HARTCROWSER

Earth and Environmental Technologies

Yacolt Hydrogeologic Study
Yacolt, Washington

Prepared for
The Town of Yacolt

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EXECUTIVE SUMMARY

This report presents the findings of the Yacolt Hydrogeologic Study conducted between December 1994 and December 1995. The principal objectives of the study were to evaluate physical hydrogeologic conditions and existing groundwater quality in the Town of Yacolt's water supply aquifer (Yacolt Aquifer) to assist the Town of Yacolt and Clark County in determining whether upgrading the Town's wastewater treatment method from on-site septics to sewer and a wastewater treatment plant is warranted. The primary findings of the study were as follows:

- During most of the year, a groundwater divide exists in the Yacolt Aquifer beneath the Town. Groundwater flows from the divide to the north toward Cedar Creek and to the south down the valley. During the driest month(s), the groundwater divide disappears and flow is toward the south from Cedar Creek.

- Cedar Creek is in direct hydraulic connection with the Yacolt Aquifer throughout the year. For most of the year, Yacolt and Weaver Creeks are in connection with the aquifer only in the southern portion of the valley. As the water table rises during the wet season, more of the creeks' upstream lengths come into contact with the water table.

- Previous delineations of the Wellhead Protection Area (WHPA) being principally east and west of the Town's water supply wells, with inclusion of the upland surface water drainage areas east and west of the valley for management purposes, is appropriate. Inclusion of the area north of Cedar Creek is likely overly conservative. With the benefit of a better understanding of groundwater flow directions, the Town water supply wells' capture zones are less extensive than previously determined.

- Groundwater quality beneath the Town meets drinking water standards, but does show impact attributable to septic discharge. Nitrate concentrations detected in the Town's water supply wells haven't changed appreciably over the period of monitoring since 1984 even though the Town's population has increased approximately 50 percent in that time. Therefore, groundwater quality should pose no threat to public health for the near future.

- A predictive water quality assessment indicates that only modest additional growth can occur within Yacolt's Urban Growth Boundary before exceeding the calculated site-specific enforcement limit under the state Ground Water Quality Standards (GWQS). Because the GWQS are more stringent than health-based drinking water standards, violation

of the GWQS serves only as indicator of water quality degradation and does not indicate a health risk.

- Assuming current projections for residential growth in Yacolt are reasonable, our evaluations indicate that transition from individual septics to sewer with a centralized wastewater treatment plant would offset predicted potential water quality impacts. Because existing groundwater quality is acceptable for drinking water and should remain so, Yacolt should have a reasonable time horizon of several years to complete a transition from septic to sewer.

- In the event that Yacolt does transition to sewer, the GWQS would require that effluent from a wastewater treatment plant (WWTP) be treated adequately such that it would not degrade groundwater quality upon discharge. Therefore, its location could be based on logistical considerations rather than potential impacts to the Town's wells. Use of a WWTP would not adversely impact the amount of recharge to the Yacolt Aquifer, since septic discharge represents only a small portion of the overall recharge.

- The existing monitoring wells installed for this study can be maintained for future water level and water quality monitoring in the Town's water supply aquifer. Although MW-2 did go dry during the driest months of the study, it remains a useful monitoring point throughout most of the year. In the event that the wells interfere with future construction or other activities, they would need to be decommissioned by a licensed well driller in accordance with Chapter 173-160-560 WAC (Abandonment of Resource Protection Wells).

YACOLT HYDROGEOLOGIC STUDY
YACOLT, WASHINGTON

INTRODUCTION

The Town of Yacolt is a small community located in northeastern Clark County, Washington, roughly 15 miles northeast of Vancouver, Washington (Figure 1). The Town is situated within an intermontaine valley (Yacolt Valley) of the Cascade Mountain foothills. Approximately 860 persons currently reside within the Town corporate limits (Paul Grooms, personal communication, December 1995). An additional approximately 130 persons reside within the valley outside of (principally south of) the Town limits (Clark County Neighbors [CCN], 1993).

The Yacolt Valley extends nearly six miles north to south, from the Town of Amboy roughly 3 miles northwest of Town limits to the confluence of Yacolt Creek with the East Fork of the Lewis River. The valley width is on the order of one mile. The focus of this hydrogeologic study was the portion of the valley from the Town of Yacolt south to Yacolt Creek's confluences with Weaver and Big Tree Creeks, as shown on Figure 2. The valley floor within the study area is relatively flat, and the Town is located on a topographically high portion of the valley floor (surface elevations typically between 700 and 715 feet above mean sea level). The topography north of the Town slopes to the north toward Cedar Creek; south of the Town, the topography slopes gently to the south (Figure 2).

Since 1984, the Town of Yacolt has obtained its entire water supply from four wells located within Town limits and producing from a relatively shallow, unconfined aquifer (Yacolt Aquifer) within unconsolidated sand and gravels which overlie a bedrock basement. These wells also provide water supply to unincorporated areas outside of Town limits located within the Yacolt Water Service Area. The valley floor is relatively flat and is covered with a veneer of high-permeability (gravelly) soils; therefore, the valley's sole source water supply (Yacolt Aquifer) is susceptible to contamination from surface sources. Wastewater treatment in the study area is accomplished using individual on-site septic systems. Septic discharge represents a possible threat to groundwater quality in the Yacolt Aquifer. Water quality monitoring of the Town's water supply wells has indicated no chemicals attributable to septic discharge at concentrations above drinking water standards. However, substantial growth is possible in Yacolt over the next decade. Increased population with corresponding increased numbers of septic systems raises concerns regarding future adverse impacts to groundwater quality.

Study Objectives

This report presents findings of the Yacolt Hydrogeological Study completed over a one-year period between December 1994 and December 1995. The objectives of the study were to:

- Further refine the understanding of hydrogeologic conditions and groundwater quality in the vicinity of the Town of Yacolt and immediately surrounding area (study area);
- Determine if groundwater quality has been impacted by existing development (septic systems) in the study area;
- Assess whether projected future residential development can be accommodated on septic without degradation of existing groundwater quality; and
- Provide generalized recommendations on the need for a centralized wastewater treatment plant to accommodate projected growth in the study area and considerations for locating a centralized plant to minimize the chance for impacts to the water supply caused by discharge of treated wastewater.

Scope of Work

Specific activities completed as part of the Yacolt Hydrogeologic Study included:

- Installation, development, and survey of three groundwater monitoring wells within the Town limits (Figure 2). The wells were drilled by Redinger Drilling Inc., of Battle Ground, Washington, using air rotary drilling methods. Monitoring well MW-2 was dry during the driest months of the study. MW-2 was the first well drilled and the water level at the time of drilling (ATD) was interpreted to be at a depth of about 23 feet below grade. After the well was installed, the water level in the well was measured at about 34 feet below grade, indicating that the ATD water level was erroneous or possibly represented a localized zone of perched water above the aquifer. The boring logs and well construction data for the three new monitoring wells are provided in Appendix A.
- Installation and survey of four stream staff gages to monitor surface water elevations in creeks bounding the study area (Figure 2);

- Monthly monitoring of water levels in the three monitoring wells, four Town water supply wells, three domestic wells, and four staff gages;

- Quarterly groundwater sampling in three monitoring wells and one domestic well and laboratory analysis for a suite of chemicals to identify potential impacts from septic discharges;

- Synthesis and evaluation of hydrogeologic data collected during this and previous studies to refine the understanding of aquifer geometry, permeability characteristics, and seasonal fluctuations in groundwater levels, groundwater flow directions, and groundwater/surface water interactions;

- Refinement of existing delineations of the portion of the Yacolt Aquifer supplying water to the Town's water supply wells (capture zone evaluation);

- Review of groundwater quality data to evaluate existing impacts to groundwater quality from existing land use in the study area;

- Assessment of potential future water quality impacts associated with increased residential development density using conventional septic systems;

- Development of general recommendations on the need for a wastewater treatment plant to accommodate projected growth without unacceptable degradation of existing groundwater quality. Considerations for locating a centralized plant are also provided; and

- Preparation of this report to summarize the data collection and technical evaluations completed for the study.

The Yacolt Hydrogeologic Study was funded under a Community Development Block Grant (CDBG) from the U.S. Department of Housing and Urban Development (HUD) through the Clark County CDBG Program.

Previous Investigations

A regional investigation of hydrogeologic conditions in Clark County was conducted by the USGS in 1964 (Mundorff, 1964). The USGS, in cooperation with the Intergovernmental Resource Center of Clark County, also prepared a regional assessment of groundwater quality conditions in Clark County (Turney, 1988). Evaluations of local groundwater conditions in Yacolt have been conducted to assess and remedy problems with the

Town's (previous) water supply wells (Sweet Edwards and Associates, 1983; Carr/Associates, 1986 and 1990). The available information from these reports was used to help delineate the wellhead protection area for the Town's water supply wells (AGI, 1992) and prepare a Wellhead Protection Plan for the Town of Yacolt (CCN, 1993).

Report Organization

Following this introductory section, the report is organized into the following sections:

- **HYDROGEOLOGIC CONDITIONS**
- **SCREENING-LEVEL CAPTURE ZONE EVALUATION**
- **EXISTING GROUNDWATER QUALITY**
- **IMPLICATIONS OF STUDY FINDINGS REGARDING A WASTEWATER TREATMENT FACILITY**
- **REFERENCES**

Tables and figures are provided at the end of the text listing and illustrating the findings of this study. Supplemental data are presented in Appendix A - Boring Logs and Construction Data for Monitoring Wells MW-1, MW-2, and MW-3, and Appendix B - Laboratory Certificates of Analysis, Coffey Laboratories, Inc.

Acknowledgements

The Town of Yacolt assisted in completion of the Yacolt Hydrogeologic Study. Special recognition to Paul Tester, Yacolt's Public Works Supervisor, who was instrumental in collecting field data and providing logistical support throughout the year-long study and abundant information on local conditions. Thanks also to Jack Witt, Eugene Slonniker, and the Swendsens for allowing access to monitor their private wells during the study. Redinger Drilling Inc. of Battle Ground, Washington, contracted with the Town of Yacolt to drill, install, and develop the three new monitoring wells for the study. Bickford-Mursell Surveying of Vancouver, Washington, completed the elevation survey of the three new monitoring wells, four new staff gages, and one private domestic well. Coffey Laboratories, Inc., of Portland, Oregon, completed all chemical analyses for the study.

HYDROGEOLOGIC CONDITIONS

Surface Water

The Yacolt Valley within the study area is bounded by creeks—Cedar Creek to the north, Yacolt Creek to the west, and Weaver and Big Tree Creeks to the east and southeast (Figure 2). The confluence of Yacolt Creek with Weaver and Big Tree Creeks represents the southern limit of the study area. Cedar Creek is a relatively old drainage, flowing within a deeply incised, meandering channel. Conversely, the other three creeks flow within shallower, straighter channels, and are inferred to be younger drainages.

A surface water divide occurs along the northern edge of the Town limits. To the north and northeast of the Town, surface water drains toward Cedar Creek. Drainage within the Town limits, and west and south of it, is toward Yacolt Creek. Weaver and Big Tree Creeks drain the easternmost portion of the valley. Yacolt Creek discharges to the East Fork of the Lewis River, roughly 2,000 feet south of its confluence with Big Tree Creek.

Geology of the Yacolt Valley (Summarized from Mundorff, 1964)

The Yacolt Valley occupies a faulted bedrock basin formed by relative vertical movement along a major north-south-trending structural fault located along the western edge of the valley (along Yacolt Creek). During extensional faulting in the region, the bedrock block underlying Yacolt slipped downward relative to the block forming the adjacent western uplands. The bedrock consists of Tertiary-aged volcanic rocks (andesite) and sedimentary rocks (e.g., shale). Data from drilling suggest the bedrock surface beneath the valley dips gently toward the south (as does the surface topography).

During the Pleistocene, the valley was filled with unconsolidated sediments of fluvial (stream deposits) and glaciofluvial (stream deposits from glaciers) origin. Prior to glaciation, the East Fork Lewis River flowed northward up the Yacolt Valley. During that time, river alluvium (sands, gravel, and some silt overbank deposits) was deposited over the bedrock valley. The maximum advance of glacial ice down the Lewis River valley (several miles north of Yacolt) from the Mount St. Helens/Mt. Adams area subsequently covered Yacolt and most of the adjacent uplands. The ice diverted the drainage course of the East Fork Lewis River from its pre-glacial northerly course through the Yacolt Valley to its present easterly course south of the valley. Glacial meltwater streams from the glacier reworked the existing fluvial deposits and deposited additional glaciofluvial outwash materials (sands and gravels with variable amounts of silt). The surficial (youngest) deposits in some portions of the valley consist of an unsorted bouldery till-like material.

The unconsolidated valley sediments consist of a variable mixture of gravel and sand with variable percentages of silt. There are few distinct lithologic units discernable within the sediments using the available information. One exception is a cobbly gravel zone observed overlying bedrock at Town water supply well Nos. 4, 5, and 6, which appears to become thinner and finer grained toward the east. This zone, interpreted as possibly being an ancient alluvial fan deposit (Carr/Associates, 1986), has been differentiated as the "Gravel Aquifer" in CCN (1993). For this report, we include these deposits as part of the Yacolt Aquifer (discussed below).

Figures 3 and 4 are subsurface cross sections across the study area. The cross section locations are shown on Figure 2.

Information from wells drilled in the study area indicates that the total thickness of unconsolidated sediments in the valley ranges from 60 to 120 feet. The valley sediments are inferred to thin toward the south end of the valley (Figure 3). Although relatively few wells have encountered bedrock, progressively greater thicknesses of unconsolidated materials were observed in wells located from east to west across the middle of study area, suggesting that the fault block under the valley may be tilted toward the west (Figure 4).

Aquifer Occurrence and Characteristics

<u>*Yacolt Aquifer*</u>

An unconfined (water table) aquifer, herein referred to as the Yacolt Aquifer, occurs within the unconsolidated valley sediments underlying the Yacolt Valley. As stated above, the valley sediments are comprised of a variable assemblage of gravel, sand, and silt. Thus, the Yacolt Aquifer is likewise expected to have variable characteristics across the valley. Based on the available information, there is no consistent low-permeability (e.g., silt) unit observed within the valley sediments which would act to significantly impede groundwater flow. As a result, all portions of the valley sediments appear to be in hydraulic connection and act as a single hydrostratigraphic unit. Town water supply well Nos. 4, 5, and 6 are completed in a productive coarse gravel zone, which has been differentiated as a distinct aquifer unit in other reports (CCN, 1993). However, because the zone does not appear to be hydraulically isolated from the surrounding unconsolidated valley sediments, it is included as part of the Yacolt Aquifer, for the purposes of this report. The Yacolt Aquifer provides potable water to the Town of Yacolt, Yacolt Water Service Area, and shallow domestic wells across the valley. Therefore, this study focused solely on the Yacolt Aquifer; however, a brief discussion of the Bedrock Aquifer is provided below.

Seasonal Water Table Fluctuations. The water table depth in the Yacolt Aquifer is variable, dependent both on location in the valley and seasonality. For example, depth to water ranged seasonally from a minimum of about 45 to a maximum of 70 feet at Town Well No. 5 in the northern portion of the study area. Depth to water ranged seasonally from about 6 to 22 feet at Domestic Well D (Witt's) in the southern portion of the valley (Figure 2). Water level data collected during this study are presented in Table 1. Figure 5 presents hydrographs (water level elevations over time) for the wells monitored during the study, which demonstrate the substantial seasonal fluctuations in water table elevations. Carr/Associates (1990) presented longer-term hydrographs for Town Well Nos. 3 through 6 which spanned seven years (1983 through 1989) and demonstrated seasonal water table fluctuations up to 28 feet. These data also indicate that recharge to the Yacolt Aquifer occurs rapidly following major precipitation events in November and December. Typically, most of the wet-season water level recovery occurs in only a two-month period between mid-November and mid-January. Water level decline in the aquifer occurs more gradually, typically from March or April until early November (Figure 5).

Hydraulic Conductivity Estimates. Eleven hydraulic conductivity estimates for the Yacolt Aquifer were derived from existing information collected during pumping tests conducted in the Town's water supply wells (Table 2). Except for one, the estimates were derived from specific capacity data (pumping rate in gpm/drawdown in feet) using the following empirical relationship developed from theoretical well hydraulic equations (Driscoll, 1986):

Transmissivity (T) in gpd/ft = 1,500 * specific capacity in gpm/ft

The hydraulic conductivity (K) is then calculated from the transmissivity and initial saturated aquifer thickness (H) as follows:

K in cm/sec = (T / H) * 4.72 x 10^{-5} (cm/sec)/(gpd-ft^{2})

In addition to the estimates from specific capacities, the driller's log for Town Well No. 1 (since decommissioned) provided adequate data from a recovery test to estimate transmissivity using a more rigorous, theoretical method (plotting residual drawdown versus a dimensionless recovery time ratio, t/t'; refer to Driscoll, 1986). This estimate was generally consistent with the other estimates from this well, but was slightly higher, likely because the specific capacity-based estimates include a component of well loss which lowers the transmissivity estimates.

The hydraulic conductivity estimates for the Yacolt Aquifer range from 2×10^{-3} to 5×10^{-1} cm/sec. The range of values is consistent with moderately permeable slightly silty sands to highly permeable gravels, and the two order-of-magnitude range is indicative of the variability in sediments comprising the aquifer. As expected, the coarse gravelly materials, which Town Well Nos. 4, 5, and 6 produce from, is the most permeable portion of the Yacolt Aquifer (for which data are available), with all estimated hydraulic conductivities above 10^{-1} cm/sec. Using these 11 estimates, the average (geometric mean) hydraulic conductivity for the Yacolt Aquifer is 4×10^{-2} cm/sec (Table 2), which represents a reasonable value for the aquifer as a whole.

Bedrock Aquifer

The bedrock underlying the Yacolt Aquifer also serves as a water supply for some wells in the valley. Available information indicates that water from the bedrock is highly mineralized, presumably requiring some treatment for potable uses. Limited available water level data from bedrock wells indicate artesian pressure in the bedrock, and higher water levels than in the overlying Yacolt Aquifer (i.e., upward hydraulic gradients). These data suggest the bedrock may provide some recharge through fractures to the Yacolt Aquifer. As mentioned above, this study did not include evaluation of the Bedrock Aquifer.

Domestic well A (Slonniker) is screened partially in bedrock (Figure 3). As a result, water levels in this well show anomalously small seasonal fluctuations (Figure 5), and somewhat high water level elevations than expected, relative to the other wells screened solely in the Yacolt Aquifer. Because this well does not appear to be representative of groundwater conditions in the Yacolt Aquifer, water level data from this well were not included in evaluations for this study.

Groundwater/Surface Water Interactions

The groundwater and surface water monitoring data indicate that Cedar Creek and the southern portions of Yacolt and Weaver Creeks are in direct hydraulic connection with the Yacolt Aquifer. As the water table rises during the wet season, longer reaches of both Yacolt and Weaver Creeks come into direct connection with the aquifer, but it appears improbable that the upper reaches of either creek are ever in direct connection with the water table. Figure 6 provides hydrographs for selected wells in the Town limits and for staff gages SG-1 on Cedar Creek north of Town and staff gage SG-3 on Yacolt Creek just west of Town (locations shown on Figure 2).

The hydrographs demonstrate that the water table surface near the north end of Town (e.g., at well No. 5) falls below the level of Cedar Creek at the driest time of the year (mid-September through mid-November). Furthermore, springs have been observed along Cedar Creek during the wet season, indicating groundwater discharge to the creek (Carr/Associates, 1990). This combined information confirms that Cedar Creek is incised deeply enough to be in connection with the Yacolt Aquifer. Cedar Creek receives groundwater discharge from the aquifer for most of the year, and recharges the aquifer for a short period during the peak dry season.

The hydrographs further show that Yacolt Creek at SG-3 remains at least 3 feet above the water table measured in the nearest well (No. 3) during the highest measured water table condition (Figure 6). [Regarding Figure 6, note that MW-3 is on the other side of the valley from SG-3 and is not representative of water table conditions near SG-3.] Weaver Creek at SG-2 similarly remains at an elevation greater than 700 feet throughout the year (Table 1). Yacolt Creek at SG-4 in the south end of the study area had the lowest measured groundwater or surface water elevation measured in each monitoring round, suggesting that the aquifer discharges to Yacolt Creek, and likely also to Weaver Creek, in the south end of the valley.

The available data suggest that both Yacolt and Weaver Creeks are losing streams year-round in their upper reaches—likely recharging the Yacolt Aquifer by infiltration through their creek beds (unsaturated flow). Recharge/discharge relationships between the aquifer and creeks in their middle reaches are uncertain and likely vary seasonally. The Yacolt Aquifer appears to discharge year-round to Yacolt Creek, and possibly Weaver Creek, near their confluence at the south end of the study area.

Recharge to the Yacolt Aquifer

The primary sources of recharge to the Yacolt Aquifer is a combination of vertical infiltration of precipitation across the valley floor and lateral recharge from the adjacent uplands. Septic discharge also provides a small component of recharge to the Yacolt Aquifer. Estimated quantities of recharge and their relative contributions to total recharge are presented in Table 3.

Empirical Estimate of Total Annual Recharge to Aquifer. To assess relative contributions of the various recharge sources, the total volume of aquifer recharge was estimated empirically. For this evaluation, the length and width of the Yacolt Aquifer within the study area were assumed to be 12,000 and 5,000 feet, respectively (Figure 2). An average annual water level rise of 24.5 feet was assumed, which is the average of maximum water table fluctuations measured in nine Yacolt Aquifer wells during this study. The water table fluctuations observed in the Town water supply wells during the 1995 study (24 to 27 feet) were in the range of those observed during the 1983 through 1989 monitoring period (Carr/Associates, 1990), indicating 1995 was an average year. Assuming a porosity of 0.3 based on literature values, the total annual recharge to the Yacolt Aquifer in the study area is on the order of 441 million (4.41×10^{-8}) cubic feet (4.41E+08 in Table 3).

Recharge from Precipitation. Using precipitation data collected by the Town of Yacolt, Carr/Associates (1990) conducted a water balance evaluation (Thornthwaite method) covering a period of seven years (1983 through 1989). The Thornthwaite method estimates what portion of monthly precipitation is potentially available for recharge after accounting for losses resulting from evapotranspiration. Table 3 summarizes the estimates of annual recharge in inches/year. From this evaluation, the average annual recharge rate is 61 inches per year (about 70 percent of annual precipitation), which is quite high. Applying this infiltration across the 12,000 foot by 5,000 foot aquifer surface area indicates direct precipitation infiltration provides approximately 306 million (3.06×10^{8}) cubic feet of recharge per year, which is about 70 percent of the total estimated annual recharge to the aquifer (3.06E+08 in Table 3). Precipitation infiltration providing the major component of aquifer recharge is consistent with the rapid rate of aquifer recharge observed following the onset of winter rains, as discussed above.

Recharge from Septic Discharge. Because on-site septic systems are used to treat wastewater in the valley, septic discharge provides some recharge to the Yacolt Aquifer. For this evaluation, an average per capita wastewater discharge rate of 44 gal/day was assumed (EPA, 1992). Assuming a current population within the Town limits of 860 persons (Paul Grooms, personal communication, December 1995) and 130 persons residing outside the Town limits but inside the study area (CCN, 1993), on-site septics provide on the order of 2.1 million (2.13×10^{6}) cubic feet of recharge per year (2.13E+06 in Table 3). This volume represents approximately 0.5 percent of the total estimated annual recharge to the Yacolt Aquifer.

Recharge from Adjacent Upland Areas. The Yacolt Valley receives surface water runoff from large watersheds in the adjacent uplands areas east and west of the valley. Similarly, available information indicates that the Yacolt Aquifer receives recharge water from the adjacent uplands, likely through a combination of surface water infiltration (via the creeks) and lateral flow from weathered bedrock on the valley walls or through bedrock fractures. Groundwater in the vicinity of the Town of Yacolt flows from the east and west edges of the valley toward the center of the valley (discussed below), further suggesting the upland areas as recharge areas. Although it would be difficult to accurately quantify this component of recharge, it can be approximated roughly for the purposes of this evaluation as the residual quantity of total aquifer recharge not accounted for by the sum of precipitation infiltration and septic discharge. By this method, recharge from the adjacent uplands is approximated as 132 million (1.32×10^8) cubic feet per year, or 30 percent of the total aquifer recharge (1.32E+08 in Table 3).

Groundwater Flow and Hydraulic Gradients in the Yacolt Aquifer

Groundwater Flow Directions

The three monitoring wells installed for this study provided the necessary additional water level monitoring control to better define previously uncertain groundwater flow directions in the Yacolt Aquifer, and their seasonal fluctuations. Water levels were monitored monthly throughout the study in nine wells completed in the Yacolt Aquifer (Table 1). For personnel and laboratory scheduling reasons, the July monitoring round was conducted on June 26, 1995. Seven of the nine wells are located within Town limits, and two of the wells are south of Town.

Figures 7, 8, and 9 show water table elevation contours and inferred groundwater flow directions for the Yacolt Aquifer for three seasonal conditions—January 1995 (wet season maximum water levels), July 1995 (declining water levels), and October 1995 (dry season minimum water levels).

Throughout most of the year, groundwater flow directions in the Yacolt Aquifer appear to be relatively consistent. From December through August, the water table surface beneath the Town forms a saddle—higher near the recharge areas east and west of Town and sloping away on both the north and south edges of Town (Figures 7 and 8). As a result, groundwater flows from both east and west of Town toward the central portion of Town and then diverges either to the north toward Cedar Creek or to the south down the valley, as indicated on Figures 7 and 8. The available data indicate that the localized east-west trending groundwater divide is near the center of the Town limits.

South of Town, groundwater flows generally toward the south, i.e., down the valley. More precise determinations of flow directions in the southern portion of the valley are not possible with the two wells monitored during this study. However, assuming that Yacolt and Weaver Creeks in this portion of the valley are in hydraulic connection with the water table (as discussed above), lines of equal elevation drawn between the creeks indicate a slope toward the southeast. Because groundwater is relatively shallow in this area and the water table slope is likely to mimic the topographic slope, groundwater in the southern portion of the valley is inferred to flow generally toward the southeast, as indicated on Figures 7 and 8.

During the driest month(s) (lowest water table), the groundwater divide beneath the Town disappears and the typical groundwater flow direction toward Cedar Creek reverses to be away from Cedar Creek (Figure 9). During the minimum water level condition, the water table remains higher east and west of Town than in the Town center, and Cedar Creek is also higher than the water table in the Town center. Therefore, groundwater flows from the west, north, and east toward the south. Cedar Creek remains at a level above the adjacent water table only between approximately mid-September and mid-November; therefore, this groundwater flow direction reversal is of similarly limited duration, and there is little net recharge to the aquifer from Cedar Creek.

Hydraulic Gradients

The monitoring data collected during this study indicate that the slope of the water table is fairly gentle through most of the Yacolt Aquifer. Horizontal hydraulic gradients (water table slopes) are particularly flat beneath the Town throughout the year, including during the dry seasonal reversal. Further south in the valley, hydraulic gradients appear to steepen somewhat.

Using the water table contour maps provided on Figures 7, 8, and 9, hydraulic gradients measured between the south end of the Town limits (MW-2 and Town Well No. 3) and Domestic well D in the southern portion of the valley were 0.0053, 0.0038, and 0.0025 ft/ft (January, July, and October 1995, respectively). These data indicate that the water table slope flattens somewhat from wet to dry seasons, consistent with wet season recharge concentrated near the northern end of the valley (including recharge from the uplands). As the recharge subsides, the water table drops more in the northern valley than in the south. The highest gradients observed in the study area occur where groundwater discharges to Cedar Creek. Gradients measured between the Town's water supply wells and

SG-1 in Cedar Creek were 0.025 and 0.0095 ft/ft in January and July 1995, respectively.

Groundwater Flux and Discharge

Using the estimates of hydraulic conductivity and hydraulic gradient discussed above, we estimated the horizontal groundwater flux through the Yacolt Aquifer. Because of the groundwater divide present for most of the year, fluxes north and south of the Town limits were estimated. Table 4 provides three approximations of groundwater fluxes corresponding to seasonal conditions observed during January, July, and October 1995 (wet, declining, and dry seasons conditions, respectively). Groundwater flux was estimated by applying Darcy's Law of the form:

$$Q = K * i * w * H * 450$$

where

Q =	Volumetric groundwater flux in gpm;
K =	Hydraulic conductivity in cm/sec;
i =	Horizontal hydraulic gradient in ft/ft;
w =	Average aquifer width in feet;
H =	Average aquifer saturated thickness in feet; and
450 =	Units conversion factor from cfs to gpm.

Assumptions for this evaluation were as follows:

- Hydraulic conductivity (K) was assumed to be 4 x 10^{-2} cm/sec, the average value for the aquifer based on available data (Table 2);

- Hydraulic gradients (i) of 0.0053, 0.0038, and 0.0025 ft/ft were measured south of the Town for January, July, and October 1995. North of the Town, gradients were 0.025 and 0.0095 ft/ft for January and July 1995 (discussed above);

- Average aquifer width (w) was assumed to be 5,000 feet; and

- Average aquifer saturated thickness (H) in the approximate middle of the valley south of Town was assumed to be the difference between the measured water table elevation at Domestic Well C and the assumed bottom of the Yacolt Aquifer (elevation 585 feet; Figure 3). Average aquifer thickness north of Town was estimated as the difference between the measured water table elevation at Well No. 5 and the observed bottom of the aquifer at elevation 615 feet.

The evaluation indicates that total groundwater flux in the Yacolt Aquifer decreases dramatically from a maximum of about 5,300 gpm when water levels are at their seasonal maximum to about 400 gpm when water levels are at their minimum. The higher measured hydraulic gradients north of Town result in higher estimated flows of groundwater toward the north than toward the south (Table 4).

SCREENING-LEVEL CAPTURE ZONE ASSESSMENT

Capture Zone Assessment Method

Simplified numerical groundwater modeling of the Yacolt Aquifer was conducted to provide a screening-level assessment of the Town of Yacolt's water supply wells' capture zones. A capture zone is that portion of the aquifer contributing flow to a well. The capture zone is essentially identical to Zone of Contribution (ZOC) in Washington State's Wellhead Protection Program (WHPP; Washington State Department of Health [DOH], 1993), except that the capture zone does not extend beyond the limits of the aquifer. The ZOC should include surface water drainages which contribute directly to groundwater recharge. Previous delineations of the wellhead protection area (AGI, 1992) did not have the benefit of the additional groundwater flow direction information provided in this study.

Because the Town's wells are in close proximity to a groundwater divide (saddle) present for much of the year, local groundwater flow directions in response to the multiple wells' pumping could be complex, resulting in significant uncertainty in assessing capture zone dimensions using simple analytical models described in the WHPP (DOH, 1993). As a result, a two-dimensional, steady state, numerical groundwater flow model was developed for the Yacolt Aquifer as part of this study (using FLOWPATH; Waterloo Hydrogeologic Software, 1992). The WHPP recognizes numerical flow models as being technically superior to the simpler analytical methods; however, the models require a greater quantity of data to develop.

For this study, the most significant uncertainties in applying a numerical model to the Yacolt Aquifer are the aquifer boundary conditions. Our interpretation of hydrogeologic conditions in the Yacolt Valley includes a significant component of aquifer recharge from the uplands bordering the valley to the east and west, recharge from the upper reaches of Yacolt and Weaver Creeks, discharge to Cedar Creek for most of the year, and discharge to the lower reaches of Yacolt and Weaver Creeks. Accurate quantification of the recharge/discharge relationships (quantities and distribution of recharge/discharge at valley boundaries) is not possible with the existing data. Because of this, the aquifer boundary conditions were simplified in the model by assigning constant head boundaries to the creeks bounding the study area using measured values from the staff gages and assuming linear gradients between gages. This simplification is reasonable for the purposes of this modeling evaluation since it allows recharge from the upper reaches of Yacolt and Weaver Creeks, and discharge to those creeks' lower reaches and to Cedar Creek for the simulation of wet season conditions. To simulate flow conditions during the driest season conditions (flow reversal near Cedar Creek), the constant head boundary cells were removed from the upper reaches of Yacolt and Weaver Creeks in the model.

The modeling assumed that the Yacolt Aquifer had uniform hydraulic characteristics (e.g., hydraulic conductivity of 4×10^{-2} cm/sec and effective porosity of 0.25) throughout its extent. The aquifer was modeled as an unconfined aquifer with an aquifer bottom elevation of 590 feet. Steady state pumping rates of 100 gpm were assumed for each of the four water supply wells based on pumping test rates from 1990 testing (Carr/Associates, 1990).

In general, the modeling provided a reasonable simulation of wet season and dry season groundwater flow directions as determined from monitoring. The model also provided a considerable level of conservatism by assuming the Town's wells are pumped continuously (steady state), when, in fact, they are operated intermittently as needed to maintain reservoir volume. Therefore, the modeling provided a reasonable conservative screening-level evaluation of the Town Wells' capture zones. More detailed numerical modeling, including more rigorous quantification of aquifer boundary conditions, model calibration, and simulation of the wells' actual pumping schedules, could be conducted as part of future studies to further refine this evaluation if warranted.

Capture Zone Assessment Results

Figures 10 and 11 provide graphical depictions of the simulated steady-state water table elevation contours and capture zones for the Town of Yacolt's wells under wet season and dry season conditions, respectively. Under wet season conditions (Figure 10), the model reproduced the observed water table saddle present beneath the Town limits and the sloping water table north and south from the saddle. Under dry season conditions (Figure 11), flow to the south from Cedar Creek was simulated. Areas within the simulated 1- and 5-year capture zones for the wells (for continuous pumping) are depicted with shading on Figures 10 and 11.

During the wet season, the simulated capture zone from Well No. 3 extends toward the west, indicating water is supplied to the well from the recharge area west of Town, as expected. The capture zone for combined Well Nos. 4, 5, and 6 extends both to the east and to the west of Town, drawing water from both recharge sources. The modeling indicates the bulk of the water supplied to these three wells is drawn from the west; however, that may be a result, in part, of the simplified model boundary conditions. The modeling indicates that no water is drawn from Cedar Creek during wet season conditions. In addition, this modeling indicates that the wells do not draw water from the southern portion of the Town limits, or from south of Town limits.

Because the groundwater flow reversal beneath the Town is a short-term dry season condition lasting less than 3 months, 90-day capture zone areas are depicted on Figure 11. Simulated flow lines are shown extending outside of the 90-day capture zone to demonstrate simulated flow directions. During this limited time period, the areas of contribution to the wells are very limited (shaded areas on Figure 11) and mostly fall within the area encompassed by pumping during the remainder of the year (as shown on Figure 10). Although flow is directed from Cedar Creek toward Well Nos. 4, 5, and 6, water is not expected to travel from the creek to the wells during this limited time period. Once the wet season rains return, the steep gradients toward Cedar Creek return, and water which had entered the aquifer from Cedar Creek during two or three months of dry season flow likely is flushed back into the creek during the following 9 or 10 months.

In short, the appropriate wellhead protection area (WHPA) for the Town's water supply wells extends east and west of Town limits, consistent with the previous determinations (AGI, 1992; CCN, 1993). This evaluation indicates that the previous determination to extend the WHPA north of Cedar Creek may be overly conservative, since there appears to be negligible opportunity for water from Cedar Creek to be drawn by the Town's wells. Maintaining the existing WHPA boundary at the southern limit of the Town is a reasonable conservative management strategy.

EXISTING GROUNDWATER QUALITY IN THE YACOLT AQUIFER

Groundwater Sampling and Analysis

For this study, we collected four rounds of quarterly groundwater quality data for the Yacolt Aquifer from four wells—January, April, July, and October 1995. For personnel and laboratory scheduling reasons, the July monitoring round was conducted on June 26, 1995. Wells sampled included MW-1, MW-2, MW-3, and Domestic Well B (Figure 2). MW-2 was dry during the October sampling round and could not be sampled. Prior to sampling with a stainless steel bailer, three casing volumes were purged from the monitoring wells using a manually driven Brainard-Killman pump. Groundwater samples from the domestic well were obtained from a spigot at the wellhead, after allowing the well to pump long enough to remove approximately 60 to 70 gallons of water. The samples were not filtered and were collected in bottles supplied by the laboratory. Groundwater samples were analyzed for a suite of chemicals to assess potential groundwater quality impacts from septic systems. Analytes included:

- Nitrate as N;
- Nitrite as N;
- Total Kjeldahl Nitrogen;
- Chloride; and
- Sulfate.

Of these, nitrate is the most important indicator of potential septic impacts. Chloride and sulfate were analyzed to help differentiate the potential sources of the nitrate. Parameters measured in the field included temperature, pH, specific conductance, and dissolved oxygen.

The Town of Yacolt provided additional groundwater quality data from the Town's water supply wells for the period 1984 through 1995. The groundwater quality and field parameter data collected during this study are presented in Table 5. The laboratory certificates of analysis for these data are provided in Appendix B. Table 6 presents nitrate data from the Town's water supply wells for the period of record.

Analytical Results

All constituent concentrations detected in groundwater samples collected during this study were below drinking water standards (Table 5). Similarly, nitrate concentrations detected in the Town's water supply wells have always been below the MCL of 10 mg/L (Table 6).

The data indicate that groundwater quality in the Yacolt Aquifer beneath the Town has been impacted by septic systems, relative to natural water quality in hydraulically upgradient locations. Nitrate concentrations detected in wells along the upgradient edges of Town (MW-1 and MW-3) are typically an order of magnitude lower than concentrations in wells downgradient of the Town's major residential area (i.e., Town Well Nos. 3, 4, 5, and 6, MW-2, and Domestic Well B). As discussed above, Town Well Nos. 4, 5, and 6 are downgradient of the Town during most of the year.

Groundwater quality beneath the Town has been impacted by the Town's septic systems, but the existing groundwater quality poses no immediate threat to public health (maximum detected nitrate of 3.1 mg/L relative to the MCL of 10 mg/L). Nitrate concentrations detected in the Town's water supply wells show no discernable increasing or decreasing trend over the past decade even though population has increased approximately 50 percent in that time (Table 6). Nitrate concentrations measured in August 1995 were 1.8 mg/L in Well No. 3, and 1.2 mg/L in a composite sample of water from Well Nos. 4, 5, and 6.

The nitrate concentrations in the Yacolt Aquifer are attributable principally to septic discharge, rather than agricultural sources like fertilizers. Nitrate concentrations in groundwater samples from the study correlate well with chloride concentrations, but correlate poorly with sulfate concentrations. Chloride is a significant component of septic discharge which is not prevalent in other nitrate sources like fertilizers. Conversely, sulfate is prevalent in many fertilizers but not in septage. Figure 12 presents the plots of chloride and sulfate versus nitrate, with regression lines through the data. The correlation coefficients (R^2) were 0.90 for chloride versus nitrate and 0.25 for sulfate versus nitrate (Figure 12).

Nitrogen-to-sulfur molar concentration ratios further indicate septic discharge as the source of detected nitrate in groundwater. Common fertilizers (e.g., ammonium sulfate) have molar concentration ratios of nitrogen to sulfur of about 2:1, whereas the ratios in septic tank effluent are expected to be closer to 7:1 (Turney, 1990). Nitrogen-to-sulfur molar ratios for groundwater samples from downgradient wells monitored during the study (MW-2 and Domestic Well B) were in the range of 4 to 7, while the ratios in upgradient wells MW-1 and MW-3 were generally less than 1 (Table 5). Data from the Town's water supply wells were not used in this evaluation since analytical detection limits for chloride (5 mg/L) were above typical detected concentrations, and sulfate was generally not analyzed.

Evaluation of Groundwater Quality Relative to State Groundwater Quality Standards

Washington State's Ground Water Quality Standards (GWQS; Chapter 173-200 WAC) apply to any activity which has the potential to adversely impact groundwater quality. Protection of groundwater quality under the GWQS is achieved through the antidegradation policy, All Known Available and Reasonable Treatment (AKART), and human health standards. The human health standard (maximum contaminant level [MCL]) for nitrate in drinking water, defined by the federal Safe Drinking Water Act, is 10 mg/L. As applied to wastewater treatment by septic in the Town of Yacolt, the state's antidegradation policy requires:

- Maintenance and protection of groundwater as a drinking water source; and

- Because existing groundwater quality beneath the Town is better than the MCL, the existing water quality must not be degraded unless it can be demonstrated that (1) AKART is applied to the wastewater and (2) the overriding public interest will be served.

Upgradient monitoring wells MW-1 and MW-3 provide data to characterize the quality of groundwater recharging the Yacolt Aquifer beneath the Town. As discussed above, nitrate concentrations detected in these wells are consistently an order of magnitude lower than concentrations in wells representing water quality downgradient of the majority of the Town's residential septic systems. Nitrate concentrations detected in MW-1 and MW-3 are used to define natural groundwater quality in the aquifer, as per the GWQS. Using statistical procedures provided in the Final Draft Implementation Guidance for the GWQS (Ecology, 1994), the natural water quality nitrate concentration for the aquifer is calculated as 0.5 mg/L (Table 7).

Definition of Existing Groundwater Quality

Although groundwater quality impacts exist beneath the Town, the assumption is made that, to date, wastewater treatment by on-site septic systems has represented AKART in this community. Although there are alternative known wastewater treatment methods (e.g., sewer with treatment plant), such a system has not been available within Yacolt and the expense to construct one or tie into an existing system has not been reasonable, given the Town's size and rural location. Furthermore, groundwater quality has presented no threat to human health to date. Given the substantial cost of upgrading to sewer and the fact that public health has been maintained, the public interest has been served to date by use of septic systems. Therefore, for the purposes of this study, the state GWQS antidegradation policy is applied in evaluating the potential impact associated with projected future residential growth in Yacolt, and existing groundwater quality is considered as ambient (baseline) conditions.

Available data from wells MW-2, Town Well Nos. 4, 5, and 6, and Domestic Well B are used to establish existing (ambient) groundwater quality beneath the Town. Using statistical procedures provided in the Final Draft Implementation Guidance for the GWQS (Ecology, 1994), the existing nitrate concentration for the aquifer is calculated as 3.6 mg/L (Table 7). The nitrate data were determined to be normally distributed, using the Shapiro-Wilk W-Test, as specified in Ecology (1994). Comparison of this value with the 0.5 mg/L natural water quality value confirms that septic discharge associated with the existing Town development has caused a statistically significant water quality impact relative to natural conditions.

Although Domestic Well B is about 700 feet south of Town limits, it is downgradient of the Town and shows similar nitrate concentrations to wells within Town limits; thus, it is included in the definition of existing groundwater quality. Detection of elevated nitrate at this location indicates the area of impacted groundwater quality extends beyond the Town's limit. The presence or extent of elevated nitrate outside of the Town limits is uncertain because of the lack of groundwater quality data in the southern portion of the valley.

Calculation of an Enforcement Limit for Nitrate

The GWQS establish enforcement limits as numerical limits for determination of compliance with the antidegradation policy. Enforcement limits are established at levels below health-based criteria (MCLs) to protect the highest beneficial use of groundwater (i.e., drinking water for the Town of Yacolt and Yacolt Water Service Area). Using the methodology presented in the implementation guidance for the GWQS (Ecology, 1994), existing water quality is compared to the MCL and the enforcement limit is established using 10 percent of the remaining assimilative capacity of the aquifer (i.e., 10 percent of the difference between existing water quality and the MCL). The enforcement limit for nitrate as N is calculated as 4.3 mg/L, which represents a 17 percent increase from the calculated existing nitrate concentration condition (Table 7).

IMPLICATIONS OF STUDY FINDINGS REGARDING THE NEED FOR A WASTEWATER TREATMENT FACILITY

Predictive Water Quality Impact Assessment

As discussed above, existing groundwater quality beneath the Town and immediately downgradient areas has been impacted by septic discharge associated with the existing residential development. The enforcement limit calculated for nitrate under the state GWQS antidegradation policy, based on available water quality data, is 17 percent higher than existing conditions. Residential growth in Yacolt is projected to potentially increase substantially over the next decade—from the current 860 persons to 1,500 persons by the year 2006 (Paul Grooms, personal communication, December 1995). The potential for groundwater quality degradation or impacts resulting from the projected development was assessed through an analysis of nitrate releases from increased numbers of septic systems and groundwater transport. The nitrate release analysis, discussed below, provides an assessment of the change in groundwater nitrate concentration which may occur as a result of the projected development.

Predictive Assessment Methods

We based our water quality assessment on a simulation of nitrogen releases associated with increased densities of conventional on-site residential septic systems. Potential water quality degradation resulting from septic system releases of nitrogen was evaluated as a function of six primary parameters:

- Total residential area and population density within the Town of Yacolt corporate limits;
- Loading of nitrogen released to a unit development area from septic system wastewater discharge;
- The amount of recharge water (precipitation) infiltrating and migrating vertically through the soil system;
- Transport of nitrogen through the root zone and soil environment to the underlying aquifer system (including nitrogen removal and conversion of various forms of nitrogen to nitrate); and
- Dilution of recharge water (and nitrate transport) in the aquifer resulting from groundwater flow from surrounding areas and mixing with natural background aquifer nitrate concentrations.

The general equation we used to determine the concentration of nitrate in groundwater beneath the project site under the various alternative development scenarios is summarized as follows:

Local Recharge
Nitrate Concentration in mg/L = Background Nitrate Concentration in mg/L +
[Nitrogen Source Area in Acres*
Number of Persons*
Unit Nitrogen Release in kg/person-yr*
Transport Fraction (1-Removal)/
Recharge Rate (inches/yr)/
Aquifer Discharge (gpm)*
Unit Conversion Factor]

The area within the Town limits (nitrogen source area for this assessment) was assumed to be the area within the Town limits, measured to be approximately 380 acres. Numbers of persons within the Town was varied (from the current 860 persons up to the projected maximum 1,500 persons) to assess relative increases in resultant groundwater nitrate concentrations associated with each population increase. Based on literature values summarized in Gilliom and Patmont (1982), Patmont et al. (1989), and Hart Crowser (1990), the average per capita nitrogen release to a septic system in Western Washington was assumed to be 2.8 kg nitrogen per year. An average septic system nitrogen removal efficiency of 65 percent was assumed based on direct measurements from studies in Western Washington (Gilliom and Patmont, 1982; Patmont et al., 1989; Hart Crowser, 1990). Additional assumptions used in the analysis included estimates of average infiltration recharge (61 inches per year) and groundwater flux (1,900 gpm) as presented above. Background water quality was represented by the average measured nitrate concentration in groundwater recharging the aquifer beneath Yacolt (i.e., average natural water quality value of 0.14 mg/L; Table 7).

The calculated percent increases in groundwater nitrate concentrations associated with given population increases within the Town limits were compared against the enforcement limit as a preliminary predictive estimate of acceptable residential growth, in terms of compliance with the state's GWQS, within the Town limits (equivalent to Yacolt's current Urban Growth Boundary). Although there is considerable uncertainty in applying this relatively simple assessment to a complex physical and chemical environment in a predictive fashion, it provides a reasonable tool for decision making by evaluating relative groundwater quality impacts between population growth scenarios. This general methodology has been adopted by regulatory agencies in other areas of Washington State (e.g., King County) for assessing potential water quality impacts associated with planned land use options.

Predictive Assessment Results

The results of this simple predictive assessment indicate that only limited additional residential growth (e.g., increased growth from current 860 persons to about 1,000 persons) could be accommodated within Yacolt's Urban Growth Boundary (UGB) without exceeding the calculated enforcement limit under the state's GWQS. Given the current projected population increases for Yacolt over the next decade (estimated at up to a doubling of the current population), the transition from individual septics to sewer and a centralized wastewater treatment plant appears warranted to offset potential water quality degradation associated with additional residential growth. The decision of whether to construct sewer and a centralized treatment plant for Yacolt would also need to consider other factors including permitting issues and economic feasibility of doing so.

Because existing nitrate concentrations are well below the MCL and are expected to remain so for several years with a foreseeable moderate rate of growth, Yacolt likely has several years available to complete a transition from septic to sewer without impacts to public health. Transitioning from septic to sewer would not adversely impact the amount of recharge to the Yacolt Aquifer, since the component of recharge from septics is negligible relative to recharge from precipitation, as previously discussed.

Existing groundwater quality measured in one well immediately south of the Town showed impact similar to that observed within the Town limits. The existing population density outside of Town limits (outside of Yacolt's UGB) is low—on the order of 130 persons (CCN, 1993) per 1,000 acres. Therefore, additional growth, beyond the projected acceptable growth within Yacolt's UGB, could likely be accommodated outside of the UGB without adverse groundwater quality impacts. There are insufficient data available to quantitatively assess an acceptable population density relative to nitrate loading for the areas outside the UGB.

Considerations for Location of a Centralized Wastewater Treatment Facility

Based on the state's GWQS, effluent from a wastewater treatment plant (WWTP) would need to be treated adequately such that it would not degrade existing groundwater quality upon discharge. The degree of wastewater treatment achievable by a WWTP will largely influence the selection of potential areas for discharge of treated effluent. If the effluent quality is at least as good as existing groundwater quality, location of a centralized treatment plant would not need to be outside of the capture zones for the Town of Yacolt's water supply wells or away from private wells outside of Town limits.

The GWQS will require comparison of any wastewater treatment plant effluent against existing background conditions. There are adequate data available from this study to define existing conditions in the northern portion of the valley; however, groundwater quality data from the southern portion of the valley were not collected or compiled for this study. Evaluation of existing groundwater quality in the southern portions of the valley may be appropriate as part of the site selection process.

Discharge of effluent to the ground (e.g., infiltration gallery) versus discharge to streams should not have any appreciable difference in terms of aquifer recharge, since in either case the expected volumes of treated wastewater effluent should be negligible relative to other recharge sources.

LIMITATIONS

Work for this project was performed, and this letter report prepared, in accordance with generally accepted professional practices for the nature and conditions of the work completed in the same or similar localities, at the time the work was performed. It is intended for the exclusive use of the Town of Yacolt for specific application to the referenced property. This report is not meant to represent a legal opinion. No other warranty, express or implied, is made.

Any questions regarding our work and this letter report, the presentation of the information, and the interpretation of the data are welcome and should be referred to the undersigned.

We trust that this report meets your needs.

Sincerely,

HART CROWSER, INC.

STEVE J. GERMIAT, CGWP
Sr. Project Hydrogeologist

TIMOTHY J. FLYNN, CGWP
Principal Hydrogeologist

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Table 1 - Water Level Data Collected during Study

Location	M.P. Elevation	4-Jan-95 DTW below M.P.	4-Jan-95 Groundwater Elevation	6-Feb-95 DTW below M.P.	6-Feb-95 Groundwater Elevation	6-Mar-95 DTW below M.P.	6-Mar-95 Groundwater Elevation	3-Apr-95 DTW below M.P.	3-Apr-95 Groundwater Elevation	8-May-95 DTW below M.P.	8-May-95 Groundwater Elevation
Monitoring Well											
MW-1	702.55	30.52	672.03	34.12	668.43	34.59	667.96	36.85	665.70	38.67	663.88
MW-2	706.08	34.19	671.89	37.62	668.46	38.51	667.57	40.91	665.17	42.99	663.09
MW-3	716.22	40.37	675.85	44.20	672.02	45.10	671.12	47.66	668.56	49.77	666.45
Town Water Supply Well											
No. 3	694.23	21.22	673.01	24.67	669.56	25.62	668.61	27.9	666.3	30.32	663.91
No. 4	709.84	39.22	670.62	43.30	666.54	43.81	666.03	46.39	663.45	47.57	662.27
No. 5	715.63	45.46	670.17	48.70	666.93	49.28	666.35	51.26	664.37	53.07	662.56
No. 6	720.53	49.89	670.64	53.12	667.41	53.67	666.86	55.86	664.67	57.66	662.87
Private Domestic Well											
A (Slonniker)	697	18.60	679	19.77	677	20.79	676	21.67	675	23.15	674
C (Swendsen)	670.07	5.98	664.09	8.51	661.56	9.63	660.44	12.92	657.15	14.94	655.13
D (Witt)	657	6.74	650	6.98	650	7.48	650	8.90	648	10.63	646
Stream Staff Gage	Elevation of 0.00 Mark	Gage Reading	Stream Elevation	Gage Reading	Stream Elevation	Gage Reading	Stream Elevation	Gage Reading	Stream Elevation	Gage Reading	Stream Elevation
SG-1	649.62	0.60	650.22	0.60	650.22	0.10	649.72	0.1	649.72	0.10	649.72
SG-2	702.76	2.90	705.66	0.34	703.10	0.20	702.96	0.16	702.92	0.21	702.97
SG-3	667.71	8.72	676.43	8.71	676.42	8.51	676.22	9.43	677.14	8.51	676.22
SG-4	607.81	8.46	616.27	8.35	616.16	8.99	616.80	7.97	615.78	8.02	615.83

Notes:

(a) All depths, gage readings, and elevations in feet. Elevations relative to National Geodetic Vertical Datum (NGVD).

(b) DTW: Depth to Water; M.P.: Measuring Point.

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Table 1 - Water Level Data Collected during Study

	5-Jun-95		26-Jun-95		1-Aug-95		5-Sep-95		4-Oct-95		9-Nov-95	
	DTW	Groundwater	DTW	Groundwater	DTW	Groundwater	DTW	Groundwater	DTW	Groundwater	DTW	Groundwater
Location	below M.P.	Elevation	below M.P.	Elevation	below M.P.	Elevation	below M.P.	Elevation	below M.P.	Elevation	below M.P.	Elevation
Monitoring Well												
MW-1	41.20	661.35	44.68	657.87	49.45	653.10	52.83	649.72	55.05	647.50	52.63	649.92
MW-2	46.21	659.87	50.07	656.01	55.22	650.86	dry	<647.2	dry	<647.2	dry	<647.2
MW-3	52.85	663.37	57.96	658.26	62.26	653.96	65.83	650.39	68.17	648.05	65.32	650.90
Town Water Supply Well												
No. 3	33.55	660.68	37.75	656.48	42.85	651.38	46.20	648.03	48.51	645.72	45.83	648.40
No. 4	50.05	659.79	53.39	656.45	58.52	651.32	62.00	647.84	64.68	645.16	61.71	648.13
No. 5	55.57	660.06	58.96	656.67	64.16	651.47	67.60	648.03	69.73	645.90	67.27	648.36
No. 6	60.30	660.23	63.70	656.83	68.92	651.61	72.40	648.13	74.53	646.00	71.93	648.60
Private Domestic Well												
A (Slonniker)	23.95	673	24.49	673	27.44	670	29.09	668	30.31	667	27.25	670
C (Swendsen)	18.83	651.24	23.51	646.56	28.30	641.77	30.86	639.21	32.57	637.50	25.98	644.09
D (Witt)	14.18	643	16.70	640	19.52	637	21.16	636	22.07	635	16.75	640
Stream	Gage	Stream	Gage	Stream	Gage	Stream	Gage	Stream	Gage	Stream	Gage	Stream
Staff Gage	Reading	Elevation	Reading	Elevation	Reading	Elevation	Reading	Elevation	Reading	Elevation	Reading	Elevation
SG-1	-0.27	649.35	-0.47	649.15	-0.63	648.99	-0.86	648.76	-0.37	649.25	1.04	650.66
SG-2	0.10	702.86	0.00	702.76	-0.18	702.58	-0.08	702.68	0.07	702.83	0.44	703.20
SG-3	8.33	676.04	8.10	675.81	7.60	675.31	dry	<674.8	7.97	675.68	8.70	676.41
SG-4	7.84	615.65	7.74	615.55	8.00	615.81	8.40	616.21	8.56	616.37	8.12	615.93

Notes:

(a) All depths, gage readings, and elevations in feet. Elevations relative to National Geodetic Vertical Datum (NGVD).

(b) DTW: Depth to Water; M.P.: Measuring Point.

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Table 2 - Hydraulic Conductivity Estimates for the Yacolt Aquifer

Well	Measured Specific Capacity in gpm/ft	Estimated Transmissivity (a) in gpd/ft	Initial Saturated Thickness in Feet	Estimated Hydraulic Conductivity in cm/sec	Data Source
No. 1					
	3.2	4,700	90	2E-03	Specific capacity from 1973 pumping test (b).
	3.9	5,800	90	3E-03	Specific capacity from 1983 pumping test (b).
	NA	7,500	90	4E-03	Recovery data from 1973 pumping test (t/t' analysis) (b).
No. 3					
	18	27,000	46	3E-02	Specific capacity from 1983 pumping test (c).
	17	25,000	48	2E-02	Specific capacity from 1990 pumping test (c).
No. 4					
	165	248,000	25	5E-01	Specific capacity from 1984 pumping test (c).
	95	143,000	43	2E-01	Specific capacity from 1990 pumping test (c).
No. 5					
	114	171,000	47	2E-01	Specific capacity from 1984 pumping test (c).
	155	233,000	42	3E-01	Specific capacity from 1990 pumping test (b).
No. 6					
	96	144,000	43	2E-01	Specific capacity from 1984 pumping test (c).
	57	86,000	38	1E-01	Specific capacity from 1990 pumping test (c).

Geometric Mean:	**4E-02** cm/sec

Notes:

(a) For estimates from specific capacity (Q/s), unconfined aquifer transmissivity in gpd/ft estimated as 1500 * (Q/s) in gpm/ft (Driscoll, 1986).

(b) Data/information in Sweet Edwards (1983).

(c) Data/information from Carr/Associates (1990).

4234/4234T2.xls

Table 3 - Estimates of Annual Recharge to the Yacolt Aquifer

			Relative Contribution to Total Recharge in %
Empirical Estimate of Total Annual Recharge Volume			
Aquifer Width		5000 ft	
Aquifer Length		12000 ft	
Average Water Level Change		24.5 ft	
Porosity		0.3	
Total Recharge Volume in cu ft		4.41E+08 cu. ft.	100
Estimated Annual Recharge from Infiltrating Precipitation			
	Year	Estimated Recharge from Precipitation (a)	
	1983	110.0 in/yr	
	1984	66.9 in/yr	
	1985	37.2 in/yr	
	1986	57.1 in/yr	
	1987	46.5 in/yr	
	1988	58.9 in/yr	
	1989	52.3 in/yr	
	Average:	61.3 in/yr	
Recharge Volume from Infiltration in cu ft		3.06E+08 cu. ft.	69.5
(a) from Carr/Associates, 1990.			
Estimated Annual Recharge from Septics			
Per capita daily wastewater discharge		44 gal	
Number of residents in Town		860	
Number of residents outside Town		130	
Recharge Volume from Septics in cu ft		2.13E+06 cu. ft.	0.5
Estimated Annual Recharge from Adjacent Uplands			
Total - Infiltration - Septic in cu ft		1.33E+08 cu. ft.	30.0

4234/4234T3.xls

Table 4 - Estimates of Seasonal Groundwater Flux through Yacolt Aquifer

Wet season (e.g., January 1995)							
Flow Toward South				**Flow Toward North**			
K:	4E-02 cm/sec =	1E-03 ft/sec		K:	4E-02 cm/sec =	1E-03 ft/sec	
i:	0.0053 ft/ft			i:	0.025 ft/ft		
w:	5000 ft			w:	5000 ft		
H:	79 ft			H:	55 ft		
thus, Q=	1,200 gpm			thus, Q=	4,100 gpm		
		Total Estimated Flux =	**5,300 gpm**				

Declining season (e.g., July 1995)							
Flow Toward South				**Flow Toward North**			
K:	4E-02 cm/sec =	1E-03 ft/sec		K:	4E-02 cm/sec =	1E-03 ft/sec	
i:	0.0038 ft/ft			i:	0.0095 ft/ft		
w:	5000 ft			w:	5000 ft		
H:	62 ft			H:	42 ft		
thus, Q=	700 gpm			thus, Q=	1,200 gpm		
		Total Estimated Flux =	**1,900 gpm**				

Dry season (e.g., October 1995)				
Flow Toward South				**Flow Toward North**
K:	4E-02 cm/sec =	1E-03 ft/sec		**No gradient toward north, thus**
i:	0.0025 ft/ft			**no flux (refer to text).**
w:	5000 ft			
H:	53 ft			
thus, Q=	400 gpm			
		Total Estimated Flux =	**400 gpm**	

Refer to text for discussion of assumptions.

4234/4234T4.xls

Table 5 - Groundwater Quality and Field Parameter Data Collected during Study

	Analytical Results						Field Parameter Data			
Well No. and Sampling Date	Nitrate as N in mg/L	Nitrite as N in mg/L	TKN in mg/L	Chloride in mg/L	Sulfate in mg/L	Nitrogen/ Sulfur Molar Ratio	Temp. in °C	Spec. Conduct. in µmho/cm	pH	Dissolved Oxygen in mg/L
MW-1										
Jan-95	0.04	0.03	0.5	1.4	0.6	0.2	10.8	110	6.5	2
Apr-95	0.03	0.01 U	0.2 U	1.3	0.1	0.6	13.3	110	8.2	3
Jul-95	0.1 U	0.1 U	0.5	2.0	1.0 U	0.3	11.8	90	7.9	1
Oct-95	0.01 U	0.01 U	0.2 U	1.3	0.1 U	0.3	11.7	80	8.4	1
MW-1 Dup.										
Oct-95	0.06	0.01 U	0.2 U	1.4	0.3	0.3	---	---	---	---
MW-2										
Jan-95	3.1	0.01 U	0.5	4.3	1.1	4.4	10.4	100	6.5	3
Apr-95	3.1	0.01 U	0.2 U	3.9	0.9	5.4	12.4	NM	8.0	4
Jul-95	2.6	0.1 U	0.2	6.0	1.0 U	4.1	12.7	90	7.7	4
Oct-95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MW-2 Dup.										
Apr-95	3.1	0.01 U	0.2 U	4.1	1.2	4.0	---	---	---	---
Jul-95	2.6	0.1 U	0.5	4.0	1.0 U	4.1	---	---	---	---
MW-3										
Jan-95	0.39	0.01 U	0.5	1.8	1.2	0.5	8.4	80	6.0	3
Apr-95	0.24	0.02	0.2 U	1.5	0.3	1.4	12.5	90	8.6	4
Jul-95	0.2	0.1 U	0.2	2.0	1.0 U	0.5	12.4	50	8.1	4
Oct-95	0.11	0.01 U	0.2 U	1.4	0.3	0.6	11.1	70	7.3	3
Domestic Well B										
Jan-95	2.1	0.01 U	0.2 U	3.1	0.5	6.5	10.0	100	6.5	5
Apr-95	2.0	0.01 U	0.2 U	3.1	0.5	6.2	12.1	NM	7.5	6
Jul-95	2.3	0.01 U	0.5	3.4	0.5	7.2	11.7	90	7.5	5
Oct-95	2.4	0.01 U	0.2 U	3.6	0.6	6.2	11.7	90	7.2	3
MCL/SMCL	10	1		250*	250*	--	--	--	--	--

Notes:
TKN: Total Kjeldahl Nitrogen.
NS: No sample could be collected because well as dry. NM: No measurement because of instrument malfunction.
*: SMCL based on aesthetic, not health-based, considerations.

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Table 6 - Nitrate Concentrations in Town Water Supply Wells

Well and Sampling Date	Nitrate as N in mg/L
No. 3	
Jul-84	2.0
Apr-87	2.0
Jul-90	2.5
Sep-93	1.5
Aug-95	1.8
No. 4	
May-84	1.4
Apr-87	1.7
Jul-90	1.7
Sep-93	1.6
No. 5	
May-84	0.8
Apr-87	0.9
Jul-90	0.7
Sep-93	0.29
No. 6	
Apr-87	0.3
Jul-90	0.2
Sep-93	0.10
Composite (Nos. 4, 5, and 6)	
Aug-95	1.2

4234/4234T6.xls

Table 7 - Calculation of Natural Water Quality, Existing Water Quality, and Enforcement Limit for Nitrate as N in Groundwater

Wells Representing Natural Water Quality

Well and Sampling Date	Nitrate as N in mg/L
MW-1, Jan-95	0.04
MW-1, Apr-95	0.03
MW-1, Jul-95	0.1 U
MW-1, Oct-95	0.033
MW-3, Jan-95	0.39
MW-3, Apr-95	0.24
MW-3, Jul-95	0.2
MW-3, Oct-95	0.11
Arithmetic Mean:	0.14 mg/L
Std. Deviation:	0.13
N:	8
K:	3.188
Natural Water Quality	**0.5 mg/L**

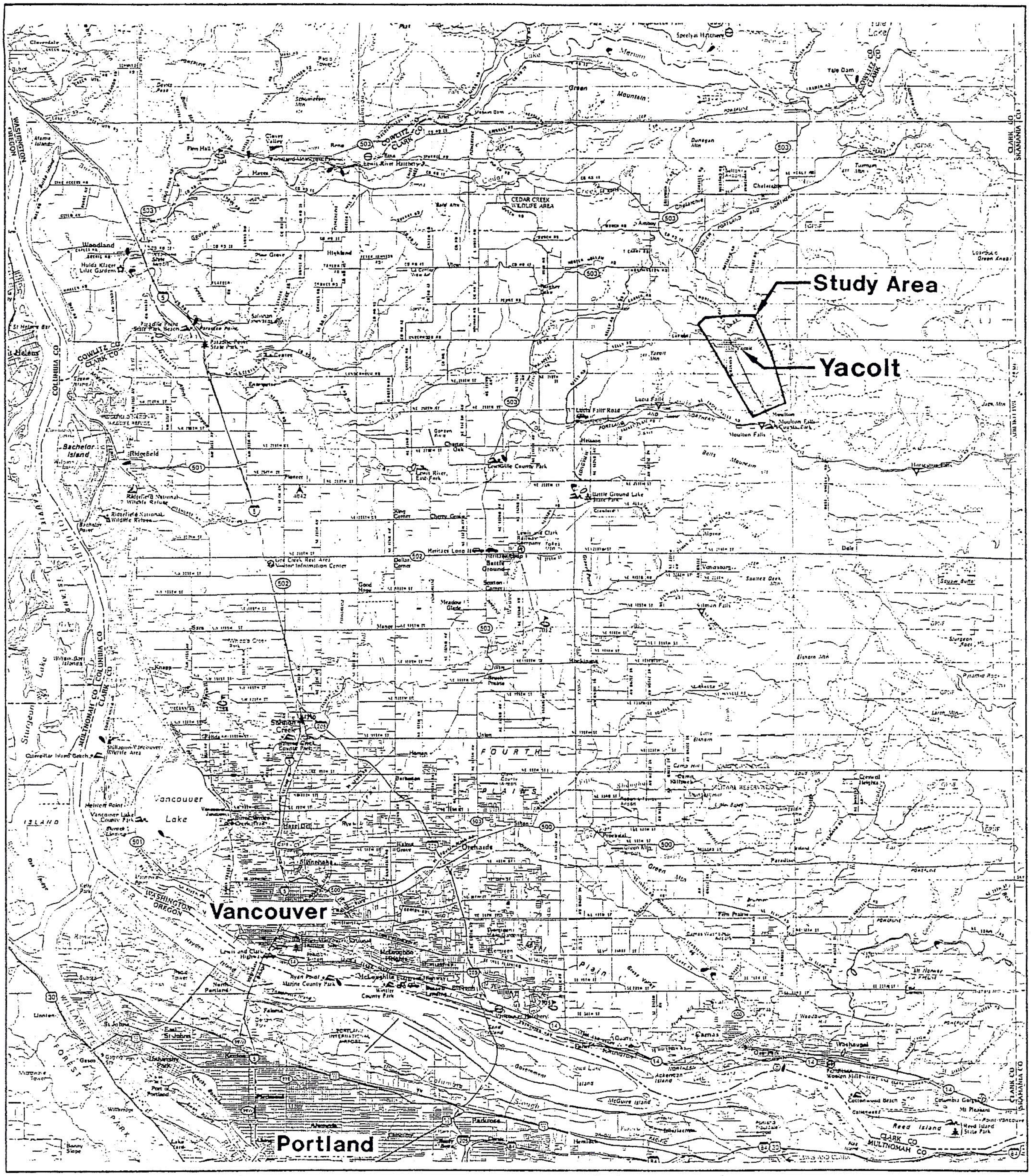
Wells Representing Existing Water Quality within Town

Well and Sampling Date	Nitrate as N in mg/L
MW-2, Jan-95	3.1
MW-2, Apr-95	3.1
MW-2, Jul-95	2.6
Well B, Jan-95	2.1
Well B, Apr-95	2.0
Well B, Jul-95	2.3
Well B, Oct-95	2.4
No. 3, Jul-84	2.0
No. 3, Apr-87	2.0
No. 3, Jul-90	2.5
No. 3, Sep-93	1.5
No. 3, Aug-95	1.8
No. 4, Apr-84	1.4
No. 4, Apr-87	1.7
No. 4, Jul-90	1.7
No. 4, Sep-93	1.6
No. 5, Apr-84	0.8
No. 5, Apr-87	0.9
No. 5, Jul-90	0.7
No. 5, Sep-93	0.29
No. 6, Apr-87	0.3
No. 6, Jul-90	0.2
No. 6, Sep-93	0.10
Nos. 4,5,6, Aug-95	1.2
Arithmetic Mean:	1.60 mg/L
Std. Deviation:	0.88
N:	24
K:	2.309
Existing Water Quality	**3.64 mg/L**
Criterion (MCL)	10 mg/L
Enforcement Limit	**4.27 mg/L**

Thus, the enforcement limit represents a 17 percent increase from existing conditions.

Notes:
N: Number of samples. K: K value for calculating tolerance intervals (Table 16 in Ecology, 1994).
Average values from field duplicate sample pairs have been used for statistical analysis (per Ecology, 1994).
Natural water quality and existing water quality calculated as the 95% upper tolerance interval with 95% confidence for the respective data sets (per Ecology, 1994).
Enforcement limit calculated as (MCL - Existing)*10% + Existing (per Ecology, 1994).
4234/4234T7.xls

Vicinity Map



0 4 8
Scale in Miles

N

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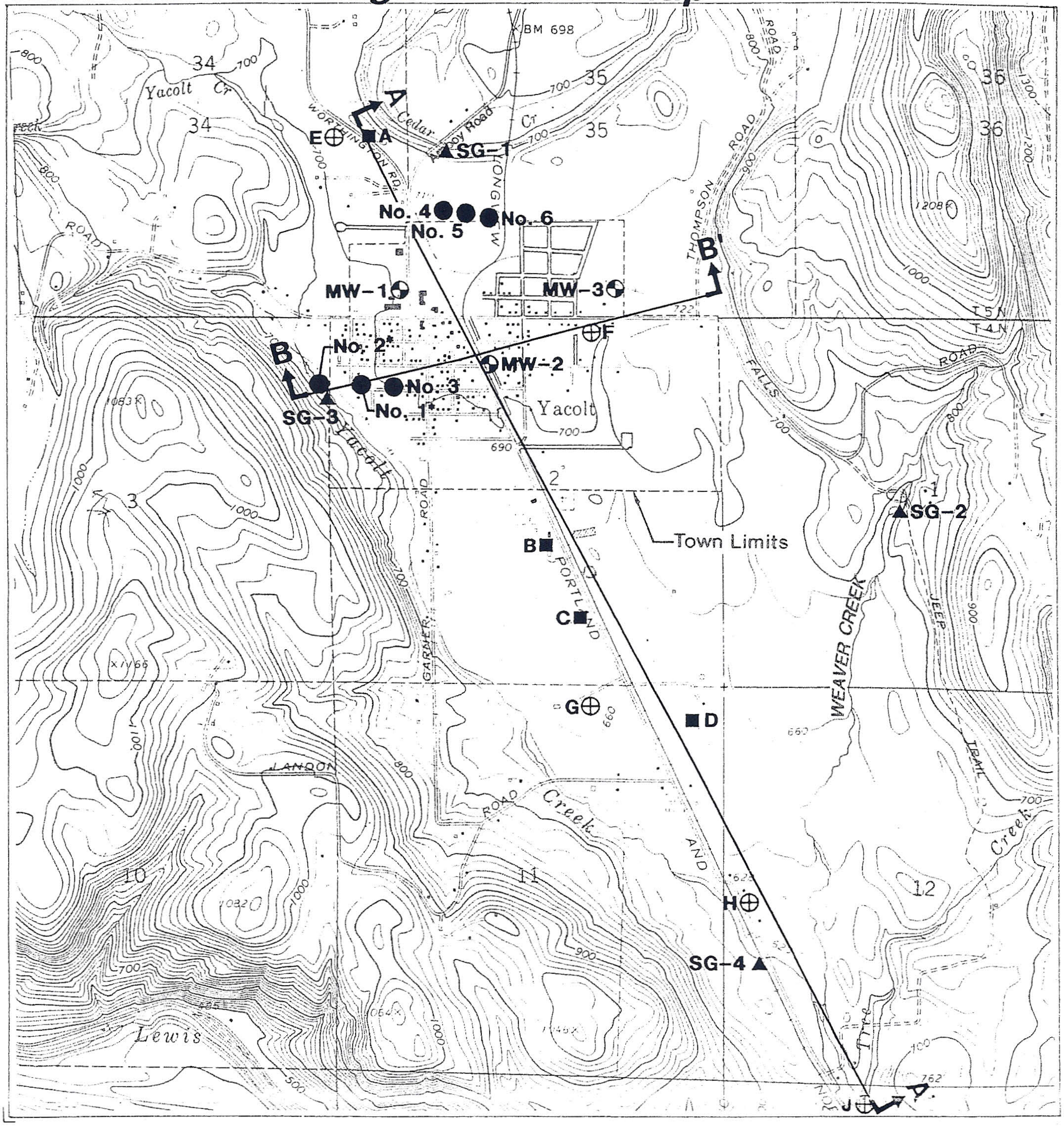
Figure 1

Well and Staff Gage Location Map



Note: Base map prepared from USGS 7.5 minute quadrangle maps of Yacolt and Amboy, Washington, dated 1971, and street map provided by Town of Yacolt, dated March 1994.

● No. 4	Town's Water Supply Well Location and Number (* = decommissioned well used for geologic control only)
■ A	Domestic Well Location and Designation (used for water level monitoring during study)
MW-1	Monitoring Well Location and Number
▲ SG-1	Stream Staff Gage Location and Number
⊕ E	Domestic Well Location and Designation (used for geologic control only)
A A'	Cross Section Location and Designation

0 2000 4000

Scale in Feet

N

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Figure 2

Generalized Subsur

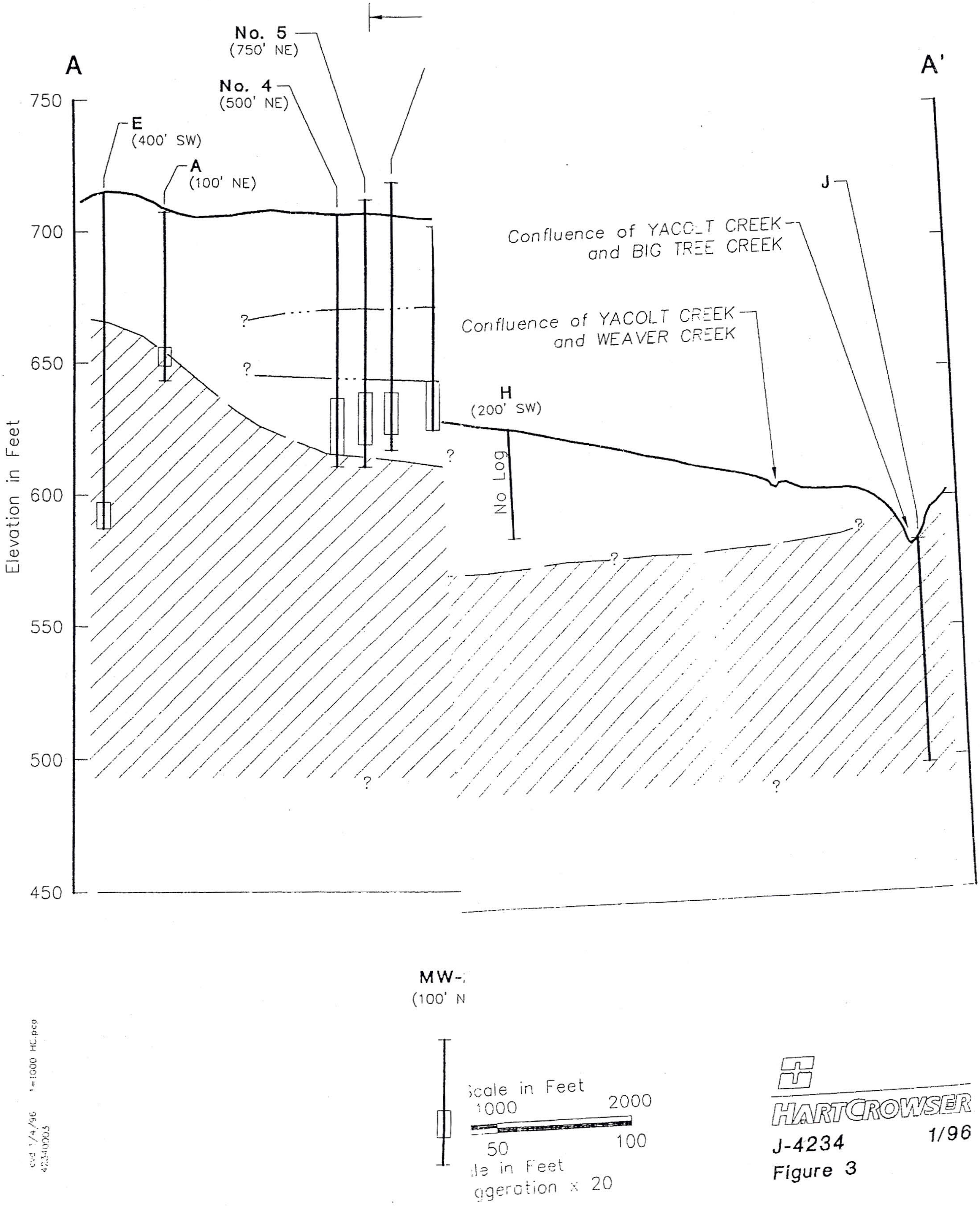

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Figure 3

SWP 1/4/96 1=1000 HC.pcp
42340006

Generalized Subsurface Cross Section B-B'

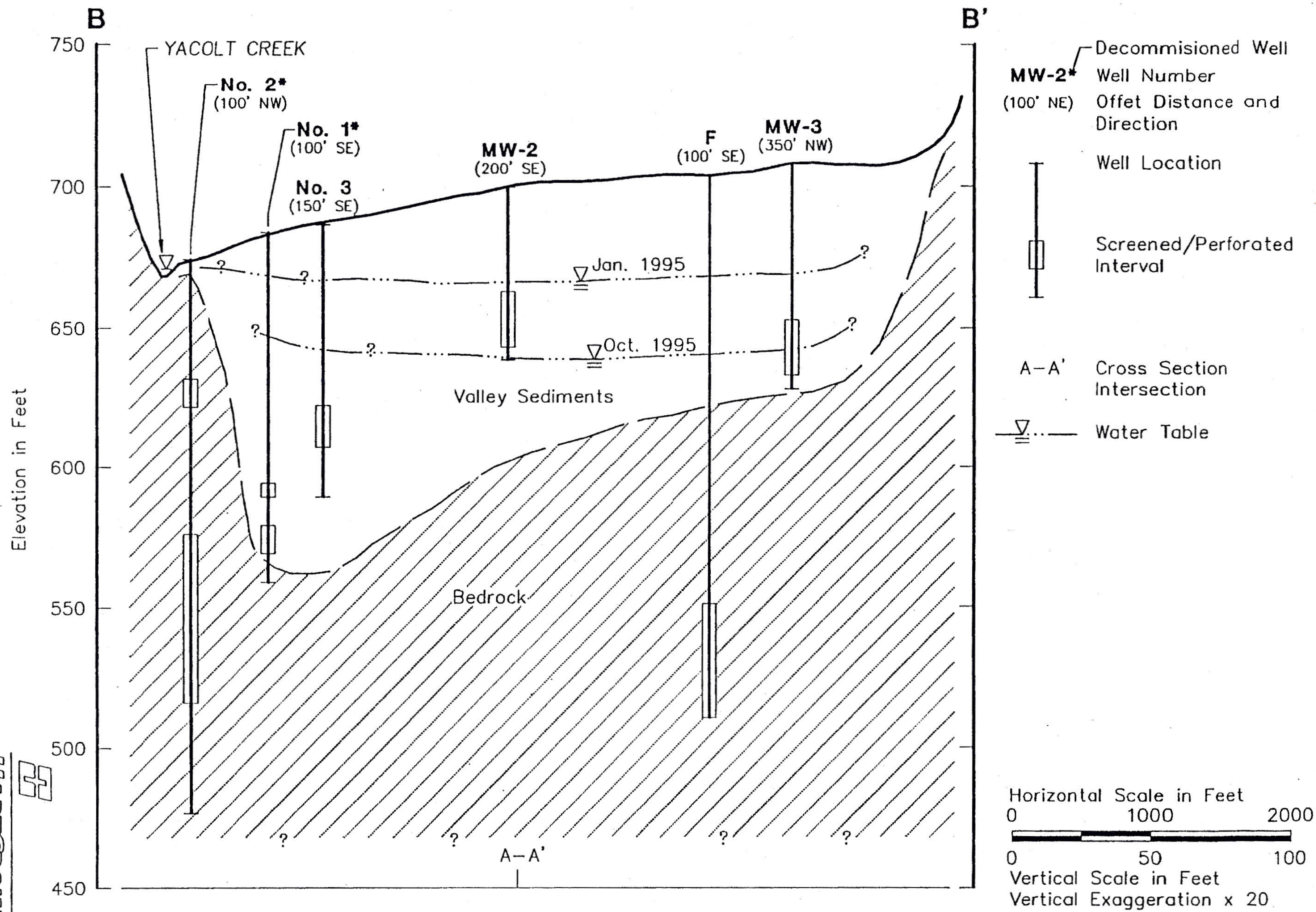

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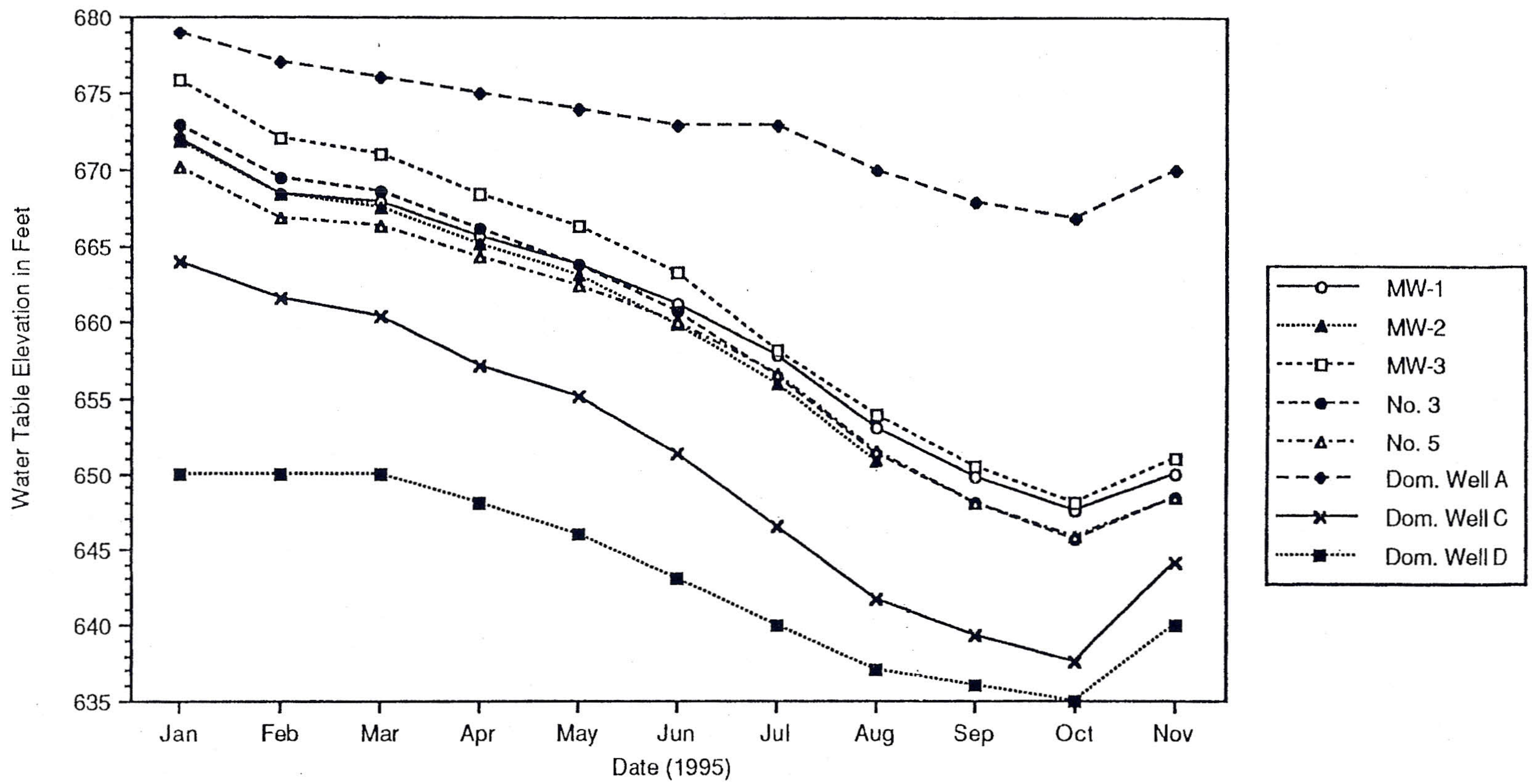
Figure 4

Hydrographs for Wells Monitored During Study



Note: Hydrographs for Town wells No. 4 and No. 6 not shown since essentially identical to No. 5.

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Figure 5

Hydrographs Demonstrating Groundwater/ Surface Water Interactions

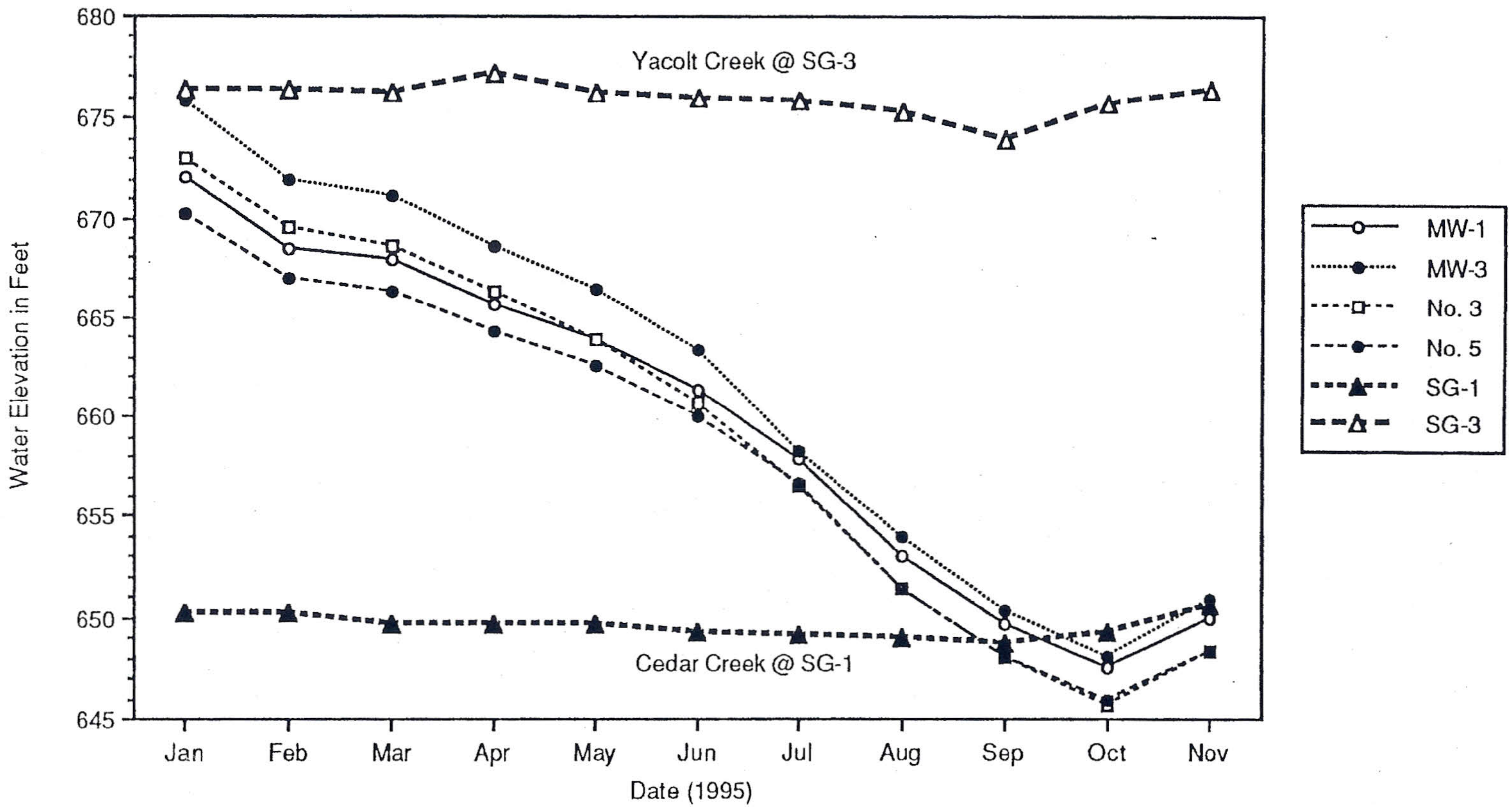

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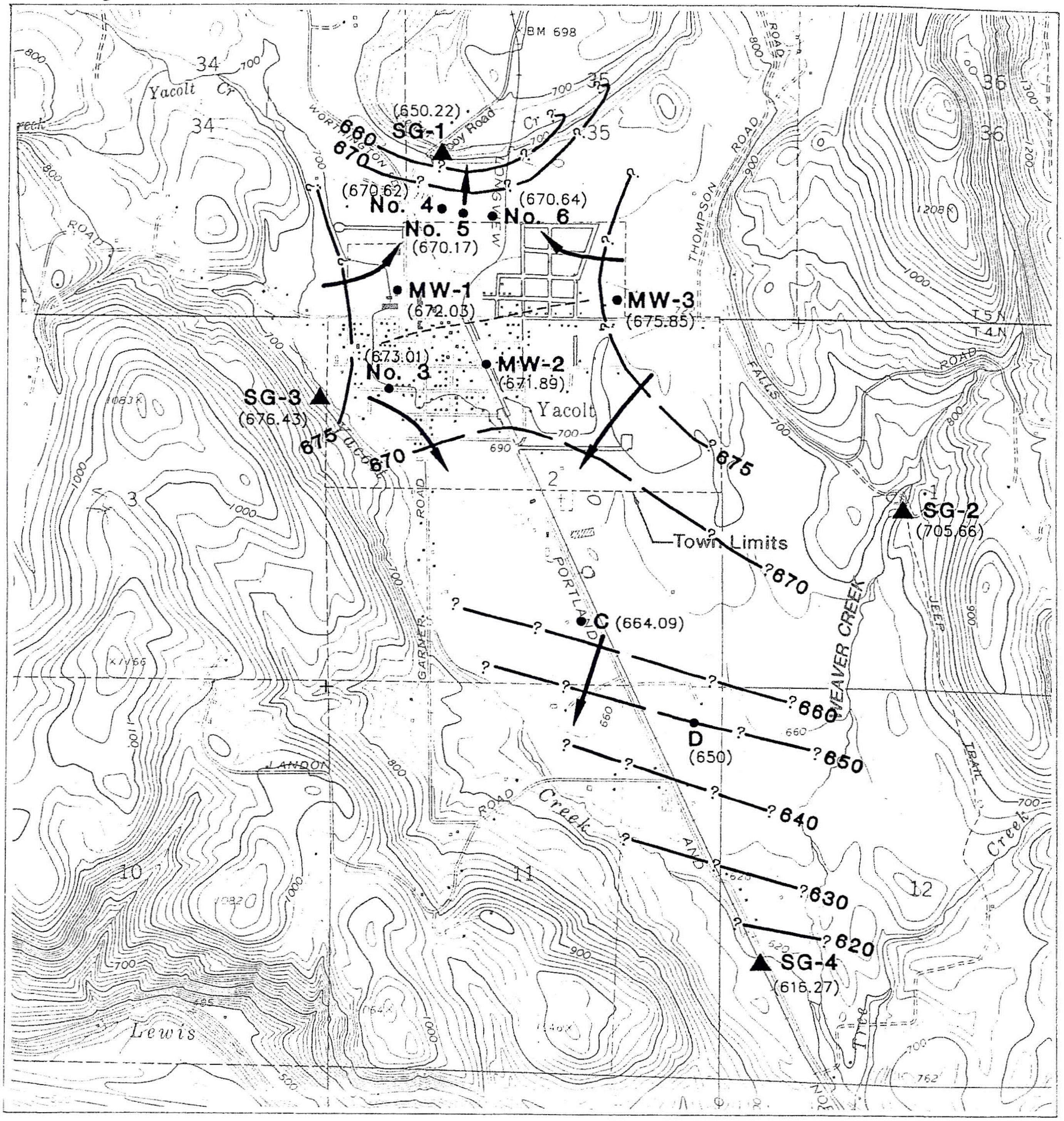
Figure 6

Water Table Elevation Contour Map
January 1995



● MW-1	Well Location and Number
▲ SG-1	Staff Gage Location and Number
(650.22)	Spot Water Table or Stream Elevation in Feet
—620—	Water Table Elevation Contour in Feet
←—	Generalized Groundwater Flow Direction
- - - - - - -	Approximate Location of Groundwater Divide

Note: Base map prepared from USGS 7.5 minute quadrangle maps of Yacolt and Amboy, Washington, dated 1971, and street map provided by Town of Yacolt, dated March 1994. Data collected on January 4, 1995.

0 2000 4000
Scale in Feet

N

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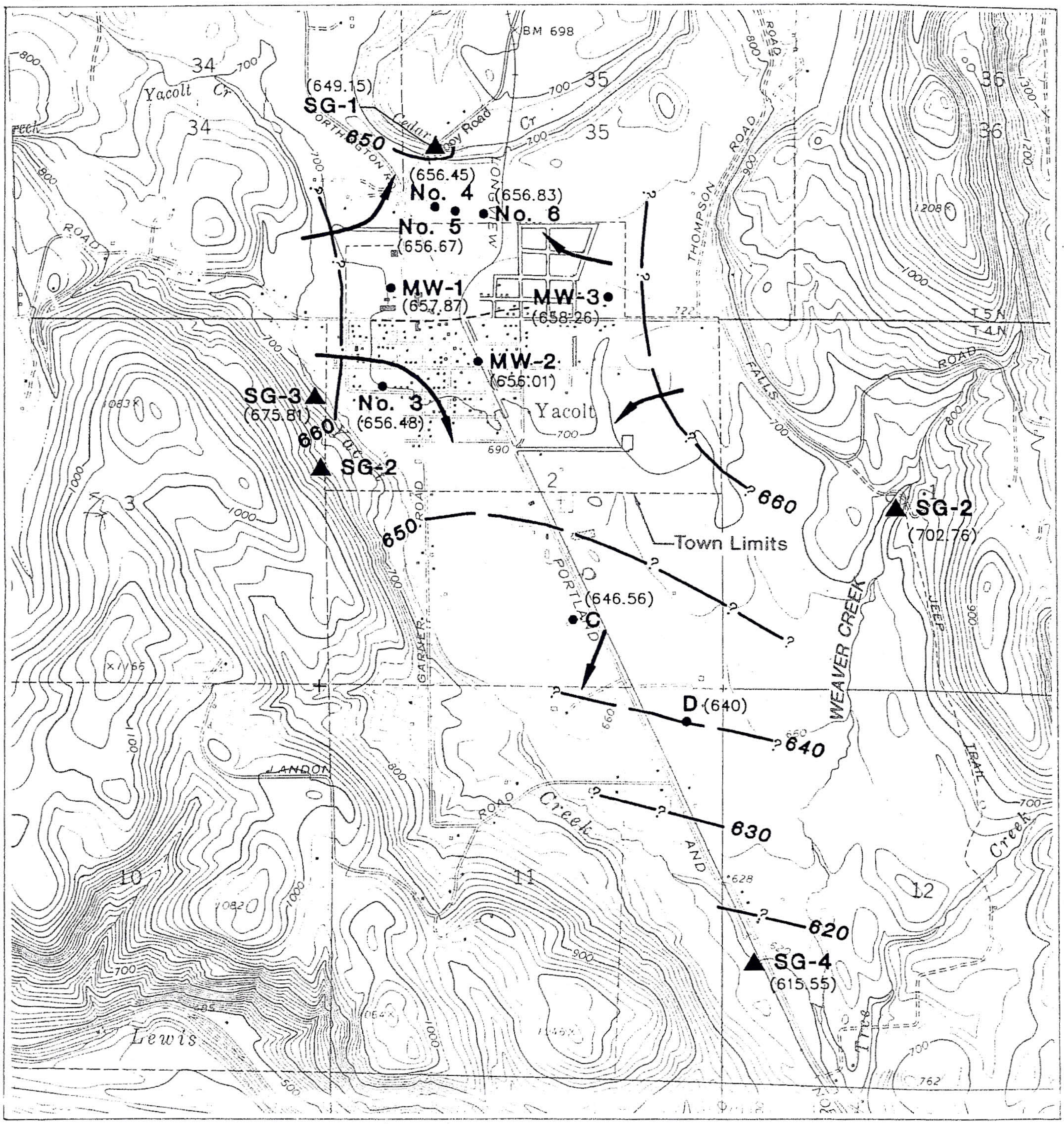
Figure 7

SWP 1/4/96 1=2000 hc.pcp
42340000

Water Table Elevation Contour Map
July 1995



● MW-1	Well Location and Number
▲ SG-1	Staff Gage Location and Number
(650.22)	Spot Water Table or Stream Elevation in Feet
—620—	Water Table Elevaton Contour in Feet
←	Generalized Groundwater Flow Direction
- - - - - - -	Approximate Location of Groundwater Divide

Note: Base map prepared from USGS 7.5 minute quadrangle maps of Yacolt and Amboy, Washington, dated 1971, and street map provided by Town of Yacolt, dated March 1994. Data collected on June 26, 1995.

0 2000 4000

Scale in Feet

N

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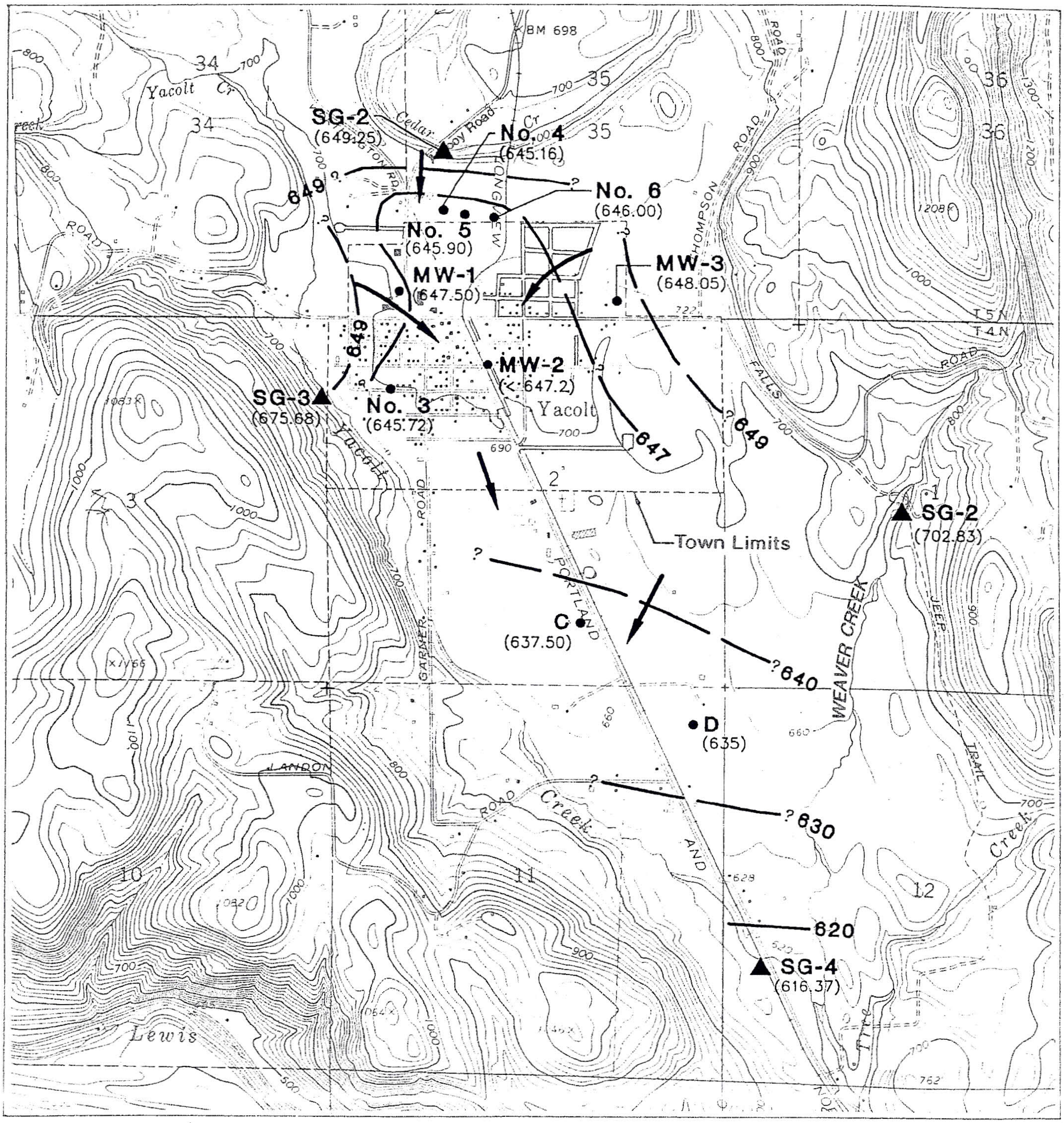
Figure 8

42340002 SWP 1/4/96 1=2000 hc.pcp

Water Table Elevation Contour Map
October 1995



• **MW-1**	Well Location and Number
▲ **SG-1**	Staff Gage Location and Number
(650.22)	Spot Water Table or Stream Elevation in Feet
—**620**—	Water Table Elevaton Contour in Feet
←	Generalized Groundwater Flow Direction

0 2000 4000
Scale in Feet

N

Note: Base map prepared from USGS 7.5 minute quadrangle maps of Yacolt and Amboy, Washington, dated 1971, and street map provided by Town of Yacolt, dated March 1994. Data collected on October 4, 1995.

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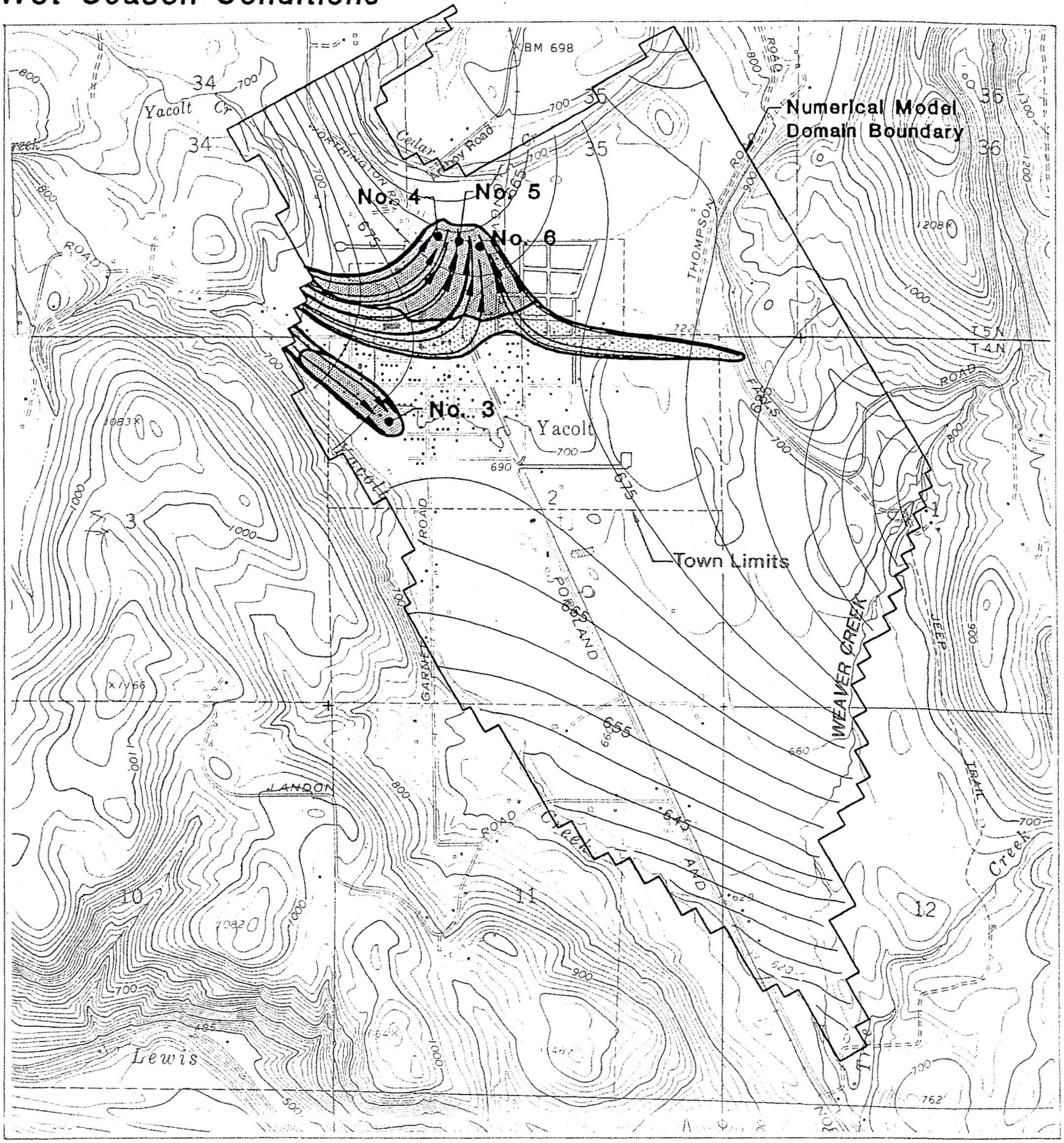
J-4234 **1/96**
Figure 9

SWP 1/4/96 1=2000 hc.pcp
42340001

Screening-Level Capture Zone Evaluation
Wet Season Conditions



●No. 3 Town Water Supply Well Location and Number

—645— Simulated Steady-State Water Table Elevation Contour in Feet

Simulated Groundwater Flow Lines

1-Year Capture Zone

5-Year Capture Zone

Note: Base map prepared from USGS 7.5 minute quadrangle maps of Yacolt and Amboy, Washington, dated 1971, and street map provided by Town of Yacolt, dated March 1994.

0 2000 4000
Scale in Feet

N

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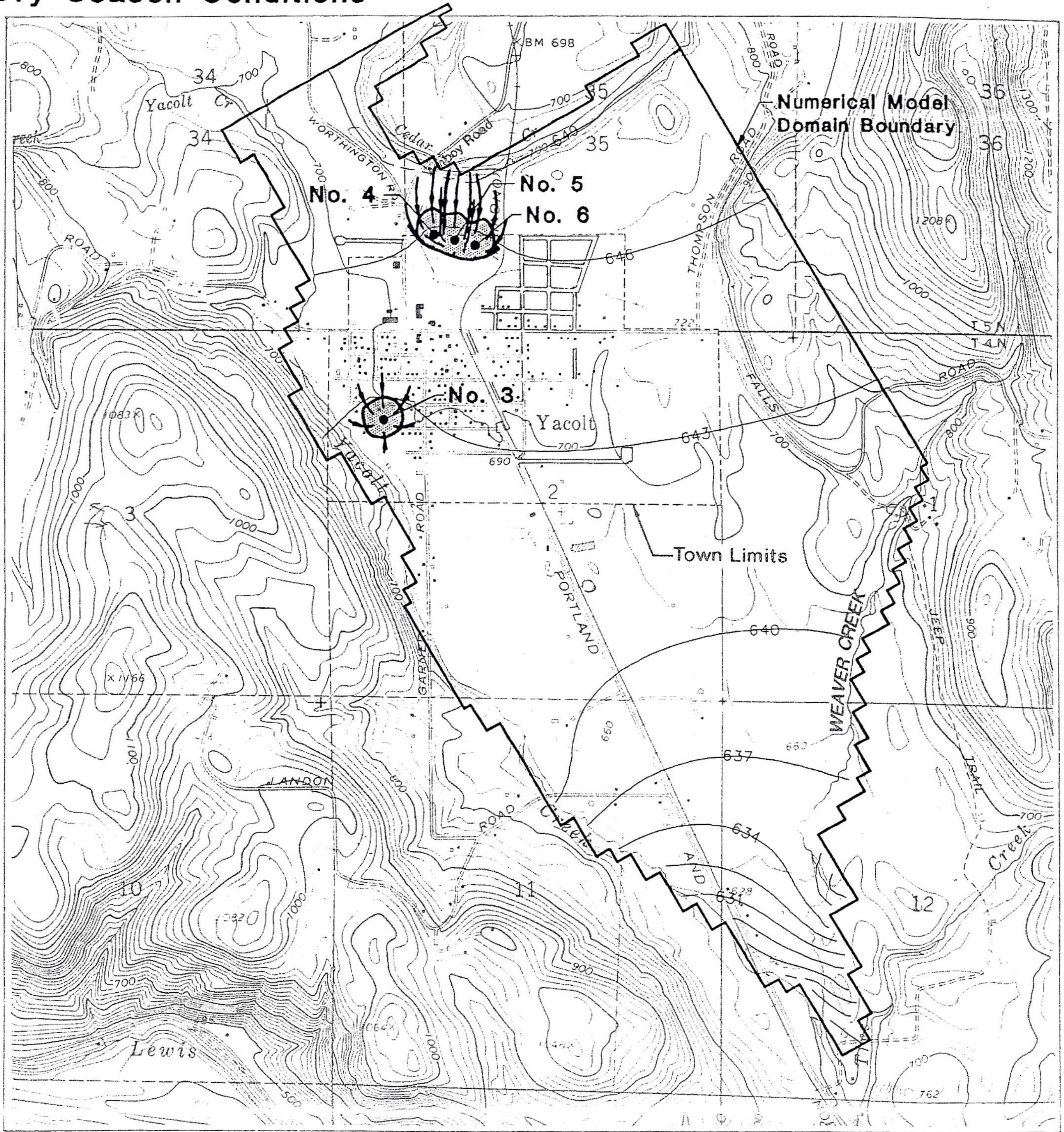
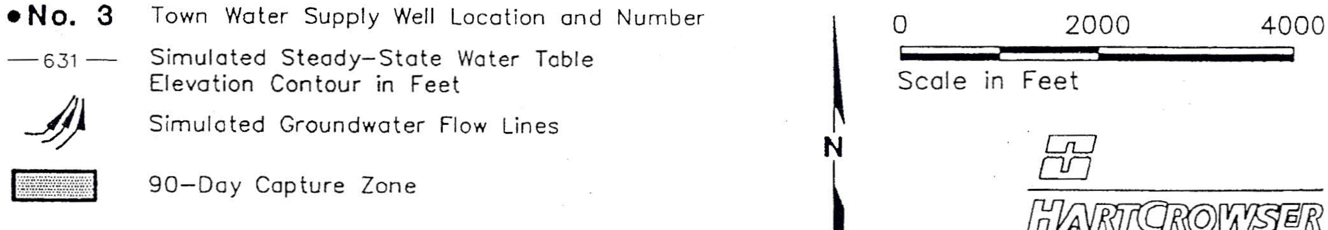
Figure 10

SWP 1/4/96 1=2000 hc.pcp
4231004

Screening-Level Capture Zone Evaluation
Dry Season Conditions





Note: Base map prepared from USGS 7.5 minute quadrangle maps of Yacolt and Amboy, Washington, dated 1971, and street map provided by Town of Yacolt, dated March 1994.

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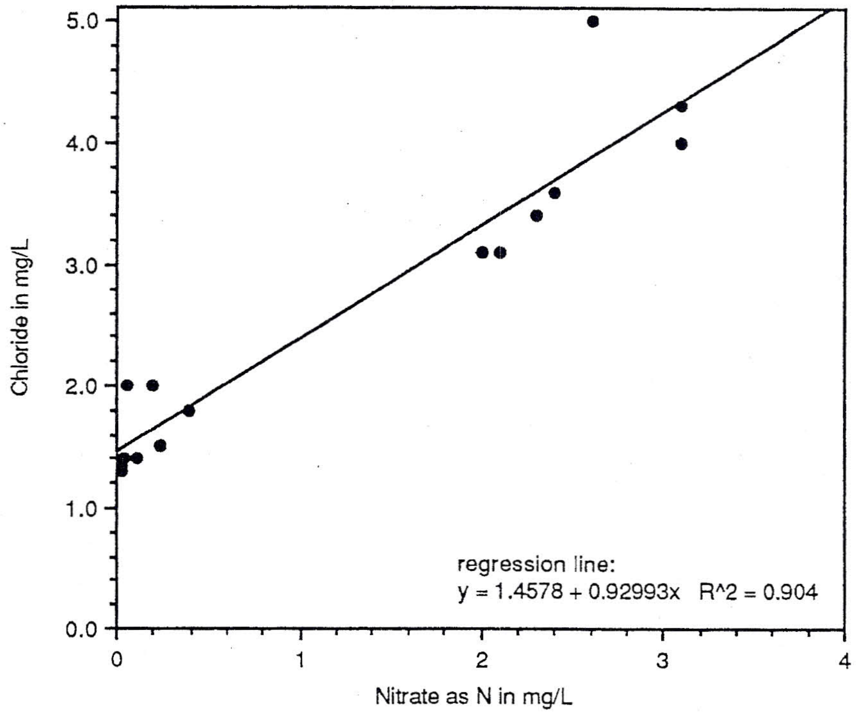
Figure 11

SWP 1/4/96 1=2000 hc.pcp
42340005

Correlation of Nitrate with Chloride



Correlation of Nitrate with Sulfate

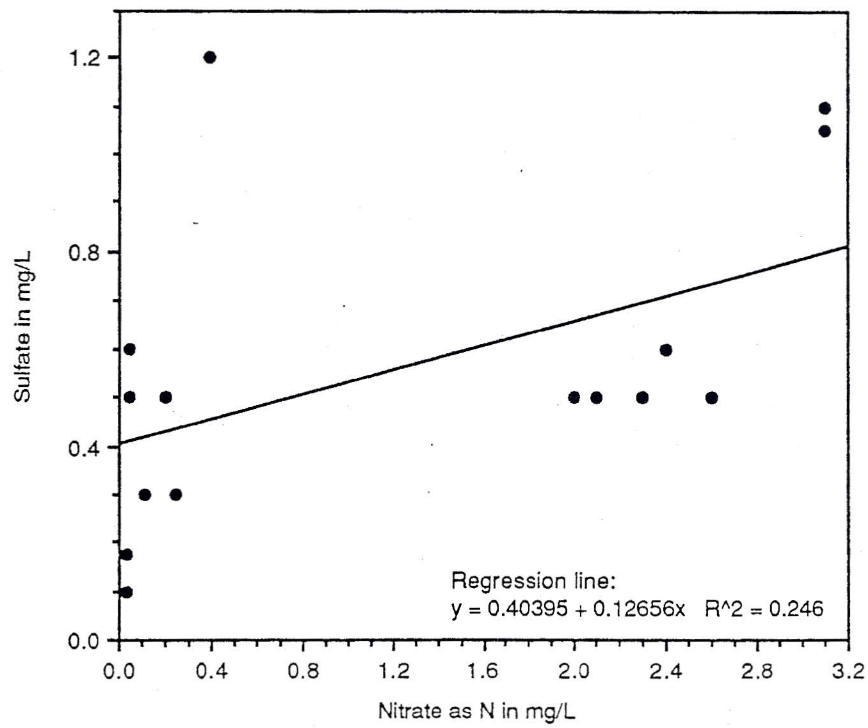


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Figure 12