478	-7.5626
	Fe(OH)3S	12.9313	16.0503	-3.1190
25% Recharge Water and 75% Beaverton Groundwater				
	Fe3(OH)8	33.2961	46.9422	-13.6462
	Fe(OH)2.7	10.5812	10.3161	0.2651
	Hematite	26.8425	23.7182	3.1242
	Goethite	13.4202	14.3283	-0.9081
	Calcite	-10.3372	-8.4133	-1.9239
	Dolomite	-20.7970	-16.7297	-4.0673
	Gypsum	-5.4027	-4.8585	-0.5443
	Halite	-6.2216	1.5500	-7.7716
	Fe(OH)3S	13.4180	16.0261	-2.6081
50% Recharge Water and 50% Beaverton Groundwater				
	Fe3(OH)8	34.3762	46.8941	-12.5179
	Fe(OH)2.7	10.9546	10.2920	0.6625
	Hematite	27.6768	23.5959	4.0809

	Phase	Log IAP	Log KT	Log IAP/KT
50% Recharge Water and				
50% Beaverton Groundwater				
	Goethite	13.8377	14.2694	-0.4317
	Calvite	-10.6106	-8.4164	-2.1942
	Dolomite	-21.3472	-16.7496	-4.5976
	Gypsum	-5.6054	-4.8579	-0.7476
	Halite	-6.4972	1.5522	-8.0495
	Fe(OH)3S	13.8362	16.0020	-2.1658
75% Recharge Water and				
25% Beaverton Groundwater				
	Fe3(OH)8	35.7088	46.8463	-11.1375
	Fe(OH)2.7	11.4225	10.2681	1.1544
	Hematite	28.7627	23.4743	5.2884
	Goethite	14.3810	14.2109	0.1701
	Calcite	-11.0204	-8.4196	-2.6008
	Dolomite	-22.1724	-16.7694	-5.4030
	Gypsum	-5.9285	-4.8572	-1.0712
	Halite	-6.9278	1.5544	-8.4822
	Fe(OH)3S	14.3802	15.9781	-1.5979